Title	Estimation of water movement in a closed landfill based on tracer tests in gas vents and changes in leachate quality
Author(s)	Kim, H. J.; Endo, D.; Sato, M.; Matsuo, T.; Matsuto, T.
Citation	Waste Management, 29(8), 2308-2315 https://doi.org/10.1016/j.wasman.2009.03.011
Issue Date	2009-08
Doc URL	http://hdl.handle.net/2115/38782
Type	article (author version)
File Information	29-8_p2308-2315.pdf

[Instructions for use](#)

Estimation of water movement in a closed landfill by tracer test in gas vents and the change in leachate quality

H.J. Kim^{*}, D. Endo, M. Sato, T. Matsuo, and T. Matsuto

Laboratory of Solid Waste Disposal Engineering,
Graduate School of Engineering, Hokkaido University,
Kita 13, Nishi 8, Kita-ku, Sapporo 060-8628, Japan

Abstract

Leachate accumulation was found in Nakazono landfill, in Asahikawa, Japan because of an insufficient leachate collection and drainage system. In order to lower leachate level in the landfill and to promote stabilization of waste, many passive gas vents were installed as well as leachate collection vaults. This study aimed to evaluate the distribution and movement of leachate in the landfill by determining leachate level and tracer test in the gas vents.

The water level varied widely among the gas vents and depended mainly on the original ground level and the depth of the vent. Leachate velocity also showed a wide variation. The leachate velocity was high in the upper layers of the saturated zone in a gas vent. However, this is only the superficial velocity caused by an inflow from unsaturated layers. A sharp decrease in TOC, which was observed in most of the gas vents by installation of vents, were likely due to the effect of aerobic biodegradation in the unsaturated layer of waste. This effect is limited to the small aerobic zone around the gas vent.

Keywords: Closed landfill; Remediation works; Tracer test; Leachate flow; TOC

^{*} Corresponding author. Tel/Fax: +81-011-706-6830/6831
E-mail: hjkim@eng.hokudai.ac.jp

1. Introduction

Landfilling is the most common method of disposing of municipal solid waste (MSW) worldwide. Compared with other disposal method, landfill needs long time to complete stabilization of waste: leachate and gas should be treated until they are met with environmental criteria. The time needed for the aftercare is estimated for several decades (e.g., Belevi and Baccini, 1989). Consequently, it will be a big financial burden for operators of the landfill. To reduce aftercare period, bioreactor landfill technology is studied, in which moisture content is kept at water holding capacity to enhance the biodegradation of wastes (e.g., Reinhart, 1996; Reinhart and Al-Yousfi, 1996). In Europe, mechanical/biological pretreatment or thermal treatment of waste has been used to reduce the amount of biodegradable wastes placed in landfills (Sormunen, K., 2008). In situ aeration is another method to decrease gas emissions and improve leachate quality in a short period of time (Heyer et al., 1999, 2005; Cossu et al., 2003). Even for bioreactor, air as well as water is supplied into waste layer in an aerobic bioreactor.

In Japan, semi-aerobic landfills have been the standard type of solid waste landfill since the 1970s (Hanashima, M., 1999). A semi-aerobic landfill has a network of leachate collection pipes and gas venting pipes that automatically provide fresh air to the layers of waste using the convection effect of the heat generated by waste decomposition. However, Nakazono Landfill, in Asahikawa, Japan was not designed as semi-aerobic landfill because it was constructed before a design guideline for construction was published. At that time, leachate treatment was required, but geomembrane liner was not obligated to be used when natural ground has low permeability.

In 1998, the Japanese Ministry of the Environment surveyed all MSW landfills in Japan after leachate leak was found at some landfills. More than a quarter of landfills were found to be labeled “inappropriate landfill.” Nakazono landfill was not labeled with the name, but the city conducted an individual survey in 2001 after the citizen had expressed concern about environmental pollution related to the landfill. Water level in the landfill, leachate and groundwater quality and landfill gas was investigated by the survey. It was found that leachate level was very high in the landfill. It suggests that leachate is not efficiently drained by leachate collection pipes due to the bad installation of pipe layout and insufficient diameter and the number of pipes. Moreover, infiltration of groundwater from the surrounding area was suspected by comparing estimated leachate generation based on rainfall with observed amount. As a result, large parts of waste are beneath leachate level, and it was feared that the waste will be remained without degradation for a long time.

In order to lower leachate level in the landfill and to promote stabilization of waste, the city government planned a five-year remediation measure starting from 2004. As a part of the remediation work, many passive gas vents were installed as well as leachate collection vaults. This study aimed to evaluate the distribution and movement of leachate in the landfill by determining leachate level and velocity in the gas vents. Tracer test was used to determine leachate velocity, and leachate quality was also measured.

2. Description of the landfill

By 2005, Nakazono Landfill was the eighth-largest of 1821 landfills in Japan, according to the Japanese Ministry of the Environment (MOE). Nakazono landfill was constructed in a mountain valley, and it is composed of two compartments whose outlines are shown in Table 1. Compartments

1 and 2 were operated during the periods 1979–1982 and 1983–2003, respectively. The waste composition in Compartment 2 is 35.4% MSW, 31.9% construction waste, and 12.8% industrial waste as shown in Table 2. The location of waste placement was not recorded.

As mentioned above, several problems including high water level were revealed by the city's individual survey in 2001. High build up of leachate around 10 m was found through the three drilled boreholes (66 or 86 mm in diameter). Although leachate and groundwater quality were met with the environmental water standard, infiltration of groundwater into the landfill was observed beneath the drainage ditch surrounding the landfill. It was identified to increase leachate generation.

Accordingly, compartment 2 was closed in 2003 and some remedial actions were taken. To lower the water level inside the landfill, leachate collection access vaults (2500 mm in diameter, 10 – 30 m of length) were installed as shown in Fig. 1a. Horizontal leachate collection pipes (75 mm in diameter) were connected to the access vaults to collect leachate around the area at the same time. The installation points of the vaults were determined by considering water level in the landfill and then five vaults were installed in 2005, and four in 2006. 0.5-1 m of final cover was placed again from 2003 to 2008 because old landfill cover was washed away due to a steep slope of the landfill. For reducing groundwater inflow from the surrounding area, preliminary research was conducted to identify its main pathway, and then drainage of groundwater is planned to be constructed in 2009.

When a new landfill is constructed, usually one gas vent is needed for 2,000 m² but this landfill had only one gas vent for 11,000 m², so the landfill was under anaerobic condition. New vertical PVC gas vents (200 mm in diameter, 30 m of maximum length) were installed on the area suspected to be anaerobic conditions by gas composition data of the survey in 2001. After making a borehole with 250 mm in diameter, perforated PVC pipe was inserted into the hole. In total 93 gas vents were installed: 30 in 2005, 38 in 2006, and 25 in 2007, respectively.

Fig. 1a shows the location of new gas vents. They were installed at intervals of about 50 m on compartment 2, not exactly on a grid. For simplicity, gas vents are identified by numbers in a rectangular coordinate system, where, for example, “45” would indicate a vent in the 4th row and 5th column. Fig. 1b shows the original ground level as well as the gas vent locations used for tracer tests. The structure of the access vaults and horizontal leachate collection pipes is given in Fig. 1c. The leachate collection pipes of 75mm were extended out from the access vaults, and neighboring vaults are connected by 250mm pipes. Leachate in gas vents and access vaults were not pumped out, but it is drained by gravity.

3. Methods

By the use of gas vents, the following test was carried out. Leachate quality was measured at 48 vents, of which water level was measured and tracer test was conducted at the 18 locations indicated by the solid black circles in Fig. 1a.

3.1. Water column height (WL)

The leachate level in a typical gas vent is illustrated in Fig. 2, where D is the depth of the vent and WL is the height of water column. The WL was calculated by the difference between the depth D and the distance between the surface of the water and the top of the vent, W. A measured rope with a 5-kg weight was lowered to the bottom of the gas vent to determine D. W was established by lowering

electrodes down the vent and detecting the depth at which they conducted electric current when they contacted the surface of water.

3.2. Leachate sampling and analysis

Leachate was collected from each gas vent in a 100-ml glass sampler. Electrical conductivity and temperature were immediately measured onsite with a pH/conductivity meter (D-54, Horiba) and a thermometer. The collected leachate was stored and sealed in plastic bottles. TOC and TN were analyzed after filtration with Shimadzu TOC-V and TNM-1 analyzers, respectively. The amount of chloride ion (Cl^-) in the leachate was determined with a spectrophotometer (Hitachi U-1101) at a wavelength of 460 nm using the mercuric thiocyanate method (JISC, 2004).

3.3. Tracer test for leachate velocity

Groundwater velocity is usually determined by measuring hydraulic conductivity and hydraulic head at several locations using Darcy's Law. In Nakazono Landfill, however, hydraulic conductivity is unknown and expected to vary significantly by location due to heterogeneity of dumped waste. The large distance between gas vents is another problem to assume uniform flow in the landfill. Another method to determine groundwater velocity is a borehole tracer method (Novakowski et al., 2006; Williams et al., 2006). This method involves monitoring the change in tracer concentration after tracer is injected into isolated area in a borehole spaced by inflated packers. Distribution of groundwater flux is identified by repeating the test along the depth of the borehole. However, it is not possible to apply this method to Nakazono landfill by the following reason. It will need too much time and several sets of equipments because leachate flux should be determined at many different points due to heterogeneity of landfilled waste.

In this study, therefore, in order to estimate the overall conditions, a simplified tracer test was conducted. NaCl was used as a tracer because it is highly soluble in water and non-reactive in many soil, and the concentration can be estimated by measuring electrical conductivity (EC) onsite (e.g., Lile, 1997; Woumeni, 2006; Williams, 2006). Because leachate velocity is not uniform along the depth, continuous monitoring of tracer concentration was desirable. EC monitoring is one of the easiest ways to measure concentration, by lowering a sensor from top to the bottom. However, EC was not constant by wells, and by depth, furthermore, EC did not return to the initial value even when Cl^- concentration did. So, Cl^- concentration was determined by sampling leachate.

Due to the limited time and equipments available, it was only possible to measure a concentration of tracer at a few discrete points along the depth. Leachate level was high in some vents, up to 15 meter. In this study, the WL (water level in Fig.2) was divided into K layers when $\text{WL} > 3$ m; $K = 2$ for 3–6 m and $K = 3$ for $\text{WL} > 6$ m. In each layer, which is too big to be assumed complete mixing condition, we could assume good mixing by leachate flow around a sampling point at fixed depth. By this way, the difference of velocity along the depth of a gas vent can be detected.

The procedure of the tracer test is shown in Fig. 3. Leachate in the gas vent was fully mixed by the rope with the 5-kg weight. Immediately after mixing, the leachate was collected at the center of each layer. The Cl^- concentration in the leachate was defined as the initial concentration (C_0 , mg L^{-1}). Then 1.5–3 L of NaCl solution (300 mg L^{-1}) was injected directly into the gas vent. The amount of the tracer was increased when WL and background EC were high. After injection of the tracer, the leachate in the vent was mixed again. The leachate was then immediately sampled again at each layer, and the Cl^- concentration at this point was defined as C_p . The initial concentration, C_0 was in the

range of 100–800 mg L⁻¹ except for around high value of 2000 mg L⁻¹ at wells 33 and 34. The difference of the background level is caused by the difference in waste. The increased concentration by tracer injection, $C_p - C_o$, was in the range of 400–3000 mg L⁻¹. Sampling of the leachate was repeated at intervals of 30–60 minutes until the concentrations of Cl⁻ remained relatively stable. Sample bottle was lowered and pulled up slowly to minimize vertical mixing of leachate in the vent. Sampling was continued for 4–6 hours, but when the decrease of Cl⁻ was very slow, leachate was sampled after 1 or 2 weeks. The change in Cl⁻ was monitored by measuring the electrical conductivity onsite. All leachate samples were transferred to the lab where the Cl⁻ concentration was determined.

3.4. Determination of flow rate

By assuming complete mixing around midpoint of each layer as mentioned in the previous section, the change in Cl⁻ concentration in the leachate over time can be expressed by Eq.(1) .

$$\alpha \left(\frac{V}{K} \right) \frac{dC}{dt} = \alpha (QC_{in} - QC), \quad (1)$$

where Q is the flow rate of the leachate, and V is the leachate volume in the gas vent. C_{in} is the concentration of leachate flowing into the vent, and “ α ” is a ratio of the vent in which complete mixing is assumed. By assuming a steady state for $T < 0$ in Eq. (1), C_{in} is equal to C_o , the initial concentration of leachate in the vent. The change in C in non-dimensional form is given in Eq. (2):

$$C' = \frac{C - C_o}{C_p - C_o} = \exp \left(- \frac{Q \times t}{V / K} \right), \quad (2)$$

Q, which is the only unknown parameter in Eq. (2), can be determined using the least squares method to minimize the error between the calculated and measured values as shown in Fig. 4. As a result, the velocity v (cm day⁻¹) across a cross-sectional area in a gas vent can be calculated using Eq. (3), where D is the gas vent diameter (20 cm):

$$v = \frac{Q}{(WL / K)D}. \quad (3)$$

It should be noted that this procedure includes several sources of error. Complete mixing at a point of sampling and no vertical mixing are only ideal. Increase of Cl⁻ by injection of tracer is not exactly the same as calculated value, which suggests that effective volume is smaller or larger than V. For example, lower increase than calculated one will be caused by space around gas well. Because the existing of a gas vent will change streamline of leachate in the landfill by extending influential area around the gas vent, Eq. (3) may give the overestimated value. In spite of these limitations, the test procedure was considered to be the best estimation of water flow.

4. Results and discussion

4.1. Water column height (WL)

The WL was measured at 18 sampling points shown in Fig.1a seven times: six times during July–November 2006 and once in October 2007. Fig. 5 shows a cross-sectional view of the sixth row of gas vents. The WL varied widely in the range of 1.4–14.5 m among the gas vents due to the shape of original ground and the depth of the vent. The WL is larger when the original surface is farther below the current surface, and the gas vent is deep.

Fig. 6 illustrates the change in WL for 18 gas vents. Time of sampling was labeled by S1 to S7. The WL fluctuates more in vents which has large WL, vents 34, 67, and 68 for example. High WL are caused by collecting water from side area, so it will be reasonable to be influenced more by the change of rainfall. In contrast, the WL and the WL fluctuation are small in gas vents such as 64 and 65, which were installed at the slope of the original surface. The profile of water table in Fig. 5 does not change significantly by WL fluctuation.

4.2. Leachate velocity

The leachate velocity was investigated using tracer tests at 18 sampling points in October 2007. The results are in Table 3, and the velocities at the sixth row are shown in Fig. 5. Generally, the velocity is low (0–13 cm day⁻¹) in the lower layer while it is high (55–148 cm day⁻¹) in the top layer. The velocity in the lower levels is influenced by geography. The bottoms of gas vents 64, 68, 6A, 6B, and 6D were below the original ground surface, so water migration in the lower layers of these vents is restricted by the low permeability of the original ground. On the other hand, higher velocity can be caused by spilled water from unsaturated zone above the water level in the vent. At several gas vents (16, 6D, and 45), the sound of water falling on the surface of the leachate table was noticed, which indicates the existence of preferential leachate flows in the unsaturated layer of the waste mass. Therefore in this case, velocity determined by Eq. (3) is influenced by the degree of vertical mixing caused by spilled water as well as leachate flow in saturated layer.

By using values in Table 3, leachate flow rate across a cross section of the landfill was estimated in the following manner:

$$50 \left(\frac{1}{K} \sum_{k=1}^K v_{jk} \right) WL_j, \quad (4)$$

where WL_j is the height of the leachate column of the j th vent at the cross section, v_{jk} is the leachate velocity at the k th layer (see Table 3), and “50” indicates the 50-m interval between gas vents. Although the number of data is too small to calculate leachate volume in the landfill which has strong heterogeneity horizontally and vertically, Eq. (4) is still effective to know the behavior of water in the landfill.

The quantity of leachate was calculated 400,000 m³ year⁻¹ for sixth row while the actual leachate discharge was 423,500 m³ in the previous year. The upper area than sixth row (see Fig.1) accounts for about the half of the total landfill area, but groundwater inflow from the top border of the landfill was estimated forty percent of leachate volume according to the author’s previous estimation. Therefore, the estimated leachate volume at sixth row was reasonable. If the leachate flow between vents 60 and 63 has been considered, the error will be smaller. For the first row, on the other hand, leachate volume was estimated to be significantly high (2,000,000 m³ year⁻¹). This seems to overestimate the leachate

collected at vents 15 and 16 by a large amount due to the nearby vertical access vaults, which make strong preferential flows with a high water head by collecting leachate around the area (see Fig. 1a)

4.3. Change of TOC and TN in leachate

The TOC and TN concentrations in the leachate were investigated in 48 gas vents from October 2005 to November 2007. Leachate was sampled at the surface in gas vents. An example of the observation is shown in Fig.7. TOC and TN decreased rapidly about 10 months after the gas vent was installed, and such decrease were found for most vents, all in summer. This fact suggests that aerobic biodegradation occurred. Aeration of waste via gas vents is possible only in unsaturated layer, and spilled water had a large contribution to the leachate volume in the top layer of water in vents. For these reasons, it is concluded that the decrease of TOC and TN was caused by aerobic biodegradation around vents in unsaturated zone.

Consequently, low TOC after the first summer is a result of the leachate quality in saturated zone and dilution by purified leachate from unsaturated zone. By considering the landfill as a big lysimeter of 700 meter long and by assuming 40 cm day^{-1} as an average velocity in the saturated zone, which is an average at sixth row in Table 3, a liquid/solid (L/S) ratio of the saturated zone for 10 years is

$$0.4 \text{ m day}^{-1} \times 365 \times 10/700 = 2.1. \quad (5)$$

Due to a high L/S ratio, solid waste in the saturated layer may have been sufficiently flushed already.

Fig. 8 shows the average values of TOC and TN before and after gas vent installation for 48 gas vents. TOC and TN levels are high at 22, 23, 24, 33, and 55, and did not decrease even after gas vent installation. These are places where sewage sludge was landfilled. Except for these points, TOC decreased 20%–60%, and there was no correlation between the decreased ratio and the row number. The decrease in TN was very low.

In summary, the decrease in TOC and TN can be explained as follows.

- 1) Leachate quality of the top layer in gas well is determined by spilled water from unsaturated zone as well as by leachate flow in saturated zone.
- 2) TOC in the saturated zone is low because of the constant washing by leachate flow.
- 3) TOC in unsaturated zone is initially high, but it is decreased in an aerobic zone created around gas vent.
- 4) As a result of points 1–3 above, the TOC of leachate in gas well decreased after gas vent installation. TOC might increase again in winter to spring because of no aeration and low temperature, though it is not sure by the lack of observed data.
- 5) Nitrogen is transformed to nitrate by aerobic microorganisms, so the TN did not diminish, while the TOC decreased.

The leachate collected at the treatment facility, however, showed no change in TOC concentration. TOC change only occurs in the gas vents and the immediate vicinity. According to Kallel (2004), when a vertical gas vent is the only source of aeration, it requires 100 years to aerate the area in a 15 m radius of the vent. Even if the gas flow depends on the waste conditions, many decades may be necessary to ensure the complete aeration of Nakazono Landfill.

5. Conclusions

This report describes the evaluations of water flow, TOC, and TN in the leachate of gas vents at Nakazono Landfill, where remedial measures had been taken to lower the leachate level and promote stabilization. The main findings are as follows:

- 1) The height of water column in gas vents shows large variation, and is dependent on the surface of the original ground and the depth of the vent.
- 2) Leachate velocity varied over a wide range of 0–2134 cm day⁻¹ depending on the gas vent, and mainly influenced by the profile of original ground.
- 3) The leachate velocity was high in the upper layers of the saturated zone in a gas vent. However, this is only the superficial velocity caused by an inflow from unsaturated layers as well as flow in saturated zone.
- 4) A sharp decrease in TOC, observed in most of the gas vents by installation of vents, were likely due to the effect of aerobic biodegradation in the unsaturated layer of waste. This effect is limited to the small aerobic zone around the gas vent, and a long time will be required to aerate the complete landfill body.

Leachate sampled from gas vent gives us information to know the condition of waste in the landfill. However, this study provided a lesson to be noted in leachate sampling:

- 5) Sampled leachate from a well is a mixture of water in saturated zone and that from unsaturated zone. The quality of the sample includes the effect of concentrations in both flow and the ratio of flow rates.
- 6) By installing gas vents, aerobic zone is created around vents, which will improve quality in unsaturated zone. Moreover, such superficial improvement of leachate quality is only happened locally around gas vent.

References

- Belevi, H., Baccini, P., 1989. Long-term behavior of municipal solid waste landfills. *Waste Management and Research* 7, 43–56.
- Cossu, R., Raga, R., Rossetti, D., 2003. Full scale application of in situ aerobic stabilization of old landfills. *Proceedings Sardinia 2003, Ninth International Waste Management and Landfill Symposium*.
- Hanashima, M., 1999. Pollution control and stabilization process by semi-aerobic landfill type: The Fukuoka Method. *Sardinia 99*, 313–326.
- Heyer, K.U., Hupe, K., Heerenklage, J., Ritzkowski, M., Dalheimer, F., Stegmann, R., 1999. Aeration of old landfills as an innovative method of process enhancement and remediation. *Sardinia 99*, 563–571.
- Heyer, K.U., Hupe, K., Ritzkowski, M., Stegmann, R., 2005. Pollutant release and pollutant reduction—impact of the aeration of landfills. *Waste Management* 25, 353–359.
- JISC, 2004. JIS K 0107: Methods for Determination of Hydrogen Chloride in Flue Gas. Japanese Industrial Standards Committee, Tokyo (in Japanese).

- Kallel, A., 2004. Basic study on passive aeration for sanitary landfill to enhance stabilization in the aftercare-phase. Graduate school of Engineering, Hokkaido University, pp. 79–99.
- Lile, O.B., Morris, M., Rønning, J.S., 1997. Estimating groundwater flow velocity from changes in contact resistance during a saltwater tracer experiment. *Journal of Applied Geophysics*, 38, 105–114.
- MOE (Ministry of the Environment Government of Japan): http://www.env.go.jp/recycle/waste_tech/ippan/h17/
- Novakowski, K., Bickerton, G., Lapcevic, P., Voralek, J., Ross, N., 2006. Measurements of groundwater velocity in discrete rock fractures. *Journal of Contaminant Hydrology* 82, 44–60.
- Reinhart, D.R., 1996. Full-scale experiences with leachate recirculating landfills: case studies. *Waste Management and Research* 14, 347–365.
- Reinhart, D.R., Al-Yousfi, B., 1996. The impact of leachate recirculation on municipal solid waste landfill operating characteristics. *Waste Management and Research* 14, 337–346.
- Sormunen, K., Einola, J., Ettala, M., Rintala, J., 2008. Leachate and gaseous emissions from initial phases of landfilling mechanically and mechanically-biologically treated municipal solid waste residuals. *Bioresource Technology* 99, 2399–2409
- Williams, A., Bloomfield, J., Griffiths, K., Butler, A., 2006. Characterising the vertical variations in hydraulic conductivity within the Chalk aquifer. *Journal of Hydrology* 330, 53–62.
- Woumeni, R.S., Vauclin, M., 2006. A field study of the coupled effects of aquifer stratification, fluid density, and groundwater fluctuations on dispersivity assessments. *Advances in Water Resources* 330, 53–62.

(a)

(b)

Fig. 1. Outline of Compartment 2: (a) layout of gas vents, leachate collection pipes, and sampling points; (b) three-dimensional view showing tracer test points; and (c) top view of the access vault and horizontal pipes.

Fig. 2. Definition sketch for WL and leachate sampling in a gas vent.

Fig. 3. Procedure of the tracer test.

Fig. 4. Example of the change in Cl^- concentration in the tracer test for gas vent 66 (NaCl solution was injected at $t = 0$).

Note: WL is the height of the water column in a gas vent, which is divided into K parts when WL > 3 m: upper, middle and lower layer.

Fig.5. Cross-sectional sketch of the landfill and leachate velocity at each gas vent in the sixth row (A-A').

Fig. 6. Change in WL at each gas vent.

Fig. 7. TOC and TN concentrations as a function of time at gas vent 15, which was installed in September 2005.

(a) TOC

(b) TN

Note: The ordinal numbers indicate the row of gas vents shown in Fig. 1a.

Fig. 8. Comparison of leachate quality before and after gas vent installation (unit: mg L⁻¹).

Table 1 Properties of Nakazono landfill

Type	Compartment 1	Compartment 2
Landfill area	75,900 m ²	422,500 m ²
landfill volume	1,580,154 m ³	5,817,646 m ³
Disposed waste	1,568,694 ton	4,861,306 ton
Period (open-close)	1979-1982	1983-2003
Waste composition	No data	see Table 2

Table 2 Waste composition of the compartment 2

Waste Category	Weight (ton)	Percent by weight (%)
Municipal solid waste	1,719,509	35.4
Construction waste	1,550,429	31.9
Industrial waste	624,395	12.8
Tree	392,516	8.1
Sludge	306,273	6.3
Household non-combustible waste	175,836	3.6
Incinerated ash	52,582	1.1
Others	39,766	0.8
Total	4,861,306	100

Table 3 Leachate migration velocity at 18 sampling points in Nakazono landfill

Gas well		64	65	66	67	68	69	6A	6B	6D
Water level (m)		1.7	1.4	3.4	14.0	14.5	3.9	6.6	3.8	7.3
Velocity (cm/day)	a	3.0	8.8	116.4	38.4	112.6	108.1	92.0	55.1	147.9
	b			42.4	8.2	37.7	2.1	41.3	11.1	35.5
	c				11.0	0.0		13.0		4.0
Gas well		43		45						
Water level (m)		7.6		6.3						
Velocity (cm/day)	a	135.0		1,652.0						
	b	6.5		10.9						
	c	7.1		12.2						
Gas well		33		34						
Water level (m)		2.2		2.2						
Velocity (cm/day)	a	1.2		0.4						
	b									
	c									
Gas well		12	13	14	15	16				
Water level (m)		5.7	1.0	2.4	3.6	6.7				
Velocity (cm/day)	a	638.9	177.0	0.5	434.6	2,134.2				
	b	514.0			74.1	718.5				
	c					41.2				

Note: a, b and c are the upper, middle and lower layer of water column in a gas vent, respectively.