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Estimation of Biogas Generation by the Use of First-order Kinetic Models for a Landfill Site in Karaj, Iran

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Abstract:
The first-degree models are widely used to estimate the gas production rate in landfills. In this article, by the use oftwo first-degree models of LandGEM and Afvalzorg, the biogas production rate in the Halgheh-Darrehlandfill site, Karaj, Iran, was estimated. According to an annual rainfall of 247 mm in this landfill and waste composition, the first-order rate constant (k) value was calculated for the Land GEM model as 0.025 yr^-1. The theoretical and practical potential values were obtained as 37.30 m3/Mg and 61.65 m3/Mg, respectively. The corresponding amounts of biogas produced by the LandGem model are respectively as 901.82 m^3hr^-1 and 1426.94 m^3hr^-1. By Afvalzorg model, the amount of biogas produced in this landfill has been estimated maximally and minimally as 5200 and 4000m^3.hr^-1, respectively.

Keywords: *Landfill, Biogas, Modeling, Land Gem, Afvalzorg*

1. Introduction

Landfill sites are one of the most important anthropogenic sources of methane (CH_4) emission, which has a global warming potential 28 times that of carbon dioxide (CO_2) [1]. In a municipal solid waste (MSW) landfill, during a bio-chemical conversion process, called decomposition or bio-degradation, a gaseous product is generated that is also called landfill gas (LFG). The process consists of five continuous stages including both, aerobic and anaerobic conditions. The initial aerobic stage is of short duration as it occurs right after waste disposal due to entrapped atmospheric oxygen. In the stage, the generated gas consists primarily of carbon dioxide (CO_2). Whereas, in the following stages, where the initially available oxygen has been exhausted, anaerobic conditions dominate generating a gas with typically 40–60 % methane and 35–50 % carbon dioxide with trace concentrations of other gases [2].Various numerical and mathematical tools have been developed to estimate landfill gas (LFG) generation or (municipal solid waste) MSW degradation based on statistical models or simulation of biochemical reaction processes. Currently, simplified approaches based on first-order decay (FOD) of organic waste are widely used for research and industrial purposes [3].And are officially regulated as the methodology for LFG emission estimation [4-5]. A first-order decay equation generally depends on two critical factors in the model: the first-order decay constant (k value) and the ultimate methane generation potential (L_0) [6]. The methane generation potential (L0) of a landfill depends on waste composition and its degradable organic content, while the rate of waste degradation (k) depends on waste composition, waste particle size, moisture, ambient temperature, and pH [7-8]. The E-PRTR (Fr) and LandGEM models are single-phase models, which do not distinguish between various waste categories. The other three are multi-phase models. The IPCC and GasSim models divide MSW into fractions. The Afvalzorg model, which was developed by a Dutch waste management company, holds datasets for different low-organic waste categories such as mixed bulky waste (unrecyclable and incombustible), construction and demolition (C&D) waste, soil (contaminated with oil and other residues), shredder (shredded pieces of end-of-life vehicles or machines) waste, street cleansing (residues from street cleansing) waste, and refuse derived fuel (RDF) [9]. In this paper, with the help of LandGEM and Afvalzorg models, the biogas production rate in the Halgheh-Darreh landfill site, Iran, was estimated. In the following, a brief description on these models is provided.

2. Landfill Gas Models

2.1. Landgem Model

This model, which is a software under Microsoft Excel, is a step by step guide for modeling gas emissions from landfill capable of estimating the rates of air pollutants and other gas emissions from urban solid waste released in the landfills. The amount of methane produced is calculated by using the methane production capacity and the mass of buried waste. LandGEM model is expressed as mathematical equation [10] (1):

$$Q_{CH_4} = \sum_{i=1}^{n} kL_0M_i(e^{-kt}) \qquad (1)$$

Q_{CH_4} = methane emission rate$[m^3CH_4.y^{-1}]$
k = methane production constant $[y^{-1}]$
L=methane production potential $[m^3CH_4.Mgwaste^{-1}]$
M = waste residual mass in the ithsection [Mg]

2.1.1. Methane Production Constant (k)

In evaluating many of the model parameters, a great attention is paid to the biodegradation fixed rate (k). Change in value of k is only due to the time change. By this coefficient, the rate of methane production is calculated for the amount of waste in the landfill. High values of k increase the speed of methane production rate. This coefficient is primarily a function of the following four factors [11]:

- The volume of water contained in the waste pile
- The ability of microorganisms to break down the waste structure to methane and carbon dioxide forms
- PH of the waste mass
- Temperature

In Table 1, k values for different areas are given according to annual rainfall rates and degradation rate of waste.

Annual rainfall	**k value (yr^{-1})**		
	Slow degradable	Moderate degradable	Fast degradable
lower than 250 mm	0.01	0.02	0.03
250-500 mm	0.01	0.03	0.05
500-1000 mm	0.02	0.05	0.08
Upper than 1000 mm	0.02	0.06	0.09

Table 1: Different values of k due to the rainfall rates and degradation rates [12]

2.1.2. Methane Production Potential Capacity (L_0)

L_0 is the amount of methane gas that the waste will produce in their lifetime. In most models of methane production, L_0 is one of the important parameters. As mentioned, landfill gas and methane are produced by decomposition of organic components of the waste. In general, L_0 expresses the total amount of methane that can be produced from the waste pile, which primarily depends on the composition of the waste. L0 for urban waste is calculated by the laboratory, and the methane yield rate will be estimated due to the combination of solid waste at the beginning for the studied landfill. In fact, the potential of methane generation capacity only depends on the type and composition of waste in the landfill [11]. Practical potential of biogas is calculated as follows [14]:

$$L_0 = P_{bio} \times (1 - MC) \times Y_{LFG} \times P_{CH_4} \qquad (2)$$

L_0: Methane production potential
Y_{LFG}: Biogas efficiency
P_{bio}: Percentage of putrescible materials
$P_{CH4:}$ Percentage of methane
In this formula, MC and Y_{LFG} were obtained according to the laboratory samples.
Y_{LFG}: Biogas yield

$$Y_{LFG} = \frac{V_g}{m_{TS}} \qquad (3)$$

Vg = Volume of gas that emerges from the dry mass unit of organic matter
m_{TS} = Mass of dry material entering the batch reactor, which is calculated based on the following equation [14]:

$$m_{TS} = m_f(1 - MC) = m_f \times TS\% \qquad (4)$$

m_f: Total mass of waste entering the reactor
The theoretical methane potential is calculated by the following formula [14]:

$$L_0 = \%CH_4 \times Y_{LFG} \times [m_{bio}(1 - MC_{bio}) + m_{paper}(1 - MC_{paper})] \ (5)$$

Where is the theoretical yield of LFG that is calculated from the following equation [14]:

$$Y_{LFG} = 1.867\sum_{i=1}^{n} OC_i\,(fb)_i\,(1 - MC_i)\,p_i \quad (6)$$

Y_{LFG}= Theory potential of biogas production from the wet mass unit in terms of m3/kgMSW

MC_i = Moisture content of the component i in terms of kg/kg
p_i= weight ratio of the component i in the total waste in terms of kg/kgMSW

2.2. Afvalzorg Multiphase Model
In this model, there are various types of waste, containing different fractions of organic material, which decompose at different rates. The advantage of a multi-phase model is its ability to identify the combination of different types of waste. In the Afvalzorgmulti-phase model, eight categories of waste and three fractions of organic matter are distinguished from one another. For each fraction of organic materials, the LFG production rate is calculated separately. The multi-phase model is a first-degree model described as the below mathematical equation:

$$\alpha_t = \varsigma \sum_{i=1}^{3} cAC_{0,i} k_{1,i} e^{-k_{1,i} t}$$

Parameters of α_t ،ζ ،$\boldsymbol{c}$ ،A ،$AC_{0,i}$ ،$K_{1,i}$ and t are the landfill gas production rate at a given time in terms of$[m^3 LFG. y^{-1}]$, dissimilar factor, conversion factor in terms of $[m^3 LFG. KgOM_{degraded}^{-1}]$, the amount of waste buried in [Mg], the amount of organic matter in waste in terms of $[KgOM. Mgwaste^{-1}]$, the constant of rate of decomposition in component i in terms of $[\boldsymbol{y^{-1}}]$ and the time passed from the burial in terms of year respectively.

3. Methodology
For calculating the k value for Halgheh-Darreh landfill site, due to the average annual precipitation in the Halgheh-Darreh landfill and the average composition of waste in the landfill, the amount of k (yr-1) was calculated. According to the Meteorological Agency reports of Alborz province, the average of annual rainfall in the province has been reported as 247.3 mm.The following Table 2 shows the average composition of waste in the Halgheh Darreh landfill.

Category	Average composition (%)
Food waste	72.08
Plastic	8.74
Glass	2.35
Textiles	3.3
Wood	0.95
C&D	0.69
Tires	0.79
Paper	8.11
Pet	0.58
Metals	1.33
Bread	1.08
Total	100

Table 2: Average composition of accepted MSW in the Halgheh-Darreh landfill site

Therefore, due to degradation and separation of waste in this landfill and the annual rainfall in the site, the value of k= 0.025 yr-1 has been estimated for the landfill. Laboratory samples were used to calculate L0. Based on the methodology, the moisture content tests were first done inside the oven at 75 ° C for 24 hours. The tests of TS (Total solid), VS (volatile solid) and analysis of the ash (Ash content) were performed at 550 ° C for 2 hours in a furnace. The 25-gram samples of food waste and vegetable waste were randomly placed in Batch small reactors, and the gas production trend was measured over time. The combinations of biogas produced were obtained with the help of portable analyzer MRU optima7 biogas device, and according to the amount of biogas produced, the L0 value was calculated that the results are given in Table 3.

Sample	MC% (moisture)	TS%	VS%	Biogas yield (m^3/kg)
1	83.33	16.66	85.48	522.57
2	82.004	17.99	82.39	533.52
3	82.35	17.64	88.56	530.8
4	86.59	13.40	81.50	486.54
5	77.51	22.48	96.61	546.59
Average	82.36	17.63	86.91	524
Standard deviation	±3.25	±3.25	±37.45	±22.64

Table 3: Results of laboratory analyses

According to the formulas (2) and (5), the amounts of theoretical and practical L0 were obtained:

With regard to 56% methane respectively as 61.65 m3/Mg and 37.30 m3/Mg. Due to the values obtained for k and L0 and the amount of waste buried in the 14 years (2003-2016) at the Halgheh-Darreh landfill, the rate of biogas produced at the landfill was estimated. The modeling results are presented in Figures 1 and 2.

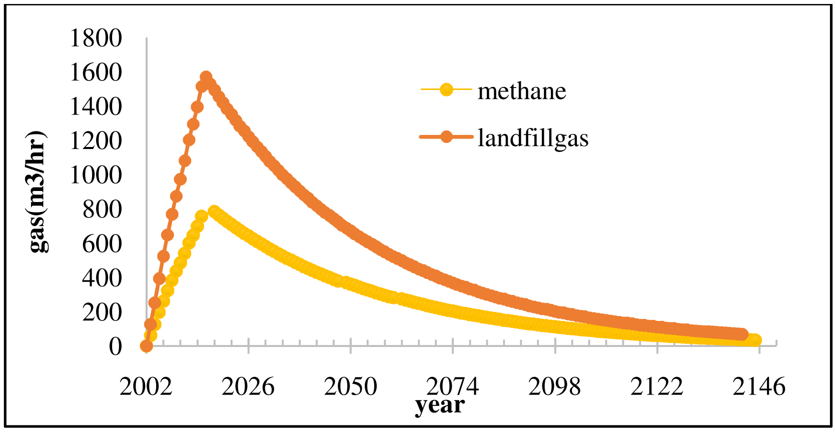

Figure 1: The modeling results with theoretical potential

According to the graph, it is clear that the greatest amount of biogas production in view of the potential theory as 12.4 million cubic meters per year has occurred in 2022.

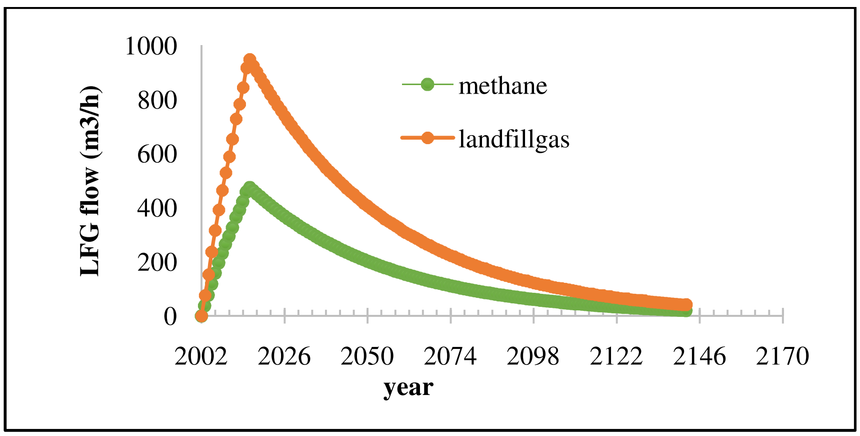

Figure 2: Results of modeling with practical potential

Given the practical potential, the value of biogas production produced in 2020 was as 9.7 million cubic meters.
In modeling with Afvalzorg model, only food, paper and cardboard wastes have been considered in the separation of waste. The AC0 and k values are calculated in Table 4.
The values of C and ζ are listed in Table 5. As we see in Tables 4 and 5, the multiphase model parameters for Halgheh-Darreh landfill have two minimum and maximum values. Thus, upper and lower limit values were obtained for the produced gas.

Category	paper	Food waste
Wet weight %	8.11	72.08
Moisture%	50	75
Dry weight (per ton)%	40.55	180.2
OC%	80	90
(AC_0)	32.44	162.18
k_{min}	0.099	0.187
k_{Max}	0.116	0.231

Table 4: parameter of Afvalzorg's equation

Parameter	$^{\zeta}$min	$^{\zeta}$max	^{c}min	^{c}max
Value	0.7	0.8	0.7	0.74

Table 5: parameter of Afvalzorg's equation

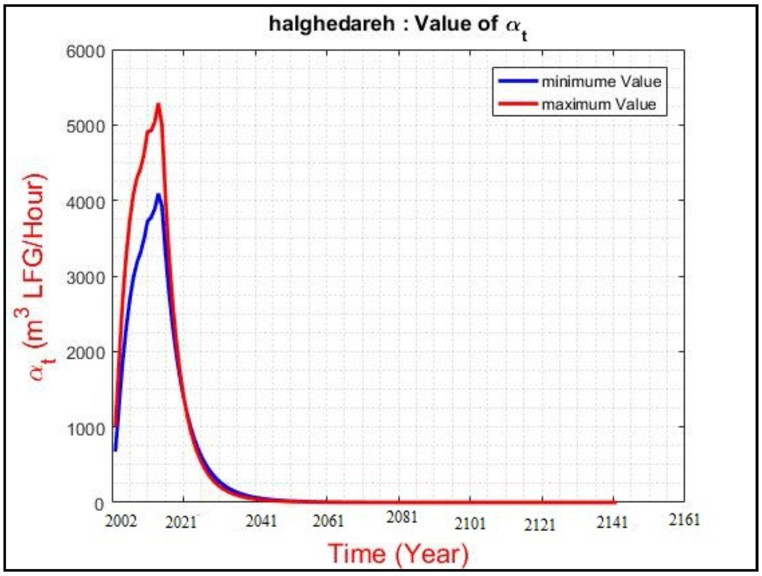

Figure 3: Results graph of modeling with Afvalzorg

According to the chart, the maximum amount of biogas accounts for 5,200 cubic meters of per hour and the minimum amount is estimated by Afvalzorg model as 4000 cubic meters per hour.

4. Results & Discussion

In comparison, values of L_0 reported in the open literature are in the range of 6–270 m^3 Mg^{-1}. Results froma study oftropical landfills by Machado et al. (2009) specified a L0 of70 m^3 Mg^{-1} based on both laboratory and on-site measurements.Bentley et al. (2005) calculated L0 for seven case-study landfills and reported values between 102 and 115 m^3 Mg^{-1}. Budkaet al. (2007) also reported methane generation potential average value of 30 for readily biodegradable waste, 84 for moderatelydegradable and 42 for slowly biodegradable waste. Studies have also reported an inverse relationship between L_0 and k (Budka et al., 2007; Huitricand Rosales, 2005). L_0 determined for case-study landfills herein are generally within ranges reported in the literature. Modeled k values ranged from 0.04 to 0.09 yr^{-1}. Literature reported values for landfills are quite variable: 0.2 yr^{-1} for higher fractions of readily biodegradable waste and higher moisture content values; about 0.02 yr^{-1} for slowly biodegradable waste and lower moisture content values (Machado et al., 2009), 0.023–0.056 yr^{-1} for 35 Canadian landfills (Thompson et al., 2009), 0.014 0.28 yr^{-1} for landfills in South America (Willumsen andTerraza, 2007), 0.04–0.5 yr^{-1} for four French landfills (Ogor andGuerbois, 2005), and 0.07–0.36 yr^{-1} for an Italian landfill (Cortiet al., 2007). Case-study landfills were assumed to have moderateto high range of moisture

During this study, theoretical and practical values of L0were respectively obtained as 61.65 m3/Mg and 37.30 m3/Mg. Due to the obtained values, the theory potential is more than practical potential because of in calculations the theory potentialof thewastes with slow degradation such as paper is considered. The L_0 calculated for the studied landfill is also within the range reported in the literature. The modeled K values are as $0.025yr^{-1}$. The values presented in the literature for the landfills werehighly variable. The k values within the values reported for landfills are similar to those in the articles. The amount of biogas produced through LandGEM model by theoretical and practical potentials were estimated as 1426.94 m^3hr^{-1} and 901.82 m^3hr^{-1}, respectively. By Afvalzorg model, the highest and lowest values were estimated as 5200 $m^3hr^{-1}$and 4000 m^3hr^{-1}, respectively.

5. Conclusions

The LFG generation rate for the MSW landfilling site of Karaj city were simulated by two kinetic first-order models using the MSW composition and ambient data. The results suggested that the LFG flow rates predicted by LandGem model by the mean of practical values of methane potential, are closer to realistic situation while Afvalzorg model estimated significantly higher amounts of gas flow rate that are hardly achievable under the practical conditions at Halgheh-Darreh landfill site.

6. References

i. IPCC. (2013). Stocker, T.F., Qin, D.H., Plattner, G. K., Tignor, M.M.B., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M., (2013). The Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
ii. Bove R, Lunghi P. (2006). Electric power generation from landfill gas using traditional and innovative technologies, Energ Convers Manage.
iii. Oonk, H., (2010). Literature review: methane from landfills. Sustainable Landfill Foundation. Rhew, R., Barlaz, M.A., 1995. The effect of lime stabilized sludge as a cover material on anaerobic refuse decomposition. J. Environ. Eng. 121, 499–506.

iv. CEC (Council of the European Communities). (2006). Regulation of the European Parliament and of the Council of 18 January 2006 concerning the establishment of a European Pollutant Release and Transfer Register and amending Council Directives 91/689/EEC and 96/61/EC, February 2006, Brussels, Belgium.

v. IPCC (Intergovernmental Panel on Climate Change), (2006). IPCC guidelines for national greenhouse gas inventories, Hayama, Japan.

vi. Amini,H .R,Rienhart, D.R, Mackie. (2012).Determination of first-order landfiil gas modeling parameters and uncertainties .Waste Management.

vii. Barltaz, M.A., Ham R.K, Schaefer, D.M., Isaacoson,R (1990). Methane production from municipal refuse: a review of enhancement techniques and microbial dynamics. Crit Rev .Environ .Sci Technol.

viii. Machado, S.l., Carvalho MF., Gour, J.P., Vilar,O.M., Do Nascimento,J.C,F (2009). Methane generation in tropical landfills: simplified methods and field results. Waste Mange.

ix. Zishen, Moue. Charlott, Scheutz. Peter, Kjeldsen. (2014). Evaluating the methane generation rate constant (k value) of low-organic waste at Danish landfills.Waste Management.

x. US-EPA, (2001). Landfill Volume III. Available from :<http://www.epa.gov/ttn/chief/eiip/techreport/volume03/iii15_apr2001.pdf>, USA

xi. EPA, (2012). Quantifying methane abatement efficiency at three municipal solid waste landfills, http://www.epa.gov/nrmrl/pubs/600r12003.html

xii. http://www.worldbank.org/404_response.htm

xiii. Afvalzorg, (2014). MS Excel sheet of the multi-phase landfill gas generation and emission model, version April 2014. NV Afvalzorg Holding. http://afvalzorg.nl/EN/Landfill-sites/Emissions-management/Methan emissions/Download_MLGGR_Model.aspx

xiv. George Tchobanoglous, (1993) ,Integrated Solid Waste Management: Engineering Principles. McGraw-Hill Publication Co., USA

xv. US EPA, 2008. Background Information Document for Updating AP42 Section 2.4 for Estimating Emissions from Municipal Solid Waste Landfills. EPA/600/R-08-116.

xvi. Bentley, H.W., Smith, S.J., Schrauf, T., (2005). Bar pneumatic estimation of landfill gas generation rates at four operating landfills. In: Proceedings of SWANA's 10th Annual Landfill Gas Symposium and Solid Waste Management, Boulder, CO.

xvii. Thompson, S., Sawyer, J., Bonam, R., Valdivia, J.E., (2009). Building a better methane generation model: validating models with methane recovery rates from 35 Canadian landfills. Waste Management.

xviii. Willumsen, H., Terraza, H., (2007). CDM landfill gas projects. World Bank Report, World Bank Workshop, Washington, DC.

xix. Ogor, Y., Guerbois, M., (2005). Comparison of landfill methane emission models: a case study. In: Tenth International Waste Management and Landfill Symposium, Sardinia, Italy.

xx. Corti A., Lombardi, L., Frassinetti, L., (2007). Landfill gas energy recovery: economic and environmental evaluation for a case study. In: Eleventh International Waste Management and Landfill Symposium, Sardinia, Italy.