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Estimation of Methane Production by LANDGEM Simulation Model from Tanjung Langsat Municipal Solid Waste Landfill, Malaysia

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ABSTRACT

Huge quantity of methane gas is emitted from no-regulated municipal solid waste landfill to the atmosphere. Many researches have been done with the purpose to estimate the quantity of generated methane gas, capture, utilize and to use of this energy source to produce electricity or heat, since then many models have been developed to calculate landfill gas generation. In this paper the improved version, LandGem 3.02, is presented to estimate emission rate for the total landfill gas, methane, carbon dioxide from Tanjulangsat, municipal solid waste landfill, Malaysia. This landfill start operation at 2002 and it is expected to have lifespan of 20 years but due to industrialization and urbanization is predicted the landfill will reach its maximum capacity at the end of 2012. LandGem determines the mass of methane generated by using the methane generation capacity, the mass of deposited waste, deposited methane generation potential and methane generation rate. Obtained result shows the rate of methane generation from solid waste by $4.436E^{+02}$ (Mg/year) in 2003, first year after waste acceptance by landfill while the maximum methane generation rate occurred during the years 2012-2015 where indicate as the peck of generation by approximately $4.17\ E^{+03}$ (Mg/year). On the basis of the theoretical information calculated by LandGem, it can be assumed that, volume of generated methane from solid waste within years of residence time in a landfill is sufficient enough to be considered for install the methane capturing facilities.

Keywords: *Municipal solid waste, Methane generation, LandGem simulation model*

1. INTRODUCTION

Landfill gas is produced continuously by microbial action on biodegradable wastes under anaerobic conditions (Couth R, 2011). Methane and carbon dioxide are the major constituents of landfill gas and greatly contribute to the greenhouse effect (Rodica C, 2007). Although in the most cases the waste will be covered by 10 to 15 cm of the soil cover to reduce the gas and odor diffusion, the small amount of these gases continues to emit into the atmosphere. Gas emission caused by disposed municipal solid waste (MSW) at open landfill sites are difficult to estimate and analysis.

Measurements the emission rate of GHGs from landfill is essential to reduce uncertainties in the inventory estimates from this source. For example, Methane emission from disposal site considered as a chemical feedback effect to environment by significant green house gas which is necessary to control. Increasing the concentration of methane has reducing the concentration of hydroxyl radical (OH) and increase the methane lifetime and the tropospheric ozone (Gardner, 1993). Decomposition of municipal solid waste buried at disposal sites during the years recognized by many studies as a one of the main causes which increase the methane emission to atmosphere. Past estimation of methane emission caused by MSW have varied greatly between 20 and 70 Tg per year (lay, 1998). Problems associated with decomposition of MSW and methane oxidation are the products and by products of these reactions which is mainly volatile organic compounds.

Capturing the generated methane from MSW landfill has been targeted in many developing countries as feasible method to reduce the green house gas emissions (GHGs) and to recovery the energy instead. In case of low volume methane production ratio, methane can be extracted and flared or oxidizes in biofilter while in high level methane content this gas becomes an valuable energy source and it is then able to sustain the fuelling of engines, producing electricity (primary fuel to increase the production of electricity power), thermal energy, vehicle fuel, pipeline quality gas and various industrial process (Tsatsarelis, 2009). Methane production in landfill typically begin 6 to 12 months after the waste placement then raise to a maximum shortly after landfill closure and finally gradually decline over the period of 30 -50 years (Falzon ,1997).

There have been many studies to estimate and capture the amount of gas produced from municipal solid waste disposal sites, since then many models have been developed to calculate landfill gas generation, oxidation and emissions but unfortunately the use of simulation software as a tool for the design, operation and monitoring is not as widespread in the field of municipal solid waste landfills as in other fields of environmental engineering. In the case of landfill process modeling, the significance of local factors such as the waste composition, disposal method and protection systems against potential impacts, makes the development of models applicable to different landfill facilities (Adrian, 2008). Their calibration is based on data observed in a specific landfill or similar facilities, which does not give rise to actual prediction tools. Nonetheless, these models are still used for approximate estimations when more refined tools are not available. Several authors have reported modeling approaches that focus on the biological and/or chemical degradation of waste that generates gas pollutants. Among these integrated models, LandGem modeling software developed for the environmental assessment of municipal solid waste landfills. LandGem estimates the volume and composition of the generated gas throughout time as a consequence of the degradation of organic matter in the landfill (EPA, 2005). The objective of this paper is to describe the LandGem model that has been prepared for gas emission in Tanjulangsat, municipal solid waste landfill, Malaysia, together with the estimation results of methane and carbon dioxide generation based on input data. The paper also provides background information of total quantity of collected municipal solid waste which annually sent for disposed at this land fill site.

2. MATERIALS AND METHODS

Models for predicting the generated gas from MSW disposal sites first appeared in 1970. Some of the works such as zero-and first order kinetic models carried out by (Pacey and Augenstein 1990), multi-phase model developed by the Norwegian Pollution Control Authority (Statens forurensningstilsyn, SFT) to calculate the methane emission from MSW disposal site, integrated waste management model (IWM) for municipalities produced by corporations supporting recycling (CSR) and the environment and plastics industry council (EPIC) which offered through the University of Waterloo (EPIC and CSR, 2004), multi-phase first order decay (FOD) model to quantify GHG emissions from solid waste disposal system (SWDS), A FOD model is used to describe nonlinear microbial kinetics which calculates GHG emissions from municipal solid waste (MSW) disposal sites for the urban population in Africa and evaluates how these may increase over the next 10 years (Couth R, 2011), UK Environment Agency (EA) GasSim model (Gregory and Rosevear, 2005) which used to estimate the Monte Carlo landfill gas simulation (GasSim) and developed for the UK EA as a risk assessment tool to be used to evaluate the impacts of landfill gas emissions and LandGem modeling software offered by US Environmental Protection Agency (EPA, 2005) which is designed to calculate the emission from solid waste based on US EPA standard are the examples of previously work by different authors.

2.1. Selected Data

LandGem is an automated tool for estimating emission rates for total landfill gas, methane, carbon dioxide and can be used either with site-specific data to estimate emissions or default parameters if no site-specific data are available. LandGem contains two sets of default parameters. The CAA defaults are based on requirements for MSW landfills laid out by the Clean Air Act (CAA), including the inventory defaults based on emission factors in the U.S. Environmental Protection Agency's (EPA's) Compilation of Air Pollutant Emission Factors (AP-42). This set of defaults yields average emissions can be used to generate emission estimates for use in emission inventories and air permits in the absence of site-specific test data. LandGem is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in MSW landfills and to estimate annual emissions over a time period base on user specification. The equation which is carried out is as follows (EPA, 2005):

$$Q_{CH_4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_o \left(\frac{M_i}{10} \right) e^{-kt_{ij}}$$

Where:
Q_{CH4} = annual methane generation in the year of the calculation (m^3/year)
i = 1 year time increment
n = (year of the calculation) - (initial year of waste acceptance)
j = 0.1 year time increment
k = methane generation rate ($year^{-1}$)
L_o = potential methane generation capacity (m^3/Mg)
M_i = mass of waste accepted in the i^{th} year (Mg)
t_{ij} = age of the j^{th} section of waste mass M_i accepted in the i^{th} year (decimal years, e.g.,3.2 years)

The models outputs are in form of excel spread sheets and include a summary of input data which includes the landfill closure year, waste design capacity, methane content, landfill open year. The outputs tables and figures also break down the emission of GHGs and criteria pollutant and present the results in the term of megagrams and cubic meter per year. In order to model the methane emission from the solid waste sector using LandGem, a set of inputs is required, these include:

- Enter waste acceptance rate (how much waste is generated and sent for land filling during the previously years, mass of waste acceptance)
- Default pollutant concentrations used by LandGem which should been corrected for air infiltration.
- Methane generation capacity rate and the potential of generation capacity
- Model parameter (user specified pollutant parameters for selected compounds)

For the implementation of the model, 2002 was chosen as a start day for disposition of MSW at Tanjulangsat disposal site due to the fact, by end of 2012 this landfill have to be close and caped since it will be reached to maximum capacity, although 2012 was chosen as a working assumption for the last year but landfill gases will clearly continue to be produced for long time after then. Recorded data about the quantity of generated waste related to possibility of methane generation were collected from Majlis Perbandaran Pasir Gudang (MPPG) or Pasir Gudang Municipal Council. Table 1 shows the available monthly quantity of collected waste from domestic and industrial sections which are dumped in Tanjulangsat landfill site.

Table 1: Available Data of the Quantity of Collected Waste from Domestic and Industrial Sections Per Month

Month	2007		2008		2009		2010	
	Domestic	Industrial	Domestic	Industrial	Domestic	Industrial	Domestic	Industrial
	Ton	Ton	Ton	Ton	Ton	Ton	Ton	Ton
Jan	2,307.35	5,818.34	2,550.00	9,485.95	2,320.00	6,581.04	2,530.00	6,539.06
Feb	2,281.03	5,534.93	2,386.00	7,931.04	2,432.00	7,131.04	2,510.00	6,139.14
March	2,298.00	5,766.40	2,250.00	6,950.85	2,210.00	5,657.51	2,687.00	7,514.81
April	2,301.00	5,885.83	2,340.00	5,894.76	2,261.00	6,021.77	2,651.00	7,418.58
May	2,271.00	5,465.02	2,145.00	7,011.28	2,320.00	6,739.19	2,572.00	7,190.02
Jun	2,275.00	5,478.87	2,280.00	7,458.52	2,265.00	6,201.21	2,500.00	6,739.19
July	2,295.00	5,800.32	2,350.00	7,713.40	2,430.00	6,924.11	2,512.00	6,804.89
Aug	2,280.00	5,531.70	2,200.00	6,626.82	2,210.00	5,916.72	2,487.00	6,375.47
Sep	2,290.00	7,118.85	2,115.00	5,998.40	2,118.00	5,135.07	2,232.00	5,836.95
Oct	2,290.00	8,081.82	2,185.00	6,003.56	2,540.00	7,183.97	2,533.00	6,779.08
Nov	2,150.00	7,035.06	2,240.00	6,881.57	2,487.00	6,725.24	7,150.00	7,046.37
Dec	2,500.00	9,404.51	2,265.00	5,586.65	2,531.00	8,272.51	2,730.00	8,058.86
Total	27,538.38	76,921.65	27,306.00	83,542.80	28,124.00	78,669.78	35,094.00	82,432.42

Result of the solid waste collected from residual and industrial around Tanjulangsat landfill reveals that the rate of the waste generation various in the different type of wards. The trend is gradually increasing with the increase of the socio economic level and population. The annual domestic waste generation during 2007 was estimated 27,538.38 tons which increase to 35,094.00 by the year of 2010.

The relation between waste generation and economic growth level can be discussed by increasing the quantity of generated industrial waste in 2007 with 76,921.65 to 82,432.42 in 2010. This trend is essentially due to increasing the number of factories and industrial section in this area. The estimation of the methane generation from landfill has been continually investigated by apply the annual quantity of dumped waste and the number of empirical constant like methane correction factor, methane generation rate, methane generation capacity in the LandGem Microsoft Excel spreadsheets.

Tanjulangsat MSW composition shows a higher content of organic matter (fruit, yard, Wood, Paper, cardboard and food waste) by the weight, 59 % (Table 2). The majority of GHG emissions from waste management activities are from disposal and anaerobic biodegradation of organic waste in landfills. Shortly after solid waste is land filled, the organic compounds start to undergo biochemical reactions.

In the presence of atmospheric air, which is near the surface of the landfill, the natural organic compounds are oxidized aerobically

The principal bioreaction in landfills is anaerobic digestion that takes place in three stages (Nickolas, 2007):

1. Fermentative bacteria hydrolyze the complex organic matter into soluble molecules.
2. Molecules are converted by acid forming bacteria to simple organic acids, carbon dioxide and hydrogen.
3. Methane is formed by methanogenic bacteria, either by breaking down the acids to methane and carbon dioxide, or by reducing carbon dioxide with hydrogen.

Table 2: Characterization of Tanjulangsat MSW (Amin Kalantarifard et al, 2011)

Biomass components	(%)	Petrochemical components	(%)
Paper/cardboard	12.9	Plastics	18
Wood	1.4	Rubber / leather	2.4
Yard waste	3.6	Textile	6.4
Food waste	30.6		
Fruit waste	10.5		
Total Biomass	59 %	Total man-made	26.8 %

3. RESULTS AND DISCUSSION

LandGem determines the mass of methane generated by using the methane generation capacity and the mass of waste deposited. LandGem recommends subtracting inert materials such as methane generation constant and potential for both CAA (Clean Air Act) and AP42 (USEPA, 1998) standards.

CAA default values have a high methane generation potential (L_0) of 170 m^3CH_4 Mg waste^{-1}, methane generation rate (K) of 0.05 and methane content 50% by volume. Table 3 shows the description of the provided supplementary data. After a model run with LandGem, the methane emission will be determined.

Table 3: Description of the Supplementary Input Data to Run the LandGem

Input Review			
Landfill Characteristics		**Model Parameters**	
Landfill open- closure year	2002-2020	Methane generation rate	0.05 Year^{-1}
Gas pollutant selected	(MW)	Potential methane generation capacity	170 m^3/Mg
Methane	16.04	NMOC concentration	ppmv
Carbon dioxide	44.01	Methane content	50% by volume

MW: Molecular weight for selected gases, Model parameters base on Clean Air (CAA) Regulations.

The Result from quantity of disposed solid waste at Tanjulangsat during the 10 years of landfill open years is shows in Table 4. The amount of disposed waste generated by municipal and industrial was approximately estimated 80.000 megagrams during 2002 to 2005 which increase to 100.000 in 2006 to 2012. According to Table 4 total quantity of disposed material 1,012.000 short tons estimated at this landfill by the year of 2012. This indicates the rapid increase in municipal and industrial waste generation in this area outpacing the population growth and increasing the industrial sections. Methane emission estimates based on LandGem is empirical method in nature which vary according to the composition of waste and management of the landfill were considered while developing this methodology. Moreover, the LandGem method assumption that total CH_4 is released in start year of MSW dumped. CH_4 emission was calculated using LandGem and distributed the total amount of estimated CH_4 emission over 50 years considering 4th year as peak emission year from 2012 to 2015. Figure 1 presents the results of the scenario calculations and also identifies dominant p rocesses contributing to total methane and carbon dioxide emissions from the Tanjulangsat landfill site during the years 2003 to 2092. The figures show a general decreasing trend in total gases emissions for each year. The difference in absolute values is significant when the highest amount of emission is between the years 2012- 2015 and calculated as an average 4.17E^{+03} megagrams and decrease to around zero in 2090 (Figure 1).

Table 4: The Amount of Disposed Waste Generated By Municipal and Industrial

Year	**Waste Accepted**		**Waste-In-Place**	
	(Mg/year)	**(short tons/year)**	**(Mg)**	**(short tons)**
2002	80,000	88,000	0	0
2003	80,000	88,000	80,000	88,000
2004	80,000	88,000	160,000	176,000
2005	80,000	88,000	240,000	264,000
2006	100,000	110,000	320,000	352,000
2007	100,000	110,000	420,000	462,000
2008	100,000	110,000	520,000	572,000
2009	100,000	110,000	620,000	682,000
2010	100,000	110,000	720,000	792,000
2011	100,000	110,000	820,000	902,000
2012	100,000	110,000	920,000	1,012,000

3.1. Methane production

The effect of the half-life duration of organic materials such as food waste, paper, wood and textiles to the overall methane production is related to the reaction rate (k) of the model through the equation k = $t1/2^{-1}$ln2. According to waste composition (Table 2) food waste contain approximately 30 % in waste stream to this landfill.

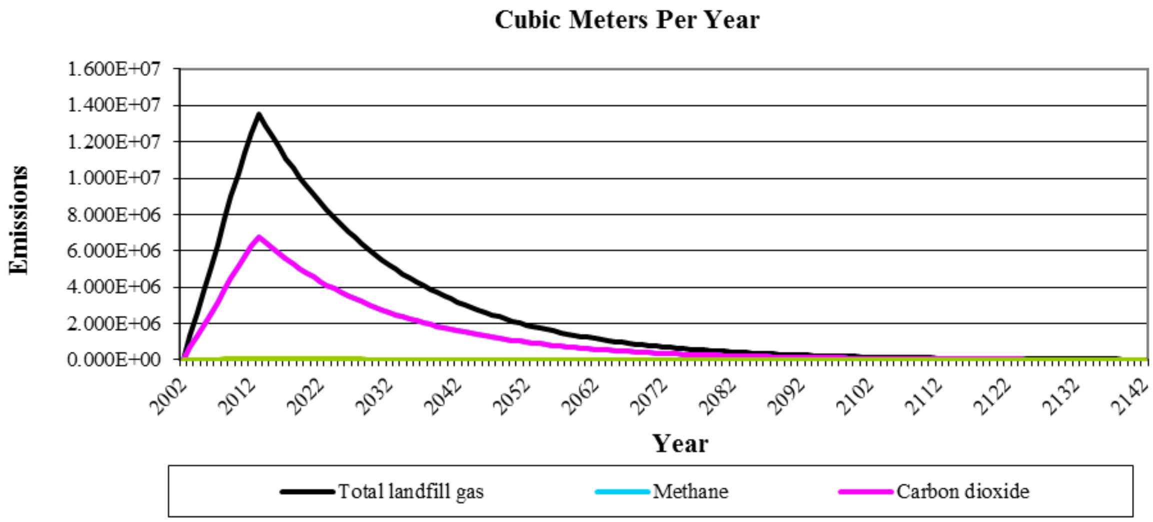

Figure 1: The amount of gas emission from Tanjulangsat landfill site from 2002 to 2082(Mg / year)

Previously research by Tsatsarelis in 2009 justified the fact that half lives of food waste are too short for their further partial differentiation to affect the estimation of methane production. Methane production for a half life of wood and textiles between 15 and 30 years appears almost identical, indicating that their variation does not affect it significantly as well, this can be expected since the amounts of wood and textiles are small in comparison to the other materials that are deposited in landfills, leading to proportionally small contribution to methane production. Paper identified as an important compound which effect the methane production. Paper with approximately 13% contributes the large quantity of disposed materials. Half life for paper estimated around 10 to 15 years which can be a reason of maximum generation of methane during the years 2012 to 2015.

Total amount of CH_4 has been estimated to be 4.436E^{+02} (Mg) in 2003 which reduce to 1.74^{E+03} in 2032 respectively. Table 5 shows the annually increasing the methane production from disposed waste at landfill. The model equation is prepared to estimate the methane emission from solid waste, but there are various factors that have positive or negative effect on the gases emission. Aerobic degradation of MSW in tropical country such as Malaysia may be higher due to higher temperature and moisture which has positive effect on methane production, weather condition such as the rate of rainfall is identified as the other important factor, significant amount of organic carbon washed out during rain and may get eliminated which caused to reduce the methane production. Fluctuation in amount of waste reaching to landfill site, increasing the organic carbon compounds such as paper and textile due to industrialization, oxidation rate of methane in upper layer of landfill and net emission to the atmosphere are all the other factors contributing to the uncertainties in GHG emission estimation from landfills.

Table 5: Annual Increasing the Methane Production from Disposed Waste at Landfill

Year	Total landfill gas *(Mg/year)*	Methane *(Mg/year)*	Carbon dioxide *(Mg/year)*
2002	0	0	0
2003	1.661E+03	4.436E+02	1.217E+03
2004	3.241E+03	8.656E+02	2.375E+03
2005	4.743E+03	1.267E+03	3.476E+03
2006	6.173E+03	1.649E+03	4.524E+03
2007	7.948E+03	2.123E+03	5.825E+03
2008	9.636E+03	2.574E+03	7.062E+03

2009	1.124E+04	3.003E+03	8.239E+03
2010	1.277E+04	3.411E+03	9.359E+03
2011	1.422E+04	3.799E+03	1.042E+04
2012	1.561E+04	4.168E+03	1.144E+04
2013	1.692E+04	4.520E+03	1.240E+04
2014	1.609E+04	4.299E+03	1.180E+04
2015	1.531E+04	4.089E+03	1.122E+04
2016	1.456E+04	3.890E+03	1.067E+04
2017	1.385E+04	3.700E+03	1.015E+04
2018	1.318E+04	3.520E+03	9.658E+03
2019	1.253E+04	3.348E+03	9.187E+03
2020	1.192E+04	3.185E+03	8.739E+03
2021	1.134E+04	3.030E+03	8.312E+03
2022	1.079E+04	2.882E+03	7.907E+03
2023	1.026E+04	2.741E+03	7.521E+03
2024	9.762E+03	2.608E+03	7.155E+03
2025	9.286E+03	2.480E+03	6.806E+03
2026	8.833E+03	2.359E+03	6.474E+03
2027	8.402E+03	2.244E+03	6.158E+03
2028	7.993E+03	2.135E+03	5.858E+03
2029	7.603E+03	2.031E+03	5.572E+03
2030	7.232E+03	1.932E+03	5.300E+03
2031	6.879E+03	1.838E+03	5.042E+03
2032	6.544E+03	1.748E+03	4.796E+03

4. CONCLUSION

The methane emission has been estimated by using LandGem model for Tanjulangsat Malaysia, solid waste disposal sites. This landfill starts operation at 2002 with the purpose to receive the generated solid waste at surrounded area until the year 2012. The amount of methane generation from solid waste calculated from $4.436E^{+02}$ (Mg/year) in 2003, first year after waste acceptance by landfill while the maximum methane generation rate occurred during the years 2012-2015 where indicate as the peck of generation by approximately $4.17E^{+03}$ (Mg/year). The intention of this paper is to demonstrate, On the basis of theoretical information presented above it can be assumed that the volume of generated methane from solid waste within one year of residence time in a landfill is sufficient enough to be considered for install the methane capturing facilities.

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