Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

Evaluation of the Keru Landfill Site's Methane and Landfill Gas Emissions (India)

**1Subhashree Tripathy,Ashish Kumar Das*
**1Asst. Professor, Dept. of Civil Engineering, NIT, BBSR*
Asst. Professor, Dept. of Civil Engineering, NIT, BBSR
*Email:*1* Subhashreetripathy@thenalanda.com,*ashishdas@thenalanda.com*

Abstract: The state of Rajasthan's Jodhpur is a heavily urbanised and inhabited metropolis. Due to the city's fast industrialization and urbanisation over the past few decades, the population has expanded significantly. Currently, Jodhpur's population produces 392 t/d or so of MSW. One of the most overlooked facets of municipal systems has been MSW management. Around 70 to 80 percent of the generated MSW is gathered and disposed at the Keru landfill. Only 100 t of the collected MSW is processed through a composting unit; as a result, the remainder of the MSW is disposed at the Keru landfill site along with composting process waste. Due to the production of GHGs, this landfill is a significant source of air pollution in the absence of an LFG collecting system. The MSW placed at the Keru landfill site was examined for characterization using a number of physico-chemical characteristics in the current investigation. The Keru landfill's LFG and methane generation potential was estimated using the first-order decay (FOD) model, and the results were compared to those obtained using the modified triangular model (MTM). According to the FOD model, the methane generation potential is projected to be 1.55 Gg/y, or 0.08–0.31% of the estimated current Indian landfill methane emission and 0.008% of the estimated global landfill methane emission. In this study, LFG and methane emission from Keru landfill for the years 2006 to 2011 have been estimated, and the consequences of national methane emission for India and the world have been examined.

Keywords: municipal solid waste; waste characterisation; landfilling; landfill gas; methane; air pollution; India.

.

1 Introduction

Landfilling is now the method used most frequently for municipal solid waste (MSW). More than 90% of the MSW produced in India is improperly dumped directly on land (Mufeed et al., 2008; Hazra and Goel, 2009). Environmental and public health risks are becoming more acute in the developing countries as a result of unregulated landfilling techniques and related MSW disposal issues. The nation's landfills receive a wide variety of trash, including food waste, plastic, rubber, cotton, leather, paper, and other debris. Unscientific disposal and distribution of the trash endangers the environment and the public's health (Ray et al., 2005).

Via decomposition and other life-cycle processes, MSW is a substantial source of greenhouse gas (GHG) emissions, accounting for around 5% of the world's carbon budget. Methane (CH4) and carbon dioxide (CO2) emissions from the anaerobic breakdown of solid waste make up this 5%. (IPCC, 2006; Chalvatzaki and Lazaridis, 2010). Methane has a potential for more than 20 times as much global warming as carbon dioxide, and its quantity in the atmosphere has been rising by 1% to 2% annually (IPCC, 1996; Kumar et al., 2004).

Through decomposition and life-cycle activities, MSW accounts for around 5% of the world's greenhouse gas budget, making it a substantial contribution to GHG emissions. Methane (CH4) emissions from the anaerobic decomposition of solid waste and carbon dioxide (CO2) emissions from the decomposition of wastewater make up the remaining 5%. (IPCC, 2006; Chalvatzaki and Lazaridis, 2010). Methane's potential to cause global warming is thought to be more than 20 times greater than that of carbon dioxide, and its quantity in the atmosphere has been rising by 1% to 2% annually (IPCC, 1996; Kumar et al., 2004).

The national level methane emission from solid waste disposal sites using the default methodology varies from 263.02 Gg in year 1980 to 502.46 Gg in year 1999 (Kumar et al., 2004). Garg et al. (2001) have estimated that the methane emission in India is amounted to approximately 18.63 Tg of methane in 2000, while landfills contributed 10% to this value (1.863 Tg). The methane emission from MSW landfill sites depend on the quantity and composition of MSW deposited and a significant amount of LFG eventually makes its way to the atmosphere. Thus, composition and characterisation of MSW disposed at landfill site is

In the present paper, an attempt has been made to estimate the LFG and methane generation potential of a Keru landfill site by analysing the characteristics of MSW. First-order decay (FOD) model was used to estimate the generations of methane from Keru landfill site and the results have been compared with modified triangular model (MTM). This could help to assess the potential use of this generated methane as an alternative source of energy.

2 Materials and methods

Study location

Jodhpur, second largest city of Rajasthan state and the past capital of Rathore clan is considered as an oasis in the arid region of the state. The population of the city on the basis of census 2001, is reported as 851,050 (NBCCL, 2004) and presently generated about 392 t of MSW daily. The MSW is dumped at a designated site near Keru about 18 km away from the city towards Jaisalmer. The designated site is spread over an area of 48 acres (1.943×10^5 m^2). It is operational since 2005 and deposited mainly residential waste, street sweeping, commercial waste, construction and demolition waste. A 50 t capacity computerised weigh bridge is used to check and record the weights of trucks which transport the MSW at the landfill site.

Sampling and analysis

The open trenches excavation and drillers are used at Keru landfill site to collect the samples from eight locations at the depth of 0–2, 2–4, and 4–6 m. The collected samples were segregated physically into various compounds like paper, glass, wood, plastic, leather, biodegradables, etc. The remaining material was a uniform mixture of organic material along with soil, mud, sand and other inert materials that were not manually separable, and is termed mixed residue. About 1 kg of this mix from each sample was collected and brought to the Environmental Engineering Laboratory of Civil Engineering Department, M.B.M. Engineering College, J.N.V. University, Jodhpur for physico-chemical analysis of parameters like pH, moisture, volatile solids, carbon, nitrogen, phosphorous, potassium and C/N ratio (Table 1). The chemical analysis was performed as per standard methods prescribed in IS: 9235-1979 (reaffirmed 1997) andIS: 10158-1982 (reaffirmed 1995).

Modelling of LFG production

FOD model

The FOD model is most popularly used for the prediction of LFG and validated the LFG generation model, as it accounts for the effect of age (Oonk and Boom, 2000). The LFG could be better estimated by using the FOD model in two phases. In the first phase, the rate of generation keeps on increasing till the peak is reached; thereafter, it keeps on declining till the material is stabilised. The FOD model provides a time-dependant emission profile that reflects the true pattern of the degradation process over time

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

(US-EPA, 1998; Kumar et al., 2004; EPA, 2005). Mor et al. (2006) outlined the equation to estimate the LFG formation using FOD model as:

$$\alpha_1 = \xi\, 1.87.A.Co.k_1.e^{-k1.t} \quad (1)$$

where α is landfill gas formation at a certain time (m^3/year), ξ is formation factor, and the value of 0.58 has been used in this paper, k_1 is degradation rate constant ($year^{-1}$), and the value of 0.094 has been used, A is amount of waste deposited (tons), Co is amount of degradable organic carbon in waste at deposition time (kg/t), t is time elapsed in years since deposition (year), and 1.87 is a factor (m^3/kg) (Mor et al., 2006).

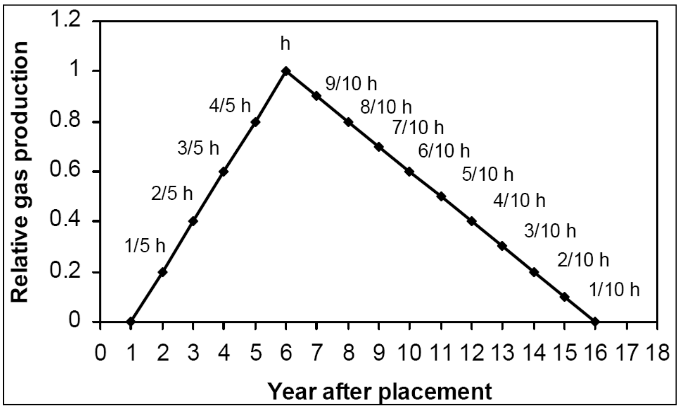
Modified triangular model

This model assumes that the degradation takes place in two phases. The first phase starts after one year of deposition and the rate increases linearly from zero to maximum value for six years. In second phase, gas generation decreases from maximum value for six years to zero for 16 years (Kumar et al., 2004; MoEF, 2010). The total gas generationwas computed by following equations given by Mor et al. (2006):

$$G = \xi\, 1.87.A_t.C_o \quad (2)$$

where G is the total gas generation during the period of t + 1 to t + 16, with t the year of waste deposition, A_t is the amount of waste deposited in t year. The gas generation pattern assumed in this model has a triangular shape (Figure 1). The 'h' value (peak value) of gas emission is calculated knowing the volume of gas and area of triangle. Using peak value other ordinates are calculated.

Figure 1 Triangular form of gas production



3 Results and discussion

MSW characteristics

Table 1 shows the physical composition of the waste on wet sample basis which includes plastic, paper, cloth, metal, leather, biodegradables, etc., whereas, the chemical

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

characteristics of the waste is also depicted. The organic fraction of waste and compostable matter are found to increase with the depth, whereas, chemical parameters do not show significant variations with depth. Moisture content plays important role in gas formation, and found to be increases with depth. The pH is in the range of 7.02–8.27 which is inclined towards alkaline phase. Volatile solids varied from 20.24% to 31.96%. The carbon content varied from 5.46% to 10.40% with an average value of 8.46%. The average nitrogen and phosphorous contents were 0.57% and 0.65% respectively.

Table 1 Physical and chemical characteristics of MSW deposited at Keru landfill

rganics	*ɪnge*	*ɪpical*	*rganics*	*ɪnge*	*ɪpical*
loth	37–5.29	92 ± 0.96	ɪ*	02–8.27	94 ± 0.29
lass	-2.07	39 ± 0.35	oisture	).62–24.17	l.03 ± 1.89
etal	-0.72	18 ± 0.21	.S.	).24–31.93	).63 ± 2.13
astic	74–7.48	69 ± 1.21	itrogen	46–0.74	57 ± 0.04
ɜather	11–3.37	92 ± 0.16	ɜrbon	46–10.4	46 ± 0.59
'ood	-3.42	16 ± 0.57	'N ratio	41–22.57	).74 ± 1.74
ɪper	-2.42	64 ± 0.37	ɪosphorous	56–0.84	65 ± 0.07
iodegradable	).89–24.82	).19 ± 2.02	ɔtassium	55–1.07	75 ± 0.14
ust/sand	).32–75.72	).07 ± 2.38	ɪlphur	il	il

Note: *All values are in percent except pH and C/N ratio.

Methane estimation

Considering ξ as 0.58, carbon content as 8.46% and k_1 as 0.094/year the LFG generation has been estimated by FOD model. The base estimation of total LFG emission is 4.31×10^6 m^3 in 2011 (Table 2). The Keru landfill site is spread over an area of 1.943×10^5 m^2 thus, it will yield a LFG potential of 22.18 m^3/m^2 in 2011. Assuming 50% of total LFG generation as methane content, Keru landfill produced 11.09 m^3/m^2 methane in 2011 or
2.17×10^6 m^3 or 1.55×10^6 kg of methane.

Table 2 Estimation of LFG emission at Keru landfill site for the year 2011 (FOD model)

ɜar sposal	*‹ t (years)*	*ɔns)*	*Co(tons)*	*ᴲG Mcum/y)*	*ane Mcum/y)*	*(basane Mcum/y)*	*(wors*
)11		).23 × 10^4	86 × 10^4	88	44	79	
)10		).77 × 10^4	83 × 10^4	77	39	66	
)09		l.55 × 10^4	98 × 10^4	83	42	68	
)08		).07 × 10^4	85 × 10^4	66	33	52	
)07		).55 × 10^4	89 × 10^4	63	32	47	
)06		).02 × 10^4	85 × 10^4	54	27	39	
ɔtal		*?.19 × 10^4*	*26 × 10^4*	*31*	*17*	*51*	

The production of LFG between 2006–2011 was also estimated by MTM. The total amount of LFG generated by waste deposited in *t* year is calculated by equating this amount to the area of triangle formed by LFG emission distribution. The peak value 'h' is calculated by knowing the total gas generated and the base of a triangle (15 years). Using

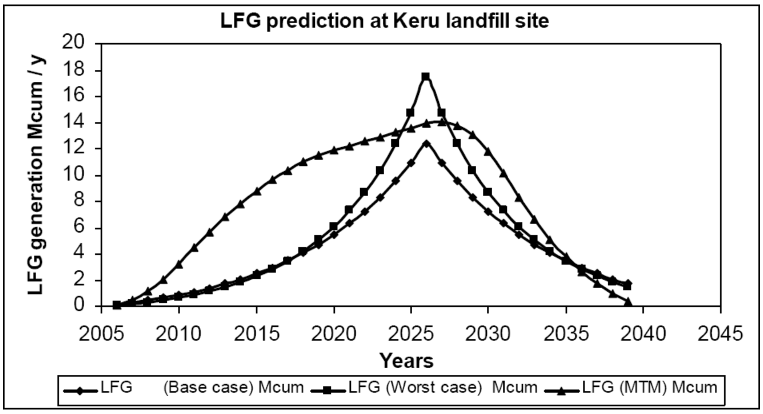
Industrial Engineering Journal
ISSN: 0970-2555
Volume : 51, Issue 04, April : 2022

this peak value, other ordinates were calculated. This process is used to the estimated amounts of waste deposited in subsequent years. The value obtained for 2011 by this method was 5.04×10^6 m^3 and the methane fraction was 2.52×10^6 m^3 or 12.97 m^3/m^2 (Table 3), which is very similar to the value obtained by FOD model. This process is used for the estimated amounts of waste deposited from 2006–2026 and for each year from 2006–2039 the emissions are calculated by summation of the contributions of the waste deposited in preceding years (Figure 2).

Table 3 Estimation of LFG emission at Keru landfill site for the year 2011 (MT model)

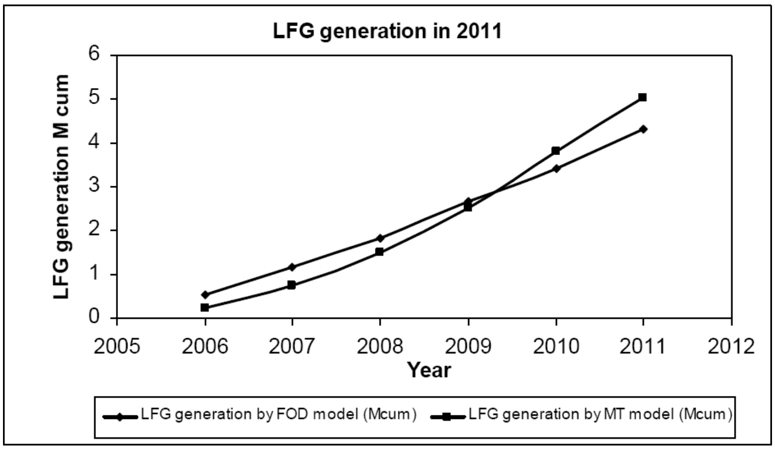
Year of	*LFG gas generation rate (Mcum/y)*					*Total*		*Methane*
sposal	*)06*	*)07*	*)08*	*)09*	*)10*	*)11*	*Icum/y)*	*Icum/y)*
)05								
)06	25		25	13				
)07	49	26		75	38			
)08	74	52	25		51	76		
)09	98	77	49	28		52	26	
)10	23	03	74	56	24		80	90
)11	19	29	98	85	48	25	04	52

Figure 2 LFG prediction at Keru landfill site, Jodhpur



Global landfill methane emission ranges from 19 to 40 Tg/y (Bogner and Matthews, 2003; Bogner et al., 2005). We estimated methane emission for Keru landfill site as
1.55 Gg in 2011. Hence, it is concluded that the maximum methane emission from Keru landfill site is 0.008% of global landfill methane emission. Further, our methane emission estimate for Keru landfill site represents 0.083% of landfill methane emission in India as estimated by Garg et al. (2001) and 0.31% as estimated by Kumar et al. (2004). The values estimated by MTM give realistic values as it is based on the assumptions that the LFG generation follows triangular form and the gas keeps on generating for the next 15 years.

Figure 3 LFG generation in 2011 at Keru landfill site, Jodhpur



4 Conclusions

The emission of LFG and methane has been calculated by FOD and MT models for MSW disposal site Keru at Jodhpur. Both the models yield similar values and can be used for the estimation of methane emission. The methane estimation value is found to be
1.55 Gg/y. The maximum methane emission for Keru landfill site is 0.008% of global landfill methane emission and 0.083 to 0.31% of the landfill methane emission in India. Considering the impact of methane in global warming, it is necessary to reduce the methane emission from landfill sites. The collection of LFG as a potential source of energy such as generation of power and domestic purpose and can be implemented to reduce these emission. Hence, LFG recovery facility should be urgently started to optimise its efficiency and feasibility. Further, the methane emission can be reduced by source segregation of MSW, biodegradable fraction of MSW should be treated by composting and only non-biodegradable fraction should be landfilled. The methane emission can also be reduced by increasing the oxidation capacity of the landfill cover.

Methane emission models show that Keru landfill site may significantly contributes to the atmospheric methane emission in near future. Hence, sanitary landfilling practices with LFG collection, extraction and flaring facilities are strongly recommended for Keru landfill site.

References

Bogner, J. and Matthews, E. (2003) 'Global methane emissions from landfills: new methodology and annual estimates 1980–1996', *Global Biogeochemical Cycle*, Vol. 17, No. 2, pp.1–18.

Bogner, J., Spokes, K., Chanton, J., Powelson, D., Fleiger, J. and Abichou, T. (2005) 'Modeling landfill methane emission from biocovers: a combinated theoretical empirical approach', *Proceedings Sardinia. Tenth International Waste Management and Landfill Symposium*, October 2005, S. Margherita di Pula, Sardinia, Italy, , Published by CISA, University of Cagliari, Sardinia [online] http://www.landfillplus.com/pdf/2005_Modeling_Landfill_CH4_ Emission.pdf (accessed 19 February 2011).

Chalvatzaki, E. and Lazaridis, M. (2010) 'Estimation of greenhouse gas emissions from landfills: application to the Akrotiri landfill site (Chania, Greece)', *Global NEST Journal*, Vol. 12,No. 1, pp.108–116.

EPA (2005) 'First-order kinetic gas generation model parameters for wet landfills', United States Environmental Protection Agency, EPR-600/R-05/072 [online] http://www.epa.gov/nrmrl/ pubs/600r05072.pdf (accessed 19 February 2011).

Garg, A., Bhattacharya, S., Shukla, P.R. and Dadhwal, V.K. (2001) 'Regional and sectoral assessment of greenhouse gas emission in India', *Atmospheric Environment*, Vol. 35/15, pp.2679–2695 [online] http://www.decisioncraft.com/energy/papers/ecc/ei/ghgei.pdf (accessed 19 February 2011).

Gurger, B.R., van Aardenne, J.A., Lelievelda, J. and Mohan, M. (2004) 'Emission estimates and trends (1990–2000) for mega city Delhi and implication', *Atmospheric Environment*, Vol. 38, pp.5663–5681.

Hazra, T. and Goel, S. (2009) 'Solid waste management in Kolkata, India: practices and challenges', *Waste Management*, Vol. 29, No. 1, pp.470–478.

Intergovernmental Panel on Climate Change (IPCC) (1996) Report of the *Twelfth Session of the Intergovernmental Panel on Climate Change*, September 1996, Mexico City, pp.11–13 [online] http://digital.library.unit.edu/ark:/67531/metadc11898/m2/1/high_res_d/ twelfthsession-report.pdf (accessed 19 February 2011).

Intergovernmental Panel on Climate Change (IPCC) (2006) *IPCC Guidelines for National Greenhouse Gas Inventories* [online] http://www.ipcc.nggip.iges.or.jp/public/2006g/index. html (accessed 19 February 2011).

IS: 10158-1982 (reaffirmed 1995) 'Indian standard, methods of analysis of solid waste (excluding industrial solid wastes)', Indian Standard Institution, New Delhi.

IS: 9235-1979 (reaffirmed 1997) 'Indian standard, method for physical analysis and determination of moisture in solid wastes (excluding industrial solid wastes)', Indian Standard Institution, New Delhi.

Kumar, S., Gaikwad, S.A., Shekdar, A.V., Kshirsagar, P.S. and Singh, R.N. (2004) 'Estimation method for national methane emission from solid waste landfills', *Atmospheric Environment*, Vol. 38, No. 21, pp.3481–3487.

Matthews, E. (2000) 'Wetlands', in Khalil, M.A.K. (Ed.): *Atmospheric Methane*, pp.202–233, Springer, Berlin.

MoEF (2010) 'India: greenhouse gas emission, 2007', Ministry of Environment and Forest, Government of India, New Delhi [online] http://www.moef.nic.in/downloads/public- information/Report_INCCA.pdf (accessed 19 February 2011).

Mor, S., Ravindra, K., De Visscher, A., Dahiya, R.P. and Chandra, A. (2006) 'Municipal solid waste characterization and its assessment for potential methane generation: a case study', *Science of the Total Environment*, Vol. 371, Nos. 1–3, pp.1–10.

Mufeed, S., Ahmad, K., Mahmood, G. and Trivedi, R.C. (2008) 'Municipal solid waste management in Indian cities – a review', *Waste Management*, Vol. 28, No. 2, pp.459–467.

National Building Construction Corporation Limited (NBCCL) (2004) 'Scheme for solid waste management for Jodhpur, Ministry of Urban Development, Govt. of India'.

Oonk, H. and Boom, T. (2000) 'Landfill gas emission measurements using a mass-balance method' [online] http://www.1st.sb.ltu.se/iclrs/web/post2000/pap/emi/Oonk.pdf (accessed 19 February 2011).

Ray, M.R., Roychoudhury, S., Mukherjee, G., Roy, S. and Lahiri, T. (2005) 'Respiratory and general health impairments of workers employed in a MSW disposal at an open landfill site Delhi', *Int. J. Hyg. Environ-Health*, Vol. 208, No. 4, pp.255–262.

Sharma, C., Dasgupta, A. and Mitra, A.P. (2002) 'Inventory of greenhouse gases and other urban pollutants from agriculture and waste sectors in Delhi and Calcutta', *Proceedings of IGES/APN Mega-city Project*, 23–25 January 2002, Rihga Royal Hotel Kokura, Kitakyushu, Japan [online] http://www.iges.or.jp/en/ue/pdf/megacity02/data/PDF/03-04/mitra.G(Agriculture).pdf (accessed 19 February 2011).

Sharma, S., Bhattacharya, S. and Garg, A. (2006) 'Greenhouse gas emission from India: a perspective', Ministry of Environment and Forest, Government of India, New Delhi, India [online] http://www.ias.ac.in/currsci/feb102006/326:pdf (accessed 19 February 2011).

Spokes, K., Bogner, J., Chanton, J.P., Morcet, M., Aran, C., Graff, C., Moreau-Le Golvan, Y. and Hebe, I. (2005) 'Methane mass balance at three landfill sites: what is the efficiency of capture by gas collection systems?' [online] http://www.landfillplus.com/pdf/article.pdf (accessed 19 February 2011).

United States Environmental Protection Agency (US-EPA) (1998) *Users Manual Landfill Gas Emission Model*, Version 2.0, Control Technology Center, Office of Research and Development, Washington, DC [online] http://www.bvsda.paho.org/bvsacd/cd25/ landfill.pdf (accessed 19 February 2011).