ARTICLE IN PRESS

Bioresource Technology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Bioresource Technology

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

Review

Salinity build-up in osmotic membrane bioreactors: Causes, impacts, and potential cures

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ARTICLE INFO

Keywords:
Osmotic membrane bioreactor (OMBR)
Salinity build-up
Forward osmosis (FO)
Draw solution
Biological treatment

ABSTRACT

Osmotic membrane bioreactor (OMBR), which integrates forward osmosis (FO) with biological treatment, has been developed to advance wastewater treatment and reuse. OMBR is superior to conventional MBR, particularly in terms of higher effluent quality, lower membrane fouling propensity, and higher membrane fouling reversibility. Nevertheless, advancement and future deployment of OMBR are hindered by salinity build-up in the bioreactor (e.g., up to 50 mS/cm indicated by the mixed liquor conductivity), due to high salt rejection of the FO membrane and reverse diffusion of the draw solution. This review comprehensively elucidates the relative significance of these two mechanisms towards salinity build-up and its associated effects in OMBR operation. Recently proposed strategies to mitigate salinity build-up in OMBR are evaluated and compared to highlight their potential in practical applications. In addition, the complementarity of system optimization and modification to effectively manage salinity build-up are recommended for sustainable OMBR development.

1. Introduction

Wastewater treatment and reuse is a pragmatic measure to address water scarcity and environmental pollution for the sustainable development of our society (Shannon et al., 2008). Safe and reliable water reuse needs effective removal of diverse contaminants, such as salts, nutrients, pathogens, and trace organic contaminants (TrOCs) from wastewater. Of these commonly known contaminants, TrOCs cannot be effectively removed by conventional wastewater treatment facilities (e.g., activated sludge treatment) and thus remains hindrance to water reuse (Besha et al., 2017). TrOCs are emerging organic chemicals from both natural and anthropogenic activities, mainly including pharmaceuticals, personal care products, endocrine disrupting compounds, pesticides, and industrial chemicals (Luo et al., 2014b). Despite their trace concentrations in wastewater (less than several μg/L), TrOCs are of significant concerns and potentially threaten human health and even the whole ecosystem by inducing toxicity, endocrine disrupting effects, reproductive impairment, and antibiotic resistance, to humans and other living organisms (Schwarzenbach et al., 2006).

Over last decades, great efforts have been dedicated for the development of innovative technologies, such as membrane bioreactor (MBR), to improve wastewater treatment and reuse. MBR is an integration of physical membrane separation process, such as microfiltration (MF) and ultrafiltration (UF), with conventional activated sludge (CAS) treatment (Hai et al., 2014). Compared to CAS treatment, MBR has several significant advantages, including better effluent quality, longer sludge retention time (SRT), lower sludge production, smaller physical footprint, and easier operation and maintenance (Judd, 2008). It has been well established that MBR can enhance the removal of moderately biodegradable and hydrophobic TrOCs in comparison with CAS treatment (Besha et al., 2017). However, several hydrophilic and biologically persistent TrOCs, such as diclofenac, atrazine, and carbamazepine, cannot be effectively removed by MBR, with removal efficacy less than 30% (Tadkaew et al., 2011). For high quality water reuse, additional treatment processes, such as reverse osmosis (RO), nanofiltration (NF), ultraviolet disinfection, and advanced oxidation, are typically used in series to purify MBR effluent (Shannon et al., 2008).

A novel MBR, namely osmotic membrane bioreactor (OMBR), has been recently developed to advance wastewater treatment and reuse. Unlike conventional MBR using hydraulic pressure MF and UF membrane processes, OMBR combines forward osmosis (FO) with biological treatment (Achilli et al., 2009; Chen et al., 2014; Nguyen et al., 2016a). In OMBR operation, biologically treated water is transported from the

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https://doi.org/10.1016/j.biortech.2018.02.101
Received 13 January 2018; Received in revised form 19 February 2018; Accepted 22 February 2018
0960-8524/

Please cite this article as: Song, X., Bioresource Technology (2018), https://doi.org/10.1016/j.biortech.2018.02.101

mixed liquor, through a semipermeable FO membrane, into a highly concentrated draw solution side, under the osmotic pressure gradient. Previous studies have demonstrated the superior performance of OMBR over conventional MBR, especially in terms of higher effluent quality, lower membrane fouling propensity, and higher membrane fouling reversibility (Holloway et al., 2015a; Wang et al., 2016a).

Despite the promise of OMBR in advanced wastewater treatment and reuse, its further development is hurdled by several drawbacks, particularly salinity build-up in the bioreactor (Luo et al., 2014a). During OMBR operation, salinity build-up in the bioreactor occurs due to high salt rejection by the FO membrane and reverse diffusion of the draw solution. Thus, salinity build-up is more severe for OMBR using inorganic draw solutions, such as sodium chloride (NaCl) and magnesium chloride ($MgCl_2$), which are able to contribute high osmotic pressure for water transport, but also have relatively high reverse permeation (Ge et al., 2013). It has been established that salinity build-up can negatively affected the OMBR performance by reducing water flux, aggravating membrane fouling, altering biomass characteristics and bacterial community structure, thereby deteriorating biological treatment (Lay et al., 2010; Wang et al., 2016a). As a result, several strategies have been proposed to mitigate salinity build-up in the bioreactor for sustainable OMBR operation. Nevertheless, the promise of these proposed strategies in practical applications has not been comprehensively evaluated and compared.

This review aims to provide an in-depth understanding of salinity build-up in the bioreactor during OMBR operation by comprehensively elucidating its mechanisms and associated impacts. Potential cures to salinity build-up in OMBR are critically evaluated regarding their pros and cons in practical applications. This review would guide and inform future research for the management of salinity build-up in the bioreactor to sustain OMBR development.

2. Osmotic membrane bioreactor for wastewater treatment and reuse

OMBR integrates FO, an osmotically driven membrane process, with biological treatment, typically CAS treatment (Fig. 1). During OMBR operation, wastewater is biologically treated in the bioreactor and then diffuses through the FO membrane into a highly saline solution, such as seawater or inorganic salt solutions. Since osmotic pressure gradient is used as driving force, OMBR has been considered as a low fouling alternative to conventional MBR, where water transport is driven by hydraulic pressure difference (Achilli et al., 2009). In addition, the semi-permeable FO membrane can effectively retain contaminants to prolong their retention time in the bioreactor for further biodegradation. Thus, the effluent quality from OMBR is higher than that of conventional MBR (Luo et al., 2017). For instance, the effective removal of TrOCs by OMBR has been well reported (Fig. 2), given the complementarity between the highly selective FO membrane and biological treatment.

OMBR can be operated either in osmotic dilution mode or in combination with an additional process to re-concentrate draw solution and produce reusable water (Fig. 1). In the osmotic dilution mode, draw solution, such as seawater and fertilizers, can be discharged or reused directly and the extraction of clean water is not necessary (Xie et al., 2015b; Ansari et al., 2016), thereby allowing OMBR to consume much less energy than conventional MBR. When the production of clean water is needed, a desalination process, such as RO or membrane distillation (MD), is commonly integrated with OMBR (Holloway et al., 2015a). The desalination process subsequent to OMBR can provide an additional barrier to further improve the product water quality. On the other hand, high contaminant removal by OMBR can prevent the downstream membrane process from severe fouling. Luo et al. (2017) demonstrated that although the RO membrane subsequent to OMBR (i.e., OMBR-RO) was operated at a high hydraulic pressure (approximately 40 bar) to overcome the osmotic pressure of draw solution (i.e., 0.5 M NaCl), its fouling was much less significant than that used for the purification of conventional MBR effluent (i.e., MBR-RO), where the hydraulic pressure applied to the RO membrane increased considerably, and frequent membrane cleaning or replacement was necessary to sustain the water flux. Given the low fouling propensity of the FO membrane and the mitigation of the RO membrane fouling, there can be a potential reduction in the operational cost of OMBR-RO for membrane cleaning and replacement in comparison with conventional MBR-RO. Cornelissen et al. (2011) reported that OMBR-RO could reduce the operational outlay of wastewater treatment and reuse by 5–25% with water flux constant at 15 L/m^2h compared to conventional MBR-RO using the UF membrane. Although such stable water flux is still a challenge to current OMBR and its hybrid systems, these studies shed light on their development to advance wastewater treatment and reuse.

Recent research progress has also led to the variation of typical OMBR by integrating the FO membrane with different biological treatment processes, such as anaerobic digesters (Chen et al., 2014; Gu et al., 2015), moving bed biofilm reactor (Nguyen et al., 2015), and attached growth biofilm reactor (Nguyen et al., 2016b). As a notable

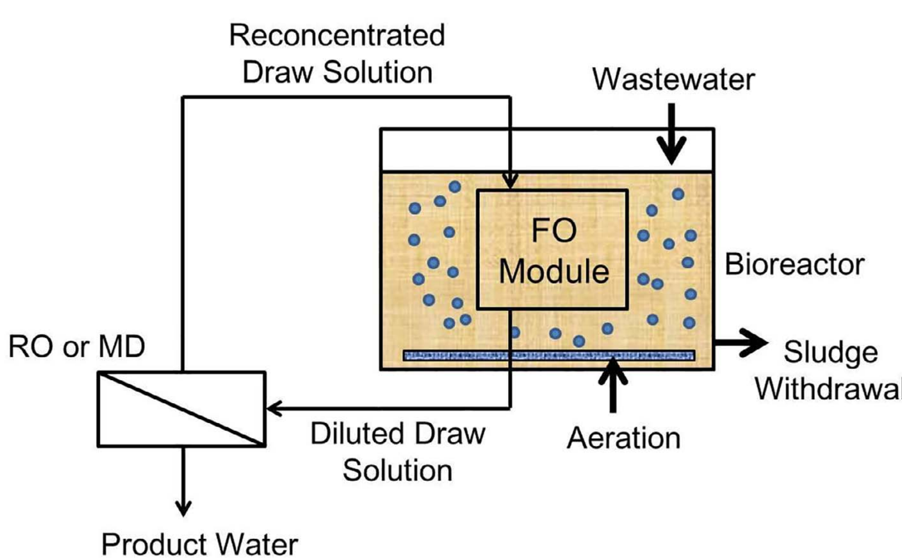

Fig. 1. Schematic diagram of the OMBR hybrid system for wastewater treatment and reuse. Varying bioreactor is applicable, depending on seeded biomass and operational conditions. OMBR can also be operated in osmotic dilution mode without post-treatment (e.g., RO and MD) for draw solution recovery and clean water production.