Investigation of the Thermal Stability of Abuja's Municipal Solid Waste as a Renewable Energy Resource

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ORIGINAL RESEARCH

Abstract- The thermal stability of Abuja's municipal solid waste has been investigated in this study. Thermogravimetric and differential thermal analyses (TGA and DTA) were carried out on the MSW samples from three selected districts of Abuja metropolis under nitrogen atmosphere. The TG curves for samples from Galadimawa district and Dutse-Alhaji market are observed to have the same thermal behavioural trends which may be due to the presence of structural similarity of substances contained in the two samples compared to the behaviour of sample from Galadimawa district. Lugbe sample exhibited three stages of decomposition while Galadimawa and Dutse-Alhaji samples have two main stages of decomposition. This study reveals that Abuja's MSW have endothermic temperature peaks of 405.75 ^oC for sample from Lugbe district, 409.51 ^oC for Galadimawa district sample and 381.42 ^oC for sample taken from Dutse-Alhaji market, respectively. These values compare well with corresponding values for Nigerian coals (Enugu with 408 ^oC), thereby showing good thermal stability, and will be better and more economic fuel, especially when used with a secondary fuel such as High Pour Fuel Oil (HPFO) or diesel oil, for the generation of energy than coal with the additional benefit of being a renewable source.

Keywords- municipal solid waste, thermogravimetric analysis, thermal stability, endothermic temperature, renewable energy.

1 Introduction

Management of municipal solid waste (MSW) has become very challenging in many cities of the developing regions of the world such as Nigeria. There is also the need for improvement of access to electricity. An effective strategy that answers these two challenges is the concept of converting waste to energy through thermal technology. This has been done in many developed economies such as China, Japan, USA and Sweden (Rogoff, 2019). The desire of 'killing two birds with one stone' in contributing to efforts in finding solution to the burgeoning problem of municipal solid waste and the epileptic power supply situation is the driving motivation for this study. These challenges in MSW management in many Nigerian cities manifest in indiscriminate waste disposal, blocked drainages, over-flowing central waste collection bins not timely transported to final disposal sites.

Deliberate efforts to create wealth from waste by obtaining energy through the conversion of wastes will provide the desired solution of improved power supply and better MSW management and will help to be a very effective driver for the management of municipal solid waste in Abuja and other cities of Nigeria and West Africa. Waste-to-energy (WtE) is the process of generating energy in either as electricity or heat from the primary treatment of waste, or the processing of waste into a fuel source (Pan et al, 2015).

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 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 (Klinghoffer et al, 2013; Seidu et al, 2021). This is because using WtE will lead to commensurate reduction in the production of energy from fossil fuels which are non-renewable and emit carbon dioxide (CO_2) and other GHG to the atmosphere. Energy from waste is from the organic fraction which is essentially biomass from plants and other organic sources which can regrow in a relatively short time. Vegetation takes in CO_2 from the atmosphere and converts it into biomass and when they die, the CO_2 is released back as a hazard into the atmosphere. MSW is also regarded as renewable source of energy because if not so used, it will have to be sent to the landfills for final disposal where they will release greenhouse gases to the environment. Renewable energy is derived from natural sources that are replenished at a higher rate than they are consumed (Panwar et al, 2010). Sunlight, hydro, biomass and wind, for example, are such sources that are constantly being replenished (Panwar et al, 2010; Ozigis et al, 2021). Renewable energy sources are abundantly available all over the world.

Municipal solid waste (MSW) refers to the materials discarded majorly from households and commercial centres, collected and disposed by the municipal authorities. MSW contains a significant fraction of paper, food waste, wood and yard trimmings, cotton, and leather, and is a source of biomass (Hefa Cheng and Yuanan Hu, 2010). Waste fractions derived from fossil fuels, such as plastics, rubber, and fabrics, are also found

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Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
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in MSW. MSW is therefore a rich source of energy that is renewable due to the high organic content.
The cost of WtE is approximately 10% of that of solar energy and 66% that of wind energy (Ying-Chu Chen, Chung-Ting Wang, 2017). The average efficiencies of WtE plants are about 18% for electricity generation and 63% for heat production (Ying-Chu Chen & Chung-Ting Wang, 2017).

This work presents investigation into thermal stability of municipal solid waste as a renewable energy resource.
Thermal stability of a material is defined as the ability of the material to resist decomposition under the action of applied heat and is determined by thermogravimetric analysis (TGA). Thermal stability of a material is therefore indicated by the temperature at which the material begins to degrade at an appreciable rate under the effect of heat (Kple et al, 2016). Fuels with high thermal stability have lower risks in handling and transportation, and easily allows for optimisation of combustion performance. The temperature at which degradation starts marks the point of release of energy when the substance is burnt. However, for the production of energy by a waste conversion process to be effective, detailed study of the MSW parameters including thermal stability is needed. This present work on Abuja's MSW aims to fill that gap and provide data on the thermal stability of Abuja's MSW as a renewable energy source. This study has the objectives of sampling MSW from Lugbe, Galadimawa and Dutse-Alhaji market, all in Abuja metropolis for the evaluation of the TG and DTA of the organic waste fraction of the MSW samples.

Thermogravimetric analysis (TGA) is an analytical technique used to determine a material's thermal stability and it is also a modern tool for the determination of the material's proximate analysis by observing the weight change that occurs as a sample is heated at a constant rate (Rajisha et al, 2011). Differential Thermal Analysis (DTA) is a process in which the temperature difference between the sample and a reference material is observed against time while the temperature of the sample, in a specified atmosphere, is programmed. This experimental procedure was first developed by Le Chatelier in 1887 but only gained popularity in recent time (Vold, 1949).

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) (Worldometer, 2020). 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 AMAC) has a central government institution responsible for solid waste management in the City known as the Abuja Environmental Protection Board (AEPB). The F.C.T has waste dumpsites located in each area council including those located at Mpape, Gosa, Ajata, Karshi and Kubwa to serve the metropolitan area (Seidu et al, 2021).

2.2 Methods

Samples of bio-degradable organic wastes from 3 locations, Lugbe, Galadimawa and Dutse-Alhaji modern market, were considered representative for the study area for the purpose of characterisation. Laboratory experimentations with the PerkinsElmer TGA 4000, PerkinsElmer Diamond Differential Thermal Analyzer (DTA) were undertaken to obtain the thermal stability of the MSW samples.

2.3 Description of Laboratory Procedures

This section gives brief description of procedures for the various laboratory tests undertaken in the work.

2.3.1 Thermogravimetric Analysis Procedure for Thermal Stability

The equipment used for this procedure is PerkinElmer TGA 4000. The ASTM E1131 standard procedure was employed in this test as follows: 5 mg of MSW sample was put into the sample holder. This is then placed in the analysis chamber and covered. The sample was cooled to a temperature of 15^o C. The desktop computer's short cut for the equipment is then selected by double clicking on it. This allows the operation of the system. All the information about the sample (name of sample, type of sample, source, etc) was then inputted into the computer.

A sample purge gas controls the sample test environment. An inert environment for the test was created by allowing in nitrogen gas to flow over the sample and exits through an exhaust. A nitrogen flow rate of 20 mL/min was selected. A heating rate of 10^0C/min was selected and the procedure started. A heat rate of about 10^0C/min is considered to be gradual rate. A higher heating rate will lead to rapid degradation of sample that cannot be effectively monitored and thereby may give erroneous results. The TGA curve is plotted automatically by the system software. The system is then shut down at end of the experiment. Differential thermal analysis (DTA) tests for the samples were also conducted for comparative purposes.

2.3.2 Thermal Analyzer Procedure

The procedure for the DTA involves the following steps (Vyazorkin et al, 2018):

a. The instrument's aluminum pan was filled with approximately 10–15 mg of the prepared sample and the sample was heated from the ambient temperature up to 600°C with heating rate of 10°C/min.
b. The analysis was done under nitrogen atmosphere with flow rate of (50 cm^3/min) and, accordingly, the corresponding weight loss was recorded.
c. The differential scanning calorimetry analyses were carried out using Shimadzu DSC-60 (Shimadzu, Japan).
d. The heating and cooling program was from 30 °C to 220 °C and from 220 °C to 30 °C, respectively, at a rate of 10 °C/min and holding time of 3 min.

3 Results and Discussion

3.1 Thermal Stability of Abuja MSW

Data for thermogravimetric and differential thermogravimetric studies of Abuja's municipal solid wastes obtained in this study are presented in Table 1.

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Table 1. TGA and DTG information of organic waste samples from selected districts of Abuja

Sample	Onset temperature (°C)	Endothermic peak temp Tp (°C)	Degradation range (°C)
GAL (Galadimawa)	299 (98.39 %)	405.75	299-539.39
LUG (Lugbe)	326.79 (94.16 %) 419.02 (61.07 %)	409.51	326.79-505.49
DUT (Dutse-Alhaji)	311.76 (91.51 %) 373.90 (61.88 %)	381.42	311.76-472.54

Also, thermogravimetric and differential thermogravimetric curves for the samples of municipal solid wastes obtained after respective the test procedures described above are as depicted in Figs. 1 and 2, respectively. The heat rate of 10°C/min was applied for all samples. Differential thermal analysis tests were also conducted on the samples and the complementary results obtained are as presented in Figs. 3 – 5.

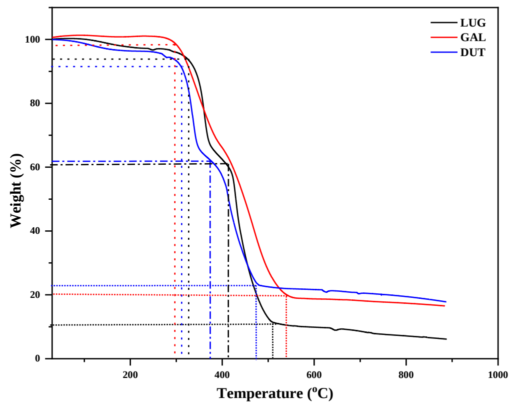

Fig. 1: TGA curves of LUG, GAL and DUT MSW samples at 10° C/min.

3.2 Thermal Stability of Abuja MSW as Solid Fuel

Thermal stability of a solid fuel is indicated by the temperature at which the material begins to degrade under the effect of heat at an appreciable rate. Fuels with high thermal stability have lower risks in handling and transportation, and easily allows for optimization of combustion performance. The temperature at which degradation starts marks the point of release of energy when the substance is burnt.

Thermogravimetric and differential thermal analyses (TGA and DTA) were carried out on the MSW samples for the determination of their thermal stability and the results are as shown in Figs. 1 - 5. From Fig. 1, the TG curves of GAL (sample from Galadimawa) and DUT (sample from Dutse-Alhaji market) are observed to have the same thermal behavioural trends which may be due to the presence of structural similarity of substances contained in the two samples compared to the behaviour of sample LUG (sample from Lugbe). It is observed that LUG exhibited three stages of decomposition while GAL and DUT have two main stages since main constituents of the waste have different degradation behaviour. These stages include moisture drying and degradation of unstable substances (volatiles) in the samples at varying temperatures. As illustrated in Fig. 3, least amount of weight loss (1.61 %) occurred until about 299 °C for GAL, followed by weight loss (7.49 %) at onset temperature of 326.79 °C for LUG and the highest weight loss (8.84 %) at onset temperature of 311.76 °C for DUT was obtained. At this temperature, it was expected that water molecule and volatile substances are released until all these substances disappeared.

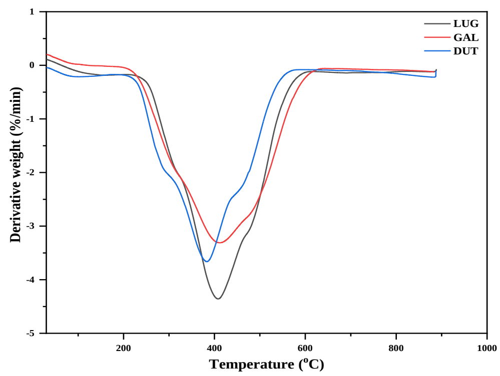

Fig. 2: DTG curves of LUG, GAL and DUT at 10 °C/min.

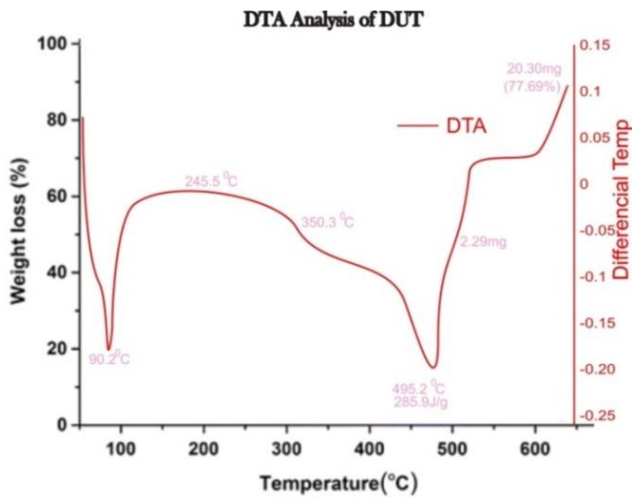

Fig.3: Organic Waste Sample DTA Analytical Curve for Dutse-Alhaji Market, Abuja MSW

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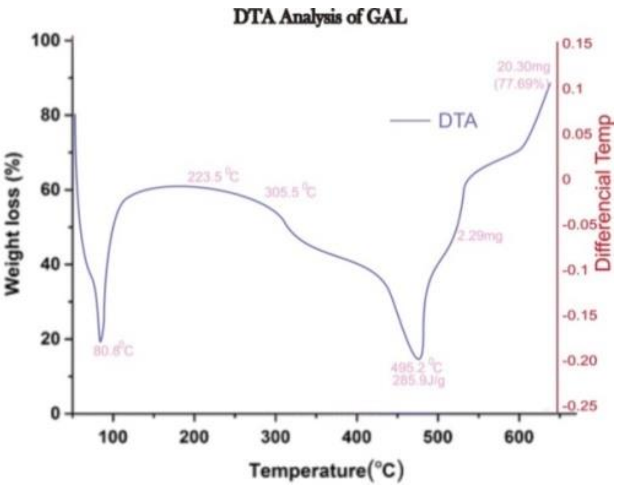

Fig.4: Organic Waste Sample Analytical Curve for Galadimawa Abuja MSW

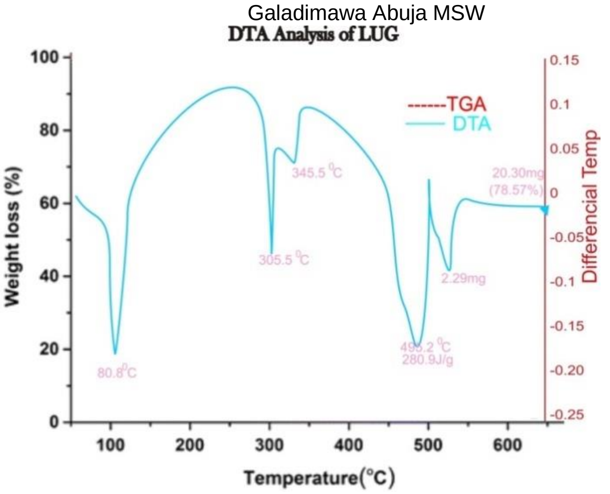

Fig.5: Organic Waste Sample DTA Analytical Curve for from Lugbe, Abuja

The DUT (Fig. 3) and GAL (Fig. 4) samples essentially manifested a single degradation rate starting at about 299 °C and ending at 540 °C. The LUG sample had a 2 step-degradation rates (from 326.79 – 419.02 °C; 419.02-505.49 °C) and (311.76 - 373.90 °C; 373.90 - 472.54 °C), Fig. 5, respectively. Hemicellulose and cellulose decomposition are expected to be within these temperatures (Vyazorkin et al, 2018). The chemical structures of the materials start to decompose at these temperature regions. It is concluded from the DTG curves, Fig. 4, that an endothermic peak appears for individual samples with LUG (405.75 °C), GAL (409.51 °C) and DUT (381.42 °C). The endothermic peaks for all samples occurring within same temperature range confirms the all the samples are organic food wastes with largely similar composition, hence similar thermal behaviour. These values compare well with corresponding values for Nigerian coals. Values are almost equal to the endothermic temperature of Enugu coal which has its peak temperature as 408 °C, though lower than values for Okaba coal in Kogi State (507 °C) and Maiganga coal in Gombe State (508 °C) coals (Mohammed et al, 2016).

Complementary results were obtained by the use of differential thermal analysis technique on the samples as shown in Figs. 3 – 5. The first endothermic peak in the DTA curves is the ignition point for the volatiles while the second and subsequent peaks indicate the commencement of the ignition of the fixed carbon in the MSW, respectively, as they are released by the decomposition of the various fractions in the MSW samples.

4 Conclusion

Thermogravimetry and differential thermal analysis were employed to study the thermal stability of Abuja's MSW. Samples of Abuja's MSW tested showed good thermal stability with endothermic peak temperature of about 400°C, which compares very well with value for Nigerian (Enugu) coal. The results showed that degradation of MSW samples begins at temperatures between 389 and 409 °C, with maximum degradation for all samples occurring 400 °C. These results prove that Abuja's MSW will be good and economic energy resource for electric power generation with the additional benefit of the conversion process being a good driver for improved management of municipal solid waste for the metropolis.

5 Recommendation

The study of all relevant parameters that influence the use of MSW as energy resource is very important. Thermogravimetry and differential thermal analysis as undertaken here to study the thermal stability of Abuja's MSW is part of the general requirements. Under such studies it is recommended that various heating rates and different atmospheres, in addition to nitrogen, be explored in order to obtain more generally applicable conclusions. This is because proven sustainable energy generation from WtE will greatly drive the national economy positively, creating wealth from waste, improving MSW management practice and without additional emission of greenhouse gases to the environment.

References

Hefa Cheng & Yuanan Hu, (2010), Municipal Solid Waste (MSW) as a Renewable Source of Energy: Current and Future practices in China, *Bio-resource Technology*, Volume 101, Issue 11,Pages 3816-3824, https://doi.org/10.1016/j.biortech.2010.01.040.

Klinghoffer, N. B., Themelis N. J., & Castaldi, M. J., (2013), "Waste to Energy Conversion Technology". [On-line]. Pp 3–14. Available: *https://doi.org/10.1533/9780857096364.1.3*.

Kple, M., Girods, P., Anjorin, M., Fagla, B., & Rogaume,Y. (2016). Thermal degradation of household solid waste in the town of Abomey-Calavi in Benin:kinetic study. *Waste and biomass valorization*, *7*, 5970.

Mohammed U. Garba, Precillia. E. Azare, Kariim Ishaq, Usman. S. Onoduku, Yahaya, S. Mohammad & Umaru Musa, (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%*, [accessed 9/7/22].

Ozigis, I. I., Adeyemi, R. A, Ondachi, P. A. & Oodo, S. O., (2021), Performance Evaluation of Kainji Hydro-electric Power Plant Using Artificial Neural Networks and Multiple linear Regression, *International Journal of Energy and Water Resources*, https://doi.org/10.1007/s42108-021-00135-3

Özsin, G., & Pütün, A. E. (2017). Kinetics and evolved gas analysis for pyrolysis of food processing wastes using TGA/MS/FT-IR. *Waste Management*, 64, pp. 315–326.

Pan, S.-Y., Du, M. A., Huang, I.-T., Liu, I.-H., Chang, E. E., & Chiang, P.-C. (2015). *Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: a review. Journal of Cleaner Production, 108, 409–421.* doi:10.1016/j.jclepro.2015.06.124

Panwar, N. L., Kaushik , S. C. & Surendra Kothari, (2010), Role of renewable energy sources in environmental protection: A review, *Renewable and Sustainable Energy Reviews,* Available: *https://doi.org/10.1016/j.rser.2010.11.037*

Rajisha, K. R., Deepa, B., Pothan, L. A. & Thomas, S., (2011), Thermomechanical and Spectroscopic Characterization of Natural Fibre Composites, Editor(s): Nikolaos E. Zafeiropoulos, In *Woodhead Publishing Series in Composites Science and Engineering, Interface Engineering of Natural Fibre Composites for Maximum Performance,* Woodhead Publishing, 2011, Pp 241-274, ISBN 9781845697426.

Rogoff, M. J., (2019), "The Current Worldwide WTE Trend", *MSW Management,*.[Online], https://www.mswmanagement.com. [accessed 11/9/20].

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 – 78.

Vold, M. J. (1949). Differential Thermal Analysis. *Analytical Chemistry, 21(6), Pp 683–688,* doi:10.1021/ac60030a011

Vyazorkin, S., Koga, N. & Schick, C., (2018), Handbook of Thermal Analysis and Calorimetry: recent advances, Techniques and Applications, Vol.6. *https://www.researchgate.net/publication/323734778*

Worldometer (2020), "Nigeria Population"[On-line]. *www.worldometers.info › world-population › nigeria.* [accessed 2/6/20].

Ying-Chu Chen & Chung-Ting Wang. (2017), "Municipal Solid Waste (MSW) Incineration's Potential Contribution to Electricity Production and Economic Revenue in Taiwan". Journal *of Taiwan Energy.* [On-line].4(1), pp 93-106.