Journal of Sustainable Energy & Environment 1 (2010) 181-184

Methane Generation Rate Constant in Tropical Landfill

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Abstract: This paper presents a practical methodology for quantifying the methane generation rate constant from four tropical sanitary landfills in Thailand. We used combination of static chamber and laser methane detection methods as well as geo-statistics to assess the total methane emission at each study site. After fitting of the estimated rate of methane emission per weight of waste deposited at the disposal sites with different age to the first order decay equation, it was found that the first order reaction rates were 0.33 yr^{-1}. This high reaction rate as compared to previous studies in developed countries is probably due to the high moisture content of the waste in which food waste was the main component (>60%) combined with a tropical climate which has high precipitation and temperatures. These factors could stimulate anaerobic degradation and produce more biogas in a shorter time after the wastes has been disposed. In order to improve the estimation of methane emission from solid waste disposal sites in a tropical climate, this first order reaction rates can be considered as a country or region specific default value.

Keywords: methane generation rate constant, k value, landfill gas, greenhouse gas, first order decay.

1. Introduction

Landfill gas (LFG) is generated as a result of physical, chemical, and microbial processes occurring within the refuse. Due to the organic nature of most waste, it is the microbial processes that govern the gas generation [1]. The composition of the LFG depends on the microbial system, the substrate (waste) being decomposed, and the site-specific variables such as oxygen access to the waste and moisture content [2]. LFG is typically described as consisting of approximately 50 percent methane and 50 percent carbon dioxide with less than 1 percent other gas constituents, including hydrogen sulfide and mercaptans [3].

Methane released from landfills has been identified as a significant contributor to greenhouse gas emissions, which contribute to global warming. Over a 100-year time horizon, in comparison with carbon dioxide, methane is considered to be 21 times more efficient at trapping heat within the atmosphere [4]. The emission rate at which the release of LFG becomes an issue with regulatory and neighboring property owners is related to a number of physical parameters including: the location of the landfill; the surrounding topography; adjacent land uses; ambient meteorological conditions; and the site characteristics that impact LFG generation and collection [5]. The total global methane emissions have been estimated at 500 Tg/year and landfills contribute 40 Tg/year (8%) of the total [6]. The Intergovernmental Panel on Climate Change (IPCC) estimates that landfill emissions are 7% of the total global methane emissions [7]. Moreover, landfills are ranked third in anthropogenic methane source, after rice paddies and ruminants [8].

The main problem of modeling LFG generation is not only forecasting the amount of LFG which will be produced, but also the rate and the duration of the production [9]. Recently, some models have been introduced to estimate the LFG generation rate of landfills. Among them, the first order decay (FOD) model is generally recognized as being the most widely used approach as it is recommended by the IPCC in the 2006 IPCC Waste Model and by the US Environmental Protection Agency in LandGEM Model for calculating methane emissions from landfills [10-11]. The objective of this study was to investigate the landfill methane emission characteristics for the evaluation of the methane generation rate constant (k) value for tropical sanitary landfills in Thailand.

2. Experimental

2.1 Configuration of study sites in Thailand

Measurements were performed at four sanitary landfills including Pattaya, Ban-Bung, Hua-Hin and Laemchabang landfills. The characteristics of the study sites are summarized in Table 1. Most of these study sites are located in the central region, within 150 km. of Bangkok. The site conditions at all study sites were managed landfill as categorized by IPCC (2006) [10] that after the waste was placed, the daily cover was covered over the compacted waste every day. However, in 2009 at Hua-Hin landfill, the operation practice changed to open dumping in some parts of the landfill due to the lack of daily cover operation practice. All waste that was deposited in these study sites was only municipal solid waste (MSW). Artificial liners (HDPE sheet) had been installed in all landfill sites. The methane emission measurements were conducted twice between December 2007 to January 2008 and from January to March 2009.

The characteristics of waste in these study sites, investigated by Pollution Control Department (PCD) of Thailand, showed that food waste is the main component at about 60%, followed by plastic (20%), paper (8%), glass (3%), textiles (1%) and other (8%). In this study, the same waste characteristics were assumed for all study sites.

Table 1. Characteristics of study sites.

Study site	Open year	Site Age (yr)	Tipping area (m^2)	Accumulation of waste in place	
				Until the end of 2007	Until the end of 2008
Pattaya	2002	7	53,618	471,364	558,965
Ban-Bung	2001	8	33,860	115,287	133,537
Hua-Hin (Phase 2)	2001	8	32,136	145,653	163,903
Laemchabang	1999	10	71,200	442,634	560,077

2.2 Methane emission rate and gas analysis

Methane emission rates from the landfill surface in this study were determined using the Laser Methane Detection (LMD) chamber method. The chamber used in this method was constructed with ϕ0.40 m - PVC pipe, 1.00 m in height with a PVC lid at the top of chamber for LMD placing. To protect the air intrusion, the chamber was sealed to the ground by compacting soil around the outside. Methane concentration in the chamber was measured by LMD - Anritsu SA3C15A (Anritsu Corporation). The concentration of methane was measured by a laser beam that reflects from the reflector in the chamber at 1 second intervals. The methane flux was determined from concentration data (C in ppmv) plotted against elapsed time (t in minutes). The data generally showed a linear relationship, in which case dC/dt was the slope of the fitted line. The methane flux, F ($g/m^2/d$), was then calculated in Equation 1 as follows:

$$F = V/A\ (dC/dt) \qquad (1)$$

where V was chamber volume and A was the area covered by the chamber. The slope of the line, dC/dt, was determined by linear regression between CH_4 concentration and elapsed time [11]. The positions of the measured points were determined using handheld global positioning system (GPS). In order to conduct the flux chamber measurements, numerous samples were collected across the landfill surface on a regular grid pattern at 30 – 40m intervals. Geospatial distributions of the methane emissions in this study were estimated by the Kriging method. This method offers the potential of calculating whole site emission estimates from limited point measurements, which could lead to improving overall methane emission estimates.

2.3 Methane generation rate constant evaluation

In this study, the annual change in the methane emission from the landfill was assumed to decrease following the FOD model kinetics (Eq. 2):

$$C_t = C_o \cdot k \cdot \exp^{-kt} \qquad (2)$$

where C_o (kg CH_4/ tons of waste) is the total amount of methane emission from landfill waste, C_t (kg CH_4/ tons of waste/yr) is the methane emission rate at year t, and k (yr^{-1}) is the first order rate constant. The fitting of the estimated time-course changes in methane emission allows an estimation of the first order decay rate (k) as well as the half-life [12]. In this study, the k value was estimated using the methane emissions from different ages of landfills.

The k value determines the rate of generation of methane from refuse in the landfill. The higher the value of k, the faster total methane generation at a landfill increases (as long as the landfill is still receiving waste) and then declines overtime after landfill closes. The value of k is a function of the following factors: (1) refuse moisture content, (2) availability of nutrients for methane-generating bacteria, (3) pH, (4) temperature, (5) composition of waste, (6) climatic conditions at the site where the disposal site is located, (7) characteristics of the Solid Waste Disposal Site (SWDS), and (8) waste disposal practices [10,13].

In the US, regulations under the Clean Air Act (CAA) suggest a default k value of 0.05 yr^{-1} for conventional MSW landfills, except for landfills in dry areas where the recommended default k is 0.02 yr^{-1}. An additional set of default values is provided based on emission factors in the US EPA's AP-42, which are a k value of 0.04 yr^{-1} for developing estimates for emission inventories that are considered more representative of MSW landfills where no leachate recirculation is practiced [14-15]. Moreover, the IPCC also recommend the default and range values of k in many cases as shown in Table 2 [10]. However, in the case of wet landfill or bioreactor landfill, Faour et al. (2007) [16] analyzed the available recovered landfill gas from wet landfills in order to estimate the gas emission parameters for wet landfills. It was found that conservative LandGEM parameters for gas collection at wet landfills suggested a k value of 0.3 yr^{-1}.

3 Results and Discussion

3.1 Methane emissions

The summary results from field investigation in Thailand are shown in Table 3. Methane fluxes were measured at 200 and 124 points in 2008 and 2009, respectively. These results indicated that high spatial heterogeneity of methane emissions can be found at all study sites. The methane flux fluctuated within the range of -35.74 to 2,061.35 $g/m^2/d$. The arithmetic mean ranged from 70.28 to 177.78 $g/m^2/d$ in 2008 and from 20.26 to 160.72 $g/m^2/d$ in 2009. The spatial average varied from 54.83 to 198.83 $g/m^2/d$ in 2008 and from 28.87 to 176.65 $g/m^2/d$ in 2009. Moreover, the results showed that the average spatial methane emission values at all study site decreased by about 11-15% from 2008 to 2009 except at Hua-Hin landfill where the decreasing of methane emission was about 60%. According to the landfilling practice at Hua-Hin landfill in 2009, waste contacted directly with the air due to the poor daily covering of waste. Most wastes at Hua-Hin were degraded under aerobic or semi-aerobic condition that retarded or reduced methane generation.

However, the results shown in Table 3 indicate that the rate of methane emission per amount of waste decreased by about 25-30% from 2008 to 2009 except at Hua-Hin landfill which decreased by 63%. When comparing between methane

Table 2. Recommended default methane generation rate constant values (yr^{-1}) from IPCC [10].

Type of Waste		Climate Zone							
		Boreal and Temperate (MAT ≤ 20°C)				Tropical (MAT > 20°C)			
		Dry (MAP/PET < 1)		Wet (MAP/PET > 1)		Dry (MAP < 1000 mm)		Moist and Wet (MAP ≥ 1000 mm)	
		Default	Range	Default	Range	Default	Range	Default	Range
Slowly degrading waste	Paper/textiles waste	0.04	0.03 –0.05	0.06	0.05 – 0.07	0.045	0.04 – 0.06	0.07	0.06 – 0.085
	Wood/ straw waste	0.02	0.01 –0.03	0.03	0.02 – 0.04	0.025	0.02 – 0.04	0.035	0.03 – 0.05
Moderately degrading waste	Other (non – food) organic putrescible/ Garden and park waste	0.05	0.04–0.06	0.1	0.06 – 0.1	0.065	0.05 – 0.08	0.17	0.15 – 0.2
Rapidly degrading waste	Food waste/Sewage sludge	0.06	0.05–0.08	0.185	0.1 – 0.2	0.085	0.07 – 0.1	0.4	0.17 – 0.7
Bulk Waste		0.05	0.04–0.05	0.09	0.08 - 0.1	0.065	0.05 – 0.07	0.17	0.15 – 0.2

MAP: the mean annual precipitation
PET: potential evapotranspiration

fluxes and waste placement history, it was found that high methane flux occurred in areas that wastes had been deposited for 3-6 months at all study sites. This may imply a delay time or lag time to perform methanogenesis process in landfill. So it can be suggested that the appropriate delay time for gas production at tropical landfill was about 3-6 months.

3.2 Calculation of methane generation rate constant

In order to avoid errors in estimating methane emissions from inappropriate operation practices, the methane emission from Hua-Hin landfill in 2009 was neglected because of the open dumping of waste practiced in this landfill. Furthermore, the methane emission levels from the landfills were assumed to be equivalent to the temporal changes that might be found at one landfill site controlled in the same manner with the same waste composition and lag phase time. The rate of methane emission per amount of waste in place and their trends are shown in Table 4 and Fig. 1.

The methane emission rates were kinetically analyzed. The fitting of the estimated methane emissions of landfills to the FOD equation suggested a first order reaction rate of 0.33 yr^{-1} which is equivalent to 2.1 years in terms of half-life (half-life= ln2/k). This is comparatively higher than the 0.17 yr^{-1} suggested as a default value in IPCC methodology probably due to the high moisture content of the waste of which food wastes was the main component. On the other hand, the k value obtained is compatible with environmental conditions on site (high temperature and water content), which tend to accelerate the process of organic matter depletion [17]. The obtained k value in tropical landfills from this study was higher than k value in US bioreactor landfill (k = 0.30 yr^{-1}) [16]. However, this obtained k value is close to a former study which used the pumping test method at Rachathewa landfill, Samut Prakan, Thailand where k was 0.32 yr^{-1} [18]. The high content of rapidly degradable organic carbon in waste streams at these landfills combined with high leachate levels in the waste body as studied in Thai landfill by Wangyao et al. (2008) [19] might be the main reason for this observation.

4. Conclusions

This study aimed to propose a practical methodology for estimating the methane generation rate constant of waste landfills for tropical countries, with specific focus on Southeast Asian urban areas where many Clean Development Mechanism (CDM) projects are in progress. The methane generation rate constant is the one of the important parameters that is used for methane generation evaluation. The methane emission measurements were conducted at four sanitary landfills located in Thailand over a two-year period. Our results indicated that high spatial heterogeneity of methane emission can be found from all study sites. The first order decay equation was used to evaluate the methane generation rate constant by using the rate of methane emissions per amount of waste in place from different age landfills. The fitting of the estimated methane emissions of landfills to the first order decay equation suggested a methane generation rate constant of 0.33 yr^{-1}, equivalent to 2.1 years in terms of half-life.

Table 3. Summary of methane emission from field investigation.

Study sites	Measurement in 2008					Measurement in 2009				
	No. of measured point	Min. ($g/m^2/d$)	Max. ($g/m^2/d$)	Mean ($g/m^2/d$)	Avg. spatial ($g/m^2/d$)	No. of measured point	Min. ($g/m^2/d$)	Max. ($g/m^2/d$)	Mean ($g/m^2/d$)	Avg. spatial ($g/m^2/d$)
Pattaya	59	0.00	2,061.35	177.78	198.83	34	-30.14	985.45	160.72	176.65
Ban-Bung	48	0.00	685.12	70.28	72.76	37	-0.28	577.53	60.19	62.13
Hua-Hin (Phase 2)	45	-1.63	1,152.11	70.62	70.00	15	-35.74	207.23	20.26	28.87
Laemchabang	48	-1.25	615.91	73.41	54.83	38	-2.73	633.47	60.14	48.23

Table 4. Rate of methane emission per amount of waste.

Study site	Measurement in 2008			Measurement in 2009		
	Average spatial methane emission ($g/m^2/d$)	Methane emission (kg/d)	Rate of methane emission per amount of waste (kg CH_4/ tons of waste/ yr)	Average spatial methane emission ($g/m^2/d$)	Methane emission (kg/d)	Rate of methane emission per amount of waste (kg CH_4/ tons of waste/ yr)
Pattaya	198.83	10,661	8.26	176.65	9,472	6.18
Ban-Bung	72.76	2,464	7.80	62.13	2,104	5.75
Hua-Hin (Phase 2)	70.00	2,249	5.64	28.87	928	2.07
Laemchabang	54.83	3,904	3.22	48.23	3,434	2.24

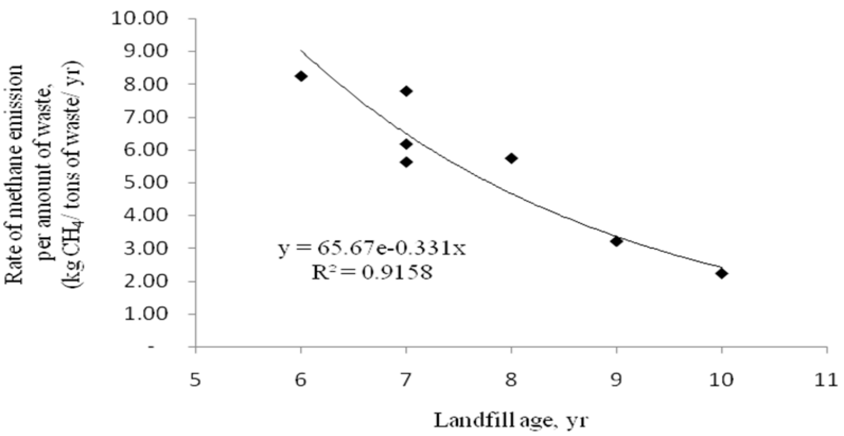

Figure 1. Methane emissions per amount of waste rate and fitted using FOD model.

The high methane generation rate constant obtained from this study might be caused by the high content of rapidly degradable organic carbon in waste combined with high moisture content in the waste body at tropical landfills that stimulated anaerobic degradation and produced more LFG in a short period. This key parameter can be considered as a country or region specific default value for methane emission inventories from the solid waste disposal sites in cases of managed landfill. An application of this monitored parameter should improve the reliability in determining of national methane emission inventories from the waste sector as compared to the suggested default values from IPCC.

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