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THERMOCHEMICAL ENERGY RECOVERY POTENTIAL FROM MUNICIPAL SOLID WASTE IN GOMBE, NIGERIA

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Abstract: Gombe, the capital of Gombe state in the north-eastern part of Nigeria like most other cities in developing countries suffers the twin problem of large quantities of waste being generated and shortage in electricity supply. This study intends to estimate the potential amount of energy that could be recovered from the solid waste disposed of at the city's sanitary landfill. A waste composition based mathematical model was used to estimate the potential amount of energy that could be generated by thermochemical waste to energy technology. Firstly, the waste was characterised and it was discovered that it contained about 65% inorganics thus making it suitable for thermochemical waste-to-energy conversion. It was also found that the city's waste has a calorific value of 2,577.81kJ/kg. When the potential amount of energy that could be recovered was estimated, it was found that for the 10-year period that the landfill has been in existence, on a daily basis an average of 232,160kwh/day could be generated. This is capable of powering 37% of the houses in the city. The study therefore recommended that the city authorities or other stakeholders should give energy recovery from municipal solid waste serious consideration.

Keywords: Waste to Energy; Municipal Solid Waste; Proximate analysis; Calorific value; Solid Waste Management

1. INTRODUCTION

Globalisation has brought about increased job opportunities and better standard of living in urban areas thus a consequential rapid population growth in urban centres all over the world [1]. Relatively higher standard of living of urban dwellers coupled with a large population is not without its attendant consequences, in most countries, some of these consequences form some of the most pervasive problems encountered by city managers - the problem of solid waste management (SWM). In developing countries where the municipal authorities do not have adequate funds for SWM, streets are littered with municipal solid waste (MSW), streets littered with MSW has become the hallmark of most cities in developing countries [2], [3]. Another problem associated with cities in developing countries is incessant power outages, in Nigeria the power shortage is dire that it is norm for some cities to go days without electricity [4]–[6]. Gombe, the capital city of Gombe state located in the north-eastern region of Nigeria is not exempted from the twin problems of SWM and electricity shortage associated with cities in developing countries, it generates a large quantity of MSW and also experiences constant power shortage like most other cities in the country.

For a city like Gombe which suffers from the dual problem of electricity shortage and how to dispose of its waste in the eco-friendliest manner, converting MSW to energy seems to be the silver bullet for solving these problems. Recovery of energy from MSW by utilising the heat generated from its combustion to heat up water which generates steam used to power turbines for electricity generation is one of the most common methods of recovery of energy from solid waste [7]–[9].

To implement a waste-to-energy (WtE) policy, a feasibility study needs to be undertaken to determine the suitability of the MSW generated in that location. The calorific value or lower heating value of the MSW is the most important parameter for determining its suitability for energy generation.

According to ASTM E711-87 standard, which is the most widely approved standard for determining the calorific value of refuse derived fuel, a bomb calorimeter is used for the process, usually a sample of the MSW weighing 1 gram is to be used for the test [10]. Researchers however have suggested that 1 gram is inadequate to accurately ascertain the calorific value of MSW due to the vast variance in its composition, this brings about the growing popularity and usage of models [11], [12].

There are three broad methods for determining the calorific value of MSW using mathematical models, these model types are based on the following parameters of the MSW: its physical composition; ultimate analysis and proximate analysis [13]. Mathematical models are thereby used as cheaper and faster alternatives for this estimation [14].

Given that Gombe generates a large quantity of MSW and also suffers from electricity supply shortage, the need to estimate the potential for electricity generation from the city's waste becomes important. This research aims to utilise a mathematical model to estimate the potential amount of energy that can be recovered from the MSW disposed of at the city's only sanitary landfill.

2. MATERIAL AND METHODS

— Description of Study Area

Gombe, the capital of Gombe State located on Latitude 9°30' and 12°30'N, Longitude 8°5' and 11°45'E has a population of 367,500 and a land area of 52km². The Bajoga Road sanitary landfill is the only landfill in the state capital, it is located about 4km away from the city centre on a 40,000m² piece of land that is unfenced, the landfill site has been in operation since 2009 [15]. The landfill is being operated by Gombe State Environmental Protection Agency (GOSEPA) which is the agency saddled with the responsibility of SWM in the whole state. It was observed from field study that the SWM technique being practiced at the landfill site is open dumping. In addition, it was also gathered that there are forty-nine (49) identical open waste temporal collection points spread around the metropolis, GOSEPA's vehicles move waste from those collection points to the landfill on a daily basis with the exception of Sundays and public holidays.

— Description of Models for the Analyses

There are three methods for determining the lower heating value of MSW using models, these methods are based on the following analyses: physical composition; ultimate analysis and proximate analysis [13].

Models based on physical composition of the MSW utilise these parameters to determine the calorific value of the MSW, Equation 1 shows a model based on the physical composition of the MSW (Kathiravale et al., 2003):

$$H_n = [88.2P_{pl} + 40.5(P_{ga} + P_{pa})] - 6W \tag{1}$$

where: H_n = Net calorific value (kcal/kg); P_{pl} = % weight of Plastics; P_{pa} = % Weight of Papers and cardboards; P_{ga} = % Weight of Garbage (textiles, woods, food waste, yard waste); W = % Weight of moisture content.

Models based on ultimate analysis use the composition of carbon (C), hydrogen (H), oxygen (O), Sulphur (S) and moisture content to determine the calorific values of the MSW. According to Abu-Qudais & Abu-Qdais (2000), Dulong's Model, Steuer's Model and Scheurer-Kestner's model are some of the ultimate analysis based models. The three models are presented in Equations 2-4.

$$H_n = 81C + 342.5\left(H - \frac{O}{8}\right) + 22.5S - 6(W + 9H) \tag{2}$$

$$H_n = 81\left(C - 3\frac{O}{8}\right) + 57\frac{O}{8} + 345\left(H - \frac{O}{16}\right) + 25S - 6(9H + W) \tag{3}$$

$$H_n = 81\left(C - 3\frac{O}{4}\right) + 342.5H + 22.5S + 57\left(3\frac{O}{4}\right) - 6(9H + W) \tag{4}$$

Models based on proximate analysis are models that utilise MSW data obtained from an ultimate analysis, these data include the percentage levels of moisture in the MSW, its volatile combustible matter content, fixed carbon and ash contents [17]. Examples of such models are Benito's model and Traditional model, these two models are represented in Equations 5 and 6 respectively.

$$H_n = 44.75V - 5.85W + 21.2 \tag{5}$$

Where: V = %Combustible volatile matter; W = %moisture content

$$LHV = 45V - 6 \tag{6}$$

— Determination of Model Parameters

To determine the composition of the MSW, ASTM D 5231-92 (ASTM, 2008) standard was adopted. This involved about 100 kg of samples being randomly collected from disposal vehicles at the landfill site in batches of about 20kg for six days, the samples were packaged in large polythene bags and labelled with the date of collection. Each batch of MSW collected was weighed using a digital weighing scale and the value obtained was recorded. The samples collected over the 6 days were mixed on a tarpaulin and hand sorting was employed. The samples were categorised into the following nine categories: papers; plastics; yard/garden waste; food waste; woods; metals; glasses; textiles; Inert materials (stones, ground, construction and demolition wastes). After the sorting, each category was weighed. The percentage of each component of the MSW was then calculated using the formula in Equation 7.

$$\%W = \frac{\text{Weight of Particular Category of Sample}}{\text{Total Weight of Sample}} \times 100 \quad (7)$$

The moisture content of the MSW was determined using ASTM 3173 method [10], 1kg of the MSW sample was placed in a dish whose weight was known, the dish was then then placed in an oven and the temperature set at 105°C, it was left there until the sample reached a constant weight. The moisture content was then estimated using Equation 8.

$$\%\text{ of Moisture content (W)} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Wet Weight}} \times 100 \quad (8)$$

— **Energy Recovery Potential**

The amount of energy that can be recovered on a daily basis from the MSW was estimated using Equation 9 [8].

$$E = H_n \times W \times \frac{1000}{859.4} \times \eta \quad (9)$$

Where: E = Energy recovered (kwh/day); H_n = Net calorific value (kcal/kg); W = Average daily waste disposal (tonnes); η = Conversion Efficiency (22%) [8]

3. RESULTS AND DISCUSSIONS

— **Landfill Characteristics**

In the ten years of existence of the landfill, a total of 1,412,519 tonnes of solid waste have been disposed there, Tables 1 and 2 show the annual quantity of waste disposed at the sanitary landfill and its composition by weight.

Table 1: Annual Quantity of Waste Hauled to the Bajoga Road Sanitary Landfill

Year	Quantity (Tonnes)
2009	29,022
2010	110,376
2011	115,920
2012	126,168
2013	71,568
2014	206,052
2015	184,548
2016	135,871
2017	139,404
2018	143,028
2019	150,562

— **Model Parameters**

It was found that a fifth of the composition of the MSW disposed of at Bajoga road sanitary landfill was made up of inert materials, while woods and metals made up just about a tenth of its total weight. Papers and plastics constituted about 8.2% and 11.4% of the waste respectively, while yard/garden wastes and food wastes constituted 13.9% and 9% respectively. Table 2 shows the composition of the waste collected on the six different days of sampling and their averages.

Table 2: Composition by Weight of Solid Waste at Bajoga Road Sanitary Landfill

Category	Total Weight of Sample Collected in 6 days (kg)							Percentage Weight (%)
	1	2	3	4	5	6	*AVG	
Papers	56.32	60.14	54.71	59.2	56.72	63.55	58.44	8.2
Plastics	78.42	81.23	82.92	77.95	79.71	83.61	80.64	11.4
Yard wastes	97.73	98.93	101.23	96.82	98.73	98.4	98.64	13.9
Food Wastes	64.21	62.59	63.52	66.72	61.25	62.59	63.48	9.0
Woods	57.20	59.18	58.44	59.21	60.08	57.25	58.56	8.3
Metals	59.33	59.14	57.25	58.14	56.25	63.41	58.92	8.3
Glasses	60.92	64.13	63.48	61.78	63.19	63.78	62.88	8.9
Textiles	68.98	67.25	70.12	71.03	68.92	70.58	69.48	9.8
Inert Materials	150.44	162.31	161.92	155.88	154.02	162.95	157.92	22.2

— **Energy Recovery Potential**

The net calorific value for the MSW in Gombe was estimated using equation 1, it was found that the waste has a lower heating value of 2,577.81kJ/kg. The potential for recovery of energy on a daily basis from the waste by thermochemical conversion within the period of the existence of the landfill is presented in Figure 1. On average, 232,160 kwh/day could be recovered from the city's MSW. It can be seen from the figure that the year the site was commissioned, 52,470 kwh/day could have been recovered from the city's waste, making it the year with the least daily energy recovery potential in its ten years of existence. While in 2014, the site's highest potential daily energy recovery was recorded: 372,531 kwh/day. The fluctuation in the potential daily energy recovery rate for the period in which the site has been in existence is directly connected to the fluctuation in the amount of MSW disposed at this site. According to GOSEPA, this fluctuation is as a result of the inconsistencies in evacuation of waste from the city, the reason being their inability to keep all their waste collection vehicles functional due to lack of funds.

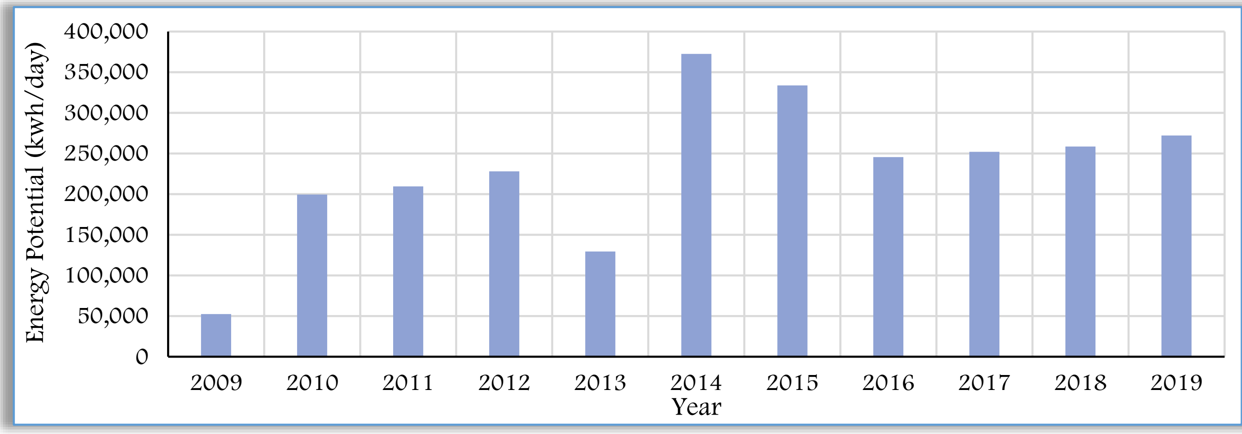

Figure 1: Daily Energy Recovery Potential for Bajoga Road Landfill

4. CONCLUSIONS

An estimation for the potential amount of energy that can be recovered from the MSW disposed of at the Bajoga road sanitary landfill in Gombe was undertaken. Firstly, the records for the quantity of MSW disposed at the landfill was obtained, then a sampling process in accordance to ASTM standard was undertaken so as to be able to characterize the MSW at the landfill. It was found that the MSW largely constituted inorganic materials which makes it more suitable for thermochemical energy recovery. A mathematical model which makes use of the waste's composition was used to determine the potential amount of energy that could be recovered from it. It was found that on an average, 232,160 kwh/day of electricity could be generated from the MSW at the dumpsite. Given that the average household electricity in Gombe is 10 kwh/day [18], the electricity recovered from the MSW disposed at the landfill has the potential to power 23,216 houses, that is about 37% of the city's 63,379 households [19]. Provision of electricity to about 37% of the households in the city from an alternative source will greatly reduce the strain on the electricity supply from the national grid and ensure an overall better supply to the city.

Given that about 37% of the households in Gombe can be powered by the waste generated in the city, this study therefore recommends that the city authorities and other stakeholders should give energy recovery a serious consideration since it solves the problem of SWM and electricity shortage in the city.

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