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Landfill leachate production, quality and recirculation treatment in northeast China

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Abstract: Landfill leachate recirculation treatment process is a promising and economic way in northeast China due to the distinct season variation. In order to study the impact of recirculation on leachate production and its quality, two simulated sanitary landfill reactors, one with leachate recirculation and the other without, were placed outdoor in Harbin. The two-year experimental results indicated that leachate production was reduced by 86% with leachate recirculation and less or no facility for leachate treatment required. Recirculation could improve the leachate quality dramatically with lower COD, SS, NH_4^+-N and higher pH level. Recirculation also could enhance waste degradation and stabilization and improve the efficiency of landfill. This study confirmed that leachate recirculation was a very feasible way for on-site landfill leachate treatment in cold areas.
Keywords: cold area; sanitary landfill; leachate; recirculation; solid waste

Introduction

Landfill is still the most common way to treat more and more municipal solid waste (MSW) in all over the world, especially in China (Feng and Chen, 2000). However, the leachate produced from landfill is very complicated and variable because of the differences in climate condition, landfill site, filling age and characteristics of MSW etc. (Tatsi and Zoubouli, 2002; Al-Yaqout and Hamoda, 2003). It is very difficult to develop a sophisticated process to treat all kinds of landfill leachate. In northeast China, there is more evaporation than precipitation and longer frozen time lasting from November to April next year. The unique climate makes landfill site in dormant status and leachate production discontinuous during the frozen time.

Leachate recirculation has gained increasing attention as an effective way in landfill leachate treatment. A landfill with leachate recirculation will become a controlled anaerobic filter which can provide sufficient moisture and nutrients, improve microorganism activity, enhance waste degradation and stabilization and reduce the volume of leachate by evaporation during recirculation (Pohland, 1975). It has a big potential for the on-site landfill leachate treatment in northeast China.

This research was conducted to study the leachate production, quality and impact of leachate recirculation on waste degradation and landfill leachate treatment, and to provide data for successful operation of landfill sites in northeast China.

1 Materials and methods

1.1 Equipment and materials

In order to study the impact of recirculation on leachate production and its quality, two simulated sanitary landfill reactors were constructed using two PVC tanks with a length of 0.75 m, a width of 0.7 m and a height of 1 m. The effective volume was 0.5 m^3 for each of them. The peristaltic pump was used to deliver the leachate collected in the storage tank to the recycled reactor 2#. Another reactor 1# without leachate recirculation was used as control. Both reactors were placed outdoor in Harbin to simulate the real landfill site. The configuration of the recycled reactor, which was the same as control reactor 1# except the recirculation system, is presented in Fig.1.

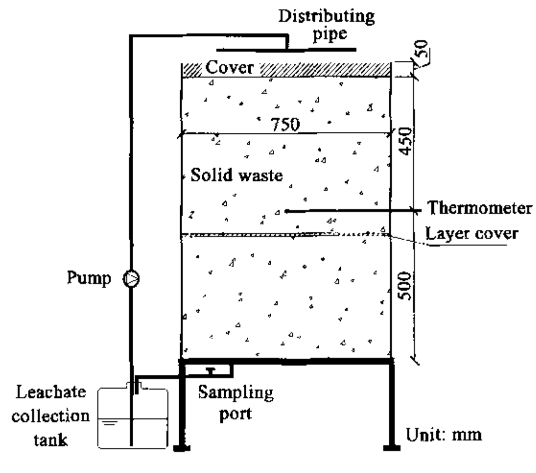

Fig.1 Pilot-scale landfill reactor with recirculation

Each reactor was filled with 300 kg solid waste which was collected from the households inside the campus to represent the typical municipal solid waste in Harbin. The composition of solid waste used in this research is summarized in Table 1. After collecting, weighting and mixing, the solid waste was filled and tamped into the two reactors with an average density of 600 kg/m^3 at twice (Reinhart and Townsend, 1998). Finally the reactors were sealed with soil covers.

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Table 1 Characteristics of solid waste

Composition	Weight, kg	Percentage, %
Food	492	82
Paper	48	8
Plastics	36	6
Textiles	9	1.5
Sand and block	9	1.5
Glass and metal	6	1
Moisture		39.2
Total	600	

1.2 Methods and analyses

The leachate was collected daily and measured its volume with flask. 100 ml sample from each reactor was used to analyze its quality by measuring pH, suspend solid (SS), ammonia nitrogen (NH_4^+-N), chemical oxygen demand (COD) and volatile fatty acid (VFA) according to the standard methods (NEPA, 2002). Total organic carbon (TOC) was analyzed using TOC-V_{CPN} analyzer (Shimadzu, Japan).

The remaining leachate from 1# reactor was stored for further treatment while the remaining leachate from 2# reactor was recycled back to the reactor with a rate of 8 mm/(m²·d) as practiced by the other researchers (Reinhart and Townsend, 1998).

The residues in both reactors were sampled to measure pH, moisture, ammonia nitrogen (NH_4^+-N), total nitrogen (TN), total solid (TS), volatile solid (VS), total organic carbon (TOC) and bio-degraded matter (BDM) according to the references (GEPA, 1990; He and Shao, 1994; Wang *et al.*, 2003).

2 Results and discussion

2.1 Leachate production

Both landfill reactors were sealed with soil cover on 26 May, 2003. The leachate was produced from 28 May to 5 Nov. in 2003 and from 1 April to 6 Nov. in 2004 which was 380 d in all. The daily leachate production and rainfall are shown in Fig.2.

It can be seen from Fig.2 that rainfall was the main factor of leachate production. There was a very big and complicated variation for daily leachate production. The leachate production kept a positive relation to the rainfall increase and to the detention time from 2 to 20 d. At the initial stage (0—10 d, 310—350 d), the leachate was produced slowly which was ranged between 300—3000 ml/d due to the adjustment to the surrounding environment. During the rain season (30—88 d, 420—470 d), the moisture in the soil cover and solid waste became saturated, which reduced the absorption capability. As the rainfall was converted into leachate directly, the leachate production became varied greatly (from 210 ml/d to 15500 ml/d) and the total leachate production was much higher than that in dry season with the water accumulation in solid waste. During the dry time (90—150 d, 350—400 d, 480—520 d), the leachate production decreased slowly and varied gently. Then it stopped during the frozen time in winter.

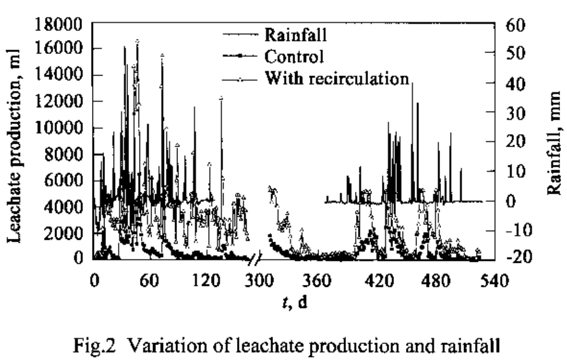

Fig.2 Variation of leachate production and rainfall

In 2004, the average 1# and 2# leachate productions were 1.05×10^{-3} and 1.57×10^{-4} m³/(m²·d) respectively, but those of them were 1.60×10^{-3} and 2.07×10^{-4} m³/(m²·d) in 2003 respectively, which showed more leachate produced in 2004 than in 2003. Because the organic matter in solid waste was already degraded in 2003, the degradation process was slower and the matter more difficult to be degraded was left in 2004.

The total volume of 2# leachate with 35447 ml was only 14% of leachate production from 1# reactor with 253545 ml. The results indicated recirculation could reduce leachate production by 86% as the leachate was mainly absorbed by the solid waste and used as necessary substrate for bacteria growth. Finally the leachate treatment facility was not required.

2.2 COD concentration in leachate

The COD and TOC concentrations of leachate are shown in Figs.3a and b. Although there was a big difference in value, they had almost the same downtrend as a whole. At the initial stage (0—25 d), the COD concentration increased up to 75160 mg/L (1#, 21 d) and 69251 mg/L (2#, 16 d) dramatically because the biodegradable matter in solid waste was degraded quickly with adequate oxygen. When the inside oxygen was used up and moisture was accumulated, both reactors were in an anaerobic condition, so the COD concentration decreased gradually due to less biodegradable matters left, more inhibitory matters accumulated and slow growth of anaerobic bacteria.

It can be seen from Fig.3a that the maximum and final COD value were 75160 mg/L (21 d) and 22160 mg/L (523 d) for 1# reactor and 69251 mg/L (16 d) and 1509 mg/L(523 d) for 2# reactor, respectively. The average COD reduction rate for 1# and 2# reactors were 106 and 134 mg/(L·d) respectively. Besides the dilution by the recycled leachate, the main reason was the leachate with sufficient moisture and nutrient substrates was recycled back. The anaerobic bacteria

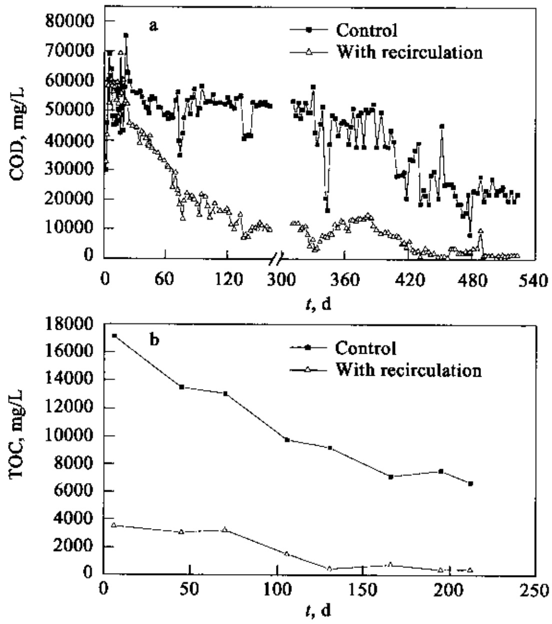

Fig.3 Variation of COD(a) and TOC(b) concentration in leachate from landfill reactors

in recycled leachate acted as inoculation, which made 2# reactor become an anaerobic bio-filter using solid waste as carrier (San and Onay, 2001). On the other hand, the recycled leachate made the contact time longer and mixing better so that 2# reactor was more effective to absorb and degrade the organic matters than 1# reactor. It was obviously shown from Fig.3a and 3b that the COD and TOC concentrations in 2# leachate were much lower than those in 1# leachate.

2.3 pH and VFAs in leachate

The pH values of leachate are shown in Fig.4a which increased gently from 5.47 to 7.81 and from 6.34 to 8.94 respectively. At the initial stage (0—70 d), the organic matter was degraded and volatile fatty acids (VFAs) was produced, so the pH in leachate was kept below 6.5. Then the degradation of organic matter became slower and less VFAs was produced which is shown in Fig.4b, so the pH of leachate increased gradually. During the periods from 390 d to 400 d and from 430 d to 460 d, the pH rose up to the maximum point unexpectedly because of the continuous heavy rain dilution.

It can be seen from Fig.4b that pH of 1# leachate was much higher than that of 2# because there was much higher VFAs concentration in 1# leachate. Acetic acid was the main composition which contributed more than 60% of total VFAs concentration in the leachate. The results indicated that 1# and 2# reactors were in acidification and methanogenesis stage respectively, which proved recirculation could accelerate the organic matter degradation and enhance waste stabilization.

2.4 NH_4^+-N and suspend solid concentration in leachate

NH_4^+-N was an important factor for bacteria

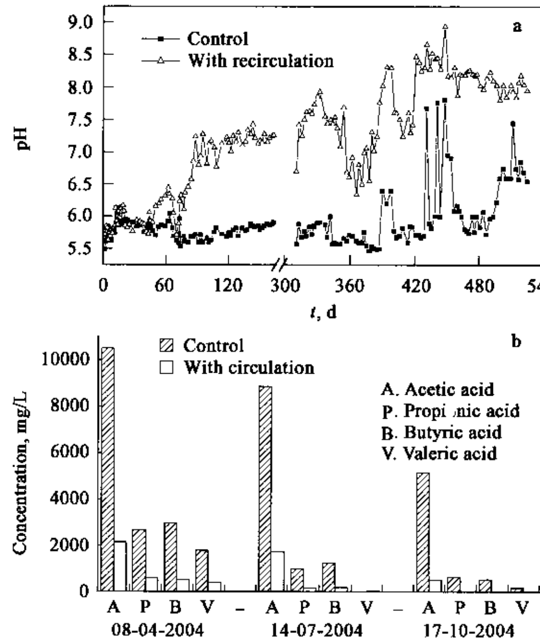

Fig.4 Variation of pH(a) and VFAs(b) in leachate from landfill reactors

growth and leachate quality. It was shown from Fig.5a that the variation of NH_4^+-N concentration in leachate had the similar trend in 2003 and 2004. At the initial stage (0—50 d, 310—380 d), the NH_4^+-N concentration increased slowly because bacteria was effective to convert amide substrate into NH_4^+-N under less or no NH_4^+-N condition. With NH_4^+-N accumulation, bacteria using NH_4^+-N as substrate became dominant species and NH_4^+-N was greatly consumed by them. At the same time, some insoluble chelate complex was produced from the complicated reactions between by-product and ammonia. There was less organic waste containing ammonia left inside the reactors. Therefore, the NH_4^+-N concentration dropped at the

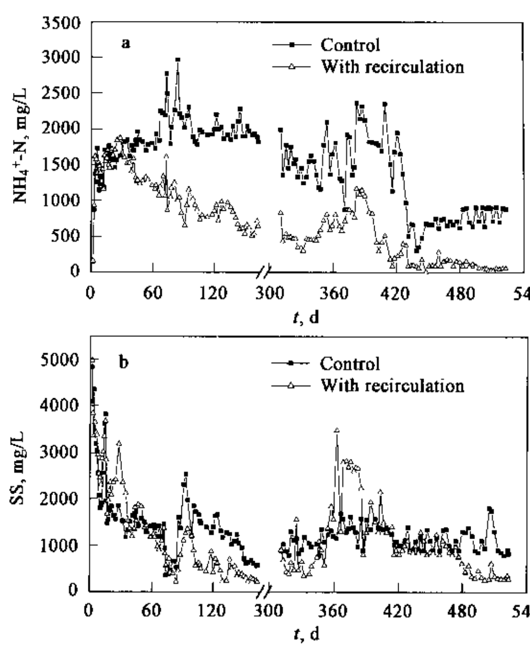

Fig.5 Variation of NH_4^+-N concentration (a) and suspend solid (SS) concentration (b) in leachate from landfill reactors

following stage (50—100 d, 380—450 d). When all the reactions were in a balanceable status, the NH_4^+-N concentration was kept a constant range from 100 d to 160 d and from 450 d to 540 d.

The suspend solid (SS) concentrations of both leachate had the similar downward trends during the experiment time (Fig.5b). At the beginning, there was a lot of spacing between the solid waste particles which made solid particles easy to go through them into leachate. The SS concentration was up to 4835 mg/L ($1^{\#}$) and 4975 mg/L ($2^{\#}$). Because of gravity and moisture accumulation in the spacing, there was less and smaller channel between solid waste, which made most particles hold by solid waste body, so that the SS concentration of leachate decreased gradually. During the rain season (86—120 d, 366—410 d), the SS concentration rose dramatically and unexpectedly because the solid particles held inside waste body were flushed into leachate by continuous heavy rain.

2.5 Waste stabilization

The pH value and VFAs concentration of leachate indicated that $1^{\#}$ and $2^{\#}$ reactors were in acidification and methanogenesis stage respectively after two years, which meant recirculation could enhance waste stabilization. In order to confirm it, solid waste samples were collected from the center of both landfill reactors using a long scoop and were analyzed according to the references (GEPA, 1990; He and Shao, 1994; Wang *et al.*, 2003). The results are summarized in Table 2.

Based on Table 2, it can be seen that pH of $1^{\#}$ solid increased from initial value of 5.53 to 6.73, which meant $1^{\#}$ reactor was in acidic stage, and that pH of $2^{\#}$ solid increased from 5.53 to 8.17, which meant $2^{\#}$ reactor was in alkaline stage. These results showed clearly that the solid waste in $2^{\#}$ reactor was more stable than that in $1^{\#}$ reactor. The moisture of $2^{\#}$ solid was higher than that of $1^{\#}$ by 4.8%, which meant solid waste in $2^{\#}$ reactor absorbed 14.4 L more water in waste body (0.5 m^3 × 600 kg/m^3 × 4.8% =14.4 kg =14.4 L). Considering TS, VS, BDM and TOC of both solid waste samples, all of the parameters indicated that leachate recirculation enhanced the organic matter degradation and waste stabilization. For NH_4^+-N and TN, the values in $2^{\#}$ reactor were lower than those in $1^{\#}$ reactor because more nitrogen was consumed as necessary nutrition for bacteria growth in $2^{\#}$ reactor. When the leachate with sufficient moisture and nutrition was recycled, a water film would be produced on the surface of the solid waste and a completely anaerobic condition was created inside the reactor which was suitable for bacteria growth. The anaerobic bacteria in recycled leachate were acted as inoculation which made landfill reactor become an anaerobic bio-filter using solid waste as carrier (San and Onay, 2001). So $2^{\#}$ reactor was more effective to absorb and degrade the organic matters than $1^{\#}$ reactor (Lawson, 1997; Warith, 2002).

Table 2 Characteristics of initial solid waste and residues in reactors after two years

	pH	Moisture, %	TS, g/g	VS, g/g	BDM, %	TOC, g/g	NH_4^+-N, mg/100g solid waste	TN, %
Initial	5.53	39.2	0.608	0.559	51.5	0.263	54.2	0.62
$1^{\#}$	6.73	37.3	0.627	0.189	16.2	0.089	33.6	0.42
$2^{\#}$	8.17	42.1	0.580	0.134	11.5	0.063	10.7	0.37

Notes: TS. Total solid; VS. volatile solid; BDM. bio-degraded matter

3 Conclusions

Based on two-year study on the landfill leachate recirculation treatment for outdoor simulated landfill reactors in Harbin, the main conclusions can be drawn as follows: (1) leachate production was mainly affected by rainfall and lagged behind it; (2) leachate production was discontinuous with big variation in northeast China. Leachate production was reduced by 86% with recirculation and less or no facility for leachate treatment required; (3) recirculation could improve the leachate quality dramatically with lower COD, SS, NH_4^+-N and higher pH level, which made leachate treatment easy and economical; (4) recirculation could enhance waste degradation and stabilization; (5) recirculation was a very feasible way to treat landfill leachate in northeast China.

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