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Research Article

Leachate Recirculation for Enhancing Methane Generation within Field Site in China

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Leachate recirculation is a critical element in the evaluation of the availability of methane production enhancement in bioreactor landfills. Field experiments in leachate injection were conducted in horizontal wells at a landfill in Hubei Province in China. The experiments included the long-term test of methane concentration and production in three cells; the test was operated with nonrecirculation (NR), continued recirculation (CR), and descending recirculation (DR). The average methane concentration in CR is 54.8%, which is higher than that in the NR and DR sites. The average biogas flow rate in the CR site was 2.2 times that in the NR site. The recirculation loading should be determined with the specific conditions, to effectively improve the methane production in field site. The position of the gas collection well was also very important, coordinating with the distribution of the leachate injection well and influence area of the liquid injection. The long-term monitoring of injection volume and gas production is essential to determine the reliability of recirculation for methane reuse.

1. Introduction

Leachate recirculation is one of the most effective methods to increase the conversion of organic matter and enhance the stability of bioprocesses in bioreactor landfills [1, 2]. The microbe degradation rate increases when the content of the organic solution increases; this condition leads to high methane production and collection recovery. The increase is largely attributed to gas reuse, such as increase in power and reduction of emissions, particularly in large-scale landfills. Therefore, leachate recirculation experiments must be conducted in the field to evaluate methane production and provide evidence for the liquid injection process.

The decomposition of municipal solid waste can be enhanced by leachate recirculation in anaerobic environments [3, 4]. This method is widely recognized. However, the pore structure and composition exhibit a heterogeneous distribution in landfills because of the difference in sample scale and cause a significant variation in recirculation volume and loading between laboratory scale and field scale [5–8]. Therefore, several studies have assessed the effect of leachate recirculation in pilot-scale experiments [9–11]. The methane generation rate increased from 15% to 700% by leachate recirculation in waste body. Jiang set up a pilot-scale column ($2.5\,m \times 3\,m \times 4\,m$) to complete a recirculation test with a highly organic waste sample. The quantity index and rate of injection of liquid volume to waste volume were established to evaluate the capacity to enhance degradation [12]. Benbelkacem reported that gas generation under recirculation loading is realistic with actual landfill samples in a $1.2\,m^3$ bioreactor. Water percolation was found to be an important factor to accelerate the degradation of solid waste. Some researchers found the leachate recirculation could accelerate VFA degradation rate [13].

A full-scale test for long-term monitoring is essential to further analyze the contribution of recirculation to gas emission in an actual landfill (Table 1) [12–16]. The methane content of landfills is often obtained to determine the biodegradation level. However, the report of recirculation in the field was little. The methane concentration was increased from 45% (before recirculation) to 55% (after recirculation) by vertical wells in Odayeri Sanitary Landfill [15]. Benson analyzed the five recirculation landfills in North America and found the definitive relation between the increase in gas production and collection wells distribution. Chung found that the methane concentration was increased from 30% (before recirculation) to 70% with injecting the leachate treated by SBR in an aged landfill. The injection time was continued to more than half a year. Recirculation loading was applied in the range of 0.1% to 1.3% per month. The contribution of leachate to methane production in the injection site increased from 1.5 to 2.2 times than in the noninjection site [13, 17, 18]. These results are related to the operating mode, such as wasteage, injection volume, and gas collection system. Di Maria et al. found that leachate recirculation in mechanically sorted organic fraction (MSOF) of municipal solid waste could achieve higher landfill gas recovery by developing a full-scale bioreactor [19].

However, no study has reported on the enhancement of gas collection by leachate recirculation in China, particularly in long-term tests in the field. The unified recirculation method may be unable to increase the methane production in Chinese regions because of the difference in waste composition and the landfill mode. A field experiment on leachate recirculation could provide useful information for the evaluation of methane collection and stability in local landfills. Therefore, a field experiment on recirculation was conducted in this study at a landfill in Hubei Province, China. Continued recirculation (CR) and descending recirculation (DR) were implemented to investigate the effect of liquid injection on methane increase in the operation state.

2. Materials and Methods

2.1. Landfill Site. H.J.W. Landfill is located in Hubei Province, China. Eight hundred tons of waste is removed daily from this landfill. The power plant was built in 2001. Municipal solid waste has been disposed to an area of 185,000 m^2 for the past 11 years. The average depth is 14 m. The amount of leachate produced per day is 120 m^3 to 150 m^3. The physical constituents of the landfill are presented in Table 2.

2.2. Leachate Recirculation and Gas Collection System. The leachate was injected into the landfill by a horizontal well. Two horizontal wells and one vertical well were designed in the test site (Figure 1). The vertical well was placed in the middle of the two horizontal wells and was used to pump gas from the landfill to the power plant. The horizontal well was placed 3 m below the cover. The influence radius of the vertical well is estimated to be 22 m [20]. The influence area of the horizontal well for liquid filling should be lower than that of the vertical well for gas pumping to increase the efficiency of methane collection within the site. The depth of the vertical well is 10 m, which is more than 70% of its total height. Barlaz et al. suggested that the evaluation of the gas collection efficiency should consider gas production and collection over the operation life. In the test process, the vertical well was operated at a continuous state by negative pressure for pumping gases, during the whole recirculation. A high-density polyethylene (HDPE) geotechnical liner and 30 cm of soil were paved onto the surface of the cells in March 2012. Geotextile and HDPE were used in the bottom system.

2.3. Test Procedures. The vertical well began operating 2 m after the cover operation. Methane concentration was determined with a spectrum analyzer. The injected leachate achieved from Section 2.2 in H.J.W. landfill was pretreated by NaOH to adjust the pH. The recirculation test was implemented at three sites in the landfill. Cell 1 is the nonrecirculation (NR) site. Cells 2 and 3 are the continued recirculation (CR) and descending recirculation (DR) sites, respectively. The leachate was continuously injected in cell 2. However, in order to compare the effect of different recirculation modes on the acceleration degradation, the DR was selected in cell 3 in small recirculation loading. The leachate injection volume in cell 2 and cell 3 is shown in Figures 5 and 6, respectively. All tests were operated under anaerobic condition and in vertical well to collect landfill gas. The characteristics of the field-site configuration are shown in Table 3. The abovementioned tests were conducted to investigate the contribution of gas increase by recirculation.

The recirculation loading could be written as follows:

$$\mathrm{RL} = \frac{V_1}{V_s \cdot t} \cdot 100\%, \tag{1}$$

where V_1 is the volume of the leachate injected into the landfill, V_s is the volume of the site, and t is the time across the recirculation.

2.4. Measurement of Landfill Gas and Leachate in Cells. The methane content in the extraction well was measured in real time with an infrared gas analyzer. The biogas flow rate was measured with an electromagnetic flow meter. The leachate sample was extracted from the drainage pipe 3 times every month. COD, BOD, and pH were recorded during 10 months.

3. Results and Discussion

3.1. Methane Concentration and Biogas Flow Rate. The average methane concentration was approximately 51.2% during the landfill operation (Figure 2). The biogas flow rate of the pumping well was 16.2 m^3/h. The biogas flow rate was attenuated during operation according to the degradation property of the waste.

Table 1: Recirculation information in some field site [14–18].

Reference	Area (m^2)	During time (year)	Injection volume (m^3)	Loading ($month^{-1}$)	Increasing amplitude
Vélez [13]	230	0.15	12.8	1.6%	50%[2]
Mehta et al. [18]	930	3	3000	1.3%	220%[2]
Morrisa et al. [15]	4000	6	1920	0.16%	700%[2]
Ozkaya et al. [14]	15000	0.2	3000	0.25%	10%[1]
	36000	8	3020/yr	—	
	97000	2	742/yr	—	
Benson et al. [21]	121000	1	19771/yr	—	14%–69%
	56000	4	1419/yr	—	
	178000	4	17035/yr	—	
Manzur et al. [17]	3000	0.5	116	0.1%	15%;[1] 150%[2]
Chung et al. [8]	2000	0.69	—	—	230%

[1]Methane concentration; [2]Methane generation rate.

Table 2: Summary of waste composition.

MSW constituents	Food	Paper	Plastic	Wood	Textile	Metal	Others
Ratio by weight (%)	57.4	7.8	13.6	5.7	2.3	1.8	11.4

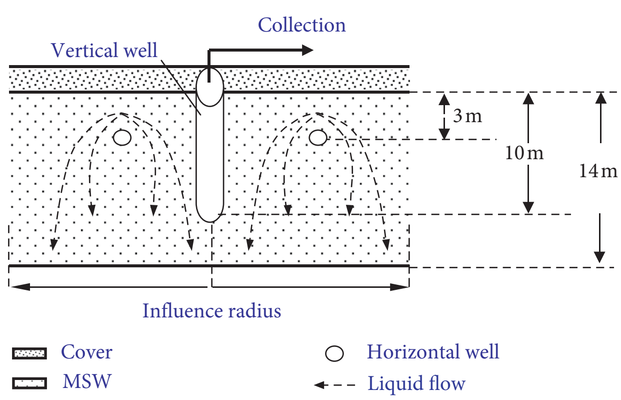

Figure 1: Design of the horizontal and vertical well within landfill.

The methane concentration and biogas flow rate during the recirculation period in cell 2 are shown in Figure 3. The average methane concentration was 53.2% during the first eight months and increased to 58.2% between the eighth and eleventh months. The high concentration of the injected leachate could be responsible for its variation in the duration. The COD of leachate empty into cell 2 was from 5800 to 9500 mg/L during recirculation (Figure 5). The average flow rate in cell 2 was 2.2 times than that in cell 1, which was 36.1 m^3/h.

Figure 4 shows the methane concentration and biogas flow rate in cell 3. The biogas flow rate increased significantly in the initial phase, which operated with recirculation in the first two months. The biogas flow rate and methane concentration increased to 49 m^3/h and 60% in the third month, respectively. When the liquid injection was ceased, the flow rate obviously decreased in the later months. The average flow rate and methane concentration decreased to 19.1 m^3/h and 51.0% in the nonrecirculation phase, respectively.

The average injection volume of the leachate introduced in the CR mode in cell 2 was about 13.0 m^3/month. The leachate recirculation rate was approximately 0.048% of the waste volume per month (Figure 5). The average injection volume was 13.6 m^3 during the first two months. In the sixth month, injection volume was 4.5 m^3. During the ninth to eleventh month, the injection volume was further decreased, to 8.1 m^3 (Figure 6).

Figure 7 presents the pH of bleeding liquid in the three cells. The pH in the recirculation cell was higher than that in the nonrecirculation cell. The pH increased from 5.7 to 6.8 in the recirculation cell. When the recirculation was ceased, the pH became slightly less than that during recirculation initialization in cell 2.

An obvious COD trend was exhibited. COD in the three cells decreased with time (Figure 8). The COD in cell 2 was higher than that in cell 1 in the second month. The COD in cell 3 was higher than that in cell 1 during leachate recirculation.

BOD/COD decreased in the three cells as the organic matter decomposed (Figures 9–11). The decision coefficient for cell 1, cell 2, and cell 3 was 0.29, 0.34, and 0.22, respectively. There was obvious discreteness of the fitting results because the leachate sampling was inhomogeneous in field site. The fitting results show that the decreasing of BOD/COD was cell 2 > cell 3 > cell 1. It was suggest that the leachate recirculation with the low loading could accelerate the biodegradation of municipal solid waste. The leachate recirculation to enhance waste degradation was also found by Ozkaya (2004) and Jiang (2007) in higher recirculation loading.

3.2. Effect of the Influence Area. The lateral impact zone of the horizontal well can be controlled with injection pressure and waste properties [22, 23]. A high gas collection rate is achieved when the impact zone of the injection system is limited by the influence area with a pumping well. This design is important to evaluate the possibility of increasing methane production with leachate recirculation.

3.3. Scaling Effect. Recirculation loading from 0.35% per week to 5.3% per week can be achieved in a pilot-scale test [3, 11, 24]. This value is much higher than that in the test

Table 3: Characteristics of the field-site configuration.

Parameters	Group		
	Cell 1	Cell 2	Cell 3
Digested mode	Anaerobic	Anaerobic	Anaerobic
Gas pumping	Vertical well	Vertical well	Vertical well
Recirculation method	No	Horizontal well	Horizontal well
Cell depth (m)	14.2	14.5	14.5
Cell area (m^2)	1980	2020	1980
Landfill age (month)	15	15	19
pH of injected leachate	No	7~8.5	7~8.5
COD of injected leachate (mg/L)	No	5800~9500	6100~10300

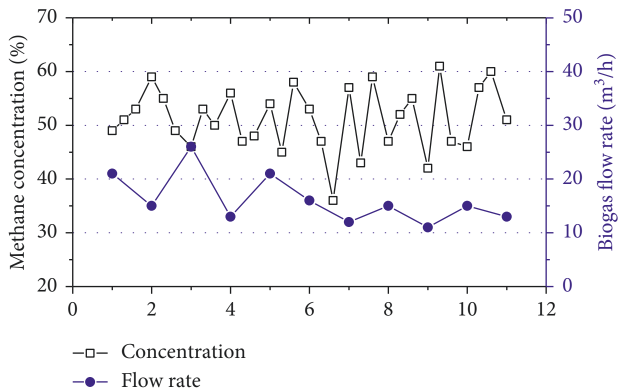

Figure 2: The distribution of the methane concentration and biogas flow rate in cell 1.

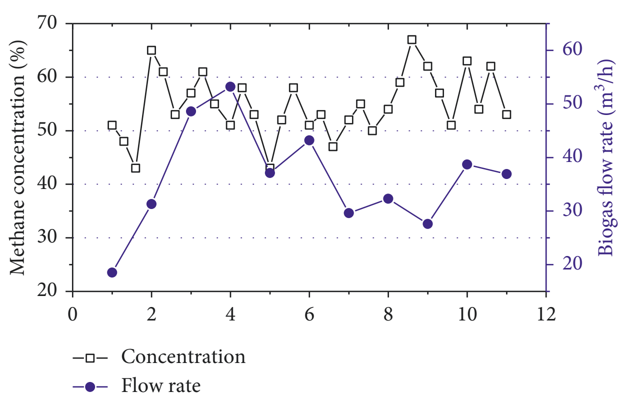

Figure 3: The distribution of the methane concentration and biogas flow rate in cell 2.

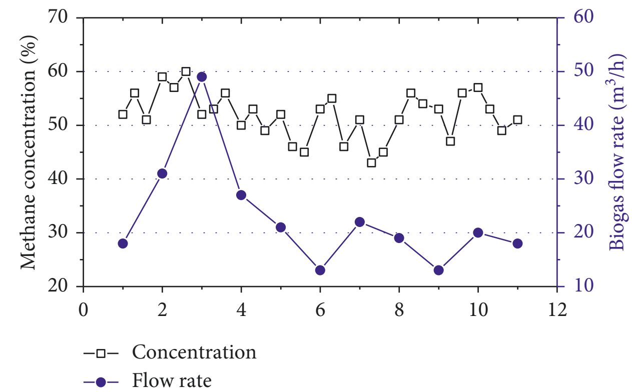

Figure 4: The distribution of the methane concentration and biogas flow rate in cell 3.

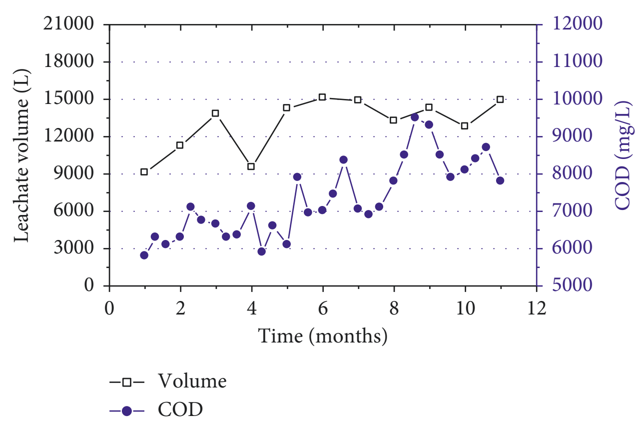

Figure 5: The distribution of the leachate injection volume and COD in cell 2.

conducted in the field. The leachate in this study was often injected into the site at a range of 0.1% to 1.3% per month mainly because the amount of liquid filled into the waste was limited. A number of factors, such as high moisture content, large filling area, and heterogeneous waste composition, also contributed to recirculation loading. Therefore, the feasibility of recirculation loading should be determined by a field test.

3.4. Methane Production with Recirculation Loading. The recirculation loading in the H.J.W. landfill (0.05% per month) is much lower than that in Yolo County (1.3% per

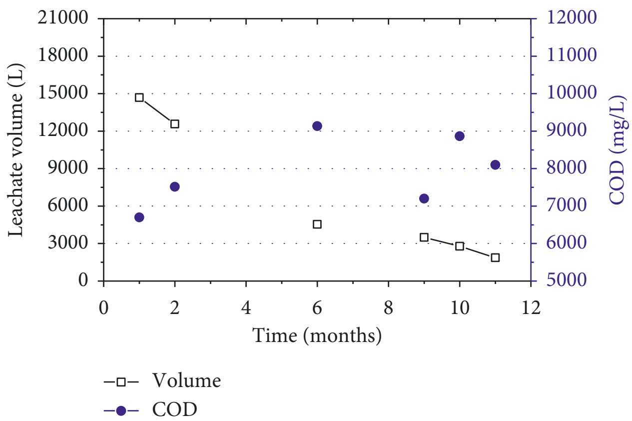

Figure 6: The distribution of the leachate injection volume and COD in cell 3.

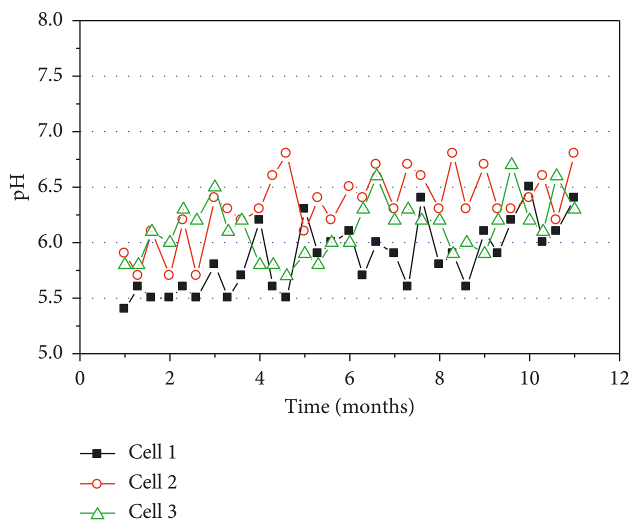

Figure 7: The variation of the pH in three cells.

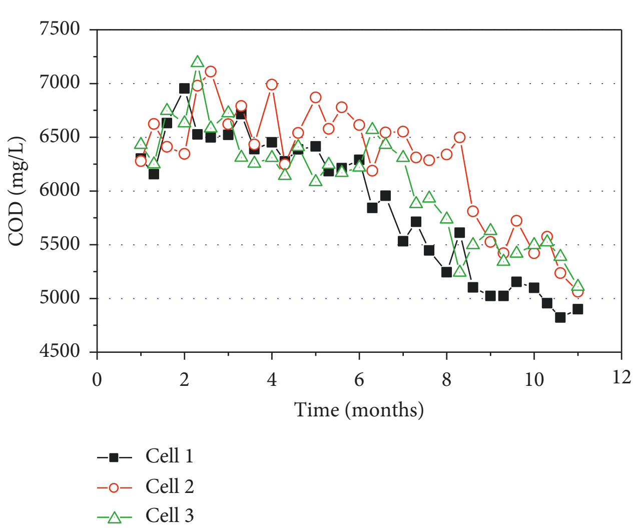

Figure 8: The variation of the COD in three cells.

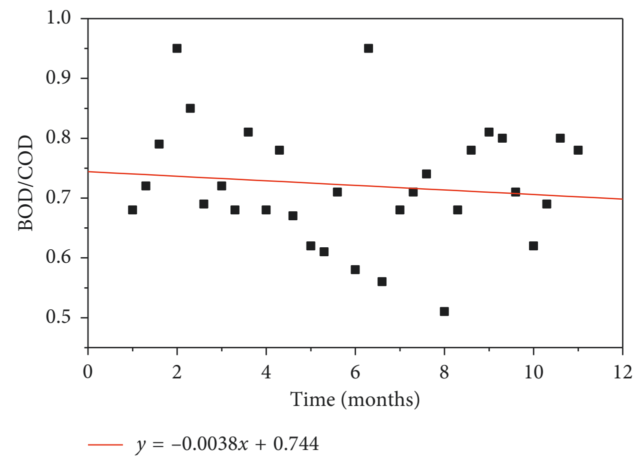

Figure 9: The BOD/COD ratio in leachate from cell 1.

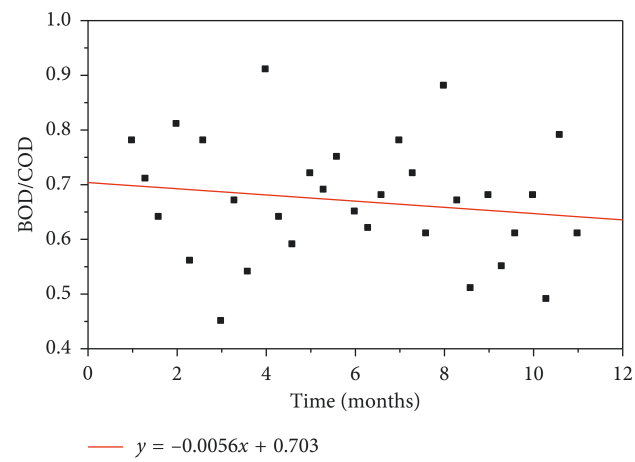

Figure 10: The BOD/COD ratio in leachate from cell 2.

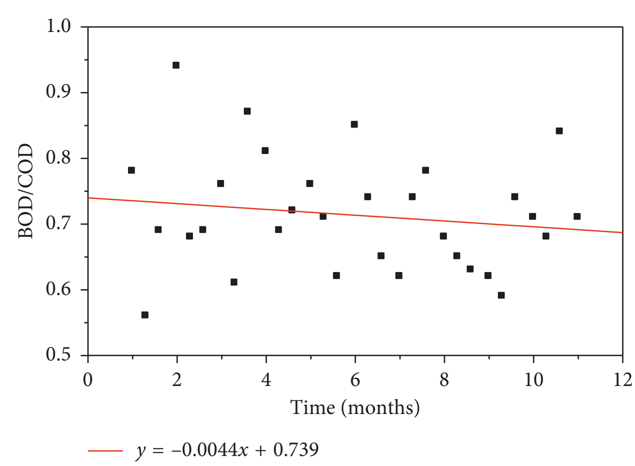

Figure 11: The BOD/COD ratio in leachate from cell 3.

month) and Denton (0.1% per month) landfills as reported by Mehta et al. [18] and Manzur et al. [17], respectively. However, the contribution of methane output is almost similar in these landfills. The reason for the frequent injection, which induces organic runoff and decreases methane production, can be eliminated [25]. Fresh waste and high leachate concentration account for the buildup of methane output in this study.

4. Conclusions

Long-term and short-term monitoring tests for leachate recirculation in the field were conducted in this study. The methane concentration and biogas flow rate were recorded during the operation phase of the landfill in NR, CR, and DR modes. High concentration and continuous injection of the leachate had a significant effect on the increase in the methane generation rate. The design of the collection well was also a critical element in the evaluation of the methane output. Determining recirculation loading based on the field scenario is essential to improve methane output. The influence area of the liquid injection and gas-pumping wells should be considered to provide significant evidence to improve the reliability of quantity analysis in methane generation by leachate recirculation in the field site.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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