International Journal of Energy and Power Engineering
2020; 9(5): 81-85
http://www.sciencepublishinggroup.com/j/ijepe
doi: 10.11648/j.ijepe.20200905.12
ISSN: 2326-957X (Print); ISSN: 2326-960X (Online)

Methodology Article

Power Generation from Landfill Gas and a Case Study

Rajaram Swaminathan*, Israel Johannes

Department of Mechanical and Marine Engineering, Namibia University of Science and Technology, Windhoek, Namibia

Email address:
rswaminathan@nust.na (R. Swaminathan)
*Corresponding author

To cite this article:
Rajaram Swaminathan, Israel Johannes. Power Generation from Landfill Gas and a Case Study. *International Journal of Energy and Power Engineering*. Vol. 9, No. 5, 2020, pp. 81-85. doi: 10.11648/j.ijepe.20200905.12

Received: July 9, 2020; **Accepted**: November 9, 2020; **Published**: November 16, 2020

Abstract: Municipal solid waste is a pool of various solid wastes by towns and cities from different types of household activities. All over the world, municipal solid wastes are dumped in permitted landfills. Landfill gas is a mixture of methane and carbon dioxide which is emitted from the dumping sites of municipal wastes. Methane is a flammable toxic greenhouse gas more damaging to the climate than carbon dioxide. Instead of discharging into the atmosphere and becoming a greenhouse gas which is harmful to the environment, methane can be collected in every landfill and used to produce useful energy. This paper outlines the basic procedure for estimation of methane from landfill site. The Landfill Gas Emissions Model (Landgem) is an automated estimation tool with a Microsoft Excel interface which is available from the EPA's Clean Air Technology Center. It can be used to estimate emissions rate of methane from municipal solid waste landfills. Based on the methane emission rate obtained from Landgem output and the heating value of methane, the net heat input available and hence the potential for generation of electric power can be computed. A typical case study on the evaluation of methane emission rate from a landfill site at Namibia and its potential for generation of electric power as well as the cost estimates are presented. It is found that the power plant would be able to provide 142 streetlights in the city with electrical energy every day.

Keywords: Landfill, Methane Generation, Potential for Electric Power Generation, Power Generation Cost

1. Introduction

As the energy demand continues to increase all over the world, alternative energy sources are being explored to mitigate the ever-increasing energy demand. The use of fossil fuels is detrimental to the environment with the issues like global warming. Alternative energy sources need to be pursued [1, 2].

Municipal solid waste is a pool of various solid wastes by towns and cities from different types of household activities. All over the world, municipal solid wastes are dumped in permitted landfills. Landfill gas is a mixture of methane and carbon dioxide which is emitted from the dumping sites of municipal wastes. [3, 4].

Municipal Solid Wastes (MSW) dumped in landfills produce landfill gas (LFG) comprising methane and carbon dioxide as by-products of decomposition with the help of methanogenic bacteria under anaerobic decomposition. By volume, LFG typically contains 45% to 60% methane and 40% to 60% carbon dioxide. It also includes small amounts of nitrogen, oxygen, ammonia, sulfides, hydrogen, carbon monoxide, and nonmethane organic compounds.

Methane and carbon dioxide are greenhouse gases and the accumulation of these gases in the earth's atmosphere leads to heat being trapped and leading to global warming. The issue of global warming is devastating as it leads to climate change and climate variabilities in certain areas all over the world. It is therefore important to monitor the emission of these gases on landfills and use them to our own advantage.

2. Basic Process

MSW biodegradation is a microbial process which takes place in sequential phases referred to as hydrolysis, fermentation/acidogenesis, acetogenesis and methanogenesis. The first phase is the hydrolysis of polymers such as cellulose and fats to yield soluble sugars. The second phase transforms the products of the first phase into short chain volatile acids with the help of acidogenic bacteria. The last phase is where methane is generated by the conversion of hydrogen and acetic acid formed by acid formers with the help of methanogenic bacteria. Carbon dioxide is also produced in this phase as a by-product [5].

3. Estimation of Methane Generation from Landfill Gas

The Intergovernmental Panel (IPCC) on Climate Change Guideline for National GHG (greenhouse gas) Inventories gives guidelines and estimation for solid waste emissions. Two methods are outlined to estimate the emission of methane from landfills. These methods are known as the default method and the triangular method. The default method is based on the mass balance approach whereby a number of empirical constants like DOC (degradable organic carbon) and dissimilated organic fraction converted to LFG (landfill gas) have been considered in the development of the default empirical formula which estimates the emissions. In the triangular method, the first-order decay (FOD) method provides a time-dependent emission profile that reflects a true pattern of degradation process over time. The FOD method requires data from current status as well as historical waste quantities, composition and disposal practices for several decades [6].

The Landfill Gas Emissions Model (Landgem) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emissions rates for total landfill gas, methane, carbon dioxide, nonmethane organic compounds, and individual air pollutants from municipal solid waste landfills. It is available from the EPA's Clean Air Technology Center. Landgem uses the first-order decay rate equation to estimate the amount of methane and carbon dioxide from landfills. The program was developed by the US EPA (United States Environmental Protection Agency) to establish the requirements of installations and operations of gas collection and control systems at landfills [7]. The program is most widely used LFG model and it is of the industry standard for regulatory and non-regulatory applications in the United States [8].

There are only three variables in the first-order decay rate equation that requires the user input when using Landgem (M_i, k and L_0). The 'user input' tab of the program allow users to determine the required values for the landfill in order for the program to model the emissions.

M_i Mass of waste accepted in the *i-th* year (Mg) k Methane generation rate ($year^{-1}$) L_0 Potential methane generation capacity (m^3/Mg)

k (Methane Generation Rate Constant): The methane generation rate constant, k, describes the rate at which waste placed in a landfill site decays and produces LFG. The k value is expressed in units of 1/year or yr^{-1}. At higher values of k, the methane generation at a landfill increases more rapidly (as long as the landfill is still receiving waste), and then declines more quickly after the landfill closes. The value of k is a function of (i) waste moisture content, (ii) availability of nutrients for methane-generating bacteria, (iii) pH, and (iv) temperature. Moisture conditions within a landfill strongly influence k values and waste decay rates. Waste decay rates and k values are very low at desert sites, tend to be higher at sites in wetter climates, and reach maximum levels under moisture-enhanced conditions. k values determined by experiment. Following are typical values.

Table 1. *Experimental values of k [9].*

Waste Category	k yr^{-1}	Norm. CH4 ($mg\ kg^{-1}\ d^{-1}$)
Sludge waste	0.16-0.19	20.1-29.6
Street cleaning waste	0.078	1.5
Combustible waste	0.024-0.025	7.1-7.6
Mixed bulky	0.013 to 0.014	0.20-0.25
Shredder waste	0.016-0.017	0.29-0.39

Table 2. *Default values of k [10].*

Default Type	Landfill Type	k yr^{-1}
Clean Air Act	Conventional	0.059 (default value)
Clean Air Act	Arid area	0.02
Inventory	Wet (bioreactor)	0.7

L0 (Potential Methane Generation Capacity): The potential methane generation capacity, or L0, describes the total amount of methane gas potentially produced by a metric ton of waste as it decays. EPA determined the appropriate values for L0 as ranging from 56.6 to 198.2 m^3 per metric ton or megagram (m^3/Mg) of waste. Except in dry climates where lack of moisture can limit methane generation, the value for the L0 depends almost entirely on the type of waste present in the landfill. Following are typical values.

Table 3. *LO values [10].*

Default Type	Landfill Type	L0 m^3/Mg
Clean Air Act	Conventional	170 (default value)
Clean Air Act	Arid area	170
Inventory	Wet (bioreactor)	96

Mi (Annual Waste Disposal Rates): Estimated waste disposal rates are the primary determinant of LFG generation in any first-order decay-based model.

After the model inputs are entered, the emission estimates can be viewed in the 'RESULTS' worksheet. The results include annual data for waste inputs, estimates of total LFG generation, methane and carbon dioxide and non-methane organic compound (NMOC) emissions. These are shown under a tabular format in this table. The same results can be viewed graphically under the 'GRAPHS' worksheet which plots the emission of the gases by year.

4. Power Plant Capacity Calculation

Based on the methane emission rate (Megagram/year) obtained from Landgem output, the emission rate per second can be computed. Multiplying this by HHV of methane and the purification efficiency, the net heat input available in kW can be computed. The potential electric power generation can be determined by using appropriate plant efficiency.

5. Typical Case Study

Kupferberg Landfill site is situated in the City of Windhoek with four (4) general waste cells and two (2) hazardous waste cells. The landfill receives about *6000 tons* of general wastes and *1000 tons* of hazardous wastes monthly from the residence of Windhoek. The total area of the waste disposal site is about *267000* m^2 [11] The site was opened in 1984 and likely to be closed by 2023. Landgem software was used to determine the methane generation rate based on the non-hazardous waste. The following input values were used:

K value=0.02 for arid area; Lo=170m^3/t for arid area; Mi=72000t/year=72Mg/year

The outputs were obtained in tabular as well as graphic form. Figures 1 and 2 give the outputs in graphic form.

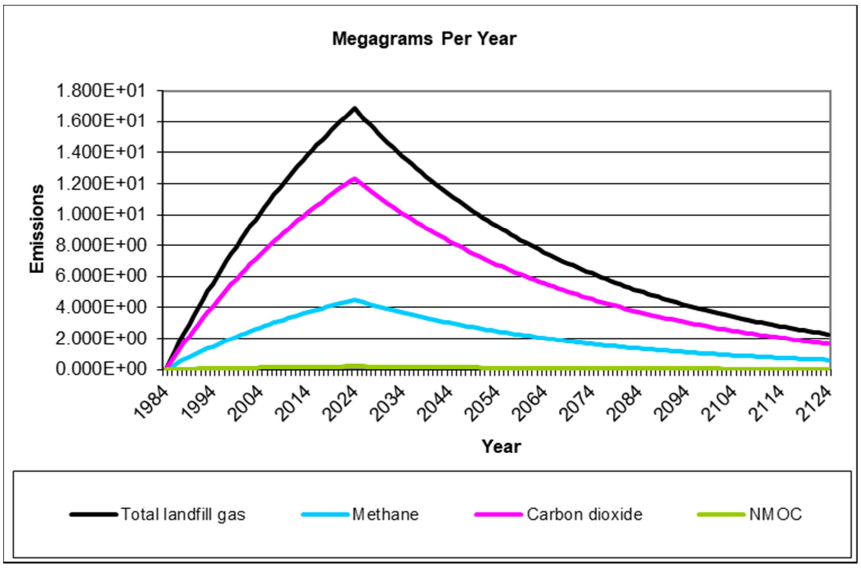

Figure 1. *Year wise emissions in Megagrams.*

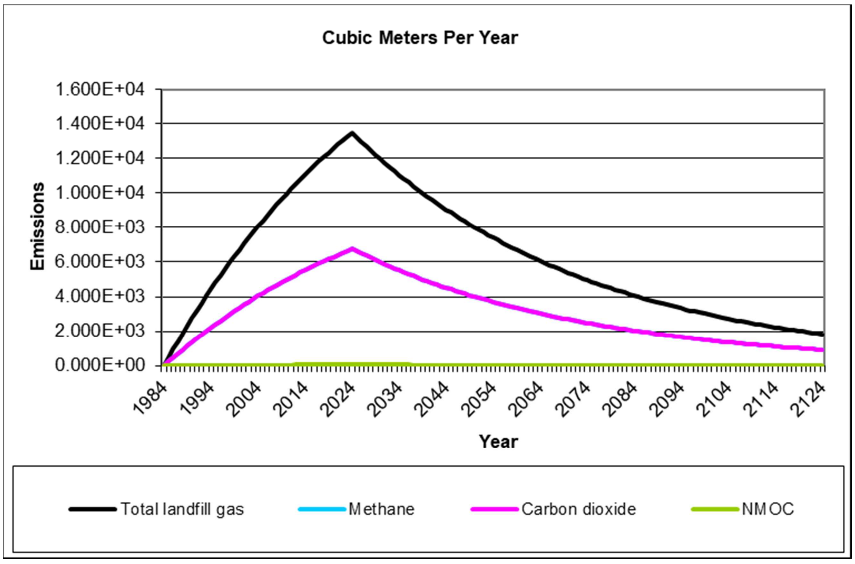

Figure 2. *Year wise emissions in Cubic meters.*

The maximum value of methane emitted from the landfill is in the year after closure, 2024. The total amount of methane emitted in 2024 according to *Table 4* is $4.5Mg / year$.

The volume of methane emitted in the same year is projected to be 6.747x$10^3$$m^3$/year.

The mass flow rate of methane

$$= \frac{4.5 \times 10^6}{60 \times 60 \times 28 \times 366} = 0.1423 g / s$$

The proposal is that LFG power plant will cater to energy for streetlights. LFG plant will consist of an Internal Combustion engine powered by methane and coupled to an electrical generator. The electricity produced will be used to power the streetlights. The streetlights operate for 12 hours per day, usually from 19h00 until 07h00. Thus the LFG plant will operate for 12 hours in, only during 19h00 to 07h00. During the day, methane will be stored in a methane storage tank to be used later. According to the SAE standards, methane should be stored under a pressure of *3.5 MPa* [12].

The methane flow rate to the engine during LFG plant operation will therefore be

$$\dot{m}_f = \frac{4.5\times10^6}{60\times60\times12\times366} = 0.2846 g/s \quad (1)$$

The commercial purification system has an efficiency of 94% and will be used to purify LFG to methane. Taking the purification system into consideration, the fuel required to be admitted to the engine will be:

$$\dot{m}_f = 0.2846\times0.94 = 0.2675 g/s \quad (2)$$

Heat input from methane is calculated as below:

$$Q_{in} = \dot{m}_f \times HHV$$

$$Q_{in} = 0.2675\times10^{-3}\times55.5\times10^3 = 14.8 kJ/s \quad (3)$$

where HHV=55.5×10^3kJ/kg

The efficiency of a methane engine is about 48% based on HHV, therefore the power output,

$$P_{out} = 0.48\times14.8 = 7.1 kW \quad (4)$$

The generated energy per year,

$$E_{generation} = 7.1\times3600\times4380 = 111.9\times10^6 kWh \quad (5)$$

An average 50W streetlight consumes about 0.600 kWh of electrical energy for lighting at rate of 12 hours/day or 219kWh/year. Therefore, the number of streetlights that can be connected to the output terminal $= \frac{7100}{50} = 142$

Based on the calculations, the power plant would be able to provide 142 streetlights in the city with electrical energy every day.

Cost analysis:

Table 4. *Components and Estimates.*

Component	Cost (US$)	Total (N$)
Methane Engine +Shipping cost	7500	105 000
Dome cement + Bricks cost		280 000
Labor cost		150 000
Methane storage tank + shipping cost	15 000	210 000
Methane Purification System	7000	105 000
Metallic piping system		30 000
Pumps and valves		10 000
Installation cost		35 000
Contingencies		60 000
Total Capital Cost		N$ 985 000

The components involved [13-15] and the rough cost estimates are as below:

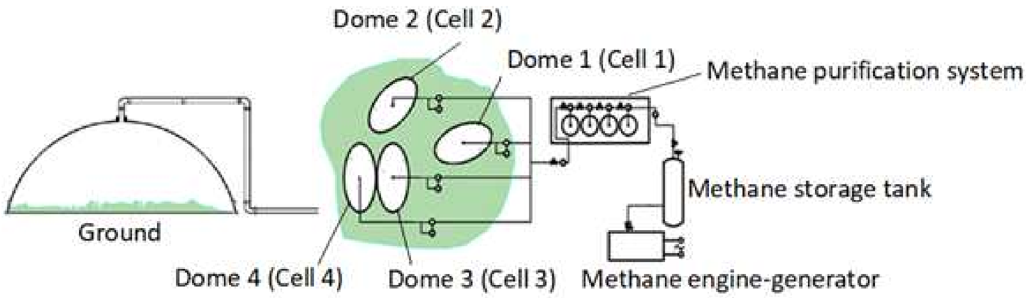

Figure 3. *Typical Scheme.*

The generated energy per year $=115\times10^6 kWh$ (6)

Using straight-line depreciation method. The salvage value is assumed at 20% of the present cost which works out to be 197000.

For fifteen years = (985 000-197000)/15 = 52533.33. N$ per year (7)

Fixed cost=Interest on capital @ 6%+Depreciation + Staff cost @10% + capital contribution per year
= 0.06x985000+52533.33+0.1x985000 + (985000/15) = 275800 (8)

Operation & maintenance cost @

0.1N$/kwh=0.1x115x$10^6$=11 500 000N$ (9)

Total cost/year=275800+11 500 000=11775800 N$ (10)

Cost/kWh=11775800 / (115x10^6) =0.102398 N$ (11)

6. Conclusion

Landgem programme gives a simple method to estimate the methane gas emission from landfill site. In the typical case study cited, the methane captured from Kupferberg landfill site is able to produce electrical energy output of about 7.1kW which can be used to power street lights.

The approximate capital cost of N$ 985,000. This cost includes the cost of the methane engine, the metallic piping system costs, the methane storage tank, the purification system as well as the raw materials used to build the four domes. With the annual electrical generation of about 115x106kWh from the power plant, the cost of electricity is about N$ 0.10 /kWh which is attractive.

Acknowledgements

The authors thank the management of Namibia University of Science and Technology for the support and encouragement.

References

[1] Intergovernmental Panel on Climate Change (IPCC) (1996). Report of the Twelfth Season of the Intergovernmental Panel on Climate Change, Mexico City.

[2] William H. L. Stafford. (2020). WtE Best Practices and Perspectives in Africa. Municipal Solid Waste Energy Conversion in Developing Countries. Elsevier. 185-192 doi: 10.1016/B978-0-12-813419-1.00006-1.

[3] J. F. Artiola. (2019). Industrial Waste and Municipal Solid Waste Treatment and Disposal. Academic Press Environmental and Pollution Science. Elsevier. 377-384. doi: 10.1016/B978-0-12-814719-1.00021-5.

[4] Ria Millati, (2019) Agricultural, Industrial, Municipal, and Forest Wastes: An Overview, Sustainable Resource Recovery and Zero Waste Approaches, Elsevier. 1-22. doi: 10.1016/B978-0-444-64200-4.00001-3.

[5] Sampurna Datta & Lauren Eastes. (2015) Biodegradation in Municipal Solid Waste landfills. Geo environmental Engineering.

[6] Kumar, S., Gaikwad, S., Shekdar, A., Singh, R. (2004), Estimation method for national methane emission from solid waste landfills. Atmospheric Environment, 3481-3487. doi: 10.1016/j.atmosenv.2004.02.057

[7] United States Environmental Protection Agency. (2005) Landfill Gas Emissions Model (LandGEM) Version3.02 User’s Guide. 1-41. EPA-600/R-05/047.

[8] LFG Energy Project Development Handbook (2016). Landfill Methane Outreach Program. EPA. 1-14.

[9] Zishen Mou, Charlotte Scheutz, Peter Kjeldsen. (2015). Evaluating the methane generation rate constant (k value) of low-organic waste at Danish landfills. Waste Management Volume 35. Elsevier. 170-176 doi: 10.1016/j.wasman.2014.10.003.

[10] Daniel P. Duffy. (2012). Land GEM: the EPA’s Landfill Gas Emissions Model. MSW Management 22 (2). 49-54.

[11] City of Windhoek (2011). Integrated Solid Waste Management Plan. Department of Infrastructure, Water and Waste Management, Windhoek. 1-12.

[12] Burchell, T., Rogers, M. (2000). Low Pressure Storage of Natural Gas for Vehicular Applications SAE Technical Paper Series. Oak Ridge national Lab. 1-5. ISSN 0148-7191.

[13] LFG Energy Project Development Handbook. (2017). Landfill Methane Outreach Program. EPA. 1-15.

[14] Robert L. Evans. (1986) Automotive Engine Alternatives. Springer. 83-104. doi: 10.1007/978-1-4757-9348-2.

[15] Landfill Gas Purification System Product Brochure. (2918). Guild Associates Inc, Dublin, Ohio.