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MODELING THE ENERGY CONTENT OF MUNICIPAL SOLID WASTE (A Case Study of Minna Metropolis)

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ABSTRACT

Waste management has assumed importance due to environmental hazards and rapid depletion of the resources of almost all the minerals. Considering the bulk quantity which form the waste in municipal areas, its utilization is posing a challenge to the environment and our natural resources. A physical characterization was performed on 120kg of MSW sampled for one week. Also an ultimate analysis was carried out on 2kg sample of waste mixed thoroughly. The results of physical characterization show there are 30.58% of paper, 29.53% of plastic, 17.17% of food waste, 32.83% of polythene, 16.42% of metals and 18.58% of glass wastes respectively. Also the ultimate analysis shows that there are 36.53% of carbon, 10.09% of Nitrogen, 3.39% of Hydrogen, and 1.10% of Sulphur, 37.37% of ash content and 11.52% of oxygen content respectively. About 23,450kg of waste was open dumped by NISEPA trucks during the study period. A HHV of 5840659.35KJ/120kg was obtained, and it was also found that approximately 488MW of electricity could be generated from the waste materials dumped at the landfill annually.

Keywords *— Characterization, Ultimate Analysis,Model, Municipal Solid Waste (MSW), Analysis of Variance (ANOVA).*

Hn: Net calorific value (kcal/kg).
R:Plastic, percent weight on dry basis.
G:Garbage, percent weight on dry basis.
P:Paper, percent weight on dry basis.
Pl: Plastic, percent weight on dry basis.
Po:Polythene, percentage weight on dry basis.
W:Water, percent weight on dry basis.
C:Carbon, percent by weight.
H:Hydrogen, percent by weight.
O:Oxygen, percent by weight.
S:Sulphur, percent by weight.
N: Nitrogen percent by weight.

1.0 INTRODUCTION

Waste management has assumed importance due to environmental hazards and rapid depletion of the resources of almost all the minerals(Lino, Bizzo, & Ismail, 2010). Considering the bulk quantity which form the waste in municipal areas, its utilization is posing a challenge to the environment and our natural resources(Adebayo, Emmanuel, Olapeju, & Tosin, 2012).MSW being, one of the source and causes of environmental pollution. So, there is accompanying need of recovering and utilizing resources from the waste materials and as well minimizing the impact of waste on the environment. Besides, Effective waste management can help us to meet regulatory requirements, recycling targets and reduce disposal cost which has been a major challenge to the local authorities(Consoni, Giugliano, & Grosso, 2005).And also reduce environmental contamination which in a long run leads to severe health conditions. (Nandini, Girish, & Prakash, 2014).

This research study was motivated by the waste disposal problem of Minna metropolis. Minna is located within the Lat. 9° 32" – 9° 40" and 6° 30" – 6° 36" and has a population of about 400 thousands inhabitants according to 2006 population census andper capital daily generation of MSW 0.44kg/day (Anijiofor, 2010).Minna metropolis is divided into five (5) zones for the collection of the MSW namely: Kpakungu, Maitumbi, Chanchaga, Bosso and Tunga by Niger State Environmental Protection Agancy (NISEPA).One of the very important research question in mind with respect to MSW is to know the energy content of the waste. At present there are three types of models that are used to predict the energy content of MSW i.e: Physical composition, Ultimate analysis and Proximate analysis.

The physical composition analysis is based on the levels of plastics, paper, polythene, metals and garbage (food wastes, textiles, and garden) wastes respectively in MSW. The ultimate analysis of waste typically involves determination of C (carbon), H (hydrogen), O (oxygen), N (nitrogen), and S (sulfur), while the proximate analysis includes an assessment of the levels of moisture, volatile combustible matter, fixed carbon, and ash. Table 1 presents a summary of the equations/models commonly used to predict the energy content of MSW, based on the analytical profiles listed, (Julius, 2005).

Table 1: *Models/Equations for predicting the energy content of municipal solid waste (Julius, 2005)*

1. Models Based on Physical Composition Analysis

Conventional Equation

$$Hn = 88.2R + 40.5(G + P) - 6W \quad 1$$

2. Models Based on Ultimate Analysis

Dulong's Equation

$$Hn = 81C + 342.5\left(H - \frac{O}{16}\right) + 22.5S - 6(9H + W) \quad 2$$

Steuer's Equation

$$Hn = 81\left(C - 3 * \frac{O}{8}\right) + 342\left(H - \frac{O}{16}\right) + 22S - 6(9H + W) \quad 3$$

Scheure-Kesiner's Equation

$$Hn = 81\left(C - 3 * \frac{O}{8}\right) + 342.5H + 22.5S + 57 * 3 * \frac{O}{4} - 6(9H + W) \quad 4$$

3. Models Based on Proximate Analysis

Traditional Equation

$$Hn = 45B - 6W \quad 5$$

Where B = Combustible volatile matter in MSW (%).

Bento's Equation

$$Hn = 44.75B - 5.85W + 21.2 \quad 6$$

2.0 MATERIALS AND METHOD

This section presented the materials and methodology used in achieving the aims and objectives of this study, as outlined in Figure I. this include sample completion and preparation, physical and ultimate analysis characterization. Also discussed, is the strategy used for modelling the energy content of Minna municipal solid waste (MSW).

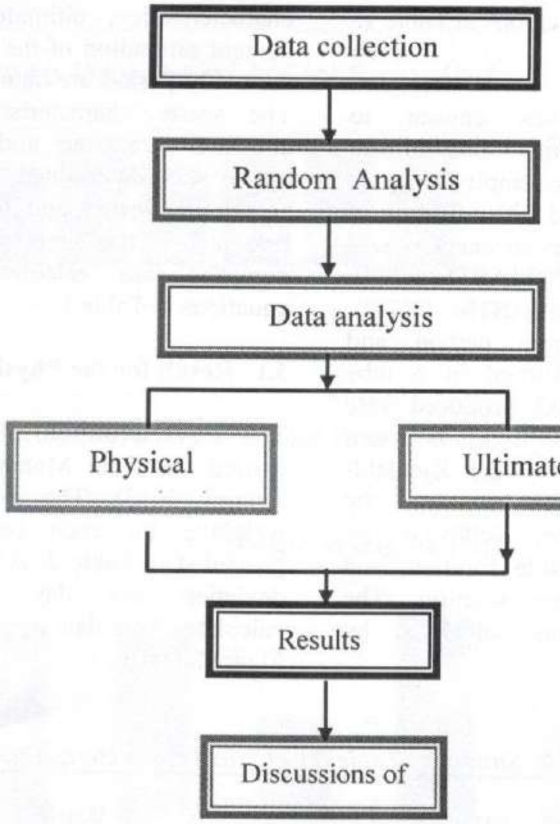

Figure 1: Methodology Chart.

2.1 Materials Used

The following materials were used in the execution of this research work, they are:

- A weighing scale (a pocket balance of 50kg).
- Shovel for mixing various components of solid waste.
- Sacs for collection of waste (Bacco sacs).
- A tray for drying of the solid waste.
- A stainless steel container. ($0.2m^3$)

2.2 Sampling Protocol

The stratified sampling technique was adopted for the collection of the representative municipal solid waste from all the 5 zones in Minna Municipal. Different categories of waste such as paper, plastic, polythene, food garbage, metal and bottles were sampled upon the arrival of the trucks. In this part only municipal solid waste trucks were considered in taking the samples. The waste from the assigned truck was dumped onto a clean, impervious floor where it was mixed rapidly with a shovel and quartered. One shovel was extracted from each quarter, then was mixed and quartered again. In order to obtain accurate measure of waste characterization, the original plan called for sorting approximately 100kg of MSW which can be considered as a representative of the total MSW composition in the study region.

2.3 Data Analysis

The sampled solid waste was characterized as discussed below. A statistical analysis (ANOVA) was performed using MS-Excel 2012.

2.4 Physical Characterization

The physical characterization (ASTM E889) generally involves the separation of different solid waste into paper, plastics, garbage, polythene, metal and bottles. This was carried out at the open dumping site at Maikunkele-Minna Niger state, at the end of the physical separation of the MSW, each of the subsamples were respectively weighted. The recorded results are shown in the Table 2.The energy content of the sample was determine using equations in Table 1.

2.5 Ultimate Analysis

Ultimate analysis was chosen to characterize the chemical composition of the organic matter in MSW. The sample used for ultimate analysis were measured with a 0.1m^3 of a stainless steel container. Elemental analysis was according to (C [ASTM E777], H [ASTM E777], O, S [ASTM E775], and N [ASTM E778]), (Agboola, 2011). To measure carbon and hydrogen, the sample was burned in a tube furnace while the water and CO_2 produced were thereby absorbed and analyzed. Nitrogen concentration was measured by the Kjeldahl-Gunning method. Sulfur was measured by conversion to sulfur-dioxide, followed by absorption in hydrogen peroxide solution, and titration with barium acetate solution. The concentration of oxygen was calculated by difference.

3.0 RESULTS AND DISCUSSION

The results of the physical characterization, ultimate analysis and energy content estimation of the MSW deposited during the study period are summarized in this section. The waste characteristics for physical and chemical parameters and composition of refuse waste was determined for various groups of samples collected and then average values are presented in this section. Thereafter, the energy potential was calculated using the model equations in Table 1.

3.1 Result for the Physical Characterization

The characterization of the solid waste was carried out from Monday to Saturday (7th-12th January 2013). The average of five samples weighted for each constituent per day are presented in Table 2. Also average and standard deviation per day per constituents are calculated.This data are presented graphically in Figure 2 and 3.

Table 2: Summary Table for physical characterization.

Days	Paper weight (kg)	Plastic weight (kg)	garbage weight (kg)	Polythene weight (kg)	Metal weight (kg)	Bottle weight (kg)	Average	S.D
1	22	37	16	25	17.50	10	21.25	9.28
2	27.50	43	15	36	17	15.50	25.67	11.86
3	35	17.50	30	27.50	14	12	22.67	9.43
4	31.50	30	18	35.0	18.50	16	24.83	8.24
5	38	28	12	39.50	17.50	23	26.33	11.02
6	29.50	23.50	12	34	14	35	24.67	9.92
Ave	30.58	29.83	17.17	32.83	16.42	18.58	24.24	9.96
Total	182	179	103	197	98.50	112	145.20	45.37

From the summary Table 2, it is evident that polythene waste has the highest composition (approximately 32.83%) basically because it is the major constituent of the waste. This is as a result of high rate of its usage for domestic, commercial as well as industrial applications.The least categories of waste products in the landfill are the paper, plastic and bottle waste which made an average composition of about (30.58%, 29.83% and 18.53%respectively). Whereas the metal and bottle component has the lowest composition with a minimal volume of (16.42% and 17.17%) with the fact that lower volume were recorded due to infrequent usages of these waste within the municipality of the study area.

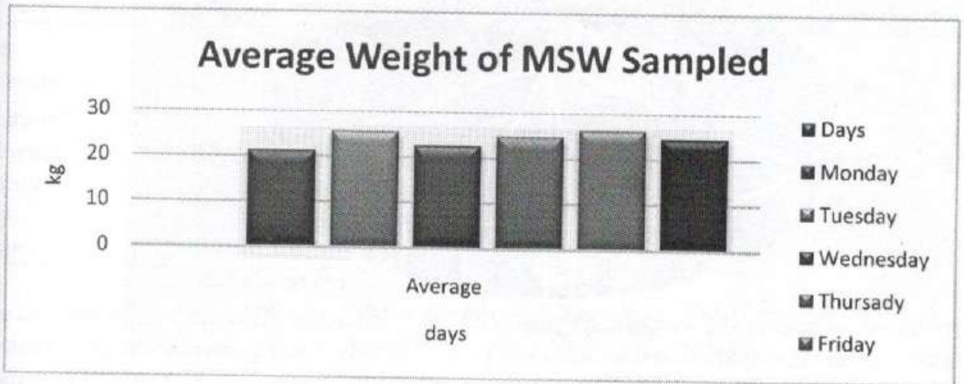

Figure 2: Average Weight of Sampled Garbage during the study period

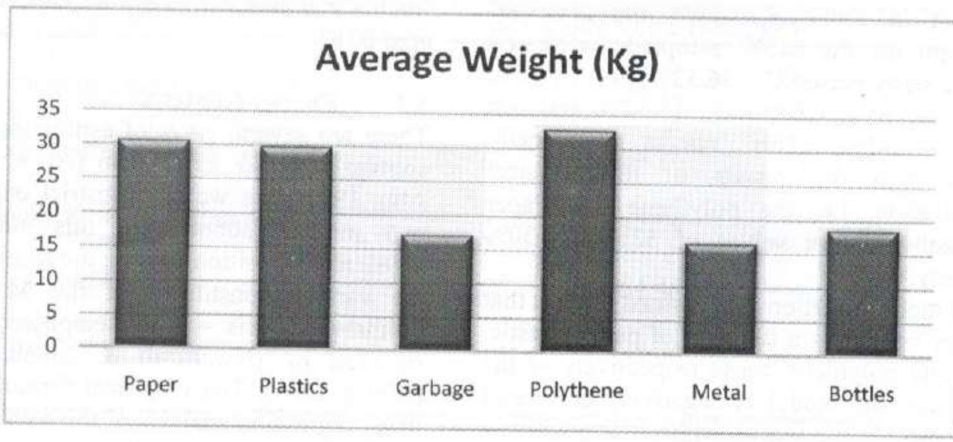

Figure 3: Average Weight of Major Components Sampled for six days.

3.2 Results for the Ultimate Analysis

The results of the chemical analysis (ultimate analysis) of the samples of combustible material taken from open dump site (Maikunkele - Minna) over the six days are tabulated in Table 3. The results given below were obtained for the chemical analysis/ultimate analysis for the samples of combustible materials that were taken.

Table 3: Ultimate Analysis Results

Elements	Sample A (%)	Sample B (%)	Sample C (%)	Average (%)
Carbon	30.42	35.02	36.12	36.53
Nitrogen	10.11	8.28	11.89	10.10
Hydrogen	3.14	3.56	3.47	3.39
Sulphur	1.24	0.96	1.10	1.10
Oxygen	10.01	12.44	12.11	11.52
Ash	37.05	39.74	35.31	37.37

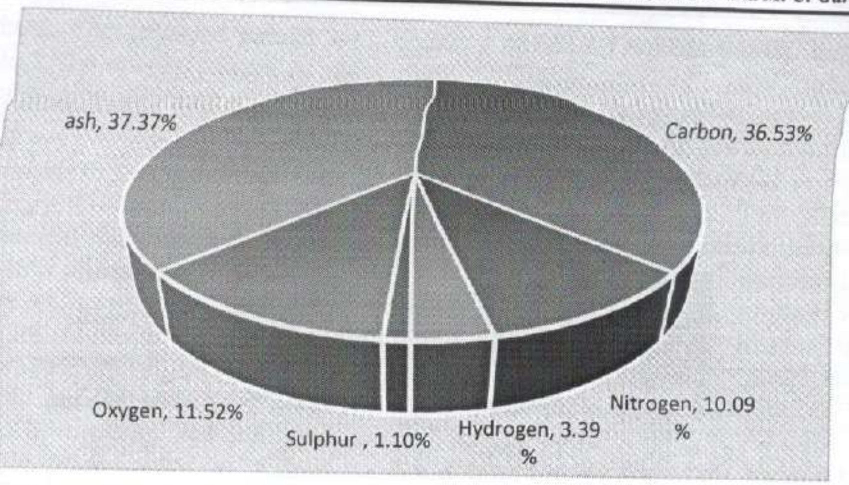

Figure 4: Result of Ultimate Analysis of Minna MSW.

The result in Table 3, shows the chemical composition for the MSW sampled and tested during the study period:C – 36.53%, N – 10.09%, H – 3.39%, S – 1.10%, O -11.52% and ash content -37.37%. This results technically conforms with the results of the physical characterization, i.e. the polythene and Paper waste hasthe highest values of 32% and 30% respectively.

Also, the model equation (7) obtained implies that the energy content is a function of paper, plastic, garbage and polythene waste respectively of the MSW. Thus, the model is negatively correlated with the glass/bottle waste, while it is positively correlated with the remaining elements of the waste. Regression analysis revealed plastic waste to be the most important variable, followed by polythene, paper and garbage waste respectively. An interesting finding is that metal waste did not contribute statistically to the energy content. This finding is in line with the work carried out by Liu *et.al* 2012.

3.3 Energy Content

There are several ways of estimating the energy content of MSW as sited in (Ali khan, Ziad, & Abu, 1991), but we shall restrict our self to the two method adopted in this study i.e. by physicalcomposition – using the heating values of the various constituent of the MSW and by ultimate analysis – using empirical formula as reported by (Nwankwo & Amah, 2016) and (Julius, 2005). The empirical formula developed using regression analysis of the data in Table 2 is presented in equation 7.The annual estimated of the energy potentials of Minna MSW is presented in Table 4. From Table 4, it could be deduced that Minna MSW has a potential of generating an estimated value of 3,882.6 Kcal/Kg from the MSW.

$$Hn = 30.4P + 58.8PL \quad 8.02G + 31.45Po + 0.073 - 0.045B + 26.74 \qquad (7)$$

Where;

Hn = net calorific value (Kcal/kg)
P = Paper, percentage weight on dry basis
Pl = Plastic, percentage weight on dry basis
G = Garbage, percentage weight on dry basis
Po = Polythene, percentage weight on dry basis

Table 4: Calculated Energy Content of MSW/Week

	Paper	Plastic	Garbage	Polythene	Metals	Glass	Total
aste mponent	20.88%	20.54%	11.82%	22.60%	11.30%	12.85%	100%
mount of aste/week	4897.12	4816.47	2771.49	5300.80	2650.40	3013.66	23450
mount of ergy J/year	35,259,759	6,743,052	554,297.2	39,756,024	795,120.5	180,819.3	166,578,144

The comparison of the different energy models using the data in 2 is presented in table 5, with Scheurer-Kesiner's equation having the highest energy prediction. Also the physical characterization models are plotted in Figure 5.

Table 5:*Comparison of energy model eqautions*

Equation	Net Calorie Value (Kcal/kg)
Dulong's equation	4,430.14
Stauer's equation	3,784.26
Scheurer-Kesiner's equation	4,445.54
Conv. Equation	4,564.45
Own model equation	3,882.06

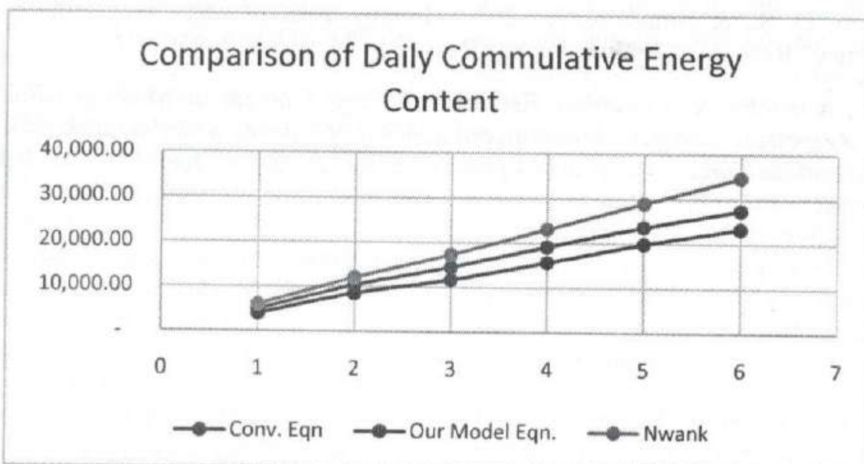

Figure 5*: comparison of the physical characterization model equations of cumulative energy values for the components.*

4.0 CONCLUSION

During the study period 23,450kg of MSW was collected and disposed at the landfill. 120kg of sample MSW was collected, sorted and weighted from two (2) trucks/day for a period of one week. Physical characterization and ultimate analysis were conducted on the sampled MSW at Maikunkele-landfill. The physical characterization of Minna MSW sampled during the study period shows that there are 30.58% of paper, 29.83% of plastic, 17.17% of food waste, 32.83% of polythene, 16.42% of metals and 18.58% of glass waste respectively. Also the ultimate analysis shows that there are 36.53% of carbon, 10.09% of Nitrogen, 3.39% of Hydrogen, 1.10% of Sulphur, 11.52 of oxygen and 37.37 of ash content respectively. A linear empirical model was formulated and compared with other existing models which shows favorable comparison between the other models by different scholars. Lastly, the study also indicates that Minna MSW has a good potential for energy recovering.

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