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Impact of anaerobic dynamic membrane bioreactor configuration on treatment and filterability performance

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ABSTRACT

Submerged and external anaerobic dynamic membrane bioreactors (AnDMBRs) have been compared in terms of removal efficiency, filtration characteristics and microbial community structure. High COD removal efficiencies were obtained with both submerged and external AnDMBRs. To obtain an effective dynamic membrane (DM) layer enabling high quality permeate, longer time was required in the external AnDMBR configuration compared to the submerged one. A difference in microbial community structure was identified using pyrosequencing analyses between the submerged and external AnDMBRs. The number of archaeal types decreased in the bulk sludge of the external AnDMBR. External sludge recirculation might have had a negative effect on the archaeal community in the bulk sludge of the external AnDMBR. However, the sludge recirculation in the external AnDMBR configuration led to a filtration at lower total filtration resistance and TMP in comparison to the submerged one at the same gas sparging rate. Results showed that the submerged AnDMBR system can provide a shorter start-up period, slightly better permeate quality in terms of COD concentration, and higher biogas production in comparison to the external one in gas-lift mode.

1. Introduction

Membrane integrated anaerobic bioreactor processes (AnMBRs) offer many advantages such as independent control possibility of sludge retention time (SRT) and hydraulic retention time (HRT), small footprint, low sludge production, high effluent quality, and net energy production. Therefore, recently, a large number of scientific investigations have been performed from laboratory scale to full scale AnMBR applications for the treatment of various kinds of wastewater [1–5]. However, membrane fouling causing flux decrease and negative consequences in terms of operating costs is still an important problem that limits the widespread application of AnMBRs, especially full scale applications [6]. Cake layer formation on the membrane surface by organic and inorganic particles is the major contributor of the fouling in AnMBRs [7,8].

Cake layer formed on the membrane surface during filtration can also be used as a filter. The applicability of the cake layer as a filter for treatment of wastewaters has been researched in recent years [9–12]. Different types of low cost materials can be used as support material enabling the formation of a cake layer, which is called a dynamic membrane (DM) layer. Filtration is conducted by the DM layer instead of the filter itself in DM filtration technology. DM technology can be used in aerobic and/or anaerobic MBRs [10,11,13,14]. High organic and particulate matter removal/retention efficiency reaching 99%, was achieved by submerged anaerobic dynamic membrane bioreactors (AnDMBRs) treating high strength wastewaters in long term operation period [15]. However, higher filtration resistances and lower fluxes may be obtained in AnDMBRs compared to conventional AnMBRs because the cake layer, which is manifested in AnDMBR systems, is the main contributor to total filtration resistance and fouling [16]. Nonetheless, AnDMBR system may represent a cost effective alternative, owing to the use of low cost filter materials compared to microfiltration or ultrafiltration membranes [17]. Moreover, the DM layer can be removed when it is necessary by several physical methods without chemical cleaning, including backwashing, vibration, brushing, and/or biogas sparging; and the DM layer can re-form on the support material. Development of cost-effective filter materials, using no chemical reagents for cleaning, and net energy production can make

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AnDMBRs feasible for the treatment of waste(water) treatment, including concentrated industrial or domestic (black water) wastewater and/or sludge.

MBR configuration is an important factor to determine the optimum operation conditions for both AnMBRs and AnDMBRs. Two common configurations, called submerged and external, are generally used for AnMBR applications. The major difference between the configurations is the location of the membrane module. The membrane module can either be located inside or outside the bioreactor in AnMBR applications. In submerged AnMBR configurations, in which the membrane is located inside the bioreactor, the membrane is operated under a vacuum, brought about at the permeate site. Biogas sparging is generally used to scour the membrane surface for fouling control in submerged AnMBRs. When the membrane is located outside the bioreactor, which is called external AnMBR configuration, the membrane unit can be operated under a vacuum at the permeate site or a pressure at the feed site [1]. In the external AnMBR configurations, liquid can be delivered to the membrane unit by a liquid pump at a predetermined cross-flow velocity, or biogas can be the driving force for the mixed liquor transfer from bioreactor to the membrane unit when applying a specified gas sparging velocity (GSV). Applications of liquid pumped [18–21] and gas-lift [7,22,23] external AnMBRs have been investigated previously. Dereli et al. [24] reported that most of the full scale AnMBRs (≥95%) treating industrial wastewaters are operated in submerged AnMBR configuration. Jeison and van Lier [25] reported that gas sparging energy and membrane cost of a submerged AnMBR were approximately three times lower than those of an external (sidestream) AnMBR, for a given flux. Similarly, it was indicated that the energy demand per produced permeate flow volume for submerged AnMBR configurations was much lower than that for pumped external AnMBRs [26].

So far, most of the AnDMBR research has been conducted by using submerged membrane modules. Only a few external AnDMBR studies have been reported [14]. However, a direct comparison of submerged and external AnDMBR configurations in terms of removal efficiency and DM filterability has not been reported yet. The purpose of this study was therefore to compare the removal efficiency and filtration characteristics of submerged and external AnDMBRs treating concentrated wastewater enabling to determine the impact of AnDMBR configuration on treatment and filterability performance. Moreover, microbial community structure including bacterial and archaeal communities, and the relative abundance of microbial species in the bulk sludge of submerged and external AnDMBRs were compared by using pyrosequencing.

2. Material and methods

2.1. Experimental Set-up

Laboratory scale submerged and external AnDMBR set-ups were used in this study (Fig. 1). Glass made completely mixed anaerobic reactors with an effective volume of 7.4 L were used in both set-ups. Flat sheet membrane modules (Fig. 1) with a total filtration area of 0.014 m^2 (0.14×0.1×0.055 m) were used in the submerged and external AnDMBRs.

A polypropylene monofilament woven fabric (Lampe BV, the Netherlands) with an average pore size of 10 µm was used as the support material. Peristaltic pumps (Watson Marlow 120U/DV) were used to feed substrate into the anaerobic bioreactors and to collect permeate from the membrane modules. Transmembrane pressure (TMP) was measured by pressure sensors (AE Sensors, ATM −800/+600 mbar) placed on the permeate lines. Both submerged and external AnDMBRs were operated in gas-lift mode. Produced biogas was recycled by diaphragm pumps (KNF, N86 KTDCB) to provide mixing inside the bioreactors and to scour the DM surface for fouling control. Mixing diffuser was located at the bottom of the bioreactor and the biogas sparging diffuser was placed under the membrane module in the submerged AnDMBR (Fig. 1). Two baffles were included in order to obtain even distributed mixing conditions in the submerged AnDMBR. Distance between the baffles was 6.5 cm. Mixing was accomplished by a diffuser located at the bottom of the bioreactor in the external AnDMBR. Biogas production was measured by a gas counter (Ritter, Milligas Counter MGC-1 PMMA) in each system. Temperature and pH inside the bioreactors were measured on-line by a probe combined with a transmitter (Elscolab, M300 ISM). Each AnDMBR system was connected to a computer equipped with a LabVIEW software (LabVIEW 10.0.1, National Instruments) for pumps control and data collection.

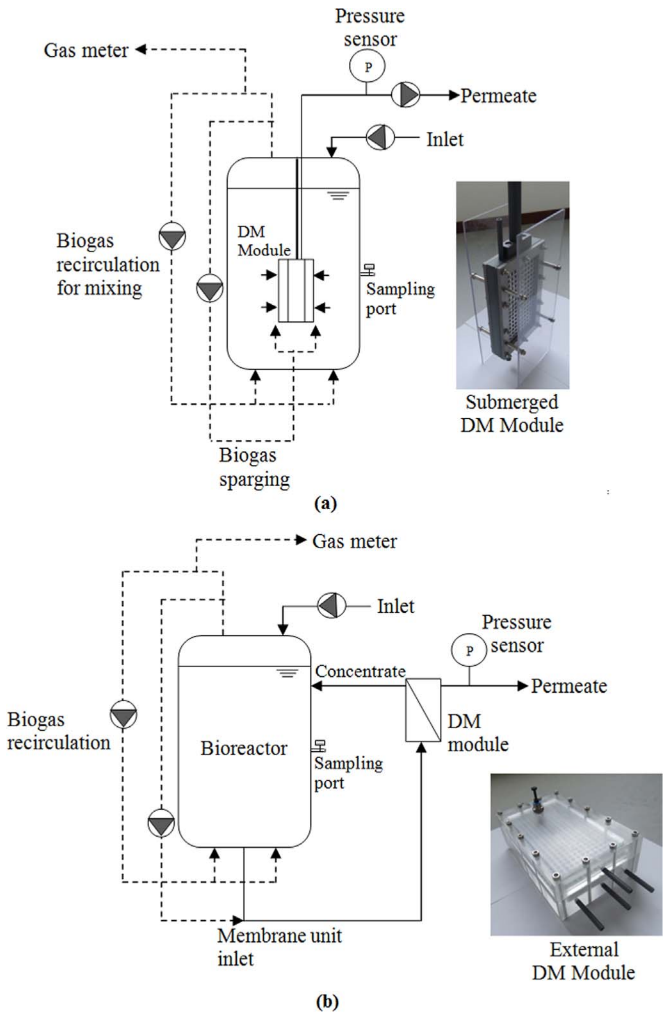

Fig. 1. Laboratory scale set-ups: (a) submerged AnDMBR, (b) external AnDMBR.

2.2. Experimental procedure

Submerged and external AnDMBRs were operated at average temperatures of 35.7 ± 0.1 °C and 35.5 ± 0.4 °C, respectively. Organic loading rate (OLR) of 2 kg COD/m^3.d was applied at a HRT of 10 days and a SRT of 40 days during the study. Average TSS concentrations inside the submerged and external AnDMBRs were 6450 ± 480 mg/L and 6400 ± 470 mg/L, respectively. VSS/TSS ratio in the bioreactors was over 85% in both configurations. The AnDMBRs were operated at a flux of 2.2 L/m^2.h. Food/mass (F/M) ratio, the ratio between the COD loading fed into the bioreactor and the MLSS concentration, was about 0.28 kg COD/kg MLSS.d in both submerged and external AnDMBRs.

Biogas sparging and backwashing were used in order to control the DM layer thickness on the surface of the woven fabric, and TMP. Both