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# Experimental Characterization of Municipal Solid Waste for Energy Production in North Western Nigeria

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**ABSTRACT**
Environmental and health degradation due to poor solid waste management has been a major source of concern in all parts of Nigeria. Municipal solid waste samples were collected during the months of February, March and April and during the rainy season in August for three years in major cities of the north western Nigeria. These cities are Birnin Kebbi, Gusau and Sokoto with high population densities and intense industrial activities. The refuse physical characteristics were then evaluated by sifting through the waste and separated into wood, grass, metal, plastic, paper and sand. The refuse samples were analyzed by proximate and ultimate analyses using ASTM standards. Proximate and ultimate analyses results showed refuse characteristics as: moisture; volatile matter; ash content and fixed carbon, as 21.426: 25.062: 30.010: 23.502; 24.535:22.145:36.130:17.190 and 21.427: 24.103: 34.470: 19.982 for Sokoto, Gusau and Birnin Kebbi, respectively. The calorific values of the refuse were low and found to fall below the limit for the production of steam in electricity generation. There is need to provide a supplementary fuel in the form of bagasse or any herbaceous biomass. It was found that population density and geographical locations are not real determining factors as whether refuse quality may change or not but rather the life style of the population and its awareness towards waste management.
***Keywords**:* north western Nigeria, municipal solid waste, ultimate analysis, proximate analysis, calorific value, electricity generation.

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## I. INTRODUCTION

Solid waste management and energy generation have been of major concern in Nigeria. Renewable sources of energy, in all its forms, offer the most potential energy conservation and development option for the future. Waste, irrespective of its nature or form, constitutes a problem to the environment, through health hazards and its polluting effects. The improper disposal of wastes is one of the major factors threatening the health and comfort of individuals in areas where satisfactory municipal, on-site, or individual disposal facilities are not available. This is so because very large numbers of different disease-producing organisms can be found in wastes [1].

Semi-arid regions of Nigeria are characterized by high temperatures (30$^o$C- 45$^o$C) in the hottest months and these regions are characterized by low annual rainfall and the whole area is mainly desertique [2]. The areas represent about 35% of the lands in Nigeria and house more than 50 million people [3].

At present, there is an almost inexistent and erratic power supply from the national grid.

Wastes are an important source of energy presently used in the generation of electricity and at the same time making the environment clean. A full understanding of wastes characteristics is crucial in the decision making stage when the “best option disposal” is to be made [4]; most importantly when electricity generation is being considered [5, 6, 7, 8, 9, 10].

This paper presents the determination of wastes characteristics in the north western semiarid region of Nigeria for the purpose of energy production. The primary sources of wastes and their availability; through collection, sampling, separation and laboratory analysis are carried out. The determination of the wastes combustion characteristics and evaluation of the amount of energy to be obtained from such wastes is also treated.

## II. MATERIALS AND METHODS

**Study area:** Major cities of the North Western Nigeria, with high population densities [3] and intense industrial activities constitute the area of study. These cities are Birnin Kebbi, Gusau and Sokoto in Kebbi state, Zamfara state and Sokoto state, respectively.

**Data collection:** Ten (10) kilograms of the municipal solid waste (MSW) were collected from the government designed refuse dumping sites in both, highly dense populated low income areas and government residential areas, during the hottest months of February, March and April and during the raining season in the month of August for three years. The samples were usually collected during the last week of the month, to catch up with the salary payment period which may take care of any change in spending patterns. The waste material was prepared for the determination of the refuse characteristics by sifting through and separated into paper, glass, plastics, metal, wood chips, etc. An initial sieving was carried out using sieves. This was followed by hand picking to remove small stones which could not pass through the sieves. The sample was again sieved again using a 2 mm mesh sieve, before being ground into powder using a porcelain mortar and pestle.

**Experimentals:** A METTLER TOLEDO AB 54 electronic digital weighting machine with limitations of 10 mg minimum and a maximum of 51 grams was used to weight the refuse samples powder. Glass ware equipment include 16 pieces of PYREX conical flasks, pipettes, burettes, beaker, volumetric flask, plastic bottles and filter papers for the titration of the samples; a digital Spectrometer SPECTRUMLAB 22 PC as well as a Gerhardt - Kjeldatherm machine were used to evaluate the organic components of the refuse.
The reagents are Sulphuric acid ($H_2SO_4$), Orthophosphoric acid ($H_3PO_4$), Ferrous sulphate ($FeSO_4$), Sodium Fluoride(NaF), Potassium dichromate ($K_2Cr_2O_7$), Diphenylamine indicator, Kjel tabs, Boric acid, Absolute ethanol, Bromolysol green methyl red, Sodium hydroxide. Nitric acid, acetic acid, magnesium sulphate, gum Arabic, barium chloride. Others are Potassium chloride (KCl), Sodium hydroxide (NaOH), Hydrochloric acid (HCl) and Phenolphthalein indicator. These were used in the chemical analyses to determine the elemental components of the wastes as C (carbon), H (hydrogen), N (nitrogen), S (sulphur) and O (oxygen) [11,12].

**Analytical techniques**
**Proximate analysis:** This is an analysis to obtain the in depth physical picture of the waste [13]; performed by weighting, heating and burning a small sample of waste inside an oven, to determine the moisture content $M'_o$ (in weight percent (w/o) by driving off the free moisture at ~ $107^o$ C for approximately 1 hour. The volatile matter content (V', w/o) is determined by driving off volatile hydrocarbons CO, $CO_2$ and combine $H_2O$ at ~ $950^oC$. The refuse is then burned and the inorganic residue is the ash content (A', w/o). The fixed carbon ($C_f'$, $w/o$) is calculated by difference as shown by Equation (1) [14].

$$C'_{f(w/o)} = 100 - \left[M'_{(w/o)} + V'_{(w/o)} + A'_{s(w/o)}\right] \qquad (1)$$

**Ultimate analysis:** This is an elemental quantitative evaluation of the total carbon (C', w/o), hydrogen (H', w/o), nitrogen (N', w/o), sulphur (S', w/o), oxygen (O', w/o) percentages after removal of the moisture and ash [15, 16]. This analysis was performed using classic oxidation, decomposition, and/or reduction technique to determine, C (carbon content, w/o), H (hydrogen, w/o), N (nitrogen, w/o) and S (sulphur, w/o). Oxygen O' (w/o) was calculated by difference using Equation (2) [14, 17]:

$$O'_{(w/o)} = 100 - \left[C'_{(w/o)} + H'_{(w/o)} + N'_{(w/o)} + S'_{(w/o)} + M'_{o(w/o)} + A'_{s(w/o)}\right] \qquad (2)$$

**Heating or calorific value:** This is a property of fundamental importance. Since the elemental composition has been known during the ultimate analysis, the ash free, dry heating value was calculated to within 2% accuracy using the empirical Dulong- Berthelot relationship [14]:

$$Q'_d = 81.37\,C' + 345\left[H' - \frac{(O' + N' - 1)}{8}\right] + 22.2\,S \qquad (3)$$

All calculations, data interpretation and graphs were carried out and generated using Microsoft Excel, 2010. The mean deviation (M.D) and standard deviation (S. D) were obtained using the statistical formulas in Equations (4) and (5) respectively.

$$M.D = \frac{\sum(x-\bar{x})}{n}\ \% \qquad (4)$$

$$S.D = \sqrt{\frac{\sum(x-\bar{x})^2}{n}}\ \% \qquad (5)$$

## III. RESULTS AND DISCUSSION

Physical characteristics of the refuse as well as the proximate and ultimate analyses results in each of the towns with higher population density; Sokoto, Gusau and Birnin Kebbi, are as shown in Tables (1 to 3) while Figure 1 depicts the calorific value's trend of the MSW. All samples taken at the various refuse dumping sites contain a large proportion of sand which had to be removed prior to any measurement. This sand was found to be an inert element in the recycling, composting and the combustion processes. Sand traces however minimal affect the quality of the finished product mainly when plastic recycling is being considered. During the composting process also, sand negatively affects the quality of the compost as it cannot be decomposed [18]. Physical characterization showed wood, grass, metal, plastic, food remnants, leaves, glass and paper were present in varying proportions in all waste samples in the study area.

**Table 1:** Physical composition of the waste in the study area

| Locality | Components (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Wood | Grass | Paper | Leaves | Food remnants | Plastic | Metal | Glass |
| Sokoto | 20.07 | 5.02 | 8.82 | 8.54 | 6.88 | 17.63 | 15.85 | 7.35 |
| Gusau | 17.99 | 17.11 | 8.18 | 14.99 | 8.03 | 16.27 | 10.73 | 6.70 |
| Birnin Kebbi | 19.78 | 5.35 | 9.82 | 5.48 | 5.98 | 34.58 | 12.96 | 6.04 |

**Table 2:** Proximate analysis of waste samples in the study area.

| Locality | Elements (%) | | | |
|---|---|---|---|---|
| | Moisture (w/o) | Volatile matter (w/o) | Ash (w/o) | Fixed Carbon (w/o) |
| Sokoto | 21.426 | 25.062 | 30.010 | 23.502 |
| Gusau | 24.535 | 22.145 | 36.130 | 17.190 |
| Birnin Kebbi | 21.427 | 24.103 | 34.470 | 19.982 |

**Table 3:** Ultimate analysis of waste samples in the study area.

| Locality | Elements (%) | | | | |
|---|---|---|---|---|---|
| | C (w/o) | H (w/o) | N (w/o) | S (w/o) | O (w/o) |
| Sokoto | 21.940 | 0.430 | 1.061 | 0.745 | 24.398 |
| Gusau | 20.460 | 0.400 | 1.437 | 0.930 | 16.508 |
| Birnin Kebbi | 23.420 | 0.420 | 1.248 | 0.083 | 18.934 |

The calorific value is a complex function of the elemental composition of the refuse or waste. The variation in the lower calorific values (LCVs) of refuse (figure 1) (i.e. 5.164 MJ/kg in Sokoto, 5.362 MJ/kg in Gusau and 5.494 MJ/kg in Birnin Kebbi) was due to differences in the gradation of the constituent materials as well as the heterogeneous nature of MSW. Slight changes in moisture content, physical constituents and physical appearance can heavily influence the heat content. The refuse LCV in Sokoto with the highest population density is lower than the one in Birnin Kebbi which has a relatively lower population density; while Gusau has an average value of the LCV from Birnin Kebbi and Sokoto. These variations could also be attributed to eating habits of the population; population's purchasing habits, age repartition of the population as well as gender repartition. The standard deviation and mean deviation of the LCVs for the 3 cities are: 0.003% and 4.20% respectively. This shows that the differences in LCVs are not significant even though these cities are in the same eco- zones and their population densities are not the same.

In all the cases incineration process needed supplementary fuel because their LCVs are lower than the 7.50 MJ/kg to 12.00 MJ/kg; an acceptable recommended range suggested by Whiting [19].

Biomasses in the form of bagasse, water hyacinth, straw and other herbaceous crops solely grown for their energy qualities are abundantly found in the study area, notably in the areas of Talatan Mafara, Jega and Ya'uri, Rima river basin in Zamfara, Kebbi and Sokoto states respectively. These areas are major producers of sugar cane and could provide a huge quantity of bagasse and other Fadama related biomasses. These biomasses can be used as supplementary fuel in the incineration process, at up to 50% of the total fuel load in the incinerator to make up for the low calorific value of the MSW.

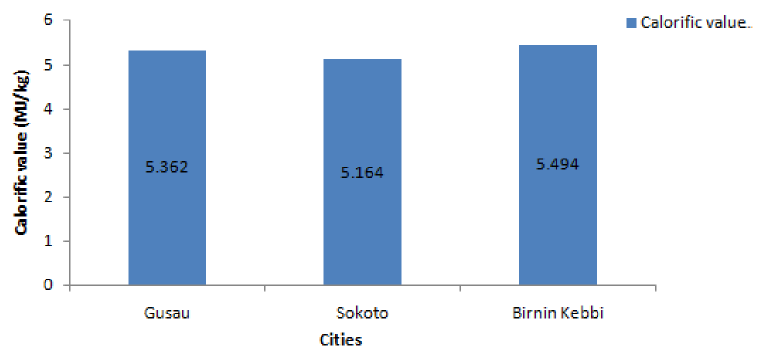


Figure 1: Average Calorific value of MSW in the study area (MJ/kg)

Population density and geographic locations are not real determining factors as whether refuse quality may change or not but rather the life style of the population and the level of awareness towards waste management efficient practices. This behaviour would help in adjusting and setting the incinerator in case of lower moisture contents by modifying the air supplies and altering the supplementary fuel quantity supply rates. Municipal solid waste characterization is a strategic base while planning the total waste management chain, from collection to disposal. It provides a basis for setting priorities in the waste management hierarchy and decides of the possible management strategies to be adopted. It also provides job opportunities in the process of collection and sorting of the MSW; at every stage of the waste management hierarchy and thus allows for interaction among the environmental, economic and social aspects of waste management.
Agricultural development and poverty reduction are constrained by the impact of climate change in the Sahel. Over time, with the proper projection the solid waste characterization will constitute a basis for an energy strategy and policy development; when environment becomes a focal point, with correct data collection and delivery. Energy policy formulation in every country needs to rely on available information on proven and non proven resources; those energy resources, both renewable and non renewable. This study could constitute a basis for that much needed energy policy formulation.

## IV. CONCLUSION

The following conclusions were made based on the findings of this work:

a. Physical characterization showed that wood, grass, metal, plastic and paper were the constituents of all waste samples in the study area, but in varying proportions.
b. Proximate and ultimate analyses of refuse in the area of study showed refuse characteristics as: Moisture: Volatile matter: Ash content: Fixed carbon, as 21.426: 25.062: 30.010: 23.502 and 21.427: 24.103: 34.470: 19.982 for Sokoto and Birnin Kebbi, respectively.
c. The LCVs were low and found to range between 5.164 and 5.494 MJ/kg, which falls below the limit for the production of steam suitable to sustain an industrial incineration process for electricity generation.
d. To make up to the low calorific values, a supplementary fuel; as bagasse, straw or water hyacinth; would be needed should incineration with energy recovery be considered.
e. The knowledge of the refuse LCV alone is not enough to conclude whether the refuse will burn rapidly and effectively or not. Its moisture content is an essential determining parameter.

**NOMENCLATURE**

$Q'_d$ - dry heating value, MJ/kg.
$M'_o$ (w/o) – moisture content in weight percent
V' (w/o) - volatile matter content in weight percent
A' (w/o) - ash content in weight percent
$C'_f$ (w/o) - fixed carbon content in weight percent
(C', w/o) - total carbon in weight percent
(H', w/o) – total hydrogen in weight percent
(N', w/o) – total nitrogen in weight percent
(S', w/o) – total sulphur in weight percent
(O', w/o) – total oxygen in weight percent
C (w/o) - carbon content in weight percent
H (w/o) - hydrogen content in weight percent
N (w/o) - nitrogen content in weight percent
S (w/o) - sulphur content in weight percent
O' (w/o) - Oxygen content in weight percent

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