Available online www.jsaer.com

Journal of Scientific and Engineering Research, **2016, 3(6):488-493**

ISSN: 2394-2630
CODEN(USA): JSERBR

Research Article

Determination of Greenhouse Gas Reduction Potential from Combustion of Methane Gas Emissions from Solid Waste Disposal Sites in Kano, Nigeria

Lawal Abdu Daura

Department of Mechanical Engineering, Hassan Usman Katsina Polytechnic, P.M.B.2052, Katsina, Nigeria

Abstract Solid waste disposal sites generates methane which is a greenhouse gas with global warming potential about 21 times that of carbon dioxide. In this study potential for reduction in greenhouse gas contribution of the methane generation from four solid waste disposal sites (SWDs) in Kano metropolis was investigated. The result show that combustion of the methane generated in the solid waste disposal sites would reduce the carbon dioxide equivalent emission of the methane by about 88.42%. The estimated average total carbon dioxide equivalent emission of the methane generation from the SWDs is about 13,034.847 tonnes/yr, while combustion of the methane would produce and estimated 1,706.941 tonnes/yr of carbon dioxide emission.

Keywords Methane, greenhouse gas, carbon dioxide, solid waste disposal sites, combustion

1. Introduction

Anaerobic reaction within solid waste disposal sites generates various gases (landfill gas) mainly methane and carbon dioxide. In addition other non methane volatile organic compounds are also produced [1-2]. Anaerobic digestion is a three stage process in which bacteria converts organic compounds to soluble molecules, convert those molecules to organic acids and break down those acids to produce biogas [3]. Both of the two primary constituents of the landfill gas (methane and carbon dioxide) are considered green house gases, which contribute to global warming, but IPCC does not considers carbon dioxide present in raw landfill gas to be a greenhouse gas (GHG) because it considers landfill gas carbon dioxide as biogenic and thus part of the carbon cycle, therefore only the methane content in landfill gas is considered as GHG. Methane is more potent green house gas than carbon dioxide, with global potential of over 21 times that of carbon dioxide [4]. Solid waste disposal sites comprise the principal sources of anthropogenic methane emissions, and are estimated to account for 5 – 20% of anthropogenic methane emissions globally [1]. Greenhouse gas and co-pollutants emission from landfills are reduced in two ways: Either by capturing the gas or reducing the organics going into landfills. Landfill gas can be controlled by installing and operating an active gas collection and control system. The gas is then routed to control device where it is combusted with or without energy recovery.

Kano city has an urban population of about three million three hundred and forty eight thousand seven hundred (3,348,700) [5] based on 2006 census. It has been estimated that Kano Metropolis generates about 156,676 tonnes of solid waste per month and with a population of about 3,348,700 the per capita solid waste generation is about 1.56 kg per capita [5], this makes Kano city the second to Lagos in terms of waste generation in Nigeria. According to Nigeria National Bureau of Statistics Demographic Report [6], the population growth rate in Nigeria between 2006 to 2014 was 3.0 percent, therefore the projected Kano urban population by 2014 was about four million one hundred and fifty two thousand, three hundred and eighty eight (4,152,388). Most of the waste generated are dumped in an open uncontrolled waste disposal sites scattered within the urban areas of the city which is typical of most developing countries where the dominant disposal method is open dumping compared to the wide use of sanitary landfills in western countries [7]. The waste disposal sites in Kano are characterized by odour and smoke coming from spontaneous fires (due to the presence of methane gas), which causes air pollution problems to the environment and can lead to serious health hazards. According to Intergovernmental Panel on Climate Change (IPCC), gaseous emissions from solid waste disposal sites particularly methane can be a local hazard and is considered a greenhouse gas (GHG) that contribute to global warming [1].

The aim of this paper is to determine the potential for greenhouse gas emission reduction by combustion of the methane generated from four major Solid waste disposal (SWD) sites in Kano metropolis, Nigeria.

2. Methodology

The four solid waste disposal sites considered in this research are Court road, Maimalari, Hajj Camp and Ubagama with total covered area of about 206,893.24 m^2.

2.1. Waste characterization

Characterization of waste at the disposal sites were carried out according to the American Society for Testing and Materials (ASTM D5231). The procedure involved random collection of waste from the solid waste disposal sites in the amount of 15 - 20kg per unit. 100 kg sample of solid waste was collected per day in each of the four dumpsites. At each dumpsite the collected sample waste was then spread on a polythene sheet and sorted into different categories of plastics, paper, textile material, glass, vegetable /Agricultural waste, metal and earth/ garbage. The categorized wastes were then weighted using a weighing scale and their percentage weight recorded. This procedure was conducted in the months of October, March and August (2012-2013) to cater for seasonal variations (wet and dry seasons).

2.2. Methane generation

Methane generations from the solid waste dumpsites were estimated using the LandGEM model. The LandGEM (landfill gas emission model) is an automated tool to quantify landfill gas emissions from landfills. It was developed by the Control Centre Technology of the American Environmental Protection Agency [8]. The methodology for the estimation of gaseous emissions using the model was based on simple degradation equation:

$$Q_{CH4}=\sum_{i=1}^{n}\sum_{j=0.1}^{1} kL_o \left[\frac{M_i}{10}\right]\left(e^{-kt_{ij}}\right) \qquad (2.0)$$

Where: Q_{CH4} = Annual methane generation in the year of calculation (m^3 yr^{-1}); i = The yearly time increment; n = The Difference between year of the calculation and initial year of waste acceptance; j = 0.1 year increment; L_0 = Methane generation potential (m^3/Mg); M_i= Mass of waste accepted in the i^{th} year (Mg); k = Methane generation rate (yr^{-1}); t_{ij} = Age of j^{th} section of waste mass M_i accepted in the i^{th} year.

The important parameters of the LandGEM equation for the generation of methane gas are L_o (methane generation potential) and k (methane generation rate) [9].

2.3. Determination of Methane generation potential (L_O)

The methane generation potential was determined from equation [1];

$$L_O=DOC \times DOC_f \times F \times 16/12 \times MCF \qquad (2.1)$$

Where: DOC = degradable organic carbon = (0.4x A) + (0.17 x B) + (0.15 x C) + (0.3 x D);

A= fraction of MSW that is paper and textiles wastes; B = fraction of MSW that is Agricultural/garden park waste; C= fraction of MSW that is food waste; and D= fraction of MSW that is wood or straw.

DOC_f = fraction of assimilated degradable organic carbon (DOC) was obtained from the IPCC default value of 0.77 (IPCC, 1996).

MCF = Methane correction factor.

This is based on the category of the solid waste disposal site (SWD) management as presented by IPCC. All the four dumpsites fall within the category of unmanaged, deep dumpsites (≥ 5m) with MCF value of 0.8. [1].

F = fraction of methane in landfill gas (0.5 default) [1].

16/12 = stoichiometric factor [1].

2.4. Determination of Methane generation rate k

The methane generation rate or decay rate k, is determined from equation (2.36) [10];

$k = 3.2 \times 10^{-5}(x) + 0.01$ (2.2)

Where: x (mm) is annual average precipitation. For Kano, based on Nigeria Meteorological Agency (NIMET) data the average annual precipitation from 1911 – 2010 is 883.47 [11].

Therefore $k = (3.2 \times 10^{-5} \times 883.47) + 0.01 = 0.038\ yr^{-1}$.

DOC_f, MCF and Computed values of DOC, k and L_o of the four dumpsites are shown in

2.5. Tonnes of carbon dioxide equivalent emission

Methane is considered a greenhouse gas with 21 time's global warming potential of carbon dioxide according to Intercontinental Panel on Climate Change [1]. Therefore the Carbon dioxide equivalent emission of the methane generation is calculated as:

$T_{CO_2} = 21 \times Q \times \rho_{CH4}$ (2.3)

Where: T_{CO_2} is the total tonnes of carbon dioxide equivalent of methane generated; Q estimated volume of methane generated (m^3); ρ_{CH4} is the density of methane (0.7168 kg/m^3).

2.6. Combustion of Methane gas

The combustion equations for the combustion of methane gas are:

$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$ (2.4)

16kg CH_4 + 64kg O_2 → 44kgCO_2 + 36kg H_2O (2.5)

Oxygen required = 64/16 = 4kg/kg (2.6)

Carbon dioxide produced = 44/16 =2.75 kg/kg (2.7)

3. Result and Discussions

The result of the composition analysis of the solid waste at the four dumpsites conducted in the months of October, March and August (2012-2013) are shown in table 1.

Table1: Average % of waste composition

Category	Court road (% wt)	Maimalari (% wt)	Hajj camp (% wt)	Ubagama (% wt)
Plastics	27.88	28.34	29.14	29.22
Paper	7.60	4.70	12.68	8.31
Textiles	11.48	5.13	8.41	10.18
Glass	1.87	3.63	1.57	2.94
Agricultural/garden park waste	21.78	15.54	18.69	17.58
Earth/ garbage	21.65	34.27	28.20	30.97
Metals	0.19	0.06	0.00	0.12
Food waste	7.49	8.33	1.32	0.67

The average annual solid waste disposal rates in the waste disposal sites are shown in Table 2.

Table 2: Average annual waste disposal rates

Dumpsite	Initial year of waste disposal (year)	Waste in place as at 2012 (tonne)	Average annual waste disposal (tonne/year)
Court Road	1991	188,304.60	9415.23
Hajj Camp	2003	72,203.40	9025.43
Maimalari	2003	120,395.29	15049.41
Ubagama	1999	13,693.38	1,141.12

LandGEM model parameters of degradable organic carbon (DOC), methane decay rate (k) and methane generation rate were determined using the solid waste composition (Table 1) and equations 2.1 – 2.2 as shown in Table 3.

Table 3: Parameters of Land GEM equation

Dumpsites	DOC (tonne /tonne)	DOC_f	MCF	k(yr^{-1})	L_O (m^3 /tonne)
Court Road	0.125	0.77	0.8	0.038	76.94
Maimalari	0.078	0.77	0.8	0.038	48.01
Hajj Camp	0.118	0.77	0.8	0.038	72.63
Ubagama	0.105	0.77	0.8	0.038	64.63

The annual potential methane gas generation was determined from the computer Land GEM model program using the calculated parameters L_O and k substituted in the model. The results for the four dumpsites are shown in figure1.

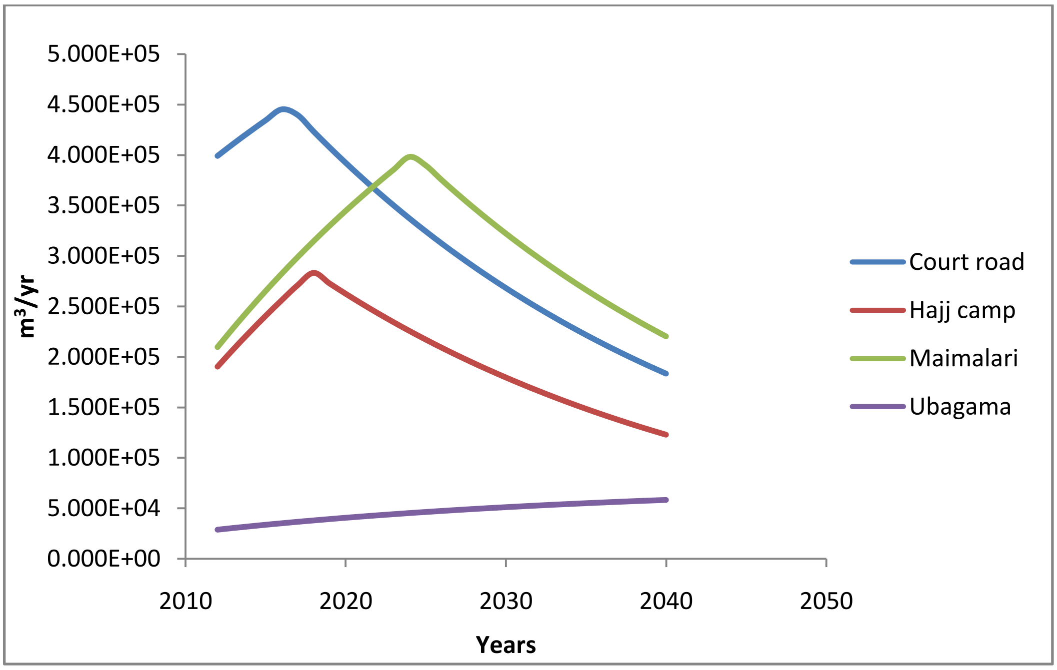

Figure 1: Methane generation potentials of the four solid waste disposal sites (2012 – 2040)

Using the average annual methane (CH_4) emissions and equations (2.3; 2.7) the average annual tones of carbon dioxide equivalent emission and potential carbon dioxide emission from combustion of the methane generation are computed for the four solid waste disposal sites and shown in Table 4. Also shown in the table are the percentage reductions in carbon dioxide emission reduction from the comparison of the greenhouse gas emission without and with combustion of the methane generated.

Table 4: Average annual GHG ($C0_2$) Emissions from CH_4 in the SWD (2012 – 2040)

Dumpsite	CH_4 Emissions from dumpsites (tonne/yr)	Tonnes of CO_2 equivalent of CH_4 (tonne/yr)	CO_2 Emission from combustion of generated CH_4 (tonne/yr)	% CO_2 Reductions
Court road	226.581	4,758.201	623.096	88.42
Maimalari	217.334	4,564.014	597.668	88.42
Hajj camp	143.790	3,019.590	395.423	88.42
Ubagama	33.002	693.042	90.754	88.42
Total	620.707	13,034.847	1,706.941	

If the methane generation from the four dumpsites are allowed to escape to the atmosphere without recovery, the carbon dioxide equivalent emission from the Solid waste disposal sites show 4,758.201 tonne/yr emission from Court road SWD, 4,564.014 tonne/yr emission from Maimalari SWD, 3,019.590 tonne/yr and 693.042 tonne/yr emissions from Hajj camp and Ubagama SWDs respectively, thus the total CO_2 emission from the dumpsites is 13,034.847 tonnes/yr. Where as if the methane is combusted the result show that the carbon dioxide emission of 623.096 tonne/yr from Court road SWD, 597.668 tonne/yr from Maimalari SWD, 395.423 tonne/yr and 90.754 tonne/yr from Hajj Camp and Ubagama SWDs respectively, thus giving a total carbon dioxide emission of

1,706.941 tonne/yr. Therefore combustion of methane generated would result in reduction of carbon dioxide emission by 88.42% when compared with carbon dioxide equivalent emission of allowing the methane to escape into the atmosphere. Figure 2 show clearly the comparison of the CO_2 emissions.

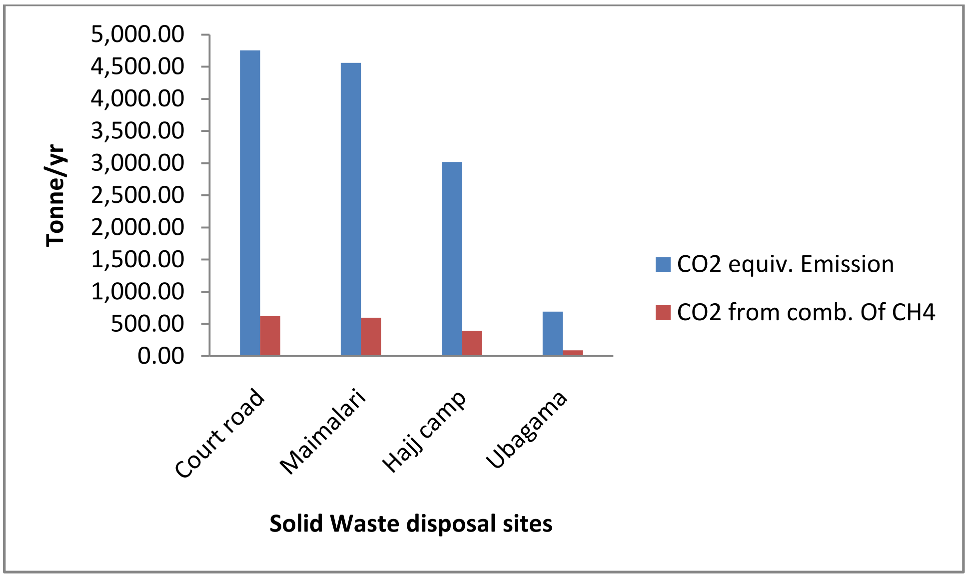

Figure 2: Comparison of average annual CO_2 equivalent emission and CO_2 emission from combustion of CH_4

4. Conclusion

The result obtained had shown that combustion of the methane generated from the four solid waste disposal sites reduces the carbon dioxide emission by about 88.42% when compared with carbon dioxide equivalent emission of the methane. It is estimated that if the methane generated from the four waste disposal sites is allowed to escape into the atmosphere, the total carbon dioxide equivalent emission would be about 13,034.847 tonnes/yr. But if the methane is combusted, the total carbon dioxide emission would be about 1,706.941 tonnes/yr. Therefore combustion of the methane generated from the solid waste disposal sites would have substantial reduction in greenhouse gas emissions.

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