



ORIGINAL RESEARCH ARTICLE

EVALUATION OF MUNICIPAL SOLID WASTES CHARACTERISTICS TOWARDS
ELECTRICITY GENERATION IN MAIDUGURI METROPOLIS

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ABSTRACT

This paper evaluates the characteristics of municipal solid waste (MSW) in Maiduguri metropolis for its potential use in electricity generation. Three key areas within Maiduguri were selected for the study: Area A (Northern Nigeria Flour Mills), Area B (Monday Market/Gwange area), and Area C (University of Maiduguri dumpsite). Additionally, three seasonal periods were considered - (1) rainy season, (2) cold/harmattan season, and (3) hot season. Refuse dumps in these areas were visited during each season to collect and analyze the MSW. The characteristics of the MSW were evaluated through physical analysis, which involved sifting through the waste and separating it into its major components. Further analysis included proximate and ultimate analyses conducted according to ASTM standards to determine the properties of the waste. The study revealed that the composition of refuse produced by communities in Maiduguri varies due to seasonal and behavioural changes. Wood, plastics, and grass were identified as the major physical constituents of the waste, with their proportions influenced by seasonal variations. The calorific values of MSW samples varied across the study areas, reflecting differences in population density and commercial activities. The highest calorific values were recorded in Area B during the rainy and cold seasons, with values of 19.81 MJ/kg and 15.055 MJ/kg, respectively. At the University of Maiduguri dumpsite (Area C), the calorific values of MSW samples were 7500 MJ/kg, 8420 MJ/kg, and 4500 MJ/kg for the rainy, cold, and hot seasons, respectively, resulting in an average of 6800 MJ/kg. This average is below the minimum calorific value of 7000 MJ/kg required for setting up an incineration plant with energy recovery. To enhance the energy potential of the MSW from the University of Maiduguri, supplementary fuels such as bagasse would need to be added to boost its calorific value and make it suitable for electricity generation. This study highlights the potential for MSW utilization in Maiduguri and identifies areas for improvement to optimize its energy recovery capabilities.

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1.0 Introduction

Solid waste generation and characterization are some of the most important parameters which affect environmental sustainability (Huseyin et al., 2016). Municipal solid waste (MSW) characterization depends on social structure and income levels. The amount of waste generated and the growing concern over health (Hamer, 2003) and environmental problems (Yang et al., 2019) related to improper waste disposal methods such as uncontrolled and crude landfilling has risen to an unacceptable point where transformation technologies and techniques are to be thought of power generating technology using municipal solid waste (MSW) as fueling resource requires that the mechanism of performance is investigated to devise ways of optimization. Typical of the performance tools are the parameters related to the waste characteristics such as basic components, moisture content, and calorific value. To enhance the performance of the MSW plant, in addition to identifying the parameters alongside their significance, it is of importance to investigate these parameters and correlate them for the development of a MSW power system. In many countries, open dumping is considered the simplest, cheapest, and most cost-effective way of managing solid wastes. Thus, in

underdeveloped economies, MSW is openly dumped (Osra et al., 2021). Improper waste disposal causes air, water, and soil pollution, impairing soil permeability and blockage of the drainage system. Solid Waste Management (SWM) can be enhanced by operating a well-engineered site with the capacity to reduce, reuse, and recover MSW.

The energy crisis and environmental degradation are currently two vital issues for global sustainable development (Leena et al., 2014). Rapid industrialization and population explosion have led to migration of people from villages to cities, which generate thousands of tonnes of municipal solid waste daily, which is one of the important contributors to environmental degradation. Improper management of MSW causes hazards to inhabitants. The management of MSW requires proper infrastructure, maintenance, and upgrades for all activities. Several kinds of research have been focusing on MSW. Status and challenges of MSW, their characterization, valuation as possible renewable resource and their management in countries such as India, Ethiopia, Nigeria, Saudi Arabia (Peter et al., (2008); Joshi and Ahmed (2016); Diego et al., (2017); Aron (2017); Ogwueleka (2009); Oumarou et al., (2012)a ; Oumarou et al., (2012)b ; Osra, et al., (2021);) and its use for energy recovery as well as the techniques (Umberto (2012); Ola and Göran (2017); Olisa and Ajoko (2018); Olisa et al., (2016) ; Olisa et al., (2017) ; Oumarou et al., (2018) ; Oumarou, et al., (2012); Altine et al., (2017); Jack and Oko (2017); Amulah et al., (2024);) amongst other, have been investigated. The calorific value, a single most important parameter, measures the energy available in a particular substance that is released as heat during complete combustion. It varies greatly for different materials and is one of the most important waste characteristics in assessing the feasibility of a waste incineration plant. The relevant composition must be known to evaluate the calorific value of combustible waste (Srivastava et al., (2014), Song et al., (2017), Soorige and Priyalal (2018), Santiago et al., (2019), Sahabo et al., (2021).

Presently, in the Maiduguri area there are several gaps, in the need for more waste studies to cover seasonality; gaps in studies coverage in accounting for material-specific treatment as well as gaps in quality of research design and consistency such as: seasonality and control for days of week, lack of local knowledge on incineration, gasification among others, and material-specific recycling tonnages. There are also gaps in basic compositional data: moisture content, feed rate, energy content, bulk density, etc. The extreme North-Eastern part of Nigeria typically Maiduguri, produces large quantities of waste that needs removal and disposal from the immediate environment. The waste generation for the year 2023 is estimated at 2.63×10^5 tonnes using a waste generation rate of 0.53 kg/capita/day, a base-year population of 1,328,100 and an annual growth rate of 2.40% for Maiduguri. This research paper investigates the basic composition of the MSW produced by communities in Maiduguri, through physical characterization, proximate and ultimate analysis to determine the MSW suitability for energy recovery and use in electricity generation.

2. Materials and Methods

Maiduguri, the study area, the most city full of activities and population in Borno state, is geographically located at coordinates 11.8311°N and 13.1510°E (OCHA, 2018). Field visits to various refuse dumps were conducted during three distinct seasons: the rainy season (June to October), characterized by high moisture content and elevated daily ambient temperatures, which accelerate the rate of putrefaction; the hot season (March to May), marked by extreme heat; and the cold/harmattan season (November to February), noted for lower temperatures and reduced moisture levels. These seasonal variations were critical for understanding the dynamics of municipal solid waste (MSW) in the study area. Three areas within Maiduguri metropolis were selected for the study and labelled as follows: Area A (Northern Nigeria Flour Mills), Area B (Monday Market/Gwange area), and Area C (University of Maiduguri dumpsite). Seasonal data collection was coded numerically as (1) for the rainy season, (2) for the cold/harmattan season, and (3) for the hot season. The MSW samples collected from these areas were analyzed to evaluate their characteristics. The waste was sifted and separated into its major components for physical analysis.

A notable observation was the high proportion of sand in all samples, which had to be removed before further analysis, as sand is an inert material that does not contribute to combustion. The sample preparation process involved an initial sieving followed by handpicking to remove small stones that could not pass through the sieve. Subsequently, the samples were re-sieved using a 2-mm mesh sieve and ground into powder form using a porcelain mortar and pestle to facilitate detailed analysis. The weighing of samples was performed using a WEDA weighing machine, Model No. 1455 (manufactured in 1974), with a maximum capacity of 100 kilograms. Advanced laboratory equipment used for analysis included a Nabertherm LH 120/14 Electrical Furnace, Model LH 120/14 (Model No. 182487 of 2005), capable of operating within a temperature range of 30–3000°C; a Parr 6100 Bomb Calorimeter for calorific value determination; and a Perkins Elmer Series II CHNS/O Analyzer

2400 for chemical composition analysis. Additional glassware and laboratory materials used in the study included 16 PYREX conical flasks, pipettes, burettes, beakers, volumetric flasks, plastic bottles, and filter papers.

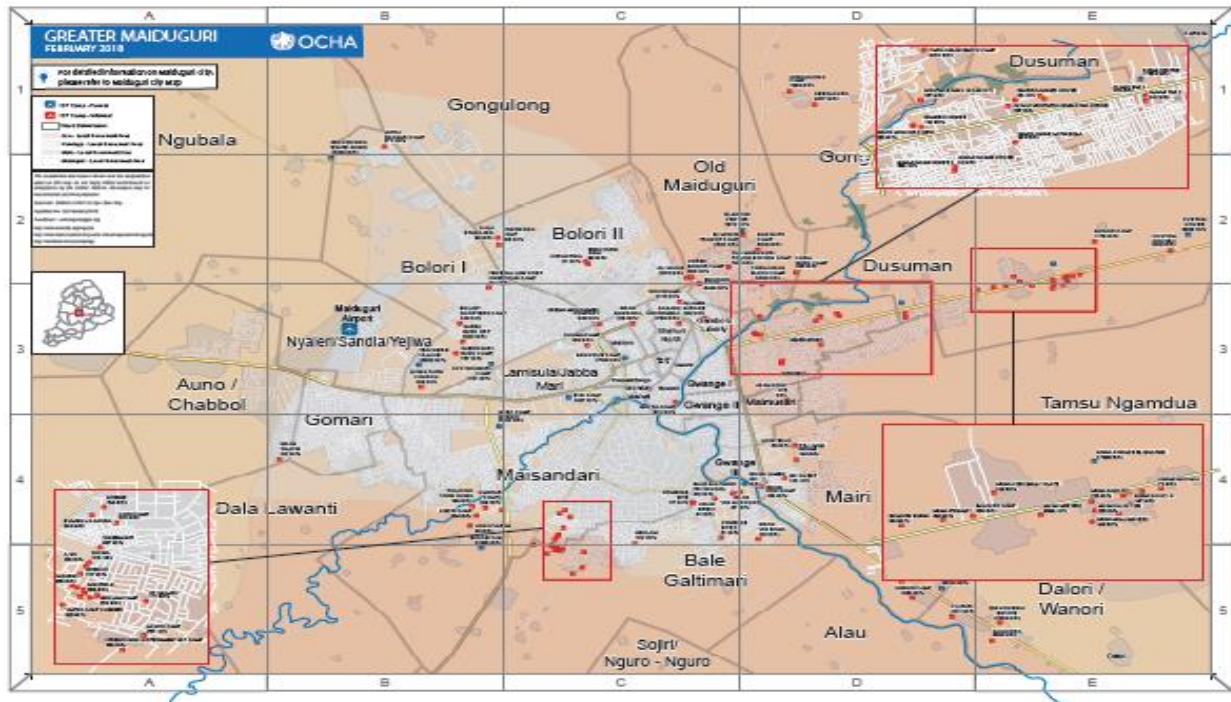


Figure 1: Map of Maiduguri Town as the Study Area (OCHA, 2018)

2.1 Waste Composition

The refuse physical characteristics were evaluated by sifting through the waste and separating it into its various physical major components. More precise methods require laboratory analyses and are explained below.

2.2 Proximate Analysis

The proximate analysis is the simplest test and is performed by weighting, heating, and burning a small sample of waste according to ASTM D3172 (2021). The analysis determines the moisture content ($M'_{(w/o)}$, in weight percent (w/o)) by driving off the free moisture at $\sim 107^\circ\text{C}$ for approximately one hour. The volatile matter content ($V'_{(w/o)}$) is determined by driving off volatile hydrocarbons CO , CO_2 and combined H_2O at $\sim 950^\circ\text{C}$. The waste sample is then burned, and the inorganic residue is the ash content ($A'_{(w/o)}$). The fixed carbon ($C'_{(w/o)}$) is then calculated by difference (Weisman & Eckart 1985).

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

2.3 Ultimate Analysis

The ultimate or elemental analysis is a quantitative evaluation of the total carbon (C'), hydrogen (H'), nitrogen (N'), sulphur (S'), oxygen (O') percentage after removal of the moisture and ash. This analysis is performed using classic oxidation, decomposition, and/or reduction technique to determine, C, H, N and S, using ASTM D3176 (2021). Oxygen $O'_{(w/o)}$ is calculated by difference (Weisman & Eckart 1985).

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

These data from the ultimate analysis are reported in weight or mass percent.

2.4 Determination of Calorific Value

The first step in the processing of waste is to determine its calorific content or heating value. This is a measure of the temperature and the oxygen requirements that the specific waste will be placed in the system (Ujamat *et al.*, 2013). The calorific value of a fuel can be determined either from its chemical analysis, using a formula or in the laboratory (Frey *et al.*, (2003), Ge *et al.*, (2019)). In the laboratory, Bomb Calorimeter is used. The analysis of the samples of MSW was carried out using a Parr 6100 Bomb calorimeter as per ASTM D5865 (Parr Instrument Company. 2013). In order to determine the calorific value, a sample of the MSW is placed inside the combustion bomb, ignited in a high-pressure oxygen environment, and the resulting temperature increase of the surrounding water bath is measured allowing for the calculation of the heat energy released during combustion, which is the calorific value. A representative sample of the fuel is measured accurately and placed in the combustion bomb, together with a small piece of ignition wire to initiate the combustion.

Temperature change is recorded, and necessary corrections are applied for heat losses using the calorimeter's built-in compensation system. The calorific value is calculated using the formula (Parr Instrument Company, 2013):

$$CV = \frac{(\text{Temperature change} \times \text{Water Mass} \times \text{Specific Heat of Water})}{\text{Sample Mass}} \quad (3)$$

3. Results and Discussion

All samples were collected “as – it is”, without any specific selection; and thus contained a large proportion of sand (up to 60% of the sample in some areas) which had to be removed prior to any measurement. This is because sand is an inert element in the combustion process. Furthermore, a fist sieving was carried out followed by hand picking, to remove small stones which could not pass through the sieve. Table I provides the physical composition of the municipal solid wastes in the study area.

Table I: Composition of MSW in the Study Area

Location	Components (%)							
	Wood	Grass	Paper	Leaves	Food Remnants	Plastic	Metals	Glass
Maiduguri Flour Mills (AREA A)								
Raining Season (1)	28.46	14.57	9.66	8.92	6.79	28.99	2.58	0.03
Cold Season (2)	16.12	11.48	3.58	16.24	10.24	38.20	3.64	0.50
Heat Period (3)	27.28	11.09	6.69	13.17	6.17	34.56	0.94	0.09
Monday Market/ Gwange Refuse Dump (AREA B)								
Raining Season (1)	22.28	6.29	14.86	13.83	5.12	24.93	7.80	4.89
Cold Season (2)	24.75	6.05	10.52	15.57	4.35	20.46	9.76	8.54
Heat Period (3)	20.07	5.02	8.80	18.40	6.88	17.63	15.8	7.35
Unimaid Central Refuse Dump (AREA C)								
Raining Season (1)	17.99	17.11	15.18	25.99	4.03	16.27	2.73	0.70
Cold Season (2)	19.78	5.35	14.82	19.48	0.98	34.58	4.96	0.04
Heat Period (3)	18.84	15.05	16.48	14.78	1.53	29.38	2.99	0.99

Wood, plastics, and grass are the major physical constituents of the refuse, with emphasis on seasons, mainly due to commercial activities and the presence of the rain. Tables (2), (3) and (4) show the proximate analysis of the MSW samples in the study area. The results for physical, proximate and ultimate analyses are in line with those from Oumarou *et al.*, (2012) whose study focused on the characterization and generation of municipal solid waste in the northeastern part of Nigeria, particularly, the present study area. According to Oumarou *et al.*, (2012) average moisture contents were found to vary from 21.917 to 24.326, at the time of the study. Wood, paper, plastic and leaves were found in varying proportions and 1.2 kg was found to be the daily average generation of waste, per person.

Table 2: Proximate Analysis Results of MSW in Area A

Sample ID No.	Percentage Composition (%)			
	Moisture Content	Volatile Matter	Fixed Carbon	Ash Content
A1	39.24	21.46	29.30	10
A2	42.58	16.37	35.05	5.2
A3	41.70	15.60	37.90	4.80

Table 3: Proximate Analysis Results of MSW in Area B

Sample ID No.	Percentage Composition (%)			
	Moisture Content	Volatile Matter	Fixed Carbon	Ash Content
B1	37.49	36.34	15.17	11
B2	42.66	17.40	24.74	15.20
B3	49.90	11.70	25.2	13.20

Table 4: Proximate Analysis Results of MSW in Area C

Sample ID No.	Percentage Composition (%)			
	Moisture Content	Volatile Matter	Fixed Carbon	Ash Content
C1	38.15	23.33	28.52	10
C2	48.78	10.22	35.40	5.60
C3	42.40	14.10	39.50	4.0

The statement on these changes and variations supports the findings by Amulah *et al.*, (2024) that the two primary factors driving MSW generation potential are population size (which depends on the population growth rate) and per capita waste generation rates. The waste generation for the year 2023 was estimated to be 2.63×10^5 tonnes using a waste generation rate of 0.53 kg/capita/day, a base-year population of 1,328,100 and an annual growth rate of 2.40%. The MSW generation prediction model is based on the assumption that the type and amount of waste generated will not change over time. Coupled with the various calorific values in the study area, MSW is in large quantity and can be seen as a sustainable source to be used for energy generation in Maiduguri (Amulah *et al.* 2024).

Tables (5), (6) and (7) show the results of the ultimate analysis of the MSW samples in the study area.

Table 5: Ultimate Analysis Results of MSW in Area A

Sample ID	Elements (%)				
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
Sample A1	46.22	0.21	41.85	11.64	0.08
Sample A2	44.87	0.24	43.94	10.83	0.12
Sample A3	43.14	0.20	47.09	9.46	0.11

Table 6: Ultimate Analysis Results of MSW in Area B

Sample ID	Elements (%)				
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
Sample B1	47.91	0.23	41.42	10.34	0.10
Sample B2	48.02	0.19	41.25	10.45	0.09
Sample B3	47.08	0.20	42.15	10.50	0.07

Table 7: Ultimate Analysis Results of MSW in Area C

Sample ID	Elements (%)				
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur
Sample C1	45.90	0.55	47.07	6.35	0.13
Sample C2	46.10	0.67	46.70	6.44	0.09
Sample C3	46.40	0.76	45.93	6.77	0.14

Table 8 presents the CVs of the MSW samples collected from the study area. The samples from Area B1 and B2 recorded the highest calorific values, followed by Area A3. This is attributed to the fact that Area B, the central market area of Maiduguri, has a highly diverse composition of waste due to its role as a hub of commercial and social activity. Being a central meeting point for the entire city, Area B sees the inflow and outflow of a wide range of commodities, contributing to the high calorific value of the waste. Specifically, the calorific values for B1 and B2 were 19.81 MJ/kg and 15.055 MJ/kg, respectively. However, the study revealed that some areas exhibited lower calorific values. These variations highlight the need for supplementary fuel, such as sugarcane straw or weeds, during the incineration process to compensate for the lower CVs. This supplementation ensures the viability of energy recovery from the waste. It is important to note that calorific value alone does not determine whether the refuse will burn efficiently; moisture content is a critical parameter that must also be considered. Additionally, while the physical constituents of the waste generally remained consistent, higher moisture levels were observed in some samples. These increased moisture levels can be attributed to two main factors: the population influx into Maiduguri in recent years and the high rainfall experienced in the area. These changes further emphasize the importance of evaluating both the physical and chemical properties of MSW to optimize its suitability for energy generation and sustainable waste management practices.

Table 8: Calorific Value of MSW in the Study Area

Collection Area	Sample No.	Calorific Value (MJ/kg)
Area A	Sample 1	4.3110
	Sample 2	7.0610
	Sample 3	10.0612
Area B	Sample 1	19.8107
	Sample 2	15.0559
	Sample 3	5.7262
Area C	Sample 1	7.5077
	Sample 2	8.4217
	Sample 3	4.5086

The results of the present research are in line with the findings from Fatih *et al.*, (2018) who analyzed MSW produced in Turkey in terms of suitability for waste incineration and energy recovery. They estimated their current and near-future amounts of MSW generated in some big cities in Turkey and their approximate calorific values in kcal/kg. MSWs produced in Turkey include combustible components at a rate of 45%, so it is reasonable to examine the combustibility of MSW for energy recovery. As a rule of thumb, the waste is theoretically feasible for combustion without auxiliary fuel when the moisture of raw waste < 50%, ash

content <6% and combustible organic fraction >25%. Additionally, the waste calorific value should be at least 2000-2500kcal/kg for energy production, and 1500-1600kcal/kg for the combustion without additional fuel. If the heating value is below 1200kcal/kg, it is understood that the solid waste cannot be economically burned (Fatih and Akif, 2018). This shows that the moisture content, the feed rate and the energy content of the MSW greatly affect the quantity of electricity generated from the municipal solid wastes of Maiduguri, with the samples from the University of Maiduguri, yielding lower electricity than the remaining locations. The MSW samples yield 7,500 MJ/kg, 8,420 MJ/kg and 4,500 MJ/kg, with an average of 6,800 MJ/kg, which is lower than the average minimum calorific value of 7000 MJ/kg, required for setting up an incineration plant with energy recovery (Olisa and Ajoko, 2018; Yeganeh et al., 2023). This implies the need to add a supplementary fuel to the MSW, in the case of university of Maiduguri as suggested by Aliabadi et al., (2023) in Iran. Sugarcane bagasse is widely available in Maiduguri and has a calorific value of up to 17.29 MJ/kg (Messayet et al., 2021).

4. Conclusion

At the end of this research work, the following conclusions were drawn:

1. The basic composition of the MSW produced by communities in Maiduguri was determined and found to vary due to seasonal and behavioural variations and conditions. Wood, plastics, leaves and grass, are the major physical constituents of the MSW, with emphasis on seasons. Metals and glass were almost non-existent.
2. The calorific values were found to vary between 4.41 MJ/kg and 19.81 MJ/kg, with the University of Maiduguri having the lowest calorific values and an average CV of 6.806 MJ/kg
3. The MSW at the University of Maiduguri requires the addition of a supplementary fuel like bagasse to boost its suitability for electricity generation.

References

- Aliabadi Y. , A. Hajinezhad, Fattahi R. and S. F. Moosavian. 2023. Analysis of Energy Generation from MSW with Auxiliary Feed in the North of Iran; Results in Engineering; 18, www.sciencedirect.com/journal/results-in-engineering
- Altine J., Ezekiel Ambo M. and Tanko B. 2017. Rice Waste Conversion for Economic Empowerment in Taraba State, Nigeria: A Review; International Journal of Trend in Research and Development, Volume 4(5).
- Amulah NC, Oumarou MB, Muhammad AB. 2024. Exergy Analysis of Waste-to-Energy Technologies for Municipal Solid Waste Management. Environment and Natural Resources Journal, 22(3): 232-243. <https://doi.org/10.32526/enrj/22/20240023>
- Aron A. 2017. Energy Recovery Possibilities from Municipal Solid Waste in Addis Ababa, Ethiopia; Lappeenranta University of Technology, School of Energy Systems; Master Thesis in Sustainability Sciences and Solutions.
- Diego M., Clay A., Germánico L. and Prasad K. 2017. Municipal Solid Waste as a Valuable Renewable Energy Resource: A Worldwide Opportunity of Energy Recovery by Using Waste-To- Energy Technologies ; 9th International Conference on Sustainability in Energy and Buildings, Energy Procedia 134: 286–295 SEB-17, 5-7 July, Chania, Crete, Greece
- Fatih T. and Akif Uslu M. 2018. Evaluation of Energy Potential of Municipal Solid; Waste for Direct Waste Combustion in Istanbul 16th International Conference on Clean Energy (ICCE-2018) 9-11 May 2018, Famagusta, N. Cyprus
- Fatih T., Öztürk, A., and Tosun, S. 2018. The Evaluation of Municipal Solid Wastes as Energy Source, Ecological Life Sciences (NWSAELS), 13(3): 131-141. DOI: 10.12739/NWSA.2018.13.3.5A0102.

Frey, H.H.; Peters, B.; Hunsinger, H.; Vehlow, J. 2003. Characterization of municipal solid waste combustion in a grate furnace. Waste Management, 23: 689–701.

Ge, X., Ren, Z., Guo, S. and Li, L. 2019. Examining the Effects of MSW Separated Collection on Reducing the Final Disposal of Waste in Beijing - A System Dynamics Analysis. *Ekoloji*, 28 (107): 1767-1781.

Goodman B.J. and Texeira R.H. 1990. Assessment of Municipal Solid Waste for Energy Production in the Western United States, Prepared for: The Western Regional Biomass Energy Program Under Task No. BF981 011, August.

Hamer, G. 2003. Solid waste treatment and disposal: effects on public health and environmental safety. *Biotechnology Advances*, 22: 71-79.

Huseyin KO., Senem YG., Lokman G. and Goksel D. 2016. Municipal Solid Waste Characterization according to Different Income Levels: A Case Study; *Sustainability*, 8, 1044; doi:10.3390/su8101044

Joshi R. and Ahmed S.. 2016. Status and Challenges of Municipal Solid Waste Management in India: A review; *Cogent Environmental Science*, 2: 1139434; <http://dx.doi.org/10.1080/23311843.2016.1139434>

Leena S., Sunderesan R. and Renu S. 2014. Waste to Energy Generation from Municipal Solid Waste in India; *International Journal of Chemical Technology Research CODEN (USA)*, 6(2):1228-1232.

Messay EG., Birhanu AA., Mulissa JM., Genet TA., Endale WA., and Gutema BF. 2021. Briquette Production from Sugarcane Bagasse and its Potential as Clean Source of Energy; *African Journal of Environmental Science and Technology*, 15 (8): 339-348. DOI: 10.5897/AJEST2021.3006; <http://www.academicjournals.org/AJEST>

OCHA. 2018. Nigeria: Borno - Greater Maiduguri City Map, Available At: <https://www.unocha.org/Publications/map/nigeria/nigeria-borno-greater-maiduguri-city-map-20th-February-2018>, Accessed on February 2024

Ogwueleka, T. C. 2009. Municipal Solid Waste Characteristics and Management in Nigeria. *Iran Journal of Environmental Health Science and Engineering*, 6(3): 173-180.

Ola E. and Göran F. 2017. Energy Recovery from Waste Incineration - The Importance of Technology Data and System Boundaries on CO₂ Emissions; *Energies*, 10, 539. DOI: 10.3390/en10040539

Olisa , Y P. and Ajoko T. J. 2018. Gross Calorific Value of Combustible Solid Waste in a Mass Burn Incineration Plant, Benin City, Nigeria; *Journal of Applied Science and Environmental Management*, 22(9): 1377–1380. DOI: <https://dx.doi.org/10.4314/jasem.v22i9.02>

Olisa, Y. P., Amos, A. E., &Kotingo, K. 2016. The Design and Construction of a Step Grate Incinerator. *Global Journal of Researches in Engineering*, 16(3).

Olisa, Y. P., Kotingo, K. W., & Amos, A. 2017. Design and Performance Test of a Small Scale Refuse Boiler for Industrial Applications. *African Journal of Engineering Research*, 5 (1): 1-6.

Osra, F.A.; Ozcan, H.K.; Alzahrani, J.S.; Alsoofi, M.S. 2021. Municipal Solid Waste Characterization and Landfill Gas Generation in Kakkia Landfill, Makkah. *Sustainability*, 13, 1462. <https://doi.org/10.3390/su13031462>

Oumarou M. B., Dauda M., Sulaiman A. T. and Babagana M. T. 2012. Characterization and Generation of Municipal Solid Wastes in Northeastern Nigeria; *Continental Journal of Renewable Energy*, 3(1): 1 - 7 DOI:10.5707/cjre.2012.3.1.1.7

Oumarou, M. B., Abubakar, A. B., & Abubakar, S. 2018. Municipal Solid Waste Incinerator Design: Basic Principles. *Sustainable Energy*, 6 (1):11-19.

Oumarou, M. B., Dauda, M., Abdulrahim, A. T., & Abubakar, A. B. 2012. Municipal Solid Waste Generation, Recovery and Recycling: a Case Study. *World Journal of Engineering and Pure and Applied Science*, 2(5).

Oumarou, M. B., Ngala, G. M., & Oluwole, F. A. 2012. Design of Municipal Solid Waste Incinerator for Use in Semi-Arid Regions. *Arid Zone Journal of Engineering, Technology and Environment*, 8: 133-138.

Parr Instrument Company. 2013. Introduction to Bomb Calorimetry ASTM D5865, "Standard Test Method for Gross Calorific Value of Coal and Coke"; <http://www.parrinst.com>,

Sahabo A., Oumarou M. B., A. M. El Jummah, and Alhaji Bukar A. 2021. Development and Performance Evaluation of a Small Scale Municipal Solid Waste Incineration Plant. *American Journal of Energy Research*, 9(2): 75-83. doi: 10.12691/ajer-9-2-1.

Santiago A., Bonie R.C. and Álvaro J.D. 2019. Municipal Solid Waste as a Source of Electric Power Generation in Colombia: A Techno-Economic Evaluation under Different Scenarios; *Resources*.

Song, J., Sun, Y., & Jin, L. 2017. PESTEL analysis of the development of the waste-to-energy incineration industry in China. *Renewable and Sustainable Energy Reviews*, 80: 276-289.

Soorige, S. D., & Priyalal, P. G. 2018. Energy Generation Using Municipal Solid Waste: Case of Waste to Energy Mega Projects. *Journal of Recent Activities in Architectural Sciences*, 3 (1): 1-12.

Srivastava, V., Ismai, S. A., Singh, P., & Singh, R. P. 2014. Urban solid waste management in the developing world with emphasis on India: challenges and opportunities. *Rev Environment Science and Biotechnology* .

Ujam, A. J., Eboh, F., & Chime, T. O., 2013. Effective Utilization of a Small-Scale Municipal Solid Waste for Power Generation. *Journal of Asian Scientific Research*, 3 (1): 18-34.

Umberto A. 2012. Process and Technological Aspects of Municipal Solid Waste Gasification. A Review; *Waste Management*, 32: 625–639, journal homepage: www.elsevier.com/locate/wasman

Weisman J. and Roy E. 1985. *Modern Power Plant Engineering*. 2nd edition, Prentice Hall International, New Delhi.

Yang, L., Liu, G., Zhu, Q., & Zheng, M. (2019). Small-scale Waste Incinerators in Rural China: Potential Risks of Dioxins and Polychlorinated Naphthalene Emissions. *Emerging Contaminants*, 5, 31-34.