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Landfill leachate treatment in assisted landfill bioreactor

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Abstract: Landfill is the major disposal route of municipal solid waste(MSW) in most Asian countries. Leachate from landfill presents a strong wastewater that needs intensive treatment before discharge. Direct recycling was proposed as an effective alternative for leachate treatment by taking the landfill as a bioreactor. This process was proved not only considerably reducing the pollution potential of leachate, but also enhancing organic degradation in the landfill. However, as this paper shows, although direct leachate recycling was effective in landfilled MSW with low food waste fraction (3.5%, w/w), it failed in MSW containing 54% food waste, as normally noted in Asian countries. The initial acid stuck would inhibit methanogenesis to build up, hence strong leachate was yielded from landfill to threaten the quality of receiving water body. We demonstrated the feasibility to use an assisted bioreactor landfill, with a well-decomposed refuse layer as ex-situ anaerobic digester to reducing COD loading in leachate. By doing so, the refuse in simulated landfill column (2.3 m high) could be stabilized in 30 weeks while the COD in leachate reduced by 95%(61000 mg/L to 3000 mg/L). Meanwhile, the biogas production was considerably enhanced, signaling by the much greater amount and much higher methane content in the biogas.

Keywords: bioreactor; landfill; leachate recycling; organics; enhancement; leachate; pretreatment

Introduction

Landfill is the major disposal route of municipal solid waste (MSW) in most Asian countries. Leachate from landfill presents a strong wastewater that needs intensive treatment before discharge. Landfill leachate dischargement with little treatment cause serious pollution of groundwater and surface water system.

Bioreactor landfill could provide an accelerated stabilization of the landfilled MSW as well as an enhancement of methane production (Pohland, 1995), meanwhile the leachate could be treated by the landfill. Full-scale tests reveal the merit of this application as a potential alternative to the conventional landfill (Rainhart *et al.*, 2002; Mehta *et al.*, 2002), with the leachate recycling as the key step to its success in operation. However, some tests conducted using MSW collected at very different composition could note no expected, enhanced effects on landfill stabilization and leachate treatment (Vasuki, 1995). Restated, simple leachate recycling through the landfill unit with MSW collected in Shanghai, China would inhibit metabolism of organic matter degradation and cause heavy leachate pollution (Zhang *et al.*, 2005). Veeken *et al.*(2000) noted a similar failure for anaerobic degradation of biowaste at a high volatile fatty acid(VFA) level.

The objective of this research was to investigate the inhibition on the landfill with leachate by directly recycling, and to evaluate the effectiveness of using a well-decomposed refuse layer as an external digester to assist in organic degradation of the recycled leachate. Then the effect of the recycled leachate on bioreactor landfill was studied and compared.

1 Materials and methods

1.1 Materials

The synthetic refuse used in this study was based on composition noted for MSW in Shanghai, China (He, 2002)(Dry basis, food waste: 53%, plastic: 16%, paper: 22%, textile: 3%, glass and metal: 6%). The relatively high fraction of food waste (53% on dry basis) led to high water content of fresh refuse (74%). The relatively high water content is a common characteristic of the refuse yielded in Asian countries. This synthetic refuse was placed in Column 1, 2 and 4 for test. Another synthetic refuse of the same compositions as mentioned except for the lower fraction of food waste (3.5%) as proposed by Kim (2001) to simulated the MSW in U.S. This refuse was placed in Column 3 as a test for comparison.

1.2 Construction and operation of the columns

Fig.1 depicts the schematics of the tested simulated columns(inner diameter of 37 cm, height of 230 cm). A drainage port equipped with a ball valve was placed at the column bottom. A gas vent and a liquid addition port were installed at the column top. Free drainage conditions at the bottom of the column were simulated by placing below the refuse a 10 cm layer consisting of 1 cm crockery balls. The refuse was

Foundation item: The Hi-Tech Research and Development Program(863) of China(No. 2001AA644010; 2003AA644020); Magnolia Science and the Technology Talent Fund(MTF) of Shanghai; * Corresponding author then placed and compacted until the total thickness of the refuse layer before testing was 170 cm. A 10-cm layer of crockery balls was placed over the refuse for even distribution of liquid added to the columns. The temperature of the columns were kept at 35 ±2℃. After being packed, the columns were gas-tight.

Tap water, simulating rainfall, was added to Column 1, which was served as the control. The

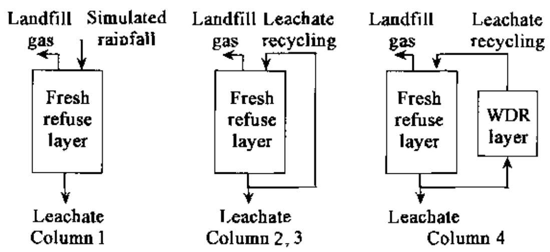

Fig.1 Simulated landfill columns used in this work

addition quantity of the tap water ranged 0.2—0.6 mm/(m^2·d), simulating the monthly rainfall data in Shanghai area (Table 1). We assumed herein that the final cover would be effective for allowing only 10% of the rainfall to flow into the landfill. The produced leachate was collected without further treatment. The leachate from Column 2 and 3 was directly recycled. Note that the refuse compositions in these two columns were different. The leachate from Column 4 was pretreated in an ex-situ anaerobic contactor containing well-decomposed refuse (WDR) layer collected from Shanghai LaoGang Landfill Works. The structure of the WDR layer was the same as the other columns. The leachate flowing through the WDR layer was recycled to the top of Column 4. The volume and the characteristics of the recycled liquids for each column were summarized in Table 2.

Table 1 Monthly rainfall data in Shanghai area

Month	1	2	3	4	5	6	7	8	9	10	11	12
Rainfall, mm	44.1	62.3	79.3	103	126	153	93.2	115	174	56.7	50.8	42.5

Table 2 The volume and characteristics of the water or leachate added to the columns

Column	Characteristics of the liquid added to the columns			Volume of recycled leachate, mm/(m^2·d)	Frequency of recycling
	pH	COD, mg/L	NH_3-N, mg/L		
1	6.9	0	0	0.2—0.6	Weekly
2	a	a	a	a	Daily
3	a	a	a	a	Daily
4	6.4—6.7	ca. 20000	1500—1700	6±2 mm	Daily

Note: a. The same as those of the effluent leachate

1.3 Sample analysis

The chemical oxygen demand (COD), total organic carbon (TOC), BOD_5, volatile fatty acids(VFA), NH_4^--N, pH, and the leachate flow rate were monitored on all leachate streams.

The COD, BOD_5 and ammonia were analyzed according to the Standard Methods(CEPA, 1989). The pH value was measured by a PHS-25 digital pH meter (Shanghai Precision and Scientific Instrument Co., Ltd.). TOC was analyzed with the TN_b/TC multi N/C 3000 Analyzer(Analytik Jena AG). The concentrations of the VFA were determined by a gas chromatograph (GC-122, Shanghai Precision and Scientific Instrument Co., Ltd.) equipped with a flame ionization detector and a 30-m dikma capillary column (Dikma Technology Co., Ltd.). Only acetate, propionate and butyrate were tested. The concentrations of methane and carbon dioxide in biogas were analyzed using a gas chromatograph (GC-102, Shanghai Precision and Scientific Instrument Co., Ltd.) equipped with a thermal conductivity detector.

2 Results

The residual air in the sealed column would be exhausted during the first several weeks of testing. This initial aerobic period was disregarded in all following discussions for providing a common basis for performance comparison.

2.1 Column 1

Fig.2 shows the time evolutions of COD, pH, and VFA concentrations of the effluent leachate collected at the column bottom. The COD concentrations of the effluent leachate from Column 1 reached 68000 mg/L in the first week and remained at a high level: 65000—75000 mg/L over the testing period (Fig.2a). The corresponding pH was all around 5.6 (Fig.2b). A mass amount of VFA (30000 mg/L) was produced, indicating a serious acid stuck in the column (Fig.2c). The methanogenesis could not be established within the experimental time span, evidenced by the very low methane concentration in the column (Fig.3). This occurrence reveals that with simulated rainfall the MSW is easily hydrolyzed to yield strong leachate, which might be attributable to the mass amount of food waste in the refuse, and the leachate has a remarked potential to pollute the receiving water body.

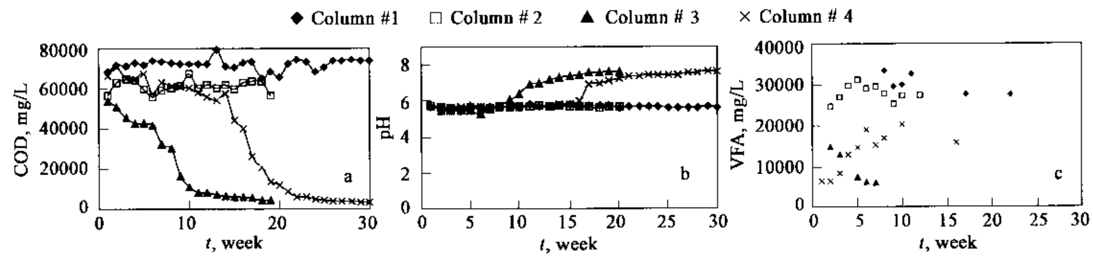

Fig.2 Time evolution of COD(a), pH(b), VFA(c) concentration of leachate from simulated landfill columns

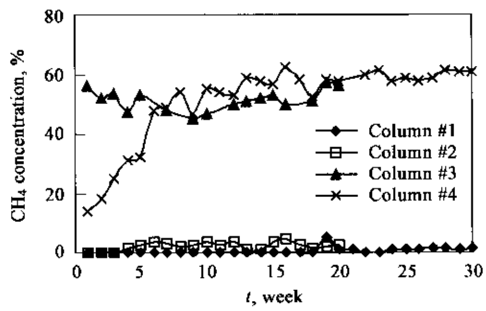

Fig.3 Time evolution of methane concentration in landfill gas from simulated landfill columns

2.2 Column 2

The leacahte was not degraded when directly recirculated into the Column 2. On the contrary, the recycled leachate produce a more serious acid stuck environment with which the MSW hydrolysis efficiency was lowered. This occurrence could be observed by the lower COD level of leacahte(55000—63000 mg/L)(Fig.2a) compared with that for Column 1. The leachate pH also remained at 5.6 during the testing period (Fig. 2b). The methane appeared in the gas phase of Column 2 in week 4(Fig.3). However, the volume fraction of methane had never exceeded 5%. Direct leachate recycling to the MSW of high food waste fraction has no benefit to assist leachate degradation and promote MSW stabilization when a mass amount of food waste is in the MSW.

2.3 Column 3

The leachate COD was reduced from 53500 mg/L to 11000 mg/L, a 80% reduction by recycling leachate for 10 weeks in Column 3 (Fig.2a). Correspondingly, pH value raised from 5.6 to 7.6 from week 9 (Fig.2b). Just on week 1, the methane concentration reached 56%, and it remained at 45%—55% throughout the experiment time(Fig.3), which indicating the establishment of methanogenesis in the landfill column. The direct leachate recycling could effective degrade the organics in leachate when the MSW contains low content of food waste (3.5%). Moreover, the present test clearly illustrates the significant role of bioreactor food waste to the success of bioreactor landfill.

2.4 Column 4

The COD concentration in leachate left was reduced by 95%(61000 mg/L to 3000 mg/L) over the testing period in Column 4(Fig.2a). The corresponding leachate pH was raised from 5.5 to 7.4 from week 16 (Fig.2b). About 5 L/kg initial refuse per week of landfill gas was producted during the first 5 weeks and it increased to 28 L/kg initial refuse per week in 9 weeks(Fig.4). The methane content reached 54%(v/v) at week 8 and remained at this level since then. This indicates that the methanogenesis was established in the Column 4. This result shows that efficient leachate degradation could be achieved by adopting an external anaerobic reactor to pretreat leachate before recycling. The biogas production rate was declined since week 20, and was only 1/3 of the peak value on week a 30. Therefore, the refuse in Column 4 was mostly stabilized over a 30-week of test.

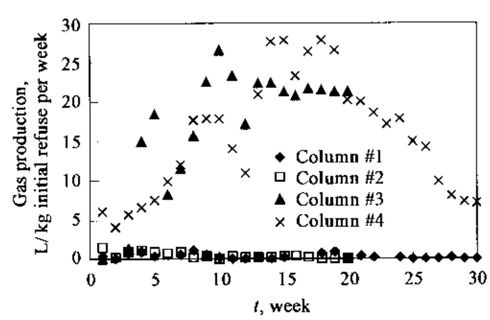

Fig.4 Time evolution of landfill gas production from simulated landfill columns

3 Discussion

3.1 Effect of food waste content

The fraction of food waste, which is easily hydrolyzed to produce acids, presents a key issue to the success of leachate recycling process. The test in Column 1 produced the strongest leachate amongst the four columns tested. However, although direct leachate recycling could effectively accelerate stabilization of refuse in Column 3, with food waste of 3.5%, it failed in Column 2 in which food waste presented 54% refuse. Hence, there exists a border between separating the regimes where direct leachate recycling is feasible. This should be a keypoint for the future research.

3.2 Effect of external anaerobic reactor for leachate pretreatment

Xu *et al.*(2002) has setup a enhanced two-phase anaerobic bioreactor system, in which a UASB reactor performed as a methanogenic reactor and the effluent from the UASB was recycled to the waste column for refuse degradation. The work by Kim (2001) also testified the importance of an *ex-situ* leachate pretreatment reactor for the bioreactor landfill. In this work, the WDR layer used as the external anaerobic reactor also shows its success. However, the WDR layer has its advantage in the application for bioreactor landfill. Landfill layers are different ages in a landfill site. To use the on-site well-decomposed refuse layer should be a more promising option than to build an external reactor such as UASB on site, and this scenario could be called assisted bioreactor landfill. After the leachate of a newly landfilled layer has been properly degraded *in situ*, with the assistance of leachate pretreated by nearby WDR layers before recycling, it could serve as the external reactor for the next newly landfilled layer, and so forth. Compared with traditional landfill practice, this operation presents a cost-effective technology to more sustainable landfill practice, together with a much less polluting leachate left, for Asian countries.

4 Conclusions

This work aims at proposing a feasible way to effectively degrade organics in landfill leachate for reducing its pollution potential to environment. Leachate from simulated landfill column with simulated rainfall containing synthetic refuse of the same compositions as collected in Shanghai revealed an extremely high COD, around 70000 mg/L after 30 weeks of test. Direct leachate recycling would not only resist organic degradation, but also inhibit solid hydrolysis in landfill. This occurrence led to a leachate not as strong as that with rainfall, but still having a high level of COD. Meanwhile, the present study demonstrated that if only the fraction of food waste were reduced, direct leachate recycling could effectively accelerate the degradation of organics in leachate. Food waste, whence the amounts of its derivatives in leachate, presented an essential part to the success of leachate recycling.

We utilized a well-decomposed refuse layer as external anaerobic reactor to reduce the COD loading in leachate. By doing so, the stabilization of refuse was accelerated considerably. After 30 weeks of operation, the COD in leachate could be reduced by 95%. The remaining COD should be of less biodegradability that would have less threat on the receiving water body. The use of on-site, well-decom- poased refuse layer instead of installing an *ex-situ* anaerobic digester presents the advantage to utilize existing aged landfill piles as the reactors. This operation stands for a cost-effective technology to more sustainable landfill practice, together with a much less polluting leachate left, to be applied in Asian countries.

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