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Harnessing Abuja's Municipal Solid Waste as a Renewable Energy Source: Scanning Electron Microscopy Analysis

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Abstract: *A study of Abuja's municipal solid waste (MSW) samples using the scanning electron microscopy analysis was undertaken in this work. In the face of the severe energy poverty being experienced in Nigeria which largely depends on diminishing fossil fuel resources coupled with the associated problem of greenhouse gas emission, the energy potential available in municipal solid wastes needs to be investigated. Using MSW as a fuel source for electric energy production will also positively impact on Abuja's waste management. This present study requires the analysis of the MSW with aim of confirming that products of its incineration will not be hazardous to the environment. ASTM E 1508 procedures for utilizing the scanning electron microscope (SEM) were followed to identify elements that would be contained in the bottom ash of the incineration process of samples of Abuja's municipal solid wastes obtained from selected districts of the city. Elemental composition of the bottom ash that will be formed from incineration of Abuja's MSW was obtained by the use of energy dispersive x-ray analysis. The micrographs plotted indicate that silicon and iron are the principal elements present in the samples with values for silicon and iron being highest at 49.5 and 19.55%, respectively, for the sample from Dutse-Alhaji. The tests also show the presence of silver in the organic wastes generated in Abuja, while presence of sulphur is very minimal. The silicon levels present in Abuja's municipal solid waste compare well with values for Nigerian coals which have percent silicon contents ranging from 39.0 – 49.4% (Enugu coal – 39.0%; Okaba – 44.8%; Maiganga – 49.4%). The test results also show that Abuja's MSW samples had grain sizes ranging from 3.5 mm 16 mm. The results indicate Abuja's MSW combustion rate will be lower than for pulverised coal which is known to have much lower grain size in the range of 75 µm to 106 µm and will need shredding before firing since grain size is a very critical determinant factor in solid fuel combustion rate and burn-out time. The tests conclusively show that Abuja's MSW will be a more environmentally friendly fuel than coal because of its lower sulphur content.*

Keywords: *Scanning Electron Microscopy, Municipal Solid Waste, Energy Dispersive, X-ray Analysis, Incineration, Elemental Composition.*

1. INTRODUCTION

The conversion of municipal solid wastes into heat and electrical energy is a veritable tool for MSW management since this strategy has capacity to drastically minimize volume before final disposal at landfill sites and also handle the problem of greenhouse gas emission associated with energy generation using fossil fuels. However, employment of the waste-to energy strategy demands for a knowledge of the waste's characterisation data, especially with regards to its combustion performance. An important method for characterisation study is the scanning electron microscopy analysis.

Scanning electron microscopy is a procedure for characterizing solid fuels by obtaining relevant information such as surface topography, crystal structure, chemical composition and electrical properties of material samples. The SEM possesses much higher magnifications than most optical microscopes (up to 200,000 x and above with an ultimate resolution of 1.0 nm) [1]. The operating principle of SEM relies on the application of kinetic energy on electrons which then interact with the electrons of the test sample to generate relevant signals thereby producing images of very high resolution. The core aim of this work is to use scanning electron microscopy techniques to analyse the suitability of Abuja's municipal solid waste as a renewable energy resource with a focus is to determining the incineration performance of the MSW as an objective. Another objective of the study is the confirmation of the composition of the ash formed by incineration of Abuja's MSW as a good resource for material recycling for civil construction after energy recovery.

The inert elements found in MSW samples affect the energy released per kg of sample and determine the quantity and type of ash formed after incinerating the samples. Therefore, the SEM analysis is very important in the classification of municipal solid wastes. Ash formation from MSW incineration depends largely on the physical composition of the material burnt as indicated by its composition, proximate analysis, grain size and the air-fuel ratio used. Table 1 gives the composition while Table 2 gives the proximate analysis for Abuja's MSW.

Table 1: Composition of Abuja's MSW

Waste component	Quantity (ton per annum)	% wt.
Kitchen waste	161,207.7	33.87
Plastic waste	92,288.6	19.39
Paper waste	28,748.0	6.04
Metallic waste	60,589.7	12.73
Textile waste	21,465.8	4.51
Garden waste	64,302.2	13.51
Cardboards	20,371.1	4.28
Polythene	26,986.9	5.67
Total	475,960.0	100

Table 2: Proximate analysis of samples of Abuja's MSW

Sample ID	Moisture Content (%)	Volatile Content (%)	Fixed Carbon Content (%)	Ash Content (%)
LUG (Lugbe)	7.70 ± 0.4	63.02± 0.7	25.44 ± 0.4	3.86 ± 0.2
GAL (Galadimawa)	7.80 ± 0.4	60.92± 0.7	27.64± 0.4	3.64 ± 0.2
DUT (Dutse-Alhaji)	7.90 ± 0.4	62.82± 0.7	25.6 ± 0.4	3.66 ± 0.2

Municipal solid waste is classified as a source of renewable energy [2]. This classification arises from the fact that the energy comes from organic sources and plants, which can be replenished more quickly than fossil fuels which require thousands of years. The process of photosynthesis in plants creates biomass by taking in carbon dioxide from the atmosphere. When these plants die, the carbon dioxide is released back into the atmosphere. Therefore, if organic waste is disposed without energy recovery there will be addition of greenhouse gases (GHG) to the atmosphere. However, applying the waste-to-energy (WtE) concept will lead to commensurate reduction in energy generation using fossil fuels which are non-renewable and emit carbon dioxide and other GHG to the atmosphere. Energy from MSW therefore promotes sustainable environmental development.

Within the period 2000 – 2010, Abuja was reported to be the most rapidly growing city in Africa. Some of its suburbs were reported to have population growth rate of as much as 20 - 30% per annum [3]. Between 2010 and 2019, Abuja's built-up expansion rate was 30.93% [4] with a population growth rate of 5% as at 2023 [5]. The rapid population increase has had negative impacts on efforts to provide an effective and efficient municipal solid waste management for Abuja's estimated urban population of 1.69 million [5]. This present study focuses on characterising the MSW as an alternative fuel source which will help in providing effective and economic solution to the ever-increasing problem of waste management in Abuja metropolis. Some studies have been undertaken with a view to addressing the issues of waste management in Abuja metropolis. Mohammed et al [6] studied Abuja's MSW generation and reported Abuja's exponential growth rate in its MSW generation due to the rapid population growth and the city's ever-changing social and economic status. That study was focused on incineration with energy recovery as an immediate solution for MSW volume reduction, and a supplementary solution to inadequate electric power supply to the metropolis. Results obtained from their work showed that the gross calorific value (GCV) for Abuja's MSW was evaluated as 9,085 kcal/kg while the net calorific value (NCV) was estimated as 9,067 kcal/kg. Abuja's MSW power generation potential of 4,832 kWh determined in the study considered only 50 tons of combustible waste and therefore requires further investigation. The study of Abuja's MSW with a view to harnessing it for electric energy production has not been sufficiently reported in literature. The objectives of this present work are therefore to characterize Abuja's MSW applying the scanning electron microscopy technique and thereby confirm its suitabilityas an alternative fuel source for commercial application.

In the high-income areas of Abuja, residents are responsible for evacuation of waste from their houses by placing their waste bins in front of their houses. These wastes are then picked up by the collectors and transported to final disposal sites. This aspect of collecting and transporting waste is both labour and capital intensive. It has been reported that waste collection and transportation accounts for about 98.9% of the total cost of solid waste management in Abuja inspite of the fact that waste collection rate is not up to 50% [7]. Most wastes remain uncollected and become responsible for blocked drainages leading to flooding in addition to other consequences on public health. The Abuja Environmental Protection Board (AEPB) is the institution responsible for coordinating and documenting of the waste management activities in

Abuja. The AEPB is part of the framework for municipal solid waste management in the metropolis. Table 3 shows waste collection data for Abuja during the period 2015 – 2019.

Table 3: Yearly waste collection data for Abuja

MSW collection (Tons) by AEPB (2015-2019)					
MONTH	**2015**	**2016**	**2017**	**2018**	**2019**
January	22229.06	21814.18	17966.754	20560.644	20615.868
February	22388.18	22539.58	17597.268	17310.852	17694.378
March	20354.06	23885.78	19286.28	20513.142	19974.942
April	23042.45	23342.90	18756.504	19995.3	21037.77
May	15306.5	22582.87	19975.176	21540.402	21046.194
June	21553.72	21682.91	19523.79	20218.068	19050.642
July	20998.22	21304.06	20676.24	21067.254	19895.85
August	23091.12	20951.66	20811.258	22201.218	21147.984
September	22674.6	21137.69	20316.582	20385.208	17216.55
October	24431.47	23867.06	20307.69	20645.352	24634.116
November	23811.84	22856.18	21255.156	20082.816	24955.164
December	23568.48	19308.74	20175.948	20223.684	24233.508
Total (tons)	**263449.7**	**265273.63**	**236,648.65**	**244,743.94**	**251,502.97**

In Abuja, waste collected is in mixed form since segregation of waste at source is hardly practiced. Presently, only itinerant scavengers are responsible for the minimal segregation or sorting observed. Collection of waste has remained problematic in Abuja due to increasing rates of MSW generation, rate of physical expansion of the city, effects of illegal structures and slum settlements and insufficient budgetary allocations.

2. WASTE-TO-ENERGY TRENDS

Waste-to-energy (WtE) refers to the process of generating energy in the form of either electricity or heat from waste. This is either through direct incineration of waste with energy recovery or converting the waste into a fuel source [8]. Incineration of waste with energy recovery remains the most common WtE process globally. Examples of combustible fuel commodities obtained from MSW processing include methane, methanol and ethanol which may be used for use in energy generation applications. Wastes that have no recyclable value are ideally suited for conversion to energy and the process represents a veritable means of MSW management. Generating energy from waste is classified as a source of renewable [8]. Obtaining energy from waste leads to directly proportional reduction in energy generation using fossil sources which are non-renewable and release carbon dioxide and other greenhouse gases to the atmosphere. Energy from waste is from the organic fraction of MSW which is mainly biomass from plants and other organic sources which can regrow in a relatively short time. The initial capital cost of a typical waste-to-energy plant is approximately 10% of that of solar energy and 66% that of wind energy [9]. The average overall efficiencies of WtE plants are in the range of 22 – 30% for plants producing only electricity while combined heat and power plant (CHP) has efficiency ranging from 30 – 60% [10].

3. METHODOLOGY

3.1 Study Area for MSW Management

Abuja is the administrative capital of Nigeria and is situated between latitudes 7° 49’ and 8° 49’ North of the equator and between longitudes 7° 07’ and 7° 33’ East of the Greenwich Meridian in the Federal Capital Territory (FCT). The population of Abuja is presently estimated as 1.69 million people [5]. The FCT is divided into six area councils which include Abuja Municipal, Abaji, Bwari, Gwagwalada, Kuje and Kwali. The total land area of the FCT is approximately 713 km2. The central government institution in charge of solid waste management in the city is the Abuja Environmental Protection Board (AEPB) and is responsible for solid waste collection and transfer, city cleaning, street sweeping, litter control and vegetation control. The study area which is Abuja Municipal Area Council is shown in the map of the FCT, Figure 1.

Landfill sites for final waste disposal are located in all area councils of the F.C.T. Landfill sites to serve the Abuja Municipal Area Council include those located at Mpape, Gosa, Ajata, Karshi and Kubwa. In 2005, the Mpape landfill site which was opened in 1989 was closed down due to public complaints about offensive odour and air pollution. It spanned an area of about sixteen (16) hectares and at the time of closure it had a waste depth of about 15 - 30 metres [11]. Ajata dumpsite was opened in 1999 while the Kubwa landfill site which was opened in 2004 has been forced to close in 2005 due to odour and random fire outbreaks. Gosa landfill, owned and operated by AEPB, was opened in 2005 and is still accepting waste. It is situated near Idu industrial layout, within the metropolitan area and covers a land size of approximately 90-hectares. The Gosa land fill site is the largest and newest landfill and when fully developed as an engineered landfill will handle all municipal solid wastes (MSW) from the entire FCT.

All the operational landfill sites for Abuja are marked by uncontrolled ground surface dumping of waste without covering with top soil nor compacting. Periodic burning of wastes at the dumpsites is carried out, especially in the dry season, in order to reduce the volume of the waste. This leads to environmental hazards, especially in the immediate vicinity.

Figure 1: Map of FCT showing Abuja municipal area council

3.2 Procedures for the Analysis

Organic waste samples were collected from locations in three (3) districts of Abuja (Lugbe, Galadimawa and Dutse-Alhaji Modern Market) considered sufficiently representative of the study area for the purpose of waste characterisation. Laboratory experimental procedures using the scanning electron microscope were carried out on the samples. This instrument is very effective for identifying the constituents of incineration bottom ash from MSW combustion since it provides information showing the type of elements and compounds present in the sample. The percentage proportions of the amounts of the various elements present in the samples were determined by using the procedure. Also, SEM analysis gave the arrangement of atoms in the single crystal particles and their degree of order which have impact on the combustion rate.

The ASTM F1372-93 (2020) procedure was applied in this study as demonstrated by Yaqoob et al in their work on pyrolysis oil [12]. Preparation of the MSW sample is done by fixing it onto sample stub using appropriate adhesive to bond the sample to the stub. By using a mini-gold sputter the sample is given a coat of gold under a vacuum pressure of about 70 mTorr (9.33 Pa) for 30 seconds. Rough or porous surfaces require a longer sputtering time. After inserting the prepared sample onto the sample stage and tightening into place, the system is started by the use of the computer software. The SEM chamber is then vented allowing the chamber to reach a high vacuum with nominal pressure of about 70 Pa. The desired operating voltage of 20kV was then selected from a range of 1–30 kV. Higher operating voltage gives better image contrast, but can yield lower resolution since charges may accumulate in the sample at such voltage.

In order to capture any sample image, the ‘Auto Focus’ function in the SEM software is started by clicking on the “key” icon. This is the step that gives a focused image of the sample for use as a starting point. The instrument magnification was set to the minimum zoom level of 50X and the ‘fast scan’ mode was selected. The level of magnification may be increased until the desired resolution of the image is achieved by adjusting the coarse focusing knob. By adjusting the fine focusing knob a focused image at the desired magnification level is obtained. When the desired magnification is reached, the fine focusing knob is then adjusted to improve clarity. direction Improved clarity of the obtained images is achieved by adjusting the stigmation in both the x and y axes.

Different relevant measurements of the MSW sample dimensions from the images formed such as grain length, area and angles as shown in Figures 5 to 7 may be obtained by using the SEM instrument. The various chemical elements present in the sample are identified and tabulated from the micrographs developed by the software, Figures 2 to 4

3. RESULTS AND DISCUSSIONS

4.1 Composition of Abuja’s MSW Bottom Ash

The composition of the bottom ash that results from burning Abuja's municipal solid waste (MSW) was examined using a scanning electron microscope (SEM). The MSW samples were subjected to energy dispersive x-ray testing, and the elemental composition that was found is shown in Figures 2 to 4.

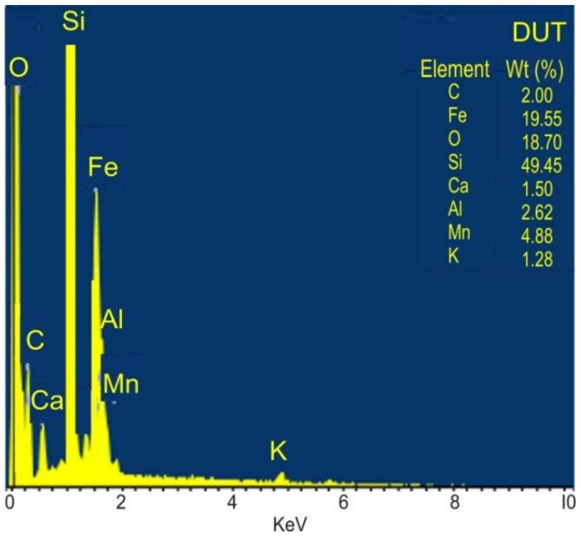

Figure 2: Elemental composition of Dutse-Alhaji MSW using energy dispersive X-Ray Analysis (EDX)

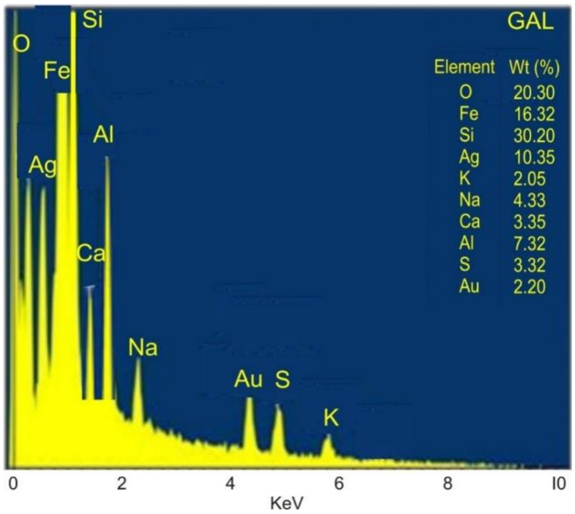

Figure 3: Elemental composition of Galadimawa, Abuja, MSW using energy dispersive X-Ray

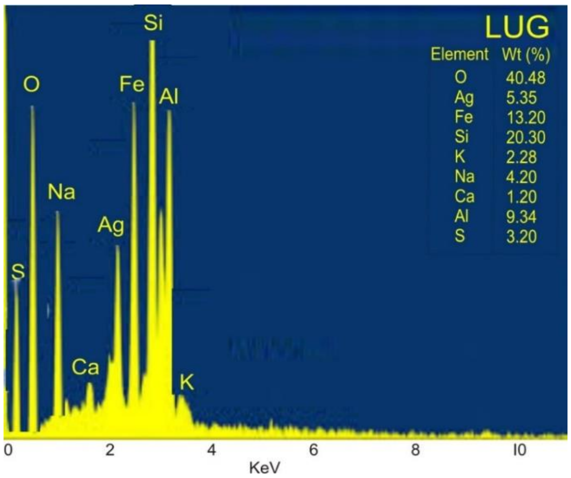

Figure 4: Elemental composition of Lugbe, Abuja, using energy dispersive X-Ray Analysis (EDX)

From the EDX micrographs, it can be observed that the bottom ash of Abuja’s MSW is high in silicon content. The Lugbe sample has the lowest silicon content of 20.3% while corresponding values for Galadimawa and Dutse-Alhaji samples are 30.2, and 49.5 %, respectively. High silicon content in solid fuels indicate good furnace performance since high silicon presence inhibits slagging tendency of ash during incineration [13]. This is due to the formation of silicon dioxide (silica) which raises the melting point of the ash formed from the incineration process thereby reducing the rate of ash deposition on furnace surfaces (slagging). Solid fuels with low silicon levels are therefore problematic for furnaces and boilers because of the high tendency of fouling of their surfaces. The silicon levels present in Abuja’s MSW samples compare well with values for Nigerian coals which have silica contents ranging from 39.0% (Enugu), 44.8% (Okaba), to 49.4% (Maiganga).

Bottom ash from Galadimawa and Lugbe MSW had 0.0% unburnt carbon while Dutse-Alhaji sample had 2.0% (Figures 2 to 4). The near-zero presence of unburnt carbon found in the bottom ash from Abuja’s MSW incineration suggests that when this ash is used together with Portland cement for civil construction, the structure’s compressive strength will compare well with compressive strength of unmixed Portland cement [14]. Also, this work revealed very low presence of sulphur in Abuja’s MSW bottom ash. Dutse-Alhaji sample had 0% unburnt sulphur while Lugbe and Galadimawa samples had 3.2 and 3.32%, respectively. The low sulphur presence in bottom ash indicates that Abuja’s

MSW is environmentally friendly even in the final disposal of the bottom ash since presence of sulphur can lead to emission of harmful oxides from the dumpsites. It may therefore be argued that the presence of the various elements in the bottom ash do not inhibit the usefulness of Abuja’s MSW as a source for renewable energy and also make the MSW bottom ash useful source of civil construction material [15].
Loginova et al obtained results for bottom ash composition from incineration of MSW in Netherlands that appear similar to results obtained in this present study [16]. Their work also found silica to be the prevalent constituent of the bottom ash. Also, results of this present work compare well with results obtained in similar work by Assi et al (2020) [17].

4.2 Abuja’s MSW Particle size

The average grain sizes and Feret angles for the MSW samples are displayed in Tables 4 to 6, while the electron microscope pictures for the three samples under study are displayed in Figures 5 to 7. The Lugbe and Galadimawa samples have average grain sizes of 6.1 and 16 mm, respectively, while the Dutse-Alhaji MSW sample has the lowest average grain size of 3.5 mm.

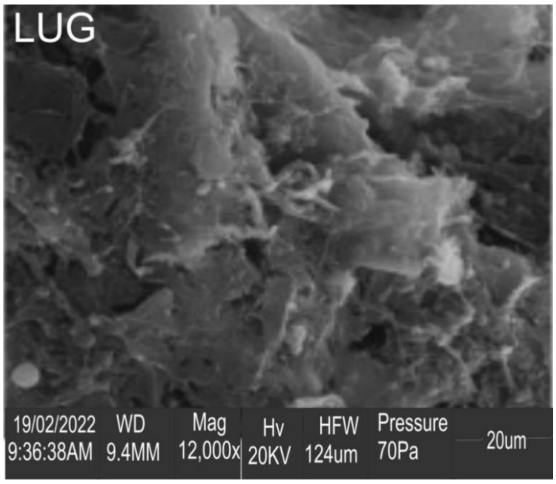

Figure 5: Scanning electron microscope image for Lugbe MSW

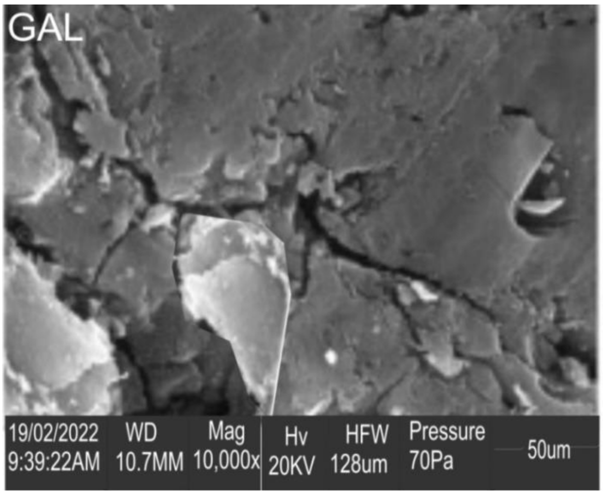

Figure 6: Scanning electron microscope image for Galadimawa, MSW

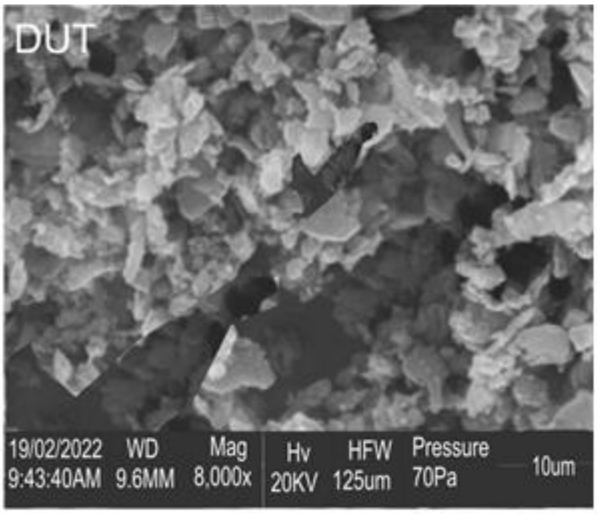

Figure 7: Scanning electron microscope image for Dutse-Alhaji MSW

The aggregate results in Tables 4–6 indicate that the average grain size of the Abuja MSW will be 8.5 mm. MSW contains far larger grain sizes than coal that has been crushed. For boiler application, pulverized coal's mean particle size ranges from 75 µm to 106 µm [18]. When it comes to the burning of solid fuels, grain size is crucial since a smaller grain size results in a higher combustion rate and a shorter burn-out period [19]. These findings suggest that shredding Abuja's MSW will be necessary to improve combustion. When it comes to grain sizes, Abuja's MSW will burn at a slower rate than coal. However, because MSW contains less sulphur, ash, and greenhouse gas emissions, it has a less harmful effect on the environment. In addition, MSW is a renewable energy source that is much less expensive to get than coal and other fossil fuels.

The observable differences in SEM images (Figures 5 to 7) may be explained as a reflection of differences in the proximate analysis (composition) of the various MSW samples tested. While grain sizes between 2 and 10 mm make up roughly 56.54% of the sample as a whole, Caviglia et al.'s work [20] on Turin's MSW produced particles sizes over 20 mm that make up almost 10% of the whole by weight. The researchers' findings are in good agreement with Abuja's aggregate grain size of 8.5 mm, which was assessed in this study.

Table 4: Summary of parameters from image analysis (Dutse-Alhaji MSW sample)

Slice	**Count**	**Total area (μm^2)**	**Average size (μm)**	**% Area**	**Perim.**	**Max. Feret**	**Feret X**	**Feret Y**	**Feret angle**	**Min. Feret**
Black & white threshold	196	685227	3496.06	59.39	148.32	23.20	677.49	370.95	103.16	13.08

Table 5: Summary of parameters from image analysis (Galadimawa MSW sample)

Slice	**Count**	**Total area (μm^2)**	**Average size (μm)**	**% Area**	**Perim.**	**Max. Feret**	**Feret X**	**Feret Y**	**Feret angle**	**Min. Feret**
Black & white threshold	56	896077	16001.38	7.562	217.569	43.368	410.911	518.339	113.09	22.05

Table 6: Summary of parameters from image analysis (Lugbe MSW sample)

Slice	**Count**	**Total area (μm^2)**	**Average size (μm)**	**% Area**	**Perim.**	**Max. Feret**	**Feret X**	**Feret Y**	**Feret angle**	**Min. Feret**
Black & white threshold	140	856489	6117.78	71.58	118.237	24.787	524.629	626.379	117.241	12.833

5. CONCLUSION

Abuja's MSW characterisation with a view to determining its suitability as fuel for electric power production has been carried out in this work. The composition of bottom ash that will be formed from incinerating Abuja's MSW was evaluated in this study. Results obtained for bottom ash composition showed silicon content for the MSW were 20.3, 49.5and 30.2 % for Lugbe, Dutse-Alhaji and Galadimawa samples, respectively. The values obtained for silicon in the samples show that Abuja's MSW will have excellent furnace performance since high silicon presence inhibits slagging tendency of ash during incineration due to the formation of silicon dioxide (silica). Silica raises the melting point of the ash formed from the combustion process hence reducing the rate of ash depositing on furnace surfaces. The study also showed that sulphur contents for the same samples were 3.2, 0.0 and 3.3%. Hazardous gas emission from incineration of Abuja's MSW will be low due to near zero presence of sulphur in the samples. The low presence of sulphur in the bottom ash indicates the environmental friendliness of Abuja's MSW when incinerated for energy recovery since final ash disposal will not lead to severe emission of oxides of sulphur from the dumpsites. The near-zero presence of unburnt carbon in the bottom ash of the samples indicate that bottom ash from Abuja's MSW combustion will be very good material for civil engineering works.

Average grain size which is a very important parameter in the combustion of solid fuels was determined for Abuja's MSW samples with the Dutse-Alhaji sample having the lowest average grain size of 3.5 mm while the Galadimawa and Lugbe samples have 16 and 6.1 mm, respectively. As an aggregate, the Abuja MSW has an average grain size of 8.5 mm. this suggests that Abuja's MSW will require shredding in order to improve its combustion efficiency. The results obtained in the study imply that while pulverized coal will have better combustion performance than Abuja's MSW, the MSW however, has lower ash formation rate, cleaner furnace surfaces and lower greenhouse gas emission rate. MSW is also a renewable energy resource that can be procured at very minimal cost compared to coal and other fossil fuels.

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