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Predicting the Methane Gas Generation Rate at Landfill Sites Using the Methane Gas Generation Rate Constant (*k*)

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ABSTRACT

In this study, the Tier 2 method recommended by the Intergovernmental Panel on Climate Change (IPCC) was used to predict the methane generation rate at two landfill sites, designated as Y and C for purposes of this study, in South Korea.
Factors such as the average annual waste disposal, methane emissions (L_0) and methane gas generation rate constant (*k*) were estimated by analyses of waste and the historical data for the landfills. The value of *k* was estimated by field experiments and then the changes in the methane generation rate were predicted through the year 2050, based on the value of *k*. The Y landfill site, which was in operation until the year 2008, will generate a total of 17,198.7 tons by the end of 2018, according to our estimations. At the C landfill site, which will not be closed until the end of 2011, the amount of methane gas generated in 2011 will be 3,316 tons and the total amount of gas generated by 2029 will be 61,200 tons. The total production rate of methane gas at the C landfill is higher than that of the Y landfill. This indicates that the capacity of a landfill site affects the production rate of methane gas. However, the interrelation between the generation rate of methane and the value of *k* is weak. In addition, the generation of methane gas does not cease even when the operations at a landfill site come to a close and the methane gas production rate is at its highest at end of the operating life of a landfill site.

Key words: IPCC, Tier 2 method, Landfill, Methane gas production rate constant, Prediction of methane emission

1. INTRODUCTION

Recently global warming has become a matter of public concern. This phenomenon can primarily be attributed to the trapping of enormous quantities of "greenhouse gases" (GHG) in the earth's atmosphere, resulting in a GHG effect that increases ambient temperatures (Sunil *et al.*, 2004). Since the Kyoto protocol was enacted on February 16, 2005, more active measures are being adopted to reduce the negative effects of GHG around the world. Landfill gas is a mixture of approximately equal quantities of methane and carbon dioxide, which are generated as a result of the anaerobic decomposition of organic waste at a landfill site (Aitchison, 1996).

Global greenhouse gas emissions were 155 million tons in 2002, an increase of about 82.6% from the 1990's (Chung, 2005). As the economy continues to grow, the total GHG emissions are expected to increase about 60% from 126 million tons in 2000 to 203 million tons in 2020. The proportion of GHG emissions in Korea in relation to global output has continuously increased from 1.1% in 1990 to 1.9% in 2002. The GHG emissions produced by the energy industry, industrial processes, the agriculture sector and the waste sectors in 2002 were 129 million tons (83.4%), 16.9 million tons (10.9%), 4.4 million tons (2.9%) and 4.3 million tons (2.8%), respectively. The energy industry is responsible for the largest proportion of GHG emissions. However, GHG emissions from environmental facilities such as landfills, incinerators and sewage treatment facilities comprise an important part of the total emissions because they are the main sources for the emission of CH_4, CO_2 and N_2O gases. Landfills have been recognized as the largest source of anthropogenic methane (CH_4) emissions and an important contributor to global warming (IPCC, 1996). Methane, which is one of the major components of landfill gas emissions, can be used for energy production in a similar manner to the use of natural gas. However, methane is still a major GHG and its emission must be reduced (Jeon *et al.*, 2005). In addition, methane is regarded as one of the most important GHG because its Global Warming Potential (GWP) is estimated to be more than 20 times that of carbon dioxide and the concentration of atmospheric methane has been increasing in the range of 1-2% y^{-1} (IPCC, 1996).

Landfills are not a point source, but a diffuse source of methane and these emissions have a high temporal and spatial variability (Scharff *et al.*, 2000). Therefore, it is not easy to measure the generation rate of methane (Scharff and Jacobs, 2006). In order to accurately predict the quantity of emissions, the estimation of methane generation at landfill sites is essential. In this study, the rate of methane gas generation of each landfill was measured and then the *k* value was inversely estimated from the rate of gas generation.

2. EXPERIMENTAL METHODS

2.1 Tier 2 Method (FOD: First Order Decay) (IPCC, 2000)

Recently, the IPCC Good Practice Guide suggested that either Tier 1 or Tier 2 could be used for suitable calculations in each nation. It's difficult to apply the Tier 1 method for predicting the methane generation rate, because that method assumes that the methane gas generated in the gas venting well is collected completely while the surface emissions are not. In Korea, methane gas is generated in abundance both in the gas venting well and at the surface. Therefore, the Tier 2 method (FOD), which was recommended by the Reference Method of the IPCC Guideline, was used in this study to calculate the methane gas emissions from the measured rate of methane gas generation in the gas venting well and at the surface.

The Tier 2 method is based on the mass balance equation and accurately reflects the actual circumstances at a landfill site unlike the Tier 1, default method which assumes temporary emissions. Therefore, the Tier 2 method can more accurately calculate methane emissions and so the Tier 2 method was utilized for our research purposes. The history of a landfill site is the primary factor in determining whether to employ the Tier 1 or Tier 2 method, as shown in Fig. 1.

The methane generation rate constant (*k*) is determined by equation (1). The *k* value was inversely estimated from our on-site measurements of the methane generation rate:

$$Q_{CH_4} = L_0 \cdot M_t \cdot \exp\{-k(t-1)\} - \exp(-kt) \qquad (1)$$

where,

Q_{CH_4} = Methane generation rate in a specific year (m^3)
L_0 = Methane emission factor (m^3/ton-waste)
M_t = Average amount of annual landfill waste during landfill period (ton/y)
k = Methane generation rate constant (y^{-1})
t = Time since first landfill measurement (y).

2.1.1 Estimation of Each Factor (L_0, *k*) (IPCC, 2000)

The methane emission factor (L_0) has two generation mechanisms: one includes a completely empirical for-

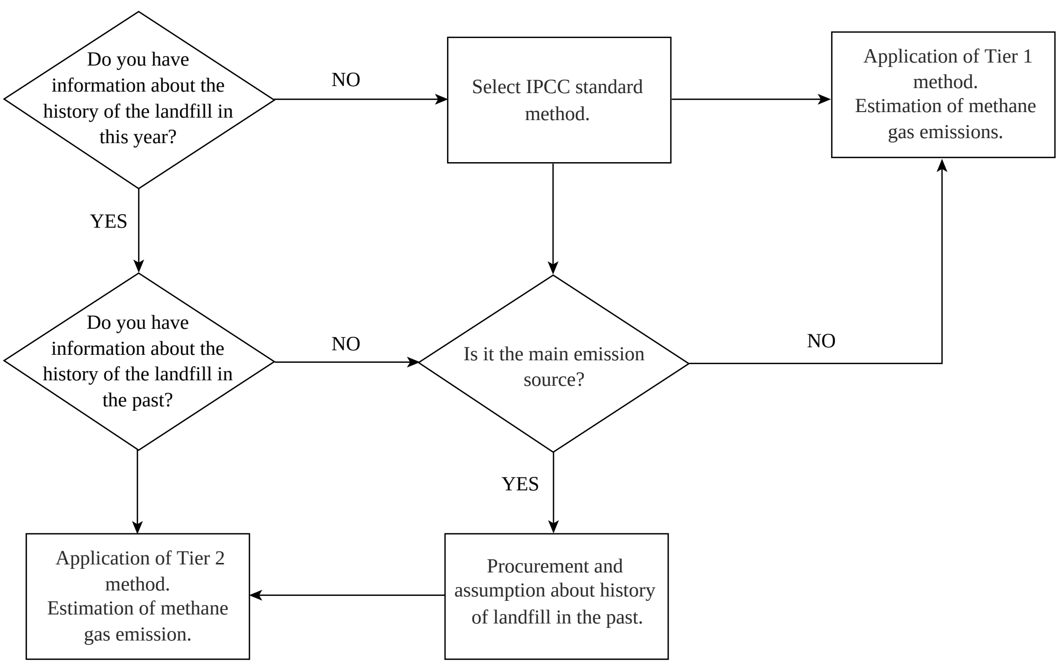

Fig. 1. Flow chart showing the estimation method for the rate of methane generation from a landfill.

Table 1. DOC value in each landfill.

	1996	1997	1998	1999	2000	2001	2002	$DOC_{Avg.}$
Y landfill	0.12078	0.17020	0.12043	0.13881	0.13374	0.13750	0.13820	0.13710
C landfill	−	−	0.15612	0.16350	0.17639	0.17955	0.17364	0.16984

mula of waste and then the maximum generation rate of methane is determined by anaerobic decomposition; the other utilizes a direct estimation from the carbon contents of organic waste. In this study, the latter estimation method was employed. The estimation method for the methane emission factor (L_0) is:

$$L_0 = MCF \times DOC \times DOC_F \times F \times 16/12 \quad (2)$$

where,

MCF = Methane Correction Factor (If it is in an aerobic condition, MCF is 0, and, if it is in an anaerobic condition, MCF is 1.)
DOC = Degradable Organic Carbon
DOC_F = Degradable Organic Carbon by microorganisms
F = Ratio of methane gas in landfill gas.

In general, DOC (Degradable Organic Carbon) is defined as organic carbon that can be decomposed biochemically and the unit is Gg/Gg-waste. DOC is closely related to the components of the waste and is estimated as the summation average value of DOC for each component of the waste. The DOC calculation method recommended by the IPCC in 1996 is shown in equation (3).

$$DOC = (0.4 \times A) + (0.17 \times B) + (0.15 \times C) + (0.3 \times D) \quad (3)$$

where,

A = Ratio of paper and fabric in waste
B = Ratio of organic wastes such, as garden and park wastes, in total waste
C = Ratio of food wastes in total waste
D = Ratio of wood and straw in total waste.

Some problems were encountered during this study. We had to develop the eigen formula, because the IPCC calculation method is more suitable for European nations and the U.S. than Korea, where garden wastes are less abundant. For this study, we classified organic wastes generated in domestic use according to their decomposition. Among these wastes, non-decomposable wastes were regarded as synthetic resins and other wastes such as food and vegetables, paper, rubber/leather, sludge, waste-fabric and waste-synthetic rubber were assumed to be decomposable materials. Therefore, the organic carbon content per unit weight of domestic landfill wastes was determined using the equation below (4).

$$DOC\,(\%) = CCF \times FW_f + CCP \times PA_f + CCW \times WO_f + CCR \times RU_f + CCA \times FA_f + CCU \times SR_f + CCL \times LE_f + CCS \times SL_f + CCA \times AN_f + CCO \times OT_f \quad (4)$$

where,

FW_f = Ratio of food and vegetable to total waste (wet%)
PA_f = Ratio of paper to total waste (wet%)
WO_f = Ratio of wood to total waste (wet%)
RU_f = Ratio of rubber and leather to total waste (wet%)
FA_f = Ratio of waste-fabric to total waste (wet%)
SR_f = Ratio of waste-synthetic rubber to total waste (wet%)
LE_f = Ratio of waste-leather to total waste (wet%)
SL_f = Ratio of sludge to total waste (wet%)
AN_f = Ratio of animal and vegetable property organic material to total waste (wet%)
OT_f = Ratio of the other organic material to total waste (wet%)
CCF = Carbon content of foods and vegetables
CCP = Carbon content of paper
CCW = Carbon content of wood
CCR = Carbon content of rubber and leather
CCA = Carbon content of waste-fabric
CCU = Carbon content of waste-synthetic rubber
CCL = Carbon content of waste-leather
CCS = Carbon content of sludge
CCA = Carbon content of animal and vegetable property waste
CCO = Carbon content of the other organic material

In order to predict methane gas emissions in each landfill, we had to know the DOC value from the nature of the physical components. Therefore, in this study we expressed the DOC and DOC_{AVG} of each landfill in Table 1. We analyzed the chemical components to determine the carbon contents (wt%). The carbon content in the Y landfill site was 49.02% food, 47.19% paper, 46.99% wood, 67.39% plastic and 39.66% rubber/leather; the carbon content of the C landfill site was 26.33% food, 41.25% paper, 46.71% wood, 30.91% plastic and 83.22% rubber/leather. To estimate the generation rate of methane gas, we calculated the degradable organic carbon content from the carbon contents of the disposed waste and its physical components. The results of this elemental analysis for each landfill are shown in Table 2.

Table 2. Results of elemental analysis of each landfill.

	Elemental analysis of Y landfill				Elemental analysis of C landfill			
	C (%)	H (%)	N (%)	S (%)	C (%)	H (%)	N (%)	S (%)
Food	49.02	6.47	4.71	0.00	26.33	3.85	1.41	0.00
Paper	47.19	6.69	0.1	0.00	41.25	5.51	0.00	0.00
Wood	46.99	5.57	0.36	0.00	46.71	5.70	0.00	0.00
Plastic	67.39	8.96	9.52	0.00	30.91	3.60	0.00	0.00
Rubber/Leather	39.66	3.97	0.26	0.00	83.22	11.49	0.00	0.25

Table 3. Present conditions of each landfill.

	Total area (m^2)	Total landfill Cap. (m^3)	Disposed Cap. (m^3)	Disposal Cap. (m^3)	Start-up	Expiry
Y landfill	83,043	1,435,000	538,000	897,000	1996	2008
C landfill	176,938	2,036,617	1,004,731	1,031,884	1998	2011

The recommended value of DOC_F is 0.5-0.6 in the IPCC Good Practice Guidance (IPCC, 2000). Therefore, the value of 0.55 was applied in this study. F values of 0.595 and 0.376 were determined by site-measurement and applied for landfill sites Y and C, respectively. Many factors such as moisture, temperature and DOC, affect the estimation of the value of *k*. The *k* value determines how fast the methane production velocity decreases and *k* is an indicator of half-life. In general, an assumed *k* value of 0.05 is applied internationally, but in this study we calculated *k* through on-site measurement using the methane production rate.

2. 2 Measurement Method of Methane Gas

2. 2. 1 Site Description

The Y landfill located in the Gyeong-gi district and the C landfill located in the Gang-won district were selected for this study. The selected landfills have several advantages for CDM (Clean Development Mechanism). The present conditions of both sites are shown below.

In order to predict the future generation rate of methane gas at each landfill site, we needed data such as the likely amount of disposal waste in the future and the past and the waste's physical and chemical composition (Seo *et al.*, 2001).

There was some information available about the landfill design and the master plan for waste management, however using this data was problematic because the data was archaic and there have been significant changes in lifestyle, consumption patterns and the regulation of waste disposal.

Therefore, the reports "Basis Data of Landfill" and "Present Condition on the Generation and Disposal of Waste in the Whole Country" (Ministry of Environment, 2005) were used in this study to determine landfill quantity.

2. 2. 2 Theory of Measurement

The infrared absorption method was the theoretical basis for the measurement technique used in this study. Gas molecules selectively absorb only quantum energy from vibration energy, as well as absorbing light from an infrared area of the vibration energy. For this reason, CO_2 and CH_4 have unique infrared absorption spectrums of $-4.25\,\mu m$ and $3.3\,\mu m$, respectively. Absorption intensity varies with gas concentration. Absorptimetry, $A(\lambda)$, in a wavelength is determined by the Lambert-Beer equation which is:

$$A(\lambda)=E(\lambda)bC$$

$$A(\lambda)=-\log\left|\frac{I(\lambda)}{I_0(\lambda)}\right|$$

where, $E(\lambda)$ is the absorption coefficient, b is penetration distant, C is the concentration of gas, $I(\lambda)$ is the intensity of light measurement and $I_0(\lambda)$ is the intensity of standard light.

According to the equation above, we can only obtain the concentration of CH_4 and CO_2 without interference of any gases by measuring the intensity of permeated light passed through the object gas with a high absorption coefficient, $E(\lambda)$, of the monochromatic light. This is due to the fact that the absorbance is in proportion to the length and concentration of the cell through which infrared light is passed.

2. 2. 3 Field Measurement of Methane

Methane gas is generated from the fermentation of organic waste in landfills. The source of methane emissions in landfills can be classified into 3 mechanisms: surface generation, generation in gas venting wells and generation by gas extraction systems. In this study, the gas extraction system was ignored be-

Table 4. Specifications of the experimental apparatus.

Experimental apparatus	Specifications	
LMSxi	Measurement gas	CO_2, CH_4, O_2, N_2 ... etc.
	Measurement range	CO_2, CH_4 : 0-100%
	Measurement error	CO_2, CH_4 : Full Scale ±3.0%
	Measurement theory	Infra-Red Sensor
Air-Velocity Transmitter	Measurement gas	Air and Gas
	Measurement range (fpm)	0-200, 0-1,000, 0-3,000, 0-12,000
	Measurement error	0-200 : ±5% 0-1,000, 0-3,000, 0-12,000 : ±2%
maMos (Measurement of surface)	Measurement gas	CO_2, CH_4
	Measurement range	CO_2 : 0-2,500 ppm CH_4 : 0-50,000 ppm
	Measurement error	Linearity error : max. of 0.5% of the value
	Measurement theory	Non-Dispersive Infrared Sensor

Table 5. Methane gas generation rate from gas venting well in the Y landfill.

Point	CH_4 (%)	CO_2 (%)	O_2 (%)	Fluid Vel. (m/s)	Press (mmbar)	Temp. (°C)	Hole Dia. (mm)	Emission (ton/y)
1	59.5	40.0	0.0	1.27	992	63.4	165	287.39
2	60.0	40.0	0.0	2.31	992	53.2	165	548.21
Avg.	59.5	40.0	0.0	1.79	992	58.3	165	417.8

Table 6. Methane gas generation rate from gas venting well in the C landfill.

Point	CH_4 (%)	CO_2 (%)	O_2 (%)	Fluid Vel. (m/s)	Press. (mmbar)	Temp. (°C)	Hole Dia. (mm)	Emission (ton/y)
1	25.5	10.6	0.0	0.27	983	38.4	220	50.25
2	51.0	0.0	0.0	0.32	983	42.3	220	117.65
3	23.0	12.2	0.0	0.36	983	39.7	220	60.18
4	51.0	0.8	0.0	0.35	983	41.0	220	129.21
Avg.	37.6	5.9	0.0	0.33	983	40.35	220	89.32

cause it is an artificial form of generation.

First, the concentrations of primary gases such as methane, carbon dioxide and oxygen emitted through the gas venting well and at the surface of the landfills were measured by using a method adopted in previous research (Chung *et al.*, 2004). Landfill gas was measured using a portable Gas Data LMSxi device in the field, which contains an Infra Red (IR) sensor. If the gas venting well had holes, we inhibited the inflow of air as much as possible. Methane emissions from the gas venting wells were estimated by measuring gas velocity using a portable hot wire manometer.

Second, methane emissions from the surface of the landfills were measured by using the flux chamber method, based on EPA Method No. 68-02-3889 (US EPA, 1985) and IAEA-TECDOC-694 (IAEA, 1992). In order to collect samples, the chamber was set up over the surface area to be sampled and was worked into the surface to a depth of 2-3 cm. Then the gas generation rate was continuously measured with the chamber, which contains a stirring fan, and pressure, temperature and concentration sensors. Specifications of the experimental apparatus are noted in Table 4.

3. RESULTS AND DISCUSSIONS

Table 5 and Table 6 show the methane gas generation rates from the gas venting wells in the Y and C landfills.

In the case of the Y landfill, the average emission of a single gas venting well was 417.80 ton/y and the total emission of all the gas venting wells was 1,253.4 tons/y. In addition, the surface emission was 95.33 tons/y. Thus the total methane gas production rate of the Y landfill site was determined to be 1,348.73 tons /y.

In the case of the C landfill, the average emission of a single gas venting well was 89.32 tons/y and the total emission of all the gas venting wells was 1,607.76 tons/y. In addition, the surface emission was 125.98 tons/y. Thus the total methane gas production rate of the C landfill site was determined to be 1,733.74 tons/y. Table 7, Table 8, Fig. 2 and Fig. 3 show the methane gas production rates from the surfaces of the Y and C landfills.

As Fig. 2 shows, the ratio of the methane gas production rate to time slowly increased at sites 1 and 2. On the other hand, sites 3 and 4 had steep ratio gradients. The following reasons explain this difference.

First, we inferred that the amount of decomposable organic matter varied between the two sites because of the variation of chemical components. Even though the same kinds of waste were disposed at both landfills, the decomposition velocity was different due to differences in the temperature and humidity of the soil. Therefore, the gradient of the methane gas generation rate was also different.

Second, we could postulate from the geological

Table 7. Methane gas generation rate from the surface of the Y landfill.

Point	Disposal area (m^2)	CH_4 emission rate ($mL/Nm^3/sec$)	Surface emission (ton/y)
1	83,043	0.4177	39.17
2		0.5012	47.00
3		2.2155	207.73
4		0.9324	87.43
Avg.	–	1.0167	95.33

Table 8. Methane gas generation rate from the surface in the C landfill.

Point	Disposal area (m^2)	CH_4 emission rate ($mL/Nm^3/sec$)	Surface emission (ton/y)
1	176,938	0.6415	128.16
2		1.5170	303.07
3		0.4403	87.96
4		0.3735	74.62
5		0.1806	36.08
Avg.		0.6306	125.98

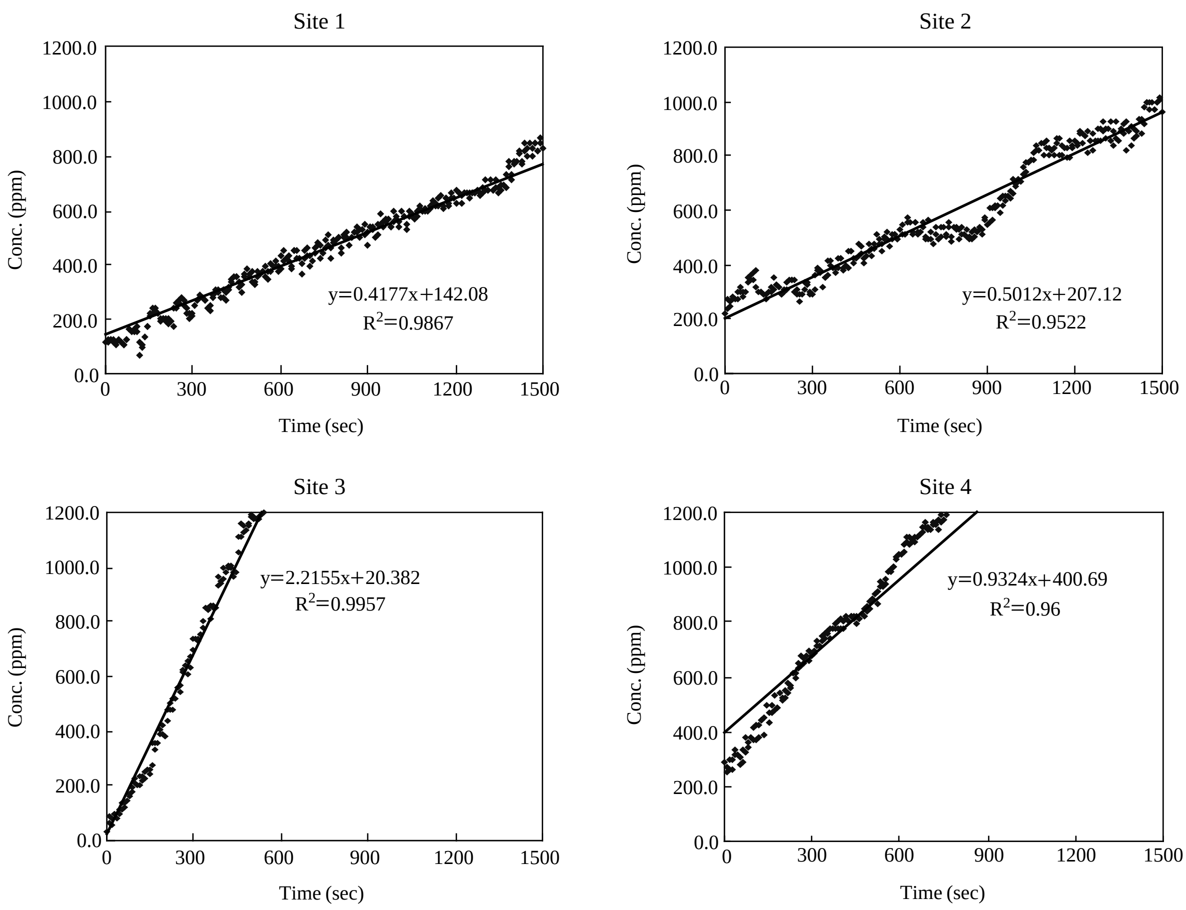

Fig. 2. Surface emission rates of CH_4 at the Y landfill.

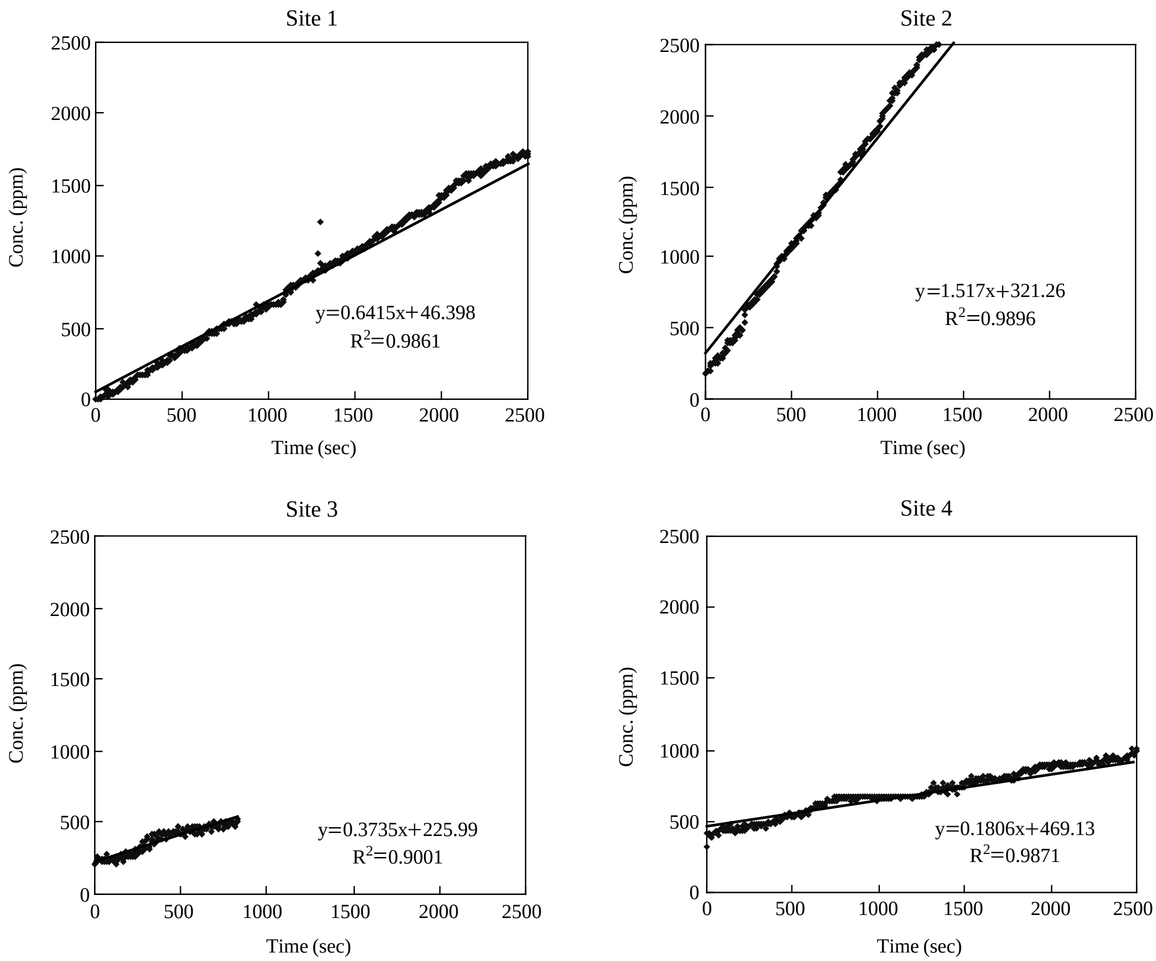

Fig. 3. Surface emissions rate of CH_4 at the C landfill.

features of the soil that the disposed waste would be varied. The methane gas generation rate would also be different depending on the density of the compaction of the soil. Even though the same proportion and quantity of cover soil was used, we estimated that the state of the geological features in each landfill was different depending on the decomposition degree of organic waste.

Third, we could estimate that the methane gas generation rate would differ due to the difference of pressure in the landfill and cover soil layers.

As Fig. 3 indicates, the ratio of the methane gas generation rate to time slowly increased at sites 3 and 4. On other hand, there were steep gradients at sites 1 and 2 at the C landfill.

In order to estimate the methane emission factor using the IPCC's Tier 2 method, we calculated L_0 using DOC, DOC_F and F values and we also directly estimated L_0 from the carbon contents of the organic waste. In general, the value of k is regarded internationally to be 0.05 [8], but in this study we calculated k using methane generation rates through on-site measurement techniques at each landfill site. DOC values in Korea differ from those in the U.S. and European nations, because the characteristics of waste are different in Korea than in those other countries. If these differing values affect the methane gas generation rate, than the k values would also be different. Therefore, it is difficult to uniformly apply the k value to both landfills. In addition, we had another method for the estimation of the eigen k value. Table 9 shows the L_0 and k value for each landfill.

Table 9. L_0 and k value in each landfill.

Sites	Y landfill	C landfill
L_0 (ton-CH_4/ton-waste)	0.05982	0.04683
k (y^{-1})	0.0662	0.0378

The L_0 value is calculated using equation (2). As shown in Table 2, the DOC_{Ave} of the Y landfill site is less than that of the C landfill site. However, the L_0 value of the Y landfill site is more than that of the C landfill site due to the difference in the average ratio of methane gas as shown in Tables 3 and 4. In addition, the *k* value of the Y landfill was different from that of the C landfill. The *k* value was variable due to many factors such as the methane emission factor (L_0), the element composition of the waste (carbon contents) and the amount of waste. Incidentally, each of the factors didn't have to correlate with the *k* value at both landfill sites. Therefore, the methane production rate constant, *k*, could have been irregular due to the differences in methods used at the landfill sites without taking into consideration the correlation of each factor.

As mentioned in prior research [9], the condition of the reaction has an effect on the *k* value which was variable according to the physical-chemical characteristics of the waste and the meteorological conditions.

The *k* values can be obtained by either experiment or calculation, but in order to obtain a satisfactory and accurate prediction of future trends, it is desirable to use the data gained from on-site measurements (Seo *et al.*, 2001). By using experimental data, more accurate results can be obtained.

k values will vary due to the actual conditions of landfills throughout the entire country without direct correlation to the factors noted above.

In order to estimate the *k* value with a high degree of reliability, it was necessary to take continuous measurements at each landfill site.

We analyzed the interrelations between total methane generation rates and the size and nature of the disposed waste at each landfill site in order to determine the factors that affect the methane gas generation rate.

The C landfill had a larger disposal area and disposable capacity than the Y landfill. The total methane gas generation rate in the C landfill was proportionately higher than that of the Y landfill in relation to the disposal area and capacity. In other words, the size and capacity of landfill sites directly affects the methane gas generation rate; the more disposed waste, the higher the methane gas generation rate. This result is in agreement with prior research (Seo *et al.*, 2001).

However, the interrelation between the methane generation rate and the *k* value is weak. As mentioned before, the reason is that the methane generation rate constant, *k*, can be irregular without direct correlation to various landfill characteristics.

The prediction of the landfill gas generation rate was based on the quantity of waste disposed at the landfills.

In order to predict the emission of methane gas from a landfill, data relating to the amount of waste disposed at each landfill site, the future generation rates of waste and the physical-chemical contents of wastes must be studied. In this study, we estimated the future generation rate of methane gas by utilizing data found in the manual "Present Condition on the Generation and Disposal of Waste in the Whole Country", issued by the local government and the ministry of environment in Korea.

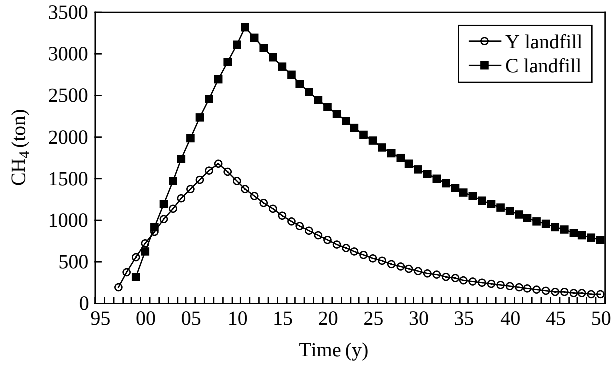

Fig. 4. Predictions of methane generation rates in the Y and C landfills.

We predicted the methane generation rate until 2050 using the L_0 and *k* values. The prediction rates are shown below.

As shown in the graph above, the methane gas production rate at the C landfill site is predicted to be higher than that of the Y landfill site. We believe this difference in the predicted production rates is due to the difference of M_t as shown in equation (1). M_t equals the amount of waste already disposed at the landfill site. The waste already disposed at the time of our experiment was 538,000 m^3 at the Y landfill site and 1,004,731 m^3 at the C landfill. In addition, the peak of the methane gas generation rate appeared towards the end of the operational life of the landfill. As noted above, the prediction of the methane generation rate in each landfill depends on the *k* value. In order to obtain the *k* value with a high degree of confidence, we obtained the *k* value using repeated measurements.

4. CONCLUSIONS

In this study, we measured the methane generation rate of each landfill and then inversely-estimated the *k* constant value based on the Tier 2 method. As a result, we obtained the methane production rate constant (*k*). Then the future methane generation rates were predicted until 2050 using this *k* value.

The average ratio of methane gas emitted through gas venting wells was 59.5% for the Y landfill and

36.5% for the C landfill. The total emission rates for the Y and C landfills were 1,348.73 tons/y and 1,733.74 tons/y, respectively. Results of the inverse-estimation *k* value for the Y and C landfill sites were 0.0662 y^{-1} and 0.0378 y^{-1}, respectively. The half-life measurement for the Y landfill was 10.47 y and it was 18.34 y for the C landfill.

In the case of the Y landfill site, the predicted gas generation rate is 1,685.41 tons in 2008, and because the half-life measurement is 10.47 y, the total methane gas production rate is 17,198.7 tons through 2018. In the case of the C landfill site, the predicted gas generation rate is 3,316 ton in 2011 and the total methane gas generation rate is 61,200.3 ton through 2029, because the half-life measurement is 18.34 y. Due to the variability of the *k* value, we obtained the estimated *k* value by taking numerous measurements.

We believe the difference in the predicted generation rate is due to the difference in M_t shown in equation (1). The Y landfill site contained 538,000 m^3 of disposed waste and the C landfill site contained 1,004,731 m^3 of disposed waste at the time of our experiment. It was determined that the size and capacity of the landfill site affects the methane gas generation rate; the more disposed waste, the higher the methane gas generation rate. Furthermore, the peak period of the methane gas production rate appears at the end of the operational life of a landfill site. The results of our experiment are in agreement with those of prior research (Seo *et al.*, 2001).

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