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Operation performance and membrane fouling of a spiral symmetry stream anaerobic membrane bioreactor supplemented with biogas aeration

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ABSTRACT

The performances and membrane fouling of the spiral symmetry stream anaerobic membrane bioreactor (SSS-AnMBR) during stable operation period with and without biogas aeration were studied. The organic loading rate (OLR) and chemical oxygen demand (COD) removal rate of the SSS-AnMBR with aeration biogas condition were 2.28 kgCOD/(m^3 d) and 98.24%, respectively, higher than those without biogas aeration (2.13 kgCOD/(m^3 d) and 97.58%, respectively). Biogas aeration could reduce effectively membrane fouling, and the service time of the membrane was twice as much as without biogas aeration. Without biogas aeration, the main causes of membrane fouling were high total solids, volatile suspended solids and total extracellular polymeric substances (EPS) on the membrane surface; with biogas aeration, the main causes of membrane fouling were high slime-EPS, polysaccharide (PS) and small value of PN/PS on the membrane surface.

1. Introduction

Anaerobic membrane bioreactors (AnMBRs) were increasingly used for treating organic wastewater since it could endure high strength influent, prevent biomass wash-out and achieve high quality effluent [8]. As a hybrid system of anaerobic biotechnology and membrane separation, the performance of AnMBR was indeed dominated by both the anaerobic bioreactor and the membrane module, whose optimizations were paid much attention to improve the overall performance of the AnMBR these years.

Recently, high-rate anaerobic bioreactors were progressively employed in the AnMBRs. A upflow anaerobic sludge blanket (UASB) reactor coupled with a submerged ultrafiltration membrane was used by Gouveia et al. [13] for the treatment of municipal wastewater at psychrophilic conditions, and reached a total oxygen chemical demand (tCOD) removal rate of around 90%. An expended granular sludge bed (EGSB) membrane bioreactor was adopted by Chu et al. [6] for treating domestic wastewater under moderate to low temperature, reaching a tCOD removal rate of 85–96%. Our group was inspired from those, a super-high-rate spiral symmetry stream anaerobic bioreactor (SSSAB) with organic loading rate (OLR) of 361.5 kg COD/(m^3 d) [4] was employed to integrate with an external type flat membrane module, and then a SSS-AnMBR system was established.

In the aspect of membrane module, it is widely acknowledged that the application of AnMBR is often hindered by membrane fouling. Many strategies have been tried by researchers to alleviate the problem. One of main strategies to alleviate the membrane fouling was circulating mixed liquor [16]. Although high shear force by the circulation of mixed liquor could reduce the membrane fouling significantly, it would also inhibit the activity of microorganisms [15]. In addition, since the concentrate was recycled to the bioreactor, it could lead to deterioration of distribution of particle size and microbial community [23]. Given this, some other measures were attempted to improve system efficiency and simultaneously alleviate membrane fouling significantly. Kim et al. [17] filled granular activated carbon as microorganism growth medium into the reactor, thus the granular activated carbon could be fluidized and then scour the surface of membrane. However, the membrane surface collision will arise and result in more serious damage of membrane material compared with other systems due to a long-term high strength scouring by activated carbon.

Interestingly, some researchers employed recirculating biogas to reduce membrane fouling. Lin et al. [20] studied the formation of sludge cake under the various biogas sparging rates in a submerged anaerobic membrane bioreactor, where biogas sparging could decrease the cake formation rate. Therefore, a gas-pressure regulator tank, which could enable the stable circulation-pressure gas to flush membrane

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surface and then prolong membrane life, was integrated into the SSS-AnMBR system.

Nevertheless, lacking of the control (without biogas aeration) for previously test (2010) made the mechanisms of membrane fouling control unclear, and the current studies about the influence of EPS on membrane fouling mainly focused on the EPS extracted from bulk sludge, while the impact of various EPS (i.e. S-EPS, LB-EPS and TB-EPS) extracted from the cake sludge has few been taken into account [10]. Moreover, the operational performance and membrane fouling characteristics of the novel SSS-AnMBR system are still unknown. Thus, the objective of this study was to investigate operational performance of SSS-AnMBR system without and with biogas aeration by analyzing their organic matter removal, volatile fatty acids (VFA), alkalinity (ALK), pH and constant membrane flux. More investigations may be of some interest for exploring membrane fouling mechanism by monitoring trans-membrane pressure (TMP) and extracellular polymeric substances (EPS) of outer membrane surface and its composition.

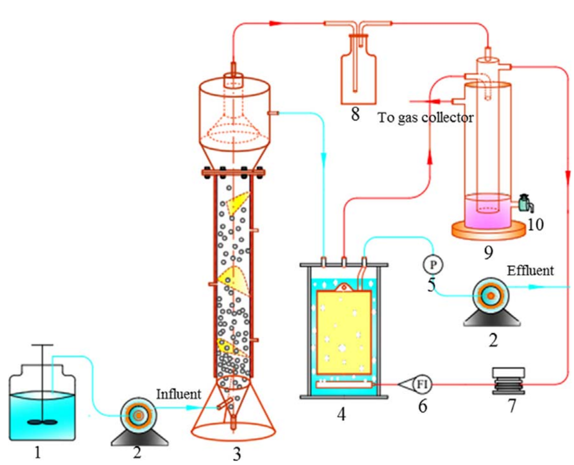
2. Materials and methods

2.1. Inoculum and wastewater

The SSSAB was seeded with anaerobic granular sludge obtained from the bottom of a 400 m^3 full-scale internal circulation reactor treating wastewater in a papermaking plant at Wuxi, China. The characteristics of the anaerobic granular sludge were previously detailed [7]. The reactor inoculated possessed a mixed liquor volatile suspended solid (MLVSS) concentration of 41.60 g/L and mixed liquor suspended solids (MLSS) concentration of 56.08 g/L, and the VSS/SS of the inocula was 0.73. The synthetic wastewater with sucrose as the carbon source was used as influent in the continuous experiments. Nutrients and trace elements solution were also added into the influent and the mass ration of C:N:P was kept about 300:5:1, and compositions of the nutrients and trace elements could be found in our previous study [5]. $NaHCO_3$ was added to buffer pH at 6.8–7.2.

2.2. Experimental setup and operational strategy

Fig. 1 presented the schematic diagram of the SSS-AnMBR system. The SSSAB involved had a total volume of 8.3 L and an effective volume of 6.5 L. The temperature of the SSSAB was kept constant at 33 ± 1 °C by circulating hot water in the insulation layer of the reactor. The membrane module used in this study was a flat microfiltration made by



1 influent tank; 2 pristaltic pump; 3 anaerobic reactor; 4 membrane module;

5 digital pressure switch; 6 gas-flow meter; 7 Diaphragm pump; 8 Safety bottle;

9 Gas-pressure regulating tank; 10 Pressure regulating valve

Fig. 1. Schematic diagram of SSS-AnMBR.

polyvinylidene fluoride (SINAP, China) with a pore size of 0.1 μm and an effective filtration area of 0.1 m^2. The membrane module was placed in an 11.0 L membrane tank (Fig. 1(4)).

A start-up period of SSSAB before membrane incorporation lasting for 33 days was conducted to ensure the subsequent stable operation of the SSSAB. After that, two operation conditions (with and without biogas) for the SSS-AnMBR could be recognized for 14 days and 28 days, respectively. The system was operated at hydraulic retention time (HRT) of 24 h and the influent COD concentration ranged from 2000 to 2500 mg/L under each conditions.

During two operation conditions of the SSS-AnMBR, the wastewater was firstly treated by the SSSAB and then entered the external MBR. The membrane permeate flux was set at 3.44 LMH by peristaltic pump for water suction (Leadfluid, BT100S) according to the influent flux of SSSAB. The membrane permeate flux was maintained constant by increasing TMP at the fixed time per day and discharged intermittently (the pump with working mode of 10 min “on” and 2 min “off”).

In order to control membrane fouling, biogas produced by the anaerobic reactor was recycled by a diaphragm gas pump (YW fluid, YW07, China) and via an air diffuser to scour the membrane surface. The biogas circulation flux was 1.0 L/Min. Membrane fouling would be indicated by an increase in the normalized TMP which was recorded by a digital pressure switch (BD-801KZ, China). The SSSAB effluent may bring out anaerobic flocs to the membrane tank, and therefore no sludge addition was required in the membrane tank. Thus slight anaerobic degradation of residue organic matters would occur in the membrane tank and no concentrate was produced for circulation.

2.3. Analytical methods

The COD, alkalinity, total solids (TS) and volatile solids (VS) were determined according to standard methods [1], respectively. Volatile fatty acids (VFA) were measured referring to Wijetunga et al. [27]. TMP was recorded by a digital pressure switch (BD-801KZ , China). The morphology of membrane was observed by scanning electron microscopy (SEM) (NOVA Nanosem230, USA), and the membrane was pretreated before observation [20]. The extraction of EPS was based on the two step heating extraction [19]. TOC concentration was evaluated by a TOC analyzer (TOC-VCPH, Shimadzu, Japan). The total EPS yields in the extracts were represented by the TOC concentration. The polysaccharide (PS) was measured using the anthrone-sulfuric acid method with glucose as the standard [11]. The protein (PN) concentration in EPS was determined by BCA method [25] with Bovine Serum Albumin (BSA) as the standard.

2.4. Calculations

The COD removal efficiency of SSS-AnMBR consists of the SSSAB removal efficiency, η, and the membrane module removal rate, η_M. The membrane module load (MLR) refers to the COD removal amount per square meter per day. Their calculations are given as follows:

$$\eta = \frac{COD_{inf} - COD_{eff}}{COD_{inf}} \times 100\% \quad (1)$$

$$\eta_M = \frac{COD_{SSS} - COD_{eff}}{COD_{SSS}} \times 100\% \quad (2)$$

$$MLR = \frac{Q(COD_{SSS} - COD_{eff})}{A} \quad (3)$$

where COD_{inf}, COD_{eff}, COD_{SSS}, Q, and A are the COD of influent, effluent of SSS-AnMBR, and effluent of the SSSAB reactor, influent flow and area of the membrane, respectively.