ARTICLE IN PRESS

Bioresource Technology xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

# Anaerobic treatment of low-strength wastewater: A comparison between single and staged anaerobic fluidized bed membrane bioreactors

Jaeho Bae [a,*], Chungheon Shin [a], Eunyoung Lee [a], Jeonghwan Kim [a], Perry L. McCarty [a,b]

[a] Department of Environmental Engineering, Inha University, Namgu, Inharo 100, Incheon, Republic of Korea
[b] Department of Civil and Environmental Engineering, Stanford University, Stanford, CA 94305, USA

## HIGHLIGHTS

- Performance of a single AFMBR was compared with that of a staged AFMBR system.
- The scouring effect of the GAC for fouling control was effective in both systems.
- A 2–4 h HRT gave effluent COD removal of 93–96%.
- Behaviors of SS, EPS and SMP were similar in both systems.
- The single AFMBR is an effective alternative to the staged AFMBR system.

## ARTICLE INFO

*Article history:*
Received 6 January 2014
Received in revised form 15 February 2014
Accepted 17 February 2014
Available online xxxx

*Keywords:*
Anaerobic
Fluidized-bed
Single-stage membrane bioreactor
Staged membrane bioreactor

## ABSTRACT

Performance of a single anaerobic fluidized membrane bioreactor (AFMBR) was compared with that of a staged anaerobic fluidized membrane bioreactor system (SAF-MBR) that consisted of an anaerobic fluidized bed bioreactor (AFBR) followed by an AFMBR. Both systems were fed with an equal COD mixture (200 mg/L) of acetate and propionate at 25 °C. COD removals of 93–96% were obtained by both systems, independent of the hydraulic retention times (HRT) of 2–4 h. Over more than 200 d of continuous operation, trans-membrane pressure (TMP) in both systems was less than 0.2 bar without significant membrane fouling as a result of the scouring of membrane surfaces by the moving granular activated carbon particles. Results of bulk liquid suspended solids, extracellular polymeric substances (EPS), and soluble microbial products (SMP) analyses also revealed no significant differences between the two systems, indicating the single AFMBR is an effective alternative to the SAF-MBR system.


## 1. Introduction

Recent concerns over green-house gas emissions through fossil fuel consumption has induced the search for more energy efficient low-strength wastewater treatment processes (Foresti et al., 2006; Gimenez et al., 2011; McCarty et al., 2011; Martinez-Sosa et al., 2011; Martin Garcia et al., 2013). Also, the difficulty and cost of disposal of the sludges associated with the typical aerobic wastewater treatment processes requires more creative solutions (Fytili and Zabaniotou, 2008; Rulkens, 2008; Murray et al., 2008; Yang et al., 2010). To help solving such problems, anaerobic treatment, which requires no aeration and produces much less sludge, has been suggested as an alternative process (Kim et al., 2011; Yoo et al., 2012; Smith et al., 2012, 2013). Although anaerobic processes are often believed to be unsuitable for low strength wastewater treatment, anaerobic membrane bioreactors (AnMBR) have demonstrated the capability to achieve a high quality effluent at hydraulic retention times (HRT) comparable to that of aerobic processes. Membranes prevent organism loss from the reactor, thus allowing the required long solid retention times (SRT) needed for anaerobic processes, and yield a good permeate quality through filtration.

An important issue remaining with AnMBRs is membrane fouling control. The most widely adapted membrane control method is biogas sparging, which recycles produced biogas into the reactor to provide a scouring effect on the membranes. However, the high energy requirements reported for gas sparging, 0.6–1.6 kWh/$m^3$ (Martin et al., 2011), diminishes the advantages of the AnMBR. As an alternative approach, Kim et al. (2011) proposed using fluidizing

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

http://dx.doi.org/10.1016/j.biortech.2014.02.065
0960-8524/

Please cite this article in press as: Bae, J., et al. Anaerobic treatment of low-strength wastewater: A comparison between single and staged anaerobic fluidized bed membrane bioreactors. Bioresour. Technol. (2014), http://dx.doi.org/10.1016/j.biortech.2014.02.065

granular activated carbon (GAC) particles to clean membrane surfaces by scouring. This system, the staged anaerobic fluidized membrane bioreactor (SAF-MBR), consists of an anaerobic fluidized bed reactor (AFBR) followed by an anaerobic fluidized bed membrane bioreactor (AFMBR). GAC was used as the fluidizing media for both reactors. Yoo et al. (2013) reported that a laboratory-scale SAF-MBR, when operated with a total HRT of 2.3 h, provided 84% COD removal efficiency of primary clarifier effluents from a domestic wastewater treatment plant (WWTP), even with temperatures as low as 10 °C. Only two chemical cleanings and no back flushing were needed over the 650 d of continuous operation studied, with energy consumption reported to be 0.049 kWh/m$^3$.

With the measured success of the SAF-MBR, further improvements in the system are being explored. One possible improvement is the elimination of the first AFBR, in effect combining both reactors into a single reactor. With a single AFMBR, costs for construction and maintenance might be reduced. However, a single AFMBR may be more vulnerable to membrane fouling as biomass concentration then might be higher. Also, more stable organic removal might be expected with a staged system than with a single AFMBR.

This study was conducted to evaluate the feasibility of the single AFMBR system. For the evaluation, a comparison of the performances of a single and a staged AFMBR, operating under similar operating conditions, was made. COD removal efficiencies and changes in TMP of each system were compared. Also, resulting concentrations of suspended solids, EPS and SMP within the bulk liquid of each reactor were compared.

## 2. Methods

### 2.1. Reactor configuration and operation

Fig. 1 is a schematic diagram of the SAF-MBR system, as described by Yoo et al. (2012). The first reactor, a 0.245 L AFBR, consisted of a 50 cm long by 2.5 cm diameter acrylic tube containing 10 × 30 mesh fresh GAC (Filtrasorb 300, Calgon Carbon, USA), and a settler on the top of the reactor to prevent GAC loss from the reactor column. One third of the reactor volume was filled with 40 g of GAC from another AFBR that had been treating an equal mixture of acetate and propionate wastewater. The second reactor in the system, the AFMBR, was used for polishing the AFBR effluent, and had the same configuration as the AFBR, but in addition contained eight 0.411 m long submerged polyvinylidene fluoride (PVDF) hollow fiber membrane strands having a pore size of 0.1 μm (Kolon Inc., Korea) with total surface area of 0.020 m$^2$. In this AFMBR, one third of the reactor volume was also filled, but with 46 g of virgin GAC.

The single AFMBR was similar to the second stage AFMBR in the SAF-MBR system except that it contained five membrane strands instead of eight, yielding a total surface area of 0.012 m$^2$. To keep the total HRT of both systems the same fewer membrane strands were used for the single AFMBR. Here, 40 g of GAC from the AFBR in the SAF-MBR system with its developed biofilm was used to fill the single AFMBR to one third of its volume.

Before this comparative evaluation began, both systems had been acclimated for 218–225 d using total HRTs of 3.3 h with influent COD (equal mixture of acetate and propionate) of about 200 mg/L. About 100 d initially were required for the systems to stabilize with COD removals higher than 90%. However 134 d from the beginning of the pre-comparison period, the SAF-MBR experienced problems with the recycle pump, and GAC fluidization stopped. After starting again following a month of idling, the TMP increased from 0.1 to 0.4 bar within 20 d, and so on day 219 the membranes were replaced with new ones to begin the comparison. On the other hand, the single AFMBR was operated continuously for the entire pre-comparison period of 225 d without any operational problems.

Operating conditions and results during the comparison period for the single and staged systems are listed in Tables 1 and 2, respectively. The single AFMBR was operated at four different HRTs, decreasing from 3.3 to 2.2 h. Accordingly, membrane flux and organic loading rate increased from 6 to 9 L/m$^2$/h and 1.6 to 2.2 g COD/L-d, respectively. At comparison day 74, the single AFMBR was almost completely drained as the permeate pump was operating when the feeding pump stopped. Two days after the restoration, TMP level jumped from 0.06 to 0.31 bar, as a result chemical cleaning was conducted on day 74 (Mode III) by soaking the membranes for one hour each time in 1000 mg/L NaOCl first, next in 1000 mg/L citric acid, then in 1000 mg/L NaOH, and finally rinsing with DI water. To compare the systems at similar HRTs, the SAF-MBR was operated at total HRTs of 3.0 (Mode I) and 2.1 h (Mode II). In Mode II, the HRT of the staged AFMBR was 1.3 h,

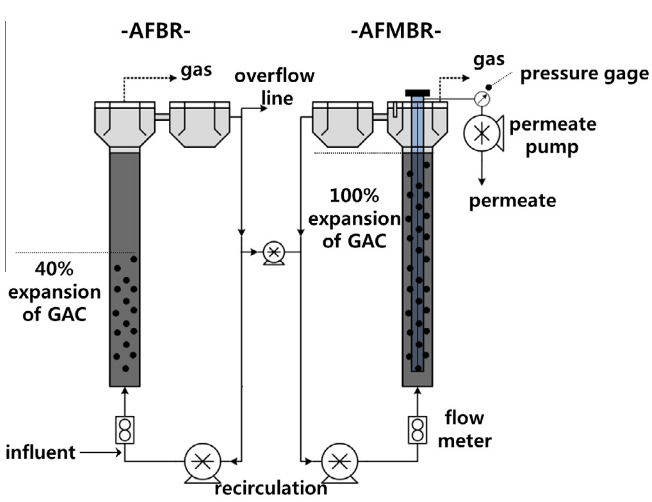


**Fig. 1.** Schematic diagram of the staged anaerobic fluidized membrane bioreactor (SAF-MBR) system.

**Table 1**
Effect of HRT on the performance of the single AFMBR.

| Mode | I | II | III[a] | IV |
|---|---|---|---|---|
| Days | 1–33 | 34–62 | 63–96 | 97–195 |
| HRT (h) | 3.3 | 2.9 | 2.5 | 2.2 |
| Membrane flux (L/m$^2$/h) | 6 | 7 | 8 | 9 |
| OLR (g COD/L-d) | 1.6 | 1.8 | 2.1 | 2.2 |
| *Influent (mg/L)* | | | | |
| TCOD | 212 (±15) | 223 (±8) | 213 (±12) | 216 (±14) |
| SCOD | 197 (±15) | 209 (±10) | 199 (±12) | 201 (±18) |
| *Effluent (mg/L)* | | | | |
| TCOD | 13 (±7) | 12 (±5) | 11 (±6) | 10 (±9) |
| SCOD | 11 (±2) | 10 (±5) | 8 (±3) | 8 (±4) |
| TSS | 4 (±1) | 1 (±0) | 4 (±3) | 4 (±2) |
| VSS | 4 (±1) | 1 (±0) | 3 (±3) | 4 (±2) |
| VFA | 0.6 (±1.1) | 0.5 (±0.6) | 1.0 (±2.0) | 1.0 (±0.9) |
| pH | 7.7 (±0.2) | 7.7 (±0.1) | 7.8 (±0.1) | 7.8 (±0.1) |
| Alkalinity | 229 (±8) | 239 (±10) | 247 (±9) | 235 (±14) |
| *n*[b] | 12 | 11 | 13 | 39 |
| *Removal (%)* | | | | |
| TCOD | 94 (±3) | 95 (±2) | 95 (±3) | 95 (±4) |
| SCOD | 94 (±2) | 95 (±2) | 96 (±2) | 96 (±2) |

[a] Day 74, chemical cleaning was performed.
[b] *n*: number of replicates.