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METHANE GENERATION POTENTIAL OF MUNICIPAL SOLID WASTE IN IBADAN

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Abstract
Energy potential from Municipal Solid Waste (MSW) of two landfills serving four local government areas in Ibadan metropolis was estimated in this study. The characterization of the MSW showed that approximately 74% is made up of organic materials with food wastes constituting the highest portion (35%). The energy content of the waste is evaluated as 13,022KJ/kg. The methane potential of the MSW between 2012 and 2020 is estimated to be 27,517 tonnes using the Intergovernmental Panel on Climate Change (IPCC) methodology. The gas when collected can be used as alternative energy source for small and medium enterprises in the locality.

Keywords: Methane emission, Municipal Solid Waste, Landfills, Energy content, Alternative Energy.

1.0 Introduction

The limited nature of petroleum resources across the globe and the attendant social and environmental effect of its consumption have made many developed and developing nations to explore other energy sources. Recently, renewable energy resources like wind and solar have gained global attention due to their sustainability. Materials such as crop residues, wood residues, biomass from processing industries have all been studied in the past as possible sources of alternative energy as they all possess the ability to reduce our over dependence on fossil fuels [1]. Another of such renewable energy resources is the landfill gas (LFG) which is obtained from the emission of methane and other accompanying gasses from municipal solid waste (MSW) dumpsites. This can be collected and utilized as a green energy source as millions of tons of MSW end up in sanitary landfills (controlled and uncontrolled) daily around the world. Due to the high organic content of municipal solid wastes, biological degradation occurs under anaerobic condition which leads to the production of a combination of gasses collectively called LFG. This process may continue for 20 to 50 years after initial dumping of the MSW. LFG is known to be produced in both managed landfill and open dumpsites. The major constituents of LFG include methane (50% - 60%) and carbon dioxide (40% - 60%) which are also key greenhouse gases with trace concentration of other non-methane organic compounds (NMOCs) such as mercaptans, hydrogen sulphide and other organic compounds [2].

The collection and utilization of the methane component of LFG presents a viable and valuable source of renewable energy and an opportunity to reduce the migration of a major greenhouse gas (methane) into the atmosphere thus mitigating the effect of global climate change [3]. Reducing methane emissions by capturing LFG and using it as an energy source can yield substantial energy, economic, and environmental benefits. This is an option that needs to be brought to the fore by relevant stakeholders in the Nigerian energy sector as we continue to witness an upsurge in electricity self-generation which comes with its own environmental and economical implications [4]. In addition, it will address some of the problems associated with solid waste management in a developing country like Nigeria [5].

The methane potential of open dumpsites in Ibadan metropolis, Nigeria was therefore investigated in this study.

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2.0 Methodology

2.1 Waste characterization

Representative samples of MSW were collected randomly from Awotan and Apete dumpsites in Ibadan metropolis in December, 2012. Field visits and preliminary survey revealed that Awotan dumpsite lies on an approximate 25-hectare land while Lapite dumpsite sits on a 20-hectare landmass. However, a large portion of both sites is yet to be put to use as only a fraction (approximately one-quarter) of each site was in use as at the time of this study. The two open dumpsites serve four local government areas: Ido, Ibadan North, Akinyele and Ibadan North-East. The projected total population of the areas in 2012 is approximately 1.2 million people. The amount of waste currently disposed per day at the dumpsites was estimated 171 tonnes using MSW generation rate of 0.71Kg/capital/day [6] and a municipal solid waste factor (MSW_f) of 74% (0.74) [7].

Characterization was carried out based on ASTMD 5231-92 (Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste) [8]. The MSW sample was homogenized by dividing the total sample into four portions and discarding two portions, then repeating the procedure until a significant weight sample of 100 kg was obtained. The waste was sorted into individual components such as food wastes, paper/cardboard, wood and plastic. The weights of the components were measured and the moisture content determined upon drying at 105^{o}C to a constant weight.

2.2 Ultimate analysis

The ultimate analysis involves determination of mass percentage of carbon (C), nitrogen (N), hydrogen (H), oxygen (O), sulphur (S) and ash content of the individual components of the MSW. This was carried out using methods stated in ASTMD 3174-3176 (StandardTest Method for Ash in the Analysis Sample of Coal and Coke from Coal) [9]. Chemical composition of the MSW resulting from the ultimate analysis was obtained and recorded.

2.3 Energy content

The energy content of MSW was evaluated using the modified Dulong formula [10] given in Equation (1). This is the high heating value (HHV) from the total combustion of the waste.

$$Q_h = 337C + 1428\left(H - \frac{O}{8}\right) + 95S \qquad (1)$$

In (1), Q_h is the energy content (KJ/Kg), C is the percentage carbon, H is the percentage hydrogen, O is the percentage oxygen and S the percentage sulphur.

The low heating value (LHV) which has been suggested a better measure of heat released by the waste under actual operating conditions [11], is evaluated using Equation (2) [12].

$$LHV = HHV - 0.0244(M + 9H) \qquad (2)$$

Where LHV is the low heating value (MJ/kg), HHV is the high heating value (MJ/kg).M and H represent the percentages of moisture and hydrogen on dry basis respectively.

2.4 Methane generation

The methane potential was estimated using the Intergovernmental Panel on Climate Change (IPCC) methodology [13] expressed in Equation (3):

$$CH_4 = MSW_T \times MSW_F \times MCF \times DOC \times DOC_F \times F \times \frac{16}{12} \qquad (3)$$

Where CH_4 is the emissions in tonnes, MSW_T is the total MSW generated in tonnes, MSW_F is the fraction of MSW disposed off to landfills and MCF is the Methane Correction Factor. The default values (0.4 to 1.0) for MCF are dependent on the types of MSW landfill practices. If most of the landfills under consideration are unmanaged, a value of about 0.6 can be used [14].

DOC =Fraction of degradable organic carbon which is based on the waste composition. It is obtained from Equation (4).

DOC_F =Fraction of total DOC that actually degrades and is converted to LFG. IPCC default value of 0.77 is usually used.

F = Fraction of methane in LFG.

$$DOC = 0.4P + 0.15K + 0.3W \qquad (4)$$

In (4), P is the fraction of paper in MSW, K is the fraction of kitchen garbage in MSW, W is the fraction of woods/leaves in MSW and MSW_T is the waste generation rate by population.

The total Municipal Solid Waste (MSW_T) was estimated by multiplying the solid waste generation rate in Ibadan, 0.71Kg/capita/day, [6] by the population of the local governments served by each dumpsite. The 2006 Census population figures were used and the current population was estimated using a population growth rate of 3.2% [15]. The population was estimated using Equation (5).

$$Population_{(Projected)} = (Population\ Growth\ Rate\ X\ Present\ Population) + Present\ Population \quad (5)$$

A value of 0.74 was adopted as the Municipal Solid Waste factor (MSW_F) as about 74% of MSW_T end up in landfills [7]. The default values of 0.6, 0.77 and 0.5 were adopted as MCF, DOC_F and F respectively [16].

3. Results and discussion

3.1 Solid waste composition

Typical compositions of the MSW at the two dumpsites are presented in Table 1. Over 30% of the solid waste materials are organics; 20% is paper and cardboard; tin cans constitute 9%; ashes and other constituents of the waste account for 6%. The moisture content of the organic fraction of the waste is 44.6% which contributes to the high heating value (HHV) of the MSW. The moisture content of the MSW is evaluated as 28.7%. The MSW composition is a reflection of the socio-economic and socio-cultural lifestyles of the people in the four local government areas (a mixture of rural, semi-urban and urban dwellers).

3.2 Ultimate analysis

Following the ultimate analysis of the MSW, recorded results are presented in Table 2. The data revealed that carbon was dominant in each of the components of the MSW ranging between 46.24 % (wood) and 64.28% (plastic). The least dominant was sulphur ranging between 0.03% (wood) and 1.24% (food waste).

The results from Table 2 were used to evaluate the chemical composition (dry mass basis) of the MSW and the results are presented in Table 3.

The main chemical component of the MSW was carbon (30.4%) ranging from 1.1% (wood) to 10.1% (food waste); oxygen constitutes 20.8%, hydrogen 3%, ash 3.4%, nitrogen 0.6% and sulphur 0.3%. This resulted in the formula for the volatile fraction given as $C_{250}H_{610}O_{290}N_5S$.

3.3 Energy content

The HHV and LHV of the MSW are evaluated as 13,022KJ/kg (13.02 MJ/kg) and 11.66 MJ/kg respectively. The energy content of the water vapour in the MSW accounts for the difference between the two values.

The value of LHV obtained is higher than 7 MJ/kg suggested by the World Bank [11] in the criteria for efficient applicability of MSW incineration projects

Table 1: Typical composition of Ibadan MSW

Component (%)	Wet Mass	Dry Mass,	Moisture Content
Food Waste	35	19.40	44.60
Paper & Cardboard	20	14.60	27.00
Plastic	5	4.10	18.00
Textile	6	4.10	31.70
Rubber	9	7.60	15.60
Wood	3	2.30	23.30
Glass	7	6.80	2.90
Tin Container	9	8.91	1.00
Miscellaneous (Dirts, Ashes, e.t.c)	6	3.50	41.70

Table 2: Ultimate analysis of the combustible components of Ibadan MSW

Component (%)	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food Waste	51.85	3.79	40.23	2.39	1.24	9.75
Paper & Cardboard	56.34	6.13	36.59	0.34	0.21	4.38
Plastic	64.28	6.89	27.44	0.96	0.39	3.04
Textile	53.26	5.76	40.07	0.69	0.18	2.43
Rubber	51.28	5.96	36.22	0.24	0.12	6.13
Wood	46.24	6.08	44.42	0.17	0.03	2.97
Miscellaneous (Dirts, Ashes, etc.)	59.78	2.76	41.79	0.42	0.25	3.79

Table 3: Chemical composition of Ibadan MSW (dry mass basis)

Component (%)	Wet Mass,	Dry Mass	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash
Food Waste	35	19.40	10.10	0.74	7.80	0.50	0.24	1.90
Paper &Cardbo.	20	14.60	8.23	0.90	5.34	0.05	0.03	0.64
Plastic	5	4.10	2.64	0.30	1.13	0.04	0.02	0.12
Textile	6	4.10	2.20	0.24	1.64	0.03	0.01	0.10
Rubber	9	7.60	3.90	0.50	2.80	0.02	0.01	0.50
Wood	3	2.30	1.10	0.14	1.02	-	-	0.10
Miscellaneous (Dirts,Ashes,etc.)	6	3.50	2.20	0.20	1.11	-	-	-
Total	84	55.60	30.40	3.02	20.84	0.64	0.31	3.40

Table 4: Methane generation potential of Ibadan MSW

Year	MSW_ttonnes	MSW_f	MCF	DOC	DOC_f	F	16/12	Methane, tonnes
2012	84,407	0.74	0.6	0.14	0.77	0.5	1.33	2,687
2103	87,108	0.74	0.6	0.14	0.77	0.5	1.33	2,773
2014	89,895	0.74	0.6	0.14	0.77	0.5	1.33	2,861
2015	92,772	0.74	0.6	0.14	0.77	0.5	1.33	2,953
2016	95,741	0.74	0.6	0.14	0.77	0.5	1.33	3,047
2017	98,804	0.74	0.6	0.14	0.77	0.5	1.33	3,145
2018	101,966	0.74	0.6	0.14	0.77	0.5	1.33	3,245
2019	105,229	0.74	0.6	0.14	0.77	0.5	1.33	3,349
2020	108,596	0.74	0.6	0.14	0.77	0.5	1.33	3,457

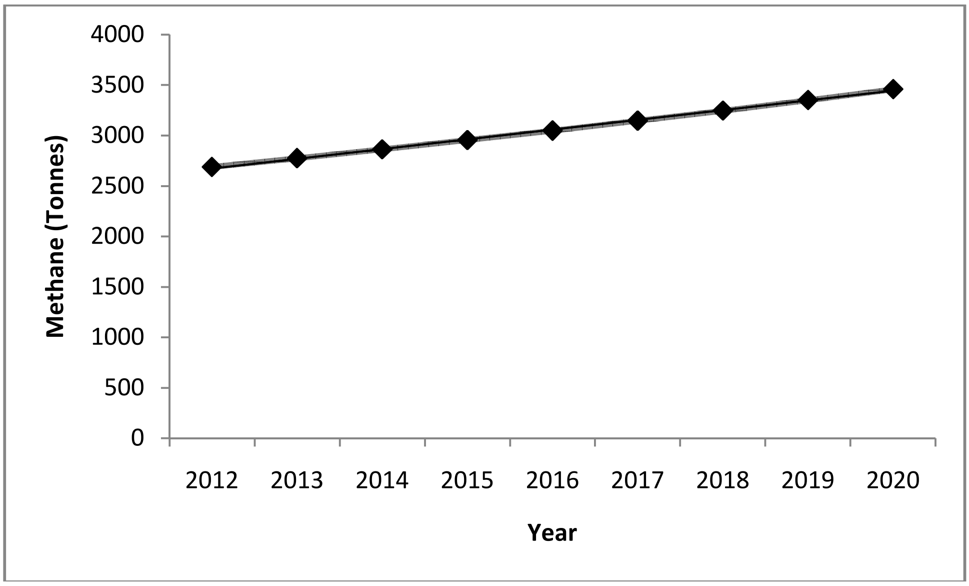

Figure 1: Expected Methane Generation between 2012 and 2020

3.4 Methane generation potential

Relevant values from Table 1 are substituted into Equation (4) to give DOC of 0.14. The obtained values were used in estimating the total CH_4 generated in the dumpsites in 2012. The total methane generation potential of the MSW from 2012 to 2020is presented in Table 4 and the trend shown in Figure 1.

It is projected that 27,517 tonnes of methane will be generated from the MSW during the period. This value will be affected by the quantity and composition of waste generated, which depend on how developed the community is and state of its economy.

3. Conclusion

The study revealed that the Ibadan MSW is predominantly organic (35%) with other recyclables such as paper and cardboard, plastic, glass accounting for up to 50%. The general formula for Ibadan MSW resulting from the ultimate analysis carried out is $C_{250}H_{610}O_{290}N_5S$ (% dry mass basis) with ash content of 3.4%. The MSW was adjudged to have energy content value of 13.02 MJ/kg and 11.66 MJ/kg representing the HHV and LHV of the MSW respectively. Based on the study, the MSW is expected to produce a total of 27,517 tonnes of methane between 2012 and 2020. The gas can be used as alternative energy source for small and medium enterprises in the community.

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