Bioresource Technology 240 (2017) 149–156

Contents lists available at ScienceDirect

Bioresource Technology

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

Influence of fertilizer draw solution properties on the process performance and microbial community structure in a side-stream anaerobic fertilizer-drawn forward osmosis – ultrafiltration bioreactor

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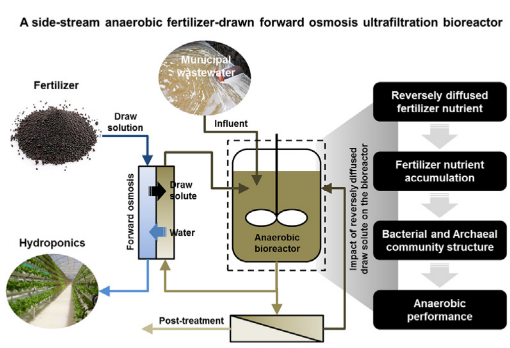
HIGHLIGHTS

- Flux decline in FDFO was very severe regardless of fertilizer DS.
- Properties of fertilizer DS significantly affected water flux recovery.
- Fertilizer properties considerably affected nutrient accumulation in a bioreactor.
- Nutrient accumulation had a significant impact on biogas production.
- Bacterial and archaeal community structure was varied by nutrient accumulation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 29 December 2016
Received in revised form 21 February 2017
Accepted 22 February 2017
Available online 27 February 2017

Keywords:
Anaerobic osmotic bioreactor
Fertilizer-drawn forward osmosis
Biogas production
Salt accumulation
Pyrosequencing

ABSTRACT

In this study, a side-stream anaerobic fertilizer-drawn forward osmosis (FDFO) and ultrafiltration (UF) membrane bioreactor (MBR) hybrid system was proposed and operated for 55 days. The FDFO performance was first investigated in terms of flux decline with various fertilizers draw solution. Flux decline was very severe with all fertilizers due to the absence of aeration and the sticky property of sludge. Flux recovery by physical cleaning varied significantly amongst tested fertilizers which seriously affected biofouling in FDFO via reverse salt flux (RSF). Besides, RSF had a significant impact on nutrient accumulation in the bioreactor. These results indicated that nutrient accumulation negatively influenced the anaerobic activity. To elucidate these phenomena, bacterial and archaeal community structures were analyzed by pyrosequencing. Results showed that bacterial community structure was affected by fertilizer properties with less impact on archaeal community structure, which resulted in a reduction in biogas production and an increase in nitrogen content.

1. Introduction

Freshwater resources are getting scarcer due to the impacts of global warming, and rapid and extensive industrialization and urbanization (Rijsberman, 2006). Agricultural sectors consume

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http://dx.doi.org/10.1016/j.biortech.2017.02.098
0960-8524/

about 70% of the accessible freshwater with about 15–35% of water being used unsustainably (Clay, 2004). Therefore, Mediterranean countries, which are stressed by water shortage, have considered wastewater reuse as a viable alternative water resource for agricultural purposes (Angelakis et al., 1999). However, since wastewater reuse is often limited due to the presence of harmful heavy metals, industrial waste, pharmaceutical and personal care products (PPCPs), and excess salts (Snyder et al., 2003), adequate treatment of wastewater before reuse for irrigation is essential not only to protect the human and plant health but also to enhance the value of the crops grown through wastewater reuse (Ferro et al., 2015). Therefore, advanced treatment processes (e.g., reverse osmosis (RO), nanofiltration (NF) or advanced oxidation) are generally required as a post-treatment process since wastewater could contain pollutants which are not removed by conventional treatment processes (Ahluwalia and Goyal, 2007).

Anaerobic membrane bioreactor (AnMBR) has been studied to treat wastewater and has several advantages including complete rejection of suspended solids, low sludge production, high organic rejection and biogas production (Stuckey, 2012). However, post-treatment processes such as RO and NF exhibit high fouling issues which ultimately increase energy requirements since these processes are driven by hydraulic pressure (Kim et al., 2014). To overcome these issues, osmotic membrane bioreactor (OMBR) has been proposed by integrating AnMBR with forward osmosis (FO) process instead of conventional pressurized membrane processes (Achilli et al., 2009). OMBR can provide high rejection of contaminants, low fouling propensity and high fouling reversibility but has limitations, such as that pure water should be extracted from draw solution (DS) and reversely transported draw solutes can be toxic or inhibit the biological processes (Achilli et al., 2009; Kim et al., 2016). Moreover, the reverse diffusion of draw solutes has been shown to exacerbate the salt accumulation in the bioreactor, which can, as a side effect, accelerate the inhibition impact on the biological performance (Luo et al., 2017; Qiu and Ting, 2013) by altering the microbial community structure and reduce the water flux in FO (Kim, 2014).

Fertilizer-drawn forward osmosis (FDFO) has received increased attention since the diluted fertilizer solution can be utilized directly for irrigation purpose and thus the diluted DS separation and recovery process is not required (Phuntsho et al., 2011). However the diluted fertilizer solution still requires substantial dilution since the final nutrient concentration can exceed the standard nutrient requirements for irrigation especially using feed water sources with high salinity (Phuntsho et al., 2011). Thus, NF can be employed as a post-treatment process for further dilution to meet the water quality requirements for fertigation (Phuntsho et al., 2013). However, FDFO was shown to be more suitable for the treatment of low salinity impaired water sources such as municipal wastewater (Chekli et al., 2017) so that desired fertilizer dilution can be achieved without the need of a NF post-treatment process. Thus, recently, an anaerobic FDFO membrane bioreactor hybrid system (AnFDFOMBR) was proposed by combining FDFO and AnMBR for simultaneous wastewater treatment for greenhouse hydroponic application (Kim et al., 2016).

Despite of many advantages (i.e., complete rejection of pollutants, low energy requirement and high fouling reversibility) of the AnFDFOMBR hybrid system, it also has critical issues including salt accumulation in the bioreactor similar to OMBR (Kim, 2014; Xiao et al., 2011). When considering the typical submerged AnFDFOMBR hybrid system, salt accumulation takes place in the bioreactor from both the influent and DS. This is due to wastewater being continuously fed into the bioreactor and the FO membrane rejecting almost 100% of ionic compounds and the back diffusion of the DS. Salt concentration will continuously increase and therefore may affect the microbial activity of the anaerobic bacteria as well as FO performances (Kim et al., 2016). Therefore, many researchers have tried to mitigate the salt accumulation by combining OMBR with porous membrane technologies (e.g., microfiltration (MF) and ultrafiltration (UF)) (Wang et al., 2014) and desalting technologies (e.g., capacitive deionization (CDI) and electrodialysis (ED)) (Lu and He, 2015).

In this study, a side-stream anaerobic FDFO-UF-MBR hybrid system (An-FDFO-UF-MBR) is proposed for simultaneous wastewater treatment for greenhouse hydroponic application based on the concept described in Fig. S1 of the Supporting Information. Side-stream FO and UF membrane modules are used since membrane fouling in the side-stream system is readily controlled by simple physical cleaning compared to the submerged system. UF plays an important role to reduce and mitigate salt accumulation in the bioreactor. In this system, raw municipal wastewater is utilized as the influent and a highly concentrated fertilizer solution is used as DS. Thus, the diluted fertilizer solution can then be obtained and supplied to greenhouse hydroponic irrigation. The UF permeate can be also utilized to recover fertilizers due to its high nutrient content (Luo et al., 2016b).

Therefore, this study aims to investigate the impact of various fertilizer DS on the anaerobic FDFO-UF-MBR hybrid process for treating municipal wastewater in order to understand how fertilizers influence the hybrid process, especially the anaerobic process via a microbial community analysis and find out the optimum design for successful and sustainable operation. FO performance in terms of flux decline was firstly evaluated with various fertilizer DS. During the operation, salt accumulation and biogas production were monitored. Besides, bacterial and archaeal community structures of the sludge were characterized through pyrosequencing analysis to investigate the effect of fertilizer DS on variations of bacterial and archaeal structures and their relationship to biogas production and composition. Even though there are some studies available on anaerobic OMBR (AnOMBR), the present study will provide valuable information on the effect of various draw solutes on the performance and microbial community variation in AnOMBR; which has not been investigated yet.

2. Materials and methods

2.1. Feed and draw solutions

Synthetic municipal wastewater with chemical oxygen demand (COD) of 400 ± 10 mg/L consisting of food ingredients, chemical compounds and trace metals was used as FS in this study (Table S1). Three different chemical fertilizers (i.e., mono-ammonium phosphate (MAP), mono-potassium phosphate (MKP) and potassium chloride (KCl)) as DS were prepared by dissolving fertilizers in the deionized (DI) water. Detailed information of fertilizer chemicals is provided in Table S2. Osmotic pressure, effective diffusion coefficient and viscosity of three fertilizers were obtained by OLI Stream Analyzer 3.2 (OLI System Inc., Morris Plains, NJ, USA). All chemicals of reagent grade were received in powder form from Sigma Aldrich (Saudi Arabia).

2.2. A lab-scale side-stream anaerobic fertilizer-drawn forward osmosis – ultrafiltration membrane bioreactor

A lab-scale side-stream An-FDFO-UF-MBR unit (Fig. 1) consisted of a completely mixing bioreactor (Applikon Biotechnology, the Netherlands) with effective volume of 2 L controlled by a level sensor (temperature 35 ± 1 °C, pH 7 ± 0.1 and stirring speed 200 ± 2 rpm), a side-stream crossflow hollow fibre UF membrane module and a side-stream crossflow flat-sheet FO membrane module. The FO membrane was provided by Hydration Technology Innovations (Albany, OR, USA) and made of cellulose-based poly-