Estimation of water flow and the effect of gas well installation in closed landfill

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1. Introduction

Today, landfill management is focused on the earlier stabilization of solid waste placed in landfill to save time and costs which are required to reduce the long-term risks to public health and environment. From this strategic point of view, however, municipal solid waste (MSW) landfill located in Japan has a lot of defects: insufficient installation of leachate collection pipes and its discontinuity, infiltrations of groundwater surrounding area. According to this, the city took the countermeasure actions: construction of drainage ditches, installation of leachate collection pipes and gas wells. The objective of this study is to evaluate the conditions of landfill body, and know the effect of the remedial works on the improvement of the condition. For these purposes, the water flows in landfill were estimated, and the changes of TOC and TN concentrations in leachate sampled from gas wells were investigated with time.

2. The description of the landfill

A landfill located in Hokkaido, Japan, is composed of compartment 1 and compartment 2, which were operated between 1979 and 1982, between 1983 and 2003, respectively. Waste composition in Compartment 2 was mainly comprised of 35.4% municipal solid waste, 31.9% construction waste and 12.8% industrial waste. Due to the structural problems, the Compartment 2 was closed in 2003, and some remedial actions were conducted: drainage ditches, final cover, 9 units of leachate collection access vaults (Ø2500mm), horizontal leachate collection pipes (Ø75mm), 93 units of vertical PVC gas wells (Ø200mm). The outline of the Compartment 2 is shown in Fig. 1. The location of gas wells are identified by numbers in rectangular coordinate system, such as “45” is located at the 4th row and the 5th column. For this study, 48 units of 93 gas wells were mainly investigated.

3. Methods

3.1. The height of water column (WL)

Leachate level in a gas well is illustrated in Fig. 2, in which D is the length of a gas well, and WL is the height of water column in the well. WL was calculated by D-W.
3.2. Leachate sampling and analysis
Leachate was collected from each vertical gas well by a 100ml of glass sampler. Collected leachate was stored in plastic bottles, and analyzed on the electrical conductivity, temperature, Cl\textsuperscript{-}, TOC and TN.

3.3. Tracer test for leachate velocity
To evaluate leachate transport through a cross-sectional area of gas well, tracer test was conducted. Considering the possible variation of leachate flow rate along the depth, WL was divided into 1 or 3 (denoted by K) parts when WL is larger than 3 meters: K=2 for 3~6m, and K=3 for >6m (see Fig. 2). Experimental flow of the tracer test is shown in Fig. 3. The change of Cl\textsuperscript{-} concentration in leachate with time elapsed can be expressed as Eq. (1) by assuming a complete mixing condition for each layer of water column, where C\textsubscript{in} is the concentration of leachate flowing into the well. By assuming steady state for T<0 in Eq.(1), C\textsubscript{in}=C\textsubscript{0}, which is the initial concentration of leachate in the well. The change of C in non-dimensional form is given in Eq. (2).

\[
\frac{V}{K} \frac{dC}{dt} = QC_{in} - QC
\]

(1)

\[
C = C_{p} = EXP\left(-\frac{Q}{V / K}\right)
\]

(2)

\[
C_{p} = \text{a concentration after injecting NaCl solution, } Q \text{ is a flow rate of leachate and } V \text{ is the volume of leachate in the gas well. } Q, \text{ only one unknown parameter in Eq.(2), can be determined by the use of Least Square Method to minimize the error between calculated and measured values as shown in Fig. 4. As a result, the velocity } v \text{ (cm/day) across a cross-sectional area in a gas well can be calculated by Eq.(3), where D is the diameter of gas well (20cm).}
\]

\[
v = \frac{Q}{(WL / K)D}
\]

(3)

4. Results and Discussion
4.1. The height of water column (WL)
The height of water column, WL, were measured at 18 sampling points 7 times: 6 times in 2006 (July to November) and once in October 2007. Fig.5 shows the cross-sectional view of the sixth row of gas wells. WL widely varied among gas well in the range of 1.4~14.5m, which are resulted from the shape of original ground and the depth of gas well. On the other hand, WL largely fluctuates at wells whose WL is large. For example, 67 and 68 show relatively high WL and high fluctuation of WL. Rainfall and
groundwater infiltrated from surrounding area might cause such fluctuation. These phenomena are also observed at other gas wells.

4.2. Leachate velocity and flux

Leachate velocity investigated by the tracer test at sixth row are shown in Fig. 5. Generally, the velocity at lower part is smaller than those at higher part: 0~13 cm/day in the lower part while 55~148 cm/day in the upper part. Low velocity in the former are influenced again by the geography. The end of gas well 64, 68, 6A, 6B and 6D reached into the original ground, so water migration in the lower part of gas well is restricted by low permeability of original ground.

Although the distance between gas wells is not short due to the limited number of gas wells, leachate flow rate across a cross section of the landfill was estimated in the following manner.

\[ 50 \left( \frac{1}{K} \sum_{k=1}^{K} v_{jk} \right) W L_j \]  

where \( W L_j \) is the height of leachate column of \( j \)-th well at cross-section, \( v_{jk} \) is leachate velocity at the \( k \)-th layer, and “50 (meters)” is the interval between gas well.

Calculated leachate quantity (435,898 m³/year) is well matched with actual leachate discharge (423,500 m³/year) though leachate flow between 60 and 63 are not considered.

4.3. Change of TOC, TN in leachate

After setting up gas wells, TOC and TN concentrations in leachate were investigated at 48 gas wells from October, 2005 to November, 2007. In most of gas wells, sharp drop of TOC and TN was observed about 10 months after the gas well was installed. Because all drops were found in Summer, the sharp decrease was obviously caused by aerobic biological degradation.

As shown in Fig. 6, overall, TOC decreased to 20 to 60 percent except for several points. There is not found the difference specific to the row number. The decrease of TN is very low.

Average velocity in saturate zone can be supposed to be 40 cm/day, therefore a liquid-solid ratio of saturate zone for ten years is

\[ 0.4 \text{ m/d} \times 365 \times 10 / 700 = 2.1 \]  

Due to high L/S ratio, solid waste in saturated layer might be flushed enough, consequently TOC and TN are not high. Therefore, TOC decrease in leachate is determined by lowered TOC in unsaturated layer. Leachate collected at a treatment facility, however, did not show any change in TOC concentration. TOC change is only happen in gas well and its vicinity.

5. Conclusion

The height of water column in a gas well, \( W L \) is strongly dependent on original ground level and the depth of a well. Leachate velocity is high in upper part in a gas well. However, it is only superficial velocity caused by inflow from unsaturated layer over leachate surface. Rapid decrease in TOC was observed in most of gas wells. It was concluded the effect of aerobic biodegradation in unsaturated layer of waste. However, the effect is only limited in the small aerobic zone around gas well, and the long time will be needed to aerate all the landfill body.