Journal of Membrane Science 527 (2017) 1–7

Contents lists available at ScienceDirect

Journal of Membrane Science

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

Development of a novel anaerobic membrane bioreactor simultaneously integrating microfiltration and forward osmosis membranes for low-strength wastewater treatment

Xinhua Wang[a,*], Chen Wang[a], Chuyang Y. Tang[b], Taozhan Hu[a], Xiufen Li[a,*], Yueping Ren[a]

[a] Jiangsu Key Laboratory of Anaerobic Biotechnology, School of Environmental and Civil Engineering, Jiangnan University, Wuxi 214122, PR China
[b] Department of Civil Engineering, The University of Hong Kong, Pokfulam, Hong Kong, PR China

ARTICLE INFO

Keywords:
Wastewater treatment
Osmotic membrane bioreactor
Anaerobic bioreactor
Forward osmosis
Microfiltration

ABSTRACT

Anaerobic osmotic membrane bioreactor (AnOMBR) has aroused growing interests for its low energy demand, ability to efficiently process low ionic strength wastewater and high effluent quality. However, salt accumulation remains a main obstacle for causing severe water flux decline, fouling aggravation and inhibitory on the microbial activity. Here, we report a novel microfiltration (MF) assisted AnOMBR (AnMF-OMBR) for mitigating salt accumulation. The results indicated that the MF membrane effectively prevented salt accumulation in the bioreactor. The stable salinity level (within the range of 2.5–4.0 mS/cm) enabled the AnMF-OMBR to achieve a long-term continuous operation together with a higher methane production in comparison with a conventional AnOMBR. The forward osmosis (FO) permeate from the AnMF-OMBR had excellent water quality, while the MF permeate required further treatment (e.g., phosphorus precipitation and activated carbon adsorption) before its beneficial reuse. A thick fouling layer combining biofouling and inorganic scaling was existed on the FO membrane. Further confocal laser scanning microscopy (CLSM) revealed the dominance of polysaccharides and microorganisms over proteins. The current study demonstrated that the AnMF-OMBR can be a promising and sustainable wastewater treatment technology for its simultaneous energy recovery (in the form of biogas) and water reuse (from both FO and MF membranes).

1. Introduction

Anaerobic technology has drawn increasing attentions for low-strength wastewater treatment owing to its low energy demand and energy recovery from methane-rich biogas [1,2]. However, the anaerobic microorganisms with a slow growing rate were the most obstacle for the anaerobic technology treating low-strength wastewater because of the lower production of biogas and worse effluent water quality [1,2]. In order to address this problem, the microfiltration (MF) and ultrafiltration (UF) membranes are integrated into the anaerobic biological process (AnMBR) for retaining the anaerobic biomass [1–3]. Compared to the conventional anaerobic technology for low-strength wastewater treatment, AnMBRs have many advantages such as improved effluent quality, enhanced methane conversion and reduced waste biosolids production [1,2,4]. However, they also have critical challenges including serious membrane fouling, low water flux, high capital and operational costs.

Forward osmosis (FO) has been recognized as a promising technology for wastewater reclamation and seawater desalination [5,6]. FO membrane has better retention for organic matters especially small molecular weight substances, nitrogen and phosphorus that cannot be retained by MF and UF membranes [5,6]. Furthermore, osmotic pressure driving and mild operating flux lead to a lower fouling trend of FO membrane [7,8]. These advantages prompted the studies on novel anaerobic osmotic membrane bioreactors (AnOMBRs) utilizing FO membrane instead of MF and UF membranes [9–11].

Previous studies have demonstrated better contaminants removal and effluent water quality of AnOMBRs [9–11], e.g., the removal efficiency of organic matters, ammonia-nitrogen (NH_4^+-N) and total phosphorus (TP) was approximately 96%, 62% and 100%, respectively. Nevertheless, Tang and co-workers [9,11] reported severe flux decline of FO membrane mainly owing to the salinity build-up in the bioreactor. Furthermore, based on previous literature on salinity build-up in osmotic membrane bioreactors (OMBRs) [12–19], salt accumulation will also induce fouling aggravation and adversely affect the microbial activity in AnOMBRs. According to the existing publications on AnOMBRs, salt accumulation was controlled only by stopping the operation for sludge sediment and periodical supernatant discharge

* Corresponding authors.
E-mail addresses: xhwang@jiangnan.edu.cn (X. Wang), xfli@jiangnan.edu.cn (X. Li).

http://dx.doi.org/10.1016/j.memsci.2016.12.062
Received 11 October 2016; Received in revised form 28 December 2016; Accepted 29 December 2016
Available online 03 January 2017
0376-7388/

[9,11], which prevents the continuous operation of AnOMBRs and also could not avoid the increase of salinity in one cycle. Thus, it is necessary to mitigate salt accumulation in AnOMBRs.

We are inspired by the successful integration of MF and UF with aerobic OMBRs in the existing literature, where the porous MF and UF membranes are used to enable the removal of soluble salts while retaining biomass in the bioreactor [8,16,17]. In the current study, we report the application of an MF membrane for mitigating the salinity build-up in AnOMBRs and the performance of a novel MF-assisted AnOMBR (AnMF-OMBR). So far, studies on using the MF membrane for controlling salinity in AnOMBRs have not been found in current literature. Thus, the aims of current study are to investigate whether the MF membrane can be used for mitigating the high salinity in AnOMBRs or not, and to evaluate the performance of AnMF-OMBR including water flux level, removals of organic matters and nutrient, biogas production rate and membrane fouling.

2. Materials and methods

2.1. Experimental set-up

A laboratory-scale AnMF-OMBR having an effective volume of 4.98 L and the on-line determinations of conductivity, oxidation-reduction potential (ORP), pH and temperature by a data collecting system was used in this study (Fig. 1). An FO and an MF membrane modules (each with an effective area of 0.025 m^2) were immersed in the anaerobic biomass. The FO membrane (cellulose triacetate (CTA), supplied by Hydration Technologies Inc.) had an orientation of active layer facing the mixed liquors. NaCl solution with a concentration of 0.5 M was used as the draw solution with a flow rate of 0.4 L/min. The draw solution salinity was kept stable through a conductivity controller equipped with a NaCl solution of 5 M. The MF membrane (polyvinylidene fluoride (PVDF)), Zizheng Environment Inc., China) with a nominal pore size of 0.20 μm was operated under the mode of stable flux, and its water flux was controlled by a peristaltic pump. Produced biogas was recycled with a recirculation rate of 2 L/min for alleviating the membrane fouling and mixing the anaerobic biomass.

During the whole experiment, the AnMF-OMBR was operated at the temperature of 25 ± 0.5 °C. Its sludge retention time (SRT) was controlled at 80 days, and its hydraulic retention time (HRT) varied in a range of 35–60 h due to the flux drop of FO membrane. The synthetic domestic wastewater was used as the influent water with the chemical oxygen demand (COD), total organic carbon (TOC), TP, NH_4^+-N and total nitrogen (TN) concentrations of 372.6 ± 7.19, 123.97 ± 2.23, 2.97 ± 0.14, 28.26 ± 0.51 and 42.42 ± 1.19 mg/L, respectively. The composition of synthetic wastewater has been listed in previous literature [20,21]. The dewatering sludge from a municipal wastewater treatment plant (Taihu Xincheng WTP, Wuxi, China) was applied as the seeded sludge. Before the seeded sludge was put into the AnMF-OMBR, it was cultivated in a fermentation flask with a volume of 5 L by the synthetic wastewater for approximately 60 days at the temperature of 25 ± 0.5 °C. The initial sludge concentration in the AnMF-OMBR was 3.2 and 2.6 g/L for mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS), respectively.

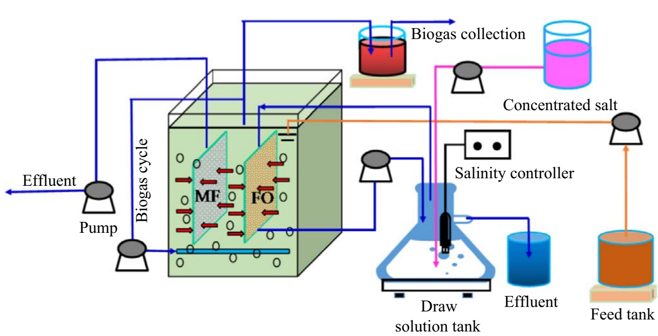

Fig. 1. Schematic diagram of the AnMF-OMBR system.

2.2. Analytical methods

The analytical methods on the general indexes of FO membrane flux, conductivity of the anaerobic biomass and TOC concentration of water samples could be found in our previous studies [15,16]. Measurements of TN, TP, NH_4^+-N, MLSS and MLVSS were conducted by the Standard Methods [22]. The specific procedures for soluble microbial products (SMP) and bound extracellular polymer substances (BEPS) extractions were summarized in previous studies [20,21], and the sum of polysaccharide (applied the phenol sulfuric acid method [23]) and protein (determined by a modified Lowry method [24]) was used to represent the concentrations of SMP and BEPS.

The fouled membranes collected from the AnMF-OMBR at the end of the operation were cut into some pieces for further analyses. Their morphology and inorganic composition were characterized by a scanning electron microscopy (SEM) (S-4800, Hitachi S4800, Japan) and an energy diffusive X-ray (EDX) analyzer (Falcon, EDAX Inc., America), respectively. The pre-treatment of FO membrane samples for SEM and EDX analyses has been listed in previous studies [16,25]. According to previous reports [25–27], Fluorescein isothiocyanate (FITC), SYTO 63, Concanavalin A (ConA) and Calcofluor white (CW) were applied as the fluorescent probes for characterizing the proteins, total cells, α-D-glucopyranose and β-D-glucopyranose polysaccharides on the FO membrane, respectively. The specific staining method can be found in our previous studies [25,26]. The stained FO membrane samples were observed by a confocal laser scanning microscopy (CLSM, LEICA TCS SP5, Germany) with the excitation/emission wavelengths of 638 nm/650–700 nm, 488 nm/500–540 nm, 552 nm/550–600 nm and 405 nm/410–480 nm for SYTO 63, FITC, Con A and CW, respectively, and then the LASAFE confocal software was applied for obtaining the three dimensional images.

3. Results and discussion

3.1. Water flux and salinity build-up

FO membrane flux and the conductivity of mixed liquor in the AnMF-OMBR are illustrated in Fig. 2. The conductivity of mixed liquor in the AnMF-OMBR was kept at a low level of 2.5–4.0 mS/cm. It was about one magnitude lower than that reported for a submerged AnOMBR treating low-strength wastewater [9], which clearly demon-

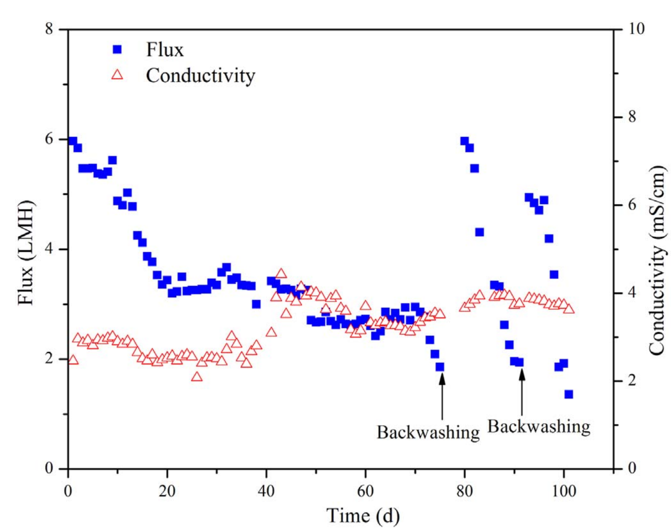

Fig. 2. Changes of conductivity of the mixed liquor and FO membrane flux in the AnMF-OMBR.