Anaerobic dynamic membrane bioreactors for high strength wastewater treatment

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Abstract
A laboratory scale external anaerobic dynamic membrane bioreactor (AnDMBR) treating high strength wastewater was operated to assess the effect of gas sparging velocity and organic loading rate on removal efficiency and dynamic membrane (DM) filtration characteristics. An increase in gas sparging velocity (GSV) results in a decrease in DM filtration resistance. DM or cake formation was identified as the main contribution to the total filtration resistance. Over 99% COD removal was obtained in the study regardless of the GSV. The results showed that the DM formation process proceeded until a stable cake layer thickness was reached. An effective pollutant removal and high permeate quality was obtained by the effective dynamic membrane layer formation at OLRs between 2-3.6 kg COD/m^3.d. The investment and operational costs are expected to be substantially lower than the conventional membrane filtration.

Keywords
Anaerobic membrane bioreactor; dynamic membrane; feasibility; biogas sparging; organic loading rate; wastewater treatment.

INTRODUCTION

Combination of anaerobic process and membrane technology, which is called anaerobic membrane bioreactors (AnMBRs), is of growing interest in terms of high treatment efficiency, small footprint, and net energy production. Both high and low strength, e.g. industrial and municipal, wastewaters can be successfully treated and biomass can be retained effectively by the application of AnMBRs (Liao et al., 2006; Jeison and van Lier, 2007; Huang et al., 2011).

Application of dynamic membrane (DM) technology to AnMBRs is a new concept in which a cheap filter material, e.g. woven or non-woven cloth, can be used instead of a membrane (Ersahin et al., 2012). Suspended solid particles, e.g. microbial cells and flocs, in the filtered solution can accumulate and form a dynamic cake layer on an underlying support material. Since the retention is provided by the DM layer, the support filter material is protected against fouling and filter itself is not a critical variable in filtration. In order to provide a feasible and stable operation, the DM layer thickness should be controlled. Biogas sparging over the support material surface can provide the required shear force to detach excess thickness of DM. In the present study, long-term operation of external AnDMBRs for treatment of high strength wastewaters is evaluated. The effects of biogas sparging rate and organic loading rate (OLR) on removal efficiency and filtration characteristics are investigated. Moreover, cost estimation in terms of support material acquisition is also presented.

MATERIAL AND METHODS

A laboratory scale AnDMBR set-up was used in this study (Figure 1). The AnDMBR system consisted of a completely stirred tank reactor with an effective volume of 6.8 L and an external flat sheet membrane module with a filtering area of 0.018 m^2. A polypropylene woven fabric with an average pore size of 10 µm was used as the support material to form the DM layer. Produced biogas was recycled by two diaphragm pumps to provide mixing inside the bioreactor, and to convey the sludge from bioreactor to the DM module and to scour the DM surface.

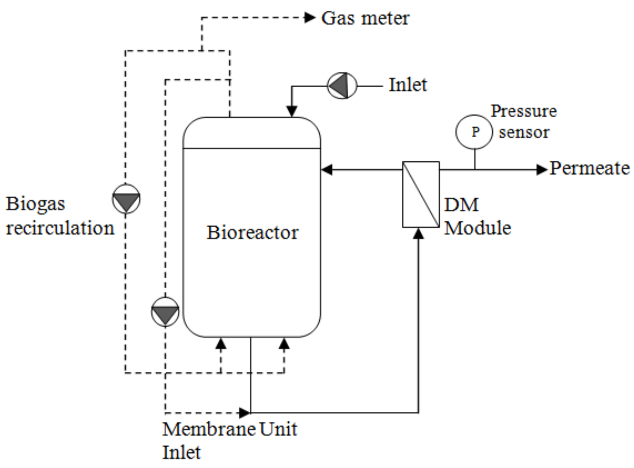

Figure 1. AnDMBR set-up lay-out

The characterization of the synthetic wastewater used in this study is given in Table 1. The AnDMBR was inoculated with anaerobic sludge from a submerged AnDMBR operated at mesophilic conditions.

Table 1. Characterization of the synthetic wastewater

Parameter	Unit	Value
COD	mg/L	20100±310
Soluble COD	mg/L	11500±95
TSS	mg/L	7400±1100
NH_4-N	mg/L	195±5
Total Nitrogen (TN)	mg/L	2340±145
Total Phosphorus (TP)	mg/L	470±10
pH	-	7.3

The AnDMBR was operated at an average temperature of 35.5±0.19 °C and a sludge retention time (SRT) of 40 days. In the first part of the study, an OLR of 2 kg COD/m^3·d was applied at a HRT of 10 days, and gas sparging velocities (GSVs) of 17, 35 and 52 m/h were tested. In the second part of the study, a constant GSV of 35 m/h was applied and the OLR was increased to 3 and 3.6 kg COD/m^3.d by decreasing the HRT to 7 and 5.5 days. The average reactor pH was 7.9±0.1 during the study. The DM unit was operated in cycles consisting of filtration phase, 190 seconds, and backwashing phase, 35 seconds by reversing the direction of the permeate pump.

RESULTS AND DISCUSSION

Effect of GSV

An effective DM layer formation is required for a stable and high pollutant removal efficiency in AnDMBRs. DM formation starts immediately after the filtration start-up (Park et al., 2004; Hu and Stuckey, 2006) and becomes effective in terms of removal in several days. DM formation duration depends on the substrate type, sludge concentration in the bioreactor and/or membrane module configuration. Effective DM layer formation was reached in 15-20 days at each GSV in this study (Figure 2). After the effective DM formation, a stable COD removal efficiency over 99% was achieved regardless of GSV within the tested range. The permeate COD concentration was below 200 mg/L after stable removal efficiency was achieved. Effluent turbidity trend (data not shown) was also consistent with COD results. The average permeate turbidity was 24.5 ±9.3 NTU standing for a turbidity removal efficiency over 99% independently of GSV. Total suspended solids (TSS) concentration of the permeate was lower than 10 mg/L over the study.

The average concentration for the mixed liquor suspended solids (MLSS) in the bioreactor was 6410±455 mg/L. The percentage of volatile suspended solids was accounted for 85% of the MLSS.

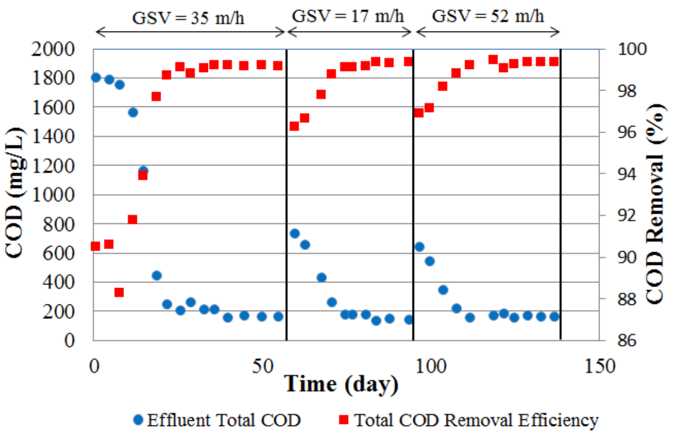

Figure 2. COD removal at different GSVs (OLR = 2 kg COD/m^3.d)

The biogas production was between 2.65-2.85 L/day and the average methane yield ranged between 0.28-0.31 L CH_4/g $COD_{removed}$ regardless of GSV. Moreover, some amount of the methane was solubilized in the effluent. Methane composition of the biogas was between 60-65%. Any noticeable effect was observed neither on the biogas production in the AnDMBR nor in the specific methanogenic activity test during the study. This result states that GSV had no remarkable effect on the biomass activity inside the reactor.

The applied flux was around 2.6 L/m^2.h during the experiments. Based on this value, support layer costs would be close to 0.15 € per m^3 of treated wastewater, assuming a filter material lifetime of 4 years and a cloth price of 13 €/m^2. Figure 3 shows the trend of TMP with operation time. It can be observed that TMP increased with operation time during the first 15-20 days until stable value was achieved. Stabilized TMP values were on average 415, 380, 360 mbar at GSVs of 17, 35, 52 m/h, respectively. These results indicate that low GSV provided a more compact and/or thicker DM layer compared to higher GSV. Most likely, at higher GSVs, abrasion occurs of larger amounts of cake layer attached on the support material and is returned back to the bioreactor. However, although the GSV was increased 1.5 times of the preceding value, the effect of GSV on the TMP trend was not in the same order of magnitude, suggesting the existence of an energetic optimum.

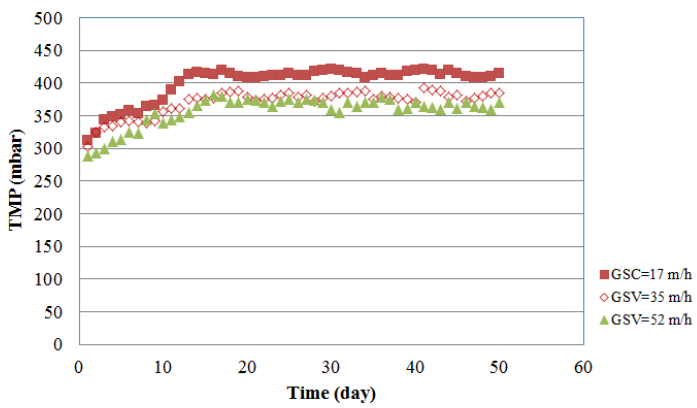

Figure 3. Variations of TMP at different GSVs.

The average filtration resistances were $7.96x10^{16}$, $7.40x10^{16}$ and $7.11x10^{16}$ m^{-1} at GSVs of 17, 35 and 52 m/h, respectively. Total filtration resistance consists of clean filter resistance, cake resistance, and pore blocking resistance. Cake resistance was expected to be the main contributor of the filtration resistance since the retention is provided by the DM layer in AnDMBRs. The resistance analysis results showed that cake layer resistance contributed over 99% to the total resistance independently of GSV. However, the cake layer resistance was 35% higher at GSV of 17 m/h compared to 52 m/h.

Effect of OLR

OLRs of 3 and 3.6 kg COD/m^3.d were applied in the AnDMBR at GSV of 35 m/h. Considering the permeate COD results, COD removal efficiency of the system was over 99% at both OLRs which was similar to the efficiency obtained for OLR of 2 kg COD/m^3.d. Although a slight increase, i.e. 15%, was observed in soluble COD concentration inside the bioreactor when OLR was increased, DM could offset this increase and the effluent COD remained stable below 200 mg/L at each OLR. Similarly, VFA results indicated that VFA concentration increased in the bulk sludge with the increase in OLR to 3.6 kg COD/m^3.d. However, the permeate VFA concentration was stable and around 10 mg/L at all OLRs, stating a VFA retention capacity of 55-65% for the DM layer. Biogas production increased to 4.5-4.7 L/day at OLR 3.6 kg COD/m^3.d.

CONCLUSIONS

The external AnDMBR process for high strength wastewater treatment achieved over 99% organic removal regardless of the GSV used, even though the total resistance increased with GSV decrease. Total filtration resistance mainly consisted of a dynamic cake layer that provided effective and stable treatment. A slight increase in TMP was observed with decreasing of GSV within the range tested. Following the OLR study, the AnDMBR achieved high COD removal efficiency at 3.6 kg COD/m^3.d. Low capital costs of support material and energy generation can make AnDMBRs feasible for those situations in which a high flux is not necessary, e.g. sludge and slurry treatment or high concentrated industrial wastewater treatment.

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REFERENCES

Ersahin, M.E., Ozgun, H., Dereli, R.K., Ozturk, I., Roest, K., van Lier, J.B. 2012. A review on dynamic membrane filtration: Materials, applications and future perspectives. *Bioresource Technology* **122**, 196-206.

Hu, A.Y., Stuckey, D.C. 2006. Treatment of dilute wastewaters using a novel submerged anaerobic membrane bioreactor. *Journal of Environmental Engineering* **132**(2), 190-198.

Huang, Z., Ong, S.L., Ng, H.Y. 2011. Submerged anaerobic membrane bioreactor for low-strength wastewater treatment: Effect of HRT and SRT on treatment performance and membrane fouling. *Water Research* **45**, 705-713.

Jeison, D., van Lier, J.B. 2007. Thermophilic treatment of acidified and partially acidified wastewater using an anaerobic submerged MBR: Factors affecting long-term operational flux. *Water Research* **41**, 3868-3879.

Liao, B.Q., Kraemer, J.T., Bagley, D.M. 2006. Anaerobic membrane bioreactors: Applications and research directions. *Critical Reviews in Environmental Science and Technology* **36**(6), 489-530.

Park, M.S., Kiso, Y., Jung, Y.J., Simase, M., Wang, W.H., Kitao, T., Min, K.S. 2004. Sludge thickening performance of mesh filtration process. *Water Science and Technology* **50**(8), 125-133.