EVALUATION OF THE FUEL PROPERTIES AND THERMAL EFFICIENCY OF SUB-BITUMINOUS COAL-BIOMASS BLENDS

BY

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CERTIFICATION

AYODELE JOHN AYOMIKUN, a Postgraduate student in the Department of Pure and Industrial Chemistry with registration number PG/MSC/12/63536, has satisfactorily completed the requirements of research work for the award of a Master of Science (MSc.) Degree in Fossil Fuel Chemistry. This research work is original and has never been submitted in part or whole for any other diploma or degree in this or any other University.

Sign é é é é é é

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(External Examiner)

Date: é é é é é é é é

DEDICATION

This research work is dedicated to all those who care about preserving a green earth.

ACKNOWLEDGEMENTS

The completion of this research work is the product of many people who have contributed in many ways- profound or not- to make me see its fulfilled end.

Big thanks to my project supervisor, Dr. C.N Ibeto. Firm and fair, energetic and enigmatic. Your inputs into this work made it a befitting reality today. You are a supervisor extraordinaire. My gratitude also goes to lecturers and laboratory staff at the Department of Pure and Industrial Chemistry and National Center for Energy Research and Development respectively.

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Finally, unto the King eternal, immortal, invisible, the only wise God, be honour and glory for ever and ever. Amen.

ABSTRACT

The improvement of the combustion properties of coal and biomass by blending and carbonization was investigated. Proximate and ultimate analysis of coal, sawdust, corn cob and their blends were carried out using ASTM methods. The proximate and ultimate analyses were repeated on the five blends after carbonization at 500^{o}C for one hour. Ten mixtures of coal-sawdust and coal-corn cob blends were made into briquettes using starch binder. The calorific values of the samples were determined using a bomb calorimeter, while the thermal efficiency of the briquettes was obtained using the water boiling test analysis. Pollution potential of the fuel samples were derived using a hypothetical power plant simulation. The quantity of CO_2, NO_2 and SO_2 that would be emitted per hour in a 20MW power plant were calculated. The result of the proximate analysis of the raw samples (coal, sawdust and corn cob) showed that coal had the highest fixed carbon (42.38%) and the lowest moisture content (4.28%). Sawdust had the lowest fixed carbon (12.35%) while corn cob had a fixed carbon content of 15.65%. The results obtained showed considerable correlation between the uncarbonized coal-sawdust and coal-corn cob blends. The carbonized blends of both the coal-sawdust and coal-corn cob blends showed an improved fixed carbon content and volatile matter, relative to the uncarbonized. The calorific values and other fuel properties were of similar trends. The results of the ultimate analysis for coal were 70.04% carbon, 5.32% hydrogen, 2.03% nitrogen and 1.02% sulphur. Corn cob had 48% carbon, 5.79% hydrogen and 0.89% nitrogen while sawdust had 48.78% carbon, 5.79% hydrogen and 0.89% nitrogen. Corn cob and sawdust had no sulphur content, while the uncarbonized coal-sawdust and coal-corn cob blends showed decreasing carbon content. This study revealed that the fuel properties of coal and biomass can be improved by blending and carbonization. The simulated power plant analysis of the fuel showed that blending of coal with biomass reduced the SO_2 and NO_2 emissions to an extent. For NO_2, the value of coal-sawdust blends ranged from 82.8-190.8 kg/hr, reduced from 198 kg/hr in coal, while the SO_2 content was reduced from 60.5 kg/hr in coal to 5.6 ï 50.4 kg/hr in different blends. Therefore, blending of coal with either sawdust or corn cob should be encouraged in coal fired power plants to reduce environmental pollution.

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ABBREVIATIONS

CS- Coal-Sawdust

CCS- Carbonized Coal-Sawdust

CC- Coal-Corn cob

CCC- Carbonized Coal-corn cob

DAF- Dry-ash free

V.M- Volatile matter

F.C- Fixed carbon

I.T- Ignition Time

A.G.T- Afterglow time

T.E- Thermal Efficiency

SD- Sawdust

COB- Corn cob

B.R- Burning Rate

S.F.C- Specific Fuel Consumption

CHAPTER ONE

INTRODUCTION

1.1General Introduction

History has revealed that many centuries ago,man made use of energy in its natural form to aid daily living. From burning wood for cooking, to utilizing the force of flowing water for irrigation and using sun light to dry and preserve foods. The use of energy has remained unabated till date, only that energy use has changed from the brute and basic methods, into more sophisticated and industrial ways.

The period from the late 1700s into early 1800s in England and Western Europe have been called the Industrial Revolution. The dawn of the Industrial Revolution paved way for an age of energy. This period witnessed drastic changes in virtually every aspect of human life. It was an advent of machines and use of mechanized methods. Ever since, manôs desire to live a better and civilized life, with the help of modern technology has caused a great demand for energy in its many forms. This also came with the adoption of lifestyles that has an increased demand for energy use.The technological advances that occurred during the industrial revolution of the 1700s have numerously been credited to coal. Before this period, wood was the major source of energy.

Consequently, the increasing adoption of a lifestyle that was energy intensive came with the quest for a better energy resource. Today, these energy needs are majorly supplied by fossil fuels such as coal, natural gas and petroleum. These fuels are known as primary energy sources, and they provide most of the energy that powers manôs modern life. Petroleum was discovered by Edwin Drake in 1859 in the United States. It was first used for lightening lamps and other basic uses. With the breakthrough of petroleum refining into various fractions, and increased use of internal combustion engines in automobiles, motor cycles and aero planes, the demand for petroleum never dwindled. In 1992, the National Energy Strategy in the United States concluded that, ñfor the foreseeable future, oil [Petroleum] will remain a critical fuel for the United States and all other industrialized nations.ò The quest for oil has continued up to the point that it has become a potential economic and security concern for developed countries, especially after the 1970s crisis. Despite these, coal has not been totally abandoned. It is used for electricity generation in countries with large coal reserves, with no cheaper alternative. For example, 73% of South Africaôs primary energy is derived from coal[1]. In China's energy strategy, coal plays the most important role especially for its electricity sector[2].

The availability of energy resources and its effective utilization has a bearing on national development and living standards. Energy is required for national development, and its presence directly betters the standard of living. The availability of vast amounts of energy resources in a nation is supposed to bring significant progress to the economy, and living standards of her citizenry. The effect of energy can be seen in its ability to multiply the work of a few labourers by many folds e.g an automobile would move many folds faster than man. The value of energy is noticed when its utilization results in a final product. Good management practices should aim at reducing the rate of exhaustion of the resource base, rather than increase or even sustain the rate of consumption[3].Consumers and manufacturers, who enjoy the efficient use of energy, should become more knowledgeable about it.

1.2 ENERGY AND ITS USES

The use of energy has increased tremendously with sophistication of technology, and the ease it brings to living. Energy usage can be divided into four main sectors; Electricity generation, Transportation, Industrial and Domestic.

1.2.1 Electricity Generation: Electric power is the largest energy demand sector in developed nations. Most electrical power is generated by converting mechanical energy to electrical energy with a turbine. Water is heated to steam, and steam at a very high temperature and pressure is used to turn the turbine. The heat used to produce the steam is gotten by burning fuel like coal, natural gas or fuel oil. Most of the electricity produced in the United States is produced by Steam turbines. Electricity is a secondary source of energy, it is referred to as an energy carrier[4].

1.2.2 Transportation: Economic development of nations has caused the need for man and goods to move, more than before. Transportation system is very essential for trade in an increasingly globalized world. With increasing use of trains, cars, trucks, speed boats and air planes, transportation has become a high demand energy sector. The transportation sector accounts for 63% of the total growth in world consumption of petroleum and other liquid fuels. Transportation activities accounted for 28% of all US energy use in 1987[5].

1.2.3 Industrial Sector: The industrial sector encompasses a large number of industries. This includes; manufacturing (food, paper, chemicals, refining, iron and steel, and others) and non-manufacturing (agriculture, mining, telecommunication and construction). Energy is consumed in the industrial sector for a wide range of purposes, such as processing, assembly, heating, cooling/ air conditioning, packaging and lighting in buildings. The type of fuel consumed by the industrial sector varies, and depends on the level of technological

development, among other factors. Although the industrial sector energy consumption is largely based on secondary energy sources like electrical power, it also make use of primary energy like natural gas and petroleum products (naphtha and natural gas liquids) which is used as feedstock to produce fertilizers for agriculture and petrochemicals for the manufacture of plastics.

1.2.4 Domestic Use: Energy is also used to a considerable extent in homes. Activities like cooking, heating, (during winter) and lightening, take a bulk of domestic energy use. Increase in population and household, causes a correlating increase in domestic energy use. The fuel used varies widely based on factors like climate, technological development, and cheap energy source. In the U.K, the fuel mix for domestic consumption has significantly changed since 1990 when 8% of consumption was coal, 63%, natural gas and 20%, electricity, to 1%, coal, 68%, natural gas and 23%, electricity in 2012.[6]

1.3 RENEWABLE AND NON-RENEWABLE ENERGY SOURCES

Renewable energy sources refer to those sources that cannot be exhausted by their continual usage. These energy sources are naturally replaced at a rate faster than its consumption. Non renewable energy sources are the direct opposite of the former. They diminish and can be exhausted after a period of usage. Presently, the world uses more of non-renewable energy than renewable energy. With increasing world population and the corresponding increasing need of energy for every day life,the worldôs non-renewable energy resources are depleting at a very fast rate. Scientists are already estimating the period when individual non-renewable resource would be exhausted. Hence, there is a need to balance the worldôs use of energy so that a future energy crisis is avoided. In the United States, most of its energy sources come from non-renewable energy sources, though there have been government push for increased renewable energy use. While it may be difficult to totally stop the use of non-renewable energy sources, it is important to carry out research in order to make them environmentally friendly.

1.3.1 Renewable Energy Sources

1.3.1.1 Biomass Energy: Biomass is the term used to describe all organic matter produced by photosynthesis. Bioenergy from biomass comes either from dedicated energy crops, or from residues generated in the processing of food crops or other products such as wood shaving and saw dust from the wood furniture industry. As long as plants photosynthesize, there would always be an inexhaustible biomass energy resource. The interest in biomass as a raw material for producing energy has emerged rapidly in many countries[7].

1.3.1.2 Solar Energy: The sun is the source of solar energy. It is an extremely hot gaseous sphere. The sun is the source of most of the energy used on earth. It is renewable, naturally replenished and does not run out. It does not produce pollutants and has minimal impacts on the environment[8]. Though solar energy is abundant, it is distributed over a wide area. Hence it needs collectors with large surface area to gather and utilize it. Also, it is very costly and requires a lot of technical knowledge for effective utilization.

1.3.1.3 Wind Energy: Wind has a potential to provide a substantial amount of clean global energy needs. It is available everywhere, does not cause pollution nor any environmental hazard during utilization for power generation. Extracting power from wind turbines is an established technology. With turbines, wind can be used for on-grid and off-grid electric power generation. It can also be used for water pumping and milling.

1.3.2 Non Renewable Energy Sources

1.3.2.1 Coal: This is a fossil fuel formed from the remains of plants that have under gone biochemical and geochemical changes over a long period of time. It is non-renewable, and is the fuel for most of the worldôs power plants.

1.3.2.2 Petroleum: It is sometimes called oil or crude oil and is a dark, viscous fluid, found in subsurface rock formations. It is formed from the fossilized remains of algae, zoo and animal plankton over millions of years. The long period of time it takes to be formed, and the present rate of consumption, makes it non-renewable. Petroleum and its refined products, is the major source of energy for many technological equipment. A large percentage of fuel used in transportation is from petroleum,it is also the major feedstock used by the petrochemical industry.

1.4 ENERGY RESOURCES IN NIGERIA

Nigeria has often been referred to as giant of Africa. This is because of the vast amounts of energy resources she possesses. Nigeria has been faced with the challenge of effectively utilizing the vast energy resources bestowed on her. These resources range from abundant sunlight, wind, hydropower, petroleum, natural gas, coal and many others. Despite these resources, the country is in short supply of electricity. The presence of energy resources should expectedly catalyze economic growth, technological advancement and creates better living standards for the people. Access to energy, specifically electricity, is an impetus for economic and social development. But in Nigeria, lack of policy implementation, corruption and rigid government control of electricity generation has caused a dismal failure of achieving reliable electric power supply. The electricity needed to power and grow the

economy, drive local development and tackle urban and rural poverty is simply inadequate or not available at all. A well-managed electric power sector has profound benefits to the economy.

In Nigeria, non-renewable energy resources includepetroleum and natural gaswhich accounts for over 90 percent of Nigeriaôs GDP. Although Nigeria has been among the worldôs top ten petroleum producing nation, she still imports most of her fuel needs because of lack of adequate infrastructure for refining.Renewable energy resources like hydro power and solar are being used, but their impact is very minimal on a national scale. Dams have been constructed at Kainji in Niger State for electricity generation. The use of solar energy from sunlight has been restricted to off grid use like street lightening, solar borehole pumps and for backup systems. In recent times, energy resources like coal and wind have been virtually neglected.

1.4.1 Coal and Biomass in Nigeria

Nigeria is blessed with an abundance of good quality coals, as well as a vast amount of biomass resource. For a long period of time, coal and biomass have been the fuel used as primary energy resource. These fuels were burnt to provide heat and power for domestic and industrial uses. Nigeria has extensive coal resource, with proven reserve of 639 million tonnes[9]. The demonstrated coal reserves in the world are enough for consumption for over 215 years at the 1998 level[10].

Coal was first discovered in Nigeria in 1909 at Udi by the mineral survey of Southern Nigeria[11]. Exploitation of Nigerian coal began in 1916. As exploration and exploitation continued, mines were opened at Okpara, Ribadu, Onyeama and later Okaba in present day Benue State. Elsewhere mines were also opened at Ezimo, Orukpa, Ogboyoga and Inyi. The mining methods were both surface/open cast and underground mining. By 1967, production ceased as a result of the civil war, and started again in 1971 with about 25000 tonnes produced that year[9].

The coal fuel was used by the Nigerian Railway Corporation to fuel their locomotives. Other users were the Electricity Company of Nigeria and Nigerian Cement Company at Nkalagu. Thus, coal was the fuel that supplied most of Nigeriaôs industrial energy needs at that time. This was before the discovery and wide spread use of petroleum products. However, in recent times, it is obvious that there is the need to reintroduce coal into our national energy matrix, hence the renewed interest in coal technology[12].

Biomass is an energy source that has interested many researchers since the awareness for the need to reduce Greenhouse gas (GHG) emissions and environmental degradation.

Biomass consists mainly of the remains of dead plants and animals. Biomass is considered the renewable energy source with the highest potential to the energy needs of modern society for both developed and developing economies worldwide.[13,14] The early man made use of fire wood, a biomass resource, as fuel for cooking. In temperate regions of the world, wood logs and shavings were burnt to keep the house warm during the winter cold. Wide availability, carbon neutrality, environmental friendliness and cheap nature of biomass fuel are its advantages. The drawbacks to biomass fuel are its low heating value and the difficulty in striking a food-fuel balance, since most foods consumed by man are biomass based.

Biomass, in the form of firewood is the major fuel source for people in the rural communities. About 70% of Nigeriaôs population lives in rural areas. Many rural dwellers cannot afford alternative fuels to biomass fuel. This is because of their low income in addition to low purchasing power, and their low standard of living. Biomass fuel used consist of dried wood, corn cobs, saw dust, wood shavings, bagasse e.t.c. This energy resource is used for cooking, heating and drying.

1.5 ENERGY CRISIS AND ENVIRONMENTAL PROBLEMS

The world energy crisis of the 1970s was a big problem for many world leaders. In an attempt to avoid a repeat of such, proactive leaders started creating what was called an energy mix. This would help in reducing their over dependence on fossil fuels such as crude oil and natural gas. The energy mix of a nation is a combination of two or more energy sources which is readily available and can be easily used. The negative economic effect of overdependence on only one energy source, especially when it is imported is grave. This spurred up researches, seeking to open up other energy sources.Beyond the past energy crisis, there is a bigger challenge ahead. The worldôs depleting crude oil reserves are already a source of concern. Scientists are already setting probable dates when specific reserves would be exhausted. At present levels of production and consumption, Nigeriaôs oil reserves are expected to run out in about forty years.[15]

Meanwhile, the negative environmental impacts of many energy resources have raised concerns. Energy exploration and delivery has its attendant cost to the environment. These range from Greenhouse gas (GHG) emissions, noise pollution, oilspillage, gas flaring and land disturbances from coal mining. Over time these activities has been significantly detrimental to manôs wellbeing and environmental stability. Greenhouse gas and its effects; global warming and climate change are the result of using fuels that harm the environment. The use of these fuels releases potentially dangerous gases to the atmosphere. This

causesacid rain and fog that destroys vegetation and create health problems like lung cancer, asthma, and pneumonia. They also deplete the ozone layer. One of the agreements of the Kyoto agreement is to reduce greenhouse gas emissions and problems related to climate change.

In Nigeria, irrespectiveof her vast petroleum and natural gas deposits and despite being a leading petroleum exporter in the world, shestill faces serious energy crisis. About 60-70 percent of Nigerians are excluded from the national grid, which is also plagued by frequent power outages that lasts about 20 hours daily in places connected to the grid[16].There is also the problem of poor waste management. Municipal and industrial wastesare disposed into rivers, streams e.t.c.Exploration and exploitation of crude petroleum have caused devastating environmental problems within the vicinity where crude oil is mined. The problem of oil spillage has been a reoccurring one which has led to the genocide of fishes in rivers of the Niger delta. Local communities no longer have access to clean drinking water. Waste waters from mining operations, boilers and cooling systems may be contaminated with heavy metals, acids, organic materials and suspended solids which affect water quality.[17] Added to these are social and political problems like oil bunkering, militancy, and inter-ethnic conflict. The problems caused by some energy sources have raised the need for a better, efficient and environmentally friendly energy source. With advances in research, there have been developments of energy sources that make little or no negative impact on the environment.

1.5.1 Biomass and Climate Change

The use of biomass materials as a source of renewable energy is a big step at combating the increasing effects of climate change. The release of greenhouse gases into the atmosphere overtime causes a gradual increase in the earthôs atmospheric temperature because the gases trap heat from the sun. The slow but steadily increasing earthôs temperature causes some climatic changes. These include the melting of ice caps, increased sea levels and drought.

One of the greenhouse gases that cause global warming is carbon (IV) oxide. This is released from the combustion of fuels. The atmospheric concentration of carbon (IV) oxide is increasing, based largely on the consumption of fossil fuels. The combustion of fossil fuels (coal, petroleum and natural gas) releases large amounts carbon (IV) oxide stored and is a major source of greenhouse gases. Considering the impact of fossil fuels, it is important to seek ways of controlling carbon (IV) oxidein sustainable methods that would not negatively

impact technological advancement. Unlike fossil fuels, biomass is not stored up for long. The combustion of biomass also releases carbon (IV) oxide, which is estimated as the net carbon (IV) oxide taken up during the biomass photosynthesis. In essence, the combustion of biomass is CO_2 neutral, as no extra CO_2 is given off. Biomass represents anabundant carbon-neutral renewable resource for the production of bioenergy andbiomaterials, and its enhanced use would address several societal needs[18]. The CO_2 emitted from biomass based fuels combustion does not increase atmospheric CO_2 concentrations, assuming the biogenic carbon emitted is offset by the uptake of CO_2 resulting from the growth of new biomass[19]. Field trials have been done on the use of Miscanthus, a rhizomatous grass.IfMiscanthus was grown on 10 percent of suitable land area in the European Union, the total carbon mitigation could be 76 Mt Carbon yr^{-1}, which is about 9 percent of the EU total Carbon emissions.[20]Hence, biomass contribution to global warming is low. It contains negligible amount of sulphur, so nosulphur oxide pollution from its use. The use of biomass for fuel would ultimately reduce the net release of greenhouse gases, and would steadily lower climate change.

1.6JUSTIFICATION OF THE STUDY

Literature has revealed that very few studies have been done on Nigerian coal and biomass blends (especially sawdust and corn cob), in an attempt to evaluate their environmental suitability and as an alternative energy source for the nation.

The combustion of coal in its natural form releases potentially dangerous gases like CO_2, SOx, and NOx, which cause air pollution, acid rain, global warming and ultimately, climate change. This study seeks to alleviate this problem by combining coal with biomass and carbonizing it. Biomass combustion is carbon neutral and environmental friendly and would make coal a better fuel in combination with coal in moderate amounts. This is expected to reducegreenhouse gas emissions.

Sawdust and corn cobs, the biomass to be used for this study, are usually burnt up at dump sites. This creates a great waste of an energy resource that could be used when processed into a better form. Studies have revealed that the lignocellulosic part of biomass is a heavy energy carrier. Also, biomass energy resource like poultry droppings and cow dung give out an odour that pollutes the air. This pollution can be minimized by converting it to a form in which it can be used as fuel.

This research is also justified by the need to have a national energy mix. In Nigeria, there is no major alternative energy resource to petroleum. This has made Nigerians the direct recipient of the unfriendly petroleum price hike and inadequate availability of

petroleum products. Nigeriaôs energy use needs to be diversified from only petroleum into other energy sources. This diversification can only be achieved when alternative fuels like coal and biomass are brought into the nationsô energy mix and overdependence on oil is stopped. The energy mix provides alternative energy sources that can cushion the negative impact of depending on just one energy source; oil, in the case of Nigeria.

1.7 OBJECTIVES OF THE STUDY

This study is aimed at achieving the following objectives:

1. To characterize sub-bituminous coal and its blends with corn cobs and sawdust (biomass)
2. To determine the most suitable sub-bituminous coal-biomass blend ratio for combustion
3. To improve the thermal efficiency of coal and its biomass blends.
4. To reduce the environmental pollution effects of coal.
5. To produce suitable fuels from waste materials e.gsawdust and corn cob.
6. To propose briquetting as a suitable way of using coal and its biomass blends as domestic fuel.

CHAPTER TWO

LITERATURE REVIEW

2.1 ORIGIN AND FORMATION OF COAL

Coal is a solid, combustible sedimentary rock, composed of mainly carbon with varying amounts of hydrogen, oxygen and impurities like sulphur and originates from plants. Coal is widely available; in fact, coal reserves can be found in every continent of our planet except Antarctica. Coal is combustible rock whose formation is a multi-stage and complicated process[21]. It is formed when plants decay anaerobically over hundreds to thousands of years, during which the plants chemical and physical properties are changed to form a solid material. Coal is formed by biological and geological processes over millions of years, and it is a heterogeneous, non-uniform material containing macromolecular organic compounds, mineral matters, elements, moisture, gases, oil and tarry material[22].

Based on nuclear magnetic studies of ancient buried wood, it is observed that coalification of woody tissue progresses directly from lignin to coal[23]. Over a period of thousands of years, there is a buildup of decomposed anaerobic residue at the bed of the water body. This accumulated organic matter is gradually covered up with a blanket of silt, clay and sand. This preserves it from complete decay. The process of coalification has just begun. Coalification is the process through which dead plants change under geologic influences to a black solid organic fossil fuel (coal) with a complex chemistry. It begins as peat and ends as anthracite. The different rank parameters of coal change as the degree of coalification[24]. Figure 2.1 shows the process of coalification and different coal ranks.

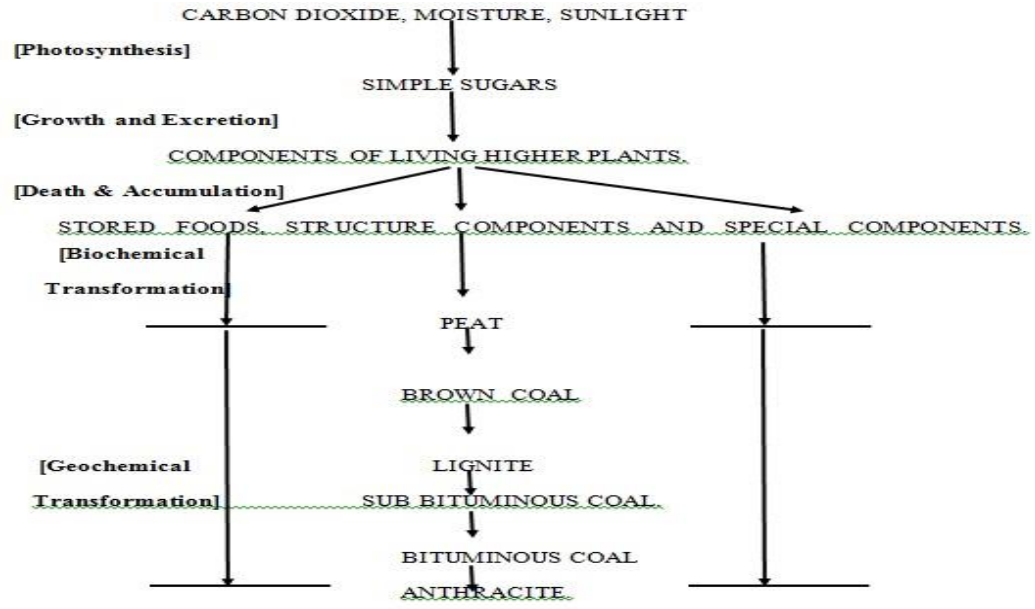

Fig 2.1: Schematic diagram showing coal formation.

2.1.1 CLASSIFICATION OF COAL

Classification of coal is done based on three factors; the percentage volatile matter, the percentage fixed carbon and the calorific value. Typically, coal class/rank increases as the amount of fixed carbon increases and the amount of volatile matter and moisture decreases. There are four main classes of coal namely; Anthracite, bituminous coal, sub-bituminous coal and lignite. There is however, no clear demarcation between them. Anthracite is the oldest coal from geological perspective.

- **Lignite:** It is also called brown coal. This is because of its brownish black colour. It is the lowest rank coal and has a lot of moisture in it. It is used exclusively as fuel for power generation plants. Its combustion releases a lot of pollutants.
- **Sub-bituminous Coal:** It is an intermediate class between lignite and bituminous coals. It is black in colour, but still reflects the brown colour of lignite. Subbituminous coals generally have heating value of between 8320 to 11149Btu[25]. This coal has a 75% carbon content with only 20% oxygen and a high volatile matter[26].
- **Bituminous Coal:** It is of a higher quality to sub bituminous coal, but lesser to anthracite. They have fixed carbon between 69 to 86%. Bituminous coal is very good for coal combustion and is the best for electric power generation. They have a relatively high heating value.
- **Anthracite:** This is the highest and oldest geologic ranked coal. It has fixed carbon content usually more than 90%. Anthracite has a structure similar to graphite.

2.2 COAL DEVELOPMENT IN NIGERIA

The development and effective utilization of coal, as well as other energy sources is important to fully realize the full benefits they possess. Coal has a significant role to play in the industrial development of Nigeria[27]. The exploration and exploitation of coal had begun, pre-independence Nigeria. Hence, such activities were controlled by the British colonial government to meet their ends. In the 1950s, an ordinance establishing the Nigerian Coal Corporation was enacted. Theirresponsibilities then wasto prospect and mine coal resources in Nigeria.

In the period just before Nigeriaôs independence, oil was struck at Oloibiri. In few more years, more oil and its refined products became readily available. The availability of cheap and plenty oil impacted negatively on coal use. Coupled with the civil war that occurred between 1967 and 1970, coal exploration, mining and utilization almost came to a standstill. The users of coal then were Electricity Company of Nigeria (ECN), Nigerian Cement Company, and the major consumer, Nigerian Railway Corporation. These companies changed technology to use cleaner and easier to handle petroleum products.

Nigeria has good coking coal that is very useful in the field of metallurgy. A Study has revealed the presence of bituminous coal in Nassarawa State with medium coking properties[28]. Coal is used to produce coke, which is used in the smelting of iron ore. For Nigeria to sustain a vigorous iron and steel industry, she needs a lot of supplies of coking coal, iron ore, and limestone. Coincidentally, Nigeria has these solid minerals, but has not been able to continuously produce iron and steel which is needed for building infrastructures like buildings, bridges, rails, etc. The multi million naira Ajaokuta steel rolling mill which should be producing iron rods and steel is in comatose. An estimated 1.2million tonnes of coking coal is required at the steel plant in Ajaokuta. Effective utilization of coke from Nigerian coal to produce iron and steel will boost national development.

The National Energy Policy of the Federal Government of Nigeria seeks to achieve ñthe effective utilization of coal for complementing the nationôs energy need and as an industrial feedstock.ò With the right policy, and governmentôs will, coal will aid the Nigeriaôs push to be one of the worldôs most developed nations by 2020.

Coal is also very useful for electricity generation. On earth, coal has the most abundant reserves, and is an important energy, which accounts for more than 24% in energy production in the world[29].Nigeria is a resource rich country, particularly well-endowed with energy resources[30], but produces its electricity mainly form natural gas. For a country like Nigeria with large reserves of coal, coal should naturally be an option for electricity generation.

2.2.1 COAL RESERVES AND MINING IN NIGERIA

Nigeriaôs coal reserves are in excess of 1.2 billion tonnes of proven, indicated and inferred categories[27]. Other researchers put Nigeriaôs reserve at between two and ten billion metric tonnes, with proven reserves between 190 ï 650 million tonnes[31,32,33]. Coal found in Nigeria range from lignite tobituminous. Coal mining involves all activity that is carried out to extract the coal from its natural formation. The type of mining method used depends on the thickness for the overburden above the coal. There are two types of coal mining methods:

2.2.1.1 Surface Mining: is used where the overburden (or coal seam) above the coal is small. In this mining method, the overburden above the coal seam is removed using shovels and draglines, thus exposing the coal seam[34]. The mines at Orukpa and Okaba are surface mines. A hole is drilled in the coal bed to provide an opening to place explosives. The explosive blasts the coal. Large shovels and electric powered buckets are used to scoop the coal into transportation trucks. An open cast mine can be operated for many years depending on the quality and quantity of coal deposit in it.

2.2.1.2 Underground Mining: is used where the distance of the coal deposit in relation to the earthôs surface is very large. Underground mining is practiced in the Enugu area where there is a steeply rising scarp overlying the coal horizons[35]. This mining method involves extraction from very deep depths. Underground mining operation is done by removing the overburden along the tunnel, when the coal deposit is reached, drilling and blasting is done. The blasted coal is scooped out. The roof of the mine is supported with pillars, timbers, rocks or concrete.

2.2.2 Coal Mining and Environmental Degradation

Coal mining causes a lot of hazards and pollutions to the environment where the mining activity takes place. Coal mining is one of the core industries that contribute to the economic development of a country but deteriorate the environment[36]. In surface mining, it involves removing large vegetation cover before the open cast pit is dug. This disrupts the ecology and destroys the earthôs natural scenery. The open cast mine would cause increased erosion, flooding and run-off. When there is run-off, contaminated water from mine can pollute surrounding water bodies like rivers and streams.

Furthermore, the mine air is filled with gases and particulate matter that are dangerous to manôs health. Gases like carbon monoxide (CO), nitrogen (IV) oxide (NO_2), carbon (IV) oxide(CO_2), sulphur oxides (SOx), and methane (CH_4) all fill the mine air. These gases are known to cause diseases in human beings. Diseases like bronchitis, lung cancer, irritation of the eyes and nose, and in rare cases, death. When particulates like coal dust is inhaled, it result in a disease called ñblack lung diseaseò.

2.3 COMPOSITION OF COAL

Coal is made up of mainly carbon, with varying quantities of other elements and compounds. The composition is determined by analysis. The result from the composition can then be used to classify the coal. Two types of analysis done to determine the composition of coal are proximate and ultimate analysis.

2.3.1 Proximate Analysis of Coal

Proximate analysis is used to determine the approximate composition of coal. The result of the proximate analysis reveals the main component of coal and their percentages. Proximate analysis is the simplest coal analysis and it shows that the main components of coal are; fixed carbon, volatile matter, moisture and ash.

- **Fixed Carbon:** is the carbonaceous part of coal. It is the main fuel component of coal. Fixed carbon acts as a main heat generator during combustion. A coal with high fixed carbon burns with a hot flame for a very long time.
- **Moisture:** refers to water in coal. Coals are generally dug from the ground, and have some amount of moisture associated with them. Gentle heating of coal at a temperature slightly above the boiling point of water causes a loss of weight from the sample that is defined as moisture. Moisture is an undesired property and effort is made to keep it at barest minimum. Moisture reduces the combustion of coal, since water cannot burn. It also reduces the flame temperature.
- **Volatile Matter:** includes the gases and volatile liquids in coal, other than moisture. Some of the gases include methane (CH_4) and carbon (IV) oxide (CO_2). The liquids, which are easily vaporized, are tars and oils. Coal with high volatile matter can easily be ignited and would burn with long smoky flames.
- **Ash:** is the inorganic residue that remains after the combustion of coal. It is made up of oxides of elements in coal that did not burn. Ash reduces handling and burning capacity and affects the combustion efficiency of coal. It also forms part of the incombustible part of coal, hence it is undesirable.

2.3.2 Ultimate Analysis of Coal

Ultimate analysis gives the elemental composition of coal. The specific chemical elements and their percentages make up the result of ultimate analysis. Ultimate analysis of coal has shown that coal contains five main chemical elements, namely; carbon, hydrogen, oxygen, nitrogen and sulphur. Carbon is the predominant element in coal. The ultimate analysis of coal can be used to monitor the impurities in coal, and prevent pollution.

2.4 COAL UTILIZATION

The utilization of coal played an important role in meeting the energy needs of man. Coal will continue to play a key role in the worldôs energy mix as demand grows especially in developing Asian countries. Coal is used for energy demanding activities such as;

2.4.1 Electric Power Generation

Modern life is impossible without electricity; hence power plays a pivotal role in development. Improving access to electricity is very necessary to reduce poverty. Coal combustion provides heat for the generation of electricity. Presently coal supplies more than two-thirds of the worldôs electricity. Coal is burnt to produce steam; the hot steam at high pressures turns the turbine to produce electricity. The availability of coal at low cost has helped it achieve high rate of electrification worldwide. The amount of heat liberated from

coal combustion is related to the percentage of carbon, hydrogen and oxygen in the coal. This can be used to estimate the heat energy expected from the coal.

$$C(s) + O_2 \longrightarrow CO_2(g) \qquad \phi H_T 208 = -393.7 \text{ KJ}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow H_2O(g) \qquad \phi H_T\, 208 = -241.78 \text{ KJ}$$

Also, the relative amounts of volatile matter and carbon determine the rate of heat liberation. The rate of heat liberation increases as the ratio of carbon to volatile matter increases. Burners are used to combust the coal fuel. The heat produced converts the water in the boiler tubes to steam.

2.4.2 Domestic Heating

Coal is consumed as fuel for domestic heating during winter seasons in temperate countries. Coal has been used as a source of domestic heat in China for many centuries. Also, coal can be made into briquettes and used for cooking. This occurs in many areas where coal is in abundance. The use of coal domestically is virtually extinct as conventional fuel like natural gas, which are better and cleaner are readily available.

2.4.3 Iron and Steel Production

The largest non-fuel use of coal is to produce coke used in smelting iron ore to make steel. Steel is very essential to our daily lives; it is used in cars, bridges, doors, refrigerators and cutleries. The smelting of iron ore is done in blast furnace. Over 50 percent of steel production worldwide comes from iron made in blast furnace which uses coal. Coal is first converted into coke. The coal must have a special coking property that makes it soften and resolidify into hard coke, suitable for reducing iron ore. Coke, iron ore, and small quantities of limestone are charged into the blast furnace. Hot air is blown into the lower sections of the furnace. This melts the charge in the blast furnace. A tap at the bottom periodically opened releases molten iron. Around 0.63 tonnes (630kg) of coke produces 1 tonne (1000kg) of steel.

2.4.4 Environmental Pollution from Coal Use

Conventional energy sources based on oil, coal and natural gas have been proven to be highly effective drivers of economic progress, but at the same time damaging to the environment and to human health[37]. The consumption of coal for use as energy has raised a number of environmental concerns.

The combustion of coal releases environmental pollutants such as oxides of sulphur and nitrogen (SOxand NOx) and particulate matter (e.g ash). Sulphur oxides (SOx) are released during coal combustion in the form sulphur (IV) oxide (SO_2), and Sulphur (VI) oxide (SO_3). These SOx when released into the atmosphere, can cause serious health

problems. When breathe in, they cause cough, dizziness, sore throats and asthma. The long term effects of SOx are greater. In the atmosphere, they combine chemically with water vapour and precipitate back to earth as acid rain. It is estimated that more than 90 million tonnes of sulphur dioxide are discharged to the atmosphere each year. A study which monitored the acid precipitation of rain water in Taiwan observed severe acidic levels with pH range of 4.21-4.49, with sulphate as the major chemical component[38]. The effects of acid rain could be devastating to both plants and animals. Acid rain increases the acidity of rivers and lakes. This could increase its concentration up to the level that can kill fishes and other aquatic lives. Similarly, the absorption of acid rain by the soil is damaging to crops. Oxides of nitrogen (NOx) also cause acid rain, but its effects are very minimal. This is because the nitrogen in coal is usually less than 1%. The production of NOx is temperature dependent and can be reduced by combusting coal at temperatures below 1000^{o}C. The ash released, which goes through the stack with other combustion gases is specifically called fly ash. If not controlled, fly ash is released into the environment, where its deposition causes a nuisance. The tiny particles of fly ash are respirable, hence a potential health hazard.

Carbon (IV) oxide is inevitably released during the combustion of coal. The release of CO_2 into the atmosphere from human activities is referred to as anthropogenic emission. The combustion of coal releases a substantial quantity of anthropogenic emissions. It is estimated that about 18 billion tonnes of CO_2 are released to the atmosphere each year. These emissions come mainly from coal fired power plants and they (greenhouse gases) contribute to global warming. To this end, scientists have been researching to meet this environmental challenge. An important issue in the determination of CO_2 mitigation cost is the ease or difficulty of altering that mix away from carbon intensive components (like coal) towards those lean or devoid of carbon[39].

2.5 BIOMASS AS AN ALTERNATIVE ENERGY RESOURCE

Biomass has been used as a fuel to provide energy from time immemorial. Biomass energy describes fuel or energy gotten from the combustion of biomass. Bioenergy is expected to become one of the major energy resources for sustainable development of mankind[40]. This energy has been utilized in its various forms and for various purposes. From burning wood for cooking and heating, to using municipal solid waste to produce steam for electricity generation. Biomass is an important energy resource that could provide a formidable alternative to other sources.

An era of industrialization saw a rapid increase in the use of fossil fuel (coal, petroleum and natural gas) and a decline in biomass use. The energy crises of the 1970s, the decline in crude oil reserves and problems caused by the emissions of greenhouse gases by fossil fuel are compelling reasons to make biomass an alternative fuel for present conventional fuels.In remote rural areas, biomass typically meets all energy needs, except for small amounts of kerosene lightning[41].Also, the use of biomass in developed countries is increasing, where it is co-generated for electric power. Energy requirement for cooking is the largest energy demand of rural masses. This is met by burning wood, twigs and other biomass resources in traditional biomass cook stoves. These stoves have low efficiency and causes pollution because of incomplete combustion.

For better utilization of biomass resource, and to make it at close par to conventional energy sources, biomass needs to be transformed. Most biomass resources are bulky, and are difficult to handle and transport. This barrier can be removed by converting it to a better form. Biomass is transformed into gas (known as biogas), liquids (alcohols, tars) and solids (chars and pellets). The value of a particular type of biomass depends on the chemical and physical properties of the large molecules from which it is made[42].

Biomass conversion is done either through biochemical or thermochemical conversion. In biochemical conversion, microorganism and enzymes breakdown the biomass resource. Biochemical conversion can be done by digestion, fermentation, or acid hydrolysis. It is usually carried out on sugar and starch crops as well as waste like cow dung and manure. The biomass product of this conversion is a secondary biomass resource, usually in liquid or gaseous state. In this form, it is cleaner and can easily be stored and used. The conversion of sugar to ethanol is a specific example of biochemical conversion. Thermochemical conversion makes use of heat to change the biomass resource into a better form. This could be through carbonization, combustion, gasification and pyrolysis. The major product of thermochemical conversion of biomass is char and heat.

2.5.1 Biomass Energy Resources

The United Nations Framework Convention on Climate Change (UNFCCC), in 2005 defined biomass as a ñnon-fossilized organic material originating from plants, animals and microorganismsò. This shall also include products, by-products, residue and wastes from agriculture, forestry and related industries as well as non-fossilized and biodegradable organic fractions of industrial and municipal waste.

The above shows that all naturally occurring biodegradable matter that has not been stored up for a very long time can be referred to as biomass. Biomass contributes a large

quota to our worldôs make up. This can be seen from trees, fruits, seeds, animal excreta and animal carcass. It also includes liquids and gasses derived from the decomposition of other biomass.

Biomass resources are renewable. Biomass is composed of a mixture of organic molecules containing carbon and hydrogen, usually including atoms of oxygen, and also small quantities of other atoms and metals. These metals are found in molecules such as the porphyrins which include chlorophyll. It contains magnesium. Plants which are botanical biomass get their food through a process called photosynthesis. Botanical biomass is formed through the conversion of CO_2 in the atmosphere into carbohydrate by the sun light in the presence of chlorophyll and water[43]. In a series of reactions aided by sunlight, plants produce and store glucose, while oxygen is given off.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Hence, as long as plants photosynthesize, there would be a large inexhaustible amount of biomass resources (both botanical and animal origin).

2.5.2 Classification and Types of Biomass Resources

Apart from the basic classification of animal and plants derived biomass, there are many other classifications. These classifications are done with different criteria like methods of conversion, state of matter and place of availability/recovery.

Based on states of matter, biomass is readily classified into the three states of matter. As solid, it occurs in forms like sawdust, cow dung etc. It occurs in liquid as ethanol and methanol. This can be mixed with conventional fuels like gasoline and diesel to make aggregate fuels like biodiesel and bioethanol. In the gaseous state, biogas is a typical example.

For classification based on recovery methods- Food biomass and waste biomass. Food biomass includes vegetables, tubers and fruits. Food biomass is good sources of natural sugars which can be fermented to derived liquid biomass.Waste biomass-which municipal solid waste, agro forestry waste, and industrial waste.

Biomass based on method of conversion: Thermochemical and biochemical biomass. Thermochemical biomass is those that are more conveniently transformed or used by heating. Examples are wood, corn cobs e.t.c. Biochemical biomass are those transformed by the use of microorganisms or enzymes. Most liquid products of biomass are derived through this method. Examples of such biomass are cow dung, poultry droppings, starch crops e.t.c.

2.5.3 Analysis of Biomass

Like every other solid fuel, biomass is analyzed mainly by proximate and ultimate analysis. Other analyses done on biomass are calorific/heating value, bulk density, ash/mineral analysis. All the tests are done to know the detailed composition of biomass. The result of the analysis describes its characteristics which further describes its uses.

Proximate analysis of biomass determines its composition in terms of moisture, volatile matter, ash and fixed carbon. Fresh biomass of plant origin contains a large amount of moisture and needs to be dried before it can be used as fuel. The large amount of moisture in wood fuels absorbs heat and lowers combustion temperatures[44]. Generally, biomass contains about twice as much volatile matter as fossil fuel (coal), about half as much (or less) fixed carbon, and generally less ash[45].

Ultimate analysis involves elemental testing for carbon, hydrogen, oxygen, nitrogen and sulphur. Biomass materials have lower carbon content and higher oxygen content than coal. The higher oxygen content is as a result of increased moisture and volatile matter that biomass possesses. Also, they generally have lower nitrogen and sulphur content than coal, with the exception of rice residue[45]. This means the combustion of biomass would not release toxic gases like sulphur oxides (SOx) and nitrogen oxide (NOx).

The calorific value is the amount of energy that can be obtained by burning a specified amount of fuel. It shows the quantity of energy that will be released during the combustion of a unit mass of a fuel. The calorific value, also called heating value is determined by a Bomb calorimeter.

2.6 SAWDUST AND CORN COB AS ENERGY SOURCES

Biomass component in waste, predominantly cellulose material, is a heavy energy carrier[46]. Sawdust and corn cob are cheap biomass based renewable energy resource that is available in large quantity. Sawdust is flammable and is a ready fuel. The utilization of sawdust waste is often difficult, because of its uneven, powdery and bulky characteristics. This is overcome by transforming it into handy and light forms. Wood from which sawdust is obtained was a major source of biomass energy, and is still used as fuel in many areas of the world.

Corn cob in addition to its nature as waste, also has a high calorific value. Based on its high calorific value, corn cob has a good potential for fuel. Although humanitarian concerns over the use of corn to produce biofuel have hampered its continuous use, corn cob is a viable substitute to make fuel, and has no impact on food prizes. The energy capabilities

of corn cobs, especially in rural communities, where cheap energy is needed cannot be overestimated.

There is growing interest in electricity generation from biomass. In China and India, electricity generation based on biomass is increasing where relatively cheap biomass waste is available. It is estimated that in Cameroon, 1,14877PJ of energy, equivalent to 41,325million KWh of electricity could be harvested annually from theoretical harvestable biomass waste arising from agricultural waste, forest residue and livestock dung[47].

Apart from electricity generation, sawdust and corn cob are good fuels for cooking. Most of the worldôs rural dwellers fall trees for their cooking. By densifying sawdust into a whole lump, it is a good substitute for fire wood, and would reduce deforestation. Attempts have also been made to produce biofuels (ethanol) from lignocellulosic materials[48]. Recently, there has been a report of novel process that converts sawdust into a mixture of oils that can be used for heat and as a motor fuel[49]. Scientific studies have concluded that a lot of potential energy abounds in these residues. They could be used to generate heat for domestic and industrial cottage applications[50,51]. The use of sawdust and corn cob must be carefully analyzed for it to offer better technical, economic and environmental alternatives as an energy source. Sawdust and corn cob are inexpensive, and turning it into a fuel is a way to cut back on fossil fuels.

2.6.1 SAWDUST

Sawdust is fine particles of wood which is a by-product of cutting, grinding, drilling, pulverizing with saw or any other tool. Sawdust is majorly produced at sawmills and furniture making factories.Sawdust is a lignocellulosic solid biomass material. It has the composition and properties of the wood from which it is derived. Sawdust is composed of cellulose, lignin and hemicellulose.

Generally, the percentage composition of lignocellulosic biomass is as follows; 40-60% cellulose, 20-40% hemicellulose and 10-25% lignin, depending on the biomass[52] as in figure 2.2.

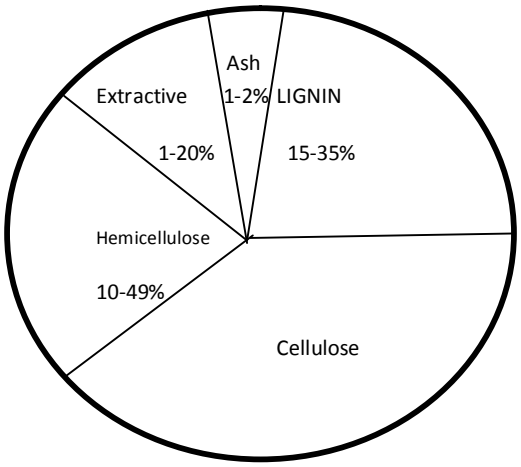

Fig 2.2: Organic Composition of wood

This shows that the organic composition of wood (sawdust). Sawdust composition can also be gotten by proximate and ultimate analysis.

2.6.2 CORN COB

Corn cob is the material that remains after the corn kernels have been removed from it. Corn (maize) is widely cultivated around the world. The United States produces 40 percent of the worldôs harvest. Corn is a staple food for many regions of the world. Maize cobs are the maize ears without grains and has little value after the corn kernels on it have been removed, hence it is a waste.

The corn kernels (grains) have been a major source of biofuel, although the food-fuel debates, which considered the effect of using staple food for fuel and its attendant effects on food prices, have limited its use. Scientists are researching into how to utilize corn cob as a fuel, either through fermentation of its lignocellulosic material to produce biofuel, or by direct combustion. Annually, approximately 204 million dry metric tonnes of corn residue are returned to the ground as waste by-product in corn grain production[53]. Corn cobs make up to 15-20 percent of corn stover. Corn stover, the largest biomass residue in the United States, has a quantity of 220 million tonnes[54].

Just like other biomass, corn cob provides renewable energy. Since corn cobs are disposed off as waste, it will not compete with food produce, but would provide cheap energy, and add more value to farmers. Corn cobs have been burnt as fuel in many developing countries. It is a good alternative to wood gotten by felling trees, which cause deforestation and increased erosion. Also, physical and chemical characterization reveals that it is a feedstock suitable for energy generation. When compared with other wastes like rice husk, studies reveal that corn cob is a better fuel[55]. The corn cobs are used for cooking and heating. Corn cobs can also be carbonized into charcoal fuel.

2.6.3 Environmental and Disposal Problems of Sawdust and Corn Cob

Sawdust is a by-product of the saw milling operation. Hence, it is usually disposed off as a refuse. Except when reprocessed to make particle board, sawdust is usually heaped at dumpsites and regularly burnt. The ways by which saw mills dispose their sawdust is usually improper and in environmentally damaging methods. Sawmills in the Brazilian state of Rio Grande do sul disposes off some of its residues (sawdust, bark and planer shavings) through environmentally incorrect means[56].

Corn cob on the other hand is usually disposed to the farm from which the corn was cultivated. This is because it acts as natural nutrients replenishment for the soil. Corn cobs also reduce erosion and surface run-off in farms. Beyond these uses, which occur in mainly commercial farms, corn cob is generally burnt as a waste.

Burning sawdust and corn cobs releases greenhouse gases to the atmosphere. Large amounts of CO and CO_2 released into the atmosphere can increase the acidity levels of oceans and rivers. During rains, dead wood hedges may release dissolved organic matter and phosphorus into runoff and thus cause eutrophication of surface water[57]. Substances like lignin in the tree, when leached into water can poison wildlife.

Furthermore, sawdust and corn cobs, if not properly managed, can easily be ignited and cause fire outbreak. When dry, it is flammable and a ready fuel. The powdery nature of sawdust also makes it easy to rapidly spread fires. Appropriate disposal of sawdust and corn cob wastes is a problem that requires a lasting solution.

2.7 BIOMASS DEVELOPMENT AND USE IN NIGERIA AND OTHER AFRICAN COUNTRIES

Nigeria has a large abundance of biomass resources. The biomass resources available in Nigeria come from the forests, agricultural produce and waste, municipal waste and industrial by-products. Biomass contributes 37% of Nigeriaôs total energy demand and is the energy of choice for the vast majority of rural dwellers and urban poor [58]. The large contribution of biomass is the same in many other sub-Saharan African countries, where wood fuels are the dominant energy source in terms of the primary energy supply and the number of people relying on it[59]. Even countries with large fossil fuels reserves are not left out.

The most widely used biomass resources available in Nigeria is wood (firewood) and charcoal. The firewood/wood fuel is gotten by deforestation or by using discarded wood from the saw milling factories. Continued deforestation has caused desertification, loss of forest biodiversity and increased surface run off and erosion. Vast forest lands with shrubs and

trees, provide wood that is used as fire wood, or for making charcoal. Although the burning of these biomass resources is environmentally friendly, the continued lumbering of forest trees for fuel has its negative impacts. Charcoal is made by the carbonization of wood logs in mud molded kilns. Charcoal producers prefer old-growth hardwood species and are responsible for the greatest loss of natural forest[60].

Utilization of biomass resource in Nigeria and other African countries is at its basic and crude form. Rural communities require no technology in gathering, processing and harnessing biomass energy. Firewood is readily and freely available within their reach. Also, most of the rural who poor cannot afford any other alternative to firewood use it. The poor urban dwellers who cannot afford conventional fuels like kerosene find an alternative in charcoal. Biomass (firewood and charcoal) is converted mainly by combustion to give heat. It is the main energy resource for domestic activities like cooking and drying. These fuels are mostly used in traditional stoves that have efficiencies ranging from 15-20 percent[61]. Coupled with these is incomplete combustion of the biomass material, thus producing poisonous carbon monoxide.

There are attempts by government institutions and foreign organizations to improve on the utilization of Nigeriaôs biomass resources. Biogas can be produced from cattle dung. The biogas can be used for heating, drying and cooking. In Kano State, a family of 40 at Kwachiri community has now depended on the UNDP biogas project (using cow dung) since 2003 for daily cooking needs[58]. The envisaged benefits of biogas use to the national economy includes stopping anthropogenic CO_2 emissions. If biogas displaces kerosene, at least between 357ï 60,952 tonnes of CO_2 per annum would be avoided[62]. Also, improved wood stove, which would combust sawdust with greater efficiency, is being introduced. Loose wood and sawdust are now made into briquette as a means of utilizing previously discarded biomass waste.

Almost all African countries are still evolving on the yardsticks used for rating development. Africa is in need of energy that will spur development in all areas of their national lives. Access to electricity in sub-Saharan Africa is about 26% and falls to less than 1% in the rural areas[63].Furthermore, wood fuel prices are steadily rising, pressured by varying factors. One of which is increased demand for firewood and charcoal for cooking as a result of rapid population growth. Added to this is the global effect of higher transportation fuel cost. Urban prices of charcoal and other biomass based fuels usually reflect the high transportation costs. Biogas is gradually gaining wide spread use in areas where it is available. With the rising price of kerosene, and reduction of forest wood, it is necessary to

seek other biomass alternatives.Biomass provides a clean, renewable energy source that could dramatically improve our environment, economy and energy security. Biomass energy generates far less air emissions than fossil fuels.

2.8 CO-GENERATION OF COAL AND BIOMASS

Co-generation is the process of combusting coal and biomass blends as fuel for generating electricity. Co-generation, also called co-firing still refers to the technology whereby biomass is fired with fossil fuels at thermal stations. Co-generation seeks to get an aggregate advantage of using a non-renewable fuel (coal) and a renewable fuel (biomass).

The use of coal to generate electricity is a well-established technology. This comes with its attendant environmental pollution. Biomass is renewable and its combustion is carbon neutral. Combining a carefully selected biomass with coal will significantly reduce the emission of pollutants. Co-ýring of biomass residues,brings additional greenhouse gas mitigation by avoiding CH_4 release from the otherwise landýlled biomass. Also, biomass generally contains no sulphur[64]. Cutting back on the emissions of pollutants is necessary to meet governmentôs minimum standards on pollution.

Sometimes, there may be need to remodify existing equipment, used solely for coal, to also accommodate biomass. Such modification usually involves the power plants burner. Biomass material usually contains more moisture and volatile matter, hence, the nature of its combustion is not similar to coal. Biomass is more suited to fixed bed burners. When co-firing coal and biomass, effort is made not to negatively impact the efficiency of the power plant. The amount of biomass used is usually below 15% of the total fuel to be used.

In several parts of the world, co-generation of coal and biomass is increasingly adopted. In India, China and the United states, biomass is added to coal as fuel for some plants.

2.9 BRIQUETTING OF SOLID FUELS

Briquetting, also called densification is a process used to upgrade raw biomass into an efficient fuel having uniform physical and thermal characteristics and a higher bulk density. A lot of work has been done using different solid fuels to make briquettes. Olorunnisola[65] produced briquettes from a mixture of waste paper and coconut husk. Briquetting often involve biomass materials because they generally have unfavourable characteristics of high moisture content, low bulk density, different particle sizes and are less attractive than fossil fuels. Other problems posed by biomass fuels are during transportation,

handling and storage. Briquetting them reduce these problems and make a better fuel for industrial and domestic use.

Briquetting technologies which can mechanically compress loose biomass have been invented. This has made it possible to use biomass waste like saw dust for fuel. The piston press and the screw extrusion are the two main technologies for briquetting. This produces biomass fuels with good durability in handling and with better combustion qualities. In places where mechanized briquetting technology is not available, briquetting can be done manually. Binders, which are materials with adhesive properties is added to keep the biomass together, since a high pressure which will bind the biomass will not be obtainable in manual briquetting.

2.9.1 Briquetting of Corn Cob and Sawdust

Corn cob and sawdust, like many other biomass materials have a bulky heterogeneous particle and is waste material, which makes them a comparatively low quality energy resource. Briquetting them will improve it as a fuel, reduce pollution, and reduce the environmental menace of these waste.

The first step involves drying and crushing the biomass material. Drying is done to reduce the biomass moisture content to below 10%. To reduce cost, drying is preferably done with the sun. Corncob is usually of low bulk density with high moisture content of up to 45% when harvested from the farm in partially dried form[66]. The corn cob is later crushed with a hammer mill reduce it to uniform size. Sieving is done to maintain the uniformity of the biomass particles. Sawdust is a powdery biomass, whose combustion smolders the fire. By using high pressure mechanical briquetting, the powdery sawdust is compressed into a compact lump. The high temperature with which the mechanical briquetting works melts the lignin component of sawdust, the lignin with its adhesive properties binds the sawdust particles firmly together, as the briquette emerge as a single lump. For corn cob, a binder like starch is added to hold the particles together.

To improve the heating value of the briquette, charcoal fines, or coal is added before briquetting. Also, binders with low ash and high heating value are used, because they will add to the heating value of the briquette. Briquetting does not increase the heating value of sawdust and corn cob, it only makes it burn better, and provide more energy per kilogramme.

2.9.2 Physico-Chemical and Combustion Characteristics of Sawdust Briquette

Briquettes are composite materials, made from previously loose particles and substances. Sawdust is one of the most widely used material for making briquettes. The use

of briquettes as a fuel has received wide interest, especially in developing countries, because of its economic and environmental advantages.

The physico-chemical characteristics of briquette are revealed by carrying out proximate and ultimate analysis on it. The combustion characteristic reveals the quantity of heat energy that would be liberated from burning it. It is also a good factor for comparing two or more solid fuels. Briquettes have more heat energy per kilogramme. This is because loose materials are compressed under pressure into a smaller volume. Hence, briquetting does not necessarily increase the calorific value of the fuel, it only increases its energy per unit mass. In addition, the total energy released by a briquette fuel depends on its moisture content.

Sawdust briquettes usually have high volatile matter content; this makes them easy to ignite, and they burn fast. The drawback to sawdust briquette is its low fixed carbon. This can be overcome with the addition of charcoal of coal to the sawdust before briquetting. Composite sawdust briquettes have been produced using sawdust and charred palm kernel[67]. The quality of a coal-biomass briquette depends on its ability to ignite easily, to provide sufficient heat, and generate less ash and smoke[68].

The combustion and thermal characterization can be further determined by carrying out test that simulate real life cooking. Water boiling test (WBT) involves heating a known amount of water till it boils with the briquettes. The water boiling test can be used to evaluate the fuel consumption, burning rate and the percentage of heat utilized.

2.9.3 Effect of Binders on the Performance of Briquette

Briquettes are made by compressing loose particles to give a firm, homogenous and compact material. This is achieved with the help of binders. Binders are adhesive substances, that cause mechanical interlocking between particles and hold them together firmly. The strength of the binderôs adhesion is aided by the application of pressure and sometimes, increased temperature. Tests show that briquetting municipal waste requires higher pressing temperature and compacting pressure[69].

The aim of a binder is to bring together different particles to give a densified bulk material. The product must be firm and solid enough to withstand rough handling without disintegrating. The densified material (briquettes) should have a bulk density greater than the original loose material. Beyond these, a good binder should make a better fuel with higher calorific value.

Organic binders are naturally occurring adhesives like starch, asphalt and coal tar. Lignin is not referred to as a binder, though it has binding ability. It is found in

lignocellulosic materials like wood and sawdust. It adhesive property takes effect only at high temperature. Inorganic binders are synthetic substances like cement and resin binders. Ultimately, the binder becomes part of the briquette and cannot be removed.

The type of binder used to make a briquette impacts on it fuel properties. Generally, organic binders contain less ash because they are combustible. This increases the calorific value per unit weight of the briquette. Hence, organic binders have a net positive impact on the briquetteôs physico-chemical and heating properties. Inorganic binders have the advantage of low smoke emission when compared to organic binders. They also make more solid and firm briquette, but whose combustion produces a lot of ash. This is because of the high mineral content the inorganic binder adds. This reduces the calorific value of the briquette and makes it less, a quality fuel.

A study undertaken by Emerhi[70] assessed the calorific value of briquettes produced using both organic and inorganic binders (starch, cow dung and ash). The result shows that briquettes produced with organic binder (starch and cow dung) had a higher calorific value than those from inorganic binders.

2.10 CARBONIZATION OF COAL AND BIOMASS

Carbonization involves the heating of organic substances (Coal and Biomass) above their decomposition temperature in the absence of air to produce a solid char residue, with some liquid and gaseous by-products. The char produced from coal carbonization is called coke or semi coke, while that produced from biomass is generally called charcoal. The char produced from the carbonization of biomass can be used as fuel, or to produce activated carbon.

Carbonization is an exothermic process, and in principle, can be made self-sustaining. Carbonization is done within a temperature range of 500 to 1000^{o}C. The production temperature determines the type and quality of coke/char. High temperatures of about 900^{o}C produces high quality activated carbon. To produce high surface area activated carbon from coconut shells using physical activation (steam activation), proper selections of carbonization temperature and activation time is essential[71]. Fixed residence time, and carbonization temperatures are the most critical parameters in the entire process[72].

The process of carbonization involves the evolution of volatile matter from coal or biomass. At 100-110^{o}C, water vapour is evaporated out. With further heating to about 300^{o}C, gasses, tars and condensable vapours are evolved. It becomes a reactive low temperature fuel at 500-550^{o}C. This can be used as a smokeless fuel.

Carbonization produces fuel of better calorific value from coal and biomass. The fixed carbon, which is the major fuel component of coal and biomass, is increased during carbonization. Energy content of fresh biomass was lower than pyrolyzed (carbonized) charcoal[73]. Other by-products can also be produced from the carbonization process. These are charcoal, biogas as well as tars.

2.10.1 Low Temperature Carbonization

Low temperature carbonization is done within a temperature range of 500-700^{o}C. At this temperature, most of the volatile matter is driven out. The product is a smokeless fuel, which burns cleaner, lasts longer and with more heat.

Biomass which is a low heating fuel can be improved by carbonization. Depending on the specific biomass involved, carbonizing biomass can increase its heating value up to that of coal. Carbonization process of wood at about 400°C could yield 19% charcoal by weight, and theoretical yield of high-quality charcoal could be produced as much as 44 to 55%[74]. Carbonization of biomass (wood) is common in developing countries to make charcoal. The charcoal is a better fuel than the original wood. Uneven biomass like sawdust or corn cob can be carbonized first before briquetting them.

Coal can also be carbonized to produce semi coke. This is a low grade coke that is very good fuel. In places where coal fines are readily available, they can be carbonized to make semi coke. Coal can also be combined with biomass to make fuel of better grade than the original material.

CHAPTER THREE

EXPERIMENTAL

3.1 MATERIALS AND EQUIPMENT

Sawdust from the tree called *Ohaha* in Igbo language was sourced from the wood market, Nsukka. The corn cobs were obtained from refuse dumps around University of Nigeria, Nsukka, while sub-bituminous coal was obtained from Onyeama mine and Starch was bought from Nsukka main Market.

Equipment used were, sieve, weighing balance, oven, electric furnace (Vecstar Model LF3), electric stove, briquetting machine, bomb calorimeter (XRY-1A), crucibles, hammer mill, CHNS analyzer (Perkin Elmer 2400 series II), thermometer, biomass stove, cooking pot and stop watch. The study was carried out at the National Center for Energy Research and Development, University of Nigeria, Nsukka.

3.2 SAMPLING AND SAMPLE PREPARATION

Preliminary steps were taken on the samples to obtain optimal results. The samples were sundried to remove inherent moisture content to approximate equilibrium and minimize moisture gain during sampling operations[75]. The block-form samples (coal and corn cobs) were crushed into coarse-fine grain particles. They were separately sieved to obtain a particle size of less than 1mm. The three samples were kept in air tight polyethene bag for further use.

3.3 PROXIMATE ANALYSIS OF SAMPLES

Proximate analysis was carried out on the samples according to standard methods of the American Standard Testing and Measurement, ASTM D-3172.

3.3.1 Determination of Moisture Content

The moisture content of the coal and biomass (sawdust and corn cob) samples were determined by measuring the weight loss of the sample after heating them above the boiling point of water. An accurately weighed sample size in a crucible was oven dried at 105^{o}C for 4 hrs. It was then cooled in a desiccator. The sample was weighed and the weight loss calculated. The moisture content is expressed as a percentage of the sample.

$$\%\text{Moisture content} = \frac{\text{weight of moisture in sample}}{\text{weight of sample}} \times 100$$

3.3.2 Determination of Volatile Matter

Accurately weighed out samples were oven dried at 105^{o}C for 4hrs to moisture. The sample was cooled and later placed in a muffle furnace maintained at 600^{o}C for 20 mins. The sample was weighted after it has cooled. The volatile matter is expressed as;

$$\%\text{Volatile Matter} = \frac{\text{[illegible]}}{\text{[illegible]}} \times 100$$

3.3.3 Determination of Ash

The ash content were determined using the ASTM standard (D-3174) for proximate analysis. An accurately weighed sample (coal, sawdust and corn cob) was burnt up in a muffle furnace receiving adequate air at 700^{o}C for 4hrs. The crucible containing only ash was cooled, and the weight of the ash was calculated after weighing the crucible. The ash weight was expressed as a percentage of weight of the whole sample.

$$\%\text{Ash} = \frac{\text{[illegible]}}{\text{[illegible]}} \times 100$$

3.3.4 Determination of Fixed Carbon

The fixed carbon of the individual samples were calculated from other proximate analysis parameters. Proximate analysis is an assay of moisture, ash, volatile matter and fixed carbon, whose percentages make up 100. Fixed carbon is simply 100 minus the addition of volatile matter, ash and moisture content.

%Fixedcarbon = 100 ï (V.M + Ash + M.C)

V.M- volatile matter

M.C- moisture content

3.4 ULTIMATE ANALYSIS OF SAMPLES

The samples were analyzed at the Elemental Analysis Section, Department of Pure and Applied Chemistry, University of Strathclyde. Glasgow, Scotland. Carbon, hydrogen, nitrogen and sulphur analysis were done on a Perkin Elmer 2400 series II, CHNS analyzer. The elements were measured as a function of thermal conductivity and the result obtained as a percentage by weight.

3.5 DETERMINATION OF FUEL RATIO

The fuel ratio of the samples were determined by dividing the fixed carbon of the fuel by its volatile matter. Before calculating the fuel ratios, the fixed carbon and volatile matter values were converted first to dry-ash free (DAF) basis on a two-step calculation with the formula.

$$\text{FC(dry)} = \text{A} \times \frac{\text{[illegible]}}{\text{[illegible]}} \quad \text{OR VM (dry)} = \text{A} \times \frac{\text{[illegible]}}{\text{[illegible]}}$$

FC(dry-ash free) = B(dry) $\times \frac{100}{100\ \%\ \text{-}\ \text{ash content}}$

OR

VM (dry-ash free) = B(dry) $\times \frac{100}{100\ \%\ \text{-}\ \text{ash content}}$

Fuel Ratio = $\frac{\text{Fixed Carbon (dry ash free)}}{\text{Volatile Matter (dry ash free)}}$

FC ï Fixed Carbon

VM ï Volatile Matter

A ï Raw sample.

B- Dry sample.

3.6 CALORIFIC VALUE DETERMINATION

The calorific value of the coal, corn cob, sawdust and their blends were determined at the National Center for Energy Research and Development, University of Nigeria, Nsukka. The calorific values were determined by using the ASTM D-3286[76]method. Weighed sample of about 1g was combusted under oxygen in the canister of a bomb calorimeter. The amount of heat produced was calculated by noting the temperature difference before and after combustion and multiplied by the energy equivalent of the calorimeter. This gave the energy equivalent of the sample.

After the combustion, the burnt up remains of the sample was washed into a beaker and titrated with sodium carbonate solution. The corrected acid, sulphur content and energy equivalent was used to calculate the gross calorific value of the solid fuel using the formular.

C.V (KJ/Kg) = $\epsilon\Delta$ – Ø – /

Where C= energy equivalent correction constant

æT = temperature change

ق= wire correction factor

V = volume of sodium carbonate used

3.7 CARBONIZATION OF SAMPLES

Coal-Corn cob (CC) and Coal-Sawdust (CS) mixtures in the percentage weight ratios 80:20, 60:40, 50:50, 30:70, 10:90 were carbonized in a muffle furnace. The sample were weighed (with strict adherence to the ratios) into porcelain crucibles and heated in a muffle

furnace in the absence of air at 500^{o}C. After 1 hr., the carbonaceous material was taken out and quickly transferred into a desiccator to cool.

3.8 POLLUTION POTENTIAL SIMULATION

Pollution potential of the produced fuel blends were derived, using modelled/simulated parameters for a coal/biomass fired power plant. The following assumptions were made;

a. A 20MW (Twenty megawatts) power plant.
b. Complete combustion of carbon, nitrogen and sulphur into carbon (IV) oxide, sulphur (IV) oxide and nitrogen (IV) oxide respectively.

The pollution potential (CO_2, NO_2 and SO_2) were calculated from the calorific value of the fuel.

1 MW = 1 MWh

1 MWh = 3600 MJ

A power plant of 20 MW would generate 72,000 MJ of energy.

Using coal with calorific value 24261.91 KJ/Kg

i.e 24261.91 KJ => 1 Kg

$$72 \times 10^{6}\text{KJ} = \frac{\square\square\square\square\square}{\square\square\square\square\square.\square\square}$$

= 2,967.6Kg of Coal per hour

Quantity of coal required to generate 20MW of electricity in 1hour.

Elemental analysis result of coal: Carbon content- 70.04%, Nitrogen content- 2.03%, Sulphur- 1.02%.

$$\text{Weight of carbon in coal} = \frac{\square\square.\square\square}{\square\square\square} \times 2967.6$$

= 2078.5 Kg of Carbon

From chemical equation

$$C + O_2 \longrightarrow CO_2$$

2078.5 kg of Carbon → ?Kg of CO_2

$$\text{?Kg of } CO_2 = \frac{\square\square\square\square.\square \times \square\square}{\square\square}$$ (Molar mass of CO_2 = 44g/mol, C = 12g/mol)

=7618Kg/hr of CO_2

The above calculations were carried out on the entire fuel samples using their calorific value to derive the CO_2, SO_2, and NO_2 weight emitted.

3.9 BRIQUETTING

Briquettes of Coal in combination with Corn cob and sawdust separately were produced. Coal-corn cob and coal-sawdust briquettes were produced in five different percentage weight ratios. The percentage weight ratios (Coal:Corn cob/Sawdust) are 80:20, 60:40, 50:50, 30:70, and 10:90. A constant weight of 200g was used during the experiment with the ratios appropriately adjusted.

200g of the coal-biomass (corn cob/sawdust) was weighed into a mixing bowl. 20g of dried starch was weighed out into a different bowl and dissolved with a little water. The starch solution was gelatinized by adding it to boiling water. The coal-biomass mixture was added to the gelatinized starch and thoroughly mixed to form thick slurry. The thickness was adjusted by either adding more hot water or by heating.

The prepared coal-biomass (corn cob/ sawdust) slurry was transferred into the molds of the manual briquetting machine. The lever of the 40 ton hydraulic jack of the briquetting machine was adjusted to press the slurry in the mold. A dwell time of 2minutes was observed, after which the hydraulic press was released. The block form rectangular briquette were withdrawn from the, machine and air dried for 7days.

3.10 DETERMINATION OF FUEL PROPERTIES OF BRIQUETTE

3.10.1 Water Boiling Test

The pot was filled with an initial known weight of water and the same weight was maintained throughout the course of the experiment. Pot was kept on the stove and covered with propped lid to minimize the losses. Thermometer was used to measure the initial water temperature. The initial weight of the briquette was recorded before it was stacked inside the stove. The briquette was ignited and the lightening time was noted. Ignition was assisted with a few piece of paper. The fuel burns with fire during combustion and started to glow having been fanned. The pot containing the known weight of water was placed on the stove with burning fuel. Final temperature of water after boiling was observed. The fire was continued by burning briquettes to heat water to vaporize until all the given briquettes were used up. The time the briquette was used up was noted. Quickly, pot lid was removed and evaporation continued for 20 mins. It was cooled and the weight of water was determined. The experiment was done in an open place under calm wind.

3.10.2 Ignition Time

The samples were ignited in a wind free corner. The fuel sample was clamped 5cm over a burner (stove). The time between exposure to the heat source and the first visible flame is the ignition time.

3.10.3 Afterglow Time

After the ignition of the briquettes, they were further heated for 30 seconds. At that point, there was a flowing stream of gas and a glow in the briquette. The briquette was removed from the heat source. The time between the removal and the last perceptible glow is the afterglow time.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 RESULTS

Table 1: Result of the proximate analysis and calorific values of Sub-bituminous Coal, Sawdust, Corn cob, Coal-Sawdust blends and Coal-Corn cob blends.

S/N	Parameters → / Sample ↓	Moisture Content(%)	Volatile Matter (%)	Ash (%)	Fixed Carbon (%)	Calorific Value (Kj/Kg)
1	COAL	4.28	36.59	16.75	42.38	24261.91
2	CORN COB	5.27	78.87	0.21	15.65	15401.58
3	SAW DUST	9.45	78.15	0.05	12.35	16184.69
4	CS- 80:20	5.00	34.83	9.72	50.45	23097.80
5	CS-60:40	6.04	46.76	7.71	39.49	20036.41
6	CS- 50:50	6.84	49.61	6.82	36.73	19636.66
7	CS- 30:70	7.39	64.06	5.13	23.42	18542.06
8	CS- 10:90	9.30	71.72	0.30	18.68	18986.14
9	CCS- 80:20	1.73	14.51	12.9	70.86	23703.07
10	CCS- 60:40	1.88	24.39	11.04	62.69	26702.14
11	CCS- 50:50	2.43	15.87	10.70	71.00	22681.86
12	CCS- 30:70	2.62	19.19	9.90	68.29	23986.35
13	CCS- 10:90	3.43	19.06	7.10	70.41	26494.43
14	CC- 80:20	6.53	36.01	9.20	48.26	26056.05
15	CC- 60:40	6.18	46.21	7.50	40.11	20823.48
16	CC- 50:50	6.37	52.73	6.40	34.50	18730.38
17	CC- 30:70	7.45	56.41	4.40	31.74	19446.71
18	CC- 10:90	8.67	67.31	3.20	20.82	16085.65
19	CCC- 80:20	1.80	13.13	14.10	70.97	25197.17
20	CCC- 60:40	1.93	14.48	13.50	70.09	27132.22
21	CCC-50:50	2.10	15.95	13.10	68.85	26750.11
22	CCC-30:70	2.54	18.80	10.30	68.36	24877.75
23	CCC-10:90	2.84	19.87	6.80	70.49	24299.52

Table 2: Result of the Elemental analysis of Coal, Sawdust, Corn cob, Coal-Sawdust and Coal-Corn cob blends.

S/N	Elements / Sample	% CARBON	% HYDROGEN	% NITROGEN	% SULPHUR
1	COAL	70.04	5.32	2.03	1.02
2	CORN COB	48	5.79	0.89	-
3	SAW DUST	48.78	5.94	1.02	-
4	CS- 80:20	65.72	5.45	1.82	0.82
5	CS-60:40	61.54	5.57	1.63	0.61
6	CS- 50:50	59.41	5.62	1.53	0.51
7	CS- 30:70	55.16	5.77	1.32	0.31
8	CS- 10:90	50.91	5.89	1.12	0.10
9	CC- 80:20	65.23	5.42	1.79	0.82
10	CC- 60:40	61.22	5.51	1.58	0.61
11	CC- 50:50	59.02	5.56	1.48	0.51
12	CC- 30:70	51.60	5.66	1.23	0.31
13	CC- 10:90	50.20	5.75	1.0	0.10

Table 3: Result of the Elemental analysis of carbonized Coal-Sawdust and Coal-Corn-cob blends.

S/N	Elements / Sample	% CARBON	% HYDROGEN	% NITROGEN	% SULPHUR
1	CCS-80:20	70.26	3.10	1.10	0.12
2	CCS-60:40	69.72	3.93	1.36	0.05
3	CCS-50:50	71.18	3.06	0.79	0.09
4	CCS-30:70	65.27	3.23	1.50	0.40
5	CCS-10:90	76.49	3.24	1.31	0.03
6	CCC- 80:20	71.01	3.66	2.36	0.28
7	CCC- 60:40	68.67	3.18	2.18	0.42
8	CCC- 50:50	74.27	3.37	2.48	0.01
9	CCC- 30:70	78.86	3.66	2.38	0.12
10	CCC- 10:90	77.12	3.72	1.31	0.15

Table 4: Result of Fuel Ratio of Coal, Corn cob, Sawdust and their carbonized and uncarbonized blends

S/N	Samples	Fixed Carbon (DAF) %	Volatile Matter (DAF) %	Fuel Ratio
1	Coal	52.90	47.11	1.12
2	Corn Cob	18.39	81.61	0.23
3	Saw Dust	17.10	82.90	0.21
4	CS-80:20	57.81	42.19	1.37
5	CS -60:40	46.37	53.64	0.86
6	CS -50:50	43.56	56.44	0.77
7	CS -30:70	29.68	70.32	0.42
8	CS -10:90	23.48	76.52	0.31
9	CCS-80:20	78.18	21.83	3.58
10	CCS-60:40	69.15	30.85	2.24
11	CCS-50:50	77.57	22.43	3.46
12	CCS-30:70	74.55	25.45	2.93
13	CCS-10:90	75.68	24.32	3.11
14	CC-80:20	56.13	43.88	1.28
15	CC-60:40	46.95	53.05	0.89
16	CC-50:50	40.89	59.12	0.69
17	CC-30:70	31.67	62.34	0.60
18	CC-10:90	26.75	73.25	0.37
19	CCC-80:20	78.92	21.08	3.74
20	CCC-40:60	77.81	22.20	3.50
21	CCC-50:50	76.45	23.55	3.20
22	CCC-30:70	74.78	25.22	2.90
23	CCC-10:90	75.31	24.69	3.05

Table 5: Pollution potential of different Fuel Blends in kilogramme per hour.

S/N	Sample	CO_2(Kg/hr)	NO_2(Kg/hr)	SO_2 (Kg/hr)
1	Coal	7618.00	198.00	60.50
2	Corn Cob	8224.10	137.00	-
3	Sawdust	7952.00	149.00	-
4	CS-80:20	7560.00	185.40	50.40
5	CS-60:40	8104.80	190.80	43.20
6	CS-50:50	7972.80	183.30	36.00
7	CS-30:70	7812.00	167.76	24.05
8	CS-10:90	7074.00	138.24	7.20
9	CCS-80:20	7815.60	109.44	7.27
10	CCS-60:40	6890.00	120.50	2.69
11	CCS-50:50	8272.00	82.80	5.60
12	CCS-30:70	7180.00	147.60	23.99
13	CCS-10:90	7614.00	117.00	16.20
14	CC-80:20	6606.00	162.40	45.00
15	CC-60:40	7754.40	179.28	42.16
16	CC-50:50	8316.00	186.48	39.60
17	CC-30:70	7002.00	149.56	22.90
18	CC-10:90	8236.00	146.88	8.88
19	CCC-80:20	7437.60	221.04	15.95
20	CCC-60:40	6681.60	189.72	22.29
21	CCC-50:50	7329.00	218.88	0.54
22	CCC-30:70	8366.00	224.08	6.94
23	CCC-10:90	8377.20	127.52	8.88

Table 6**:** Combustion Properties of Coal-Sawdust and Coal-Corn cob briquette

	CS-80:20	CS-60:40	CS-50:50	CS-30:70	CS-10:90	CC-80:20	CC-60:40	CC-50:50	CC-30:70	CC-10:90
I.T (sec)	40	33	30	25	14	29	31	20	13	6
A.G.T (sec)	37	42	40	149	37	31	110	149	108	72

I.T ï Ignition Time

A.G.T ï After Glow Time

Table 7: Result of Water Boiling Test

	SD	COB	CS-80:20	CS-60:40	CS-50:50	CS-30:70	CS-10:90	CC-80:20	CC-60:40	CC-50:50	CC-30:70	CC-10:90
T.E	0.165	-	0.115	0.072	0.078	0.129	0.82	-	0.156	0.192	0.51	-
Power Output (KJ/s)	2.14	1.60	2.46	2.26	1.59	1.44	1.25	0.99	1.63	2.34	2.78	2.29
S.F.C (Kg/s)	0.46	0.38	0.49	0.57	1.14	0.51	0.57	0.41	0.52	0.28	0.35	0.37
B.R (Kg/s)	0.13	0.10	0.11	0.11	0.08	0.08	0.06	0.04	0.08	0.12	0.14	0.14

T.E- Thermal Efficiency
S.F.C ï Specific Fuel Consumption
SD- Sawdust
COB-Corn cob

B.R- Burning Rate

4.2 DISCUSSION

The result of proximate analysis for the raw samples (Table 1) showed that moisture content was lowest in coal, at 4.28% and highest in sawdust at 9.45%. Corn cob had a moisture content of 5.27%. The raw samples all showed moisture content below 10%. It is expected that moisture content of good fuels should be below 15%. High moisture content of fuel is disadvantageous because it decreases system capacity and increases operational cost[77]. As expected, the biomass (corn cob and sawdust) showed a higher moisture content than coal, this is because the moisture in coal has been removed during the process of coal formation. The coal-sawdust blend 80:20 had the lowest moisture content of 5%, and coal-sawdust blend 10:90 had the highest moisture content of 9.3%. Coal-corn cob moisture content on the other hand trends from the lowest at 6.53% (CC-80:20) till the highest at 8.67% (CC-10:90). Both coal-sawdust and coal-corn cob had similar trends, with the moisture content increasing as the biomass content (sawdust and corn cob) increased. This shows that biomass material holds a larger volume of moisture than coal. The ash content of the uncarbonized coal-sawdust blend showed a reverse trend from the moisture content. It decreased as the biomass (sawdust and corn cob) in the fuel increased.

The volatile matter of the fuel sample was highest in corn cob at 78.87% and sawdust at 78.15%. Coal had a volatile matter of 36.59%. Raw biomass contains high volatile matter of about 70 ï 86%, which makes it a highly reactive fuel, giving it a faster combustion rate[78]. The volatile matter of the coal-sawdust blends increased from 34.83% in CS-80:20 to 71.72% in CS-10:90. This trend is repeated, with the coal-corn cob blends also. CC-80:20 had a volatile matter of 36.01% being the lowest, while the highest volatile matter is 67.31%

forCC-10:90. The coal-sawdust blends have slightly higher volatile matter than the coal-corn cob blend. The volatile matter of the blends comes largely from the sawdust and corn cob, because they possess a higher volatile matter than the coal. The volatile matter would make the fuel smoky with a lot of pollutants during combustion. The utilization of biomass residues in their natural form as fuel is quite challenging due to their low bulk density, low heat release and the excessive amounts of smoke they generate[79]. This large volatile matter in biomass can also be extracted in a reactor system to produce bio-oil. It has been confirmed that that the yield of bio-oil from biomass input is as high as 80 %wt.[80]

The ash content showed a different trend from the volatile matter, coal ash content was 16.75%, corn cob, 0.21% and sawdust 0.05%. While the ash content of coal is high, those of corn cob and sawdust were very low. The lower the ash content of the fuel, the better its quality. The ash content of a solid fuel is significant to its combustion characteristics. The slagging and fouling in boiler tubes in power plants during combustion is a result of ash. CS-80:20 had the highest ash content of 9.72%, and CS-10:90 had the lowest ash content of 0.3%. Also, CC-80:20 showed an ash content of 9.2%. It decreased through the fuel blends grade till its lowest value at 3.2%. An increase in biomass content of the blend showed a corresponding decrease in the ash content of the coal-sawdust blend. Both ash and moisture contents are non-fuel components of the blends and are undesired. From the result, the ash contents of the blends are all below 10% which is a positive indication of a good fuel. From literature, typical biomass contains fewer ashes than coal, and their composition is based on the chemical components required for plant growth, whereas coal ashes reflect the mineralogical composition[77].

The fixed carbon of the fuel was highest in coal, at 42.38%, and lowest in sawdust at 12.35%. Corn cob had a fixed carbon content of 15.65%. The fixed carbon is the most important thermal property of the fuel, and its value can be directly related to the heating/calorific value of the fuel. The result of the fixed carbon of the coal-sawdust blend revealed that CS-80:20 had 50.45%. It went on a downward trend, with CS-60:40 being 39.49%, CS-50:50, 36.73%, CS-30:70, 23.42% and CS-10:90, 23.42%. The coal-corn cob blend also showed similar trend with CC-80:20 being 48.26%, CC-60:40 -40.11%, CC-50:50 -34.5%, CC-30:70 -31.74% and CC-10:90 -20.82%. The percentage of the fixed carbon is important and it directly imparts on the calorific value. The decrease in the fixed carbon content from CS-80:20/CC-80:20 to CS10:90/CC10:90 can be attributed to the increased moisture content and volatile matter. These two proximate parameters (moisture and volatile matter) increase as the sawdust/corn cob incorporated into the blends also increase.

Also from Table 1, it is observed that the effect of carbonization is significant in changing the fuel proximate parameters. Moisture content of all the blends (coal-sawdust and coal corn cob) were reduced to below 5%, with the highest being CCS-10:90 (3.43%). After carbonizing at 500^{o}C, most of the moisture had evolved. Thus carbonization enhances the fuel by removing moisture which is an undesired property. This corroborates Yang etal[81] who concluded that moisture content is a very important property which affects the burning characteristics of biomass. The moisture left in the carbonized fuel is the inherent moisture, required to maintain balance with atmospheric moisture. The volatile matter was also reduced significantly by carbonization. CCS-80:20 had a volatile matter content of 14.51%, while CCS-60:40 had the highest volatile matter with a value of 24.39%. The volatile matter of the carbonized coal-sawdust blends did not adhere to any particular trend. The coal-corn cob blend showed an increasing volatile matter content from CCC-80:20 at 13.13% till the highest value at 19.87%. All the volatile matter contents of the blends were below 20%.

The ash content of the carbonized blends were higher than the uncarbonized forms. CCS-80:20 had 12.9% ash content, while CCS-10:90 had 7.1% ash content. Also, CCC-80:20 had an ash content of 14.14% and CCC-10:90, 6.8%. The percentage increase in ash content by carbonization is marginal. Since the proximate parameters are measured in percentages, and carbonization reduced the mass of other proximate parameters, the ash content only increased on a percentage basis.

The fixed carbon of the carbonized blends had also increased significantly by carbonization. Coal-sawdust blends ranged from 62.69% (CCS-60:40) to 71% (CS-50:50). The coal-corn cob blends showed fixed carbon of between 68.36% (CCC-30:70) to 70.97% (CCC-80:20). Carbonization increased the fixed carbon content of the uncarbonized samples from an average value of about 33.75% to about 68.73% in the coal-sawdust blends. In the coal-corn cob blends, carbonization increased the fixed carbon from an average of 30.08% to 69.75%. Correlation of the results revealed that carbonization had a significant effect on volatile matter, fixed carbon and calorific value. (Appendix 2).

Calorific value results as shown on Table 1 indicated that coal had 24261.91Kj/Kg, corn cob had a calorific value of 15401.58 Kj/Kg and sawdust had 16184.69 Kj/Kg. The calorific value is influenced majorly by the fixed carbon content and volatile matter of the fuel. Coal had the highest fixed carbon content, hence its high calorific value. The fixed carbon content and volatile matter of corn cob and sawdust are relatively close, which may have contributed to their close calorific values. The slightly higher calorific value of the sawdust can be attributed to the lower ash content of sawdust, compared to corn cob. Ash has

a significant influence on the heat transfer to the surface of a fuel as well as the diffusion of oxygen to the fuel surface during char combustion[82]. This inference agrees with the statistical data (Appendix 1) which showed that ash and moisture content had a significant effect on calorific value. The correlation value, R=0.853 is very significant.Ash is an incombustible material and it lowers the calorific value of solid fuels. Also, sawdust had a slightly higher elemental carbon than corn cob. The calorific value of lignocellulosic wastes (sawdust and corn cob) is relevant to their exploitation and potential application as fuel[83].

The uncarbonized coal-sawdust blend with the highest calorific value is CS-80:20 (23097.80 Kj/Kg). The highest calorific value for the uncarbonized coal-corn cob is CC-80:20 (26056.05 Kj/Kg). These fuel blends had the highest calorific value because of their high fixed carbon content. The carbonized coal-sawdust blends had it highest calorific value blend from CCS-60:40 (26702.14 Kj/Kg) while the carbonized coal-corn cob blend had it highest calorific value blend from CCC-60:40 (27132.22 Kj/Kg). Generally, the coal-corn cob blends showed a higher calorific value than the coal-sawdust blends. This is most likely because of the higher percentage elemental carbon of coal-corn cob blends. Calorific value of natural fuel can be estimated from its percentage carbon content together with other elements[84,85]. Studies have shown that after carbonization, the calorific value of biomass increase two fold because of the proximate parameters (fixed carbon, volatile matter and ash) and the elements (carbon, hydrogen and oxygen) present in the biomass[73]. Correlation of the results (Post Hoc TestsAppendix 2) revealed that carbonization had a positive effect on calorific value. Also this result is irrespective of the fact that the raw sawdust had a slightly higher calorific value than raw corn cob. This reveals that the calorific value of coal-biomass blends differ moderately from the calorific value of their individual material. Statistical result showed that there is a significant difference ($P<0.05$) in the calorific value of the fuels as a result of blending. (Appendix 3)

The result of the elemental analysis is shown on Tables 2 and 3. Raw samples had higher carbon contents, incomparism to the hydrogen, sulphur and nitrogen content determined. Coal had a carbon content of 70.04%, corn cob had 48% carbon content, and sawdust, 48.78% carbon content. Ragland etal[86] in their study found out that the carbon content of wood is between 47-53%. From the result, the biomass materials had carbon content below 50%, while coal showed the highest percentage carbon content. Fossil fuels like coal have larger carbon content because it had been fossilized through a process of diagenesis and catagenesis.

The hydrogen content of the three raw materials is approximately the same. Coal showed hydrogen content of 5.32%, corn cob, 5.79% and saw dust 5.94%. Biomass materials like corn cob and sawdust contains hydrogen in the form of water (H_2O) and other volatile and tars (CH_4, C_6H_6). The carbon and hydrogen content of the sawdust agrees closely with values reported by Akowuahetal[87].

The elemental analysis also showed that coal contains 2.03% and 1.02% nitrogen and sulphur content respectively. Corn cob and sawdust contain only nitrogen, with no sulphur content detected. Corn cob has a nitrogen content of 0.89% and sawdust 1.02%. Nitrogen and sulphur in solid fuels are potential pollutants when combusted. They are capable of contaminating the environment, and affecting manôs health. The zero percent sulphur content of the biomass is an advantage, it can be blended with other solid fuel to reduce aggregate sulphur content.

On Table 2, the result of the coal-sawdust blends showed that CS-80:20 had a percentage carbon content of 65.72%, CS-60:40 had 61.54%, CS-50:50 showed 59.41%, CS-30:70, 55.16% and CS-10:90 had a carbon content of 50.91%. The carbon content of the blends declined as the coal content of the blends reduced. Coal had a larger contribution to the blendsô carbon content because coal had a carbon content of 70.04%. The carbon content of a fuel is indicative of its CO_2 releasing potential. Blending of coal and biomass is done to reduce anthropogenic CO_2 emissions, especially from non-renewable energy sources like coal. Co-firing of biomass fuels with coal, for example, is presently being considered as a means for reducing the global CO_2 emissions[88]. It is expected that CS-10:90 would release the least anthropogenic CO_2 emission, because of its lower carbon content, which is largely renewable. The carbon content of the carbonized coal-sawdust blends showed marked difference from its uncarbonized blends. Carbon content of CCS-80:20 is 70.26%, CCS-60:40 is 69.72%, CCS-50:50 is 71.18%, CCS-30:70 is 65.27% and CCS-10:90 is 76.49%. The carbonized coal-sawdust blends did not align to any particular order, but are higher than its uncarbonized blends. The process of carbonization breaks down and re-arranges the cellulosic and lignin compounds in the biomass, transforming it into an aromatic like substance. In coal, carbonization expels ether, carboxylic, alcoholic functional group fusing the aromatic structure left to become like graphite. Products of carbonized coal showed structural properties similar to an ordered graphite-like component[89]. This is likely an aromatic compound. Thus, carbonization increases the elemental carbon content of blends.

The percentage hydrogen content of theuncarbonized coal-sawdust blends are approximately the same with CS-10:90 being the highest at 5.89% and CS-80:20, the lowest

as 5.45%. The hydrogen content of the blends was similar to that of it raw blends. The higher the hydrogen to carbon ratio of the blends, the higher the heating value of the fuel. The hydrogen content of the carbonized blends on the reverse decreased from its uncarbonized blends, and it was of relatively equal amounts. CCS-60:40 showed the highest hydrogen content at 3.93% and the lowest is CCS-50:50 at 3.06%. The reduction in hydrogen content results from the removal of moisture content of the fuel blends. Water (moisture) is chemically H_2O, thus, a reduction of moisture leads to a reduction in hydrogen content.

The percentage nitrogen content of the coal-sawdust uncarbonized blends was highest in CS-80:20 at 1.82% and lowest in CS-10:90 at 1.12%. The sulphur content ranged from 0.82% in CS-80:20 to 0.1% in CS-10:90. The nitrogen and sulphur content is indicative of the potentials of the coal to cause air pollution during combustion. The percentage sulphur in these fuel blends are very low, and are not expected to lead to acid rain. The nitrogen content of all the carbonized blends were all below 2%. CS-50:50 had the lowest nitrogen content (0.78%) and CS-30:70 had the highest nitrogen content (1.5%). The sulphur content in the carbonized fuel were all below 1%. The result revealed that CCS-30:70 had the highest sulphur content (0.4%) and CCS-10:90had the lowest sulphur content (0.03%). The carbonized blends showed reduced sulphur content, compared with its uncarbonized blend. Co-pyrolysis of high sulphur coal and biomass at 600^{o}C significantly enhanced coal desulphurization by about 2% sulphur loss.[90]

The carbon content of theuncarbonized coal-corn cob blend are as follows: CC-80:20 (65.23%), CC-60:40 (61.22%), CC-50:50 (59.02%), CC-30:70 (51.6%), and CC-10:90 (50.2%). The similarities in the carbon content of both coal-sawdust fuel blends and coal-corn cob blends shows that when coal is blended with different biomass materials, it could give close carbon content values. The result of the carbon content of the carbonized coal-corn cob were CCC-80:20 (71.01%), CCC-60:40 (68.67%), CCC-50:50 (74.27%), CCC-30:70 (78.86%) and CCC-10:90 (77.12%). Averagely, the carbon content of the carbonized coal-corn cob blends was higher than the carbonized coal-sawdust blends. This reveals that carbonization had a greater effect on the carbon content of the coal-corn cob blend than on the coal-sawdust blend.

The hydrogen content values were also approximately the same. CC-80:20 showed hydrogen content of 5.42% as the lowest, this increased through the blends of fuel up to 5.75% for CC-10:90. Result of the hydrogen content of the carbonized coal-corn cob blendswere CCC-80:20 (3.66%), CCC-60:40 (3.18%), CCC-50:50 (3.37%), CCC-30:70, (3.66%) and CCC-10:90, (3.72%). The trend is similar to the carbonized coal-sawdust blends.

The reduction in the hydrogen content can be attributed to removal of moisture (H_2O) and reduction of volatile matter (e.g methane, cellulose, benzene e.t.c) by carbonization. This can be inferred because the moisture content and volatile matter of the blends reduced significantly after carbonization. Carbonization of lignocellulosic material involves polymerization, dehydration and cracking of lignin and cellulose in the biomass[91,92].

The nitrogen and sulphur content ranged from 1% to 1.79% for nitrogen and 0.1% to 0.82% for sulphur content. The nitrogen content of the coal-corn cob blends were lower than the coal-sawdust blends. This shows that coal-corn cob blends would release lower amount of nitrous oxides during combustion. The sulphur content of the coal-corn cob blend gave the exact values as the coal-sawdust blend. Nitrogen content of the coal-corn cob sample increased after carbonization. The blend with the highest nitrogen content is CCC-50:50 (2.48%) and the lowest is CCC-10:90 (1.31%). Sulphur content of the blends ranged from 0.01 to 0.42%. The values of the nitrogen and sulphur contents are relatively moderate and should not cause significant environmental pollution. They are below the maximum sulphur acceptable limits of 1.5 ï 1.6%[93].

Table 4 shows the fuel ratios, which is an indication of the combustion characteristicsof solid fuels. Coal has a fuel ratio of 1.12 which is above 1. This indicates that the fixed carbon in it is more than the volatile matter. Corn cob and Sawdust have a fuel ratio of 0.23 and 0.21 respectively. Based on its fuel ratio, coal would burn for a longer time during combustion than both corn cob and sawdust. This is because Coal has a higher fixed carbon content. The combustion of both corn cob and sawdust would be characterized by the evolution of tars and light hydrocarbons. It would also burn very rapidly.

The uncarbonized coal-sawdust blends revealed the following fuel ratios, CS-80:20 -1.37, CS-60:40 -0.86, CS-50:50 -0.77, CS-30:70 -0.42 and CS-10:90 -0.31. As the sawdust in the fuel increased, the fuel ratio decreased. This is because sawdust has a larger amount of volatile matter than fixed carbon. The combustion of a fuel with a higher quantity of volatile matter than fixed carbon would cause the evolution of tars form the fuel. This causes pollution. Thus, a fuel blend with a higher amount of volatile matter (i.e lower fuel ratio) would emit smoky pollutants than a fuel with a higher fuel ratio. Only CS-80:20 showed a fuel ratio above 1. Thus, CS-80:20 is the best fuel among the uncarbonized coal-sawdust fuel blends in terms of smoky pollution during combustion.

The carbonized coal-sawdust blends showed a significant improvement than the uncarbonized ones. CCS-60:40 showed the lowest fuel ratio (2.24), while CCS-80:20 had the highest fuel ratio (3.58). All the blends had fuel ratio above 1. Carbonization of the fuel blend

reduced the volatile matter content and increased the fixed carbon content. This is reason for the improved fuel ratio of the carbonized fuel. Thus, a carbonized fuel blend would emit much less pollutants during combustion.

The fuel ratio of the uncarbonized coal-corn cob blend ranged from 1.28 (CC-80:20) to 0.37 (CC-10:90). CC-80:20 showed a good quality fuel ratio above 1. This means the combustion of fuel blend CC-80:20 would not cause much pollution, and would burn for longer time. CC-60:40, CC-50:50, CC-30:70 and CC-10:90, with fuel ratio 0.89, 0.69,0.6 and 0.37 would burn out quickly. This is because they showed a higher volatile matter content. Volatile matter as a fuel component, does not burn for a long time. The fixed carbon keeps glowing and burning after the volatile matter component of the fuel is totally consumed. Thus, fuel with higher volatile matter content would not only emit a higher pollution, but would be quickly consumed during combustion.

The result showed that the carbonized coal-corn cob blend had the values CCC-80:20-3.74, CCC-60:40 -3.5, CCC50:50 -3.2, CC-30:70 -2.9, and CCC-10:90 -3.05. The fuel ratio values showed no particular trend, though they were all above 2. The high fuel ratio of these blends shows that they would be good fuels for combustion, without environmental pollution, and would last burn longer, before burning out into ashes.

Results of the pollution potential simulation of Coal, Corn cob, Sawdust and blends are on Table 5. Coal would emit 7618kg of carbon (IV) oxide, 198kg of nitrogen (IV) oxide and 60.5kg of sulphur (IV) oxide per hour. In the same plant conditions, Corn cob would release 8224.1kg of carbon (IV) oxide and 137kg of nitrogen (IV) oxide, while sawdust would release 7952kg of carbon (IV) oxide and 149kg of nitrogen (IV) oxide per hour produced. The biomass released a greater amount of carbon (IV) oxide than the coal per hour, this is because biomass has a lower calorific/energy value compared to coal, and would need a larger quantity of the biomass (sawdust and corn cob) to produced 20MW power capacity of the power plant. Thus, despite its lower carbon content, it still produced a higher amount of carbon (IV) oxide. This shows that the combustion of corn cob and sawdust, in this particular power plant would contribute more carbon (IV) oxide to the environment than coal.

The nitrogen (IV) oxide of coal, corn cob and sawdust per hour are 198kg, 137kg and 149kg respectively. Coal showed higher nitrogen (IV) oxide pollution, followed by sawdust and corn cob. While the value is largely moderate, the potential for the formation of nitrous oxide is based on power plant operating conditions.The coal would emit 60.5kg of SO_2 per hour. The result showed both corn cob and sawdust does not emit any sulphur (IV) oxide.

This is because they do not have any sulphur content. The combustion of these fuels aid in reduction of SO_2 pollution to the environment.

The carbon (IV) oxide, nitrogen (IV) oxide and sulphur (IV) oxide showed similar pattern across the coal-sawdust fuel blends (both uncarbonized and carbonized). The coal-sawdust blend with the highest CO_2 emission per hour is CCS-50:50 (8272kg) and the lowest is CCS-60:40 (6890kg). The result showed that the CO_2 emission values of coal-sawdust blends was a relative average of raw coal and sawdust. The calorific values of the fuel have an impact on the CO_2 emission of the fuel since it is measured, per hour (energy consumed) basis. A fuel with high calorific value would have moderate CO_2 emission per hour, depending on it carbon content.

Table 5 also shows the nitrogen (IV) oxide and sulphur (IV) oxide of the coal-sawdust blends. The SO_2 and NO_2 pollution potential decreased in the uncarbonized blends from CS-80:20 to CS-10:90. The uncarbonized blend with the highest SO_2 is CS-80:20 (50.4 kg/hr). The decline in sulphur (IV) oxide content in the blends as sawdust content increase is because sawdust has no sulphur, hence, it reduces the aggregate sulphur content. The carbonized blends showed an irregular pattern for both SO_2 and NO_2. CCS-30:70 showed the highest nitrogen (IV) oxide, and sulphur (IV) oxide values (147.6 and 23.99 kg/hr).While the blend with the lowest nitrogen (IV) oxide is CCS-50:50 (82.8 kg/hr), the blend with the lowest sulphur (IV) oxide value is CCS-60:40 (2.69kg/hr). Overall, the results revealed a significant reduction in the sulphur (IV) oxide and nitrogen (IV) oxide from the uncarbonized blends to the carbonized. Carbonization therefore reduces the quantity of obnoxious gases in solid fuels.

The coal-corn cob blend with the highest CO_2 emissions was CCC-10:90 (8377.20 kg/hr). The fuel blend with the lowest emission is CC-80:20 (6606kg/hr). The result showed no significant difference between the carbonized and uncarbonized fuel blends. The coal-corn cob blends showed close emission pattern to the coal-sawdust blends. The kilogrammes of CO_2 emission per hour was influenced by the calorific value of the individual fuels.

The kilogrammes of NO_2 and SO_2 emissions per hour respectively for all the coal-corn cob blends are CC-80:20(162.4), (45), CC60:40- (179.28), (42.16), CC-50:50 (186.48), (39.6), CC-30:70- (149.56), (22.90), CC-10:90 (146.88), (8.88), CCC-80:20 (221.40), (15.95), CCC-60:40(189.72), (22.29), CCC-50:50 (218.88), (0.54), CCC-30:70 (224.08), (6.94), and CCC-10:90(127.52), (8.88). The result shows that coal-corn cob blends have a higher nitrogen (IV) oxide emission than the coal-sawdust blends. While the average $CO_2$and SO_2gases released from the coal-corn cob blend are lower than those released from coal and

coal-sawdust blends.In an experimental analysis, the co-firing of coal and bio-waste had no adverse effect on boiler efficiency but reduced SO_2 emissions[94].

The combustion test on the fuel briquettes (Table 6) showed that the Ignition time of the coal-sawdust briquettes range from 14 ï 40 seconds, while that of the coal-corn cob briquettes was from 6 ï 31 seconds. The result reveal that the higher the biomass content (sawdust and corn cob) in the briquette, the lower its ignition time. A briquette with larger biomass content is generally expected to ignite faster. This is because of its higher volatile matter content, which consists of tars and other hydrocarbons that are combustible and have a low flash point. The volatile matter content in coal is lower and it does not easily ignite. Since, a low ignition time briquette indicates safety concerns during storage, the risk of ignition and fire is increased in briquettes with low ignition time. Thus, caution must be taken to keep briquettes free from sparks and extreme heat. All the briquettes were uncarbonized blends.The result of the afterglow time showed an irregular trend. The briquette blend CS-30:70 and CC-50:50 had the highest afterglow time of 149 seconds (2 minutes 29 seconds). The irregular pattern of the afterglow time value can be attributed to factors like duration of initial combustion, adhesion between briquette particles and ventilation during and after combustion.

The thermal efficiency of the coal-sawdust briquette (Table 7) had CS-80:20-11.5%, CS-60:40-7.2%, CS-50:50-7.8%, CS-30:70-12.9%, CS-10:90-82%. The CS-10:90 briquette has the highest thermal efficiency, while CS-60:40 briquette has the lowest thermal efficiency. This indicates that the coal-sawdust briquette CS-10:90 would be the best fuel for domestic cooking. This briquette would require the least quantity in kilogrammes to bring an amount of water to boil and evaporate. For the coal-corn cob briquettes, CC-80:20 and CC-10:90 were not thermally efficient as it did not bring the water to boil. CC-80:20 was smoldering and did not burn with good flames till it was totally burnt into ashes. This is because of the higher coal content in the briquette. CC-10:90 on the other hand burnt out so fast that it didnôt boil the water.

The thermally efficiencycoal-corn cob briquettes are CC-60:40 (15.6%), CC-50:50 (19.2%), and CC-30:70 (51%). The CC-30:70 briquette has the highest thermal efficiency among the coal-corn cob blends; the lowest thermal efficiency is CC-60:40 (15.6%). From the results, the coal-sawdust briquettes have the higher thermal efficiency, and would be a better domestic fuel than the coal-corn cob. An increase in the corn cob of the coal-corn cob briquette yielded a corresponding increase in its thermal efficiency.

The power output ranged from 1.25 to 2.46 KJ/s for the coal-sawdust briquette, and 0.99 to 2.78KJ/s for the coal-corn cob briquette. The power output is the quantity of energy released by burning a mass of briquette per time. The power output of the coal-sawdust briquette decreased with increase in biomass (sawdust) content, the reverse trend was observed in the coal-corn cob briquette, the power output increased as the biomass (corn cob) content increased. The power output of the briquette is influenced by different factors like the rate of combustion of the briquette fuel and calorific value of the briquette fuel. The briquette CS-10:90 showed the highest power output of 2.78KJ/s. The power output of the coal-sawdust and coal-corn cob was higher than the values reported by Kuti[57] who worked with charred palm kernel shell and sawdust blend.

The specific fuel consumption of the coal-sawdust briquettes were 0.49kg (CS-80:20), 0.57kg (CS-60:40), 1.14kg (CS-50:50), 0.51kg (CS-30:70), 0.57kg (CS-10:90). This is the mass of water heated per kilogramme of the fuel briquette burnt. The specific fuel consumption increased from 0.49kg in CS-80:20, and peaked at 1.14kg in CS-50:50. This shows that increasing the coal-sawdust ratio from 80:20 to 50:50 would increase the specific fuel consumption. From the briquette CS-50:50, the results declined to 0.51kg (CS-30:70) and increased slightly to 0.57kg (CS-10:90). The coal-corn cob briquettes showed lower specific fuel consumption when compared to the coal-sawdust briquettes. The specific fuel consumption of the coal-corn cob blends were CC-80:20 (0.41kg), CC-60:40 (0.52kg), CC-50:50 (0.28kg), CC-30:70 (0.35kg), CC-10:90 (0.37kg). The specific fuel consumption result is in tandem with that reported by Kuti[57] for charred palm kernel and sawdust briquette. The results show that it would require a lower quantity of coal-corn cob briquette for cooking.

The burning rate of the coal-sawdust and coal-corn cob briquettes is the rate of combustion of the briquette. The burning rate of the coal-sawdust briquettes shows a stable and decreasing trend. As the sawdust content in the blend increased from 20% in CS-80:20 to 90% in CS-10:90, the burning rate also increased. The burning rate of the coal-corn cob briquette increased as the quantity of corn cob in it increased. Overall, the briquette CC-10:90have the highest burning rate. The burning rate values are within range report by Kuti[57].

4.3 CONCLUSION

This study sought to investigate the fuel properties, as well as the environmental suitability of coal and its blends with corn cob and saw dust. Blending of biomass (corn cob

and sawdust) with coal reduced sulphur, nitrogen and nitrogen (IV) oxide of the fuel blends. Carbonization increased the calorific value, elemental carbon and fuel ratio of the fuel blends. It also reduced the percentage sulphur and sulphur oxide emitted. Among all the briquettes made from the uncarbonized fuel, Coal-sawdust briquette (CS-10:90) and Coal-corn cob briquette (CC-30:70) have thermal efficiency above 50%. Blending of solid fossil fuel like coal with biomass (e.gsawdust, corn cob and bagasse) should be encouraged in coal fired power plants to reduce environmental pollution. The use of briquettes, made from sawdust and corn cobs, as domestic fuel would effectively utilize waste materials. This would further reduce the rate of deforestation, in using firewood for cooking.

The results of this study would assist policy makers in formulating a workable National Energy Policy which would solve the problems associated with the nationôs diminishing oil reserve. These results also strengthen the need to research into other alternative energy sources that would be efficient and can be economically priced.

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APPENDICES

APPENDIX 1

EFFECT OF MOISTURE CONTENT AND ASH ON CALORIFIC VALUE

Descriptive Statistics

	Mean	Std. Deviation	N
Calorific Value Kj/Kg	22135.3974	3729.96969	23
Moisture Content %	4.8726	2.59129	23
Ash %	8.1230	4.56008	23

Correlations

		Calorific Value Kj/Kg	Moisture Content %	Ash %
Pearson Correlation	Calorific Value Kj/Kg	1.000	-.798	.812
	Moisture Content %	-.798	1.000	-.781
	Ash %	.812	-.781	1.000
Sig. (1-tailed)	Calorific Value Kj/Kg	.	.000	.000
	Moisture Content %	.000	.	.000
	Ash %	.000	.000	.
N	Calorific Value Kj/Kg	23	23	23
	Moisture Content %	23	23	23
	Ash %	23	23	23

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.853[a]	.728	.701	2040.76639

a. Predictors: (Constant), Ash %, Moisture Content %

b. Dependent Variable: Calorific Value Kj/Kg

ANOVA[a]

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	222784276.143	2	111392138.071	26.747	.000[b]
	Residual	83294549.250	20	4164727.463		
	Total	306078825.393	22			

a. Dependent Variable: Calorific Value Kj/Kg

b. Predictors: (Constant), Ash %, Moisture Content %

APPENDIX2

EFFECT OF CARBONIZATION ON THE CALORIFIC VALUE, VOLATILE MATTER AND FIXED CARBON

Descriptive

SAMPLES

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
VOLATILE MATTER	10	17.5250	3.37111	1.06604	15.1135	19.9365	13.13	24.39
FIXED CARBON	10	69.2010	2.51849	.79642	67.3994	71.0026	62.69	71.00
CALORIFIC VALUE	10	25182.4620	1528.78692	483.44487	24088.8337	26276.0903	22681.86	27132.22
Total	30	8423.0627	12083.34592	2206.10704	3911.0671	12935.0582	13.13	27132.22

ANOVA

SAMPLES

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	4213175342.257	2	2106587671.128	2703.981	.000
Within Groups	21034864.404	27	779069.052		
Total	4234210206.661	29			

Post Hoc Tests

Duncan[a]

CARBONIZATION	N	Subset for alpha = 0.05	
		1	2
VOLATILE MATTER	10	17.5250	
FIXED CARBON	10	69.2010	
CALORIFIC VALUE	10		25182.4620
Sig.		.897	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 10.000.

APPENDIX3

EFFECT OF BLENDING ON THE CALORIFIC VALUE

Descriptive

Calorific Value Kj/Kg

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
1	2	24576.9250	2091.79864	1479.12500	5782.8599	43370.9901	23097.80	26056.05
2	2	20429.9450	556.54253	393.53500	15429.6087	25430.2813	20036.41	20823.48
3	2	19183.5200	640.83673	453.14000	13425.8304	24941.2096	18730.38	19636.66
4	2	18994.3850	639.68415	452.32500	13247.0509	24741.7191	18542.06	19446.71
5	2	17535.8950	2050.95615	1450.24500	-891.2149	35963.0049	16085.65	18986.14
6	2	24450.1200	1056.48824	747.05000	14957.9498	33942.2902	23703.07	25197.17
7	2	26917.1800	304.11248	215.04000	24184.8377	29649.5223	26702.14	27132.22
8	2	24715.9850	2876.68716	2034.12500	-1130.0237	50561.9937	22681.86	26750.11
9	2	24432.0500	630.31498	445.70000	18768.8945	30095.2055	23986.35	24877.75
10	2	25396.9750	1552.03575	1097.45500	11452.4871	39341.4629	24299.52	26494.43
Total	20	22663.2980	3365.67795	752.58847	21088.1122	24238.4838	16085.65	27132.22

ANOVA

Calorific Value Kj/Kg

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	193226230.801	9	21469581.200	9.758	.001
Within Groups	22001742.548	10	2200174.255		
Total	215227973.349	19			

Mean Plots of Calorific Values