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Anaerobic treatment of municipal wastewater with a staged anaerobic fluidized membrane bioreactor (SAF-MBR) system

Rihye Yoo [a], Jeonghwan Kim [a], Perry L. McCarty [a,b], Jaeho Bae [a,*]

[a] Department of Environmental Engineering, Inha University, Namgu, Yonghhyun dong 253, Incheon, Republic of Korea
[b] Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA

HIGHLIGHTS

- Domestic wastewater was treated with an anaerobic fluidized membrane bioreactor.
- GAC fluidization prevented membrane fouling over the 192 days of operation at 25 °C.
- A 2.3 h HRT gave effluent COD of 25 mg/L, BOD_5 of 7 mg/L, and no suspended solids.
- Biosolids production of 0.049 g VSS/g BOD_5 is much less than with aerobic systems.
- Methane energy potential was much greater than the 0.047 kWh/m^3 needed for operation.

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ABSTRACT

A laboratory-scale staged anaerobic fluidized membrane bioreactor (SAF-MBR) system was used to treat a municipal wastewater primary-clarifier effluent. It was operated continuously for 192 days at 6–11 L/m^2/h flux and trans-membrane pressure generally of 0.1 bar or less with no fouling control except the scouring effect of the fluidized granular activated carbon on membrane surfaces. With a total hydraulic retention time of 2.3 h at 25 °C, the average effluent chemical oxygen demand and biochemical oxygen demand concentrations of 25 and 7 mg/L yielded corresponding removals of 84% and 92%, respectively. Also, near complete removal of suspended solids was obtained. Biosolids production, representing 5% of the COD removed, equaled 0.049 g VSS/g BOD_5 removed, far less than the case with comparable aerobic processes. The electrical energy required for the operation of the SAF-MBR system, 0.047 kWh/m^3, could be more than satisfied by using the methane produced.

1. Introduction

With growing concerns over climate change associated with fossil-fuel utilization, anaerobic treatment of domestic wastewater is receiving increased attention (Foresti et al., 2006). Anaerobic processes not only produce methane as a renewable source of bioenergy but also consume less energy for operation than aerobic systems. In addition, the lower anaerobic waste biosolids production compared with aerobic treatment reduces the costs and difficulties associated with biosolids management. However, anaerobic treatment of domestic wastewater alone has generally not been sufficient to meet stringent effluent requirements (Gomec, 2010; Seghezzo et al., 1998; Singh et al., 1996; Takahashi et al., 2011; Yule and Anderson, 1996). To address this problem, aerobic or other post-treatment has often been used (Chan et al., 2009; Chernicharo, 2006; Khan et al., 2011; Madan et al., 2007).

An alternative treatment system is the anaerobic membrane bioreactor, which permits a long solids retention time (SRT), but a short hydraulic retention time (HRT), as microorganisms can more easily be retained within the system. In addition to allowing a smaller reactor footprint, a long SRT enhances the degradation of particulate and colloidal organics, thus improving effluent quality and reducing waste biosolids production. However, membrane fouling caused by deposition or adsorption of foulant materials on surfaces or within membrane pores is a long-standing problem. Many attempts have been made to reduce membrane fouling as the high resulting energy and operating costs have been major barriers to its application (Alan et al., 2010; Berube et al., 2006; Huang et al., 2011; Martinez-Sosa et al., 2011; Vyrides and Stuckey, 2009).

In order to reduce energy costs for membrane fouling control, a staged anaerobic fluidized membrane bioreactor (SAF-MBR) system has been proposed (Kim et al., 2011). This anaerobic system consists of an anaerobic fluidized-bed reactor (AFBR) followed by an anaerobic fluidized-bed membrane bioreactor (AFMBR). In laboratory studies with this system treating a 500 mg/L chemical

* Corresponding author. Tel.: +82 10 6242 7507; fax: +82 32 865 1425.
E-mail address: jhb@inha.ac.kr (J. Bae).

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oxygen demand (COD) synthetic wastewater with a total HRT of 5.0 h at 35 °C, an overall COD removal near 99% with permeate COD of 7 ± 4 mg/L was obtained. Membrane fouling was successfully controlled through the scouring effect of fluidized granular activated carbon (GAC) on the membrane surface, with total system energy consumption of 0.058 kWh/m^3, which is significantly less than reported for other anaerobic submerged membrane bioreactors where gas sparging has been used for fouling control.

Although the SAF-MBR system was used successfully with synthetic wastewater at elevated temperature, further research is needed to address other questions that arise before practical application. Complex suspended as well as soluble organics in settled wastewater tend to be less readily biodegradable than the soluble constituents used in the synthetic wastewater tested, which may adversely affect effluent quality (Wiegant and de Man, 1986). Furthermore, waste biosolids production with real municipal wastewater is likely to be higher than with simple synthetic wastewater. The efficiency of the SAF-MBR system when operating at ambient wastewater temperatures needs evaluation, as heating of domestic wastewater is not practical. Also of importance is the effect of sulfate reduction on methane production and effluent quality. The stability of the SAF-MBR under long-term operation needs more evaluation. Finally, for further improvements a better understanding is needed of the mechanisms by which the fluidized-bed system controls fouling without the need for the backwashing and periodic chemical cleaning that is normal for membranes when using gas-scouring for control.

To answer at least some of these questions, performance of a laboratory-scale SAF-MBR system fed primary settled municipal wastewater and operated at ambient temperature was evaluated. Evaluated were effluent quality, biosolids production, energy requirements and production, and procedures for membrane fouling control.

2. Methods

2.1. Reactor descriptions and operation

Fig. 1 is a schematic diagram of the laboratory-scale SAF-MBR system used, which is similar to that described previously (Kim et al., 2011). The first reactor in the series was an AFBR and the second an AFMBR used for effluent polishing. Both reactors were operated at 25 °C in a temperature-controlled room. The 0.245 L AFBR consisted of a 50 cm long by 25 mm diameter acrylic tube containing 30 g of 10 × 30 mesh fresh GAC (MRX-M, Calgon Carbon Corp., Pittsburgh) as support medium for bacterial growth. In addition, a 20 ml volume of GAC with attached biofilm from a laboratory-scale AFBR fed with acetate, propionate, and yeast extract was added separately. A settler at the top of the reactor was made from a 10 cm long by 75 mm diameter tube, and had a total volume of 0.442 L. A magnetic pump (Pan world magnet pump, NH-100PX-Z, Korea) was used for recirculation to maintain fluidization of the GAC.

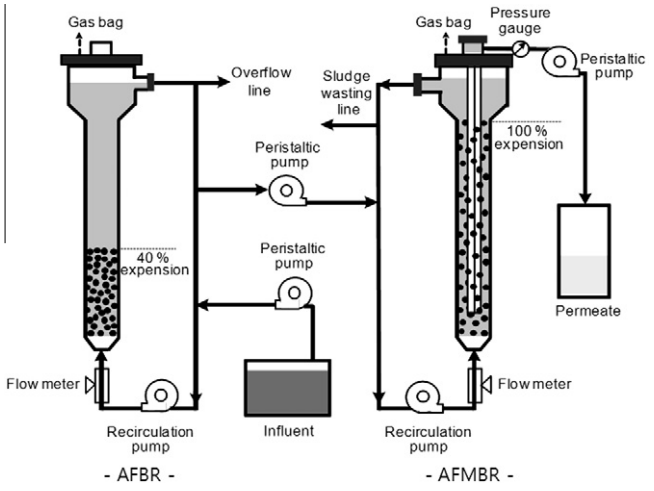

Fig. 1. Schematic diagram of the SAF-MBR system.

The AFMBR was similar to the AFBR. It also consisted of a 50 cm long by 25 mm diameter acrylic tube, but contained 54 g of fresh GAC. Additionally it contained a submerged membrane module consisting of eight 0.45 m long, polyvinylidenefluoride (PVDF) hollow-fiber membranes (Kolon Inc., Korea) with inside diameter of 1.9 mm, nominal pore size of 0.1 μm, and a total membrane surface area of 0.0215 m^2. The AFBR effluent was delivered to the AFMBR with a peristaltic pump (Masterflex, Model No. 7520-57, USA) at a flow rate that was automatically controlled to maintain a constant water level at the top of the AFMBR. Fluidization of GAC was also maintained with a magnetic pump using a controller (Blue-white, F-450) to maintain the desired flow rate (Table 1). To generate a constant permeate flow from the reactor, the top open sections of the membrane fibers were connected to a peristaltic pump (as above) set to achieve the desired membrane flux. The trans-membrane pressure (TMP) required to maintain the permeate flow was monitored with a pressure gauge.

The primary-effluent wastewater fed to the AFBR was obtained from a domestic wastewater treatment plant located in Bucheon, Korea. Primary clarifier effluent was collected weekly and stored in a 4 °C refrigerator. Before feeding, the wastewater was filtered through a 10 μm cartridge filter to remove larger particulate materials. With this filtering, about 60% of the total suspended solids (TSS) were rejected.

No efforts were made to control biofilm formation or preselected suspended solids concentrations in the reactors. However, since membranes in the AFMBR prevented the escape of suspended solids from that reactor, a procedure was used to periodically withdraw excess suspended solids form it. Here, each week an arbitrary 280 ml of reactor fluid along with the constituents it contained was withdrawn from the AFMBR's recirculation line. Additional suspended materials were periodically removed from the recirculation line walls and pumps, and were quantified. These withdrawals contained the excess biosolids or sludge production resulting from the treatment process.

The SAF-MBR system was operated under four different Modes based at hydraulic retention time (HRT), organic (COD) loading rate (OLR), and fluidization conditions as summarized in Table 1. Mode I (not listed) lasted 59 d, representing an acclimation period to reach near steady-state performance. Steady-state performance was evaluated during Modes II and III using a set-point permeate flux of 6 L/m^2/h (LMH) and 9 LMH, respectively. In Mode IV, an evaluation was made to determine the sustainable flux from the AFMBR that could be maintained without producing significant membrane fouling.

2.2. Analytical procedures

COD, 5-day biochemical oxygen demand (BOD_5), total and volatile suspend solids (TSS, VSS), ammonia, and phosphate were determined according to procedures in Standard Methods (APHA, 1998). COD was analyzed by the closed reflux titrimetric method and BOD_5 by the 5-d BOD test. To eliminate the effect of hydrogen sulfide on COD and BOD_5 measurements, effluent samples were first purged with air for 15 min after reducing sample pH to 2 by addition of hydrochloric acid. For soluble COD (SCOD) determinations, samples were filtered through 1.2 μm GF/C filters. Alkalinity was measured by the titration method (APHA, 1998) using an end