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BEHAVIOUR OF HIGH-RATE ANAEROBIC PROCESSES TREATING LANDFILL LEACHATE

Hyeong-Seok Kim†, Ean-Ho Kim*, and Chul Kim**
Department of Environmental Science, Silla University, Pusan 617-736, Korea
*Nakdong River Research, Silla University, Pusan 617-736, Korea
**Department of Environmental System Engineering, Dongeui Institute of Technology, Pusan 614-053, Korea
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Abstract : The behaviour of a upflow anaerobic sludge bed filter (UBF) and a upflow anaerobic filter (UAF) treating a landfill leachate was investigated. The UBF and UAF treating the landfill leachate containing 10 g SCOD/L were successfully started up within a month through the control of upflow velocity, although the initial organic loading rate was high at 11.67 g SCOD/L · day. The maximum organic loading rate was 18.23 kg SCOD/m^3 · day for the UBF and 14.12 kg SCOD/m^3 · day for the UAF, determined by monitoring the SCOD removal, biogas production and bicarbonate alkalinity.

The SCOD removal efficiency for both reactors was over 90% during steady state except near the maximum organic loading rate. The trend of CH_4 production for the two processes was similar to the SCOD removal, and the maximum CH_4 production was 0.24 L CH_4/g COD for the UBF and 0.20 L CH_4/g COD for the UAF. The biomass yield of 0.398 g VSS/g COD in the UBF was higher than that in the UAF, and resulted in better for the UBF.

Key Words : anaerobic, filters, leachate

INTRODUCTION

During the last 30 years, in Korea, disposal of municipal solid waste has been done by landfill, and the landfill sites are spread all over the country.

However, limited understanding of the post-closure care of the landfill sites has resulted in severe environmental problems including ground water pollution around the landfill sites.[1] These days, safe management of landfill leachate is one of the important public concerns. The treatment of leachate has been usually done by both the physicochemical methods such as flocculation-sedimentation, chemical oxidation and adsorption by activated carbon, and some aerobic biological methods. The physicochemical treatments of leachate are the effective methods in removal of heavy metals and special substances causing color.

However, there are some problems related with the less removal of organic substances as well as the high production of sludge.[1] Organic substance could be easily removed by the aerobic processes, but there are also a lot of deficits such as high cost and technical difficulties in the process operation.[1,2] Then some advantages have been reported in the anaerobic treatment of landfill leachate. The process does not require any dilution of the raw leachate, and can obtain the CH_4 gas as a

†Corresponding author
E-mail: khs@silla.ac.kr
Tel: +82-51-309-5054, Fax: +82-51-309-5176

by-product. Moreover, the anaerobic process can be applied to a leachate containing less phosphorus than that does not require much nutrients.[3,4] A study on the anaerobic treatment of leachate was initiated by Boyle & Ham.[2]

However, the conventional anaerobic processes have some problems including the high initial capital cost, the low volumetric loading rate due to slow growth of anaerobes and characteristics of the leachate containing the heavy metals, salts and ammonia, and so on. However, it has been reported that those could be overcome through the high-rate anaerobic processes in previous studies.[3~5] On the other hand, the studies on the comparison of the performances between high-rate anaerobic processes treating a landfill leachate are still a few, lead to the fewer applications of the processes to the leachate.

Therefore, in this research, the performances of upflow anaerobic sludge bed filter (UBF) including the removal of organics, CH_4 gas production, biomass retention and the changes of environmental conditions were compared with those of upflow anaerobic filter (UAF) treating a landfill leachate.

MATERIALS AND METHODS

Experimental Apparatus

Figure 1 is a schematic diagram of the two high-rate anaerobic systems used in the study. The UBF was constructed using a thin acrylic column with 9.5 cm of inner diameter and 72 cm of height, filled with a Pall-Ring media of 2 cm size from 40 cm to 60 cm over the bottom. The empty bed volume of the UBF was 4.4 L.

The inner diameter and total height of the UAF were 7.5 cm and 111 cm, respectively. The UAF was also filled with 2.5 L Pall-Ring of 55 cm high, and the empty bed volume was 3.2 L.

The operating temperature was controlled at 37±1℃ by heated air using a thermostat. The influent was pumped to the distributor over 2 cm from the bottom. The biogas production was monitored using the volume change collector that was filled with a 1N-NaOH.

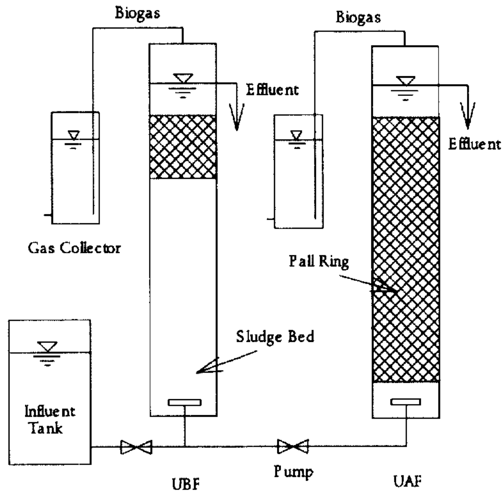

Figure 1. Schematic diagram of two high-rate anaerobic processes.

Table 1. Characteristics of the raw leachate obtained from E-landfill site (unit : mg/L except pH)

Contents	Concentrations
pH	5.9~7.6
SS	560~1,340
VSS	420~780
TCOD	27,000~53,500
SCOD	21,580~46,600
T-P	6,050~10,650
PO_4^{-2}-P	1,330~10,550
T-N	2,270~3,750
NH_4^+-N	2,070~3,250
SO_4^{-2}	6,200~26,400

Methods and Analysis

The raw leachate was obtained from the E-landfill site located in Pusan metropolitan area. The composition of the raw leachate was SCOD 21,600~46,600 mg/L, SS 560~1,340 mg/L, NH_4^+-N 2,670~3,247 mg/L, and pH 5.93~7.6 as detailed in Table 1.

The leachate used in the study was diluted to 10 g SCOD/L using tap water. The seed sludge was obtained from the anaerobic sludge digester in J. domestic sewage treatment plant, and SS and VSS of the sludge were 34.9 g/L and 16.1 g/L, respectively. The amount of inoculated sludge was about 80% of the effective volume of the reactors. During the start-up period of the processes, the upflow velocities for both processes were maintained at 0.72 m/day for the UBF and 0.85 m/day for the UAF.

When the processes reached steady state, based on COD removal efficiency, the variation of pH, and the ratio of VFA (volatile fatty acids) to BA (bicarbonate alkalinity), the organic loading rate was increased by 10% over the initial loading rate. Effluent pH and CH_4 production were monitored daily, and VFA, COD, and alkalinity were determined according to Standard Methods[6] at the 3 day intervals.

RESULTS AND DISCUSSION

Removal of Organic Substances

The operation of UBF was started-up at organic loading rate of 11.67 kg SCOD/m^3 · day on 0.72 m/day of upflow velocity. Figure 2 shows the trends of the SCOD removal according to the organic loading rate. The SCOD removal efficiency in the UBF gradually increased with operation time and was over 90% from the 35th day. This indicates that the start-up of the UBF process was successful at the selected upflow velocity in spite of the high initial organic loading rate. In previous studies,[7] the upflow velocity to ensure efficient start-up in a high-rate anaerobic process ranged from 0.72 to 0.96 m/day. At that value, the mixing between influent and seeded sludge can be enhanced and the inactive light sludge particles also can be removed, selectively. It also depends on the amount of seeded sludge.

High amount of seeded sludge can yield high OLR at start-up. After start-up, the SCOD removal efficiency was affected by the increase of organic loading rate. When the organic loading rate was increased by stages to 18.23 kg SCOD/m^3 · day, the SCOD removal efficiency remained in the 85～95% range. However, when the organic loading rate was increased to 20 kg SCOD/m^3 · day, the SCOD removal efficiency decreased to below 50% indicating the system failure. It appears that the maximum organic loading rate for the UBF treating a leachate of 10 g SCOD/L was about 18.23 kg SCOD/m^3 · day. In the UAF, a stable SCOD removal of over 90% was obtained by the 28th day. However, the trend of SCOD removal with the increase of organic loading rate was different from that of the UBF. On the 38th day, when the organic loading rate in the UAF was increased to 12.84 kg SCOD/m^3 · day from 11.67 kg SCOD/m^3 · day, the SCOD removal efficiency dropped sharply to about 70%. It took 2 days to recover to 90% SCOD removal efficiency.

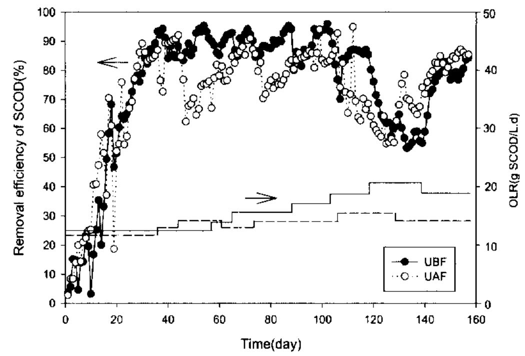

Figure 2. Soluble COD removal efficiency at different organic loading rates in the UBF and UAF.

On the other hand, when the organic loading rate increased to 14.12 kg SCOD/m^3 · d in the 43rd day, the SCOD removal efficiency decreased to 60%, and could recover to only 80% during 14 days of operating. Then, when the organic loading rate was decreased again to 12.84 kg SCOD/m^3 · day, the SCOD removal efficiency increased to over 90% within only 3 days. It indicates that the UAF requires enough time to increase the activity of microorganisms at an organic loading rate before their organic loading rate was increased. After the organic loading rate was maintained at 12.84 kg SCOD/m^3 · day for 13 days, it was increased to 14.12 kg SCOD/m^3 · day. The SCOD removal efficiency was decreased to 70%, but it was gradually recovered up to over 85% within 8 days. However, when the organic loading rate was increased to 15.53 kg SCOD/m^3 · day, the SCOD removal efficiency gradually decreased to below 55% and did not recover during 30 days, indicating that the UAF had failed.

Then, the SCOD removal efficiency could be recovered to over 85% within 7 days by the decrease of organic loading rate to 14.12 kg SCOD/m^3 · day. These result mean that the leachate could not be safely treated in the UAF operating at over 14.12 kg SCOD/m^3 · day of organic loading rate.

Biogas Production

After the start-up of UBF, CH_4 production rate was rapidly increased to over 8.0 L CH_4/day in the 26th days (Figure 3). When the organic loading rate was increased to 16.85 kg SCOD/m^3 · day from 11.67 kg SCOD/m^3 · day, the CH_4 production rate also increased to about 13.0 L CH_4/day. The trend of CH_4 production in the UBF was similar to the SCOD removal as shown in Figure 2. Then, no more increase of the CH_4 production rate was observed at 18.23 kg SCOD/m^3 · day of the organic loading rate in the 103rd day, and the CH_4 production rate was decreased to 6.7～8.42 L CH_4/day at 20.06 kg SCOD/m^3 · day.

However, when the organic loading rate was returned to 18.23 kg SCOD/m^3 · day, the CH_4 production rate was recovered. These results indicate that the maximum CH_4 yield for the UBF was about 0.24 L CH_4/g SCOD removed at 16.85 kg SCOD/m^3 · day of organic loading rate, although the allowable organic loading rate for the UBF was 18.23 kg SCOD/m^3 · day. The CH_4 production rate in the UAF reached steady state on the 30th day as shown in Figure 3. When the organic loading rate was increased in stages to 14.12 kg SCOD/m^3 · day, the CH_4 production rate first decreased, but gradually recovered. However, the CH_4 production rate at steady state did not increase according to the increase of organic loading

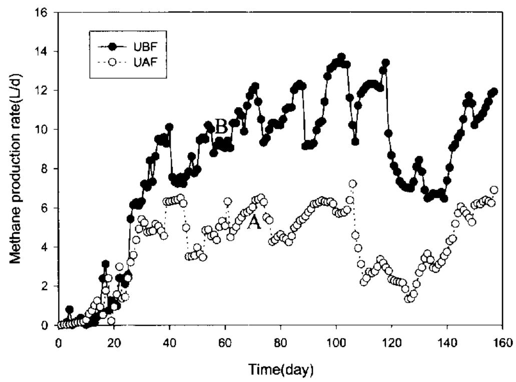

Figure 3. CH_4 production rate with the operating time in the UBF and UAF.

rate ranged from 11.67 kg SCOD/m^3 · day to 14.12 kg SCOD/m^3 · day.

Then, as the organic loading rate was increased to 15.53 kg SCOD/m^3 · day, the CH_4 production rate was rapidly decreased and was not recovered until the organic loading rate was decreased again to 14.12 kg SCOD/m^3 · day. Therefore, the maximum CH_4 yield in the UAF was estimated as about 0.20 L CH_4/g SCOD removed at the 11.67 kg SCOD/m^3 · day of the organic rate.

Changes of Environmental Conditions

The concentration of VFA in the UBF was over 2,500 mg HAc/L until the 10th day, and pH was below 6.5 (Figure 4). It resulted from the unbalance between the production and the consumption of VFA due to the slow growth of methanogenic microorganisms. After the 10th day, pH was 6.8～7.9. In the 26th day, the concentration of VFA was reduced to below 1,000 mg HAc/L, indicated that the system was reached a steady state. In the case of the UAF, favorable pH and VFA for efficient digestion were obtained after 27 days as shown in Figure 4. The relationship with VFA and BA could be used an operational parameter in an anaerobic digester. It has been reported[3)] that the concentration of BA in a normal anaerobic digester was between 1,000 mg/L and 5,000 mg/L as $CaCO_3$.

Figure 5 shows the changes in alkalinity and VFA/BA ratio with time. The concentrations of

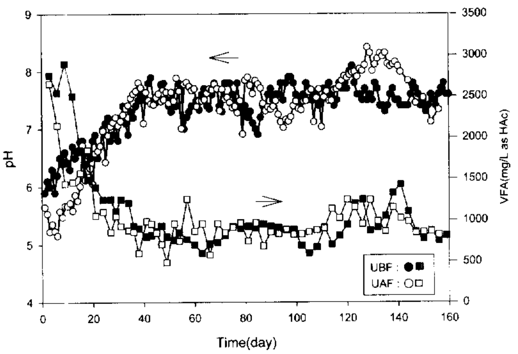

Figure 4. Behaviours of VFA and pH with time in the UBF and UAF.

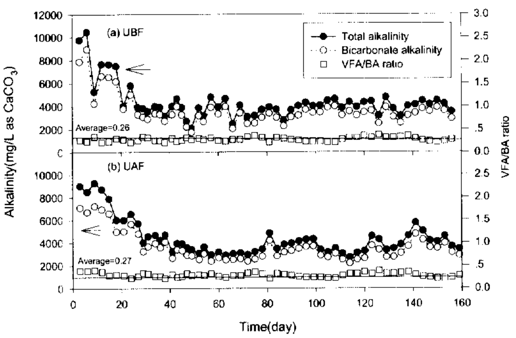

Figure 5. Alkalinity and ratio of VFA/BA changes with time in the UBF(a) and UAF(b).

BA in both systems were in the range of 2,200~4,000 mg/L as $CaCO_3$ except for the initial unsteady state period, although it was seldom affected by the changes of the organic loading rate.

It means that there was not any problem in buffering capacity for the anaerobic treatment of leachate, although the concentration of BA was increased a little according to the increase of organic loading rate.

However, when the organic loading rate was increased to 20.06 kg $SCOD/m^3 \cdot day$ for the UBF and 15.53 kg $SCOD/m^3 \cdot day$ for the UAF, the concentration of BA approached 5,000 mg/L as $CaCO_3$. It indicates that the capacity for treating leachate of both processes had reached limit. It has been reported that pH control was not needed in anaerobic reactors in which the ratio of VFA/BA was below 0.5, but

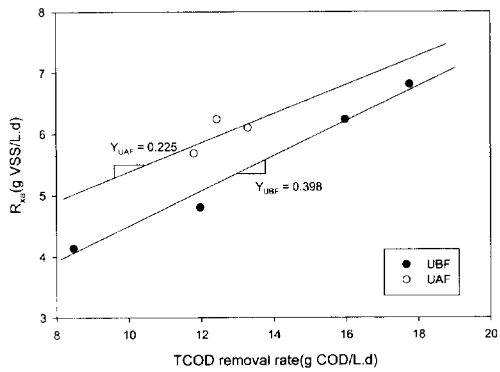

Figure 6. Rate of biomass accumulation for the UBF and UAF according to TCOD removal rate.

the rapid pH drop and severe inhibition in the biogas production could be caused at a ratio above 0.8.[8] The ratio of VFA/BA in both reactors was maintained at 0.22~0.38 through the operating period. It implies that the control of pH is not required in the anaerobic treatment of this leachate.

Biomass Retention

The rate of biomass accumulation in an anaerobic reactor could be indirectly estimated from a mass balance for the biodegradable COD of influent and effluent and CH_4 production at steady state by the use of the following equation.[7]

$$R_{xa} = DS_i - (DS_e + R_{CH4}) \qquad (1)$$

Where R_{xa} is the rate of biomass accumulation (g COD/L, conversion factor ; 1.42 g COD/g VSS), D is the dilution rate (d^{-1}), S_i is the soluble substrate concentration in the leachate influent (g COD/L), S_e is the total concentration of COD in the effluent (g COD/L), and R_{CH4} is the specific CH_4 production rate (g CH_4-COD/L · day). The rates of biomass accumulation for the UBF and UAF were calculated, and plotted to the total COD removal rate as shown in Figure 6. The rates of biomass accumulation were linearly increased according to the increase of total COD removal rate. It means that the rate of biomass accumulation can be increased according to the organic rate within the allowable value considering the COD removal rate with the organic loading rate. The biomass yields were obtained from the slope of the curve for the biomass accumulation rate to the TCOD removal rate. Those values for the UBF and UAF were 0.398 and 0.255, respectively. It means that more active biomass can be retained in the UBF than in the UAF. The biomass accumulation yields reported in previous studies are presented in Table 2.[5,8,9)]

The biomass accumulation yields varied between 0.19 and 0.22 depending on the process type and characteristics of the waste-water.

The biomass accumulation yields in this study were a little higher than the reported values. It seems that the values were over estimated by this indirect method due to the methanogenically inactive portion of the biomass. However, it was enough for the UBF and UAF to compare the ability of the active biomass retention.

CONCLUSIONS

The performance of a UBF treating landfill leachate was compared to that of a UAF, and the following conclusions resulted.

1. The UBF and UAF treating the landfill leachate of 10 g SCOD/L was successfully started up within a month through the control of upflow velocity within a month, although the initial organic loading rate was as high as 11.67 g SCOD/L · day.
2. The maximum allowable organic loading rate was 18.23 kg SCOD/m^3 · day for the UBF and 12.84 kg SCOD/m^3 · day for the UAF, those could be estimated by the behaviours of SCOD removal, biogas production and bicarbonate alkalinity.
3. The trend of CH_4 production for the two processes was similar to SCOD removal, and the maximum CH_4 was 0.24 L CH_4/g COD for the UBF and 0.20 L CH_4/g COD for the UAF.
4. The maximum CH_4 yield was 0.24 L CH_4/g SCOD at the organic loading rate of 18.23 kg SCOD/m^3 · day for the UBF and 0.20 L CH_4/g SCOD at the organic loading rate of 14.12 kg SCOD/m^3 · day for the UAF.
5. The biomass yield was 0.398 g VSS/g COD for the UBF and 0.255 g VSS/g COD for the UAF, and lead to the better performance of the UBF.

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Table 2. Comparison of the yield methanogenic consortia in the various high-rate anaerobic reactors

Reactor Type		Substrate	Temperature (℃)	Y (g VSS/g COD)
UASB[4)]		Wood ethanol stillage	37	0.191
Contact[5)]		Cane sugar stillage waste	35	0.192
Semicontinuous contactor[7)]		Glucose	35	0.208
Contact[8)]		Piggery effluent	35	0.213
This Study	UBF	Leachate	37	0.398
	UAF			0.255

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