Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Impact of Physical and Chemical Properties of Municipal Solid Waste on its Electrical Power Rating Potential

Impact of Physical and Chemical Properties of Municipal Solid Waste on its Electrical Power Rating Potential

Ibikunle R. A[1, 2], Titiladunayo I.F[1,2], Akinnuli B.O[2], Osueke C.O[1] Dahunsi S.O[3] and Olayanju A[4]
[1]Department of Mechanical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria
[2]Department of Mechanical Engineering, Federal University of Technology, Akure, Ondo State, Nigeria
[3]Biomass and Bioenergy Group, Environment and Technology Research Cluster, Landmark University, Omu-Aran, Kwara State, Nigeria
[4]Agriculture and Biosystems Engineering Department, Landmark University, Omu-Aran, Kwara State, Nigeria

E-mail: ibikunle.rotimi@lmu.edu.ng

Abstract. Waste-to-energy (WTE) management method, has been considered as the best option; because, it reduces the quantity of waste generated by about 71 %, and ensure energy recovery for efficient waste management. In this study, physical, chemical and the heating properties of the waste components, generated in Ilorin were determined. The heating value was modelled against the physicochemical properties of MSW components to ascertain their correlation. The electrical power rating potential of the MSW was determined using Dulong's model. The regression model developed on the correlation analysis was used to predict the effect of the physicochemical properties on the heating value and the power generation potential. It was concluded that 1 % increase in fixed carbon and volatile matter, total carbon and Nitrogen content, increases electrical power rating by 8 %, 37 %, 21 % and 10.80 % respectively; while 1 % increase in moisture and hydrogen content, reduces the electrical power rating by 11 % and 69.3 % respectively.

1. Introduction

Waste generation as a product from man's activities as he interacts with his environment, can be traced back to the early man's era; when man used materials like animal skins, bones and ivory to make the sheath for their swords, clothing, tools, weapons and others. Sheaf, leaves, wood, raffia and bamboo materials were used for shelter, coverings, carts and different tools. The bulk of waste generated then was from animals, plants, shrubs and food leftovers [1]. The advancement in civilization, urbanization, industrialization and demographic growth has consequently increased the rate of municipal solid waste generation [2]. The United States of Environmental Protection Agency [3], defines municipal solid waste (MSW) as wastes generated on daily activities, which includes items like packaging box, grass and garden trimmings, damaged furniture, rags, bottlesand cans, food residues, papers, electronics and electrical appliances. MSW do not include agricultural wastes, hazardous wastes and industrial wastes, automobile bodies, radioactive waste, demolition debris sewage sludge. According to Tay [4], Municipal Solid Waste management (MSWM) is concerned with the act of storing, collecting, movement, handling, conversion, and disposal of MSW in such a way that good health and stable economy. can be guaranteed. The Egyptian Environmental Policy Program support unit [5] and the U.S. Agency for International Development [6] defines MSWM as the systematic way of managing the activities involved in planning, funding, collecting, transporting and processing of municipal solid waste. The processes include: storage, collection, separation, transportation, treatment, energy recovery from waste, recycling, composting and landfill of municipal solid waste [7]. The inability or unwillingness of most municipal authorities to make provision for efficient and functional waste collection and disposal services has been the cause of poor MSWM in developing countries [8]. Factors like culture, education and socio-economic development also constitute major obstacles to efficient management of MSW.

Improper management and disposal of MSW would result to environmental challenges such as: pollution, infection transmission, flooding, surface water contamination, environmental degradation, emission of greenhouse gases and ozone depletion and. A typical case is the Ogunpa River flood of 1983 in Ibadan; which claimed many lives and properties. In Kano city, over 67 % of humanity are faced with the problem of inadequate and improper facilities for municipal solid waste management and disposal which led to the indiscriminate dumping of solid waste into streams, open dumps and public places [9]. In Nigeria, landfill is a major method of waste disposal because of its cost effectiveness; nevertheless, it has disadvantages which include: greenhouse gases emission, contamination of ground water through leaching and degradation of the land required for landfill construction [10]. Where incineration method is adopted, challenges like particulates, pollutants such as carbon dioxide (CO_2) and dioxins that contribute to climatic change, nervous system and heart diseases, as well as smog are encountered [2]. The MSW generated in the cities nowadays is too enormous for the traditional method of waste management. The global MSW data showed a generation rate of 0.68 billion tons per year in 2000 and 1.3 billion tons per year in 2010, while the projection for 2025 stands at 2.2 billion tons per year and 4.2 billion tons per year by 2055 [11]. MSW generation as reported by Kawai and Tasaki [12] shows 1.34 kg/capita/day (United Kingdom), 2.13 kg/capita/day (United States), 2.00 kg/capita/day (South Africa), 0.09 kg kg/capita/day (Ghana) and 0.58 kg/capita/day in (Nigeria).

Despite the rise in MSW generation rate in developing countries, the countries still face energy crisis wish poses their economic and social development to grave challenges. Adopting an integrated MSW management method that encompasses thermal degradation and energy recovery, recycling and others will ensure adequate and efficient waste management system [13]. In recent years, technologies were developed to generate power by utilizing renewable energy sources; despite the technological advancement on energy generation, only about 59 % of Nigeria population have access to electricity [14]. This indicates that about 74 million people in Nigeria are still without access to electricity. Since the quest and emergent need for sustainable renewable energy sources which include: wind, solar, hydro, photovoltaic and biomass; biomass energy source has been cited as the world's largest renewable energy source and its resources are distributed around the world [15].According to Tan *et al*. [16], [17]; clean energy and green environment are very essential to the growth and living standard of every nation; this could be obtained from waste-to-energy (WTE) practices. This requires thermochemical and biological processes to extract useful energy from combustible biogenic fractions of the MSW to produce heat (steam) or power (electricity) or both (combined heat and power). Ayodele *et al*. [18] reported that average electrical energy and power rate in Nigeria is in the range of 107 kWh, 12 W per capita per annum. This is quite insufficient for social and economic demand. Energy supply in Ilorin and the entire Kwara State by the Power Holding Company of Nigeria (PHCN) is far below the power requirement for industrial and economic growth of the state and it is characterized with fluctuations, failures and outages. This accounts for widespread usage of fossil fuel generators in the metropolis. The unpredictable rise in the cost of fossil fuel products and the occasional/periodical scarcity makes the use of generators unreliable and uneconomical for most institutions and industries.

The municipal solid wastes generated in Ilorin Kwara State is huge, and the waste management system in place is insufficient and inefficient; hence the people indulge in illegal and indiscriminate disposal of wastes into open dumps and water ways. This consequentially causes pollution, unsightly scenes, direct blockage of waterways and biodegradation of organic fractions of the wastes that release greenhouse gas (GHG) such as methane which contributes to depletion of Ozone layer as well as climate change [19]. Therefore waste-to-energy method of MSW management will serve a dual purpose of converting the waste generated to clean energy as well as ensuring an adequate and efficient waste management practice. For WTE to be established in a metropolis, there is a need to first determine the power potential of the available waste fractions and validate the correlation between the power potential and the physicochemical properties.

2. Overview of municipal solid waste (MSW) management

Power can be considered as one of the principal input factors in the development of a nation. It plays a major role in the social and economic growth of a nation, thereby improving the quality of peoples' life. Nevertheless, the continuous utilization of natural resources, becomes dangerous to the ecosystem and the climate globally [20]. This necessitates the continuous search for clean and green energy sources that will serve as sustainable and reliable alternatives to natural resources particularly fossil. MSW is considered as reliable alternative because, waste to energy (WTE) system plays a dual purpose of efficient waste management and energy generation [21] The appropriate usage of MSW will improve on sanitation practices and as well ameliorate the emission of greenhouse gases (GHGs) in the landfill system of waste disposal [20], [22]. The WTE technology to be adopted in a locality, is determined by the quantity and quality of the waste streams, the composition, the heating value of the waste stream and the sustainability of the MSW flow [10] In WTE using incineration technology, it is necessary to determine the effect on the physical component on the power production potential, to ascertain whether it increases rate of power generation or otherwise.

2.1. MSW generation and composition

MSW generation refers to the quantity of material that enters the waste stream before recycling, reuse, recovery, composting, or combustion. Recovery refers to materials sorted from the waste stream for recycling or composting purposes [23]. MSW generation has increased globally because of an increase in family income, education level, and change in fashion, consumption pattern, and socioeconomic practices. In the developing nations of the globe, the organic components of wastes are more predominant [7], [24], reported that a lower quantity of MSW was associated with the nations, with lower GDP. The characteristics of municipal solid waste streams depend on their sources, seasons of generation, types of wastes, as well as the rate of generation and composition. MSW could be characterized into various types depending on the kind of exercises, materials and the environment concerned in the waste generation; they are: household wastes, garbage, ashes, rubbish, bulky wastes, Street wastes, dead creatures, construction and demolition wastes, industrial wastes, abattoir wastes, Medical or Hospital squanders, hazardous wastes and E-wastes [25]. Poorer households, with a lower level of income, generate more organic food waste. It has also been reported that waste components such as plastic, metals, and glasses, are predominant in high-income households due to high consumption of processed foods. According to Ajadi and Tunde [26], certain distinctions and likenesses exist in municipal solid waste generation and pattern of composition in Ilorin city, variation is shown inaccessibility of dumpsters (Roro-bins) according to neighbourhoods in Ilorin.

In the old residential areas, such as Magaji-Ngeri, food wastes, bones, polythene bags, rags, leathers, rubbers and aluminium form the largest solid waste components that are generated there. Food waste is about 28 % of the wastes generated, while other wastes mentioned takes about 21 %. Paper waste and nylon constitute about 27.3 %, leaves and human excrement constitutes 11.50 % while non-organic wastes like bottle and tins constitute about 11.5% of the aggregate wastes generated. In the new residential location, Oko-Erin war. Paper wastes have the largest proportion amounted to 27.8 % of the aggregate solid waste followed by food wastes with 25 % then leaves and nylon components amount to 26.1 %. In the Government Reservation Area (GRA), food wastes constitute 30.9 % of aggregate waste; followed by paper waste 23.0 %. The wastes classified as others constituting 16.0% while leaves and nylon 15 % and tins/bottles constitute 14.01 %. The data of the solid analyzed shows that food and paper wastes have formed a high percentage of the wastes generated. The food wastes from preparation processes left over after consumption, all contribute to a high rate of food wastes. Paper wastes, polythene sacks, metals, rubber among other wastes are generated by all independent of age or status in view of their various uses, for example, writing, packages, structures among others.

The high food waste rate from the Government Reservation Area (GRA), can be associated with the socio-economic attributes and household factor in the area. About 75 % of the inhabitants in the GRA are high wage workers. This is high when comparing the old residential area to the new residential location; 27.1 % and 52.0 % of the general population falling into high pay. Both the Government Reservation Area (G.R.A). and Old Residential Area display comparative pattern in the family unit (household) estimate, as the rate of food waste is wide in the two zones. In the G.R.A, we have the largest constituents of tins/containers waste. This is in support of Awomuti [27], that rate of waste created in Residential and Commercial (market) land utilization is higher than the other land utilization regions. The municipal solid waste stream consists of a wide range of materials which depends on classes of people, socioeconomic development, population density and type of human activities as shown in Table 1. Municipal solid waste composition varies from one municipality to another [28], the variation is significant with time. In where there is a standard waste recycling system, the waste stream consists majorly the intractable wastes like packaging materials that are not recyclable and plastic film.

Table 1. Municipal Solid Waste Composition

Waste Fractions	aUK (%)	aUS (%)	bMalaysia (%)	cShanghai (%)	dGhana (%)	eNigeria (%)
Paper/Cardboard	23	31	20.9	4.46	7.2	9.8
Food	18	13	41.1	63.39	72.6	35.5
Garden/Yard waste	14	13	2.5	-	-	5.3
Plastics	10	12	22.2	19.98	4.0	19.5
Metals	4	8	2.0	0.27	2.8	4
Textiles	3	8	7.7	1.8	1.5	9.2
Wood	4	7	-	-	1.2	1.8
Glass	7	5	3.6	2.72	2.0	3.4
Others	17	3	-	5.87	0.9	11

Sources: a. Trevor and Daniel, (2011) [7]. b. Sie *et al*. (2014) [29]. c. Dong *et al.* (2010) [30]. d. Martin and Jose, (2013) [31]. e. Adegboyega, (2010) [32].

2.2. Energy Recovery from waste

Energy recovery from waste can be defined as the conversion of waste materials that are not recycled into fuel, heat and or electricity, that are of economic value through a variety of processes that includes combustion, gasification, pyrolization, anaerobic digestion, also landfill gas (LFG) recovery. Energy recovery from municipal solid waste can be obtained by utilizing different technological methods. The method to be adopted for a waste stream depends on the composition, its energy content, the desired form of the energy output, the thermochemical conditions in which the WTE plant is to operate, and the overall energy efficiency. WTE is an optimal method of solving waste management problems in a sustainable way while harnessing its hidden energy [33]. The most important parameters, which determine the potential of energy recovery from wastes (including MSW), are quantity and quality (physico-chemical characteristics) of waste. The important physical parameters of waste requiring consideration include density, moisture content and calorific value. The energy recovery process is part of the non-hazardous waste management hierarchy. The process of converting non-recyclable waste materials into heat or electricity provides another source of renewable energy and this tends to ameliorate the emission of carbon because this is an alternative source of energy generation to fossil sources, thereby reducing the generation of methane from landfills. In the United States currently, there are 86 facilities for combustion of municipal solid waste (MSW), with energy recovery. In China, there are about 434 WTE power plants, about 126 in France, 121 in Germany and 71 in US. The first major WTE plant in Africa is 110 MW in Ethiopia; Ghana is proposing 60 MW and South

Africa has more than 6,377 MW [34]. The various technological methods available to convert solid waste to energy (WTE) is presented in Fig. 1.

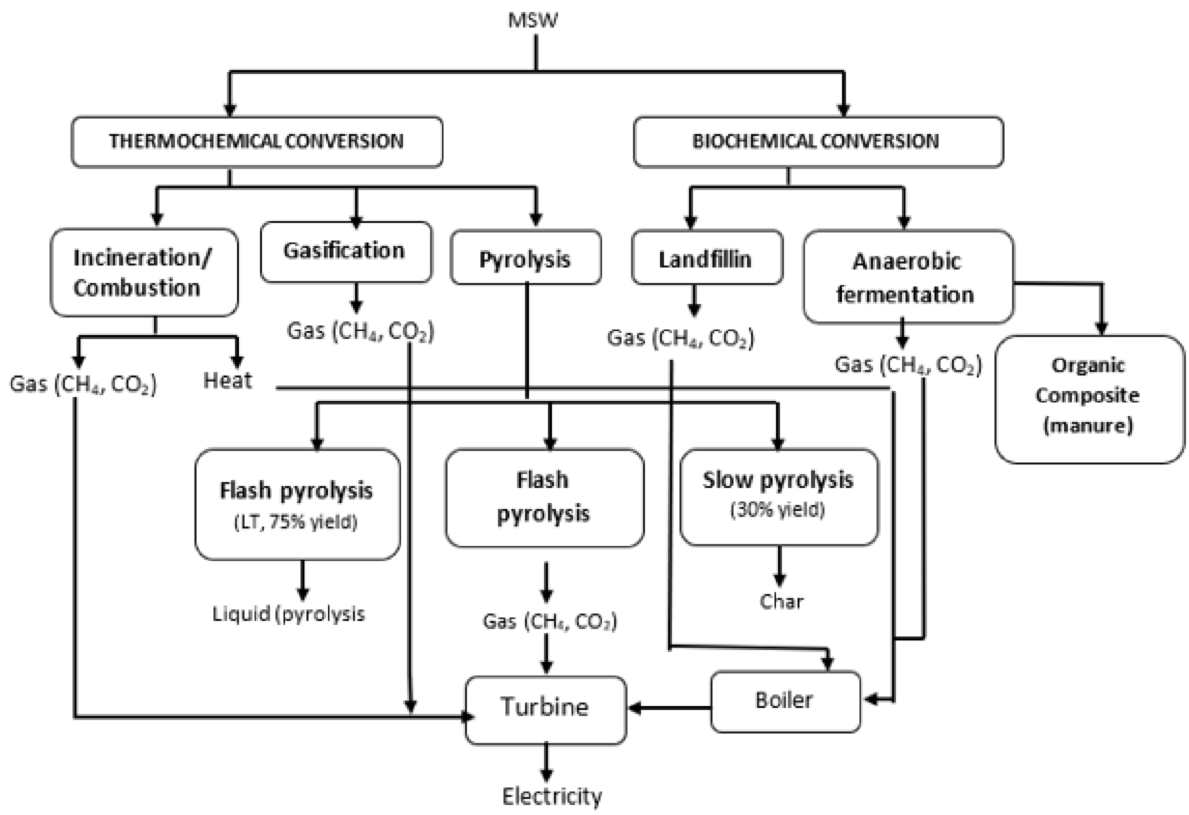

Fig 1: Schematic diagram of electricity generation from MSW by thermochemical and biochemical conversion technology (Cynthia *et al.*, 2013) [35].

3. Material and Methods

3.1. Materials

The MSW components characterized in the waste streams of Ilorin metropolis at Lasoju dumpsite during this study include food residue, paper, packaging-box, plastic-bottles, wood, grass/trimmings. Nylon, tins, bones, leather, toiletries (spent toilet tissues, sanitary pads and pampers) cow-dung, excrement faeces), ceramics, polythene-sac, textile (rags), rubber, sand/ash and others (a crumped mixture of unidentified organic matters).

3.2 . Methods

3.2.1. Data Collection Procedure

The sampling and characterization of MSW streams (field work) was carried out at (Lasoju) the only functional dumpsite of Ilorin metropolis during this study, for a total period of eight months. Detail survey was carried out; it involves direct visitation and observation at both collection centres and the dumpsite [36], interviewing of MSW management officers in Kwara state environmental protection agency and ministry of environment and forestry as suggested by Abdellahand Balla [37]. Direct door-stepping-questionnaire administration approach was used after the method adopted by Phillips *et al* [38].

3.2.2.Physical Characterization.

Several subsets of MSW components were collected from the dumpsite, mixed together on a polythene mat with the aid of shovel and heaped to a cone shape, and was divided into four (4) slices [39], [40]. A pair of diagonally opposite slices were discarded, and the other two parts were thoroughly mixed together to obtain a representative sample of a specific waste bin volume of 240 litres [41]. **S**ixty – two samples (62) were taken to reduce error due to insufficient samples. Each sample was sifted and screened on a screening equipment, 1.5 m x 3 m with 10 mm x 10mm mesh surface designed for heterogeneous solid waste [42]. The waste sample was hand sorted into different fractions, kept in different receptacles and weighed to get the corresponding weight.

3.2.3. Preparation of Laboratory Samples

The samples were shredded into smaller pieces of about 25 mm and further grounded to less than 1 mm using grinding machine. This was done to increase the surface area of the samples to allow easy digestion and penetration of heat during laboratory analyses. The samples prepared for the laboratory tests are shown in Plates 4 to 12.

3.3. Laboratory Analysis

3.3.1. Proximate analysis.

Proximate analysis was performed based on ASTM D7582 – 12 [43] Standard methods. The moisture content was determined using an electric oven (DHG 9053). Experimental sample of 1g of grinded air-dried sample was measured into a crucible and dried in the oven, maintained at about 110 °C for about 1 h. The loss in weight is reported as moisture material according to Vairam and Ramesh [44], [45] by using Equation 1:

$$M_w = \frac{(w-d)}{w} \times 100 \qquad (1)$$

whereM_w is the wet moisture content %, *w* is the initial mass of sample as delivered (kg), and *d* is the mass of sample after oven drying (kg).

After moisture contents determination, the residue left was heated in electric furnace (TDW) maintained at 950°C for 7 min, based on ASTM D1348-94 [46]. The loss in weight is reported as volatile matter in percentage terms according to Shi *et al*. [45], [10] in equation 2

$$V_d = \frac{A}{B} \times 100 \, (2)$$

where V_d is the percentage volatile matter, *A* is the mass loss of the sample, and *B* is the mass of the sample taken. The residue left after determination of volatile matter was heated without the lid inside a furnace at 700 ^{O} C for 30 min. Ash content is the amount of residue obtained after ignition of solid waste which was obtained according to Kuleape *et al.* [20], [21] using equation 3:

$$Ash\ (\%) = \frac{w}{W} \times 100 \qquad (3)$$

where w, is the mass of ash and W is the mass of the sample considered for the test.

The fixed amount of carbon left was calculated according to ASTM D3172-73 [47] by deducting the percentage amount of ash, moisture, and volatile matter from 100, using equation 4.

Fixed carbon (%) = 100 - (Moisture + Volatile matter + Ash). (4)

3.3.2. Ultimate analysis.

The percentage composition of the total carbon (C), hydrogen (H), nitrogen (N), Sulphur (S), and oxygen (O) after removal of volatile matters, the moisture and ash contents were determined. This analysis was performed based on ASTM C1111-10 by using Inductively Coupled Plasma – Optical Emission Spectrometer (ICP – OES Perkin Elmer 8000). About 1 ml of sample was digested in tubes inserted to Gerhardt – Kjeldatherm digestion machine, when maintained at about 180 ^{0}C for 1hour. The digests became clear to light yellow, then temperature was raised to 240 ^{0}Cand further heated to dryness. The tubes were then offloaded and to cool. The residue was dissolved in 1 ml of concentrated HCL and add 10 ml of 5 % HNO_3 The aqueous solution formed was injected to ICP and was

nebulized to form aerosol. The sample was dissociated into constituent atoms by argon plasma and excited to emitted light of characteristic wavelength that was measured as a quantity. The light was resolved into its component radiation (by means of a diffracting grating), and intensity of the light was measured with a photomultiplier tube at specific wavelength for each element line. The intensity of the electron signal was compared to previous measured intensities of known concentration of the element and the concentration was computed in the data analyzer of the system. The mineral constituents in each sample
was analyzed by ICP – Spec. using“WINLAB 32” software. The spectrometer data collectionparameters were configured,viewed graphically and the results of the analysis was printed.Theexperiment was repeatedthree times on each sample of the waste components [10].

3.3.3. Heating value.
The HHV was determined using a bomb calorimeter (*e2k* combustion Calorimeter), based on standard ASTM D5468-02 [45]. 0.5 g of sample was burnt in a high- pressure oxygen environment in the bomb. About 0.5 g of test sample was inputted to the system through the computer input device. The output was displayed on the screen after completion. The test samples were replicated three times and the average value was considered as the ‘typical’ value (MJ/kg).

3.3.4. Modelling of the heating value.
Multiple regression analysis was used for the modelling of the energy content of the municipal solid waste (MSW). The higher heating value of the MSW, was estimated based on proximate analysis, ultimate analysis, and physical composition of MSW. The regression analysis was performed using GRETL statistical software [21]. Diagnostic check was performed by using Jarque-Bera test to determine the error distribution. The correlation of the regressors were examined by using variance inflation factor (VIF) for a diagnostic check of a problem of multicollinearity. Three models were developed; in the models, the dependent variable was the heating value (HV).

*3.3.5***.** *Estimation of Electrical Power Potential of the MSW (EPP_{msw})*
Low heating value (LHV), is calculated using Dulong’s model in equation 5:

$$\text{LHV} = 81C + 342.5\left(H - \frac{O}{8}\right) + 22.5S - 6(W + 9H \quad (5)$$

Where LHV is the low heating value, C, H, O, S are the wt. % of carbon, hydrogen, oxygen, and Sulphur elements respectively.
Electrical power potential is calculated in equation 6:

$$EP_{msw} = [81C + 342.5\left(H - \frac{O}{8}\right) + 22.5S - 6(W + 9H)] \times w_{msw} \times \frac{1000}{3.6} \quad (6)$$

Where, EPP_{msw} is the electrical power potential, w_{msw} is the weight of MSW (tons), 277.8 is the conversion factor and ɿ is the converting efficiency in a power plant; Klein *et al*., (2003),
Muhammad *et al*. [48], [49] gives the conversion efficiency (ɿ) range to be 20-40%. The conversion efficiency of 30 % is adopted.

4. **Results and discussion**

4.1. Physical Characterization.
The characterization process was completed after the period of eight months. The characterization result reveals that the highest waste fraction is Food residue 10.37 %, followed by Plastic bottle 9.79 %, Packaging box (carton) 9.69 %, Textile (rag) 8.91 % and the least is Leather 0.07 %. The mean distribution range is from 39.80 $\pm$ 35.00 to 0.2 $\pm$ 0.36. Nine waste fractions which include: food residue, carton, rags, paper, poly-sac, wood, nylon, plastic-bottle, and grass were considered for laboratory tests out of nineteen waste components characterized as presented in Tables 2 and 3; because of their regular occurrence in the flow of the waste stream and combustibility.

4.2. Chemical Characterization.

Proximate analysis results given in Table 2. Show that the range of moisture content of the components analyzed is 6-13 % and the dispersion is 0.58-1.16 %; the highest is wood 13 %, followed by grass/trimmings 10 % and the least is packaging box (carton) 6 %. Volatile matter's range is 2 -67 % and the dispersion is 0.58 -15.18 %; the highest is paper 68 %, wood 67 % and the least is plastic bottle 2 %. Ash content range is 1 -36 % with dispersion of 0.00 -4.04 %; the highest is grass 36 %, followed by Textile (rag) 23 % and the least is plastic 1.00 %. The ultimate analysis results in Table 2, shows that

the carbon range of the components analyzed is 21-38 % with dispersion of 0.04-0.85 %; the highest is food residue 38.08 %, followed by wood 37.45 % and polythene 21.07 %. Hydrogen range is 0.09-0.17 % with standard deviation of 0.001 -0.031 %; the highest is food residue 0.17 %, Polythene-sac is 0.15 % and the least is Textile (rag) 0.09 %. Nitrogen range is 2.12 -5.10 % with dispersion of 0.01-0.71 %; the highest is paper 5.10 % followed by food residue 5.01 % and the least is Polythene-sac 2.12 %. Oxygen range is 0.065 -0.085 % with dispersion of 0.0006-0.001 %; the highest is nylon 0.085 %, followed by packaging box (carton) 0.083 % and grass/trimmings 0.065 %. Sulphur range is 0.05- 3.13 %. With dispersion of 0.002-0.039 %; the highest is food residue 3.13 %, followed by wood 0.13 % and the least is nylon 0.52 %.

Table 2: The physicochemical analysis of municipal solid waste fractions

Waste Fractions	Proximate Analysis				Ultimate Analysis					Heating Value
	FC %	VM %	Ash %	M %	C %	H %	N %	S %	O %	HV %
Carton	67.0	14.0	15.0	4.00	38.1	0.16	4.91	S %	0.08	18.0
Mean	71.3	16.0	14.0	4.66	38.0	0.16	4.94	3.07	0.08	18.6
SD	12.1	3.46	1.73	1.15	0.05	0.00	0.06	3.10	0.00	0.55
Nylon	85.0	14.0	1.00	0.00	35.7	0.08	4.56	0.03	0.07	18.4
Mean	80.0	18.3	1.67	0.00	36.5	0.11	4.50	0.08	0.07	18.4
SD	8.6	9.29	1.16	0.00	0.85	0.03	0.05	0.10	0.01	0.03
Textile (rag)	29.0	47.0	18.0	6.00	35.4	0.09	4.52	0.03	0.07	16.1
Mean	43.0	30.7	20.0	6.33	35.3	0.11	4.75	0.08	0.07	17.0
SD	12.7	15.2	2.65	0.57	0.10	0.03	0.31	0.08	0.00	0.92
Paper	28.0	55.0	10.0	7.00	21.1	0.11	2.69	0.00	0.08	15.4
Mean	24.3	59.7	10.3	5.66	20.9	0.11	2.76	0.05	0.08	15.8
SD	6.35	7.23	0.57	1.15	0.09	0.004	0.13	0.08	0.00	1.21
Food-residue	91.0	1.00	2.00	6.00	30.7	0.08	3.92	0.04	0.06	17.7
Mean	88.7	2.67	2.33	6.33	30.8	0.09	3.86	0.07	0.06	17.8

SD	4.04	2.88	0.57	0.57	0.15	0.03	0.08	0.07	0.00	0.25
Poly-sac	88.0	4.00	8.00	0.00	34.3	0.09	4.37	0.00	0.07	13.9
Mean	90.0	4.33	5.67	0.00	34.1	0.09	4.37	0.08	0.07	15.7
SD	3.46	0.58	4.04	0.00	0.18	0.00	0.00	0.08	0.00	2.83
Wood	20.0	66.0	1.00	13.0	22.2	0.11	2.83	0.01	0.08	46.3
Mean	27.6	59.0	1.67	11.7	22.1	0.11	2.82	0.05	0.08	46.2
SD	12.4	13.0	0.57	1.53	0.11	0.00	0.02	0.05	0.00	0.25
Grass	14.0	59.0	17.0	10.0	21.1	0.09	2.69	0.00	0.07	38.6
Mean	15.3	51.7	23.3	9.67	20.9	0.11	2.69	0.04	0.07	39.3
SD	1.15	11.0	10.9	0.57	0.15	0.03	0.02	0.05	0.00	0.65
Pet-bottle	97.0	2.00	1.00	0.00	23.1	0.10	2.94	0.01	0.08	37.0
Mean	97.7	1.33	1.00	0.00	23.1	0.11	2.92	0.05	0.08	37.2
SD	0.57	0.57	0	0	0.04	0.01	0.02	0.05	0.00	0.73

4.3.Heating Value

In Table 3, the net heating value of the waste components is determined to be about 20 MJ/kg. Nylon is the waste component that has the highest heating value of 20.4 %, Poly-sac 17.4 %, Plastic 16.5 % and the least is Textile (rag) 6.9 %.

Table 3: The result of heating value determination

Types	Food residue	Wood	Paper	Carton	Grass	Textile	Nylon	Poly-sac	Plastic-bottle
HHV	18.03	18.42	16.09	15.44	17.75	13.90	46.34	38.69	37.01
Mean	19±0.6	18±0.0	17±0.9	16±1.2	18±0.3	16±2.8	46±0.2	39±0.7	37±0.1
HV %	8.23	8.14	7.53	7.02	7.88	6.96	20.39	17.39	16.47
LHV	1.93	0.15	1.03	1.54	0.80	1.40	7.03	2.09	3.65
TOTAL	$\sum_{1}^{9} HHV = 226.342$ and $\sum_{1}^{9} LHV = 20$								

4.4.Estimation of Electrical Power Potential (EPP_{MSW}) of the MSW

The result of the calculation carried out to determine the energy potential and the electrical power potential of the MSW is presented in Table 4.

Table 4: The result of the estimated energy and power potentials of MSW

W_{MSW} (to/day)	LHV (MJ/kg)	EP_{MSW} (MWh)	EPP_{MSW} (MW)	EP (MW)
584	20	3244	41	27
		Conversion ratio		
1000 kg = 1 ton	10^6J = 1MJ	1kWh = 3.6 MJ	η = 30%	η_g = 90% and η_p = 75%

4.5. Regression model

Three regression models developed and fitted to variables derived from proximate analysis, ultimate analysis and the physical compositions of MSW are in equations 7 to 9 respectively.

Model developed on proximate analysis:

$$\hat{HV} = -7.19477 + 0.116768\hat{FC} - 0.34728\hat{M} + 0.151701\hat{VM} \quad (7)$$

Model developed on ultimate analysis

$$\hat{HV} = 1.3849 + 85.0807\hat{C} - 28.9675\hat{H} - 666.125\hat{N} + 11.6296\hat{S} \quad (8)$$

Model developed on physical components of MSW:

$$\hat{HV} = 0.171002 + 0.010962\hat{G} + 0.008054\hat{CE} + 0.010242\hat{P} \quad (9)$$

where: HV is the heating value, FC is the fixed carbon, M is the moisture content, VM is the volatile matter, C is the carbon percentage content of the municipal solid waste, H is the hydrogen content percentage, N is the nitrogen percentage content and S is the Sulphur percentage content, G is the percentage garbage component, CE is the percentage cellulose component and P is the percentage polythene content.

Fixed carbon and volatile matter have positive effect on heating value while moisture has a negative effect. The model reveals that 1 % increase in fixed carbon will increase heating value by 8 %, and by calculation will increase electrical power generating potential by 8 %. From the model 1 % increase in volatile matter will increase heating value by 37 % and by calculation increases electrical power generating potential by 37 % meaning that the volatile matter present is a combustible one. While 1 % increase in moisture content will reduce the heating value and the electrical power generating potential by 11 % concurrently. The model presents that 1% increase in carbon will increase heating value by 79.08 % and by calculation increases electrical power potential of the MSW by 21%. Nitrogen will increase heating value by 10.83 % and the electrical power potential by 10.80 %; while 1 % increase in hydrogen reduces the heating value by 30.2 % and reduces electrical power potential by 69.3 %. It implies 1 % increase in Garbage, Cellulose and Polyethylene fractions, will cause the heating value to increase by 2 %, 17 % and 3 % respectively and will consequently increase the electrical power potential by 2 %, 17 % and 3 % respectively.

5. Conclusion

It is concluded that 1% increase in fixed carbon content of MSW characterized in Ilorin metropolis will increase electrical power generating potential by 8 % and 1 % increase in volatile matter will increase the electrical power generating potential by 37 %, which implies the volatile matter present is combustible; while 1 % increase in moisture content will reduce the electrical power generating potential by 11 % this could be as a result of heat lost during vapourization. 1% increase in carbon will increase electrical power potential of the MSW by 21 %. Nitrogen increases the heating value by 10.83 % indicating that the gas got combusted to generate heat and it increases the electrical power potential by 10.80% while 1% increase in hydrogen reduces the heating value by 30.2 % and reduces electrical power potential by 69.3%. It implies 1 % increase in Garbage, Cellulose and Polyethylene fractions, will cause the heating value to increase by 2 %, 17 % and 3 % respectively and will consequently increase the electrical power potential by 2 %, 17 % and 3 % respectively. By conclusion every physico-chemical property (FC %, M %, VM %, Ash %, C %, H %, N %, S % and O %) of MSW that causes an increase in the heating value, also help to positively improve on the electrical rating potential of the MSW if used as fuel for power generation.

References

[1] Onipede AIM 2004 The role and practice of Engineering in society. R.R.R Press, Nigeria.
[2] Lilliana AG, Ger. M, William H 2013 Solid waste management challenges for cities in developing countries *J. Waste Manage,***33**: 230-232.
[3] U.S. EPA (U.S. Environmental Protection Agency) 2016 Inventory of U.S. greenhouse gas emissions and sinks:1990–2014.EPA430-R-16-002. Available from www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html. (Accessed16 November 2016)
[4] Tay JH2007 Solid Waste Management: Issues and challenges in Asia. Available from www.apo.tokkyo.org. (Accessed 20 November 2017).
[5] Egyptian Environmental Policy Programme (EEPP) Programme Support Unit (PSU), 2000The National Strategy for Integrated Municipal Solid Waste Management- A Framework for Action.
[6] U.S. EPA (U.S. Environmental Protection Agency), 2016. Inventory of U.S. greenhouse gas emissions and sinks: 1990–2014.EPA430-R-16-002. Available from www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html.(Accessed16 November 2016).
[7] Trevor ML, and Daniel AV 2011 Waste: A handbook for management, Academic Press.
[8] Issam A, Maria M, Abdul SF, Abu Z, Hafez QS, and Despo K, 2010 Solid waste characterization, qualification, and management practices in developing countries *J.Env. manage*. Solid waste characterization, qualification, and management practices in developing countries**91**:1131 – 1138.
[9] Aliyu BN2008 An analysis of Municipal Solid Waste in Kano Metropolis, Nigeria*J. Human Ecol.* **31**(2):111-119.
[10] Titiladunayo IF, Akinnuli BO, Ibikunle RA, Agboola OO, Ogunsemi BT 2018 Analysis of Combustible Municipal Solid Waste Fractions as Fuel for Energy Production: Exploring its Physicochemical and Thermal Characteristics*Int. J. Civil Eng. Technol.* **9**(13): 1557-1575.
[11] Hoornweg D, and Bhada-Tata P2012 What a Waste: a Global Review of Solid Waste Management. World Bank, Washington, DC.
[12] Kawai K and Tasaki T 2016Revisiting Estimates of Municipal Solid Waste generation per Capita and their Reliability*J. Mater. Cycles and Waste Manage*.**18**: 1-13.
[13] Omari A, Said M, Njau K, John G, and Mtul, P 2014Energy Recovery routes from Municipal Solid Waste, A case study of Arusha-Tanzania*J.Energy Tech. Policy.*
[14] World Bank, 2018 "Sustainable Energy for all Database from SE4ALL Global Tracking Framework led jointly by the World Bank; International Energy Agency, and Energy Management Assistance Programme.". Available from https://data.worldbank.org. (Accessed 24 April 2018).
[15] AkhatorEP, Obanor AI, and Igbinomwanhia DI 2016Thermal Analysis of Small-Scale Solid Waste-Fired Steam Boiler for Power Generation in Benin City*Nig. J. Technol.***3**: 555-561.
[16] Tan ST, Hashim H, Lim JS, Ho WS, Lee CT, and Yan J2014Energy and emissions benefits of renewable energy derived from municipal solid waste: analysis of a low carbon scenario in Malaysia*Appl. Energy**136***: 797–804.

[17] Ogunjuyigbe, ASO, Ayodele TR, and Alao MA2017 Electricity Generation from Municipal Solid Waste in some Selected Cities of Nigeria: An Assessment of Feasibility, Potential and Technologies*J. Renew. Sus. Energy Rev*.**80**: 149-162.

[18] Ayodele TR., Ayodeji SM, Alao, MA2017 Life Cycle assessment of WTE technologies for electricity generation using municipal solid waste in Nigeria. *Appl. Energy***201**: 200-218.

[19] Ahmed YA, 2012Potential impacts of Climate change on waste management in Ilorin Nigeria*Glob. J. Hum. Soc. Sc*. **12**(6): 39-45.

[20] Kuleape R, Cobinna SJ, Danpare SB, Duwiejuah AB, Amoako EE, Asare W 2014 Assessment of the energy recovery potentials of solid waste generated in Akosombo, Ghana Afr. *J. Env. Sc. Tech*.**8**: 297-305.

[21] Ibikunle RA, Titiladunayo IF, Akinnuli BO, Lukman AF, Ikubanni PP, and Agboola OO. 2018Modelling the Energy Content of Municipal Solid Waste and Determination of Its Physicochemical Correlation, Using Multiple Regression Analysis*Int. J. Mech. Eng. Technol.* **9** (11): 220-232.

[22] Possolli L, Coelho VL, Ando Junior OH, Neto JM, Spacek AD, Oliveria MO, Schaeffert L, Bretes AS, 2013 Inter. Conf. Renew. Energies and Power Quality (ICRE PQ' 2013) (RE AND PQJ). Electricity Generation by use of Urban Waste. ISSN 2172-038X, N0 11, March 2013

[23] Ayhan D, 2011 Biogass Production from the Organic fraction of Municipal Solid Waste*Int. J. Ambient Economy* Available from www.tandfonline.com. (Accessed 25 November 2017).

[24] Shekdar AV, 2009 Sustainable Solid Waste Management: An Integrated Approach for Asian Countries. Available from www.researchgate.net. (Accessed 8 January 2018).

[25] Reddy PJ 2011 Municipal Solid Waste Management: Processing Energy Recovery Global Examples, BS Publications, India.

[26] Ajadi B, and Tunde AM 2010Spatial variation in solid waste compositionandmanagement in Ilorin Metropolis Nigeria*J. Hum. Ecol.* **32**(2): 101-106.

[27] Awomuti AA 2008An Analysis of Waste Generation Rate and Pattern in Ilorin, Nigeria*Int. J. Manage. Soc. Sc*.**1**(1): 171- 183.

[28] Kumar JS, Subbaiah Kand Rao PP 2010 Waste to Energy-A case study of Eluru city, Andhara Pradesh.*Int. J. Env. Sc***2**: 151- 162.

[29] Sie TT, Chew TL, Haslenda H, Wai SH and Jeng SL 2014 Optimal process network for Municipal Solid Waste in Iskandar Malaysia*J. clean. prod*.**71**:48-58.

[30] Dong QZ, Soon KT, Richard, MG, 2010 Municipal Solid Waste Management in China: Status, Problems and Challenges *J. Env. Manage*.**91**: 1623 -1633.

[31] Martin OA, Jose EMA, and Offira G2014Solid Waste Management in Africa cities: Sorting the facts from the fads in Accra, Ghana*J. Habit. Inter.* **39**: 96-104.