ASSESSMENT OF ENERGY GENERATION POTENTIAL FROM SOLID WASTES IN ABUJA MUNICIPAL

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ABSTRACT

There are improper solid waste management processes in Abuja metropolis which leads to causes of ill health and environmental hazards to inhabitants. The effect of pollution caused by solid waste in open dumps and landfills can be minimised through conversion of the waste to energy.This study focuses on assessing energy generation potential from solid waste generated in Abuja municipal. The study investigated available energy conversion in solid waste using four sample of waste from two sites, Gossa and Kubwa. It involves characterising the physical property, determination of proximate analysis, ultimate analysis, analysis of caloric value of the waste and prediction of total estimated caloric value of solid waste in Abuja. A sample of 0.5 g per waste was used in the analysis except for caloric value where 0.6 kg was adopted per each sample. The proximate analyses revealed thatSW1 (food, wood and paper) has a moisture content of 14.68 %, SW2 (textile, rubber and plastic) has a moisture content of 16.58%, SW3 (metal-aluminium) has a moisture content of0.11%and SW4 (glass and ceramics) has a moisture content of 0.1%respectively. However, volatile matter of SW1, SW2, SW3 and SW4 include49.41 %, 55.37 %; 0.13 % 0.29 % respectively. The ash content of the listed samples is 9.92%, 13.50%; 0.35%, and0.12% respectively and the fixed carbon content (FCC) is 25.99 %, 14.55 %; 99.41 % and 99.49 % respectively. The ultimate analyses revealed thatthe three samples had high mass ratio of carbon content and they include sample A1; A2 and B2 respectively. In these samples carbon had 15.6 %, 22.28 % and 13.22 % respectively that is represent the carbon -fuel in the sample. The predictedcaloric value of the waste is 0.123 MJ/kg.The study concludes that adaptation of solid waste as source of alternative energy will be beneficial for electricity generation and this will lead the nation at large to improve growth and development.

TABLE OF CONTENTS

Title **Page**

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

Table **Page**

LIST OF FIGURES

LIST OF PLATES

Plates **Page**

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

The challenge in solid waste management over past few decades includes finding sustainable solution to solid waste management problem. The adoption of integrated solid waste management strategies and maintenance of sanitary landfills do not really solve the problem (Abdel-Shafy and Mansour, 2018). The solution is not perfect especially in developing nation as a result of urbanisation and population growth. These are solely responsible for high increasing rate of solid waste and its proper management is a major problem of municipal agency in developing world (Alam, 2013). The developing nations such as Nigeria witnessed a rapid population growth over the past decades and thus providing a large market for manufacturing industries and organisations and this leads to increases in wastes generations (Olukanni *et al.,* 2016). Thus urbanisation trends and industrialisation in Nigeria have led to a rapid growth in the volume of waste generated in the country. Abuja population is growing faster than the authority's capacity of waste collection and disposal, a condition which has led to inadequate waste management; this is not only in Abuja municipal but all Nigeria cities. The waste generated in Abuja has been enormous due to lack of appropriate techniques for managing generated waste (Olukanni, 2013).

Improper waste management have potential risks to environment and human health from handling. Direct health risks concern mainly the workers in this field, who need to be protected, as far as possible, from contact with wastes. There are also specific risks in handling wastes from hospitals and clinics. For the general public, the main risks to health are indirect and arise from the breeding of disease vectors, primarily flies and rats (Alam, 2013).

The pile of solid waste gives unconditional ill health and environmental hazards due to population growth especially in urban area in Abuja (Imam *et al.,* 2008).

Ahmed (2002) refers that the solid content of generated waste as refuse and also refers the liquid content of generated waste as effluent. To preventing the risk posed by solid waste the need for waste to energy conversion is best solution. Waste-to-energy is recognized by U.S. Environmental Protection Agency (EPA) as a clean, reliable, renewable source of energy. The combustion of municipal solid wastes for generating electricity has been recognized by several US states as a renewable source of energy. The search for renewable energy sources is motivated by the desire to reduce use of fossil fuels. In the traditional sense, renewable sources of energy are those that nature can replenish, such as waterpower, wind-power, solar radiation and biomass (wood and plant waste). The European Union (EU) targets for 2020 is that 20% of the energy need in a European country must come from renewable energy and half of this need must be covered by biomass (Dolgen *et al.,* 2005).

Municipal solid waste (MSW) contain a large fraction of paper, food wastes, cotton and leather, all of which are renewable materials. Solid waste can be directly combusted (known as mass burning) in waste-to-energy facilities (WTE) as a fuel with minimal processing, or it can be gasified using digestion, pyrolysis or thermal gasification techniques (Dolgen *et al.,* 2005). Energy availability is perhaps a worse problem than solid waste management in Nigeria of today. Energy is not readily available a condition which cause unfold poverty to Nigerian (Okeye *et al.,* 2007). Energy can be generated from source of total of 727 estimated trips in weekly basis in different locations in Nigeria Federal Capital, Abuja dumping site. Each waste truck is estimated to have a carriage capacity between 8 to 10 tonnes. In view of the above, the total estimate of tonnes of solid waste evacuated for year 2010 in the Federal capital, Abuja lie between 302,372 to 378,040 tonnes (302472000kg to 378090000kg) and the average solid waste generation rate is also estimated to lie between 0.59 to 0.74

kg/person/day (Abur *et al.,* 2014). The potential energy production and income from energy sales depend heavily on the energy content (net calorific value) of the waste. The amount of energy or heat value in an unknown fuel can be estimated by ultimate analysis, compositional analysis, proximate analysis and calorimetric analysis if the arises. However, as a result of this pile of solid waste in Abuja metropolis, present study concept tends to assess energy generation potential from solid waste material in Abuja municipal.

1.2 Statement of the Research Problem

The increase of solid waste is emerging challenges facing Municipal solid waste management (MSW) in Abuja metropolis. This is resulted from population growth due to urbanisation and modernisation in the cities. However, abnormal solid waste management process in Abuja metropolis leads to causes of ill health and environmental hazards to inhabitants because of solid waste are kept in open dumps and landfills. The municipal solid wastes which are dumped along roadsides, open culverts and waste channels require attention weekly basis in Abuja metropolis. Improper MSW disposal and management causes all types of pollution: air, soil, and water. Indiscriminate dumping of wastes contaminates surface and groundwater supplies.

There are MSW clogs drains, creating stagnant water for insect breeding and floods during rainy seasons in Abuja. The natural organic components of MSW (food and plant wastes) can be composted aerobically that is in the presence of air to generate carbon-dioxide (CO2) water and a compost product that can be used as soil conditioner from the waste generated but it is not been assessed. There is need to assess the huge deposit of solid waste as alternative source of energy in Abuja metropolis. The generated waste can help in conversion of waste-to-energy (WTE). In a WTE plant, non-recyclable MSW is combusted at high temperatures. The heat of combustion is used to produce steam that drives a turbine generator of electricity. In this process, a sophisticated air pollution control system can be used to remove particulate and gaseous pollutants before the process gas is released into the atmosphere.

Nigeria as whole largely dependent on hydroelectric power though the gas power plant in the recent and to reduce energy crisis failure the need for renewable energy from biomass source needs high consideration. This will help identifying a great potential to biomass energy in Nigeria in which only municipal solid waste will highly be major source. Most studies concentrate in Nigeria only on waste management strategies in Abuja and little have done on assessing of energy generation potential from solid waste material in Abuja municipal which support and boost electricity supply in Abuja metropolis.

1.3 Aim and Objectives

This study is to assess energy generation potential from solid waste generated in Abuja municipal. The objectives include to:

i. characterise the physical property of the solid waste
ii. determine proximate analysis of the solid waste
iii. determine ultimate analysis of the solid waste
iv. analyse caloric value of the waste
v. prediction of total estimated caloric value of the waste

1.4 Justification of the Study

Biomass is a very promising resource for energy production and bio fuels due to the wide array of conversion methods, abundance, availability, and greenhouse effect around the world. The outcome of the study would be useful energy sustainability which better strategy for Nigerian energy generation and development. The outcome of the research will be useful for students and researchers of power plant engineering. Thus, the finding of the research tends to improve the standard of living and environmental protection in Abuja through evacuation of solid waste that can cause ill health and environmental pollution. Therefore the Abuja environments will be safe to live because hazards posed by the solid waste will not be significant. The outcome of the study will support the potential of energy generation in Nigeria and it will help future researchers in the field of study.

1.5 Scope of the Study

This study will make use of available secondary data to estimate available quantity of solid waste in Abuja. Also to determine if the quantity is huge enough for waste to energy (WTE) conversion in support energy generation in Nigeria. The study will physically characterise the solid waste available in most landfills in Abuja metropolis. However, the use of proximate analysis, ultimate analysis and caloric value analysis of solid waste will help analysing the potential of solid waste presently in Abuja municipal especially at dumping sites or landfill within the environs.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Wastes to Energy Generation

Substantial expansion in quantity, quality and access to infrastructure services, especially electricity, is fundamental to rapid and sustained economic growth, and poverty reduction of any nation in the world. For the past three decades, inadequate quantity and quality and access to electricity services has been a regular feature in Nigeria, a country with approximately 200 million people with a majority living on poverty level. The electricity industry, dominated on the supply side by the state-owned electricity utility, National Electric Power Authority (NEPA), and succeeded by the Power Holding Company of Nigeria (PHCN), has been unable to provide and maintain acceptable minimum standards of electricity service and reliability, accessibility and availability (Rada, 2018). As a result of this, MSW require thinking of waste to energy (WTE) strategies in which energy content of each MSW fraction must be converted to achievable heating value to generate electricity.

WTE refers to a family of technologies that treat waste to recover energy in the form of heat, electricity or alternative fuels such as biogas. WTE is recognized by the U.S. Environmental Protection Agency (EPA) as a clean, reliable, renewable source of energy. In addition combustion of municipal solid wastes for generating electricity has been recognised by several US states as a renewable source of energy. The search for renewable energy sources is motivated by the desire to reduce use of fossil fuels. In the traditional sense, renewable sources of energy are those that nature can replenish, such as waterpower, wind power, solar radiation and biomass (wood and plant waste). However, MSW contain a large fraction of paper, food wastes, cotton and leather, all of which are renewable materials under proper stewardship of the Earth. The scope of the term ‘Waste-to-Energy’ is very wide, encompassing a range of technologies of different scales and complexity. These can include the production of cooking gas in household digesters from organic waste, collection of methane gas from landfills, thermal treatment of waste in utility size incineration plants, co-processing of Refuse Derived Fuel (RDF) in cement plants or gasification. WTE can be used as large-scale plants at the municipal level using the following technologies:

i. Incineration
ii. Co-processing
iii. Anaerobic digestion
iv. Landfill gas collection
v. Pyrolysis/gasification

2.2 Municipal Solid Waste

The solid waste is a kind of waste that is in form of solid state when generated (Puopiel, 2010). Solid waste is defined as a discard/useless or unwanted garbage, refuse that include discard material that obtainable from busiest sources such as farm, industry, commercial and social outlet (Abur *et al*., 2014). Puopiel (2010) also defines solid waste as any material that derived from sources that includes domestic, commercial centres, and industry. This waste source may arise from human/animal excrement or faeces and human gadgets that have no value in its functions. The sources of solid waste in Abuja include medical/clinic centres, food canteen/stores, construction sites, animal slaughters points, markets, schools and homes.

The solid wastes are generated but may not properly manage through better techniques. The solid waste generated in the city are refers to municipal waste with appropriate management technique. Municipal solid waste (MSW) refers to household waste combined with a minor portion of commercial waste collected together. It is regarded as a source of renewable energy because it contains high proportion of biomass materials such as paper/cardboard, wood, plastic can, glass, polyethene and food (Al. Ansari, 2012).

2.3 Characteristics of Municipal Solid Waste

Characterisation of municipal solid wastes is simply a descriptive means of identifying the various constituent of the waste stream in times of quantity and quality generation taking into account location as well as seasons in which these wastes are generated (Alamgir *et al.,* 2005). It is a means of finding out how much paper, glass; food waste is discarded in the municipal waste stream. The characteristics of municipal solid waste are influenced by certain factors, which include the area (residential, commercial), the economic level (differences between high- and low-income areas), the season and weather (differences in the amount of population during the year, tourist places) and culture of people living or doing business in the area. High-income areas usually produce more inorganic materials such as plastics and paper, while low-income areas produce relatively more of organic waste. Characterisation of municipal solid waste helps in determining the quantity of waste generated in a particular location at a particular time of the year. However, characterisation is also important to determine its possible environmental impacts on nature as well as on society. There are two basic approaches as form of characterisation of solid waste and it includes material flows and sampling approach (Tchobanoglous and Kreith, 2002). The material flow waste includes residents, commercial/institutional centres and industry and the waste is regional specific with characterises of moisture basis. The sampling waste includes facilities and site waste and it is site specific with characterises of dry and moist in nature. Accurate information in these areas is necessary in order to monitor and control existing waste management systems and to make regulatory, financial and institutional decisions (Alam, 2013). Alam (2013) characterise solid waste on basis of following parameters that include:

i. Source
ii. Types of wastes
iii. Generation rates and composition

Solid waste is characterised on the basis of following parameters (Moeller, 2005).

i. Corrosiveness: these are wastes that include acids or bases that are capable of corroding mental containers for instance tanks
ii. Ignitability: this is waste that can create fires under certain condition, e.g. waste oils and solvents reactive. These are unstable in nature; they cause explosions, toxic fumes when heated.
iii. Toxicity: waste which are harmful or fatal when ingested or absorb.

2.4 Technology of Waste to Energy Generation

There are many areas in environmental technologies that facilitate both waste treatment and energy generation in a cycle according to (Dolgen *et al.,*2005). Solid waste is one of the typical examples of energy recovery systems using biomass. The term biomass means all carbon containing materials (solids, liquids or gases) that can be converted into energy (bio-energy).Bio energy is the energy derived from biomass (organic matter), such as plants. Biomass include corn, wheat, soybeans, wood, and residues or wastes an also be used to produce chemicals and materials that we normally obtain from petroleum. Industry has already begun to use corn starch to produce commodity plastics, such as shrink wrap, plastic eating utensils, and even car bumpers (Papoutsidakis *et al.,* 2018).

European Union (EU) targets for 2020 is that 20% of the energy need in a European country must come from renewable energy and half of this need must be covered by biomass and the directive is established that the organic fraction of MSW and the biogas produced and exploited from MSW are considered biomass and energy from biomass respectively (Rada, 2018). Biomass materials can be burned directly to produce heat, power or converted to bio fuels (charcoal, biodiesel and others). Biomass can come either directly from a primary source, such as plants for example, or indirectly from urban, industrial or rural waste. Urban waste is classified as residual biomass, derived from human activities, also includes the organic fraction of urban solid waste and urban waste water is separated into household waste and sewage directly from households. The wood residue obtained from processes such as cutting, barking of plants is also biomass. Agricultural residues also belong to the residual forms of biomass. Their main feature is their high energy density where it is combined with their smallest volume; they have a much lower cost, making them more energy-efficient. They include agricultural crop residues and processing of agricultural products. Finally, another major source of bio energy is energy crops (Papoutsidakis *et al.,* 2018). The form conversions of solid waste to energy include incineration, sanitary landfill (landfill gas), gasification, pyrolysis, anaerobic digestion and others. All these technologies have merits and demerits.

The choice of the technology should be based on the local and socio-economic conditions as well as waste quality and quantity (Dolgen *et al.,*2005). Arias *et al.* (2018) opined that energy conversion from MSW is either by thermal conversion, or bioconversion. Thermal types include incineration, gasification and pyrolysis. Theoretically, these processes can capture the energy in the waste and transform it into heat, electricity or chemical products for other applications. The bioconversion involving micro-organisms decompose waste in the form of solids, sludge or gas. Anaerobic digestion and landfill gas are examples of biological conversion. There are five known WTE technique and they include incineration, co-processing, anaerobic digestion (AD), landfill gas (LFG) and pyrolysis/gasification (called alternative technologies) which is summarised in Figure 2.1 (Dieter *et al.,*2017).

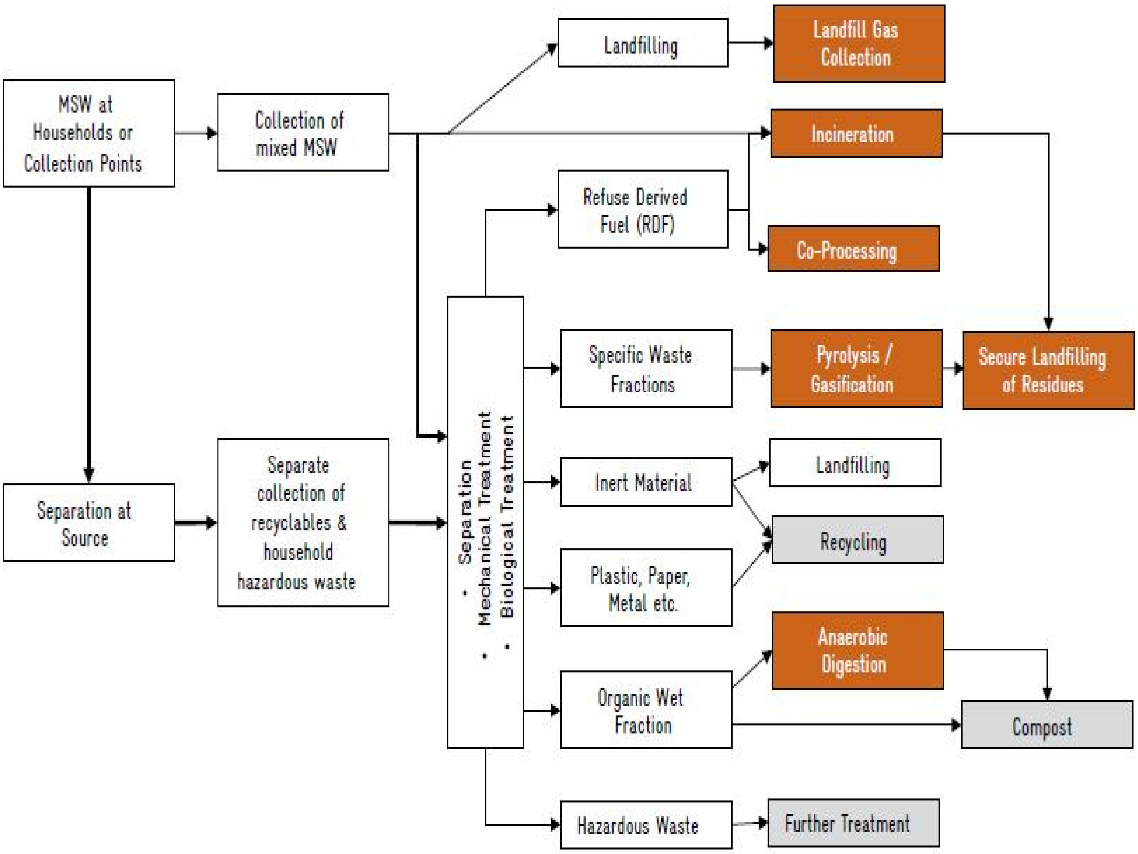


Figure 2.1: WTE Technology (Dieter *et al.,* 2017)

2.4.1 Alternative Technology

Presently there is no plant for the treatment of MSW is in operation on a larger scale in Europe, Africa or Latin America except few in Japan (Dieter *et al.,* 2017). The method includes:

i. Gasification: A process called gasification: the conversion of biomass into gas, which is burned in a gas turbine is another way to generate electricity. The decay of biomass in landfills also produces gas, mostly methane, which can be burned in a boiler to produce steam for electricity generation or industrial processes. It is the partial combustion of SW and biomass to produce gas and carbon. The resulting gases are mainly CO_2 and H_2O, which are reduced to CO and H_2 using coal. An amount of methane and other hydro-carbon gases is produced, depending on the design of the reactor and its operation parameters. Large-scale electricity production from SW gasification is not widely documented. In Colombia, there is a small-scale project with 40kW generation plant that produces power by gasifying biomass in the form of two-inch wood cubes which, when subjected to high temperatures with a controlled amount of oxygen to produce lean gas that can be injected into a conventional engine-generator (Arias *et al.,* 2018).

ii. Pyrolysis: Biomass can also be heated in the absence of oxygen to chemically convert it into a type of fuel oil, called pyrolysis oil as in Figure 2.2 which is pyrolysis plant.

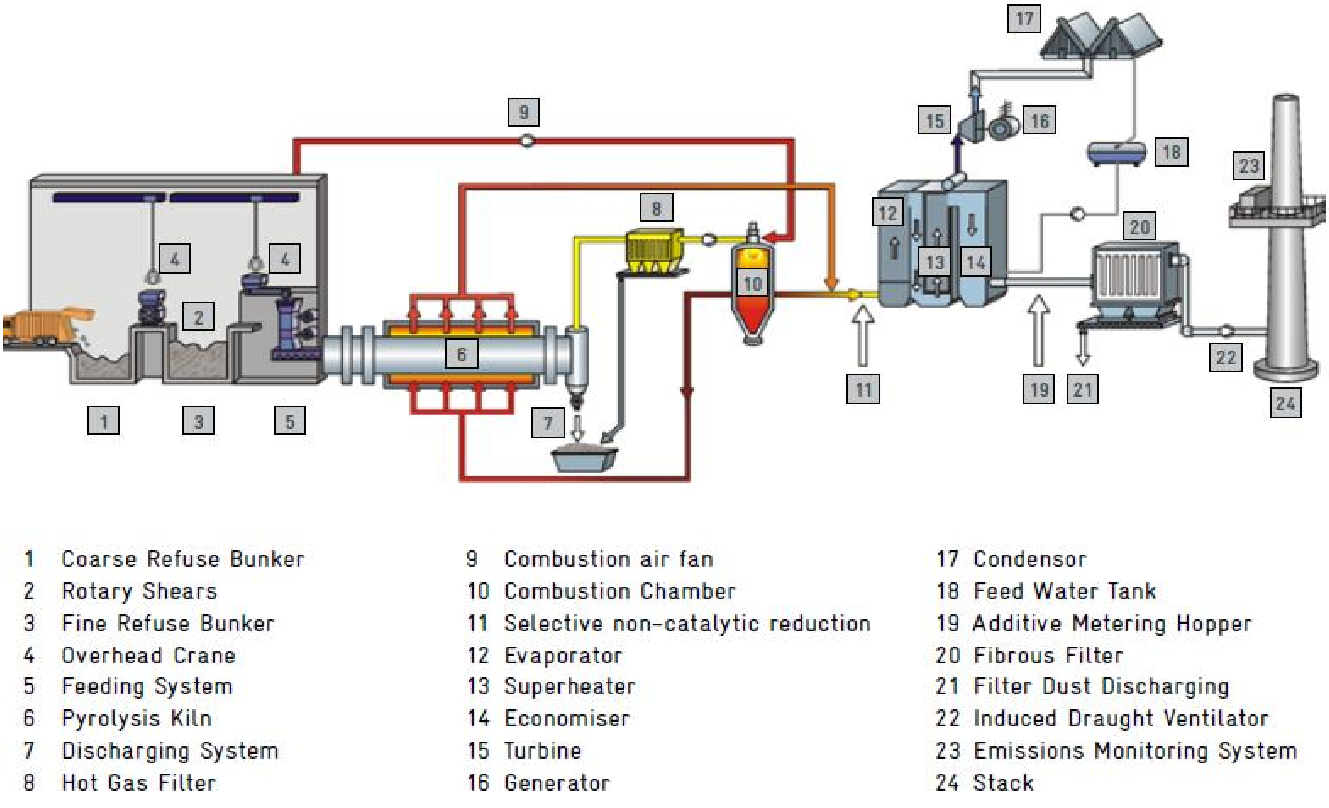


Figure 2.2: Pyrolysis Plant (Dieter *et al.,* 2017)

Pyrolysis oil can be used for power generation and as a feedstock for fuels and chemical production (Dolgen *et al.,* 2005). Rada (2018) explains that pyrolysis is an endothermic process developed in reducing conditions (in extreme cases in absence of free oxygen) that converts waste in three streams: syngas, exploitable directly (after treatment) in cycles of co-generation, fuel oil and combustible solid matrix.

2.4.2 Bio fuel

Biomass can be converted directly into liquid fuels, called bio fuels. Because bio fuels are easy to transport and possess high energy density, they are favoured to fuel vehicles and sometimes stationary power generation. The most common bio fuel is ethanol, an alcohol made from the fermentation of biomass high in carbohydrates. The current largest source of ethanol is corn or corn waste. Some cities use ethanol as a gasoline additive to help meet air quality standards for ozone. Flex-fuel vehicles are also now on the market, which can use a mixture of gasoline and ethanol, such as E85 “a mixture of 85 percent ethanol and 15 percent gasoline”. Another bio fuel is biodiesel, which can be made from vegetable and animal fats. Biodiesel can be used to fuel a vehicle or as a fuel additive to reduce emission (Dolgen *et al.,*2005).

2.4.3 Incineration

According to (Dieter *et al.,* 2017) Municipal solid waste incineration (MSWI) is the burning of waste in a controlled process within a specific facility that has been built for this purpose. The primary goal of MSWI is to reduce MSW volume and mass and also make it chemically inert in a combustion process without the need of additional fuel (autothermic combustion). As a side effect it also enables recovery of energy, minerals and metals from the waste stream. There are always about 25% residues from incineration in the form of slag (bottom ash) and fly ash. The process of incineration requires being range between 750 °C and 1000 °C. This will be enough to obtain heat and electricity and these generation processes can be combined. A typical controlled incineration system (electricity and heat) is composed of a waste storage chamber, an incinerator/furnace, a vapour/generator turbine, a fuel-gas cleaning system and a waste treatment system. The calorific value of waste is an important parameter that greatly contributes to the efficiency of the incineration plant. Incineration is a mature technology, used in several developed countries. France, for instance, widely uses incineration: in 2003, 12.6 million tons of non-hazardous wastes were treated at 130 incineration plants. A total of 2.9 TWh of electricity were generated, and 9.1 TWh were consumed in the form of heat by private and public users. China actively promotes the production of energy by incineration and in year 2014, the country was building 75 plants to process 110,000 tons per day and has a total in-stalled capacity of 2.2 GW. Germany has an incineration plant, property of the German Cleaning Company, capable of incinerating 520,000 tons per day and generates 188 kWh of electricity every year (Somorin *et al.,*2017). There is viability of obtaining energy from incineration in countries like Bangladesh, Nigeria and KSA (Kingdom of Saudi Arabia). One of the greatest advantages of this process is that it can treat organic and inorganic waste. Therefore, waste volume can be reduced up to 80%. The plant can be continuously fed, and the treatment is fast. The complexity of the plant is low; it can be installed in urban areas and meet all the technical and environmental regulations. One of its drawbacks is that it is not viable to build plants to treat a volume lower than 100T of SW per day (Ofori-Boateng *et al.,*2013).

2.4.4 Combustion

Combustion of solid waste has been used as an efficient way to convert the energy stored in it into useful heat. The energy content (heating value or so-called lower calorific value) of the waste is a crucial parameter, and it is mainly dependent upon its composition. Different types of waste that is wood, plastic and others have heating values. The high heating value of this waste supports fuel for waste-to-energy plants. Adversely, wastes including inert matters, such as construction and demolition wastes, glass and metals, are not suited for incineration. Besides, in many developing countries, the domestic waste has a high moisture or ash content (or both), thus making the incineration alternative inappropriate. (Dolgen *et al.,* 2005) stated that World Bank report on incineration plants is that average lower calorific value of the MSW must be at least 6,000–7,000 kJ/kg throughout all seasons. Therefore, the wastes, which are theoretically feasible for combustion without auxiliary fuel, should have met the limits in terms of heating value and water, ash, and combustible matter contents. In order to assess the fuel characteristics of a particular waste, ash content, combustible fraction and moisture of raw waste should be established in percentage by weight.

2.4.5 Landfill Gas

The decomposition of organic waste in garbage dumps is slightly similar to anaerobic digestion in biogas digesters. Micro-organisms living in the organic material, such as residues of food and paper, cause decomposition as well as methane and carbon dioxide release (Arias *et al.,*2018). Landfill gas (LFG) can be successfully used to replace other energy sources. This is burnt to produce heat, supplying gas engines or turbines to produce electricity. The volume of LFG generated from a landfill depends on the proportion of materials in the MSW. Organic materials are not decomposed in equal proportions because the degradable fraction varies from product to product. The decomposable constituents of LFG are assumed to have a form of $C_aH_bO_cN_d$ (carbon, hydrogen, oxygen and nitrogen). The decomposed chemicals combine with water molecules (H_2O) to form LFG, which comprises methane, carbon dioxide and other trace gases (Dolgen *et al.,* 2005). This technology has been successfully applied in countries like Brazil, where a potential of 660 MW from landfills was estimated in 2009 and In fact, in 2014, 69 MW were produced from biogas recovered from landfills in Sao Paulo. Producing landfill biogas is a low-cost alternative to generate electric or thermal energy. However, its efficiency is limited to 30 or 40% of the generated gas. Since the natural resources are returned to the soil, swamps might become useful areas. The level of complexity of this kind of plants is low; for that reason, their operation does not require qualified staff. Summary of the process is presented in Figure 2.3.

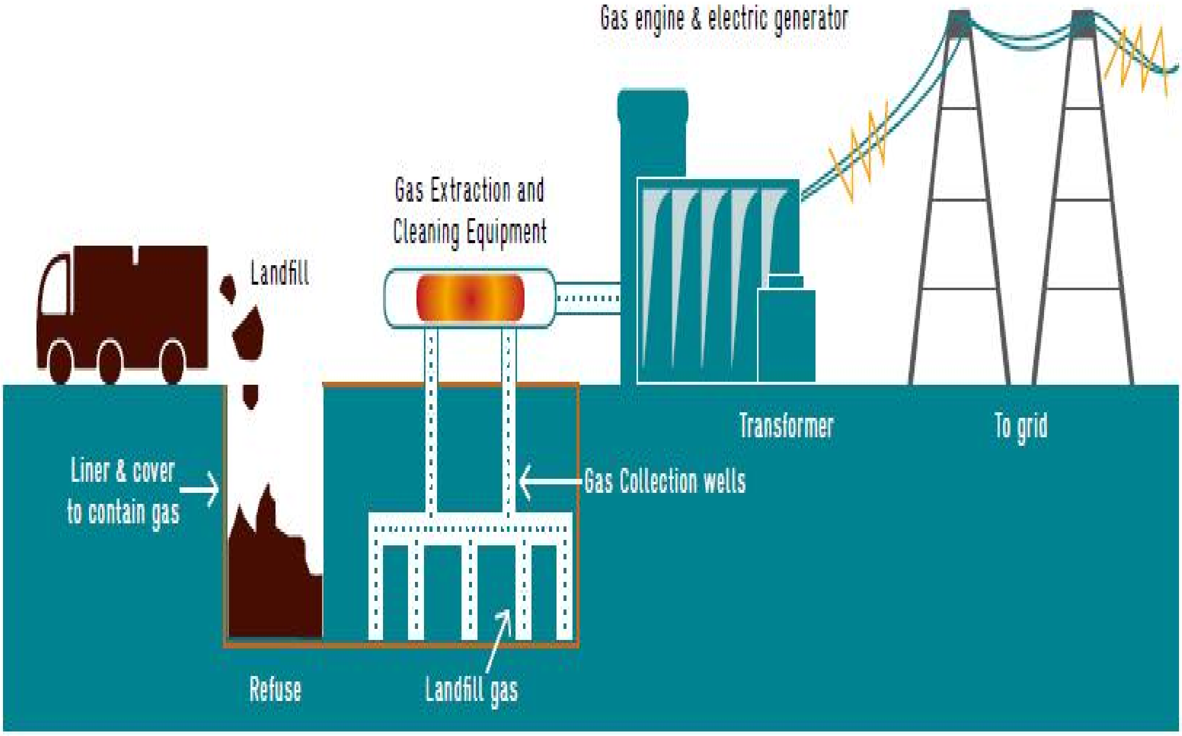


Figure 2.3: Landfill Gas Process (Dieter *et al.,* 2017)

2.4.5 Anaerobic Digestion

The process also known as bio methanation this is biological conversion technology transforms organic waste into liquid or gaseous fuels by means of biological reagents. This process involves four stages: hydrolysis, acidification, aceto genesis and methano genesis. It is carried out in a closed container (biogas digester), where bacteria ferment the organic material under oxy-gen-free conditions to produce biogas. Such biogas can be used in a boiler or alternative engine. In Brazil, anaerobic digestion has been successful in producing electricity in small scale. In Colombia, there is implementation stage in 2016 to produce 2 million m^3 of biogas and 500 kW of electric power from 15,000 Ton/year of organic SW. Anaerobic Digestion is profitable and applicable to a production greater than 2 Tons/day of SW. However, the plant must only be fed the organic fraction, which means waste sorting is necessary.

2.4.6 Co-processing

Co-processing is the use of waste derived materials to replace natural mineral resources (material recycling) and/or traditional fossil fuels such as coal, fuel oil and natural gas (energy recovery) in industrial processes. Co-processing is applied worldwide mainly in the cement industry and in thermal power plants; in a few cases it is also applied in the steel and lime industry. In thermal plants where only energy recovery takes place this is called co-incineration. In the European cement industry, the thermal substitution rate of traditional fuels by waste can reach up to 80% in certain facilities (averaged over the year), while the average substitution rate across European Union amounts to about 39 %. Co-processing in cement plants has also become a wide-spread part of waste management systems in a number of developing and emerging countries. Nevertheless, the share of MSW used in co-processing is still low compared to special waste streams such as used tires, hazardous industrial waste, contaminated soil, biomass residues or sludge from wastewater treatment plants (Dieter *et al.,* 2017).

2.4.7 Sources and Types of Municipal Solid Wastes

There are many categories of municipal solid waste (MSW) such as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste and sanitation waste (Sharholy *et al.*, 2007). Waste is being categorised by Environmental Protection Department Air Management Group, EPDA, in the year 2001 as household, municipal, commercial and industrial wastes in which some are hazardous and toxic. The waste includes food wastes, paper, cardboard, plastics, textiles, leather, yard wastes, wood, glass, metals, ashes, special wastes such as bulky items, consumer electronics, white goods, batteries, oil and tires and also household hazardous wastes (EPDA, 2001). (Abur *et al.,* 2014) categorises waste generated in developing nation's cities as commercial stores, hotels, restaurants, markets generate paper, cardboard, plastics, wood, food wastes, glass, metals, special wastes. (Jha *et al.,* 2003) also categorises the municipal solid waste as follows:

i. Recyclables such as paper, plastic, glass and metals
ii. Toxic substances such as paints, pesticides, used expired batteries/medicines
iii. Compostable organic matter such as fruit and vegetable peels and food waste
iv. Soiled waste such as blood-stained cotton, sanitary napkins and disposable syringe

The quantity of MSW generated depends on a number of factors such as food habits, standard of living, degree of commercial activities and seasons (Sharholy *et al.,* 2007). This depends on sources of solid waste generated especially in Nigeria. Sources of solid waste generation in Nigeria among others are commercial, industrial, household, agricultural and educational establishments. The solid waste types in Nigeria include paper, nylon, wood, dust, cloth, metal scraps, electronic gadgets, bottles, food remnants and vegetables; saw dust, ashes, rubber, bones and plastics (Ukem, 2008). There are used computers which are imported to Nigeria through Lagos seaport monthly turns to become electronic waste in Nigeria and (Adewumi *et al.,* 2005). Alam (2013) agreed that waste source is such as residential, industrial, institutional, construction and demolition and municipal services wastes. Sharholy *et al.,* (2007) also identified sources of waste as residential, commercial, institutional and industrial in developing countries cities as shown in Table 2.1.

Table 2.1: Source of Wastes

Source	Examples
Residential	Single-family homes, duplexes, town houses, apartments
Commercial	Office buildings, shopping malls, warehouses, hotels, airports, restaurants
Institutional	Schools, medical facilities, prisons
Industrial	Packaging of components, office wastes, lunchroom and restroom wastes (but not industrial process wastes)

Sources: (Sharholy *et al.,* 2007)

2.4.8 MSW Generation Rates

It has been reported that one of the greatest environmental threats being experienced by developing countries is MSW (Ayuba *et al.,*2013; Egun, 2012). The rates of waste generation vary from 0.4 to 0.79 kilogram per person per day (kg/capita/day) (Abur *et al.,*2014). The waste generation for high income countries ranges from 2.75 to 4.00 kg/capita/day and for low-income countries it is 0.5 kg/capita/day. The yearly waste generation has also shown an upward trend because of population increases and urbanization. It was 6601 Giga-tonne (Gt) in year 1960 and increased to 23,243 Giga-ton in year 2010. This amount is projected to reach 29,850 Giga-tonne by 2020 and 36,250 Giga-tonne (Gt) by 2030. The annual waste generation with projections is shown in Table 2.2.

Table 2.2: Generation of Waste in Nigeria

Year	Waste (Gt)
1960	6601
1970	8195
1980	10760
1990	13961
2000	17940
2010	23243
2020	29843
2030	36251

Source: (Yusuf *et al.,* 2019)

The city of Lagos is the greatest generator of waste followed by Kano and these two cities have the highest densities of population in Nigeria as in Table2.3. However, it was observed after these cities, Abuja metropolis is next city of waste generation. Abuja has highest growing waste generation per day in kg/capita/day.

Table 2.3: Waste Characterisation in Selected Cities in Nigeria

Year	Waste (Gt)	Waste (kg/capita/day)
Abuja	147.9	0.66
Lagos	255.56	0.63
Kano	156.68	0.54
Ibadan	135.39	0.51
Kaduna	114.83	0.58
Port Harcourt	117.83	0.60

Source: Yusuf *et al.,*(2019); (Ogwueleka 2009)

The solid waste characterisation in Abuja metropolis is characterised as in Table 2.4.

Table 2.4: Waste Characterisation in Abuja Metropolis

Waste Type	Waste (%)
Food/organic	54.10
Plastic	5.13
Paper	11.23
Textile	1.01
Rubber	6.88
Glass/ceramics	4.51
Metals	1.65
Others	15.49

Source: (Abur *et al.*, 2014); (Bichi and Amatobi 2013)

2.5 Treatment of Municipal Solid Waste

Waste treatment techniques seek to transform the waste into a form that is more manageable, reduce the volume or reduce the toxicity of the waste thus making the waste easier to dispose of. Alam (2013) stated that current treatment strategies are directed towards reducing the amount of solid waste that needs to be land filled, as well as recovering and utilising the materials present in the discarded wastes as are source to the largest possible extent. Different methods are used for treatment of solid waste and the choice of proper method depends upon refuse characteristics, land area available and disposal cost they are as follows (Moeller, 2005).

i. Incineration
ii. Compaction
iii. Pyrolysis
iv. Gasification
v. Composting

Treatment methods are selected based on the composition, quantity, and form of the waste material. Some waste treatment methods being used today include subjecting the waste to extremely high temperatures, dumping on land or land filling and use of biological processes to treat the waste. It should be noted that treatment and disposal options are chosen as a last resort to the previously mentioned management strategies reducing, reusing and recycling of waste. The destruction of MSW using heat energy is called thermal treatment. Although there are many thermal processes incineration is the most widely used and it includes (Jha *et al.,* 2003).

2.5.1 Thermal Treatment

The thermal techniques include:

i. Incineration

Incineration is the process of control and complete combustion, for burning solid wastes. It leads to energy recovery and destruction of toxic wastes, for example, waste from hospitals. The temperature in the incinerators varies between 980 and 2000 ^{o}C. One of the most attractive features of the incineration process is that it can be used to reduce the original volume of combustible solid waste by 80–90%. In some newer incinerators designed to operate at temperatures high enough to produce a molten material, it may be possible to reduce the volume to about 5% or even less (Jha *et al.,* 2003).

ii. Gasification and Pyrolysis Technology

Incineration of solid waste under oxygen deficient conditions is called gasification. The objective of gasification has generally been to produce fuel gas, which would be stored and used when required. There are few gasifiers in operation, but they are mostly for burning of biomass such as agro-residues, sawmill dust, and forest wastes in existence. Gasification can also be used for MSW treatment after drying, removing the inert and shredding for size reduction (Sharholy *et al.,* 2007). Pyrolysis and gasification are similar processes they both decompose organic waste by exposing it to high temperatures and low amounts of oxygen. Gasification uses a low oxygen environment while pyrolysis allows no oxygen. These techniques use heat and an oxygen starved environment to convert biomass into other forms. A mixture of combustible and non-combustible gases as well as pyroligenous liquid is produced by these processes. All of these products have a high heat value and can be utilised. Gasification is advantageous since it allows for the incineration of waste with energy recovery and without the air pollution that is characteristic of other incineration methods.

iii. Refuse Derived Fuel (RDF) Plant

(Sharholy *et al.,* 2007) explains that the main purpose of the refuse derived fuel (RDF) method is to produce an improved solid fuel or pellets from MSW. Gasification–combustion seems to be promising as it can reduce pollution and increase heat recovery. RDF is another promising technology, which is going to be used for producing power. In addition, the RDF plant reduces the pressure on landfills. Combustion of the RDF from MSW is technically sound and is capable of generating power. RDF may be fired along with the conventional fuels like coal without any ill effects for generating heat. Operation of the thermal treatment systems involves not only higher cost, but also a relatively higher degree of expertise.

iv. Open burning

Open burning is the burning of unwanted materials in a manner that causes smoke and other emissions to be released directly into the air without passing through a chimney or stack. This includes the burning of outdoor piles, burning in a burn barrel and the use of incinerators which have no pollution control devices and as such release the gaseous by products directly into the atmosphere. Open burning has been practiced by a number of urban centres because it reduces the volume of refuse received at the dump and therefore extends the life of their dumpsite. Garbage may be burnt because of the ease and convenience of the method or because of the cheapness of the method. In countries where house holders are required to pay for garbage disposal, burning of waste in the backyard allows the householder to avoid paying the costs associated with collecting, hauling and dumping the waste. Open burning has many negative effects on both human health and the environment. This uncontrolled burning of garbage releases many pollutants into the atmosphere. These include dioxins, particulate matter, polycyclic aromatic compounds, volatile organic compounds, carbon monoxide, hexa-chlorobenzene and ash. All of these chemicals pose serious risks to human health.

The dioxins are capable of producing a multitude of health problems; they can have adverse effects on reproduction, development, disrupt the hormonal systems or even cause cancer. The polycyclic aromatic compounds and the hexa-chlorobenzene are considered to be carcinogenic. The particulate matter can be harmful to persons with respiratory problems such as asthma or bronchitis and carbon monoxide can cause neurological symptoms. The harmful effects of open burning are also felt by the environment. This process releases acidic gases such as the halo-hydrides; it also may release the oxides of nitrogen and carbon. Nitrogen oxides contribute to acid rain, ozone depletion, smog and global warming. In addition to being a greenhouse gas carbon monoxide reacts with sunlight to produce ozone which can be harmful. The particulate matter creates smoke and haze which contribute to air pollution (Sharholy *et al.,* 2007).

2.5.2 Biological Treatment

The biology treatments include:

i. Composting

Composting is the controlled aerobic decomposition of organic matter by the action of micro-organisms and small invertebrates. There are a number of composting techniques being used today. These include: in vessel composting, windrow composting, vermin composting and static pile composting. The process is controlled by making the environmental conditions optimum for the waste decomposers to thrive. The rate of compost formation is controlled by the composition and constituents of the materials i.e. their Carbon/Nitrogen (C/N) ratio, the temperature, the moisture content and the amount of air. The C/N ratio is very important for the process to be efficient. The micro-organisms require carbon as an energy source and nitrogen for the synthesis of some proteins. If the correct C/N ration is not achieved, then application of the compost with either a high or low C/N ratio can have adverse effects on both the soil and the plants. A high C/N ratio can be corrected by dehydrated mud and a low ratio corrected by adding cellulose. Moisture content greatly influences the composting process. The microbes need the moisture to perform their metabolic functions. If the waste becomes too dry and the composting is not favoured. If however there is too much moisture then it is possible that it may displace the air in the compost heap depriving the organisms of oxygen and drowning them. A high temperature is desirable for the elimination of pathogenic organisms. However, if temperatures are too high, above 75°C then the organisms necessary to complete the composting process are destroyed. Optimum temperatures for the process are in the range of 50-60°C with the ideal being 60°C (Sharholy *et al.,* 2007).

ii. Aeration

This very important and the quantity of air needs to be properly controlled when composting. If there is insufficient oxygen the aerobes will begin to die and will be replaced by anaerobes. The anaerobes are undesirable since they will slow the process, produce odours and also produce the highly flammable methane gas. Air can be incorporated by churning the compost (Sharholy *et al.,* 2007).

iii. Anaerobic Digestion

Anaerobic digestion like composting uses biological processes to decompose organic waste. However, where composting can use a variety of microbes and must have air, anaerobic digestion uses bacteria and an oxygen free environment to decompose the waste. Aerobic respiration, typical of composting, results in the formation of Carbon dioxide and water. While the anaerobic respiration results in the formation of Carbon Dioxide and methane. In addition to generating the humus which is used as a soil enhancer, Anaerobic digestion is also used as a method of producing biogas which can be used to generate electricity. Optimal conditions for the process require nutrients such as nitrogen, phosphorous and potassium, it requires that the pH be maintained around 7 and the alkalinity be appropriate to buffer pH changes, temperature should also be controlled (Sharholy *et al.,* 2007).

2.6 Characterising Technique of Solid Biomass Fuel

Proximate analysis, ultimate analysis and calorific value are commonly used to characterise solid biomass fuels (Beith, 2011). The proximate analysis serves as a simple means for determining the behaviour of a solid biomass fuel when it is heated. It determines the contents of moisture, volatile matter, ash and fixed carbon of the fuel. On the other hand, the main purpose of an ultimate analysis is to determine the elemental composition of the solid fuel substance. The calorific value of a fuel is a direct measure of the chemical energy stored in the fuel. Due to the inhomogeneous nature of solid biomass fuels, it is notoriously difficult to prepare small quantities (in the order of grams) of representative samples for biomass characterisation tests. Therefore, strict sampling and preparation procedures specified by the British/European standard BS EN 14778-1:2005 have to be followed by any proximate, ultimate and calorific value tests of solid biomass fuels that include proximate analysis, ultimate analysis and calorific value

2.6.1 Proximate analysis

The appreciable amount of water vapour is released when a solid biomass fuel is heated to above the boiling temperature of water, the first parameter of a proximate analysis is the moisture content of the fuel. The moisture content is determined by drying solid biomass samples at 105 °C in air atmosphere until constant mass is achieved and percentage moisture calculated from the loss in mass of the sample. Standard procedures for the determination of moisture content of solid biomass fuels are specified by three British/European standards BS EN 14774-1:2009, BS EN 14774-2:2009 and BS EN 14774-3:2009 (Beith, 2011).

Another major loss occurs when a solid biomass fuel is heated in a covered crucible or in other apparatus which prevents the oxidation of the carbon residue. This loss is referred to as the volatile matter and constitutes the second parameter of the proximate analysis. Volatile matter is determined with the sample being heated out of contact with ambient air at 900 °C for 7 minutes. Standard procedures for the determination of volatile matter of solid biomass fuels are specified by the British/European standard BS EN 15148: 2009. If the remaining residue is further combusted, the residue left after the combustion is called ash, and the weight loss on combustion is referred to as ‘fixed carbon’. Fixed carbon and ash contents constitute the third and fourth parameters of the proximate analysis. This part of proximate analysis, that is combustion of the residue, is carried out in a furnace at 550 °C and the standard procedures are specified by the British/European standard BS EN 14775:2009.It is not always practical to conduct the above various determinations stepwise. Therefore, one set of samples could be used for the moisture content determination, and another set of samples for the combined moisture and volatile matter loss, and still another set of samples for ash determination (Beith, 2011).

2.6.2 Ultimate analysis

Ultimate analysis helps in determine the elemental composition of a solid biomass fuel. The main elements of solid biomass fuels include carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O) but for some solid biomass fuels chlorine (Cl) and other elements may also be of interest. Nowadays, the ultimate analyses of sold biomass fuels are usually carried out with fully automated instruments. The instrumental method for the determination of total carbon, hydrogen and nitrogen contents in solid biomass fuels is described by the British/European standard CEN/TS 15104:2005. The methods for the determination of the total sulphur and total chlorine content in solid biomass fuels are specified by the British/European standard CEN/TS 15289:2006. Sometimes, the determinations of the major elements (Al, Ca, Fe, Mg, P, K, Si, Na and Ti) and the minor elements (As, Cd, Co, Cr, Cu etc.) of solid biomass fuels are also necessary and required (Beith, 2011).

2.6.3 Calorific value

The calorific value of a fuel is the number of heat units evolved when unit mass (or unit volume in the case of a gas) of a fuel is completely burned and the combustion products are cooled to 298 K. This definition of calorific value includes the provision that the products of combustion are cooled to 298 K which means the sensible heat and the latent heat of condensation of the water produced during combustion are included in the heat liberated. Therefore, the calorific value of the fuel is designated as ‘gross calorific value (GCV)’ or ‘high heating values (HHV)’. However, with many industrial applications, the latent heat of condensation is not given up and the total heat liberated per unit mass (or volume) of the fuel is less. The calorific value in the case where the water remains as vapour is designated as ‘net calorific value (NCV)’ or ‘low heating value (LHV) (Beith, 2011).

The gross calorific value of a solid biomass fuel is usually determined experimentally by a bomb calorimeter, whereas the net calorific value of the fuel is usually calculated from the gross calorific value and the ultimate analysis of the fuel. Specific experimental procedures and calculation formulae are detailed by the British/European standard BS EN 14918:2009. Many solid biomass fuels contain high moisture content which greatly affects the net calorific value as illustrated in Table 2.5.

Table 2.5: Solid Biomass Fuel’s Average Net Calorific Value

Fuel	**Net Calorific Value**	
	(GJ/tonne)	**(GJ/m^3)**
Wood (green, 60% moisture)	6	7
Wood (air-dried, 20% moisture)	15	9
Wood (oven-dried, 0% moisture)	18	9
Grass (fresh-cut)	4	3
Straw (as harvested, baled)	15	1.5
Domestic refuse (as collected)	9	1.5
Coal (UK average)	28	50

(Source: Beith 2011)

2.7 Benefits of Waste to Energy Generation

Reduction of pollution into the atmosphere from renewable resources can be achieved through the use of WTE which is renewable (Yusuf *et al.,* 2019). Waste to energy (WTE) is called biogas is both environmentally and economically important to every nation. Hence it plays a key role in cost effectiveness of any nation's economy. It also creates among other benefits, direct employment of labour and fosters the development of micro- industries. Economic considerations appear to be the most important factor that drives the process of the generation of WTE systems. Factors other than economic that are considered when deciding whether or not to use the energy include issues of pollution, greenhouse gas generation and the security of the energy resources, among others. The cost of energy produced however appears to almost exclusively dominate design decisions. Environmental factors are however also becoming increasingly significant in such a decision making procedures (Oisamoje and Oisamoje, 2013).

2.7.1 Environmental benefits

The largest disadvantage of the fossil fuels is the emission of carbon dioxide to the atmosphere, which creates the "greenhouse effect". Also, this type of energy not only affects the degradation and deforestation of land but as well water, air pollution, human illness and accumulation of solid waste. Those factors contribute to the current issue of the global warming, formation of the smog, endangerment of the flora, fauna and marine life, and others (Greenhalgh, 2002). Furthermore, burning coal produces sulphur dioxide that contributes to the formation of the acid rain. The open mining coals, so called "strip mining", harms the environment by destroying quite large areas of the landscape. The environmental advantages include:

i. The energy plants do not generate much noise (unlike as diesel generators).
ii. All the environmental advantages result in better health of citizens
iii. Comparatively simple and can be produced easily.
iv. Burns without smoke and without leaving ash as residues.
v. Household wastes and bio-wastes can be disposed of usefully and in a healthy manner.
vi. The slurry from the biogas plant is excellent manure.

Thus, major environmental and health concern is the uncontrolled surface emission of waste during burning into the atmosphere. Other substances emitted from MSW especially through landfills are non-methane organic compounds (NMOCs) in addition to CH_4 and CO_2 (Yusuf *et al.,* 2019). The NMOCs include hazardous air pollutants and volatile organic compounds that are precursors to ozone formation. The emissions of methane and NMOCs are significantly reduced by burning the landfill gas (LFG) to extract its energy. When landfill gas energy projects are executed, cleaner air and reductions of smog, odour and greenhouse gas emissions are assured. Using WTE will reduce subsurface migration from landfills to other areas within or outside the landfill property, leading to a reduction in the risk of explosion and fire. As a cleaner source of fuel, the use of LFG will reduce the emissions of polluting substances from the burning of fossil fuels that can be harmful to the ozone layer, flora, and fauna.

The small sizes of LFG power plants result in minor pollution discharges into receiving water bodies, unlike other power plants that rely on withdrawing water for cooling. By providing energy to the grid, renewable sources reduce the demand for electricity from traditional sources, which are more polluting and contribute to global warming. Gas generation at an active landfill is continuous, unlike solar and wind power. Hence, LFG combustion can act as buffer when there is cloud cover or low wind velocity (Abushammala *et al.,* 2016).

2.7.2 Economic benefits

A major benefit to be derived from the use of WTE will be a reduction in ozone layer depletion. When the electricity generated from the WTE is quantified in monetary terms. It could have attracted revenue of US$ 365.04 billion in 2015. The revenue is projected to reach US$390.14 × 106, US$431.97 billion andUS$473.82 billion respectively, for the years 2020, 2025, and 2030 (Yusuf *et al.,* 2019). Job's creation in relation to WTE projects could be done in the areas of design, construction, and operation of energy recovery systems. Renewable energy sources could be included in the energy mix for the power sector. Other benefits include a lower transportation footprint in comparison with more conventional fuels, such as uranium and coal, as the hauling of the garbage will not be much further in terms of the distance covered in comparison to other fuel sources. There will be no additional extraction costs, unlike the case with fossil fuels. The economic benefits of the application of energy are as follows:

i. Operation Costs:
    a) Fixed operating costs (salaries, depreciation, cost of capital)
    b) Variable operating costs (maintenance, utility usage, operation of emissions systems)
    c) Disposal of process wastes (ash from incineration, other unconverted waste).

ii. Revenues:
    a) Tipping fees paid by waste producer
    b) Sales from electricity, heat, and steam
    c) Sales from other co-products (recovered metals, compost).

2.8 Advanced Researches

Korai *et al.* (2016) on estimation of energy potential from organic fractions of Municipal Solid waste by using empirical models at Hyderabad, Pakistan. The MSW (Municipal Solid Waste) now-a-day is considered as a precious renewable energy resource for various purposes. In view of above fact, one hundred samples of MSW were collected from different locations of study area. Quantities of each organic waste component were determined by using physical balance and also their proximate analysis was performed by using oven and muffle furnace. In this study, nine empirical models were used for estimating the energy value in terms of heat from OFMSW (Organic Fractions of Municipal Solid Waste), namely two of them were based upon physical composition, four of them were on the basis of its proximate analysis and remaining three of them was according to ultimate analysis of OFMSW. From comparison

of all energy models, the empirical Model No. 3 and No. 4 based upon proximate analysis have highest energy recovery potential than all of others. Moreover, the result of Model No.3 on the basis of proximate analysis is closer to the calorific value of mixed OFMSW than the values obtained by rest of models. Therefore, this is the best model to be used. From the outcomes of Korai *et al.,* (2016) study it can be realized that the energy recovery from the OFMSW plays a vital role for economy growth of the country. On that account, a systematic approach should be performed in detail before making a decision on such option. This study will play bigger role on the present study and however, the gap the present study with both organic and non-organic waste fraction of Abuja metropolis.

Dolgen *et al.* (2005) study on energy potential of municipal solid wastes in which energy potential of solid wastes of Izmir (third biggest city of Turkey) is then estimated. There are basically two conclusions that can be drawn about energy recovery facilities from MSW. The first is that landfill gas LFG seems to be environmentally beneficial, and, in most cases, an economical source of energy. The LFG has a gross heating value of about17,000 kJ/m^{3}a great energy potential available with prediction of production for 15 years of life span of landfill site including 5 years after closure. Then, total LFG production is determined to be 1,023,000,000 m^3. This value corresponds roughly to 1,023,000,000 Kw energy. If the electricity prices are taken as10 cents per kWh, then it would be worth almost 100 million USD through 15 years. Thus, energy recovery is likely to make some positive contributions to revenues, and municipalities are able to derive income for solid waste management activities.

For the combustion alternatives of MSW, it is applicable only if certain criteria stated above are fulfilled. For instance, preliminary assessment of using MSW as fuel can be made on the basis of the content of ash, combustible matter and moisture. Another most crucial factor is the calorific value of waste. In order to implement incineration system, the lower calorific value of MSW must be at least 7 MJ/kg, and must never fall below 6 MJ/kg in any season, and stable combustible waste supply (at least 50,000 metric tons/year)should be maintained. Consequently, if the mandatory criteria for waste combustibility are not fulfilled, the incineration plant should not be implemented. However, since the MSW has high moisture or ash content (or both), incineration alternative is not fitted to many developing countries like Turkey. Particularly for Izmir, as organic material content of MSW is quite rich and the heating value is less than 6 MJ/kg, incineration (or burning of waste) should not consider as final disposal option for MSW. The study conducted by Dolgen *et al.,* (2005) serves as guide for the present study.

The work conducted by Uche-Soria and Rodríguez-Monroy (2019) on efficient WTE model in isolated environments using La Gomera -Canary Islands as case study serves as a guide for the present. Municipal solid waste (MSW) management is a controversial aspect of environments because the production of waste grows exponentially. The research studies the potential of MSW recovery on the island of La Gomera (Canary Islands) as an alternative to landfill deposition, being an additional energy source for heat and electricity. The methodology followed consists, first of all, on estimating the annual amount of MSW and waste deposited in the landfill. Second, the characterization of representative samples of each municipality is carried out. Third, according to these characteristics, the thermal treatment is chosen and, finally, the energy generated is evaluated. The results are encouraging, and many advantages are derived from this model. The annual recycling figure increases by about 5000 tons per year, the percentage of renewable energy from waste reaches 35.5% (most installed capacity is diesel), and greenhouse gases (GHG) are reduced by more than half. To overcome the challenges in the integral management of MSW, it is necessary to move from a linear economy to a circular economy that takes into account the priorities established by the European Union to solve the problem of these isolated environments in terms of energy. It was understood that insularity of municipal waste management (collection, transport, treatment, recycling and disposal), recovery of hazardous materials from municipal waste, recovery and valorisation of those waste fractions feasible from a unified technical, economic and environmental perspective.

Akhator *et al*., (2016) on electricity generation in Nigeria from municipal solid waste using Swedish waste to energy model. Waste-to-energy (WTE) technology in Nigeria is still at the infancy stage where as in Sweden the technology is now so advanced that energy in the form of heat and electricity has commercially been recovered from waste. This study examines WTE development and its success factors in Sweden with a view to instigating the deployment of a modified Sweden's waste-to-energy model in Nigeria to enhance her WTE capacity. The study was carried out in two phases. The first phase involved field visits to some waste-to-energy plants in Sweden and the second phase was a desk research of available data on current WTE development in Nigeria, Sweden's energy sector as well as factors responsible for its successful WTE development. The result from the study showed that Sweden generated about 2 TWh of electricity from about 5.7 million tonnes of waste in its WTE plants in 2014.The success of WTE development and growth in Sweden is hugely as a result of the support from the Swedish government via enacting enabling policies and adequate funding. With about 14 million tonnes of combustible waste available in Nigeria, about 4.4TWh of electricity could be generated annually if WTE development in the country receives similar support from the Nigerian government.

The work of Akhator *et al* (2016) showed importance of WTE towards electricity generation and however the work will serve as guideline present study. The gap between Akhator *et al.*, (2016) and present study is the present will not apply modified Sweden's waste-to-energy model but will quantify energy value of MSW presently generated in Abuja metropolis. Rominiyi *et al*. (2017) on synergetic effect of proximate and ultimate analysis on the heating value of municipal solid waste of Ado–Ekiti Metropolis, Southwest Nigeria serves as guide for the present study. The municipal solid waste which is a threat to the environment can be effectively utilized to boost the economic prosperity of where this waste is being generated. One of the way by which it can be utilized is energy production. The results generated in the proximate and ultimate analysis of the waste sample can be used to determine the specific energy content of the solid waste in the absence of bomb calorimeter.

The samples of the Municipal Solid Waste (MSW) were sorted, sundried, pulverized and sieved. These analyses were carried out on the combustible components of MSW in Ado-Ekiti to determine the percentage moisture content (MC), fixed carbon (FC),volatile matter (VM) ash content (AC), nitrogen content (N_2), sulphur content (S) and total Carbon (C) by monitoring the weight change at different desired temperatures according to the standards of the American Society for Testing and Materials (ASTM) carried out on the combustible components of MSW in Ado–Ekiti showed that the moisture content of the components varied from0.82% in polythene products waste to 12.79% in leaves and vegetables, volatile matter ranged from 6.70% in textiles to 67.12% in bones, the fixed carbon varied from 13.89% in rubber and leather to 81.62% in textiles, ash content ranged from 4.78% in coconut and palm kernel ton76.48% in charcoal, the total carbon varied from 57.85% in paper and cardboards to 88.37% in textiles. The nitrogen content ranged from 0.36% in polythene products to 5.88% in fruits. Sulphur content also varied from 0.03% in coconut and palm kernel to 0.26% in leaves and vegetable. The lower the moisture content, volatile matter, ash content and nitrogen content the higher the specific energy content of the MSW while the higher the, sulphur content, total carbon and fixed carbon the higher the specific energy content of the MSW .The heating value of waste can be determined by the analytical method using the data obtained in the proximate and ultimate analysis of the solid waste sample. This study gives practical guide for the present study and the study gap is Rominiyi *et al.* (2017) do not characterise the solid waste used for analysis.

Gravalos*et al.* (2010) on study on calorific energy values of biomass residue pellets for heating purposes. Combustion is the most developed and most frequently applied process used for solid biomass fuels because of its low cost and high reliability. The interest in using biomass residue pellets for heating purposes is increasing. Clean and dry residue pellets are an ideal fuel for combustion in small-scale installations. The study presented an experimental study on calorific energy values of biomass residue pellets for heating purposes. The fuel samples used, were biomass residues of agricultural (cotton and cardoon) and forest (pine, fir, beech) wastes. The research is part of a continuing program into a in precise thermal analysis data from different kinds of agricultural and forest by-products. A bomb calorimeter (Model C5000) was used to determine the calorific values by the standard ASTM method. The experimental results obtained are encouraging and show that these materials can be used as alternative fuels. The main conclusions that may be drawn from study on the calorific energy values of biomass residue pellets for heating purposes are listed as follow:

i. Quantitative calorific energy analysis in crop and forage plants showed that significant differences exist in calorific energy distribution on different plant organs. Root and main stem had the same calorific energy values. The lowest mean calorific energy value in all plant organs was observed
ii. Pellets from forest residues show higher calorific values and lower ash content in comparison with pellets from agricultural crop and forage residues. The experiments have verified that the residual biomass can be adapted to a wide variety of solid fuels.

The study of Gravalos *et al.* (2010) served as research guideline to the present study and the gap is the present study will municipal solid waste which is differ from residue from crops, though all biomass material.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The following materials were used for this work.

i. Solid wastes
ii. Crusher
iii. Crucible
iv. Digital spectrometer
v. Digital weighing scale
vi. Covered/container bucket
vii. Shovel and sieving equipment
viii. Helmet and face mask
ix. Protection clothes, safety boots and gloves
x. Grabber and cleaning brush

3.2 Characterisation of Physical Property of the Solid Waste

3.2.1 Collection of waste

Solid wastes (SW) were collected from two major locations in Abuja landfill sites which were Gossa landfill and Kubwa dumping sites. Plate II was Google map showing the site of waste collection site at Kubwa Express dumping site and Gossa dumping site in Abuja municipal.

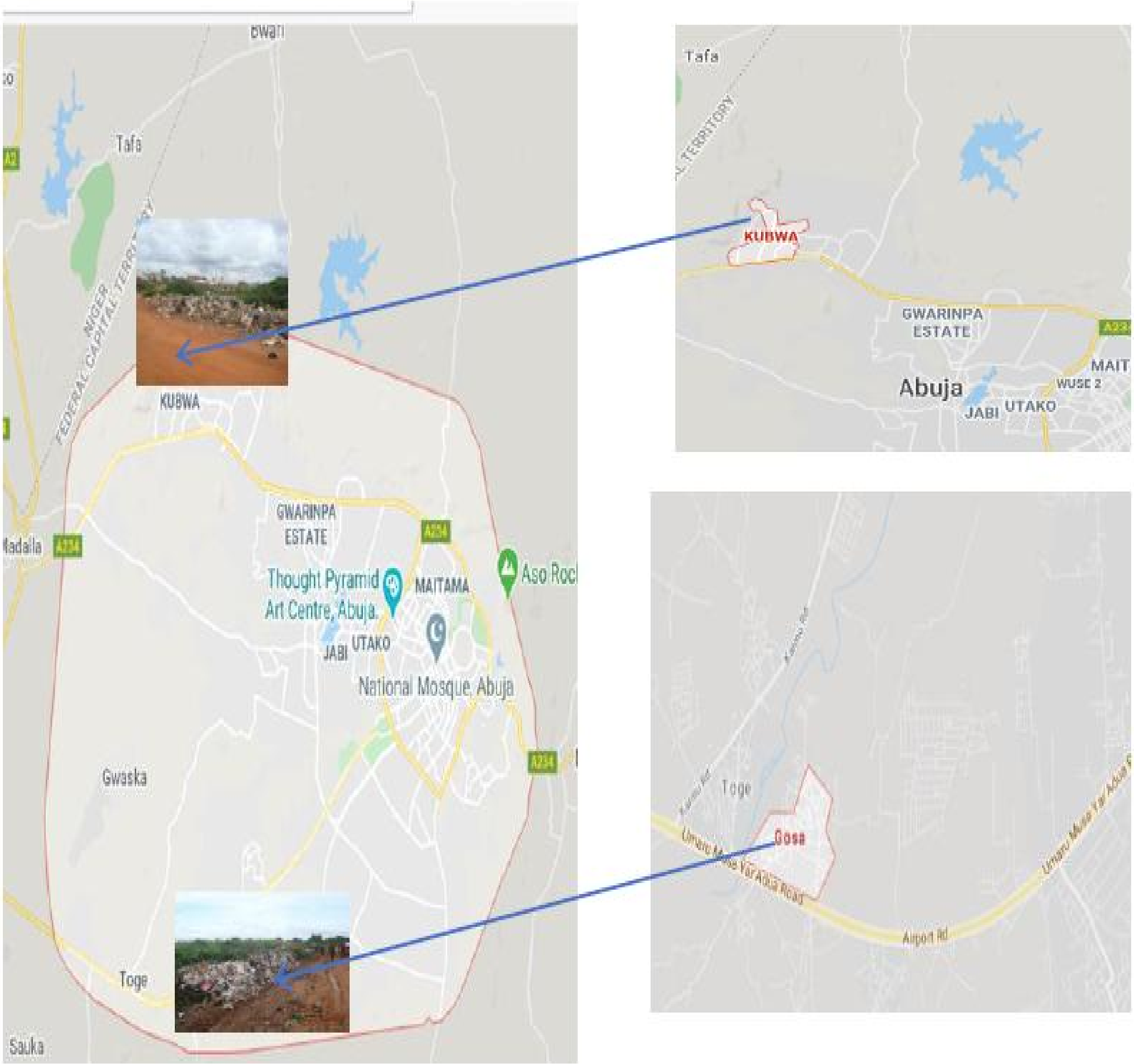


Plate I: Google Map of two dumping sites in Abuja Municipal

Collection is carried out from three major sites and it is labelled as A "Gossa waste" and B as "Kubwa waste" respectively. The waste was sorted into characterisation listed above on sieving picked through visual inspection. The collected waste sorted to remove non-combustible materials from the collecting site. The study handled only the combustible materials which was total of remaining waste. This was put in airtight containers and taken to laboratory for analysis.

3.2.2 Sample preparation

The samples were shredded and grounded into smaller quantities of between 1 mm size and 5 mm size in order to increases heating surface area (Yusoff and Zakaria, 2012). The size and distribution of the components of wastes are important for the recovery of materials.

3.3 Methods

3.3.1 Experimental methods

The study adopted characterisation system studied by Abur *et al.* (2014); Bichi and Amatobi on Abuja solid wastes. The waste characterisation includes Abur *et al.*, (2014); Bichi and Amatobi (2013):

i. Food/organic wood and paper
ii. Plastic, rubber and textile
iii. Glass/ceramics,
iv. Metals (aluminium alloy waste only)

The experiment was conducted in Spectral Laboratory Services, Tudun-wada, Kaduna. Plate I was hammer mill machine for crushing the solid wastes before experimentation.

Plate II: Hammer mill machine (Spectral Laboratory Services, Tudun-wada, Kaduna)

3.3.2 Proximate analysis of the waste

The proximate analysis was carried out for estimating the heating value of solid waste fuel collected from two (2) different sites in Abuja. The wastes were designated in order of A and B for carrying out proximate analysis. Proximate analysis to be conducted includes the following:

i. Moisture content
ii. Volatile matter
iii. Ash content
iv. Fixed carbon content

3.3.2.1 Moisture content

The moisture content was determined according to ASTM E1756-01 standard as follows (Omari, 2015):

i. 100 gram of waste was placed into an oven at 105℃ for two hours.
ii. The sample was cooled in desiccators and reweighed using digital weighing balance
iii. The difference in weight represents the moisture content of the sample expressed in percentage
iv. The weight is noted and recorded asm_m is and determined as (Durogbitan, 2019):

m_1 = mass of empty crucible (g)

m_2= mass of empty crucible + sample (g)

m_3= mass of empty crucible + sample after heating (g)

$m_m = m_2 - m_3$ = Moisture content

$$\% \, m_m = \frac{m_2 - m_3}{m_2 - m_1} \times 100\% \qquad (3.1)$$

3.3.2.2 Volatile matter

It is the vapour released when fuel is heated through the following methods (ASTM A1102, 2013; Omari, 2015) include:

i. Initially, the remaining content waste from moisture analysis in section 3.2.3.2 was subjected to volatile matter analysis. The content was reheated in a covered crucible to avoid contact with air during devolatilization process. However, covered crucible was with its content was placed in furnace at 950°C for two hours.
ii. On two hours after heating, the crucible was removed and cooling was done in desiccators and thus possible reading was taking such as weight difference.
iii. The weight difference is measured as a result of devolatilization which is volatile matter and this is noted and recorded as m_{VM}
v. The percentage of volatile matter is related as (Durogbitan, 2019):

m_2= mass of empty crucible + sample before heating (g)

m_3= mass of empty crucible + sample after heating (g)

$m_m = m_2 - m_3 =$ Moisture content

$$\% \, m_{VM} = \frac{m_2 - m_3}{m_2 - m_1} \times 100\% - \% \, m_m \qquad (3.2)$$

3.3.2.3 Ash content

Ash is solid residue left after the fuel is completely burned. The procedure used to determine ash content is based on ASTM D1102. The steps according to Omari, (2015) include

i. The remaining sample from volatile matter analysis was placed in the furnace at 575°C for an hour for combustion processes.
ii. All carbon was burnt, and sample was cooled and reweighed

iii. It was recorded as m_{ash} and percentage is:

$$\% \, m_{ash} = \frac{m_2 - m_3}{m_2 - m_1} \times 100\% - (\% \, m_m + m_{VM}) \qquad (3.3)$$

3.3.2.4 Fixed carbon

Fixed carbon is the solid carbon in the MSW that remains in the char after devolatilization process. Fixed carbon in fuel is determined as difference from the moisture, volatile matter and ash contents. According to Omari, (2015) it is given by:

$$m_{Fc} = 100 - m_m - m_{VM} - m_{ash} \qquad (3.4)$$

Where:

m_{Fc}= Fixed carbon

m_m = Moisture content

m_{VM} = Volatile matter

m_{ash} = Ash content

3.4 Ultimate Analysis of the Waste

The ultimate analysis is carried out for quantifying elements presents in the wastes. These elements will include carbon (C), hydrogen (H), nitrogen (N), sulphur (S), oxygen (O) percentages after removal of the moisture and ash. The results used to characterize the chemical composition of the organic matter in the collected wastes. The Atomic Absorption Spectrometer was used to trace the elements under present. The following procedure is based on combination of AAS, EPA, BS and ASTM principles and this will be adopted according to Omari, (2015):

i. The cation was determined by drying the sample at 105°C for 3 hours
ii. The cooling of sample in the desiccators was carried out
iii. Grounding of sample to powder form by using pestle and mortal

iv. The samples weight was noted and recorded.

v. 20mm of aqua regia solution was added to the waste

vi. On cooling as settle as paste in the beaker there will be addition of 20mls of de-ionized water

vii. Swirling was carried out by using the glass rod

viii. The paste was mixed and filtered using funnel with filter paper into the 100ml volumetric flask.

ix. The portion of 20ml was added to the paste in beaker, mixed with aid of glass rod and then pass through the filter on the funnel.

x. The process was repeated until the desired volumetric flask volume was achieved.

xi. The sample was aspirated in the atomic absorption Spectrometry machine mode AA240.

Atomic Bomb Spectrometer machine displayed average results for these elements base on EPA 5050 as:

a) carbon (C)
b) hydrogen (H)
c) nitrogen (N)
d) sulphur (S)
e) oxygen (O)
f) Zinc (Zn)
g) Lead (Pb)
h) Chromium (Cr)
i) Cadmium (Cd)
j) Iron (Fe)
k) Copper (Cu)
l) Sodium (Na)
m) Potassium (K)
n) Manganese (Mn)

3.5 Determination of Caloric Value of Waste

The calorific value is amount of chemical energy in a given waste components, which depends on its carbon, moisture and hydrogen contents of the waste. The calorific value of the sample is determined using standard bomb calorimeter type called Wagtech Gallenkamp Auto bomb. Kathiravale *et al*. (2003) identified following procedure:

i. The waste samples were dried and grinded to small particles
ii. The particles were sieved and compress to form pallets.
iii. The bomb was assembled and filled with pressurized oxygen about 30bars.
iv. The firing of circuit was tested and the calorimeter was adjusted by weighing sufficient water into the calorimeter vessel to submerge the bomb completely.
v. The bomb was refried and after the temperature stabilization the differences will be noted and recorded.
vi. The calorific values of the municipal solid waste were calculated according to ASTM D240 and determined as:

$$HHV = \frac{\Delta T C_p}{m_w} \tag{3.5}$$

Where:

HHV= high heating value or high caloric value (HCV) in MJ/K

ΔT = Change in temperature in Kelvin

C_p = heat capacity in MJ/kg

m_w = mass of waste in kg

3.6 Prediction of Total Estimated Caloric Value of Waste in Abuja

The study used sample of waste collected from two waste sites and the size of tonnes was related and predicted with outcome of samples A and B using regression analysis base on least square method.:

$$HHV = \beta_o + \beta_1 x_1 + \ldots \beta_n x_n + \epsilon \quad (3.6)$$

Where:

HHV = high heating caloric value

ϵ = Random error

Constant = β_o , β_1 , β_n

The least square function is: $L = \Sigma\, \epsilon^2\, \Sigma(Q - (\beta_o + \beta_1 x_1 + \ldots \beta_n x_n + \epsilon))$ (3.7)

To minimize L with respect to β_o , $\beta_1 .\ \beta_n$ and the least squares of the estimates must satisfy:

$$\partial L/\beta_o = -2\Sigma(Q - (\beta_o + \beta_1 x_1 + \ldots \beta_n x_n)) = 0 \quad (3.8)$$

$$\partial L/\beta_1 = -2\Sigma x_1(Q - (\beta_o + \beta_1 x_1 + \ldots \beta_n x_n)) = 0 \quad (3.9)$$

$$\partial L/\beta_n = -2\Sigma x_2(Q - (\beta_o + \beta_1 x_1 + \ldots \beta_n x_n)) = 0 \quad (3.10)$$

Simplifying equations (3.6 to 3.10), the least squares normal equations are:

$$\Sigma HHV = n\beta_o + \beta_1 \Sigma x_1 + \ldots . \beta_n \Sigma x_n \quad (3.11)$$

$$\Sigma Q x_1 = n\beta_o \Sigma x_1 + \beta_1 \Sigma x_1{}^2 + \ldots \beta_n \Sigma x_1 x_n \quad (3.12)$$

$$\Sigma Q x_n = n\beta_o \Sigma x_1 + \beta_1 \Sigma x_1 x_n + \ldots \beta_n \Sigma x_n{}^2 \quad (3.13)$$

Gaussian elimination method is employed for solving the equations:

$$y = X\beta \quad (3.14)$$

Where: $X = [xij\,]$ is an n × n matrix with constant coefficients

The column vector $\beta = (x_1 \ldots x_n)^T$ is required solution vector

Column vector $\beta = (Q_1 \ldots Q_n)^T$ contains the constant non-homogeneous.

$$\begin{vmatrix} \Sigma HHV \\ \Sigma HHVx_1 \\ \Sigma HHVx_n \end{vmatrix} = \begin{vmatrix} n & \Sigma x_1 & \Sigma x_n \\ \Sigma x_1 & \Sigma x_1{}^2 & \Sigma x_1 x_n \\ \Sigma x_n & \Sigma x_1 x_n & \Sigma x_n{}^2 \end{vmatrix} \begin{vmatrix} \beta_o \\ \beta_1 \\ \beta_n \end{vmatrix}$$

The augmented array corresponding is given as:

$$\begin{vmatrix} n & \Sigma x_1 & \Sigma x_n \\ \Sigma x_1 & \Sigma x_1{}^2 & \Sigma x_1 x_n \\ \Sigma x_n & \Sigma x_1 x_n & \Sigma x_n{}^2 \end{vmatrix} \begin{matrix} \Sigma HHV \\ \Sigma HHVx_1 \\ \Sigma HHVx_2 \end{matrix} \Bigg| = \begin{vmatrix} \beta_o \\ \beta_1 \\ \beta_n \end{vmatrix} \tag{3.15}$$

Equation (3.15) reduces to one unknown since the study consider mass (x_1)relationship with high heating caloric value (HHV):

$$\begin{vmatrix} n & \Sigma x_1 \\ o & \Sigma x_1{}^2 \end{vmatrix} \begin{matrix} \Sigma HHV \\ \Sigma HHVx_1 \end{matrix} \Bigg| = \begin{vmatrix} \beta_o \\ \beta_1 \end{vmatrix} \tag{3.16}$$

The solution is equivalent to the equation:

$$\beta_1 = \frac{(\Sigma HHVx_1)}{\Sigma x_1{}^2} \tag{3.17}$$

On knowing equation (3.17) then β_o is calculated as:

$$\beta_o = \frac{\Sigma HHV - \beta_1 \Sigma x_1}{n} \tag{3.18}$$

After solving the equation (3,17) the final regression is related as:

$$\Sigma HHV = n\beta_o + \beta_1 \Sigma x_1 \tag{3.19}$$

3.6.1 Calculation of caloric value of waste in Abuja

The cumulative value of the HHV by this study are such as 147.2, 148.9, 8.0, 21.8, 128.1, 118.3, 9.7and 9.6 MJ/kg respectively with corresponding value of mass 0.6 kg. The regression equation is model based on regression analysis in section 3.25 and model was given as:

$$\sum HHV = 596.1$$

$$\sum x_1 = 4.8$$

$$\sum {x_1}^2 = 2.88$$

$$\sum HHVx_1 = 354.86$$

$$\therefore HHV = 4.644 + 123.22x_1$$

Where:

HHV= high heating value in MJ/kg

x_1= the mass of the waste

The estimate of HHV per tonne of waste predicted as:

$$HHV = 4.644 + 123.22(1000)$$

$HHV = 4.644 + 123.22 \times 10^3$ =0.123 MJ/kg

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Characterisation of Physical Property of the Waste

The characterised of collected sample of the solid waste obtained from Abuja municipal, Federal Capital Territory of Nigeria is shown in Plate III and IV. The sample was labelled as A "Gossa waste" and B as "Kubwa waste" respectively.

Plate III: Gossa Solid Waste

Plate IV: Kubwa Solid Waste

The samples are further classified as A1, A2, A3, A4, B1, B2, B3 and B4 as shown in Table

Table 4.1: Classification of the Solid Waste used in Experimentation

Classification	Classification Type
A1	Organic waste such as food, wood/paper in Gossa
A2	Textile, rubber/plastic waste in Gossa
A3	Metal (aluminium can) in Gossa
A4	Glass/ceramic in Gossa
B1	Organic waste such as food, wood/paper in Kubwa
B2	Textile, rubber/plastic waste in Kubwa
B3	Metal (aluminium can) in Kubwa
B4	Glass/ceramic in Kubwa

Table 4.1 showed that sample 1 belonged to organic waste such as food, wood/paper, textile/rubber and plastic waste were sample 2, metal (aluminium can) was sampled as 3 while sample 4 was glass/ceramic sample. The samples were collected from both dumping sites in Gossa and Kubwa. The sample was crushed with crushing machine called Hammer mill machine in Spectral Laboratory Services, Tudun-wada, Kaduna. The physical property of the wastes was listed in Table 4.2. The sample taken for experiment was 10g in which sample 1 contains 50% of food sample waste and 50% of wood/paper waste. The sample 2 contains 50% of textile (50) waste and 50% of rubber/plastics waste. The sample 3 consists of waste of metal-aluminium which was 100% while sample 4 contain 50% of glass and 50% ceramic waste respectively.

	Particle size range (mm)	Percentage of Composition (%)	Waste Density ($\frac{g}{cm^3}$)
A1	1-5	Food (50), wood/paper (50)	1.40
A2	1-5	Textile (50),rubber/plastics (50)	1.70
A3	1-5	Metal-aluminium can (100)	2.40
A4	1-5	Glass (50), ceramic (50)	2.50
B1	1-5	Food (50), wood/paper (50)	1.42
B2	1-5	Textile (50),rubber/plastics (50)	1.73
B3	1-5	Metal-aluminium can (100)	2.35
B4	1-5	Glass (50), ceramic (50)	2.48

Table 4.2: Classification of 10g of Solid Waste used in Experimentation

Table 4.2 indicated eight classifications of the samples as A1, A2, A3, A4, B1, B2, B3 and B4.

4.2 Proximate Analysis of the Waste

The estimation of the heating value of solid waste in the sites are analysed through proximate analysis.

4.2.1 Moisture content

The results of the moisture content of the waste are indicated in Table 4.3. Gossa is coded as A1 for food, wood and paper as 15.98 %, A2for textile, rubber and plastics sample was 11.97%, A3 for metal-aluminium can sample was 0.01% while the sample of glass and ceramics coded as A4was 0.13%. Also, moisture content observed in Kubwa were coded as B1 food, wood and paper sample with 13.37%, coded B2 as textile, rubber and plastics sample was 21.197 %, coded B3 as metal-aluminium can sample with 0.21 % while the sample of glass and ceramics coded as B4” with 0.07 %.

Classification	**Moisture content (%)**
A1	15.98
A2	11.97
A3	0.01
A4	0.13
Sum of A’s moisture %	28.09
Average of A’s moisture %	**7.02**

Classification	**Moisture content (%)**
B1	13.37
B2	21.19
B3	0.21
B4	0.07
Sum of B’s moisture %	34.84
Average of B’s moisture %	**8.71**

Table 4.3: Moisture Percentage of 0.5 g of Air-dried Solid Waste

Therefore, average of sample A moisture percentage content was 7.02 % while average sample B was moisture content was 8.71 %. Sample B collected from Kubwa has higher moisture content as shown in Table 4.3.

Table 4.4 indicates average moisture percentage of two site that SW1 was food, wood and paper sample at 14.68 %, SW2a textile, rubber and plastics sample was 16.58 %, SW3 which was metal-aluminium can sample was 0.11 %.

SW1	14.68
SW2	16.58
SW3	0.11
SW4	0.10
Grand Average of moisture %	**7.88**

Table 4.4: Moisture Percentage of 0.5 g of Air-dried Solid Waste (SW) per Site

SW4 sample was glass and ceramics sample with moisture content of 0.10 %. The outcome indicates that moisture content of air-dried 0.05g of solid waste found in the sites was 7.88 %.

4.2.2 Volatile matter

Table 4.5 indicates that volatile matter of A1 sample of food, wood and paper in Gossa was 51.23 %, A2a textile, rubber and plastics sample were at 57.51 %; A3 a metal-aluminium can sample was 0.13 % while the sample of glass and ceramics “A4” was 0.25%. The volatile matter found in Kubwa solid were such as B1 food, wood and paper sample at 47.59 %, B2 atextile, rubber and plastics sample were 53.22%, B3 a metal-aluminium can sample at volatile matter of 0.12 %.

Table 4.5: Volatile Matter of 0.5 g of Air-dried Solid Waste

Classification	Volatile matter (%)
A1	51.23
A2	57.51
A3	0.13
A4	0.25
Sum of A's volatile matter %	109.12
Average of A's volatile matter %	**27.28**

Classification	Volatile matter (%)
B1	47.59
B2	53.22
B3	0.12
B4	0.33
Sum of B's volatile matter %	101.26
Average of B's volatile matter %	**25.31**

The volatile matter of glass and ceramics "B4" found in Kubwa was 0.33 %. The average volatile matter found in Gossa solid waste was 27.28 % while the Kubwa wastes sample was found to at average volatile matter of 25.31 % using air-dried solid waste during experiment procedure.

Therefore, Table 4.5 showed the average volatile matter content of waste found in the two sites include SW1 was food, wood and paper sample at 49.41 %, SW2a textile, rubber and plastics sample were55.37 %; SW3, metal-aluminium can sample volatile matter was 0.13 %. The SW4 sample of glass and ceramics, its volatile matter was at 0.29 % as shown in Table 4.6.

Table 4.6: Volatile Matter of 0.5 of Air-dried Solid Waste (SW) per Site

Classification	Average Volatile Matter (%)
SW1	49.41
SW2	55.37
SW3	0.13
SW4	0.29
Grand Average of Volatile matter %	**26.3**

Table 4.6 indicated that average volatile matter percentage of solid waste used in experimentation of air-dried 0.5g was 26.3 %.

4.2.3 Ash Contents

Table 4.7 indicated the ash contents of the solid waste collected from the Gossa in which A1 sample of food, wood and paper in Gossa were at 9.72 %, A2 a textile, rubber and plastics samples were at 13.84 %. The ash content of A3 sample of metal-aluminium was at 0.36 % while the ash content of A4, the sample of glass and ceramics was 0.12 %. The ash content of the solid waste found in Kubwa were such as B1 food, wood and paper sample at 10.12 %, B2 a textile, rubber and plastics sample were13.15 %. The ash content of B3 a metal-aluminium can sample was 0.34 % while the ash content of the glass and ceramics “B4” found in Kubwa was 0.11%.

Classification	Ash Content (%)
A1	9.72
A2	13.84
A3	0.36
A4	0.12
Sum of A’s Ash content %	24.04
Average of A’s Ash content %	**6.01**

Classification	Ash Content (%)
B1	10.12
B2	13.15
B3	0.34
B4	0.11
Sum of B’s Ash content %	23.72
Average of B’s Ash content %	**5.93**

Table 4.7: Ash Content of 0.5 g of Air-dried Solid Waste

In Table 4.7 it was understood that the average ash found in Gossa solid waste was 6.01 %. The ash content of Kubwa solid wastes sample was at average of ash content of 5.93 % using 0.5 g of air-dried solid waste. The average ash content percentage of solid waste used in experimentation of air-dried 0.5g was 5.97 % per site as illustrated in Table 4.8.

Classification	Average Ash content (%)
SW1	9.92
SW2	13.50
SW3	0.35
SW4	0.12
Grand Average of Ash Content %	**5.97**

Table 4.8: Ash Content of 0.5 g of Air-dried Solid Waste (SW) per Site

The average ash content of waste found in the two sites include SW1 was food, wood and paper sample at 9.92 %, SW2 a textile, rubber and plastics sample were 13.50 %; SW3, metal-aluminium can sample ash content was 0.35 %. The SW4 sample of glass and ceramics, its ash content was at 5.97 % as shown in Table 4.8.

4.2.4 Fixed carbon content (FCC)

The fixed carbon of the waste is differences of sum of percentage of moisture, volatile matter and ash contents from 100 percent stated by Omari, (2015) in equation (3.4). Therefore, the analysis of FCC is presented in Table 4.9.

Table 4.9: FCC of 0.5 g of Air-dried Solid Waste

Classification	m_{Fc} (%) $= 100 - m_m - m_{VM} - m_{ash}$	**FCC** %
A1	100 -(76.93)	23.07
A2	100 – (83.32)	16.68
A3	100 – (0.5)	99.5
A4	100- (0.5)	99.5
Sum of A's FCC %		238.75
Average of A's FCC %		**59.69**

Classification	m_{Fc} (%) $= 100 - m_m - m_{VM} - m_{ash}$	**FCC** %
B1	100 -(71.08)	28.92
B2	100 – (87.56)	12.44
B3	100 – (0.67)	99.33
B4	100- (0.51)	99.49
Sum of B's FCC %		240.18
Average of B's FCC %		**60.05**

Table 4.9 indicated that the FCC of the solid wastes collected from the Gossa were such as A1 was 23.07 %, A2was 16.68 % and both A3 and A4 were 99.5 % respectively. The FCC of the solid waste collected in Kubwa were such as B1 was 28.92 %, B2 was 12.44 %, B3 was 99.33 %an B4was 99.49 %. The average value of FCC in Gossa solid waste was 59.69 % while that of Kubwa solid FCC was at average of FCC value of 60.05 %. This outcome was based on 0.5 g of air-dried solid waste as shown in Table 4.9. The average value of FCC percentage of solid waste of air-dried 0.5g per site is presented in Table 4.10.

Table 4.10: FCC of 0.5 g of Air-dried Solid Waste (SW) per Site

Classification	m_{Fc} (%) $= \mathbf{100} - m_m - m_{VM} - m_{ash}$	**FCC Average (%)**
SW1	100 - (74.01)	25.99
SW2	100 – (85.45)	14.55
SW3	100 – (0.59)	99.41
SW4	100- (0.51)	99.49
Grand Average		**59.86**

The result in Table 4.10 showed that 0.5 g of air-dried solid waste per site includes SW1 at 25.99 %, SW2 was 14.55 %; SW3was 99.41 % while SW4 was 99.49 % respectively. It was understood the average of the FCC in the site was 59.86 based on air-dried of 0.5 g solid waste.

Graph in Figure 4.1 illustrates required mass of air-dried waste in relative 0.5 g for obtaining FCC ratio. The FCC ratio of 0.5 g was presented in relation with require amount of mass of waste to form the FCC in axis of Figure 4.1.

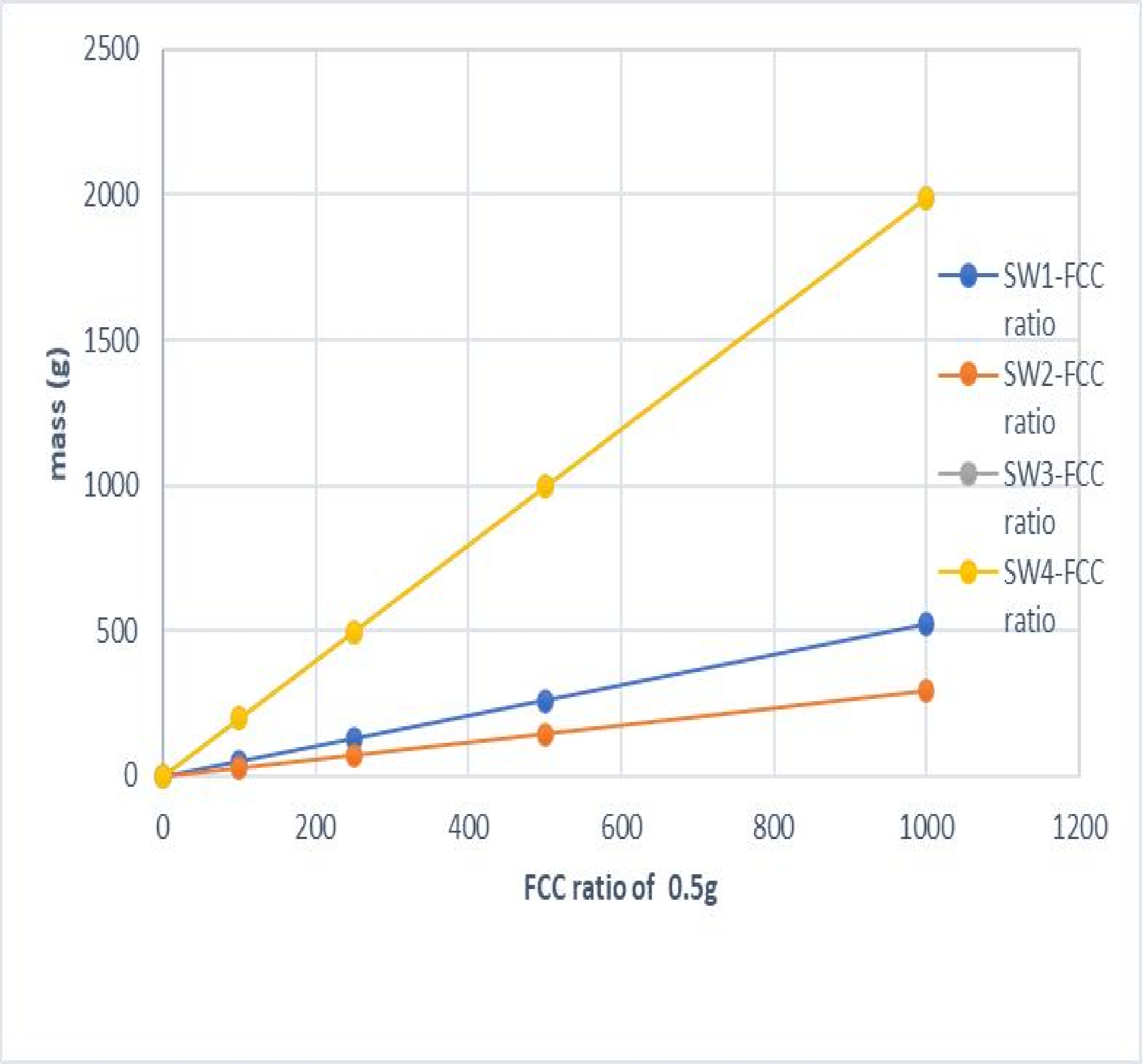


Figure 4.1: Mass of FCC ratio of 0.5g

Graph of Figure 4.1 indicated that the FCC ratio in relative to 0.5 g obtained in this experiment that 1000 g of air-dried leads to FCC of 519.8, 291, 1988.2 and 1989 of SW1, SW2, SW3 and SW4 respectively. The FCC ratio of SW3 and SW4 are very close relatively by this study. The SW2 and SW3 has high percentage of FCC according to the result in Figure 4.1.

4.3 Ultimate Analysis of the Wastes

The quantification of elements in the solid waste of air dried of 0.5g are presented in this section. Table 4.11 is the A1 ultimate analysis.

Table 4.11: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of A1 Sample

Element Symbol	Atomic Concentration	Mass ratio
K	11.67	16.27
C	36.44	15.61
Ag	2.79	10.75
Ca	5.55	7.93
O	12.42	7.08
Nb	2.03	6.73
Si	6.03	6.04
Cl	3.94	4.98
Y	1.45	4.58
Al	4.48	4.31
S	3.65	4.17
Fe	1.50	2.98

P	2.66	2.93
Mg	2.29	1.98
Element Symbol	**Atomic Concentration**	**Mass ratio**
Ti	1.04	1.77
C	47.92	22.28
V	0.44	0.81
Ca	13.72	21.28
Si Na	[illegible]	[illegible]
N	0.84	0.42

Table 4.11 showed that three elements are above 10% of mass ratio and they include potassium (K), carbon (C) and Silver (Ag) with 16.27%, 15.6% and 10.75% of ratio in A1 sample. These are the major elements in the wastes sample A1.

Table 4.12 presented waste sample A2 ultimate analysis.

Table 4.12: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of A2 Sample

Cl	4.11	5.64
Nb	1.57	5.64
Ag	1.32	5.51
Al	4.97	5.19
Y	1.31	4.52
K	2.93	4.44
Fe	1.41	3.05
S	2.06	2.55
Ti	1.37	2.54
O	3.00	1.86
P	1.10	1.32
V	0.49	0.97
Mg	0.91	0.86
Na	0.66	0.59
N	0.62	0.34

Table 4.12 showed that three elements are above 10% of mass ratio and they include Carbon (C), calcium (Ca) and silicon (Si) with 22.28 %, 21.28 % and 11.42 % of ratio in A2 sample. These are the major elements in the wastes sample A2.

Table 4.13 presented waste sample A3 and it was understood that one element is above 10% of mass ratio and it is aluminium (Al) only with 74.96%insample A3.

Table 4.13: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of A3 Sample

Element Symbol	Atomic Concentration	Mass ratio
Al	67.34	74.96
Fe	5.47	7.06
Al	13.24	7.06
Na	3.78	1.72
Ag	0.59	1.25
Mn	0.96	1.04
Nb	0.50	0.93
Ti	0.85	0.80
Ca	1.00	0.79
Cr	0.72	0.74
Si	1.28	0.71
K	0.82	0.64
Cl	0.86	0.60
Cu	0.41	0.52
C	0.28	0.50
V	0.44	0.45
S	0.67	0.43
P	0.14	0.12

Table 4.13 indicated that in this sample A3 only one element was major element in the wastes sample A3 and it was aluminium.

Table 4.14 presented sample A4 waste elemental analysis. It was discovered that two elements are above 10% of mass ratio and they include iron (Fe), and aluminium (Al) with 41.29 %and 39.42 % of ratio respectively in A4 sample.

Element Symbol	Atomic Concentration	Mass ratio
Fe	27.58	41.29
Al	55.44	39.91
Cu	2.93	4.97
Si	5.59	4.19
Ca	2.16	2.31
Cl	2.35	2.22
Cd	0.32	0.95
K	0.72	0.75
Mn	0.39	0.58
Ag	0.19	0.56
C	0.19	0.48
Y	0.15	0.12
S	0.42	0.36

Mg	0.54	0.35
Na	0.54	0.33
Ti	0.24	0.31
Cr	0.16	0.23
Element Symbol	**Atomic Concentration**	**Mass ratio**
O	0.09	0.07
K	17.28	23.54

Table 4.14: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of A4 Sample

The major elements in the sample of waste A4 were iron (Fe), and aluminium (Al) as illustrated in Table 4.14.

Table 4.15 illustrated those two elements are above 10% of mass ratio and they include potassium (K) and carbon (C) with 23.54 % and 13.22 % of ratio in B1 sample. This is differed similar sample taken on A1 in which Silver (Ag) has 10.75% sample ratio in A1 sample but in sample B1, silver (Ag) was 6.84 %.

Table 4.15: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of B1 Sample

C	31.60	13.22
Ca	5.83	8.14
Nb	2.27	7.33
O	12.87	7.17
Ag	1.82	6.84
Cl	4.93	6.08
S	4.23	4.72
Si	4.19	4.10
Al	4.13	3.88
V	2.14	3.80
P	3.14	3.38
Ti	1.76	2.93
Y	0.91	2.83
Mg	1.25	1.06
N	1.11	0.54

Na	0.55	0.44
Fe	0.00	0.00

The major elements in the sample of waste B1 were potassium (K) and carbon (C) as illustrated in Table 4.15.

Element Symbol	**Atomic Concentration**	**Mass ratio**
Cl	27.80	27.11
Ca	18.28	20.45
Si	3.69	2.89
Nb	0.44	1.13
Fe	0.71	1.11
Ti	0.80	1.07

Table 4.16 presented elemental analysis of B2 and two elements were above 10% of mass ratio and they include chlorine (cl), calcium (Ca) and Carbon (C) with 27.11 %, 20.45 %, 30.76 % of ratio in B2 sample. This is differed from similar sample A2 taken with three elements are above 10% of mass ratio and with only calcium (Ca) is the similarity in both samples.

Y	0.38	0.95
S	10.93	10.84
Al	1.08	0.81
Ag	0.25	0.76
C	32.26	30.76
K	0.66	0.72
O	1.30	0.58
N	0.66	0.26
P	0.22	0.19
Na	0.30	0.19
Mg	0.25	0.17
V	0.00	0.00

Table 4.16: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of B2 Sample

The major elements in the sample of waste B2 were chlorine (cl)and calcium (Ca) and Carbon (C) as illustrated in Table 4.16.

Table 4.17 presented sample of waste B3 and it was showed that two elements are above 10% of mass ratio and they include aluminium (Al) and iron (Iron)with 70.73 % and 20.06 % of ratio in B3 sample. This is similar to sample A3with highest value of aluminium alloy (Al) with 74.96 % is the similarity in both samples with iron (Fe) is the highest in both samples.

Element Symbol	**Atomic Concentration**	**Mass ratio**
Al	34.79	70.73
Fe	56.84	20.06
Si	2.87	2.11
Cu	1.01	1.68
Ca	0.69	0.73
Ag	0.22	0.62
Zn	0.32	0.54
K	0.44	0.45
Mn	0.30	0.44
C	0.18	0.43
Cl	0.40	0.37
Mg	0.50	0.32

S	0.35	0.29
Cr	0.21	0.28
Y	0.12	0.27

Element Symbol	**Atomic Concentration**	**Mass ratio**
Ti	0.20	0.25
Fe	73.12	79.27
Na	0.33	0.20
Cr	4.03	4.07
N	0.10	0.05

Table 4.17: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of B3 Sample

As it was presented in Table 4.17 the major elements of sample B3 was aluminium (Al) and iron (Iron).

Table 4.18 presented the elemental analysis of sample waste B4 with only one elementis above 10% of mass ratio and it is iron (Iron). The element has 79.29 % in B4 sample. This is similar to sample A4 in which iron (Fe) is the highest confirmed at 41.29 %.

Table 4.18: Ultimate Analysis of 0.5 g of Air-dried Solid Waste of B4 Sample

Si	7.14	3.89
Al	5.05	2.65
Zn	1.33	1.68
Ca	2.15	1.67
Mn	1.12	1.19
Cu	0.82	1.02
K	1.04	0.79
Ag	0.31	0.66
Cd	0.20	0.44
Ti	0.48	0.44
S	0.64	0.40
Na	0.88	0.39
C	0.51	0.35
Y	0.20	0.34
Nb	0.19	0.33

O	0.58	0.27

The results of ultimate analysis showed that only three samples had high mass ratio of carbon content and they include sample A1; A2 and B2 respectively. In these samples carbon had 15.6 %, 22.28 % and 13.22 % respectively that is represent the carbon -fuel in the sample.

Plates V and VI were results of Scanning Electron Microscope energy dispersive X-ray spectroscopy (SEM-EDS) through Phenom Prox model were illustrated for both sample A1 and B1 respectively in Plate V and Plate V1 respectively.

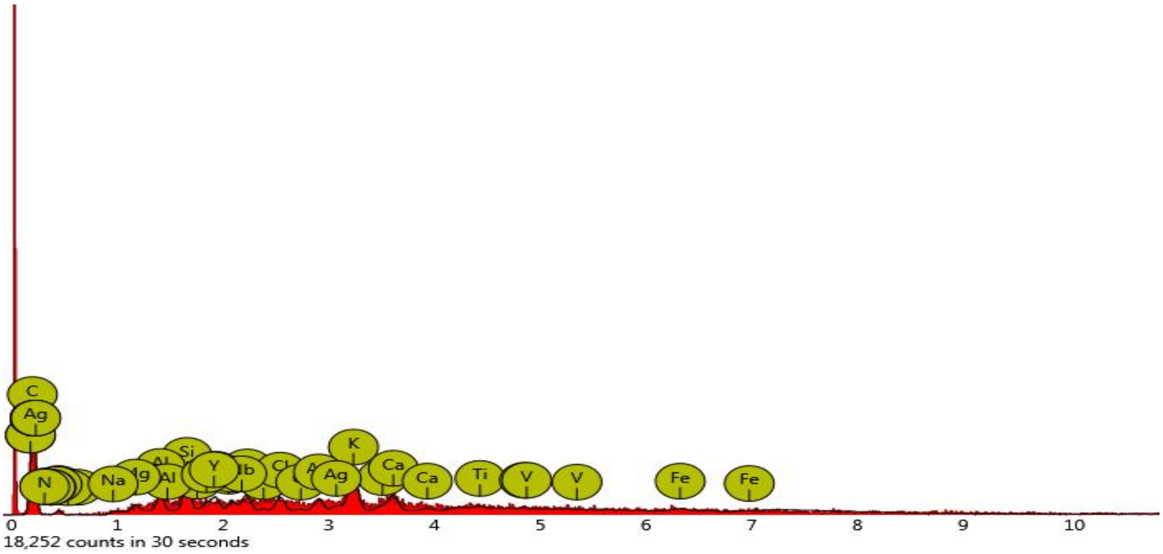
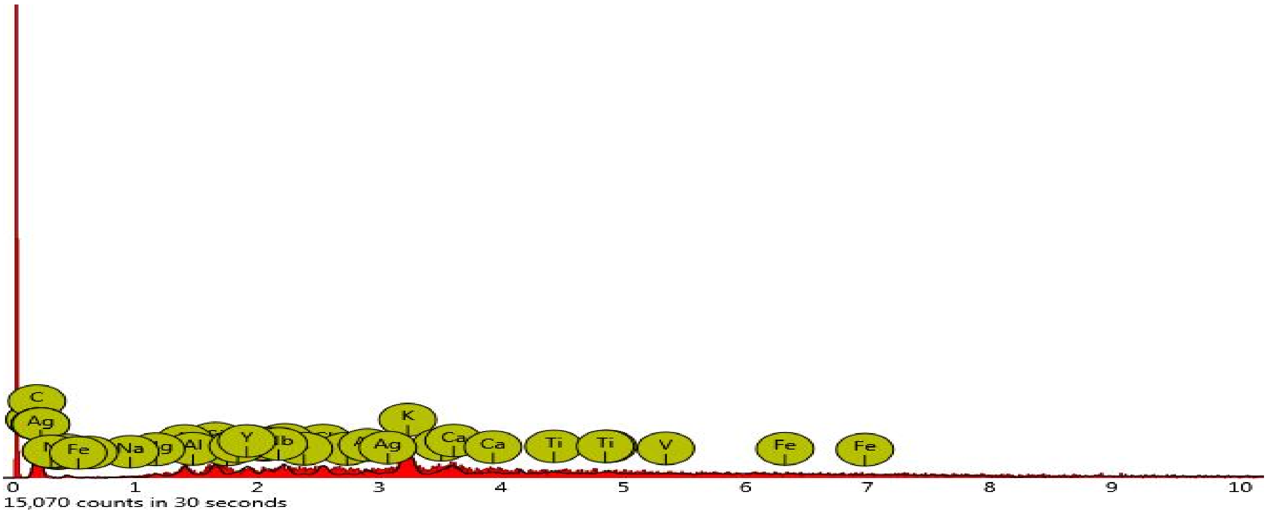


Plate V: Phenom Prox model showing high carbon content along y-axis in Sample A1



Sample	$C_p(\frac{MJ}{kg})$	$\Delta T(oC)$	HHV (MJ/kg)	Cumulative HHV (MJ/kg)	Mass (kg)
A1	44.39	1.99	147.2	147.2	0.6
A2	37.37	2.39	148.9	296.1	1.2

Plate VI: Phenom Prox model showing high carbon content along y-axis in Sample A2

From the model it was understood that both samples A1 and B1 carbon element has high percentage in within 1 count of the model. This confirmed ultimate analysis in which carbon content was higher in both A1 and B1

4.4 Analysis of Caloric Value of the Waste

The caloric value of the solid waste is determined based on equation (3.5) after taking necessary data from oxygen bomb calorimeter in the laboratory. The mass used for the experiment was 0.6 kg and the outcome is tabulated in Table 4.19.

A3	4.10	1.17	8.0	304.1	1.8
A4	7.11	1.84	21.8	325.9	2.4
B1	46.86	1.64	128.1	454.0	3.0
B2	43.01	1.65	118.3	572.3	3.6
B3	3.76	1.55	9.7	582.0	4.2
B4	3.82	1.51	9.6	591.6	4.8

Table 4.19: Heating Value of the Waste

Table 4.19 indicated that the caloric value or high heating value was experienced in A1 and A2 with 147.2 MJ/kg and 148.9 MJ/kg respectively which belong to sample A. This meant Gossa sample has high caloric value of solid waste in comparing to Kubwa sample in B1 and B2 with 128.1 MJ/kg and 118.3 MJ/kg.

Graph of Figure 4.2 was plotted to show average value of HHV in Table 41.9 with cumulative result of samples A and B. The cumulative value of A and B is plotted y-axis with respect to expected required amount of waste.

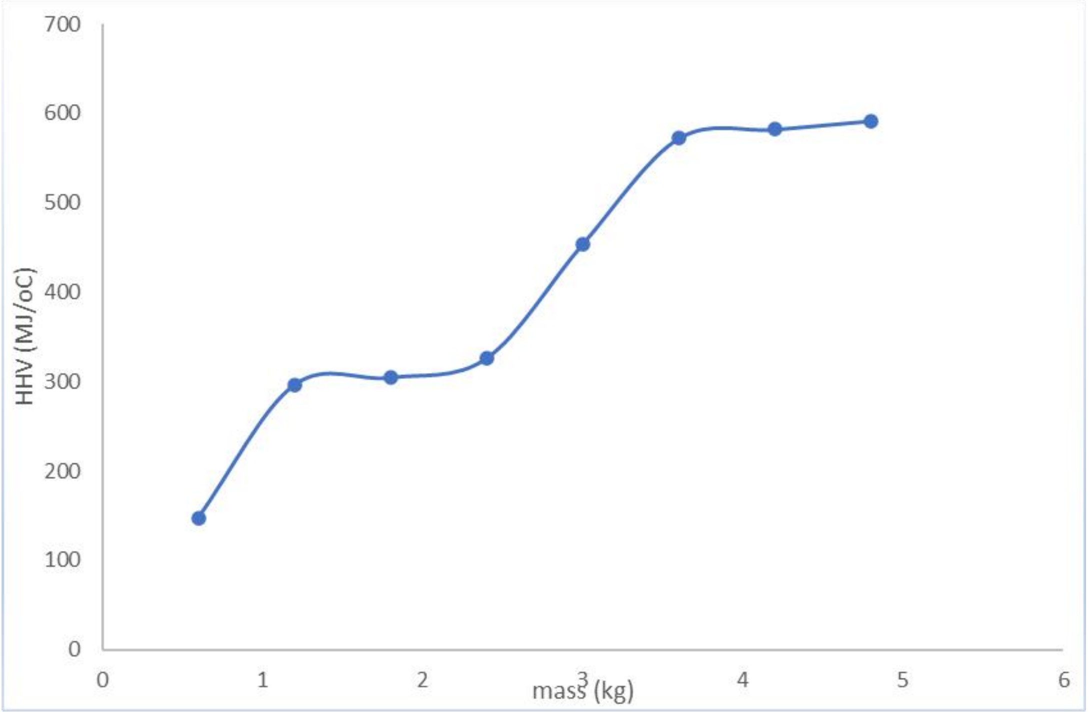


Figure 4.2: High heating value of the wastes

Figure 4.2 Illustrated that 4.8 kg mass of waste will give high caloric value (HHV) of 596.1 MJ/kg. Average of 123.25 MJ/kg of HHV will be acquired by one (1) kg of wastes in the metropolis. This means average value of 123.25 MJ/ kg of the waste.

4.5 Discussion

The outcome of the result showed that in Table 4.4 that moisture content of 0.5 g of air-dried solid waste per site includes SW1 at 14.68 %, SW2 was 16.58 %; SW3 was 0.11 % while SW4 was 0.1 % respectively. SW1 was sample of paper and wood, SW2 sample textile and rubber, SW3 sample of aluminium can while the sample of glass and ceramic was labelled S4. The volatile matter in Table 4.6 showed that 0.5 g of air-dried solid waste per site includes SW1 at 49.41 %, SW2 was 55.37 %; SW3 was 0.13 % while SW4 was 0.29 % respectively. The ash content in Table 4.8 of 0.5 g of air-dried solid waste per site includes SW1 at 9.92 %, SW2 was 13.50 %; SW3 was 0.35 % while SW4 was 0.12 % respectively. The result in Table 4.10 showed that 0.5 g of air-dried solid waste per site includes SW1 at 25.99 %, SW2 was 14.55 %; SW3 was 99.41 % while SW4 was 99.49 % respectively. It was understood the average of the FCC in the site was 59.86 based on air-dried of 0.5 g solid waste.

The outcome of the study on the ultimate analysis that three samples had high mass ratio of carbon content and they include sample A1; A2 and B2 respectively with carbon of 15.6 %, 22.28 % and 13.22 % respectively which is carbon -fuel. The caloric value or high heating value is higher in A1 and A2 with 147.2 MJ/kg and 148.9 MJ/kg which sample A. This meant Gossa sample has high caloric value of solid waste in comparing to Kubwa sample. The outcome of HHV of solid waste in Abuja is estimated 0.123 MJ/kg.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated available energy conversion in solid waste using four sample of waste from two sites, Gossa and Kubwa. It was observed that:

The proximate analyses are such as moisture content of 0.5 g of air-dried solid waste per site includes SW1 at 14.68 %, SW2 was 16.58 %; SW3 was 0.11 % while SW4 was 0.1 % respectively. Volatile matter is such as SW1 at 49.41 %, SW2 was 55.37 %; SW3 was 0.13 % while SW4 was 0.29 % respectively. The ash content is such as SW1 at 9.92 %, SW2 was 13.50 %; SW3 was 0.35 % while SW4 was 0.12 % respectively while FCC content was SW1 at 25.99 %, SW2 was 14.55 %; SW3 was 99.41 % while SW4 was 99.49 % respectively.

Three sample contain high content and they are sample A1, A2 and B2 with carbon of 15.6 %, 22.28 % and 13.22 % respectively.

The sample obtainable from Gossa has high caloric value of 148.9 MJ/kg and these were sample of textile, rubber and plastics.

The predicted caloric value of the waste was estimated as 0.123 MJ/kg using regression analysis.

5.2 Recommendations

Recommendations in the following areas:

i. Investigation of different energy conversion of waste to energy
ii. Evaluation of recovery cost of waste energy production
iii. Analysis of investigation physical classification of waste based on economic value
iv. Assessment of availability of liquefied gas in Abuja municipal solid waste

This outcome of the study indicates that there are huge deposits of solid waste in Abuja with high caloric value. There is need to develop appropriate technique for conversion of waste into energy generation purpose and will reduce dependency on hydropower station. This will boost availability energy production in Abuja municipal.

5.3 Contribution of the Study to Knowledge

The study highlighted that outcome of HHV was 0.123 MJ/kg using regression analysis. The study has contributed in the area of quantity of energy per unit tonne of waste which is huge and available from solid waste and this is renewable energy that support greenhouse emission control. The production of energy from solid waste will boost electrical energy availability in Abuja.

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