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A Comparative Study of Aerobic Granule and Activated Sludge Based Dynamic Membrane Reactors for Wastewater Treatment

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Abstract

Dynamic membrane bioreactor (DMBR), as a new development of membrane bioreactor (MBR) technology, has attracted increasing attention recently. However, the effluent quality is usually affected by an incomplete rejection of sludge flocs and other suspended solids (SS) by the meshes. Herein, a novel aerobic granule dynamic membrane bioreactor (AGDMBR) is proposed. A comparison of the AGDMBR and DMBR systems was made in this study. According to the results, AGDMBR not only had higher NH4+ and turbidity removal, but also exhibited better anti-fouling capability than DMBR, implying a high potential of this technology for low-cost and efficient wastewater treatment.

Keywords: Aerobic granule (AG); Activated sludge (AS); Dynamic membrane bioreactor (DMBR); Membrane fouling; Wastewater treatment

Introduction

Membrane bioreactor (MBR), as a compact and high-efficient biological wastewater treatment technology, has seen rapid development and widespread application in the past few decades. However, high cost and membrane fouling are still two major challenges of this technology in practical application [1,2]. This has intrigued intensive studies to lower the membrane cost and improve the anti-fouling ability of membranes [3]. Among these, one important research direction is to substitute the conventional microfiltration (MF) or ultrafiltration (UF) membranes with low-cost macro-pore materials (usually above 10 μm), such as nylon mesh, stainless steel mesh and nonwoven fabrics [4-6]. These materials are used as a support media to facilitate the built-up of a layer of biocake, which features numerous micropores and micro-channel structures and can thus serve as the real filter for sludge- water separation [7,8]. Since the thickness and composition of this biocake layer may vary dynamically with the proceeding of filtration, such reactors are also referred to as dynamic membrane bioreactor (DMBR) [9,10]. This biocake can be readily in-situ removed and rapidly rebuilt on the surface of macro-pore materials, thus membrane fouling can be easily controlled [8]. Moreover, the low material cost and gravity-driven filtration mode further add up to its economic benefits over conventional MBR [11]. However, one common disadvantage of most DMBRs is a relatively high SS in the effluent, attributed to an unstable biocake layer that cannot reject all the SS. This is especially true at the initial stage of biocake formation when the size of pores is relatively large. In that case, the fine floc sludge and other particles may directly penetrate through the thin biocake layer, leading to poor effluent quality [12]. The effluent SS would decline with the built-up of a dense biocake. But when the biocake becomes too thick and dense, the filtration resistance would increase rapidly, leading to “membrane” fouling [8]. Thus, a key to the success of this technology is to maintain an appropriate biocake layer.

In view of the fact that biocake properties are closely associated with the sludge characteristics [13,14], it is thus reasonable to expect that better filtration performance can be achieved by a proper manipulation of the sludge characteristics. This creates a possibility of integrating aerobic granules (AG) into DMBR operation. AG have also attracted increasing interest recently for wastewater treatment application, attributed to its many superior properties, such as higher settleability, better treatment efficiency and easier separation, over activated sludge (AS) flocs [15,16]. On the one hand, AG, with larger size than AS, would have less chance to directly penetrate through the biocake and mesh, thus ensuring better effluent quality. On the other, a more porous biocake layer would form attributed to the more compact and strong structure of AG than AS, thus further lowering the filtration resistance and extending the stable filtration time.

Therefore, this study aims to validate the above two assumptions and compare the performances of AGDMBR and conventional DMBR for wastewater treatment. Apart from sludge characteristics, the filtration and treatment performances of this process are also significantly affected by the filtration flux. Thus, the filtration and wastewater treatment performances of these two systems under different filtration flux were evaluated.

Materials and Methods

Reactor setup and operation

The AGDMBR was consisted of a 4L column plexiglass reactor and a dynamic membrane module. A schematic diagram of the reactor and membrane module configurations is shown in Figure 1. The total effective membrane surface was 0.02 m2, and the average pore size of nylon mesh was 70 μm. Wastewater was continuously fed into the reactor at a constant rate of 0.6 L/h, except when the impact of different filtration fluxes was investigated. Effluent was discharged semi-continuously under the control of a solenoid valve at cycles of 10-min on/ 10-min off. Aeration was provided at the bottom of the

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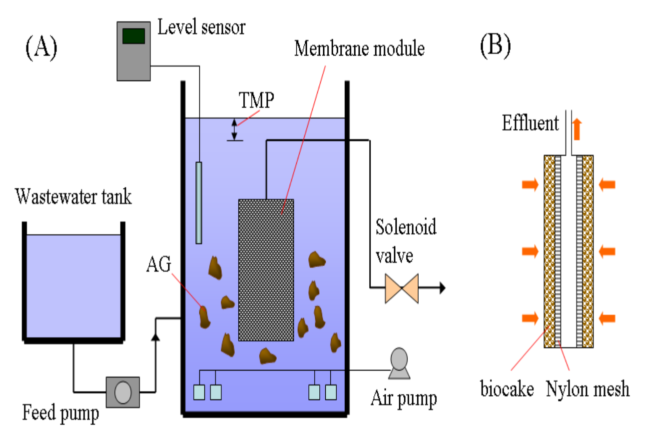

Figure 1: Schematic diagram of A) AGDMBR and B) membrane module.

reactor by an air pump. For comparison, an identical reactor but under normal DMBR mode (continuous effluent discharge and seeded with AS) was used as the control.

Gravity-driven filtration was adopted in both reactors. The transmembrane pressure (TMP) can be reflected by the water head drop across the membrane. Once the TMP increase exceeded 4 cm in water head, the membrane module was taken out to physically remove the biocake through water flushing, and then installed back for a next cycle of filtration.

AG and AS, both from other bench-scale reactors, were seeded into the AGDMBR and DMBR respectively. Synthetic wastewater, with similar composition as reported by Kimura et al. [17] except for a chemical oxygen demand (COD) concentration of 400 mg/L, was used for the experiment. During the operation, the mixed liquor suspended solids (MLVSS) concentration in both reactors were maintained at about 4 g/L, and the aeration rate were 0.1 m3/h. All the reactors were operated at ambient temperature of 25°C.

Analysis

The water levels of the reactors were real-time monitored by a level sensor (LD187, Leide Electronic Technology, China). The MLVSS, sludge volume index (SVI), COD and ammonia (NH4+) concentrations were measured following the Standard Methods (APHA-AWWA-WEF, 1998). The effluent turbidity was measured using a turbidimeter (WGZ-20, XinRui Instrument Co., China). The EPS content was analyzed using the method described in previous studies [18]. In addition, a piece of fouled nylon mesh cut from the membrane module, after removal of the surface biocake, was observed using scanning electron microscopy (SEM, XL-30 ESEM, FEI Co., USA). The procedures of pretreatment and SEM analysis were the same as described in Li et al. [8].

Results and Discussion

Characteristics of AS and AG

When treatment performances of the reactors became stable, the AG and AS sample were taken from the reactors and characterized. Compared with the fine flocs of AS, AG exhibited larger size, more compact structure, better settleability (reflected by a lower SVI) and higher content of extracellular polymer substances (EPS) (Figure 2 and Table 1).

Wastewater treatment performances

The wastewater treatment performances of the two reactors in terms of COD, NH4+ and turbidity removal were evaluated. As shown in Figure 3A, AGDMBR showed comparable high COD removal rates with DMBR (up to 97%) throughout the experimental period. However, a slightly higher NH4+ removal was achieved in the AGDMBR (95% in average) than the DMBR (89% in average), possibly attributed to a better retention of the slow-growing nitrifying bacteria in AG than AS (Figure 3B). More significant difference was observed in the effluent turbidity of the two reactors (Figure 3C), indicating a rejection of more solid particles in the AGDMBR.

Anti-fouling capabilities

Figure 4 illustrates the filtration performances of the two reactors during the 28d operation. Once the TMP exceeded 4 cm, the membrane was taken out and flushed to remove the biocake layer. During this period, the membrane was flushed for three times for the DMBR, but only once for the AGDMBR, indicating a better anti-fouling capability of the AG system than AS. Although AG had a higher EPS content than AS, this did not cause severe membrane fouling because the EPS is not a major pollutant in such DMBR system during short-period operation [8].

Furthermore, the impact of filtration flux on the fouling behaviors of the two reactors was investigated. To facilitate the comparison, both systems were operated on a continuous basis with a filtration flux of 60 L/ (m2.h). It is shown in Figure 5 that AG system showed a lower fouling rate than AS system, which is consistent with the results in Figure 4.

This better anti-fouling capability of AG might be attributed to the formation of a more porous biocake layer than AS. While the AS biocake tends to be compacted when it gets thick, the AG can remain a good porous structure attributed to its higher mechanical strength. After the 18h of filtration, the membranes were taken from both reactors to remove the surface biocake layer before SEM observation. As shown Figure 6, there was no pore blocking in the AG system attributed to a higher AG size than the mesh pore size. In contrast, a

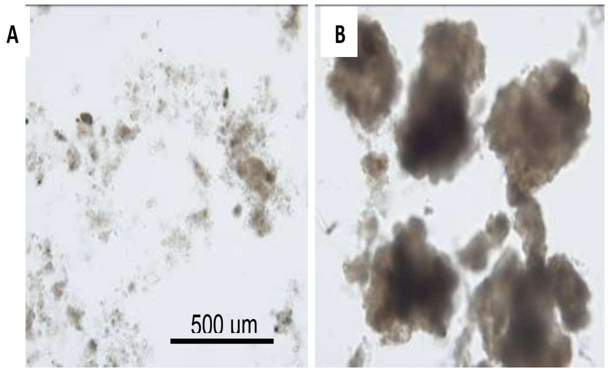

Figure 2: Microscopic photos of A) floc sludge, and B) granules.

Properties	AS	AG
SVI (mL/g)	112 ± 7	41 ± 4
Size (mm)	<0.1	0.4~1.1
EPS content (mg/g-MLVSS)	135.0 ± 10.7	94.8 ± 6.5

Table 1: Characteristics of AS and AG in DMBRs.

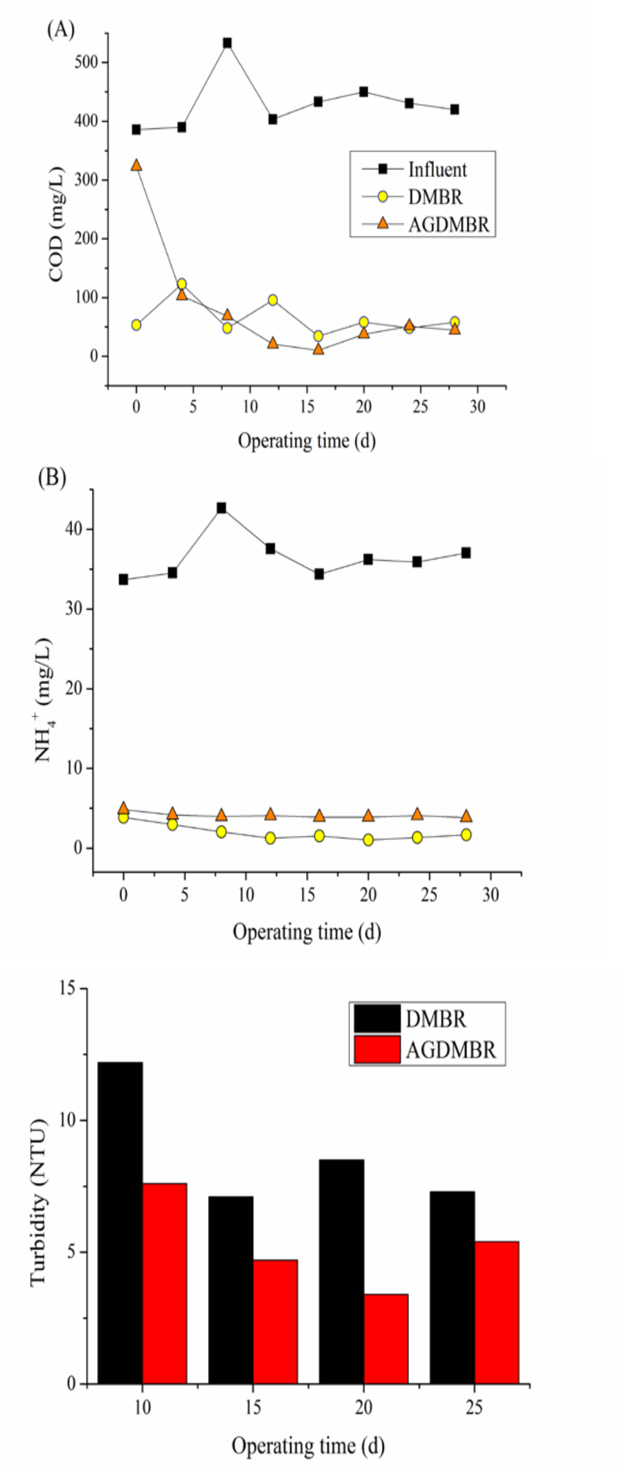

Figure 3: Treatment performance of DMBR and AGDMBR: A) COD removal; B) NH4+ removal; C) effluent turbidity.

considerable amount of AS was found in the pores, leading to higher filtration resistance.

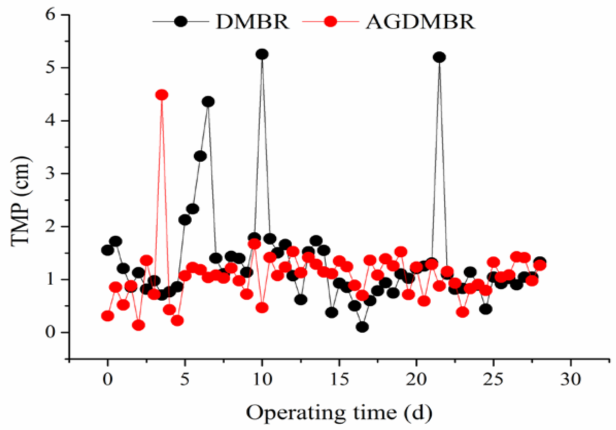

Figure 4: TMP variations during filtration operation of DMBR and AGDMBR.

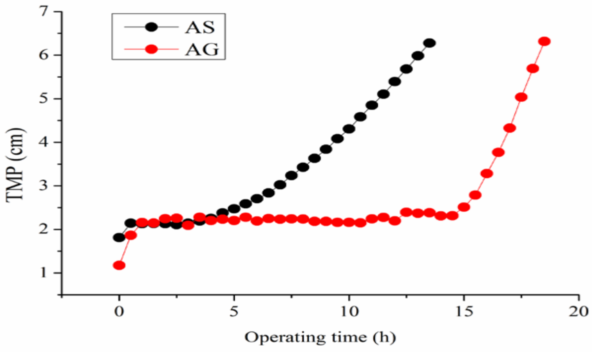

Figure 5: TMP profiles for continuous process with filtration flux of 60 L/ (m².h).

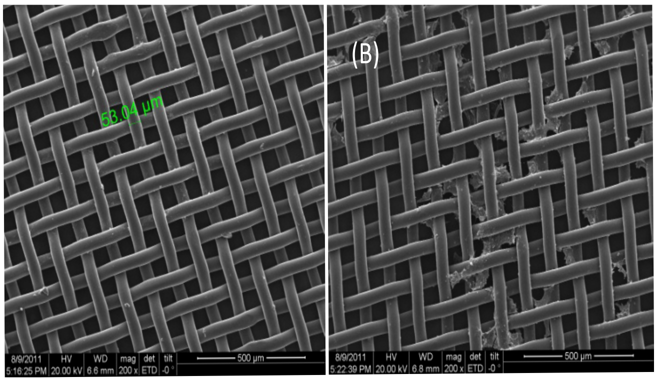

Figure 6: SEM images of fouled nylon mesh, after cleaning, from: A) AG system; B) AS system.

Conclusion

In this study, a novel AGDMBR system was introduced for wastewater treatment, and its performance was compared with an AS-based DMBR. The AGDMBR featured excellent COD removal and higher NH4+ and turbidity removal than the DMBR. In addition, it also exhibited better anti-fouling capacity than DMBR attributed to the formation of a more porous biocake layer, implying a high potential of this ADGMBR process for low-cost and efficient wastewater treatment.

Acknowledgements

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