ABUAD Journal of Engineering Research and Development (AJERD)
ISSN (online): 2645-2685; ISSN (print): 2756-6811

Volume 6, Issue 1, 038-043

Physicochemical Characterisation of Abuja's Municipal Solid Wastes as a Renewable Energy Resource

Paul Adah ONDACHI[1], Idris Ibrahim OZIGIS[2], Musa Tanko ZARMAI[2]

[1]*Department of Mechanical Engineering, Baze University, Abuja, Nigeria*
paul.ondachi@bazeuniversity.edu.ng/ idris.ozigis@uniabuja.edu.ng

[2]*Department of Mechanical Engineering, University of Abuja, Abuja, Nigeria*
musa.zarmai@uniabuja.edu.ng

Corresponding Author: paul.ondachi@bazeuniversity.edu.ng, +2348054173798

Date Submitted: 10/01/2023
Date Accepted: 23/04/2023
Date Published: 13/05/2023

Abstract: *Physical and chemical composition analyses of Abuja's municipal solid waste samples have been carried out in this study. Laboratory procedures were employed to determine the higher calorific value, the proximate analysis and ultimate analysis of MSW samples from selected districts of Abuja metropolis. An analytical methodology was therefore employed to determine whether the city's MSW will be good resource for energy generation as a strategy for effective waste management. Abuja's MSW has an aggregate higher heating value of 38.13MJ/kg. Moisture content of less than 8% obtained for all the samples compares very well with values for Nigerian coals. Volatile matter was found to be above than 60% for each samples tested while fixed carbon was determined to be less than 26% for each sample. The MSW samples gave excellent results for ash content of less than 4% when compared to most Nigerian coals with minimum ash content of 10.72%. The ultimate analysis shows the MSW samples compares fairly well with Nigerian coal samples in terms of elemental carbon, the least value being 41.80%. The least value for elemental carbon in most coal samples is 53.27%. Also, the sulphur content of the MSW samples is much less (not higher than 0.15%), compared with the least value of 0.58% for the coal samples. All the factors considered above indicate that the Abuja's MSW will perform very well as a primary solid fuel when incinerated for energy recovery. The economic significance of this study lies in the confirmation that Abuja's MSW is a good and cheap source of energy for electric power generation, replacing the expensive fossil fuel sources with their attendant hazardous emission to the environment. This will make the study area to be a cleaner and healthier* ***environment.***

Keywords: Municipal solid waste, proximate analysis, ultimate analysis, higher heating value,

1. INTRODUCTION

Physicochemical study of a substance is an analytical method which is very useful for characterising solid fuels such as MSW. It is the field of chemistry dealing with the interrelation between the composition and properties of matter and is the process of determining a material's composition [1]. Samples of MSW from selected districts of Abuja, Nigeria were taken for laboratory analysis in this work. The study involved the determination of the higher calorific value, the proximate analysis and ultimate analysis of MSW samples taken from Lugbe, Galadimawa and Dutse-Alhaji districts of Abuja metropolis [2].

The higher heating value (also known as gross calorific value or gross energy) of a fuel is the amount of heat released by a specified quantity (initially at 25°C) once it is combusted and the products have returned to a temperature of 25°C, which takes into account the latent heat of vaporization of water in the combustion products [3]. Bomb calorimetry is used to determine the enthalpy of combustion of a given substance. This parameter gives a picture of the energy released by incinerating a kilogram of MSW as fuel.

Proximate analysis is the process of determination of the compounds contained in an organic substance such as MSW. The analysis usually gives moisture content, volatile matter, fixed carbon and ash content and the process can be contrasted with ultimate analysis which is the process for determining the elemental composition of the given substance [4].

Result of an ultimate analysis gives the percentage composition of the MSW sample in terms of oxygen, nitrogen, hydrogen, carbon and sulphur on an as-received basis. Precise information about these parameters is crucial for a successful application of the MSW as an alternative fuel.

The need to evaluate the MSW in Abuja is for the purpose of increasing the resources for energy generation. This will simultaneously provide an effective solution for waste management in the metropolis. The aim of the study therefore is to determine the physicochemical characterisation of Abuja's municipal solid wastes as a renewable energy resource.

The study carried out in this work has the objectives of sampling and characterising Abuja's MSW from Lugbe and Galadimawa districts and the Dutse-Alhaji market. The aim of the study is the evaluation of the proximate analysis, ultimate analysis and the higher heating value of the organic waste fraction of the MSW samples for the purpose of characterisation. These are the key parameters that determine a material's energy yield when incinerated.

Waste-to-energy (WtE) is the process of generating energy in the form of electricity and/or heat from the primary treatment of waste, or the processing of waste into a fuel source [5]. Most WtE processes generate electricity and/or heat directly through incineration, or produce a combustible fuel commodity such as methane, methanol, ethanol or synthetic fuels for use in energy generation applications. WtE is a method of managing MSW, and is ideally suited to wastes that cannot be recycled in any other way. Using waste to generate energy is classified as a source of renewable energy [6]. This is because using WtE will lead to commensurate reduction in energy generation using fossil fuels which are non-renewable and emit carbon dioxide and other greenhouse gases (GHG) to the atmosphere. Energy from waste is from the organic fraction which is essentially biomass from plants and other organic sources which can be regrown in a relatively short time. Plants take in carbon dioxide from the atmosphere and convert it into biomass and when they die, it is released back into the atmosphere. Therefore, disposal of waste without energy generation will add GHG to the atmosphere. The cost of WtE is approximately 10% of that of solar energy and 66% that of wind energy [7]. The average efficiencies of WtE plants are about 18% for electricity generation and 63% for heat production [7].

2. MATERIALS AND METHODS

2.1 Study Area

Abuja is Nigeria's capital city and is located at latitude 9^0 12' north of the equator and along longitude 7^0 11' east of the Greenwich Meridian. Abuja has an estimated population of 3.3 million people, (urban population) [8]. The FCT has a total land area of approximately 713 km^2 which is divided into six area councils i.e. Abuja Municipal, Abaji, Bwari, Gwagwalada, Kuje and Kwali. Abuja which principally constitutes the Abuja Municipal Area Council has a central government institution responsible for solid waste management in the City known as the Abuja Environmental Protection Board (AEPB) with a statutory mandate covering city cleaning, street sweeping, litter control, solid waste collection and transfer and vegetation control. The F.C.T has waste dumpsites located in all the area councils including those located at Mpape, Gosa, Ajata, Karshi and Kubwa to serve the municipal area [9].

2.2 Materials

The materials used for this study include: properly labelled medium size (10 litre) polyethylene bags for waste sorting; MSW samples from selected districts of Abuja metropolis (Lugbe, Galadimawa and Dutse-Alhaji modern market); hot-air oven, Muffle furnace, Hot plate, Soxhlet extractor, Kjeldahl digester and Kjeldahl distilling unit for proximate analysis; the LECO CHN 2000 Elemental analyser for ultimate analysis; the Biobase bomb calorimeter for HHV; weighing balance.

2.3 Methods

Samples of bio-degradable organic wastes from 3 locations, Lugbe district, Galadimawa district and Dutse-Alhaji modern market, were considered representative for the study area for the purpose of characterisation [10]. Laboratory experimentations using the hot-air oven, Muffle furnace, hot plate, Soxhlet extractor, Kjeldahl digester and Kjeldahl distilling unit for proximate analysis were carried out. The LECO CHN 2000 Elemental Analyzer was utilized for the ultimate analysis tests, while the bomb calorimeter was used for the determination of the higher heating value (HHV) of the prepared MSW samples. Values of results were calculated using standard equations applicable to works on the determination of energy content of municipal solid wastes as reported by Rominiyi et al., (2017) [11]. Determination of moisture content and the ash percentage after combustion in this study followed methods reported by Tursunov and Abduganiev, (2019) [12].

2.3.1 Proximate of Abuja's MSW

The percentage content of compounds present in Abuja's MSW was determined using procedures for proximate analysis.

1) Laboratory procedure for proximate analysis

The scope for proximate analysis usually covers the determination of moisture content, volatile matter, fixed carbon and ash content in a sample.

2) Determination of moisture content

The procedure for moisture content determination was done following ASTM-E871 standards as reported in literature [12, 13] and shown in Equation 1.

$$\%M_w = \frac{M_i - M_f}{M_i} \times 100 \quad (1)$$

Where M_i is the initial mass of sample and M_f is the mass of dry sample. The results of the tests are as reported in Table 1.

3) Percentage volatile matter determination:

The amount of volatile matter present is equal to loss in weight after heating the sample to 600 °C and is calculated using the formula [11], given in Equation 2:

$$\%\, VM\ at\ 600°C = \frac{M_f - M_b}{M_i} \times 100 \quad (2)$$

Where M_i = Initial mass of the sample, M_f = mass of dry sample, M_b = final constant mass of the sample before oxidation.

4) **Percentage ash content determination:** The amount of residual matter is determined by difference, as shown in Equation 3.

$$\%\, Ash\ content = \frac{M_a - M_o}{M_i} \times 100 \quad (3)$$

Where M_a is the mass of crucible plus ash, M_o is the mass of empty crucible.

5) **Percentage fixed carbon determination**: The amount of fixed carbon is calculated using the formula given in Equation 4

$$\%\, C_{Fixed} = 100 - (\%\, M_w + \%\, VM + \%\, ash) \quad (4)$$

2.3.2 Ultimate Analysis of Abuja's MSW

Ultimate analysis which is the process for the determination of the elemental composition of an organic substance was also carried out in this work.

1) **Laboratory procedure for ultimate analysis**

The LECO CHN 2000 is the instrument was used for this test. The test was carried out following the ASTM 3174-76 procedure, with the samples sieved using a 6 mm sieve. Dry matter was determined by residual weight after drying, heating from initial temperature to about 105^{o}C. This process ensures that the inherent moisture content is total removed.

Mass of 2g of each MSW sample was combusted in the ultimate analyzer, which measures the weight percentage of carbon, hydrogen, nitrogen, sulphur, and oxygen of the sample. The total carbon, hydrogen, and nitrogen are determined at the same time from the same sample in the analyzer. Total oxygen is then calculated from the other values. The steps followed as summarised below and the values obtained are presented in the subsequent sections.

2) **Determination of carbon and hydrogen in solid waste**

Test procedure used follows ASTM D: 5868-10a as demonstrated by Rominiyi et al., (2017) [11], in their analysis of municipal solid waste for energy. Per cent hydrogen and elemental carbon contents in the samples were then calculated using Equations 5 and 6, respectively:

$$\%\, H_2\ content = \frac{2Y}{18X} \times 100 \quad (5)$$

$$\%\, C\ content = \frac{12Z}{44X} \times 100 \quad (6)$$

Where: Y is the increase in the weight of CaCl2 tube; Z is the increase in the weight of KOH tube; X is the weight of waste sample taken.

3) **Determination of nitrogen content in waste sample**

Nitrogen content is estimated using Kjeldahal's method as outlined by Rominiyi et al, (2017) [11], with the calculation based on Equation 7.

$$\%\, N_2\ content = \frac{V_{Acid} \times N}{M_s} \times 1.4 \quad (7)$$

Where V_{Acid} the volume of sulphuric acid used and N is the normality of acid. M_s is the mass of MSW sample used.

4) **Determination of sulphur in the waste sample**

Determination of Sulphur in the Waste Sample was in compliance with ASTM D-5868-10a as applied by Rominiyi et al, [11]. Equation 8 was applied for the evaluation of % S.

$$\%\, S = \frac{32W}{233X} \times 100\,\% \quad (8)$$

Where X is the weight of waste sample taken; W is the weight of $BaSO_4$ precipitate formed.

2.3.3 Procedure for Determination of Higher Heating Value (HHV)

The procedure for determining the HHV of MSW using the Biobase BCY-1A bomb calorimeter is according to ASTM D240-09, [14]. The system consists of the sample (s), the bomb (b), and the calorimeter water (w) and bucket. The sample is contained within the bomb, which is immersed within the water contained by the calorimeter bucket. Applying the First Law of Thermodynamics to this system gives, (Equation 9):

$$\Delta U = Q_v - W \quad (9)$$

Where:
Δ U is the change in internal energy of the system; Q_v is the heat transfer at constant volume. W is work performed on or by the system.

Since there is no work crossing the system boundary, being a constant volume process, the change in internal is the heat transfer at constant volume, Equation 10.

$$\Delta U = Q_v \tag{10}$$

If the entire system is adiabatic, the heat of combustion is used to change the temperature of the water and the bomb, only changing the internal energy, hence $Q_v = \Delta U = \int_{T_0}^{T} mC_p dT$, as given in Equation 11.

$$\text{i.e } HHV = \Delta U = \int_{T_0}^{T} [(mC_p)_b + (mC_p)_w] dT \quad [15] \tag{11}$$

Therefore by measuring the temperatures, the heating values of the samples are obtained from Equation 11 and presented in Table 3.

3. RESULTS AND DISCUSSIONS

3.1 Proximate Analysis

Results of tests for proximate analysis for MSW samples from Lugbe (Lug), Galadimawa (Gal) and Dutse-Alhaji market are presented in Table 1. It is observed that test parameters for all samples have values falling in close ranges. This compares well with results obtained by other researchers, such as Oluwadre, 2019 [13]. Results obtained in this study also compare well with Rominiyi and Adaramola, 2020 [16], in their work "Proximate and Ultimate Analysis of Municipal Solid Waste for Energy Generation".

These results from proximate analysis show that Abuja's MSW will be a very good source of renewable energy. Moisture content of less than 8% obtained for all the samples compares very well with values for Nigerian coal (5.17%, Maiganga coal; 5.44%, Okaba coal; 6.20%, Enugu coal), [17]. The MSW samples gave excellent results for ash content (less than 4%) compared to 13.98, 10.72 and 20.02 for Maiganga, Okaba and Enugu coals, respectively. However, the MSW samples are rich in volatile matter (more than 60% for each sample) but low in fixed carbon (less than 26% for each sample) compared to the coal samples where the maximum volatile matter content is 28.98%, for Enugu coal, and the least value for fixed carbon is 52.65%, also for Enugu coal. In solid fuels, the lower the volatile matter and the higher the fixed carbon the better the energy yield from combustion. Corresponding values for the coal samples are as shown in Table 1. These results for volatile matter and fixed carbon contents indicate that maximum temperature achievable in the incineration of Abuja's MSW will be lower than what can be achieved in coal combustion.

Table 1: Proximate analysis data of Abuja MSW samples showing comparison with some Nigerian coals

Sample ID	Moisture Content (%)	Volatile Matter Content (%)	Fixed Carbon Content (%)	Ash Content (%)
LUG (Lugbe)	7.70	63.02	25.44	3.86
GAL (Galadimawa)	7.80	60.92	27.64	3.64
DUT (Dutse-Alhaji)	7.90	62.82	25.60	3.66
Maiganga coal*	5.17	19.19	61.66	13.98
Okaba coal*	5.44	21.54	54.86	10.72
Enugu coal*	6.20	28.98	52.65	20.02

* Adapted from Garba et al, [17]

3.2 Ultimate Analysis

Results of tests for ultimate analysis for MSW samples from Lugbe (Lug), Galadimawa (Gal) and Dutse-Alhaji market are presented in Table 2. It may be observed that values for each parameter fall into close ranges, for example, carbon content was 42.8, 43.82 and 41.8 for Lugbe, Galadimawa and Dutse-Alhaji, sample, respectively. The similarity in waste content may be responsible for this, all samples being organic fraction, though from different locations.

The ultimate analysis (Table 3) shows the MSW sample compares fairly well with the coal samples in terms of elemental carbon, least value being 41.80%, with corresponding value for Maiganga coal samples being 56% [18].

All the factors considered above indicate that the Abuja MSW will perform very well as a primary solid fuel when incinerated for energy recovery. Also, the sulphur content of the MSW samples is much less (not higher than 0.15%), compared with the least value of 0.58% for the coal samples. This is a difference of about 387% and indicates that the MSW will be a much more environmentally friendly fuel than coal. All the corresponding values for the coal samples are as shown in Table 2.

Table 2: Ultimate analysis data of Abuja MSW samples showing comparison with some Nigerian Coals

Sample ID	Nitrogen Content	Elemental Carbon (%)	Hydrogen (%)	Sulphur (%)	Oxygen (%)
LUG (Lugbe)	0.40	42.80	7.34	0.15	40.55
GAL (Galadimawa)	0.39	43.82	9.38	0.12	37.55
DUT(Dutse-Alhaji)	0.40	41.80	8.34	0.15	40.55
Maiganga coal*	1.37	59.23	7.10	0.58	13.53
Okaba coal*	2.20	57.94	6.02	0.98	13.76
Enugu coal*	2.67	53.27	4.97	1.82	12.43

* Adapted from Garba et al, [17]

3.3 Higher Heating Value

Also, tests were conducted to obtain the heating values of Abuja's municipal solid waste in order to ascertain its suitability as alternative renewable solid fuel for commercial energy generation. Results of the tests are as shown in Table 3. The values obtained are in the same range and compare very well with values for Nigerian coals, Table 3. From Table 3, it may be seen that the Galadimawa MSW sample has the highest HHV of 24.45 MJ/kg, while). Lugbe and Dutse-Alhaji have 23.27 and 19.47 MJ/kg, respectively. High values of HHV means that energy yield per kilogram will be very high, making Abuja's MSW to be a very good and cheap fuel source to replace coal and other fossil sources.

Table 3: Calorific values of Abuja MSW samples

Sample ID	HHV (MJ/kg) MSW	HHV (MJ/kg) Coal*
LUG (Lugbe)	23.27	--
GAL (Galadimawa)	24.45	--
DUT (Dutse-Alhaji)	19.47	--
Maiganga	--	27.40
Okaba	--	25.74
Enugu	--	22.92
Aggregate	22.40	--

* Garba et al, [17]

4. CONCLUSION

Physicochemical characterisation and energy content of MSW Abuja Metropolis, Nigeria was investigated in this study. Results from the qualitative analysis shows that Abuja's MSW can be used to improve the quality of life of residents of the metropolis through conversion to renewable energy which will also be a positive driver to the improved management of municipal solid waste in the study area.

This study has shown the good results for HHV, proximate and ultimate analyses obtained for Abuja's MSW. Abuja's MSW has an aggregate HHV of 38.13 MJ/kg while values for proximate analysis determined showed very low moisture and moderate carbon content. Content of volatile matter obtained at more than 60% is judged to be high. The MSW samples gave excellent results for ash content (less than 4%) compared to 13.98, 10.72 and 20.02 for Maiganga, Okaba and Enugu coals, respectively. The results from ultimate analysis also proved that Abuja's MSW will be very environmentally friendly with very low sulphur content.

The study shows conclusively that Abuja's MSW is a good and economic alternative energy resource waiting to be harnessed. Establishing a WTE plant in Abuja to run on MSW generated within the metropolis will be good source of wealth creation.

ACKNOWLEDGMENT

The authors hereby express their profound gratitude to Dr. Alo Francis Ireti of the Department of Material Science and Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria, and his staff for the technical support rendered in the laboratory analysis for this work.

REFERENCES

[1] Kalkan, S., Otağ, M. R. & Engin, M. S. (2020). Physicochemical and bioactive properties of edible methylcellulose films containing Rheum ribes L. extract. *Food chemistry*, Vol. *307*, 125524.

[2] Gotze R., Boldrin, A., Scheutz, C., Thomas F. & Astrup, T. F. (2016), Physico-chemical Characterisation of Material Fractions in Household Waste: Overview of Data in Literature, *Waste Management*, Volume 49, Pages 3-14, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2016.01.008.

[3] Taki, M. & Rohani, A. (2022). Machine learning models for prediction the Higher Heating Value (HHV) of Municipal Solid Waste (MSW) for waste-to-energy evaluation. *Case Studies in Thermal Engineering*, Vol *31*, 101823. ISSN 2214-157X, https://doi.org/10.1016/j.csite.2022.101823.

[4] Noushabadi, A. S., Dashti, A., Ahmadijokani, F., Hu, J. & Mohammadi, A. H. (2021), Estimation of Higher Heating Values (HHVs) of Biomass Fuels Based on Ultimate Analysis Using Machine Learning Techniques and Improved Equation, *Renewable Energy*, Volume 179, pp 550-562, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2021.07.003.

[5] Shah, S. A. A., Cheng, L., Yasir, A. S., Munir, A. & Ali. S. (2021), Energy Trilemma Based Prioritization of Waste-to-Energy Technologies: Implications for Post-COVID-19 Green Economic Recovery in Pakistan." *Journal of cleaner production*, Vol. 284, 124729, ISSN 0959-6526, https://doi.org/10.1016/j.jclepro.2020.124729.

[6] De-Campos, V. A. F., Silva, V. B., Cardoso, J. S., Brito, P. S., Tuna, C. E. & Silveira, J. L. (2021), A Review of Waste Management in Brazil and Portugal: Waste-to-Energy as Pathway for Sustainable Development, Renewable Energy, Volume 178, 2021, pp 802-820, ISSN 0960-1481, https://doi.org/10.1016/j.renene.2021.06.107.

[7] Chen, Y. & Wang, C. (2017), Municipal Solid Waste (MSW) Incineration's Potential Contribution to Electricity Production and Economic Revenue in Taiwan, Journal of Taiwan Energy, 4(1), pp 93-106.

[8] Worldometer (2020). Nigeria Population [On-line]. Available: *www.worldometers.info › world-population › nigeria*

[9] Seidu K., Muhammad I. D. & Ozigis I. I. (2021). Characterization of Gosa Municipal Solid Wastes at Abuja, Nigeria, FUOYE Journal of Engineering and Technology, 6(1), pp 72 – 76.

[10] Fugard, A.J.B. & Potts, H.W.W. (2015), Supporting Thinking on Sample Sizes for Thematic Analyses: A Quantitative Tool, *International Journal of Social Research Methodology*, Vol. 18, No. 6, 669–684, http://dx.doi.org/10.1080/13645579.2015.1005453

[11] Rominiyi O. L., Fapetu, O., Owolabi, J. & Adaramola, B. (2017). Determination of Energy Content of the Municipal Solid Waste of Ado – Ekiti Metropolis, Southwest, Nigeria. *Current Journal of Applied Science and Technology*. 23 (1). 1-11, Doi: 10.9734/CJAST/2017/32340.

[12] Tursunov, O., & Abduganiev, N. (2019), A Comprehensive Study on Municipal Solid Waste Characteristics for Green Energy Recovery in Urta-Chirchik: A Case study of Tashkent Region. *Materials Today: Proceedings.* Vol 25, pp 67 – 71, doi:10.1016/j.matpr.2019.11.108.

[13] Anguruwa G. T. & Oluwadare A.O. (2019), Temperature Regime and Its Effect on Energy Potentials of Bio-Oil From Ficus Exasperata Wood Residue, *Journal of Energy Technologies and Policy*, www.iiste.org, ISSN 2225-0573 (Online) Vol.9, No.8, pp 1 – 11. DOI: 10.7176/JETP/9-8-01

[14] Biobase Ltd., (2023), Biobase Table-Top Oxygen Bomb Calorimeter: Product Description, Available: https://biobasemeihua.en.made-in-china.com/product/rBSmepRJuVUQ/China-Biobase-Table-Top-Oxygen-Bomb-Calorimeter.html

[15] Rajput R. K., (2007), Engineering Thermodynamics, Third Edition, *Laxmi Publications,* New Delhi, India.

[16] Rominiyi, O. L. & Adaramola, B. A. (2020), Proximate and Ultimate Analysis of Municipal Solid Waste for Energy Generation, *ABUAD Journal of Engineering Research and Development*, Volume 3, Issue 1, 103-111.

[17] Garba, M.U.; Musa, U., Azare, P. E., Ishaq, K., Onoduku, U. S. & Mohammad, Y. S. (2016), Characterization and Ash Chemistry of Selected Nigerian Coals for Solid Fuel Combustion, *Petroleum and Coal*, http://repository.futminna.edu.ng:8080/jspui/bitstream/123456789/915/1/XXXGARBA%20ET%20AL%.

[18] Ozigis I. I. & Zarmai M. T. (2019), Determination of Maiganga Lignite Coal Combustion Characteristics for Application in Thermal Power Plant Using Standard Mathematical Models, *Arid Zone Journal of Engineering, Technology and Environment*, Vol. 15(2), pp 418 – 434. Available: https://azojete.com.ng/index.php/azojete/article/view/84/65.