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STATISTICAL MODELLING OF THE ENERGY CONTENT OF MUNICIPAL SOLID WASTES IN NORTHERN NIGERIA

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Abstract
The ability to predict the quantity of energy to be produced is of paramount importance in every country. It would assist in setting up a waste management plan which will lead to a sustainable energy policy. This paper presents the development of a statistical linear regression mathematical model to predict the amount of energy contained in municipal solid wastes from the knowledge of such characteristics of the wastes as physical composition and/or moisture content. Major cities of Kano, Katsina, Dutse, Damaturu, Maiduguri, Bauchi, Birnin Kebbi, Gusau and Sokoto in Northern Nigeria, with high population densities and intense industrial activities constituted the area of study. Ten kilogram each, of the municipal solid waste was collected from the government designated 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 rainy season in the month of August for three years. The waste material was prepared for the determination of its physical characteristics by sifting through. Proximate, ultimate analyses and calorific values were determined using ASTM analytical techniques and formulas from the literature. An empirical linear regression based mathematical model was developed using statistical methods and experimental data. Comparison between experimental and predicted values of the calorific values showed an agreement of about 70% with an average deviation of 5.03% while the standard deviation was found to be 5.29%.

Keywords: Mathematical model, municipal solid waste, energy policy, calorific value, moisture content.

1. Introduction

Energy problems and solutions should always be guided by local economic, environmental and social considerations. Energy policy formulation should bring together national energy development policies with the locally perceived priorities. There needs to be increased emphasis on non-fossil fuel alternatives to the provision of energy services in developing countries (FAO, 2016).These alternatives range from the modern renewable energy sources, such as improved biomass conversion (including liquid biofuels, biogas, gasification, incineration), solar energy (PV), wind and geothermal energy and small-scale hydropower, to lower energy intensity industries, material and energy recycling and better means of utilizing traditional energy sources, such as improved cooking stoves. Developing countries in general produce more wet waste with lower calorific value but if dried it can easily reach high calorific values. The improvement of waste collection and treatment in those countries is slow and mostly not integrated (Filip and Niko, 2013).

One of the most difficult tasks in waste management remain the prediction of the nature and composition of the waste, its moisture content as well as the energy content when waste-to-energy schemes are to be considered. Beigl *et al.* (2003) opined that an understanding of the relationships between the quantity and quality of environmentally relevant outputs from human processes and regional characteristics is a prerequisite for planning and implementing ecologically sustainable strategies. Apart from process-related parameters, continuous and discontinuous socio-economic long-term trends often play a key role in the assessment of environmental impacts. Karajgi *et al.* (2012) modelled the generation of electrical energy from municipal solid wastes (MSW). They emphasized that it is a complex process since the waste has to undergo various unit operations before it is put in to the process of energy production. The modelling of power generation from MSW therefore has to include all these unit operations, waste flow paths etc. The modelling must also be capable of providing information on important issues like economic, environmental, among many others.

All difficulties lie in the heterogeneous nature of the MSW which makes it even difficult to design and develop a thermal treatment plant. These difficulties thus make the development of a mathematical model a necessity. This paper presents the development of a statistical mathematical model to predict the amount of energy contained in MSW from the knowledge of such characteristics of the wastes as physical composition and/or moisture content. Source separation and collection centres separation are only suitable for places where the waste management authority is well structured and equipped, and places where poverty, homelessness, roads, and other infrastructures are no longer a problem.

2. Materials and Methods

2.1 Study Area

Major cities of Northern Nigeria, with high population densities (National Bureau for Statistics, 2006) and intense industrial activities constitute the area of study. These cities are Kano, Katsina, Dutse, Damaturu, Maiduguri, Bauchi, Birnin-Kebbi, Gusau and Sokoto in Kano state, Katsina state, Jigawa state, Yobe state, Borno state, Bauchi state, Kebbi state, Zamfara state and Sokoto state, respectively.

2.2 Data Collection

Ten kilogram of the municipal solid waste (MSW) was collected from the government designed refuse dumping sites in both, high densely populated low income areas and government residential areas, during the dry season corresponding to hottest months of the year (February, March and April) and during the raining season in the month of August for three years (2012-2015). The samples were collected twice a month. Collection was done in a random manner and carried out across the waste dump using shovels. First collection was carried out midway in the month and the second collection during the last week of the month. This was done so, as to account for fluctuations in patterns due to the salary payment period and other 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 to remove sand. This was followed by hand picking at first to remove small stones which could not pass through the sieves and then crushing inside the mortar to a fine powder.

2.3 Experimental

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 including 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 used 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) using ASTM D 874, ASTM D 4530, ASTM D 5453 and ASTM D 1160 respectively (Behling *et al.*, 2012).

2.4 Analytical Techniques

Proximate analysis of the MSW was carried out using the method suggested by Elmer (1966) 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) was determined by driving off volatile hydrocarbons CO, CO_2 and combine H_2O at ~ 950^oC. The refuse was then burned and the inorganic residue was the ash content (A', w/o). The fixed carbon ($C_f^{'}, w/o$) was calculated by difference as shown by Equation (1) (Weisman and Eckart 1985).

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

2.4.1 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 (Tabatabai, 1974). This analysis was performed using classic oxidation, decomposition, and/or reduction technique (Golightly and Simon, 1989) 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) (Weisman and Eckart 1985; Lee and Hauffman, 2001):

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

2.4.1 Heating or Calorific Value

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 (Weisman and Eckart 1985):

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

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

$$AverageDeviation(A.D) = \frac{1}{n}\sum\left(\frac{LCV_{pred.} - LCV_{exp.}}{LCV_{exp.}}\right) \times 100 \quad (4)$$

$$StandardDeviation(S.D) = \sqrt{\frac{1}{n}\sum\left(\frac{LCV_{pred.}-LCV_{exp.}}{LCV_{exp.}}\right)} \times 100 \quad (5)$$

3. Results and Discussion

Physical characterization of the MSW showed that 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 shows the source of secondary data for the model to be generated.

Table 1: Physical Composition of the Waste in the Study Area

Locality	Components (%)							
	Wood	Grass	Paper	Leaves	Food remnants	Plastic	Metal	Glass
Kano	28.46	6.57	9.66	8.92	6.79	18.99	12.58	8.00
Damaturu	16.62	11.48	3.58	16.24	6.03	38.20	3.64	4.21
Maiduguri	27.28	5.59	6.69	13.17	6.17	32.56	2.94	5.599
Dutse	19.04	5.73	11.34	19.14	5.94	23.93	6.46	8.39
Bauchi	22.28	6.29	14.86	13.83	5.12	24.93	7.80	4.87
Katsina	24.75	6.05	10.52	15.57	4.35	20.46	9.76	8.54
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
BirninKebbi	19.78	5.35	9.82	5.48	5.98	34.58	12.96	6.04

(Source: Oumarou *et al.*, 2012a and b)

MSW characteristics form each city of the study area such as the basic constituents of the waste are considered. Of prime importance are the moisture content, ash content and volatile matter. These form the basis of the model, which is empirical in nature. Thus a linear regression mathematical model developed using the knowledge of the physical component of the MSW in the study area is as shown in equation below:

$$Q'_d = 1.0325 - 0.0011a + 0.2254b - 0.0046c - 0.0068d + 0.3184e - 0.0119f - 0.0053g + 0.1099h. \quad (6)$$

where: Q'_d is the calorific value of the MSW and represents the independent variable of the model. Variables a, b, c, d e, f, g and h represent the percentage composition, after drying, of Wood, Grass, Paper, Leaves, Food remnants, Plastic, Metal and Glass respectively.

Table 2: Average Actual and Predicted Generated Values of Calorific Values of MSW in the Study Area.

Locality	Actual Calorific value (MJ/kg)	Predicted Calorific Value (MJ/kg)
Kano	5.667	5.1255
Katsina	5.345	5.3837
Maiduguri	5.078	4.3191
Damaturu	5.277	4.6152
Dutse	5.379	4.0908
Bauchi	5.476	4.2431
Gusau	5.362	4.7479
Sokoto	5.164	7.7724
BirninKebbi	5.494	7.9444

Average Deviation (A.D) = 5.03%, Standard Deviation (S. D) = 5.29%

A comparative analysis of the results in Table 2 show an agreement of 69.6% say 70% between the actual experimental values of the calorific values and those values predicted by the statistical model. This model takes into consideration all the components of the MSW even though some components such as glass, metal and some plastics could easily find their ways back to the usefulness stream. 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 separated at first, then recycled, composted or re-used. Other components such as wood, leaves, paper, certain category of plastic from which very little or no other future benefits could be derived, and grass would be left over.

Energy policies either local or national are directed by the three main objectives, namely the security of supply, the competitiveness of the energy market, and the environmental protection (Doukas *et al.*, 2008). Even though this research is not directly focused towards the development of an energy policy, it would assist in achieving some the keys objectives; namely the security of supply and the environmental protection. The fact that energy policy is developed through a number of social and economic challenges makes this model suitable to the local waste management schemes which are largely based on the informal sector, made of scavengers and town/ city cleaners often grouped now into associations, groups. Waste management is not only about removing waste from the environment and returning it as new products or raw material. It is also a tool of social integration and economic well-being. A collection scenario focused on material recovery and recycling from municipal solid wastes in a selected metropolis of the Sub-Saharan region of Nigeria and Niger republic was designed. The scenario involved 2000 respondents/participants operating at open dump areas. Data obtained were analyzed using simple statistical methods and their findings revealed an annual estimate of the recovery as 16.8 tons of bottles/glasses, 158.4 tons of plastics/rubber, and 264 tons of metal. It also indicated that considerable amount of money could be made from material recovery and recycling. These recoverables have paved great means of livelihood to many people involved in this activity. In addition to this, governments must pose suitable environmental and economic policies and the free market imposes the necessary energy changes.

4. Conclusion

At present there are no environmental models in the study area that take care of energy potentials of municipal solid wastes. The present approach integrates the impacts of regional socio-demographic and economic dynamics on the municipal solid waste generation. A qualitative approach was combined with the econometric methodology in order to assess these relationships for nine heterogeneous cities representing the northern Nigeria.

The results showed that the model, with about 70% agreement, can be implemented as a helpful decision support tool for energy policy set-up. In future work, this model will be statistically refined by eliminating all components of the municipal solid waste from which a secondary or additional value could be derived (especially glass, metal, plastics, organic components).

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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