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Evaluating ionic organic draw solutes in osmotic membrane bioreactors for water reuse

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ABSTRACT

The performance of two ionic organic draw solutes, namely sodium acetate (NaOAc) and ethylene-diamine-tetra acetic acid disodium salt (EDTA-2Na), during osmotic membrane bioreactor (OMBR) operation was investigated in this study. Their performance was compared to that of sodium chloride (NaCl). A reverse osmosis (RO) process was integrated with OMBR to form an OMBR-RO hybrid system for draw solute recovery and clean water production. Results show that the NaOAc and EDTA-2Na draw solutes significantly reduced salinity build-up in the bioreactor in comparison with NaCl during OMBR operation. At the same osmotic pressure, these two ionic organic draw solutions produced slightly lower water flux, but considerably less reverse salt flux than NaCl. Compared to NaCl and NaOAc, EDTA-2Na resulted in significantly less fouling to the forward osmosis membrane. Regardless of the draw solutes, the OMBR-RO hybrid system could remove all 31 trace organic contaminants investigated in this study by more than 97%. Results reported here suggest that ionic organic draw solutes can be used to mitigate salinity build-up in the bioreactor during OMBR operation.

1. Introduction

Inadequate access to clean water is a pervasive problem currently afflicting billions of people globally [1]. Water scarcity is further exacerbated by climate change, urbanisation, population growth, and environmental pollution. In recent years, there have been many dedicated efforts to develop and improve treatment processes that utilize alternative water sources, such as municipal wastewater, to augment water supply and alleviate water scarcity.

Water reuse has been identified as an effective and pragmatic approach to simultaneously address water scarcity and environmental pollution. A major obstacle to water reuse is the unreliable and often low removal of trace organic contaminants (TrOCs) by conventional wastewater treatment processes [2]. TrOCs occur ubiquitously in municipal wastewater at trace concentrations (from a few ng/L to several μg/L) that present a potential health risk to humans and other living organisms [3]. As a result, a typical indirect potable water reuse scheme requires a series of advanced treatment processes to further purify the secondary treated effluent from a conventional wastewater treatment plant. These treatment processes often include microfiltration (MF) or ultrafiltration (UF), reverse osmosis (RO), and ultraviolet (UV) irradiation or other advanced oxidation processes [1,4]. The operation of multiple treatment barriers is, however, inherently complex and expensive. Thus, a strategic focus of the water industry is to simplify operation and reduce treatment cost while maintaining a high treatment standard.

Recent research progress in wastewater treatment and reuse has led to the development of osmotic membrane bioreactor (OMBR) [5–8]. OMBR utilizes forward osmosis (FO) to extract treated water from a bioreactor mixed liquor into a highly concentrated draw solution. A subsequent separation process, such as RO or membrane distillation, is often used for draw solute recovery and clean water production [9]. By employing a selective, semi-permeable FO membrane, various emerging TrOCs can be effectively retained in the bioreactor for further biodegradation. Indeed, several studies have demonstrated the potential of OMBR for enhanced removal of TrOCs [10,11]. In addition, due to the use of osmotic pressure as the driving force, FO has a lower membrane fouling propensity than pressure-driven membrane processes (e.g. MF and UF) [12]. Although fouling does occur to the FO membrane, it is reversible in most cases [13].

Salinity build-up in the bioreactor is a key issue associated with

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OMBR due to the reverse draw solute flux and high salt rejection by the FO membrane. The elevated salinity in the bioreactor can reduce the effective driving force (i.e. transmembrane osmotic pressure) for water permeation, alter microbial community [14,15], and increase soluble microbial products (SMP) and extracellular polymeric substance (EPS) in the mixed liquor, thereby deteriorating the biological treatment and aggravating membrane fouling [16]. Thus, several approaches have been proposed to address the challenge of salinity build-up during OMBR operation. These include regular sludge wastage and integrating an MF or UF process with OMBR to bleed out dissolved inorganic salts from the bioreactor [11,17,18].

Another promising approach to control salinity build-up in OMBR operation is to use ionic organic draw solutes because organic salts that diffuse into the bioreactor can be biodegraded by activated sludge [9,19,20]. However, with a very few exceptions, ionic organic draw solutes have only been evaluated in FO applications. Bowden et al. [19] investigated the performance (i.e. the water and reverse salt fluxes) of several ionic organic draw solutes in FO operation and proposed the potential of sodium and magnesium based organic draw solutes for OMBR applications. Ansari et al. [20] subsequently suggested the benefits of ionic organic draw solutes, particularly sodium acetate (NaOAc), over their inorganic counterparts in anaerobic OMBR applications by evaluating their performance in FO operation to pre-concentrate municipal wastewater for subsequent anaerobic treatment. In a recent study, Nguyen et al. [8] observed a stable water flux and low salinity build-up in the bioreactor over 68 days when ethylene-diamine-tetra acetic acid disodium salt (EDTA-2Na) coupled with polyethylene glycol *tert*-octylphenyl ether (Triton X-100) was used as the draw solute for a novel OMBR, in which FO was integrated with a moving bed biofilm reactor (MBBR). Nevertheless, the performance of ionic organic draw solutes in OMBR applications with conventional activated sludge treatment is still mostly unknown.

This study aims to evaluate the performance of two ionic organic draw solutes, namely NaOAc and EDTA-2Na, in OMBR operation. Their performance was compared to that of a widely used sodium chloride (NaCl) draw solute in terms of water flux, membrane fouling, and biological stability of OMBR. A cross-flow RO process was integrated with OMBR to form an OMBR-RO hybrid system for draw solute recovery and clean water production. TrOC removal by the hybrid system with each draw solute was also analysed. Results reported here provide important insights for managing salinity build-up in the bioreactor and determining suitable draw solutes for practical OMBR applications.

2. Materials and methods

2.1. Draw solutes

NaOAc and EDTA-2Na were selected to represent ionic organic draw solutes widely used in recent FO applications. NaOAc is highly biodegradable and produces comparable water flux, but considerably less reverse salt flux than NaCl during FO operation [19,20]. EDTA-2Na has been proposed as an alternative draw solute to NaCl due to its small reverse salt flux in FO applications for sludge dewatering [21] and wastewater pre-concentration [20].

In this study, the performance of these two ionic organic draw solutes was compared to that of NaCl at a solution osmotic pressure of 23 bar (approximately the osmotic pressure of seawater). Based on the simulation results obtained from the OLI Stream Analyser software (OLI Systems, Morris Plains, NJ), the three draw solutions were 0.6 M NaOAc, 0.3 M EDTA-2Na, and 0.5 M NaCl. To completely dissolve the solute, the EDTA-2Na draw solution pH was adjusted to pH 8 using a concentrated NaOH solution. No pH adjustment was applied to the NaOAc and NaCl draw solutions, which had an intrinsic pH of approximately 8.5 and 7.5, respectively.

2.2. Synthetic wastewater and trace organic contaminants

A synthetic wastewater, simulating medium strength municipal sewage, was used to feed the OMBR. The synthetic wastewater was prepared daily and contained 100 mg/L glucose, 100 mg/L peptone, 17.5 mg/L KH_2PO_4, 17.5 mg/L $MgSO_4$, 10 mg/L $FeSO_4$, 225 mg/L CH_3COONa, and 35 mg/L urea [22].

A stock solution containing 25 μg/mL of each of the 31 TrOCs was prepared in pure methanol and stored at −18 °C in the dark. The stock solution was introduced into the synthetic wastewater to obtain a concentration of 5 μg/L of each compound in each draw solute experiment. The TrOC stock solution was used within a month. These TrOCs were selected to represent four major groups of emerging contaminants of significant concern – endocrine disrupting compounds, pharmaceutical and personal care products, industrial chemicals, and pesticides – that occur ubiquitously in municipal wastewater. Key physicochemical properties of these TrOCs are summarized in Table S1 of the Supplementary data. Based on their effective octanol-water partition coefficient (Log D) at solution pH 8, the 31 TrOCs investigated here could be classified as hydrophobic (i.e. Log D > 3.2) and hydrophilic (i.e. Log D < 3.2) [23].

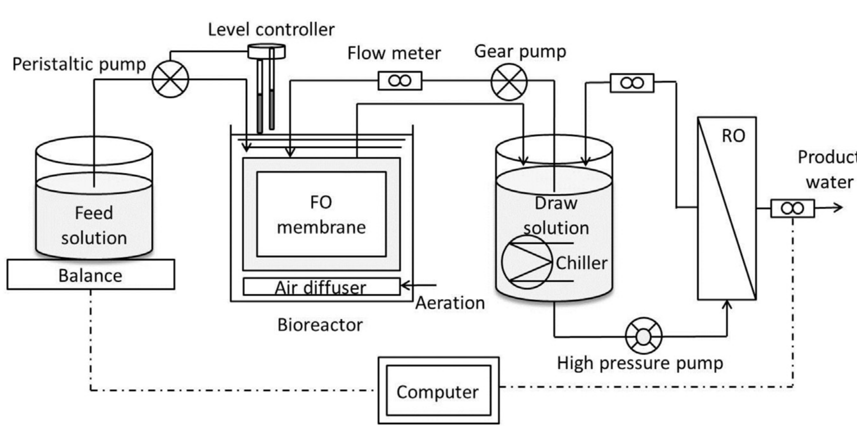

Fig. 1. Schematic diagram of a bench-scale OMBR-RO system.