Estimation of the Methane Generation Potential of the Tamale Landfill Site Using LandGEM*

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Abstract

Though inevitable, waste generation due to man’s activities must be appropriately managed as a security measure to safeguard public health. This is seen in the efforts by many municipal assemblies to address sanitation issues. For a lower middle-income country such as Ghana, most of the waste generated ends up at the landfill. Disposing waste at landfill sites solves immediate public health concerns such as the foul odour; it provides the right conditions for generating methane anaerobically. Methane is a potent greenhouse gas and a very rich energy source. The study was conducted to estimate the methane generation potential of landfills in Ghana. The waste was characterised according to ASTM D5231-92 and the various waste fractions were as follows; food 43.1%, plastics 17.8%, glass bottles 2.3%, paper and cardboards 9.0%, metals 3.3%, textiles7.3%, wood 0.8% and inert 16.6%. It also revealed negligible variation in the waste characteristics across the two major seasons in Temale, Ghana. The LandGEM model was used to estimate the methane generation potential of the landfill site based on the waste characterisation data. The study showed that 77% of the total waste disposed of at the Tamale landfill site could decompose to generate methane at an average rate of 921.95 m^3/hr during the 30 years lifespan of the Tamale landfill site and would reach a peak of 2222 m^3/h in 2036. This shows enough gas can be generated for any LFG emission project.

Keywords: Landfill gas, methane, emissions, Greenhouse Gas, Wastes

1 Introduction

Due to the increase in the world’s population, the demand for improved sanitation has increased steadily (UN, 2019; Bolaane and Ikgopoleng, 2011). This has led to the adaptation of various forms of solid waste management such as incineration, open dumps and landfills (Nanda and Berruti, 2021). Many developing countries such as Ghana are still phasing out open dumps and establishing controlled disposal (U.S Environmental Protection Agency, 2012).
Majority of the waste discarded in landfills mitigates many public health issues but creates additional environmental considerations (Iravanian and Ravari,2020). This provides the anaerobic conditions for the waste to decay causing the generation of landfill gas (LFG), odours, and a host of other potential air, water and land pollutants (Dudek *et al*., 2010). The methane produced by landfills is of environmental significance because methane is a potent greenhouse gas (GHG), and its global warming potential is 20 times greater than that of carbon dioxide as suggested by Friesenhan *et al*. (2017) and Allen (2016), with a relatively shorter lifespan making it the most prudent method for reducing the effect of humans on climatic change (EPA 2023; Ghoosh *et al*., 2018). This study was therefore initiated to estimate the methane generation potential of the Tamale Landfill site.

1.1 Landfill Gas Generation

Landfill sites act as bio-reactors in which landfill gas is produced in biochemical processes from the decomposition of organic matter (Dudek et al., 2010). Landfill gas is produced due to the decomposition of solid waste in landfills. It comprises approximately 50% methane (CH4) and 50% carbon (IV) oxide (EPA, 2023). Landfill gas also comprises small amounts of nitrogen, oxygen, ammonia, sulphides, hydrogen, carbon monoxide and non-methane organic compounds (NMOCs) such as trichloroethylene, benzene and vinyl chloride.

Waste deposited in landfills initially undergoes aerobic decomposition to produce small amounts of methane. Afterwards, anaerobic conditions are created and methane-generating bacteria degrade the waste and produce methane and carbon dioxide (Bolan *et al*., 2013). The various stages the waste deposited at landfill sites goes through includes:

- Hydrolysis; where the complex carbohydrates, proteins and lipids are broken down into carbondioxide and nitrogen,

- Acidogenesis: which commences after the oxygen is used up. Anaerobic bacteria convert compounds created by the aerobic bacteria into acetic, lactic, formic acids, and alcohols,

- Acetogenesis: where organic acids generated in the acidogenesis stage are converted to acetate, hydrogen and carbon dioxide. This process creates a neutral environment conducive for the methane-producing bacteria to thrive

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- Methanogenesis: This Phase commences when the constitution and generation rates of LFG remain constant.

The LFG mostly consists of about 45% to 60% methane by volume, 40% to 60% carbon dioxide and 2%to 9% other gases such as Sulphides, NMOCs. Also, gas production at this stage is static and can continue for about two decades but landfill gas emission may continue to 50 years based on the prevailing conditions at the landfill.

The rate and quantity of landfill gas generated at a specific landfill site depends on the waste's characteristics and other environmental factors such as oxygen, moisture content, refuse age and temperature (Zhang *et al*., 2019). The composition of waste determines the quantity of LFG produced. Generally, LFG generation increases when organic matter content is very high. LFG is produced by anaerobic bacteria that begin degrading the waste only in the absence of oxygen. High levels of oxygen in the waste retards the degradation and impedes the LFG generation. LFG generation is also known to increase with increasing moisture content, however high moisture content (above 60%) is known to impede the generation rate. Freshly deposited waste is known to generates LFG at a much faster rate than old refuse. High temperatures (above 57°C) are indicative of aerobic activity in the landfill site; hence the LFG generation is impeded (U.S Environmental Protection Agency, 2012).

Landfill gas generation has been relatively well researched (Malmir *et al.*, 2023; Mbazima *et al*., 2022; Manasaki *et al*., 2019). However, the gas generation process is influenced by a gamut of factors, and given the critical variable site conditions, any theoretical appraisal of the gas generation rate is overly complicated. Empirical models have been developed as due to the need for predictions with very high accuracy of the volume of methane emissions (Dudek et al., 2010).

Landfill gas (LFG) modelling is the act of predicting the generation and recovery rates of LFG based on

i. waste disposal histories

ii. future disposal estimates,

iii. collection system efficiency

A landfill methane model anticipates methane generation from waste per annum. The unit for the parameter time is a year (US Environmental Protection Agency, 2012). This study uses the US Environmental Protection Agency's (EPA) Landfill Gas Emission Model (LandGEM).

1.2 Description of Study Area

Tamale is the capital town of the Northern region of Ghana. It is located in the transitional forest zone and is about 600 km north of Ghana's capital, Accra. It lies in latitude 9.4075° N and longitude 0.8533°W, an elevation of 183 m above sea level with an area of about 750km^2. The average minimum temperature is about 22.5 °C and a maximum average temperature of 33.3°C. The average humidity is about 46.8%. The city draws an average of 1090mm of rainfall per year or 90.8 mm per month.

The Tamale landfill site is an engineered landfill site situated 18km away from the central business district of The Tamale municipality. It was commissioned on the 31st July, 2006. The landfill spans over an area of 20 hectares of land. The land serves the people of the Tamale municipality which has an average of three hundred thousand inhabitants. An average of twenty-five (25) trucks visit the landfill site daily. Two hundred and thirty tonnes of waste is received daily at the landfill site. (Puopiel & Owusu-Ansah, 2014) The organic matter content of the waste can generate LFG which can be utilized for the production of electricity or other alternate energy sources. (Ghoosh, et al., 2018)

2 Resources and Methods Used

2.1 Characterisation of Waste

Waste characterisation is the separation of waste into various components. The method used to characterise the solid waste is according to the standard test method for determining the composition of unprocessed munici-pal solid waste described by the American Society for Testing and Materials D5231-92 (American Society for Testing and Materials International, 2016).

Samples are collected from discharged vehicles, composited and reduced to about a representative sample of 100 kg by the quartering and coning method. The sample is manually sorted out into various constituents; food, plastics, glass bottles, paper and cardboards, metals, textiles, wood and inert. The weight fractions of the various components are calculated. The average waste composition is calculated using the individual sample composition results using the equation (1) specified by Seshi *et al*,, 2020

$$\%Composition\ of\ separated\ waste = \frac{weight\ of\ separated\ waste}{total\ mixed\ weight\ of\ sample} \times 100\% \qquad (1)$$

2.2 Estimation of the Methane Generation Potential Using Landgem

The amount of landfill gas generated on the landfill is estimated using LandGEM. (U.S Environmental Protection Agency, 2011; U.S Environmental Protection Agency, 2012).

This model calculates the generation rate of methane using the first-order decay equation. It was originally designed for use by US regulatory institutions but it is now applied globally (Ghoosh *et al.*, 2018). The LandGEM equation estimates the methane produced for a particular year from the accumulated waste from inception to the specified year. The underpinning equation is shown in the equation (2) below.

$$Q = \sum_{i=1}^{n} \sum_{j=0.1}^{1} kL_0 \left[\frac{M_i}{10}\right] \left(e^{-kt_{ij}}\right) \qquad (2)$$

Where:

Q = maximum methane generation flow rate expected

i = 1 year time increment

n = (year of the calculation) - (initial year of waste acceptance)

j= 0.1 year time increment

k = methane production rate (〖yr〗 ^(-1))

This accounts for the rate at which waste decomposes to produce methane. The methane production is trammelled for small values because only a comparatively small percentage of the landfilled waste decomposes annually to produce LFG. At greater values of k, a larger fraction degrades generating LFG. High values of k results in a speedy increase in LFG generation with time while the disposal is in progress, but causes a rapid decline after the closure of the landfill site. The k value depends on the biodegradability and moisture content (average annual precipitation)

L_o = potential methane generation capacity (m^3/Mg). This describes the quantity of methane gas a tonne of waste generates as it degrades. It is a function of the waste composition; the greater the cellulose content in the waste, the greater the value of L_0.
M_i= mass of solid deposited in the ith year (Mg)
t_{ij} = age of the jth portion of waste mass M_i discarded in the ith year (U.S Environmental Protection Agency, 2011).

3 Results and Discussion

3.1 Characterisation of waste

The waste was characterised to ascertain the composition of the waste deposited at the landfill site. Waste characterisation is a preliminary analysis that is carried out to determine the organic content of the waste streams. The organic matter content of waste streams is integral to generating methane gas, without which methane will not be generated. This study found that the organic matter content of the waste deposited was about 77%. This is more than value, 50%, reported for developing countries (Kumar and Agrawal, 2020). Food waste contributed about 43%. The high organic matter contents indicate that significant methane gas will be generated from the landfill site. Fig.1 Shows the average composition of the waste streams at the Tamale Landfill site. The figure shows a surge in plastic quantity,which is also an environmental concern. This can be attributed to the increasing urbanization of the Tamale municipality (Puopiel and Owusu, 2014).

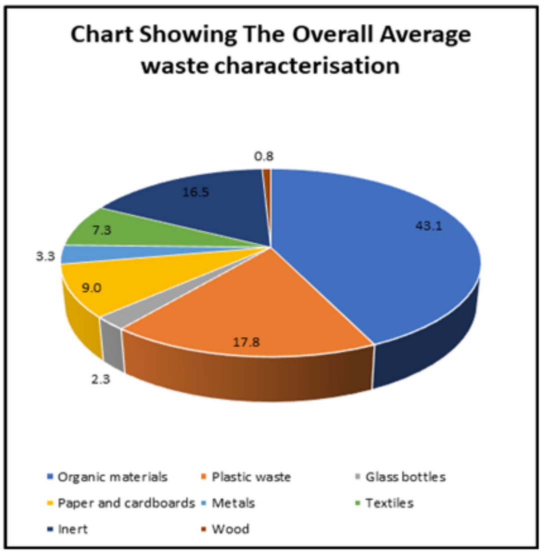

Fig. 1 Average Waste Characterization for Tamale Landfill Site

Table 1 shows the compositional analysis of the waste stream deposited at the Tamale Landfill site. Table 1 spells out the compositional analysis across the two major seasons in Ghana. This was done to check the variation of the waste composition with the seasons. From the results, we can posit that the variation in the waste composition with seasonal changes is insignificant. This assertion is corroborated in studies done by Rockson *et al.*, (2011), Miezah *et al.* (2015) and Osei-Mensah *et al.* (2014).

Table 1 Waste Characterization Data for the Seasons in Ghana

Fraction of waste	Wet season	Dry season	Overall
Food	46.4 ± 3.6	39.8 ± 4.3	43.1 ± 5.1
Plastics	17.0 ± 2.4	18.6 ± 3.8	17.8 ± 3.3
Glass bottles	2.6 ± 1.8	1.9 ± 2.	2.3 ± 2.0
Paper and cardboards	7.9 ± 1.7	10.2 ± 4.4	9.0 ± 3.5
Metals	3.2 ± 1.6	3.3 ± 1.3	3.3 ± 1.5
Textiles	7.8 ± 2.1	6.9 ± 2.6	7.3 ± 2.4
Inert	14.4 ± 6.0	18.7 ± 5.8	16.6 ± 6.3
Wood	0.6 ± 0.7	0.9± 0.8	0.8 ± 0.8
Total	100	100	100

3.2 Landfill Gas Generation Using LandGEM

Methane emission results from the LandGEM are shown in Fig. 2 The estimated total methane emission was 197.59 Gg which is equivalent to 296173800 cubic metres of methane. It was estimated that the peak generation of methane will be in the year 2036 with an estimated amount of 2222 m^3/hr using LandGEM. This coincides with the expected year of closure of the landfill site according to the design capacity of the landfill. The steady decline of LFG generated is because no fresh waste will be deposited at the landfill site. This implies that the continual generation of methane gas after the landfill's closure depends solely on the organic content of the waste already deposited there. The average methane generation over the lifespan of the landfill is 921.95 m^3/hr.

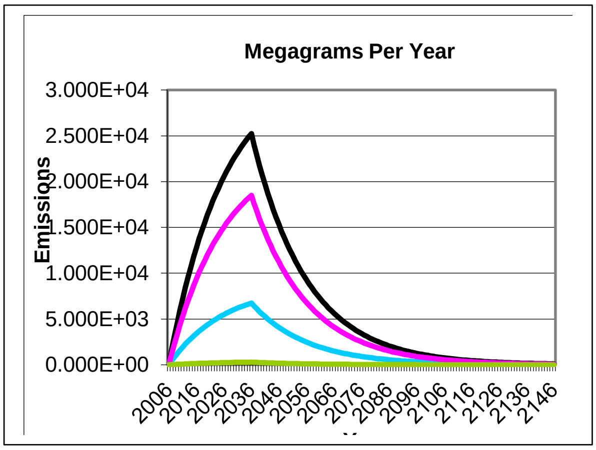

Fig. 2 Estimated Methane Generation from the Tamale Landfill Site

It can also be observed from Table 2 that the amount of methane generated increases steadily with time. This means that while the landfill is in use, the methane generated is expected to rise daily and decline when the landfill has been decommissioned.

Table 2 Estimated Annual Methane Generation

Year	Annual Volumetric flow rate m^3/yr of CH4	Annual Mass flow rate Kg/yr of CH4
2006	0.00E+00	0
2007	6.34E+05	428786.8
2008	1.24E+06	836888
2009	1.81E+06	1224912
2010	2.36E+06	1594008
2011	2.88E+06	1944852
2012	3.37E+06	2278796
2013	3.84E+06	2596516
2014	4.29E+06	2898688
2015	4.71E+06	3185988
2016	5.12E+06	3459768
2017	5.50E+06	3719352
2018	5.87E+06	3966768
2019	6.22E+06	4202692
2020	6.55E+06	4426448
2021	6.86E+06	4639388
2022	7.16E+06	4841512
2023	7.45E+06	5034172
2024	7.72E+06	5217368
2025	7.98E+06	5391776
2026	8.22E+06	5558072
2027	8.46E+06	5715580
2028	8.68E+06	5865652
2029	8.89E+06	6008288
2030	9.09E+06	6144164
2031	9.21E+06	6224608
2032	9.46E+06	6396312
3033	9.64E+06	6513260
2034	9.80E+06	6624124
2035	9.96E+06	6730256
2036	1.01E+07	6827600
2037	9.61E+06	6497712
2038	9.14E+06	6180668
2039	8.70E+06	5879172
2040	8.27E+06	5592548

4 Conclusion

The waste deposited at the Tamale landfill site is heterogeneous with the average compositions; food 43.1%, plastics 17.8%, glass bottles 2.3%, paper and cardboards 9.0%, metals 3.3%, textiles7.3%, wood 0.8% and inert 16.6%. The high organic content of the waste deposited at the landfill is about 77% of the total waste, means that enough methane gas can be generated from the landfill for various utilisation options. The slight variations in the composition during the dry and wet seasons show that seasonality has little effect on the waste generated in the Tamale metropolis.

The estimated average amount of methane gas generated from the landfill during the 30 years lifespan is 921.95 m^3/hr. Moreover, the peak methane generation rate is 1.01×10^7 m^3/yr equivalent to 2222 m^3/h and is expected to occur in 2036. The average amount of methane gas generated shows enough gas can be generated for any LFG emission project.

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