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Generation, characteristics and energy potential of solid municipal waste in Nigeria

Ityona Amber

Daniel M Kulla

Nicholas Gukop

Department of Mechanical Engineering, Ahmadu Bello University, Zaria, Nigeria

bstract

The generation, characteristics and energy potential of municipal solid waste for power generation in Nigeria is presented in this paper. Nigeria generates 0.44-0.66 kg/capita/day of MSW with a waste density of 200-400 kg/m^3 leading to large volumes of poorly managed waste. The direct burning of these wastes as a waste management option in the open air at elevated temperatures liberates heat energy, inert gases and ash which can be conveniently used for power generation and other applications. The net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, size and shape of the constituents and design of the combustion system. MSW samples used in this study were obtained randomly from different dump sites in selected state capitals, at least one from each of the six geopolitical zones in Nigeria based on the spot sampling method of Corbit. An average calorific value of 17.23 MJ/kg with variable high water content of 20-49% was determined for MSW using a bomb calorimeter and on the basis of an incineration plant of capacity 1500 ton of MSW/day, 700kW/day of power can be generated.

Keywords: municipal solid waste, calorific value, waste to energy, proximate and ultimate analysis

1. Introduction

Municipal solid waste (MSW) comprises of combined domestic, commercial and industrial waste generated in a given municipality or locality (Fobil, 2005 Kothari, et al., 2010). The integrated solutions to problems of the waste management in the modern era provided by waste to energy or energy from waste, by the direct burning of mixed waste in open air at elevated temperatures in mass burning facilities liberates energy in the form of electricity or heat that can be conveniently used for power generation (Voelker, 1997). Traditionally this waste would have been disposed in a land fill site or incinerated in mass burning facilities without heat or energy recovery (IEA, 2003, Tsia, 2006, Kothari, et al., 2010). Waste to energy (WTE) technologies have the potential to reduce the volume of the original waste by 90%, depending on the composition, by recovering otherwise lost energy and metals in MSW, thus providing a means of alternate/renewable energy and a reduction of society's use of precarious energy resources can be realised (Voelker, 1997; Wang, 2009; Kathiravale, 2003; Kothari, et al., 2010). The heating value of mixed MSW is approximately about one-third of the calorific value of coal (8-12 MJ/kg as received for MSW and 25-30 MJ/kg for coal) (IEA, 2003). The net energy yield depends upon the density and composition of the waste; relative percentage of moisture and inert materials, which add to the heat loss; ignition temperature; size and shape of the constituents; design of the combustion system (fixed bed/ fluidised bed), etc (Fobil, 2005; Akkaya & Demir, 2009). Table 1 has heating values over that of coal such as plastic, polyethene and tyres.

Solid waste management has emerged as one of the greatest challenges facing state and local government environmental protection agencies in Nigeria. The volume of solid waste being generated continues to increase at a faster rate than the ability of the agencies to improve on the financial and technical resources needed to parallel this growth. Solid waste management in Nigeria is characterized by inefficient collection methods, insufficient coverage of the collection system and improper disposal of solid waste. As such, most cities and towns are characterised by waste disposal dumpsites situated on any available free land roads streets, drainages etc. (www.punchng.com/news).

Nigeria, at present, peak power generation as supplied by the power holding company of Nigeria (PHCN) is below 4 MW to cater for a population of over 150 million, which has resulted in an acute and interrupted power supply (Nigeria power road map, 2010). This has led to the use of petrol and diesel generators and in 2009 it was reported that about 60 million Nigerians own generators for their electricity, while the same number of people spend a staggering N1.56 trillion ($13.35m) to fuel them annually.

At a current population growth rate of 2.03% and 7% economic growth, energy consumption and waste generation in Nigeria is expected to soar over the next few years. The exploitation of the non-conventional energy locked up in the urban solid municipal waste into grid energy through WTE will provide the dual advantage of minimising waste and recovering the 'hidden' energy. This makes it a very attractive waste management/power generation option for Nigeria.

The average waste density currently ranges between 280 to 370 kg/m^3 with waste generation rates ranging from 0.44 to 0.66 kg/capita/day (Ogwueleka, 2009). Table 2 shows the current populations and volumes of municipal solid waste generate in a few Nigerian cities for the years 1982, 1990, and projection for 2000 and 2010. It is evident that the amount of waste in these cities has more than doubled over the last two decades. The quantity and rate of MSW generation in each state is a function of the population, level of industrialization, social-economic status of the citizens and the kind of commercial activities predominant in the area. (Babayemi & Dauda, 2009; Nabegu, 2010.). The literature available presents some idea of what quantity of waste is generated, its composition and characteristics, but its suitability for power generation has not yet been fully addressed and needs to be if a certain waste is being considered for power generation.

The objective of this paper is to assess the quantity (generation), quality (physical and chemical) and energy of Nigerian MSW for power generation in Nigeria. The challenges and changes in quantity and quality of the Municipal Solid Waste in Nigeria has been reported in Ogwueleka, 2009, Onwughara,*et.al.,* 2010; and Babayemi & Dauda, 2009. Ogwueleka (2009) also in his paper reports that the Federal Government of Nigeria laws and regulations in Nigeria promulgated to protect the environment of which include the Federal Environmental Protection Agency Act of 1988 and the Federal Environmental Protection Agency (FEPA), created in 1999 under the FEPA Act decrees where each state and local government in the country set up its own environmental protection body for the protection and improvement of the environment within its jurisdiction, thus making municipal solid waste management as a major responsibility of state and local government environmental agencies. Assessments of MSW have been reported from China (Cheng *et al.,* 2007), South Korea (Ryu, 2010), Malaysia (Kathiravale *et.al.,* 2003) and Taiwan (Tsai and Kuo, 2010).

This paper presents the generation, characteristics and energy potential of municipal solid waste in Nigeria for power generation.

Table 1: Heating values for various fuels and MSW components

Source: Voelker, IEA (2003)

Fuel	Heating value (kJ/kg)
Anthracite coal	6454.274
Bituminous coal	6693.322
Peat	1721.14
Oil	8605.699
Natural gas	11474.27
Mixed MSW	2294.853
Mixed paper/ newsprint	3251.042/3800.85
Cardboard	3367.219
ployethene	8934.15
polystyrene	7849.832
Mixed plastic	6741.131
Tyres	6597.703
leaves	2390.427

2. Methodology

The spot sampling method of Corbit, 1998 was adopted in the sampling and sorting protocol. The spot sampling method requires for the samples to be taken from dump sites from the same source where an amount of waste (about 30–50 kg) is to be taken and the total amount collected will form a sample size of about 200 kg, which is then sorted. Five samples of 10 kg each of the raw MSW is taken randomly from dump sites whose sources are generated by different activities from some selected state capitals which harbour the largest population and being the economic nerve of the respective states. The states were selected to reflect at least one city in each of the six geopolitical zones of Nigeria. The sampling was done between January and February, a period of dry season in most Nigerian cities. The sorting is carried out based on 5 different components as listed in Table 4. Segregated waste components were weighed. Subsamples, each weighing 5 kg were taken from the composite samples and oven-heated at 85°C to constant weight for determination of moisture content.

Table 2: Waste generation for 1982, 1990 and 2000
Source: Ogwueleka, (2009); Onwughara,et.al., (2010); Babayemi and Dauda, (2009)

City	*Population*	*Waste generated1982 (Tonnes)*	*Waste generated1990 (Tonnes)*	*Waste generation projected for 2000 (Tonnes*	*Waste generated 2010 (Tonnes)*	*Density (kg/m^3)*	*kg/ capita/ day*
Lagos	9 000 000	625 399	786 079	998 081	3 066 672	294	0.63
Kano	3 626 068	319 935	402 133	535 186	1 880 112	290	0.56
Ibadan	3 565 108	350 823	440 956	559 882	1 624 692	330	0.51
Kaduna	1 582 102	257 837	324 084	431 314	1 373 196	320	0.58
Port Harcourt	1 148 665	210 934	265 129	352 853	1 413 900	300	0.6
Makurdi	292 645	44 488	57 243	79 835	290 904	340	0.48
Onitsha	561 066	242 240	304 477	386 593	1 009 644	310	0.53
Nnsuka	111 017	144 000	370	0.44			
Abuja	99 871	135 272	197 660	177 420	280	0.66	
Abeokuta	NA	NA	NA	0.66			
Ado-Ekiti	NA	NA	NA	0.71			
Akure in	NA	NA	NA	0.54			
Ile-Ife	NA	NA	NA	0.46			
Ibadan	NA	55 200	NA	0.71			
Ilorin	NA	NA	NA	0.43			
Aba	NA	131 903	169 719	236 703	2 840 436	NA	NA
Uyo	NA	251 076	NA	NA			
Maiduguri	NA	1 020 000	NA	NA			
Warri	NA	67 447	91 396	133 531	800 652	NA	NA
Benin	NA	NA	NA				

Experimental determination of the physical and chemical characteristics, important parameters that determine energy recoverable from MSW was carried out by a proximate and ultimate analysis. The calorific value of MSW was determined in accordance to ASTM E 711-87.

The calculation of the potential of recovery of energy from MSW is obtained from equation 1 – 4, which requires the knowledge of its calorific value and organic fraction, as in thermo-chemical conversion of all of the organic matter, biodegradable as well as non biodegradable, which contributes to the energy output. Total waste quantity (W tonnes) is calculated from a rough estimated of waste in place using equation 1 (Akkaya, & Demir, 2009).

$$\text{Total waste land filled (W tonnes)} = \text{Urban population} \times \text{Waste generation rate (kg/person/year)} \times \text{Fraction of waste in landfills or open dumps} \times \text{Years of land filling} \times 0.001 \quad (1)$$

$$\text{Energy recovery potential (kWh)} = NCV \times W \times 1000/860 = 1.16 \times NCV \times W \quad (2)$$

$$\text{Power generation potential (kW)} = 1.16 \times NCV \times W/24 = 0.048 \times NCV \times W \quad (3)$$

$$\text{Conversion efficiency} = \eta$$

$$\text{Net power generation potential (kW)} = \eta \times 0.048 \times NCV \times W \quad (4)$$

3. Results

The current waste generation rate for some Nigerian cites, the associated population of each city, and the tonnage per month is also given in Table 2.

4. Discussion

Waste characteristics influence the amount of energy within landfills. Different countries and regions have MSW with widely differing compositions.

The population and generation rates for selected cities sampled in this study are presented in Table 2. The waste composition and their percentages by weight are presented in Table 3. Further analysis of the sorted waste showed that constituents were quite similar except for the amount and proportion present in a waste dump site differed in proportion for each sample and this greatly influenced the type of activity dominant in the environment where the waste is generated and deposited.

The average percentage composition of various waste stream (Table 2) shows 43% organic component, 8% paper /cardboard/plastics and rubber, 26% glass, 3% metal and cans, 2% textile materials, and 2% residue.

Table 3: Percentage composition of waste stream characteristics

	Nnsuka	*Lagos*	*Makurdi*	*Kano*	*Onitsha*	*Ibadan*	*Maiduguri*	*Zaria*	*Average*
Food/organics	59.8	63	59.3	58	56.9	58.5	60.8	58.8	59.38
Paper/ Paper/ polythene/polythene	25.72	45	23.22	38.42	39.11	37.6	35.6	39.07	35.46
Textile	1.57	3.1	2.5	7	6.2	1.4	3.9	2.13	3.47
Glass &metal	2.5	3	3.6	2	9.2	0.6	4.3	5.15	3.79
Others (dust, ash, rubber, soil, bones, ceramics	9.4	19	14	22	15.4	8.9	31.3	4.33	15.545
Moisture content	20.79	28.36	20.27	18.88	21.17	23.52	17.95	18.33	21.15

Table 4: Energy content of MSW

Components	*Energy content (MJ/kg)*
Organic / food	11.59
Paper	10.14
Cardboard	11.033
Plastics	14.89
Polyethene	46.5
Metal glass and cans	
Textile	9.27
Net calorific value(MJ/kg) -	17.23
Moisture content	49.90%

The average calorific value for the raw waste analysed for drying or preheating is 11.38MJ/kg while for the oven dried MSW at 85oC gave a calorific value of 17.38 MJ/kg and a moisture content of 49.90%. The collected waste sample reveals organic wastes containing high concentration of bio-degradable matter which are suitable for energy recovery through anaerobic de-composition or dried and combusted and a high proportion of polythene waste from sachet drinking water popularly known as 'pure water', and shopping bags which has a calorific value of 14.89MJ/kg. The MSW samples collected from southern Nigeria cities had higher moisture content than the samples collected in the northern part which is attributed to the relative humidity of the location of interest.

The ultimate and proximate analysis (Table 4) shows the chemical analysis by mass of important elements of the MSW sample. These are important parameters for technical viability of energy recovery through different and selected treatment routes. The proximate analysis, ultimate/elemental analysis and the calorific values are required for the design of a suitable incineration plant.

On the basis of a 1500 ton of MSW/day incineration plant, MSW with average calorific values of 17.23MJ/kg, a conversion efficiency of 25% and 49% water content, the thermal treatment of MSW resulted in the generation capacity of 700 kWh of electricity per ton of MSW combusted. In practice, about 65 to 80 % of the energy content of the organic matter can be recovered as heat energy, which can be utilised either for direct thermal applications, or for producing power via steam turbine generators (with typical conversion efficiency of about 30%). Modern incinerators can reduce waste volume by 97% and convert metal and glass to ash which is currently being researched to be used in materials development.

Incineration is extensively used as an important method of waste disposal; it is associated with some polluting discharges which are of environmental concern, although in varying degrees of severity. These can fortunately be effectively controlled by installing suitable pollution control devices and by suitable furnace construction and control of the combustion process. The challenges using waste as fuel is poised in the heterogeneous composition of each dumpsite, strong variations in the composition which is both regional and seasonal dependent, variations in the calorific value, possibilities of and the presence or production of hazardous substances as well as the challenge of consistent collection and supply waste to operate a plate 24/7.

WTE adoption in Nigeria is at the moment not feasible due to a few of the factors as listed:

i) lack of advanced technology,

Table 5: Proximate and ultimate analysis

Proximate analysis (wet)	*Weight (%)*	*Elemental analysis (Dry)*	*Weight (%)*
Moisture content	49.90	Carbon content	51.33
Volatile matter content	38.28	Hydrogen content	6.77
Fixed carbon content	5.27	Nitrogen content	1.42
Ash content	5.25	Oxygen content	30.92
		Sulphur content	1.34

ii) lack of knowledge of the composition of specific landfills
iii) strength of solid waste management policy
iv) lack of proper enforcement and environmental education
v) low awareness and technical know how
vi) income status of individuals.

5. Conclusion

The generation, characteristics and the energy potential of MSW in Nigeria has been presented in this study. A calorific value of 17.23MJ/kg was obtained using a bomb calorimeter.

On the basis of a 1500 ton capacity incineration plant, 700 kWh of electricity per ton of MSW combusted can be generated.

Knowledge of the composition of specific landfills is very important. Lack of proper existing policies, legislation, waste handling and lack of awareness are obstacles for WTE Technology adoption in Nigeria.

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