2015 5th International Conference on Environment Science and Engineering
Volume 83 of IPCBEE (2015)
DOI: 10.7763/IPCBEE. 2015. V83. 3

Methane Generation from Landfills: Malaysia Specific Parameters

Mohammed F.M. Abushammala[1 +], Noor Ezlin Ahmad Basri[2] and Mohammad K. Younes[2]

[1]Department of Civil Engineering, Middle East College, knowledge Oasis Muscat, P.B. No 79, Al Rusayl 124, Sultanate of Oman

[2]Department of Civil and Structural Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract. Methane emissions and oxidation were measured during the wet and dry seasons at two sanitary landfills and one open dumping landfill in Malaysia. The resulting levels of methane emissions and oxidation were then modeled using the Inter-governmental Panel on Climate Change 1996 first order decay model to obtain methane generation rate and potential values. The methane potential value was 151.7 m^3 t^{-1} for the sanitary landfills and 75.9 m^3 t^{-1} for the open dumping landfill. The methane generation rate value of the sanitary landfills during the wet season was 0.136 y^{-1}, while that during the dry season was 0.072 y^{-1}. The methane generation rate values of the open dumping landfill during the wet and dry seasons were 0.008 and 0.0049 y^{-1}, respectively.

Keywords: Flux chamber, Methane emission, Methane oxidation, Open dumping, Sanitary landfill

1. Introduction

Accurate estimation of methane (CH_4) emission from Malaysian landfills is crucial for the development of clean development mechanism (CDM) projects. Estimating CH_4 emissions from landfills entails large uncertainties due to the lack of data on waste management and emissions. In the past, CH_4 emissions from landfills have usually been estimated using statistics on population and waste quality and quantity [1]. However, many models for estimating CH_4 emissions are currently available [2]. The Inter-governmental Panel on Climate Change (IPCC) introduced three tiers for estimating total national CH_4 emissions from landfills: Tier 1, Tier 2, and Tier 3. The Tier 1 method, defined as the default method, is based on a mass balance approach to estimate total national emissions and uses a number of empirical constant parameters, e.g., a methane correction factor (MCF), degradable organic carbon (DOC), and dissimilated organic fraction converted into landfill gas (LFG) (DOC_f) [3]. The Tier 2 and Tier 3 methods are based on a First Order Decay (FOD) model to calculate the level of emissions [4]. Selection of the most appropriate method to determine CH_4 emissions is based on the availability of current and historical country-specific data on waste deposited in landfills.

The FOD model is one of the most important and widely used models for the estimation of CH_4 emissions from landfills. It has been formalized as an IPCC Waste Model by the IPCC [1], [4], and a Landfill Gas Emission Model (LandGEM) by the US Environmental Protection Agency [5], [6]. As such, both the IPCC and USEPA recommend this model as a standard tool for the estimation of CH_4 emissions from landfills. The FOD model provides a time-dependent emission profile reflecting the pattern of waste degradation over time. It assumes that the DOC in waste decays slowly over time during which CH_4 and CO_2 are formed. Thus, the CH_4 emissions from deposited waste are highest during the first few years after deposition and then gradually decline with the reduction of DOC content in the waste [4]. The IPCC has provided two FOD models for estimating CH_4 emissions from landfill sites, the first was developed using the

[+] Corresponding author. Tel.: + 96893948805; fax: + 968 24446028.
E-mail address: eng_abushammala@yahoo.com.

Revised IPCC guidelines in 1996 and the second is provided in the 2006 IPCC guidelines. These two FOD models are referred to herein as the IPCC 1996 FOD and IPCC 2006 FOD models, respectively. The IPCC 1996 FOD model requires data on the average annual waste acceptance rate during a landfill's active life, the CH_4 generation rate (*k*), and the CH_4 generation potential (L_o) [1]. The IPCC 2006 FOD model provides a spreadsheet interface to facilitate its implementation for national emission estimations. In contrast with the IPCC 1996 FOD model, the IPCC 2006 FOD model is easier to apply and is more precise in cases where country-specific key parameters and high-quality country-specific activity data on waste landfilling are available. Due to the absence of historical waste composition data for Malaysian landfills, implementation of the IPCC 2006 FOD model results in inaccurate emission estimation. However, application of the IPCC 1996 FOD model requires knowledge of *k* and L_o values. This assertion is supported by Abushammala et al. [7], who reported the limitations of both the IPCC 1996 FOD and the IPCC 2006 FOD models in estimation of total CH_4 emission from landfills in Malaysia. These limitations were the lack of historical waste composition data and the assumptions made for *k* and L_o values. It is reported by the IPCC [1], that L_o values range from less than 100 to over 200 $m^3\ t^{-1}$ based on buried waste compositions, while *k* values may range from less than 0.005 to 0.4 y^{-1}. Accordingly, the main aim of this study is to improve estimation of CH_4 emissions from Malaysian landfills using the IPCC 1996 FOD model by generalizing values for *k* and L_o.

2. Materials and Methods

2.1. Landfill selection

To measure CH_4 emissions and oxidation, landfills were selected from the Selangor state based on the landfill operational type (sanitary landfill or open dumping), landfill status (in operation or closed), location in Selangor, the availability of an inactive area at operational landfills, and ease and safety of landfill access. Thus, three landfills were selected: the Air Hitam sanitary landfill, the Jeram sanitary landfill, and the Sungai Sedu open dumping landfill (Fig. 1). Table 1 provides a summary of the specifications of the selected landfills.

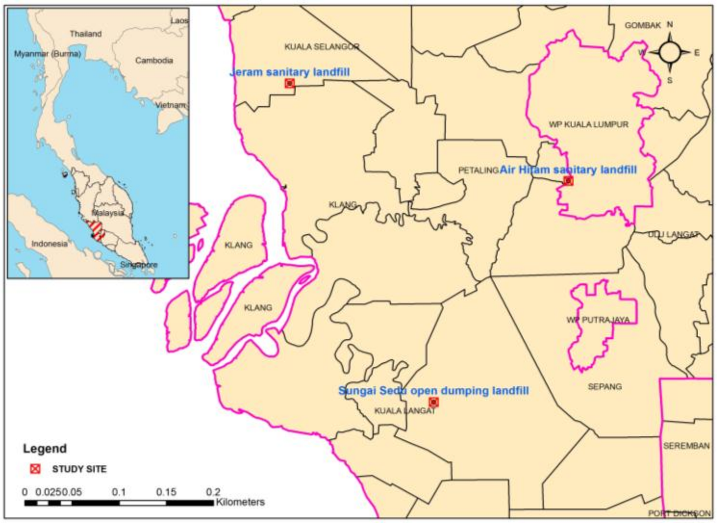

Fig. 1: Map of Selangor state shows the location of study landfills.

Table 1: Summary of landfill specifications.

Characteristic	Air Hitam	Jeram	Sungai Sedu
Disposal Practice	Sanitary	Sanitary	Open dump
Status	Closed	In operation	Closed
Area (ha)	42	52	5.5
Year operation began	1995	2007	1996
Closure year	2006	2017	2010
Date of study	October 2010	September 2010	September 2010

2.2. Experimental design

To provide data to quantify total CH_4 emissions from the three landfills, a square portion at each study area was overlaid with a grid of small squares to identify the measuring points. The grid square centers were marked with wooden sticks to specify sampling point locations [8]. Additional sampling locations were marked at shorter distances to provide an adequate number of samples to better develop a semi-variogram model and to define the flux spatial variability at small distances [8]. Grid characteristics and the total number of measuring points from each landfill are shown in Table 2. Surfer 8 software was used to estimate the average CH_4 emissions using inverse distance weight (IDW) method. For CH_4 emission measurements, a square flux chamber was fabricated following Abushammala et al [9]. Four sequential gas samples were extracted from the chamber headspace into a 50 mL gas-tight syringe at predetermined intervals (5 min).

Table 2: Characteristics of square grid sampling in each landfill.

Grid characteristics	Air Hitam	Jeram	Sungai Sedu
Area (m^2)	1,764	3,600	992
Dimensions (m×m)	7×7	10×10	3.5×3.5
Number of samples	73	81	80
Minimum samples spacing (m)	3.5	5	3.5
Average waste depth (m)	23	10	40

The wet and dry seasons in the landfills under the study were classified based on 19 years (1990-2008) monthly rainfall data obtained from the Department of Irrigation and Drainage, Ampang, Malaysia. The months provided highest rainfall relative frequency were considered as wet season, while those provided lowest rainfall relative frequency were considered as dry season. Emissions measurements during the wet season were undertaken from September to December 2010 at the three landfills, whereas dry season measurements were undertaken during February, March, May, and June from the Jeram and Sungai Sedu landfills only. Measuring CH_4 emissions at the Air Hitam landfill during the dry season was not possible because a gas collection system was being constructed during the measurement period. All measurements were performed between 8 and 11 am to minimize the diurnal effect. The total number of measuring points during the wet and dry season was identical at the two landfills that had readings taken during both wet and dry seasons. Atmospheric pressure and air temperature were also monitored.

Four monitoring locations at each landfill were chosen randomly to investigate the CH_4 oxidation capacity. LFG (CH_4 and CO_2) emissions on surface and soil gas concentration profiles at those locations were measured between 9 and 11 am twice a month from October 2010 to January 2011 at the Air Hitam landfill and from September 2010 to July 2011 at the Jeram and Sungai Sedu landfills. Soil gas was trapped by preinstalled stainless steel tubes in accordance with Kiese and Butterbach-Bahl [10], and collected using 10-mL gas-tight syringes for direct analysis. The concentrations of three main soil gases were investigated: CH_4, CO_2, and O_2. The combination of surface LFG emissions and soil gas concentration profiles was used to estimate CH_4 oxidation in the soil cover in accordance with Christophersen et al [11].

2.3. Gas concentration analysis and emission calculation

To A Varian Micro-GC (CP-4900) equipped with an MS5Å (Molar sieves 5Å, 10 m) and a PPQ (PolarPlot Q, 10 m) column module was used for analysis of landfill and soil gas concentrations [9]. Each gas sample was analyzed at least twice and the average was determined [12]. The level of emissions, F (g m^{-2} d^{-1}), was calculated as given in Eq. (1) [13]:

$$F = PVMU(dc/dt)/(ATR) \tag{1}$$

where P is pressure (1 atm), V is the chamber volume (80 L), M is the molar mass (16 and 44 g/mol for CH_4 and CO_2, respectively), U is the units conversion factor (0.00144 L min / (µL d)), A is the area covered by the chamber (0.4 m^2), T is chamber temperature (K), and R is the gas constant (0.08205 L atm/(K mol)). A nonzero flux was reported only when the regression coefficient (R^2) for the linear regression of four sequential concentrations over time (dc/dt) was larger than 0.85 [14]; otherwise a zero flux was reported [15].

2.4. Method of calculation of L_o and k values

To estimate the L_o and k values, the total CH_4 emissions from the field investigation and CH_4 oxidation results were modeled using the IPCC 1996 FOD model (Eq. 2):

$$Q = \left[0.717 \times 10^{-6} \times L_o \times W \times \left(e^{-kc} - e^{-kt}\right) - R\right] \times \left(1 - OX\right) \quad (2)$$

where Q is the total CH_4 emission in the current year (Gg), 0.717×10^{-6} is a conversion factor, W is the average annual waste acceptance rate (t) during the active life of the landfill, c is the time since the landfill was closed (y), t is the time since the landfill was opened (y), R is the CH_4 recovered (Gg), and OX is the oxidation factor (fraction). The OX value reflects the amount of CH_4 oxidised in the soil.

The total CH_4 emissions from each landfill site were estimated by multiplying the study area by the geospatial CH_4 mean emissions. The total CH_4 emissions value was input into the model in Gg y^{-1}. The value of L_o depends on waste composition and the fraction of organic carbon present, while the value of k is controlled by a number of factors such as moisture content, nutrient availability, pH, and temperature [1]. However, waste moisture content is the main factor that affects the k value [1]. The estimation of the L_o value in this research was based on the assumption that the composition of municipal solid waste (MSW) in Malaysian regions was almost same and comprised similar amounts of degradable organic carbon. Therefore, the value of L_o (in m^3 t^{-1}) in Eq. (2) was assumed to be the same for both the Air Hitam and Jeram sanitary landfills. While both landfills supported fully anaerobic processes, the Sungai Sedu open dumping landfill was a semi-anaerobic environment, with aerobic processes at shallow depths due to air penetration and anaerobic processes in the deeper layers. This variation in the waste decomposition processes resulted in different L_o values for sanitary and open dumping landfills. Therefore, the L_o value for the Sungai Sedu open dumping landfill was assumed to be 50% of that for the Air Hitam and Jeram sanitary landfills [9], [16]. Because waste moisture content is the main controlling factor affecting the value of k (y^{-1}) in Eq. (2), the k value was estimated during the wet and dry seasons for each landfill.

The W (t) in Eq. (2) was estimated using study site surface area (A, m^2), depth of waste (d_w, m), number of operation years (n), and waste density in landfill (ρ_w, t m^{-3}) (Eq. 3). Williams [17], reported that typical waste densities in landfills ranged from 0.60 to 0.85 t m^{-3} based on the amount of biodegradable and inert waste present. Landfill waste densities in this study were assumed to be in the range of 0.60-0.85 t m^{-3} based on site characteristics and taking into account that biodegradable waste accounted for up to 85% of total waste generation in Malaysia [18]. Estimation of the current waste depth was taken into account waste settlement depth over years of landfills closure. Williams [17], reported that waste settlement in landfills ranges between 10% and 40% based on the amount of organic content of the waste. Thus, it was assumed that 10% waste settlement occurred at the Jeram landfill where the cell was recently closed and the waste depth was less than at the other landfills (Table 2). The waste settlement at Air Hitam was assumed to be 20% due to the longer time of closure and greater waste depth. Waste settlement at the Sungai Sedu open dumping landfill was assumed to be 15% due to the longer time required for waste stabilization compared with a sanitary landfill.

$$W = \left(\frac{A \times d_w \times \rho_w}{n}\right) \quad (3)$$

The values for c and t in Eq. (2) were based on the landfill study area information shown in Table 2. The R parameter was set at zero throughout the calculation, where the landfills did not have a gas collection system in place during field sampling. The mean fraction of CH_4 oxidation (OX) was estimated from each study landfill and used in the model.

3. Results and Discussion

3.1. CH_4 emission rate from field investigations

The average and total CH_4 emission rates from the three landfills for both wet and dry seasons are shown in Table 3 (Note that only wet season data are available for Air Hitam).

Table 3: CH_4 emissions at the three landfills during wet and dry seasons

Landfill	Average CH_4 emissions (g m^{-2} d^{-1})[a]		Total emissions (Gg y^{-1})	
	Wet season	Dry season	Wet season	Dry season
Air Hitam	30.4	-	0.0196	-
Jeram	264.8	169.8	0.3480	0.2231
Sungai Sedu	21.3	13.25	0.0077	0.0048

[a] Geospatial average estimated using the IDW method

3.2. CH_4 oxidation capacity

The CH_4 oxidation capacity was investigated at the three landfills. The total number of oxidation measurements performed in the Air Hitam, Jeram, and Sungai Sedu landfills were 32, 72, and 78, respectively (Table 4). The average CH_4 oxidation capacities were 27.45%, 16.33%, and 52.47% at the Air Hitam, Jeram, and Sungai Sedu landfills, respectively.

Table 4: Summary of descriptive statistics of the CH_4 oxidation (%) from the three landfills

Landfill	Air Hitam	Jeram	Sungai Sedu
Number of samples	32	72	78
Min.	0.99	0	0.81
Max.	89.32	92.9	97.87
Arithmetic mean	27.45	16.33	52.47
S.D.	21.7	20.46	30.60

3.3. IPCC 1996 FOD model parameters

To estimate the L_o and k parameters of the IPCC 1996 FOD model and to generalize them for Malaysian landfills, the landfill study area information shown in Table 2, the total CH_4 emissions during the wet and dry seasons for the three landfills presented in Table 3, and the average CH_4 oxidation capacities at each landfill (Table 4) were used in Eq. (2). The L_o and k values are shown in Table 5. Using Air Hitam and Jeram landfill information and the field investigation results in the IPCC 1996 FOD model resulted in L_o having a value of 151.7 $m^3 t^{-1}$, and k having a value of 0.136 y^{-1} during the wet season. The L_o value of the Sungai Sedu open dumping landfill was assumed to be 50% of that found for both sanitary landfills, as open dumping landfills involve semi-anaerobic processes which tend to produce less CH_4 in contrast with sanitary landfills, which are fully anaerobic systems.

Table 5: k and L_o values at the three sites

Landfill	L_o ($m^3 t^{-1}$)	k-wet (y^{-1})	k-dry (y^{-1})
Air Hitam	151.7	0.136	-
Jeram	151.7	0.136	0.072
Sungai Sedu	75.9	0.008	0.0049

The k values of the Jeram sanitary landfill during the wet and dry seasons were approximately 17 and 15 times, respectively, higher than the k values for the Sungai Sedu open dump. The higher k value at the sanitary landfill indicates increasing CH_4 generation over time and implies faster waste decomposition at sanitary landfills than at open dumping landfills. Wang-Yao et al. [19], reported higher k values of sanitary landfills than open dumping landfills during both wet and dry seasons. The k values of both the Jeram sanitary landfill and the Sungai Sedu open dumping landfill during the wet season were higher than those during the dry season by approximately 1.9 and 1.7 times, respectively. This greater value was attributed to a higher amount of waste moisture content during the wet season, which accelerates waste decomposition to produce more CH_4 and facilitates nutrient transportation through waste layers. However, Wang-Yao et al. [19], found that the k values were approximately 7.5 to 9.6 times higher in the wet season than in the dry season for sanitary landfills, and between 2.1 and 11.5 times higher for open dumping landfills.

4. Conclusions

This study attempted to evaluate L_o and k values for Malaysian landfills for both the wet and dry seasons to accurately estimate total CH_4 emissions from Malaysian landfills. The L_o value found in this research for both sanitary landfills was 151.7 $m^3 t^{-1}$, while the L_o value for the pen dumping landfill was assumed to be 50% of that for sanitary landfills. The k values of the sanitary landfills during the wet and dry seasons were approximately 17 and 15 times, respectively, higher than k values for the open dump landfill. The higher k value at sanitary landfills indicates increasing CH_4 generation over time due to faster waste decomposition at sanitary landfills compared with open dumping landfills.

5. Acknowledgements

This work was financed by Universiti Kebangsaan Malaysia (UKM) under research grant UKM-GUP-ASPL-08-06-208. The authors also acknowledge the support given by the Middle East College for this research.

6. References

[1] IPCC. Revised 1996 IPCC guidelines for national greenhouse gas inventories. *Reference Manual, Intergovernmental Panel on Climate Change*. 1996, Available from: http://www.ipcc-nggip.iges.or.jp/public/gl/invs6e.html. [Accessed 10 October 2009].

[2] H. Scharff, and J. Jacobs. Applying guidance for methane emission estimation for landfills. *Waste Management*. 2006, **26** (4): 417-429.

[3] S. Kumar, S.A. Gaikwad, A.V. Shekdar, P.S. Kshirsagar, and R.N. Singh. Estimation method for national methane emission from solid waste landfills. *Atmospheric Environment.* 2004, **38** (21): 3481-3487.

[4] IPCC. 2006 IPCC guidelines for national greenhouse gas inventories. *Prepared by IPCC National Greenhouse Gas Inventories Programme* S. Eggleston, L. Buendia, K. Miwa, T. Ngara, K. Tanabe (eds.). 2006, Japan: IGES.

[5] USEPA (United States Environmental Protection Agency). User's manual: Landfill gas emission model version 2.0. *Office of Research and Development*. 1998, USEPA, Washington, DC.

[6] USEPA (United States Environmental Protection Agency). Landfill gas emissions model (LandGEM) version 3.02 user's guide. *Office of Research and Development*. 2005, USEPA, Washington, DC.

[7] M.F.M Abushammala, N-E.A. Basri, H. Basri, A.H. El-Shafie, and A.A.H. Kadhum. Regional landfills methane emission inventory in Malaysia. *Waste Management and Research.* 2011, **29** (8): 863-873.

[8] D.J. Mulla, and A.B. McBratney. Soil spatial variability. In: A.W. Warrick (eds.). *Soil physics companion*. CRC Press, 2002.

[9] M.F.M Abushammala, N-E.A. Basri, H. Basri, A.A.H. Kadhum, and A.H. El-Shafie. Methane and carbon dioxide emissions from Sungai Sedu open dumping during wet season in Malaysia. *Ecological Engineering.* 2012, **49**: 254-263.

[10] R. Kiese, and K. Butterbach-Bahl. N_2O and CO_2 emissions from three different tropic forest sites in the wet tropics of Queensland, Australia. *Soil Biology and Biochemistry.* 2002, **34** (7): 975-987.

[11] M. Christophersen, P. Kjeldsen, H. Holst, J. Chanton. Lateral gas transport in soil adjacent to an old landfill: factors governing emissions and methane oxidation. *Waste Management and Research.* 2001, **19** (6): 595-612.

[12] B. Eklund. Practical guidance for flux chamber measurements of fugitive volatile organic emission rates. *Air and Waste Management Association.* 1992, **42** (12): 1583-1591.

[13] T. Abichou, J. Chanton, D. Powelson, J. Fleiger, S. Escoriaza, Y. Lei, and J. Stern. Methane flux and oxidation at two types of intermediate landfill covers. *Waste Management.* 2006a, **26** (11): 1305-1312.

[14] H. Zhang, P. He, and L. Shao. Methane emissions from MSW landfill with sandy soil covers under leachate recirculation and subsurface irrigation. *Atmospheric Environment.* 2008, **42** (22): 5579-5588.

[15] T. Abichou, D. Powelson, J. Chanton, and S. Escoriaza. Characterization of methane oxidation at a solid waste landfill. *Journal of Environmental Engineering.* 2006b, **132** (2): 220-229.

[16] C. Chiemchaisri, J.P. Juanga, and C. Visvanathan. Municipal solid waste management in Thailand and disposal emission inventory. *Environmental Monitoring and Assessment.* 2007, **135** (1-3): 13-20.

[17] P.T. Williams. *Waste Treatment and Disposal*, 2nd. Ed. John Wiley & Sons Ltd, 2005.

[18] S. Kathirvale, M.N.M. Yunus, K. Sopian, and A.H. Samsuddi. Energy potential from municipal solid waste in Malaysia. Renewable *Energy.* 2003 **29** (4): 559-567.

[19] K. Wang-Yao, S. Towprayoon, C. Chiemchaisri, S.H. Gheewala, and A. Nopharatana. Seasonal variation of landfill methane emissions from seven solid waste disposal sites in central Thailand. *The 2nd joint international conference on: sustainable energy and environment (SEE 2006)*. Bangkok, 21-23 November. 2006, Thailand: Bangkok.