B−17 Recovery of dissolved methane with a degassing membrane in a UASB reactor

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1. INTRODUCTION

There is an increasing interest in developing renewable energy technologies. Anaerobic digestion has been known as a renewable energy-producing process. The methane (CH_4) produced in this process can be used as a fuel. In especial, an upflow anaerobic sludge blanket (UASB) reactor is considered to be effective in treating high-strength wastewaters. In a UASB reactor, the biogas is produced in the liquid phase (bulk liquid) and then evolved to the gas phase (headspace) while a part of CH_4 is still dissolved in the bulk liquid. The dissolved CH_4 should be considered as it is not possible to be captured in the usual processes. Significance of the dissolved CH_4 has been recognized by some researchers. For example, a comparative analysis by **Hartly *et al.***[1)] confirmed that CH_4 super-saturation resulted in significant loss of CH_4 in the effluent. The CH_4 super-saturation is more significant at lower temperatures. Therefore, we operated a bench-scale UASB reactor equipped with a degassing membrane to recover the dissolved CH_4. The effect of temperature on CH_4 recovery efficiency was investigated.

2. MATERIALS AND METHODS

A bench-scale UASB reactor was operated[2)] at various temperatures and trans-membrane pressures (**Table 1**). A three-layer composite hollow fiber membrane (MHF) (Mitsubishi Rayon Engineering Co., Ltd., Tokyo, Japan) was installed in a degassing membrane reactor (DMR), which followed the UASB reactor to recover dissolved CH_4 in the bulk liquid. The UASB reactor was covered with a water jacket to maintain the temperature, on the other hand, the DMR was operated at room temperature. The UASB reactor was fed with a synthetic wastewater[2)] at a HRT of 10 h. After the gas production reached steady-state, dissolved gas in the bulk liquid was recovered through the degassing membrane using an air pump (Model APN-110KV-1, Iwaki Co., Ltd., Tokyo, Japan). The experiment was divided into 13 experimental phases based on operating conditions (i.e., trans-membrane pressure and temperature) (**Table 1**). The gas compositions in the headspace of the UASB reactor and the membrane were measured by a gas chromatography system (GC-14B; Shimadzu Co., Kyoto, Japan). The dissolved gas compositions were measured by the headspace method[2)]. The biogas volumes were measured at ambient temperature. The total CH_4 was defined as the sum of CH_4 evolved into headspace, recovered from membrane and discharged into effluent. The CH_4 recovery efficiency was defined as a ratio of headspace CH_4 plus CH_4 in the membrane to headspace CH_4. The concentrations of total COD (T-COD) and dissolved fraction of COD were measured using a Hach method (Method 8000). Particulate COD (P-COD) was calculated as T-COD minus D-COD. VFA concentrations were determined by a high-performance liquid chromatography system.

Table 1 Reactor operating condition.

Phase	Temperature (°C)	Trans-membrane pressure (kPa)
1	35	0
2	35	-50
3	35	0
4	35	-50
5	35	-80
6	35	0
7	25	0
8	25	-80
9	25	0
10	15	0
11	15	-80
12	15	0
13	35	0

3. RESULTS AND DISCUSSION

(1) COD removal.

The study was divided into 13 experimental phases based on operating conditions. Reactor performance (i.e., COD concentrations and gas production rate), temperature and pH for 13 phases are presented in **Figure 1** and average (± standard deviation) values are summarized in **Table 2**. Effluent T- and D-COD concentrations were low at the beginning of the operation with T-COD removal efficiency of more than 85%. After adjusting pH to around 7 at day 51, gas production rates into headspace became stable. These rates were significantly correlated positively with temperature. Decrease in gas production rates at lower temperatures reflected lower COD removal efficiency due to decrease in microbial activity and could be explained by increase in solubility of biogas in bulk liquid at lower temperatures. In general, most reactions in the biodegradation of organic matters require more energy to proceed at lower temperatures than at the optimum temperature of 37°C for anaerobes[3]. Hence, lowering the operational temperature leads to a decrease in the maximum specific growth and substrate utilization rates of the anaerobes. As a result, biological reactions proceed much slower under psychophysics conditions than under mesophilic conditions. Identical COD removal and gas production rates in the normal operation conditions between changes in the operating conditions (phases 1, 3, 6 and 13) showed good reproducibility of the reactor operation. Interestingly, the removal efficiency of P-COD rather than D-COD at lower temperatures tended to be improved during degassing periods. **Lettinga *et al.***[3] indicated that in psychrophilic reactors, particles would settle more slowly because of the deterioration of liquid-solid separation probably attributed to increase in the viscosity of bulk liquid at lower temperatures. This result opens up the possibility to improve COD removal efficiency by degassing of bulk liquid in a UASB reactor operated at lower temperatures.

(2) Gas production.

Figure 2 shows the headspace gas composition profiles, the production rates of CH_4 gas evolved into headspace, recovered from membrane and discharged into effluent, and CH_4 recovery efficiency in the UASB reactor. Average (± standard deviation) values of these rates and CH_4 recovery efficiency throughout the operation are summarized in **Table 3**. Degasification did not significantly affect gas compositions in the headspace of the

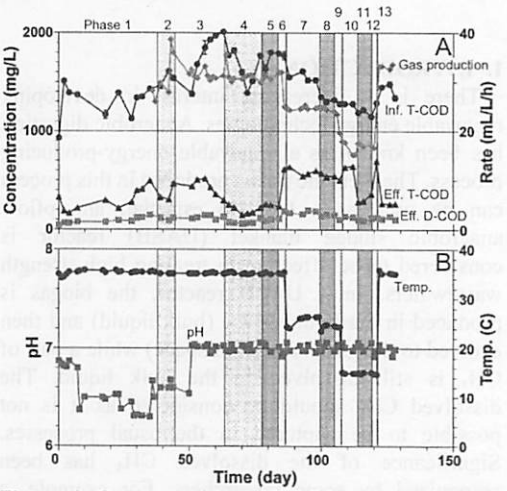

Figure 1 Concentrations of T-COD in influent and T- and D-COD in effluent, and gas production rate (A) and temperature and pH (B) in the UASB reactor. The gray area and the dotted lines represent degassing periods and the timing of change in temperature, respectively.

Table 2 Summary of average (± standard deviation) of the rates of T-COD lading, P-COD discharged and D-COD discharged, and the removal efficiencies of T-COD and D-COD in the UASB reactor. The gray area represents degassing operation.

Phase	T-COD loading (mg/L/h)	P-COD discharged (mg/L/h)	D-COD discharged (mg/L/h)	T-COD removal (%)	D-COD removal (%)
1	121 ± 13	18 ± 7	9 ± 2	78 ± 9	93 ± 2
2	140 ± 9	23 ± 8	10 ± 1	76 ± 6	93 ± 1
3	173 ± 28	28 ± 8	12 ± 2	77 ± 7	93 ± 1
4	179 ± 44	12 ± 3	8 ± 2	89 ± 3	96 ± 2
5	174 ± 15	15 ± 2	10 ± 1	86 ± 1	94 ± 1
6	169	41	18	65	89
7	152 ± 8	40 ± 5	18 ± 2	62 ± 3	88 ± 1
8	132 ± 5	40 ± 4	15 ± 1	58 ± 1	89 ± 1
9	125	39	10	61	92
10	124 ± 7	49 ± 2	13 ± 1	50 ± 1	90 ± 1
11	118 ± 6	21 ± 3	10 ± 1	74 ± 4	91 ± 1
12	129	57	12	46	90
13	143 ± 7	15 ± 2	12 ± 2	81 ± 1	92 ± 1

UASB reactor (**Figure 2A**). Exceptionally, CH_4 concentration slightly increased and CO_2 concentration decreased at 15°C. CH_4 evolution rate into headspace decreased with decrease in temperature (**Table 3**) due to decrease in gas production rate (**Figure 1A**). Dissolved CH_4 concentration increased from 63 ± 1 mg-COD/L at Phase 6 to 81 ± 6 mg-COD/L at Phase 7 and 103 ± 5 mg-COD/L at Phase 10 due to increase in solubility of CH_4 in bulk liquid at lower temperatures, resulting in more significant loss of dissolved CH_4 from the UASB reactor (**Figure 2B**). By degasification, CH_4 could be recovered from bulk liquid in the DMR and dissolved CH_4 concentration decreased (**Table 3**). The CH_4 recovery rates from membrane were higher at lower temperatures (Phases 8 and 11) as compared with that at 35°C (Phase 5) because of higher dissolved CH_4 concentrations at lower temperatures. Consequently, the CH_4 recovery rate from the headspace and the membrane at lower temperatures (Phases 8 and 11) were comparable to that during normal operation at 35°C (Phases 1, 3 and 6)). CH_4 recovery efficiencies during degassing periods were between 1.09 and 1.19 at 35°C, 1.32 at 25°C and 1.53 at 15°C. Thus, degasification was more efficient at lower temperatures. Particularly under temperate climate conditions, many low and medium strength wastewaters are discharged at low ambient temperatures. On the other hand, practically all full-scale applications of anaerobic wastewater treatment so far were restricted to wastewater with temperatures exceeding 18°C[3]. Hence, in general, a significant amount of energy is required to bring the wastewater temperature up to the optimal mesophilic range (30 to 40°C). This puts a heavy burden on the economy of the wastewater system. We concluded that the UASB reactor equipped with the DMR was a promising alternative to the conventional UASB reactor.

CONCLUSIONS

A UASB reactor equipped with the degassing membrane reactor was operated to recover dissolved CH_4 in bulk liquid. Decrease in temperature resulted in decrease in CH_4 evolution rate to the headspace. Degasification could improve total CH_4 recovery efficiency especially at lower temperatures.

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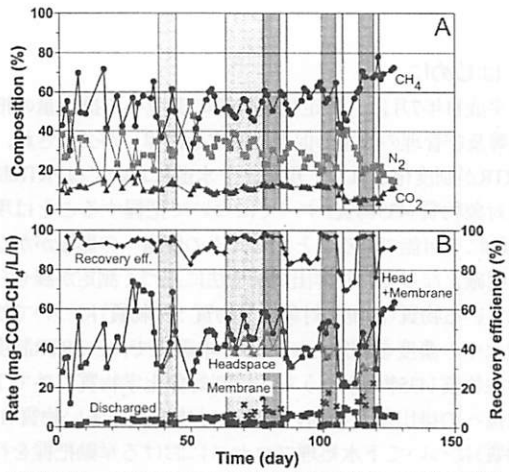

Figure 2 Headspace gas composition profiles (A), and the production rates of CH_4 gas evolved into headspace, recovered from membrane and discharged in effluent, and CH_4 recovery efficiency in the UASB reactor (B).

Table 3 Summary of average (± standard deviation) of the production rates of CH_4 gas evolved into headspace, recovered from membrane and discharged in effluents from the UASB and the degassing membrane reactors, and CH_4 recovery efficiency in the UASB reactor. The gray area represents degassing operation.

Phase	CH_4 production rate to head space (mg-COD/L/h)	CH_4 loss from the UASB reactor (mg-COD/L/h)	CH_4 recovery rate from membrane (mg-COD/L/h)	CH_4 loss from the membrane reactor (mg-COD/L/h)	CH_4 recovery efficiency (-)
1	46 ± 18	5 ± 1		3 ± 1	
2	44 ± 14	5 ± 0	4 ± 2	2 ± 0	1.09 ± 0
3	40 ± 9	6 ± 1		5 ± 1	
4	42 ± 4	6 ± 0	7 ± 4	2 ± 0	1.18 ± 0
5	47 ± 4	6 ± 0	9 ± 1	1 ± 0	1.19 ± 0
6	42 ± 10	6 ± 0		5 ± 0	
7	37 ± 4	8 ± 1		7 ± 1	
8	39 ± 3	9 ± 1	12 ± 3	1 ± 0	1.32 ± 0
9	24 ± 4	8 ± 0		7 ± 1	
10	22 ± 1	10 ± 1		9 ± 1	
11	29 ± 3	10 ± 0	15 ± 4	1 ± 0	1.53 ± 0
12	30	11 ± 1		9 ± 0	
13	58 ± 7	7 ± 1		6 ± 0	