Formulating LandGem model for estimation of landfill gas under Indian scenario

Article *in* International Journal of Environmental Technology and Management · January 2014

DOI: 10.1504/IJETM.2014.061800

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Abstract: Mostly in India, solid waste without any segregation is deposited into open dumping sites. Through these sites, there is uncontrolled emission of methane and landfill gas. The landfill gas has tremendous potential in terms of converting and using them as source of fuel. The emission of landfill gas depends on types of wastes, its rate of biodegradability, its methane potential, level of segregation and many more. In order to estimate the level of landfill gas emission, there are various US EPA recommended models are available. One of them is LandGem. But this model has been derived as per the US climatic conditions and their type of waste. It is needed to be converted into Indian conditions before applying it for Indian landfill site. This paper formulates the criteria required for converting the LandGem equation as per Indian condition and using it for Indian landfill sites. The model is verified with its application for two landfills sites of Mumbai, Deonar and Mulund.

Keywords: municipal solid waste; MSW; LandGem; model; GHGs; methane; energy; India.

Reference to this paper should be made as follows: Sil, A., Kumar, S. and Kumar, R. (2014) 'Formulating LandGem model for estimation of landfill gas under Indian scenario', *Int. J. Environmental Technology and Management*, Vol. 17, Nos. 2/3/4, pp.293–299.

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This paper is a revised and expanded version of a paper entitled 'Formulating LandGem model for estimation of landfill gas under Indian scenario' presented at International Brainstorming Workshop on Waste to Energy, Mumbai, India, 24–25 August 2012.

1 Introduction

Mostly in India, municipal solid waste (MSW) is dumped in open landfill site without any prior treatment. These open landfills are not scientifically designed. In these open landfills, MSW is allowed to decompose, thereby producing methane (CH_4), carbon dioxide (CO_2) and traces of non-methane volatile organic compounds (NMVOCs). Initially the waste is decomposed by aerobic bacteria, till oxygen is depleted. The remaining waste is broken down by anaerobic bacteria into substances such as cellulose, amino acids, and sugars, which are then fermented into the gases and short-chain organic compounds that form substrates for the growth of methanogenic bacteria. The amount of CH_4 generated depends on quantity and composition of wastes, moisture content, pH, and waste management practices. In general, CH_4 production increases with higher organic and moisture content in landfills. Anaerobic condition created at solid waste disposal site also generates more CH_4. CH_4 is the main component of landfill gas (LFG) and it has global warming potential of 21 times that of CO_2 (UNFCCC).

In order to predict the annual methane potential from a landfill, various predictive models such as Intergovernmental Panel on Climate Change (IPCC) (1997, 2006) models, the Shell Canyon model (Thompson et al., 2009) and LandGem (US EPA, 2005) are commonly used. Landfill gas models continue to receive criticism due to their poor accuracy and insufficient validation. Most model results have not been evaluated against methane recovery data (Barlaz et al., 2004). A few studies (Spokas et al., 2006; Barlaz et al., 2004) have compared methane recovery data to estimates of methane generation from models, but only for a few landfills. Despite the IPCC's (2006, 1996) attempt to establish a suitable universal method, different countries still use different methods for collecting and reporting their methane production from landfill sites. Thomson et al. (2009) has compared various models for methane emission from various landfill sites and concluded that LandGem model estimated methane emission with better accuracy as compared with other models. The results of their finding are highlighted in Table 1. Hence, authors selected LandGem model for estimating the methane from landfills sites of India. LandGem was primarily developed by US EPA's researchers to bring most of the large US landfills into the air quality regulatory program (under Clean Air Act amendments) and to extend them for regional emission inventories. It is governed by two main factors, the methane potential (L_0) and the decay rate (k) of landfill waste (Cho et al., 2012). The methane potential of waste depend on quantity of biodegradable waste, level of segregation, microbial application rates, volatile solids, climatic conditions like temperature and humidity (Xiaoli et al., 2010; Xi et al., 2012). This model has been derived as per climatic conditions and waste characteristics of USA. Therefore, the aim of this research was to derive the LandGem model as per Indian climatic condition and its waste characteristics. In order to achieve the same, the waste characterisation was carried out on the basis of living standards of India.

Table 1 Comparison of different models for estimation of landfill gas

Model type	*Mean absolute error and standard error (%)*	*Error median*	*Correlation (r)*	*Mean relative error (%)*
German EPER model	589 + 666	238	0.85	312
TNO model	376 + 356	322	0.87	289
Belgium model	171 + 177	125	0.86	111
Scholl Canyon model	115 + 152	43	0.91	111
LandGem model	81 + 17	–86	0.92	–81

Source: Thomson et al. (2009)

2 Material and methods

2.1 Waste sampling and analysis

Waste samples were collected from the landfill site of Mumbai, as well as from housing societies. They were collected manually and stored in zip locked bags and brought to laboratory for analysis. The waste characterisation was carried out through manual method (Wakadikar et al., 2012). The mixed solid waste was dried and manually separated, the quantity of dry waste and wet waste was quantified using electronic weighing balance.

2.2 Developing LandGem model as per Indian scenario

LandGem is a US EPA model which is used for predicting landfill gas emission from landfill sites. The equation used for the model is given below:

$$Q_t = 2 * L_o * m_o * \left(e^{k*t_a} - 1\right) * e^{-k*t}$$

where

Q_t expected gas generation rate in the t^{th} year, m^3/yr

L_o methane generation potential, m^3/yr

m_o constant or average annual solid waste acceptance rate, Mg/yr

k methane generation rate constant, yr^{-1}

t age of the landfill, yr

t_a total years of active period of the landfill, yr.

Recently, in order to estimate the methane generation, MCGM has carried out pump test (US EPA, 2007) at Deonar landfill site, Mumbai (US EPA, 2006). As per their report, the methane generation constant (k) for different waste is given in Table 2.

Table 2 Methane generation constant for different waste

Type of waste	*Methane generation constant*
Organic waste (compostable)	0.40
Paper waste (medium decay organic waste)	0.08
Rubber (slow decay organic waste)	0.02

Source: US EPA (2006)

In order to derive the methane generation constant (k) of the entire landfill site, the methane generation constant for the different types of waste as per their quantity was determined by the formula:

Sr. no.	*Type of waste*	*Equation*
A	Compostable	% × decay constant
B	Paper (medium decay waste)	% × decay constant
C	Rubber (slow decay waste)	% × decay constant

The methane generation constant for the entire landfill site was derived as per formula:

$$\text{Methane generation constant for entire landfill} = A + B + C$$

Other details like methane generation potential (m^3/yr), constant or average annual solid waste acceptance rate (Mega gram/yr), age of the landfill (yr) and total years of active period of the landfill (yr) was provided by MCGM (US EPA, 2006).

3 Result and discussions

The physical analysis of the waste showed that 55.25% of the waste consists of biodegradable components, about 8.85% of paper waste and remaining 35.9% of inert waste. Sharholy et al. (2007) reviewed that waste characteristics of most the Indian cities consist of about 40–45% of biodegradable waste, 3–10% of paper and remaining of inert waste. They also reported that metropolitan cities consist of higher percentage of biodegradable waste (about 57%). All these findings are similar to the analysis carried out by authors. As per MCGM analysis (US EPA, 2006), the methane generation potential (L_o) of the landfill site of Mumbai was 68 m^3/Mg (cubic metre per mega gram or metric ton). As per the above mentioned equation the methane generation constant (*k*) for compostable, medium and slow decay waste was 0.221, 0.007 and 0.007 respectively. Various studies has reported the *k* value (per yr) for compostable waste, medium decay waste and slow decay waste 0.17–0.70, 0.15–0.2 and 0.03–0.005, respectively, for wet climatic condition. Similarly, Gioannis et al. (2009) has reported *k* value (per yr) for compostable waste, medium decay waste and slow decay waste 0.693, 0.139 and 0.046, respectively. Our findings were similar to the available literature (Thompson et al., 2009), except for medium decay waste. This is mainly due to improper segregation of waste. A properly segregated waste shows better *k* value as compared with un-segregated ones (Chattopadhyay et al., 2009). Gioannis et al. (2009) has also estimated the *k* value of entire landfill site and it was found to be 0.39 and 0.2 for Brogborough landfill, UK and Yolo County landfill, USA, respectively. In Mumbai, there are three landfill sites which are located at Gorai, Deonar and Mulund. Gorai landfill site has already being closed down by the Government and thus currently, there are only two active landfill sites, Mulund and Deonar. The details of the landfill sites are given in Table 3. In our study, the *k* for the entire landfill was found to be 0.235 (sum of compostable, medium and slow decay waste). This is similar to the value reported in various other literatures (Gioannis et al., 2009).

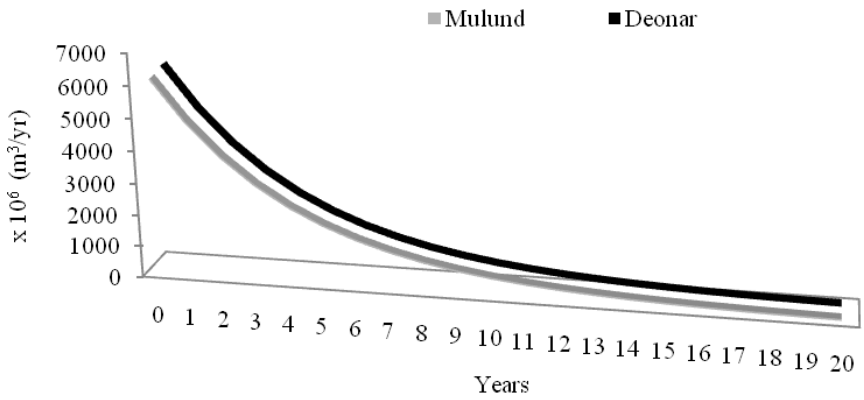
Table 3 Characteristics of landfill sites of Mumbai

Data	*Site*	
	Deonar	*Mulund*
Type of landfill	Open dump	Open dump
Landfill size	132.1 Ha	25 Ha
Waste in place (as of Jan 2006)	7.88 million metric tons	0.94 million metric tons
Designed landfill capacity	Not designed	Not designed
Waste depth	5–7 m	3.6 m
Year filling began	1927	1968
Year landfill was closed or will close	Partial closure planned in 2008–09	Not yet planned
Quantity of waste accepted annually at landfill	192,317 Mg/year	73,222 Mg/year

The average waste acceptance rate (m_0) was estimated by dividing total waste in place by number of functional years. The m_0 for Deonar and Mulund is 192,317 Mg/year and 73,222 Mg/year respectively. The Deonar site is operating since 1927 while Mulund is from 1968. Thus, the age of landfill and total active period was also estimated from landfill characteristics (Table 3). LandGem is a model which predicts the landfill gas emission for a period of 20 years (Yuan and Abchoi, 2010; Cho et al., 2012).

Emissions from landfill gas depend on the biodegradation rates of MSW (Kim and Townsend, 2012). Various studies have indicated that waste degradation process follows growth curve reactions (Wakadikar et al., 2012). Initially, the rate of degradation is high (Xi et al., 2012), thus there is more emission of landfill gas (Zhang et al., 2012). Thereafter, the rate of biodegradation slows down and thereby decreasing the rate of emission of gas (Wakadikar et al., 2012). In our findings, initially the rate of methane generation was high as compared to later stages (Figure 1). This was mainly due to the fact that due course of time the component of the waste got exhausted for microbial degradation and thereby reducing the methane generation rate.

Figure 1 Methane emission from landfills of Mumbai



Talyan et al. (2007) has reported similar finding from Delhi sites. They had developed a model for estimation of methane from landfill site and their results were more or less similar with the findings of our studies. Similarly, Jha et al. (2008) has found the methane generation from Chennai landfill site was about 0.12 Gg/yr. In our study, for the first two years, the methane generation from Deonar and Mulund landfill sites were approximately 5,630 × 10^6 m^3/yr and 5,524 × 10^6 m^3/yr, respectively. As the time progresses the methane generation also reduced. Hence, the LandGem model can be used for predicting the methane and landfill gas from the Indian landfill sites.

4 Conclusions

In this study, the LandGem model has been converted using Indian scenario. This model has been developed under US condition. The equation is remodelled in terms of Indian conditions and this model should be validated with different landfill sites of India in terms of methane generations. The methane generation constant (*k*) for compostable, medium and slow decay waste was found to be 0.221, 0.007 and 0.007 respectively for Indian conditions. This model is exclusively used for predicting methane potential from landfill sites especially for financing modelling for CDM mechanism. Hence, it needed to be formulated as per Indian scenario. Thus, this remodelled software would significant application in determining the landfill gas and methane emissions from different landfill sites in India. The annual methane emission would be estimated and then proper option can be adopted for utilisation of methane for different landfill sites of India.

References

Barlaz, M.A., Green, G., Chanton, J.P., Goldsmith, C.D. and Hater, G.R. (2004) 'Evaluation of a biologically active cover for mitigation of landfill gas emissions', *Environmental Science and Technology*, Vol. 38, No. 4, pp.4891–4899.

Chattopadhyay, S., Dutta, A. and Ray, S. (2009) 'Municipal solid waste management in Kolkata, India – a review', *Waste Management*, Vol. 29, No. 4, pp.1449–1458.

Cho, H.S., Moon, H.S. and Kim, J.Y. (2012) 'Effect of quantity and composition of waste on the prediction of annual methane potential from landfills', *Bioresource Technology*, Vol. 109, pp.86–92.

Intergovernmental Panel on Climate Change (IPCC) (1996) *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* [online] http://www.ipcc-nggip.iges.or.jp/public/gp/english/5_Waste.pdf (accessed 24 September 2005).

Intergovernmental Panel on Climate Change (IPCC) (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*, IPCC/OECD/IEA, Paris, France.

Intergovernmental Panel on Climate Change (IPCC) (2006) *IPCC Guidelines for National Greenhouse Gas Inventories*, IPCC/OECD/IEA/IGES, Hayama, Japan.

Jha, A.K., Sharma, C., Singh, N., Ramesh, R., Purvaja, R. and Gupta, P.K. (2008) 'Greenhouse gas emissions from municipal solid waste management in Indian mega-cities: a case study of Chennai landfill sites', *Chemosphere*, Vol. 71, No. 4, pp.750–758.

Kim, H. and Townsend, T. (2012) 'Wet landfill decomposition rate determination using methane yield results for excavated waste samples', *Waste Management*, Vol. 32, No. 7, pp.1427–1433.

Spokas, K., Bogner, J., Chanton, J.P., Morcet, M., Aran, C., Graff, C., Moreau-Le Goluan, Y. and Hebe, I. (2006) 'Methane mass balance at three landfill sites: what is the efficiency of capture by gas collection systems?', *Waste Management*, Vol. 26, No. 5, pp.516–525.

Talyan, V., Dahiya, R.P., Anand, S. and Sreekrishnan, T.R. (2007) 'Quantification of methane emission from municipal solid waste disposal in Delhi', *Resources, Conservation and Recycling*, Vol. 50, No. 3, pp.240–259.

Thompson, S., Sawyer, J., Bonam, R. and Valdivia, J.E. (2009) 'Building a better methane generation model: validating models with methane recovery rates from 35 Canadian landfills', *Waste Management*, Vol. 29, No. 7, pp.2085–2091.

US EPA (2005) *First-order Kinetic Gas Generation Model Parameter for Wet Landfills*, EPA-600/R-05/072.

US EPA (2006) *Preliminary Assessment for Landfill Biogas Project Opportunities: Deonar Landfill*.

US EPA (2007) *Report of the Pump Test and Pre-feasibility Study for Landfill Gas Recovery and Utilization at the Deonar Landfill, Mumbai, India*, Prepared for Landfill Methane Outreach Program.

Wakadikar, K., Sil, A., Kumar, S., Kumar, R. and Mudhoo, A. (2012) 'Influence of sewage sludge and leachate on biochemical methane potential of waste biomass', *Journal of Bioremediation and Biodegradation*, Special Supplement S8.

Xi, B.D., He, X.S., Wei, Z.M., Jiang, Y.H., Li, M.X., Li, D., Li, Y. and Dang, Q.L. (2012) 'Effect of inoculation methods on the composting efficiency of municipal solid waste', *Chemosphere*, Vol. 88, No. 6, pp.744–750.

Xiaoli, C., Ziyang, L., Shimaoka, T., Nakayama, H., Ying, Z., Xiaoyan, C., Komiya, T., Ishizaki, T. and Youcai, Z. (2010) 'Characteristics of environmental factors and their effects on CH_4 and CO_2 emissions from a closed landfill: an ecological case study of Shanghai', *Waste Management*, Vol. 30, No.3, pp.446–451.

Yuan, L. and Abchoi, T. (2010) 'Methane emission estimation and control through the life cycle of MSW landfills', *Geotechnical Special Publication*, Vol. 199, pp.2888–2895.

Zhang, Y., Yue, D. and Nie, Y. (2012) 'Green house gas emissions from two-stage landfilling of municipal solid waste', *Atmospheric Environment*, Vol. 55, pp.139–143.