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Submerged anaerobic membrane bioreactor for low-strength wastewater treatment: Effect of HRT and SRT on treatment performance and membrane fouling

Zhi Huang[a], Say L. Ong[a], How Y. Ng[b,*]

[a] Department of Civil Engineering, National University of Singapore, 7 Engineering Drive 1, Singapore 117576, Singapore

[b] Centre for Water Research, Division of Environmental Science and Engineering, Block EA #03-12, 9 Engineering Drive 1, Singapore 117576, Singapore

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ABSTRACT

Three 6-L submerged anaerobic membrane bioreactors (SAnMBRs) with solids retention times (SRTs) of 30, 60 and infinite days were setup for treating synthetic low-strength wastewater at hydraulic retention times (HRTs) of 12, 10 and 8 h. Total COD removal efficiencies higher than 97% were achieved at all operating conditions. Maximum biogas production rate was 0.056 L CH_4/g MLVSS d at an infinite SRT. A shorter HRT or longer SRT increased biogas production due to increased organic loading rate or enhanced dominancy of methanogenics. A decrease in HRT enhanced growth of biomass and accumulation of soluble microbial products (SMP), which accelerated membrane fouling. A drop in carbohydrate to protein ratio also inversely affected fouling. At 12-h HRT, the effect of SRT on biomass concentration in SAnMBRs was negligible and membrane fouling was controlled by variant surface modification due to different SMP compositions, i.e., higher carbohydrate and protein concentrations in SMP at longer SRT resulted in higher membrane fouling rate. At 8 and 10-h HRTs, infinite SRT in SAnMBR caused highest MLSS and SMP concentrations, which sped up particle deposition and biocake/biofilm development. At longer SRT, lower extracellular polymeric substances reduced flocculation of particulates and particle sizes, further aggravated membrane fouling.

1. Introduction

In recent years, interests in anaerobic biological treatment for low-strength wastewater have increased because of merits such as lower energy consumption, low sludge production and biogas generation. The difficulty in retaining slow-growth anaerobic microorganisms with short hydraulic retention time (HRT) is an issue of concern (Haandel and Lettinga, 1994). However, this issue could be resolved by applying membrane separation in anaerobic processes as the membrane can retain biomass effectively, producing a solids-free effluent and prevent unintended sludge wasting. Short HRT coupled with long solids retention time (SRT) to achieve high biomass concentration in a bioreactor is now possible through the use of membrane for solids–liquid separation.

Among the reported anaerobic MBR studies, most of them combined cross-flow membrane modules with anaerobic reactors and focused on high strength wastewater. Typically, extremely high biomass concentrations are achieved in anaerobic MBRs, which leads to very high COD removal efficiency of

* Corresponding author. Tel.: +65 68744777; fax: +65 67744202.
E-mail address: esenghy@nus.edu.sg (H.Y. Ng).
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around 90–98% (Ince et al., 1997; Fuchs et al., 2003). However, due to a high membrane flux or trans-membrane pressure, rapid fouling development becomes an obstacle to full-scale application of cross-flow anaerobic MBR (Ince et al., 1995, 1997; Choo and Lee, 1996; Kang et al., 2002; Fuchs et al., 2003; He et al., 2005). In addition, high hydraulic shear force stemmed from high-speed circulation pumps reduces the activity of microorganisms that, in turn, leads to reduction in biogas production (Kim et al., 2001, 2005). Only a few are related to low-strength wastewater treatment. The technical and economic feasibility of treating relatively low strength wastewater using membrane biological reactors (MBRs) under anaerobic conditions had been assessed (Sutton et al., 2004; Hall and Bérubé, 2006).

Compared to cross-flow anaerobic MBR, submerged anaerobic membrane bioreactor (SAnMBR) has attracted more interest recently with the positive experiences gained from the successful application of aerobic submerged MBR for wastewater treatment. Membrane fouling, the main operational issue, is governed mainly by membrane flux, membrane pore size and materials, operation pressure and temperature, hydrodynamics and sludge characteristics (Liao et al., 2006). To control fouling development, different strategies had been studied, including interval operation, sub-critical flux operation, periodic physical or chemical cleaning, etc. (Chang et al., 2002; Jeison and Lier, 2006a; Liao et al., 2006). Although it is expected that certain fundamental principles derived from aerobic submerged MBR are similar in SAnMBR, more detailed investigation of SAnMBR with regards to optimizing operating conditions, elucidating membrane fouling mechanism and developing fouling control strategy is required. An earlier work done by Vallero et al. (2005) has shown that SAnMBR could retain sulfate-reducing bacteria with slow-growth rate and achieve high sulfate reduction rate. Based on the concept of critical flux (Field et al., 1995), fouling mechanisms and controlling strategies were also studied (Vallero et al., 2005; Jeison and Lier, 2006b; Liao et al., 2006). However, all of these studies were conducted with high strength wastewater and under different operational conditions.

As controllable operation parameters, HRT and SRT are two major factors that contribute to different treatment performance and biomass characteristics, which inevitably affect membrane fouling development in a SAnMBR (Haandel and Lettinga, 1994; Liao et al., 2006). Membrane fouling is significantly affected by extremely high MLSS concentrations, which are found either in an aerobic MBR with long SRT (Ng and Hermanowicz, 2005) or from an anaerobic MBR treating high strength wastewater at long SRT (Jeison and Lier, 2006b). However, for a SAnMBR treating low-strength wastewater, the impacts of HRT and SRT on treatment performance and membrane fouling are still unclear. In addition, to investigate membrane fouling mechanism, soluble microbial products (SMP) and extracellular polymeric substances (EPS), which were identified as two key factors affecting membrane fouling in aerobic MBR, need to be further studied in SAnMBR systems.

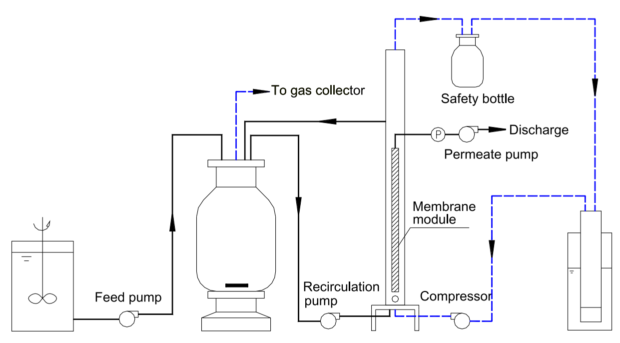
In this study, a new configuration of SAnMBR was introduced. The aim of this paper was to investigate the influences of HRT and SRT on treatment performance of the SAnMBR for treatment of low-strength wastewater. Secondly, the mechanism of membrane fouling in terms of the effect of biomass concentration, SMP and EPS at different HRTs or SRTs were elucidated.

2. Material and methods

2.1. SAnMBR setup and operating conditions

By changing the volume of daily sludge wasting, three bench-scale SAnMBRs with different SRTs, namely 30, 60 and infinite days (denoted as R30, R60 and R∞, respectively. Infinite SRT means no sludge wasting was carried out except a small-volume sludge was sampled for analysis) were operated at HRTs of 12, 10 and 8 h, successively. The ambient operating temperature varied from 25 to 30 °C.

As shown in Fig. 1, each SAnMBR system consisted of a 5-L completely mixed anaerobic reactor coupled with a 1-L gas lifter, in which a submerged plate and frame membrane module with a membrane surface area of 0.059×2 m^2 was installed. This design of having the membrane unit external to the anaerobic rector allowed ease of membrane cleaning and replacement while maintaining a strictly anaerobic environment in the bioreactor at all time. The membrane module was fabricated by mounting 2 pieces of PES microfiltration (MF) membrane (GE Osmonics, pore size 0.45 μm), with one on each side, on an acrylonitrile butadiene styrene (ABS) risen plate. Three peristaltic pumps (Masterflex, L/S) were individually used to feed influent into the anaerobic reactor, recycle mixed liquid from the anaerobic reactor to the gas lifter and withdraw permeate from the membrane module. Produced biogas was recycled by a diaphragm gas pump (KNF, NMP850) to scour the membrane surface for fouling control via an air diffuser (located below and inline with the membrane plate). Membrane fouling would be indicated by an increase in the normalized trans-membrane pressure (TMP) which was recorded by a digital pressure switch (SMC, ZSE50F) installed between the membrane module and the permeate pump and was normalized by deducting initial TMP from temporal TMP. Biogas production was measured according to the volume of biogas collected in the wetted gas collector, in which the gas pressure was maintained at 1 atm pressure. A conductance-type point level controller was applied to balance the influent



	R30	R60	R•	R30	R60	R•	R30	R60	R•
HRT, h	12	12	12	10	10	10	8	8	8
SRT, d	30	60	infinite	30	60	infinite	30	60	infinite
OLD, kgCOD/m^3.d		1.1			1.32			1.65	
Flux, L/m^2•h		5.3			6.4			7.9	
Scouring rate, cm/s		0.84			0.84			0.84	
Suction cycle					8 min on, 2 min off				

Fig. 1 – Schematic diagram of a SAnMBR and operating conditions of the three SAnMBRs.