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Methanogenesis acceleration of fresh landfilled waste by micro-aeration

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Abstract: When municipal solid waste(MSW) with high content of food waste is landfilled, the rapid hydrolysis of food waste results in the imbalance of anaerobic metabolism in the landfill layer, indicated by accumulation of volatile fatty acids(VFA) and decrease of pH value. This occurrence could lead to long lag time before the initiation of methanogenesis and to the production of strong leachate. Simulated landfill columns with forced aeration, with natural ventilation, and with no aeration, were monitored regarding their organics degradation rate with leachate recirculation. Hydrolysis reactions produced strong leachate in the column with no aeration. With forced aeration, the produced VFA could be effectively degraded, leading to the reduction in COD of the leachate effluent since the week 3. The CH_4 in the landfill gas from the column with aeration rate of 0.39 $m^3/(m^3 \cdot d)$ and frequency of twice/d, leachate recirculation rate of 12.2 mm/d and frequency of twice/d, could amount to 40% (v/v) after only 20 weeks. This amount had increased up to 50% afterward even with no aeration. Most of COD in the recirculated leachate was removed. Using natural ventilation, CH_4 could also be produced and the COD of the leachate effluent be reduced after 10 weeks of operation. However, the persistent existence of oxygen in the landfill layer yielded instability in methanogenesis process.

Keywords: MSW landfill; methanogenesis; leachate recirculation; forced aeration; natural ventilation

Introduction

The key technology of bioreactor landfill (Pohland, 1995) and ecologically based landfill (Bramryd, 2001) consists in the initiative regulating of microbial activities in landfill layers, so as to accelerate waste degradation and landfill stabilization, as well as to decompose recirculated leachate simultaneously. Therefore, it is essential to promote balanced and stable anaerobic digestion in landfill layers (Pohland, 2000), because the balances between biodegradation steps, including hydrolysis, acidogenesis, acetogenesis and methanogenesis, are vulnerable to variation of reaction environment (Pohland, 1999). The landfilled waste in the developing countries consists of a vast amount of food waste, whose rapid hydrolysis would lead to rapid accumulation of volatile fatty acids (VFA) and to low-pH environment in landfill layers. This occurrence is unfavorable for methanogenesis development, signalling by the long lag time before methanogenesis (Zhang, 2004) and the production of strong leachate(Martin, 1997).

Recirculation of leachate with high VFA content could simply impede further methanogenesis in landfilled refuse. By adding specific microbes, the VFA in leachate could be assistantly degraded(Vavilin, 2001; Bae, 1998). Zou(Zou, 2003) and Martin(Martin, 2003) pretreated leachate before recirculation to provide a preferable condition for methanogenesis. These approaches either complicated the external treatment facilities or needed intensive power input, and for aeration pretreatment of leachate, the residual oxygen might have potential to inhibit methanogenesis processes. This study utilized micro-aeration in landfill layers to aerobically degrade VFA redundant for promoting methanogens, by means of intermittent forced aeration and natural ventilation.

1 Methods and materials

1.1 Materials

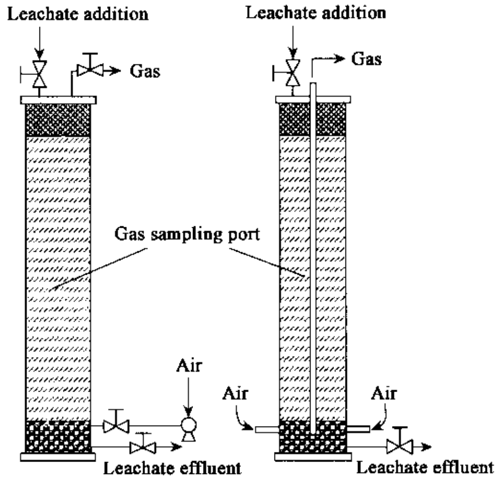
The synthetic refuse was prepared in compositions according to a recent survey for MSW in Shanghai, China (He, 2003), as listed in Table 1.

Table 1 Composition of the synthetic refuse

Composition	Food waste	Papers	Plastics	Textiles	Metals	Glasses
Mass content, %	56	19	14	3.5	0.5	7

1.2 Experimental apparatus

The simulated landfill columns were made of PVC plastic with inner diameter of 38 cm and height of 230 cm. As shown in Fig.1, the free drainage condition at the bottom of the columns was simulated by placing a 10 cm ceramsite layer of 1 cm grain size below the refuse. For the column with forced aeration(Fig.1a), air was blasted into the refuse layer at the bottom of the column intermittently. A gas vent was installed at the top. Gas sampling pipe and thermometer were installed in the middle of the column. For the column with natural ventilation (Fig. 1b), a hollow pipe (internal diameter of 5 cm) perforated with Φ5 mm holes of total area greater than 30% of the surface area, was inserted at the center of the column. Air could flow into the refuse layer because of the action of natural convection.



(a) Forced aeration (b) Natural ventilation

Fig.1 Diagrammatic sketch of experimental apparatus

1.3 Procedures

The synthetic refuse was compacted in the column with the total thickness of 170 cm and its average density was 0.8 t/m^3. A 10 cm water distribution layer composed of ceramsite was placed over the filled refuse. Then cement blocks were put on the ceramsite layer at a loading of 100 kg/m^2 for simulating actual landfill site. The temperature of the column was kept at 30 ± 5℃.

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A reference column, column # 1, was installed with no aeration. 1 L of the produced leachate (8.82 mm/d) was recirculated into the refuse layer daily, with the COD diluted to 25 ± 5 g/L.

The simulated landfill column with forced aeration, column # 2, was used for orthogonal experiments. At first, 5 L/min of air was ventilated for 12 min through the packed refuse per day, totally giving 0.31 $m^3/(d \cdot m^3)$ of air of refuse, almost equaling to the gas volume contained in the interspace of the refuse layer. 1 L of leachate was recirculated daily into the refuse layer, similarly to that in column # 1. On the week 19, the COD of leachate from column # 2 became much lower than that from column # 1. Since then, the orthogonal experiments were performed to study the optimal operating parameters, shown in Table 2. Each scenario in Table 2 was operated for 10 d. The COD of recirculated leachate was controlled at 19 ± 2 g/L. When the aeration frequency was more than once per day, the corresponding ventilation interval was set at 2 h, and the leachate was recirculated prior to aeration.

Table 2 Parameter design of the orthogonal experiments

Parameters		Level		
		1	2	3
A_1	Aeration rate, $m^3/(m^3 \cdot d)$	0.39	0.52	0.26
A_2	Aeration frequency, 1/d	1	2	3
A_3	Recirculation loading, mm/d	8.82	12.2	4.41
A_4	Recirculation frequency, 1/d	1	2	3

The simulated landfill column also with forced aeration, column # 3, was operated at the optimal conditions determined based on column # 2. Aeration and recirculation process was carried out till the methane content in gas phase exceeded 40%. Afterward, the aeration ceased with sole leachate recirculation proceeded.

The structure of column # 1— # 3 can be seen in Fig. 1a.

The simulated landfill column with natural ventilation was termed column # 4. Temperature difference between the air in the perforated pipe and the atmosphere resulted in natural ventilation in the column (Fig. 1b). The leachate was recirculated at 8.82 mm/d with COD at 10—25 g/L.

Leachate before and after recirculation was analyzed for COD and pH value according to the Standard Methods (NEPA, 1989). VFA (acetate, propionate and *n*-butyrate) concentration of leachate was determined by GC122 gas chromatography with FFAP capillary column and FID detector. Landfill gas of column # 1— # 3 was sampled prior to ventilation from the gas vent at the top of the columns. Gas sample of column # 4 was collected at the sampling port, whose CH_4 and CO_2 contents were measured by GC102 gas chromatography equipped with packed column and TCD detector. Oxygen concentration in the refuse layer was determined at the sampling ports by O_2 analyzer (CY-1).

2 Results and discussion

2.1 Column # 1

Despite an initial release of CO_2, little gas was produced in 19 weeks. No CH_4 was detected during the testing period. But considerable organics had already been released with leachate from the column, as shown in Fig.2. The VFA measurement revealed that, after seven weeks, most COD was contributed by VFA (Fig.3).

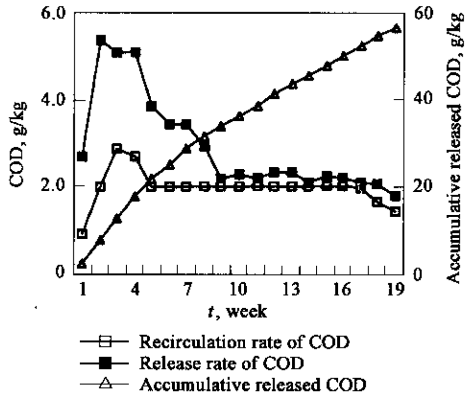

Fig.2 COD evolution of the leachate from column # 1

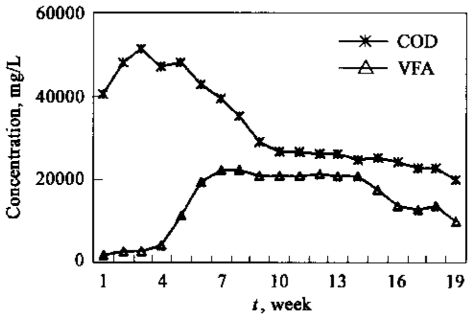

Fig.3 COD and VFA evolution of the effluent leachate from column # 1

Initial biodegradation of the tested MSW was dominantly contributed by hydrolysis, which would inhibit the subsequent acetogenesis and methanogenesis stages, thereby producing strong leachate. Hence, direct recirculation of leachate could on the contrary deteriorate pollutants removal. When the VFA increased to a level to reduce pH to about 5.5, hydrolysis would also be somewhat restrained (Veeken, 2000). As shown in Fig.2, the release rate of COD varied little after 10 weeks.

2.2 Column # 2

As shown in Fig.4, forced aeration accelerated degradation of organic MSW in the landfill. Only after 2 weeks, did the COD of the leachate start to decline while the corresponding pH increased. The latter reached to 6.0 at week 14. From Fig. 5, it can be found that the rapid reduction of released COD was due to intermittent aerobic degradation of organics (indicated by oxygen consumption) within 2 h after aeration.

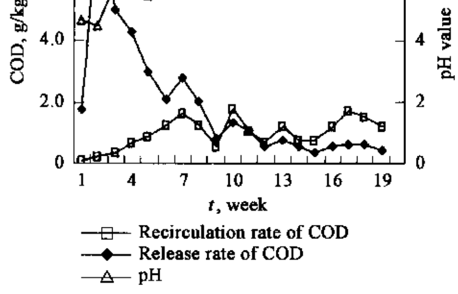

Fig.4 COD evolution of the leachate from column # 2

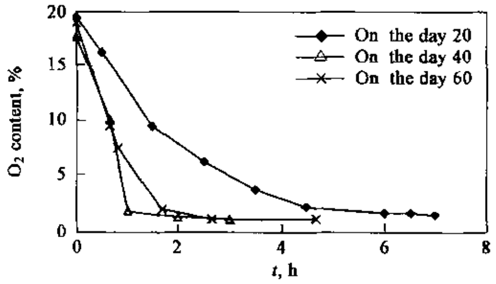

Fig.5 O_2 evolution in column # 2 after intermittent aeration

COD removal rate of the recirculated leachate was taken as an evaluation index for the orthogonal experiments, calculated as COD removal amount (the difference between COD amount recirculated into the column and that released from the column in the leachate) divided by the initial volume of landfilled refuse. The optimal conditions were determined based on data listed in Table 3 as follows: 0.39 $m^3/(m^3 \cdot d)$ of aeration rate, twice/d of aeration and recirculation frequency, and 12.2 mm/d of leachate recirculation.

Table 3 Analytical results of the orthogonal experiments and extremum differences

Option	A_1 Aeration rate, $m^3/(m^3 \cdot d)$	A_2 Aeration frequency, 1/d	A_3 Recirculation loading, mm/d	A_4 Recirculation frequency, 1/d	COD removal rate, $mg/(m^3 \cdot d)$
1	0.39	1	8.82	1	93.4
2	0.39	2	12.2	2	219
3	0.39	3	4.41	3	89.8
4	0.52	1	12.2	3	123
5	0.52	2	4.41	1	56.0
6	0.52	3	8.82	2	77.7
7	0.26	1	4.41	2	42.4
8	0.26	2	8.82	3	92.5
9	0.26	3	12.2	1	138
K_1	$K_{11} = 134$	$K_{21} = 86.2$	$K_{31} = 87.9$	$K_{41} = 95.9$	
K_2	$K_{12} = 85.5$	$K_{22} = 123$	$K_{32} = 160$	$K_{42} = 113$	
K_3	$K_{13} = 91.1$	$K_{23} = 102$	$K_{33} = 62.7$	$K_{43} = 102$	
R	$R_1 = 48.7$	$R_2 = 36.4$	$R_3 = 97.3$	$R_4 = 17.2$	

2.3 Column # 3

Column # 3 was operated under the abovementioned optimal conditions, and the average COD concentration of the recirculated leachate was kept at 25 g/L. The testing results were shown in Fig.6.

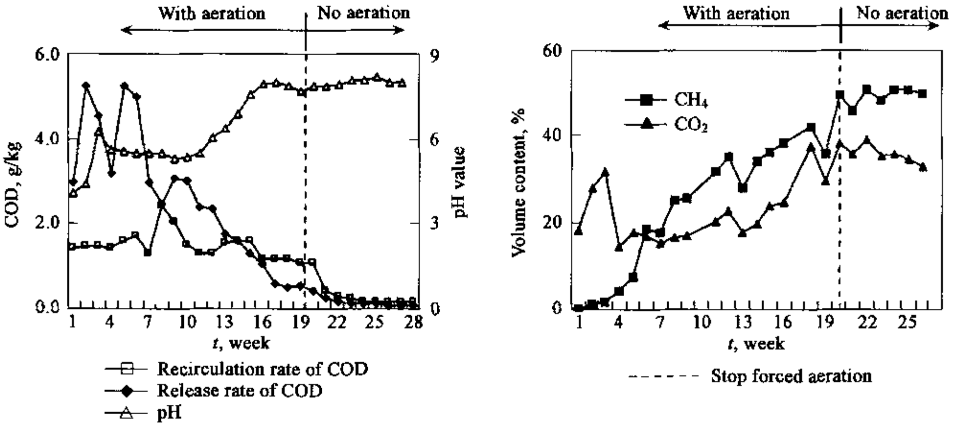

Fig.6 COD of the leachate and gas composition evolution from column No.3

Compared with Fig.4, the pH in column # 3 increased more obviously under optimal conditions, yielded by rapid degradation of VFA. CH_4 was evidently produced after 7 weeks and further increased to above 30% after 13 weeks. Meanwhile, the corresponding COD drastically decreased, as a result of simultaneous occurrence of intermittent aerobic metabolism and methanogenesis. After CH_4 content increased to 40% on the week 20, the aeration was ceased. Stable methanogenesis could continue without intermittent aeration. Intermittent aerobic condition assisted degradation of VFA to a great extent, but still provided anoxic conditions most of the time and it had no inhibition to methanogen (O' Keefe, 2000). When methanogen was proliferated enough to counteract the VFA inhibition, switch off aeration would not influence the stable anaerobic metabolism. It was feasible to accelerate methanogenesis by intermittent micro-aeration at the initial stage of landfill.

2.4 Column # 4

Natural ventilation continuously provided the landfill layer with oxygen to assist in forming coexistent aerobic and anaerobic zones in the column. This process could also effectively degrade organics in the recirculated leachate (Fig. 7). However, this aerobic/anaerobic distribution did not benefit to the establishment of steady methanogenesis in the whole landfill layer, indicated as the unstable methane content noted in the produced landfill gas.

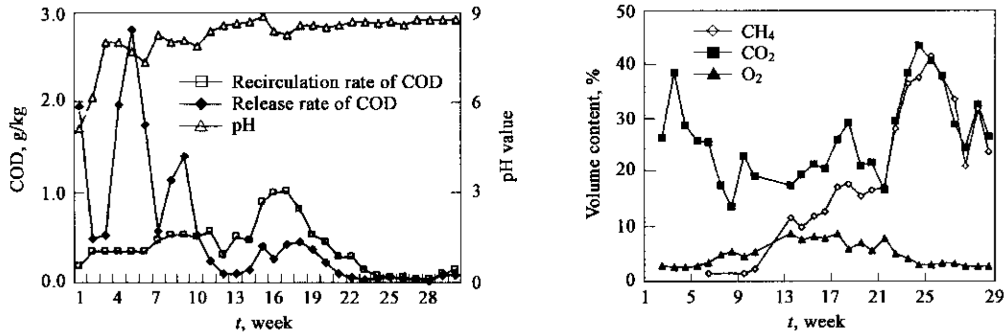

Fig.7 COD of the leachate and gas composition evolution from column # 4

3 Conclusions

At the initial landfill stage of MSW mainly composed of food waste, the rapid hydrolysis of organic fraction would result in the accumulation of VFA and inability to keep a balanced methanogenesis process in the landfill layer. As a result, strong leachate would be produced. Micro-aeration in landfill layers could help in neutralizing acid environment by aerobic degradation of VFA. Furthermore, the proliferation of methanogens would not be considerably inhibited under the proposed intermittent aerobic environment. Therefore, steady methanogenesis could be developed and the lag time before methanogenesis could be shortened. In the column with forced aeration rate of 0.39 $m^3/(m^3 \cdot d)$ and frequency of twice/d, leachate recirculation rate of 12.2 mm/d and frequency of twice/d, CH_4 in the landfill gas could amount to 40% (v/v) after 20 weeks of test, which would further increase up to 50% when aeration ceased. CH_4 could also be produced (above 20%) with continuous natural ventilation, but the persistent existence of oxygen in the landfill layer resulted in the instability of methanogenesis process.

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