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Experimental Characterization of Municipal Solid Waste for Energy Production in Niger Republic

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Abstract Solid waste management and energy generation have been of major concern in Niger Republic. 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 Diffa, Dosso, Maradi, Niamey and Zinder in Niger Republic. 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 of refuse in the area of study showed refuse characteristics as moisture: volatile matter: fixed carbon: ash content, as 19.693: 26.877: 19.310 and 34.120 for Niamey and 17.539: 25.950: 19.111: 37.40 for Zinder. The standard deviation and the mean deviation of the lower calorific value were found to be 7.35% and 1.60 % respectively for the five cities in the study area. The lower calorific values of the refuse were low and found to fall below the limit for the production of steam in electricity generation, therefore would not to be able to sustain an industrial incineration process. There is need to provide a supplementary fuel in the form of bagasse, any herbaceous biomass at up to 50% of the total fuel to be loaded in the incinerator. 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 techniques like recycling, re-use and composting.

Keywords: *municipal waste, ultimate analysis, proximate analysis, calorific value, energy from waste, Niger Republic*

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1. Introduction

The West African country of Niger republic has oil potentials, however largely unexplored as well as abundant solar energy and large uranium ore deposits. Niger Republic has been and still remains a net importer of electricity as 90% of its electricity needs is met from Nigeria by Power Holdings Company of Nigeria (PHCN) even though the country started its oil exploitation, production and distribution by the end of year 2011 [1].

According to the 2013 national population census conducted in Niger republic, the population has reached 17,129,076 people with 49.45% men and 50.6% women [2]. The country was ranked very low in the 2013 Human Development Index of the United Nations Development Programme, with 76 per cent of its people living on less than US$2 a day [3], and yet having one of the youngest populations in the world [4].

The SIE- Niger [5] report for Niger Republic showed that households’ basic electricity consumption was 49%, against 39% for industries, 11% for commerce and services and 1% for agro-water schemes, for a total of 491Gwh. The rural population being 84% of the total population consumed only 1% of the final households’ electricity against the urban population, being 16% of the total population, consuming 99% of the total electricity. Solar energy, biomasses, wind energy are very much under-utilized, with firewood used at 84% of the overall domestic energy uses [1].

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 facilities are not available. This is so because very large numbers of different disease-producing organisms can be found in wastes [6]. This improper and inefficient disposal of municipal solid wastes (MSW), particularly in Niamey, has been one of the main causes of recent floods.

A full understanding of refuse characteristics is crucial in the decision making stage when the “best option disposal” is to be made; and most importantly when electricity generation is being considered [7-12]. Several researches [13,14] mention that sand is found in proportions varying between 30% and 50% of the municipal solid wastes collected. They tend to compare and base their studies on developed countries models from France, USA but fail to realise that the priorities and goals are different.

While developed countries are developing techniques and technologies of waste avoidance, developing countries are still wrestling with which technology of waste treatment or management to adopt. Wastes, irrespective of their nature, source or effects; are dumped haphazardly, treatments options short- term focused, changed at will and not adapted to the wastes categories.

Treatment methods differ in dealing with different waste streams, and huge amounts of wastes are generated by municipalities and need to be removed from the environment. Amidst various waste treatment methods like recycling, composting; incineration is the thermal treatment method of solid wastes dealing with the non-reusable and non-organic portion of wastes; it offers the advantages of: recovering the heat content of the wastes, reduction in the volume and mass of wastes (up to 90% of the volume and up to 75% of the mass); detoxification (incineration can achieve almost 100% destruction of any pathogen, toxic, or hazardous substance contained in the waste, to make them suitable for final disposal) and destruction of organic components of biodegradable waste that may generate landfill gas (LFG) [15].

This paper presents the experimental characterization of municipal solid wastes in the southern part of Niger Republic for electricity generation. The primary sources of the MSW, and their availability were identified; through collection, sampling, separation and laboratory analysis. Determination of the MSW combustion characteristics and evaluation of the amount of energy to be obtained from such wastes, were also carried out using the proximate, ultimate analyses and the Dulong-Berthelot formula.

2. Materials and Methods

2.1. Study Area

Major cities of the southern part of Niger Republic, with high population densities and intense industrial or commercial activities constitute the area of study. These cities are: Diffa, Dosso, Maradi, Niamey and Zinder.

2.2. Data Collection

Ten (10) kilograms of the 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.

2.3. 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.

2.4. Analytical Techniques

2.4.1. Proximate Analysis

This is an analysis to obtain the in depth physical picture of the waste; 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°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°C. 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) [16].

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

2.4.2. 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 [17], [18]. 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) [19]:

$$Q'_{(w/o)} = 100 - \left[\begin{array}{l} C'_{(w/o)} + H'_{(w/o)} + N'_{(w/o)} \\ +S'_{(w/o)} + M'_{(w/o)} + A'_{(w/o)} \end{array} \right]. \quad (2)$$

2.4.3. 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 [16]:

$$Q'_d = 81.37C' + 345\left[H' - \frac{\left(O' + N' - 1\right)}{8} \right] + 22 \quad (3)$$

where:

Q'_d - dry heating value, MJ/kg.

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.

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

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

3. 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; Diffa, Dosso, Maradi, Niamey and Zinder, are as shown in Table 1 to Table 3 while Figure 1 depicts the calorific value 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. While this sand was found to be an inert element in the combustion process, it is not so the recycling and composting 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 [20]. 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. These organic and biodegradable components of the refuse (Table 1), which account for an average of 57% of the total refuse, would need to be sorted at first, then recycled, composted or re-used for a thorough and integrated solid waste management scheme. Jobs creation can be thought of at the sorting, separation, recycling and composting stages.

Table 1. Physical composition of the waste in the study area

Locality	Components (%)							
	Wood	Grass	Paper	Leaves	Food remnants	Plastic	Metal	Glass
Diffa	19.84	15.05	12.48	5.78	5.53	29.38	6.99	4.95
Dosso	16.92	10.19	21.29	13.35	4.90	17.91	10.93	4.51
Maradi	22.29	4.30	12.06	7.63	4.55	31.32	10.30	7.55
Niamey	29.29	9.69	4.85	10.91	8.30	19.76	7.33	9.87
Zinder	19.74	7.66	8.43	6.33	3.85	29.05	17.03	7.90

The desertic nature of the study area, economic situation, coupled with the huge electricity consumption and lack of proper solid waste management imposes the adoption of a suitable energy production scheme. Not every component of the refuse can be recycled, composted or re-used. The non-recyclable, non-compostable and non-reusable portion of the refuse would need to be taken care of. Options and solutions to problems are mostly locations specific. Incineration of the left over portion of the MSW for electricity production would need to be considered.

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

Locality	Elements (%)			
	Moisture (w/o)	Fixed Carbon (w/o)	Volatile matter (w/o)	Ash (w/o)
Diffa	17.411	23.489	24.960	34.140
Dosso	23.318	12.532	31.920	32.230
Maradi	22.819	11.051	34.520	31.610
Niamey	19.693	26.877	19.310	34.120
Zinder	17.539	19.111	25.950	37.400

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)
Diffa	24.960	0.360	0.792	0.054	22.279
Dosso	24.920	0.130	1.018	0.065	24.090
Maradi	23.916	0.230	1.926	0.022	19.477
Niamey	26.877	0.510	0.986	0.036	17.778
Zinder	20.261	0.330	0.583	0.075	23.812

The calorific value is a complex function of the elemental composition of the refuse or waste. The standard deviation and the mean deviation of the lower calorific value were found to be 7.35% and 1.60 % respectively for the five cities in the study area. These variations in the lower calorific values (LCVs) of refuse (Figure 1) (i.e. 5.86 MJ/kg in Niamey, 5.02 MJ/kg in Zinder) were due to differences in the gradation of the constituent materials as well as the heterogeneous nature of MSW. These results also show that slight changes in moisture content, physical constituents and physical appearance heavily influence the heat content of the municipal solid waste.

The refuse LCV in Niamey with the highest population density was high due to high rate of urbanization and the cosmopolitan nature of the city. However, the LCV of the waste in Diffa which has a relatively lower population density exceeds that of Zinder which has a higher population density while it approaches the one of Maradi, a city with more commercial activities. The differences in LCVs are not significant even though these cities are in the same eco-zones but their population densities are not the same.

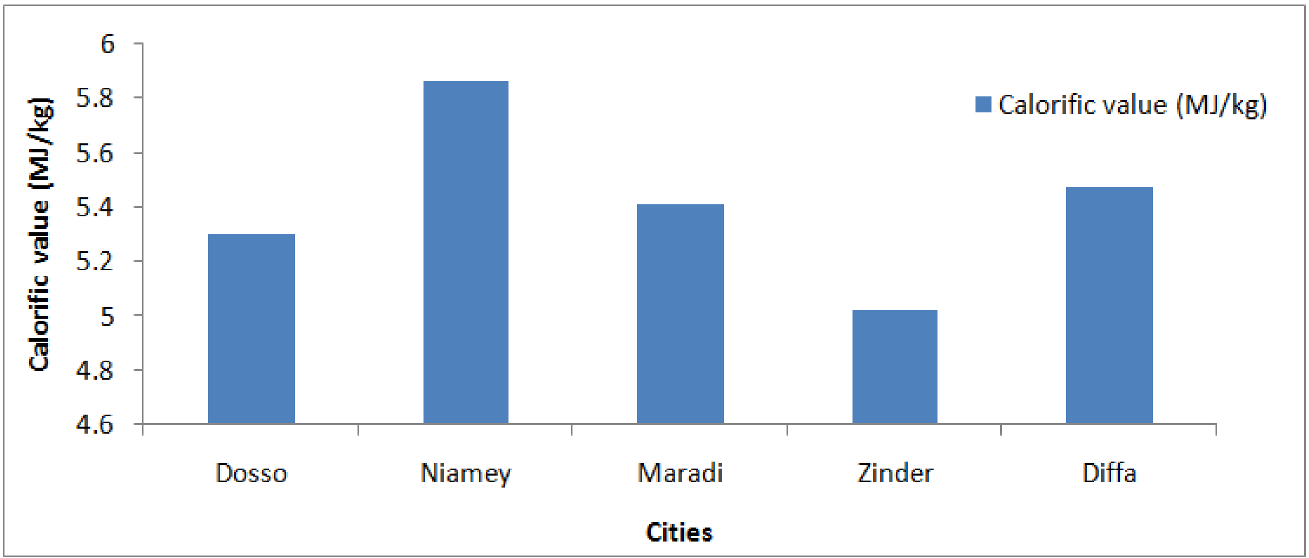

Figure 1. Calorific value of the MSW in the study area (MJ/kg)

In all these cases, electricity production through incineration process needs supplementary fuel because the LCVs in the study area are lower than the 7.50 MJ/kg to 12.00 MJ/kg (an acceptable recommended range suggested by Whiting [21]. Biomasses in the form of bagasse, water hyacinth, straw and other herbaceous crops, known for their energy qualities are abundantly found in the study area as wastes [1], notably in areas of Gaya, Konni, Magaria, Kantche, Diffa, which are major producers of sugar cane in Niger Republic. 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.

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 practices such as recycling, composting and/or re-use. 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.

4. Conclusion

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

1. Physical characterization showed wood, grass, metal, plastic and paper were present in varying proportions in all waste samples in the study area. Proximate and ultimate analyses of refuse in the area of study showed refuse characteristics as: Moisture: Volatile matter: Fixed carbon: Ash content, as 19.693: 26.877: 19.310: 34. 120 for Niamey and 17.539: 25.950: 19.111: 37.40 for Zinder.

2. 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 its awareness towards waste management.

3. To make up to the low calorific values, a supplementary fuel; as bagasse, straw or water hyacinth; would be needed at up to 50% of the total fuel load of the incinerator.

4. An integrated solid waste management scheme could be used to provide supplementary energy in Niger Republic, reduce the dependence on fossil fuel; and the same time to provide a clean and healthier environment as well as provide job opportunities to a certain portion of the population, engaged in collection, sorting, recycling and composting.

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