

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background of the study

Biomass, particularly agricultural residues seem to be one of the most promising energy resources for developing countries (Patomsok, 2008). Rural households and minority of urban dwellers depend solely on fuel woods (charcoal, firewood and sawdust) as their primary sources of energy for the past decades (Onuegbu, 2010). Of all the available energy resources in Nigeria, coal and coal derivatives such as smokeless coal briquettes, bio-coal briquettes, and biomass briquettes have been shown to have the highest potential for use as suitable alternative to coal/ fuel wood in industrial boiler and brick kiln for thermal application and domestic purposes. Global warming has become an international concern. Global warming is caused by green house gasses which carbon dioxide is among the major contributors. It was shown that increased emissions of CO<sub>2</sub> have been drastically reduced owing to the fact that the rate of deforestation is higher than the afforestation effort in the country.

The use of fuel wood for cooking has health implications especially on women and children who are disproportionately exposed to the smoke apart from environmental effects. Women in rural areas frequently with young children carried on their back or staying around them, spend one to six hours each day cooking with fuel wood. In some areas, the exposure is even higher especially when the cooking is done in an unventilated place or where fuel wood is used for heating of rooms. Generally, biomass smoke contains a large number of pollutants

which at varying concentrations pose substantial risk to human health. Among hundreds of the pollutants and irritants are particulate matters, 1, 2-butadiene and benzene (Schirnding and Bruce, 2002). Studies showed that indoor air pollution levels from combustion of bio fuels in Africa are extremely high, and it is often many times above the standard set by US Environment Protection Agency (USEPA) for ambient level of these pollutants (USEPA, 1997). Exposure to biomass smoke increases the risk of range of common diseases both in children and in adult. The smoke causes acute lower respiratory infection (ALRI) particularly pneumonia in children (Smith and Samet, 2000; Ezzati and Kammen, 2001).

Agro waste is the most promising energy resource for developing countries like ours. The decreasing availability of fuel woods has necessitated that efforts be made towards efficient utilization of agricultural wastes. These wastes have acquired considerably importance as fuels for many purposes, for instance, domestic cooking and industrial heating. Some of these agricultural wastes for example, coconut shell, wood pulp and wood waste can be utilized directly as fuels.

Fortunately, researches have shown that a cleaner, affordable fuel source which is a substitute to fuel wood can be produced by blending biomass (agricultural residues and wastes) with coal. Nigeria has large coal deposit which has remained untapped since 1950's, following the discovery of petroleum in the country. Also, millions of tones of agricultural wastes are generated in Nigeria annually. But it is unfortunate that farmers still practice "slash-and-burn" agriculture.

These agricultural wastes they encounter during clearing of land for farming or during processing of agricultural produce are usually burnt off. By this practice,

not only that the useful raw materials are wasted, it further pollutes the environment and reduces soil fertility.

On the other hand, the majority of the huge materials are not suitable to be used directly as fuel without undergoing some processes. This is probably as a result of inappropriate density and high moisture contents and these factors may cause problems in transportation, handling and storage. Most of these wastes are left to decompose or when they are burnt, there would be environmental pollution and degradation (Jekayinfa, and Omisakin, 2005). Researchers have shown that lots of potential energies are abounding in these residues (Fapetu, 2000). Hence, there is a need to convert these wastes into forms that can alleviate the problems they pose when use directly. An assessment of the potential availability of selected residues from maize, cassava, millet, plantain, groundnuts, sorghum, oil palm, palm kernel, and cowpeas for possible conversion to renewable energy in Nigeria has been made (Jekayinfa and Scholz, 2009).

However, these health hazard faced by people from the use of fuel wood, along with the agricultural wastes management and reduction of pressure mounted on the forest can be mitigated if Nigeria will switch over to production and utilization of bio-coal briquette; a cleaner, and environmental friendly fuel wood substitute made from agricultural wastes and coal. Moreover, this will offer a good potential for utilization of a large coal reserve in Nigeria for economic diversification and employment generation through bio-coal briquette.

In countries like Japan, China and India, it was observed that agricultural waste (agro residues) can also be briquetted and used as substitute for wood fuel. Every year, millions of tonnes of agricultural waste are generated. These are either not used or burnt inefficiently in their loose form causing air pollution to the

environment. The major residues are rice husk, corn cob, coconut shell, jute stick, groundnut shell, cotton stalk, etc. These wastes provide energy by converting into high-density fuel briquettes. These briquettes are very cheap, even cheaper than coal briquettes. Adoption of briquette technology will not only create a safe and hygienic way of disposing the waste, but turn into a cash rich venture by converting waste into energy and also contributing towards a better environment.

Coal can be blended with a small quantity of these agricultural waste (agro residues) to produce briquettes (bio-coal briquettes) which ignites fast, burn efficiently, producing little or no smoke and are cheaper than coal briquettes.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Briquetting Process

A briquette is a block of compressed coal, biomass or charcoal dust that is used as fuel to start and maintain fire (Grainger *et al*, 1981).

Briquetting is a mechanical compaction process for increasing the density of bulky materials. This process is used for forming fine particles into a designed shape. It can be regarded as a waste control measure in the case of production of briquettes from agricultural wastes. However, depending on the material of interest, briquetting can be used to provide fuel source as a preventive measure to many ecological problems. Briquetting is a high-pressure process which can be done at elevated temperature (Zhanbin, 2003) or at ambient temperature (Mohammad, 2005) depending on the technology one wants to employ.

During this process, fine material is compacted into regular shape and size which does not separate during transportation, storage or combustion. In some briquetting techniques, the materials are simply compressed without addition of adhesive (binderless briquettes) (Mangena and Cann, 2007) while in some, adhesive material is added to assist in holding the particles of the material together.

Generally, briquetting process has focused more on the production of smokeless solid fuels from coal and agricultural wastes. There are various techniques which have been used to produce smokeless solid fuel from coal fine. The most common technique is the use of roller press using only moderate pressure and binder. Note that the machines employed for this process are also used to make other kind of

non-fuel briquettes from inorganic materials such as metal ores. However, briquetting of organic materials (agricultural wastes) requires significantly higher pressure as additional force is needed to overcome the natural springiness of these materials. Essentially, this involves the destruction of the cell walls through some combination of pressure and heat. High pressure involved in this process suggests that organic briquetting is costlier than coal briquettes.

Various briquetting machines have been designed, ranging from very simple types which are manually operated to more complex ones mechanically or electrically powered. Generally, briquetting operations have developed in two directions, mechanically compression (hydraulic or pistons) and worm screw pressing types.

## **2.2 Historical Background of Briquetting Process**

Although, compaction of loose combustible materials for fuel making purposes is a technique which has been in existence thousands of years ago but industrial method of briquetting seems to be dated back to eighteenth century. In 1865, report was made on machines used for making fuel briquettes from peats and are recognized as the predecessors of the present briquetting machines. Since then, there has been a wide spread use of briquettes made from brown coal and peat etc.

The use of organic briquettes (biomass briquettes) started more recently compared to coal briquette. It seems to have been common during world war and during the 1930s depression. The modern mechanical piston briquetting machine was developed in Switzerland based upon German development in the 1930s. Briquetting of saw dust are widespread in many countries in Europe and America during World War 11 because of fuel shortages. However, after the World War, briquettes were gradually phased out of the market because of availability and cheapness of hydrocarbon fuels.

Common types of briquettes so far in use are coal briquettes, peat briquettes, charcoal briquettes, and biomass briquettes, etc. Most recently, researchers have studied the effect of blending of coal and biomass such as enhancing the properties of coal briquettes using spear grass (Onuegbu *et al*, 2010a), enhancing the Efficiency of coal Briquette in Rural Nigeria using pennisetumpurpurem (Onuegbu *et al*, 2010b). Onuegbu *et al*, (2012)

### **2.3 Advantages of briquette production:**

Briquette production will:

- i. Provide a cheap source of fuel for domestic purposes, which will be affordable by all Nigerians.
- ii. Provide a good means of converting coal fines, low rank coal, and waste agro residue into a resourceful substance of economic value.
- iii. Help to conserve some of natural resources since it is a good substitute for fire wood. Therefore, it will help to reduce the quantity of firewood, oil and gas that is used in the production of energy for domestic uses and generating plants.
- iv. Help to develop the demand for coal. Coal is used in making bio-coal and coal briquette. This will in turn promote coal mining which seems dormant for sometime.
- v. Create employment opportunities for people since people will be needed to operate the briquette machine, get the raw materials (i.e. coal and agro-residue, etc.), sell the briquettes produced, etc (Bhattacharya, 1985).

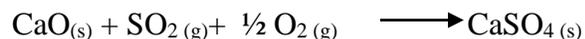
### 2.3.1 Bio-Coal Briquettes

Bio-coal briquette is a type of solid fuel prepared by blending coal, biomass, binder, and sulphur fixation agent. Other additives may also be added. A research showed that bio-coal briquettes may be prepared by blending the following (Mohammad, 2005):

- Biomass (25% to 50%)
- Coal (75% to 50%)
- Sulphur fixation agent (up to 5%)
- Binder (up to 5%)

In this process,  $\text{Ca(OH)}_2$  acts as both sulphur fixation agent and the binder.

The high pressure involved in the process ensures that the coal particles and the fibrous biomass material interlace and adhere to each other as a result, do not separate from each other during combustion, transportation and storage. During combustion, the low ignition temperature of the biomass simultaneously combusts with the coal. The combined combustion of both gives a favourable ignition and fire properties; emits little dust and soot, generates sandy combustion ash. Also, the desulphurizing agent such as  $\text{Ca(OH)}_2$  in the briquette effectively reacts with the sulphur content of the coal to fix about 60-80% of it into the ash (<http://www.nedo.go.jp/sekitan/cc.eng-pdf/2-3c3pdf>). It was showed that lime ( $\text{CaO}$ ) as a desulphurizing agent was able to capture up to 90-95% of the total sulphur in the coal, leaving only 5-10% emitted as sulphur oxides. The equation of the reaction is as follows:



Evidence also showed that lime when used as desulphurizer also acts as a binder. Also clay has been reported to be a good desulphurizing agent. Clay contains CaO and MgO which acts as desulphurizing agents. Also it contains Fe<sub>2</sub>O<sub>3</sub> which has been shown to have a catalytic effect on the sulfation reaction (Somchai *et al.*, 1988).

There are various biomass resources available for production of biomass briquettes. Some of them are straw, sugar bagasse (fibrous residue of processed sugar cane), corn stalk, groundnut – shell, wheat straw, palm husk, rice husks, corn cob, forest wastes, and other agricultural wastes. Several researches on bio-coal briquette have been carried out using some of these biomass resources.

Furthermore, it has been shown that many grades of coal can be used for bio-coal production, even low grade coal containing high sulphur contents (Patomsok, (2008). This implies that, by this technology, extra cost of carbonizing low grade coal before briquetting is saved. Binder is an adhesive material which helps to hold the particles of the material together in the briquette. Apart from its function to hold the particle from separation, it also protects the briquette against moisture in case of long storage. There are several binders that can be used some of them are starch (from various starchy root such as cassava, and cereals), molasses, clay and tree gum etc. some chemical substances have also been used as binding agent for production of briquettes. Some of them are asphalt, magnesia and pitch. Though, the use of starch as binder is satisfactory in every respect, it disintegrates under moist or tropical condition. However, the use of small additional hydrocarbon binder such as pitch or bitumen has been reported to improve the water resisting property (Wilfred and Martin, 1980). Moreover, the nature of the binder has influence in the combustibility of the briquette produced. For instance, briquette produced using clay takes longer time to ignite than the one produced using starch.

### **2.3.2 Characteristics of Bio-Coal Briquettes**

(1) Bio-coal briquette decreases the generation of dust and soot up to one-tenth that of direct combustion of coal (<http://www.nedo.go.jp/sekitan/cc.eng-pdf/2-3c3pdf>). Combustion of coal generates dust and soot because, during the combustion, the volatile components of the coal are released at low temperature (200-400°C) as incomplete combusted volatile matter.

(2) Bio-coal briquette has a significant shorter ignition time when compared with coal or conventional coal briquette Biomass has low ignition time.

(3) Bio-coal briquette has superior combustion-sustaining properties. Because of low expansibility and caking properties of bio-coal briquette, sufficient air flow is maintained between the briquettes during combustion in a fire-place. Hence it has very good combustion-sustaining properties and does not die out in a fireplace or other heater even when the air supply is decreased. This property offers the opportunity of adjusting the combustion rate of the bio-coal briquette easily.

(4) Bio-coal briquette emits less SO<sub>2</sub>. It contains desulphurizing agent and the high pressure involved in the process enables the coal particles to adhere strongly to the desulphurizing agent. During combustion, the desulphurizing agent effectively reacts with the sulphur content of the coal to form a solid compound instead of being released as oxides of sulphur to the atmosphere. However, it is widely accepted that bio-coal briquette technology is one of the most promising technologies for the reduction of SO<sub>2</sub> emission associated with burning of coal (Patomsok, 2008).

(5) Bio-coal briquette has high breaking strength for easy transportation. The high pressure involved in the process coupled with the binder, compressed the raw

material into a rigid mass which does not break easily, hence can be stored and transported safely

(6) Bio-coal briquette generates sandy ash which can be utilized in agriculture for soil improvement. In the briquette, since the fibrous biomass intertwined with the coal particles, the resulted ash after combustion does not adhere or form clink-lump; therefore, the ash is always sandy.

(7) Bio-mass briquette burns nearly perfect; therefore the flame has significant higher temperature than simple biomass burning or coal (Hayami, 2001).

### **2.3.3 Advantages of bio-coal briquettes:**

1. Briquette from biomass and coal are cheaper than briquette from coal. This is so, since some of the biomass materials used are of less economic importance and are always left to waste, except in cases where they are to be used, which is rare.

2. High sulphur content of oil and coal when burnt pollutes the environment. In bio-coal briquettes, part of the coal is substituted with biomass; hence the sulphur content is reduced (Bhattacharya, 1985).

3. Bio-coal briquettes have a consistent quality high burning efficiency, and are ideally sized for complete combustion.

4. Combustion of bio-coal briquettes produces ashes which can be added to soil to improve soil fertility.

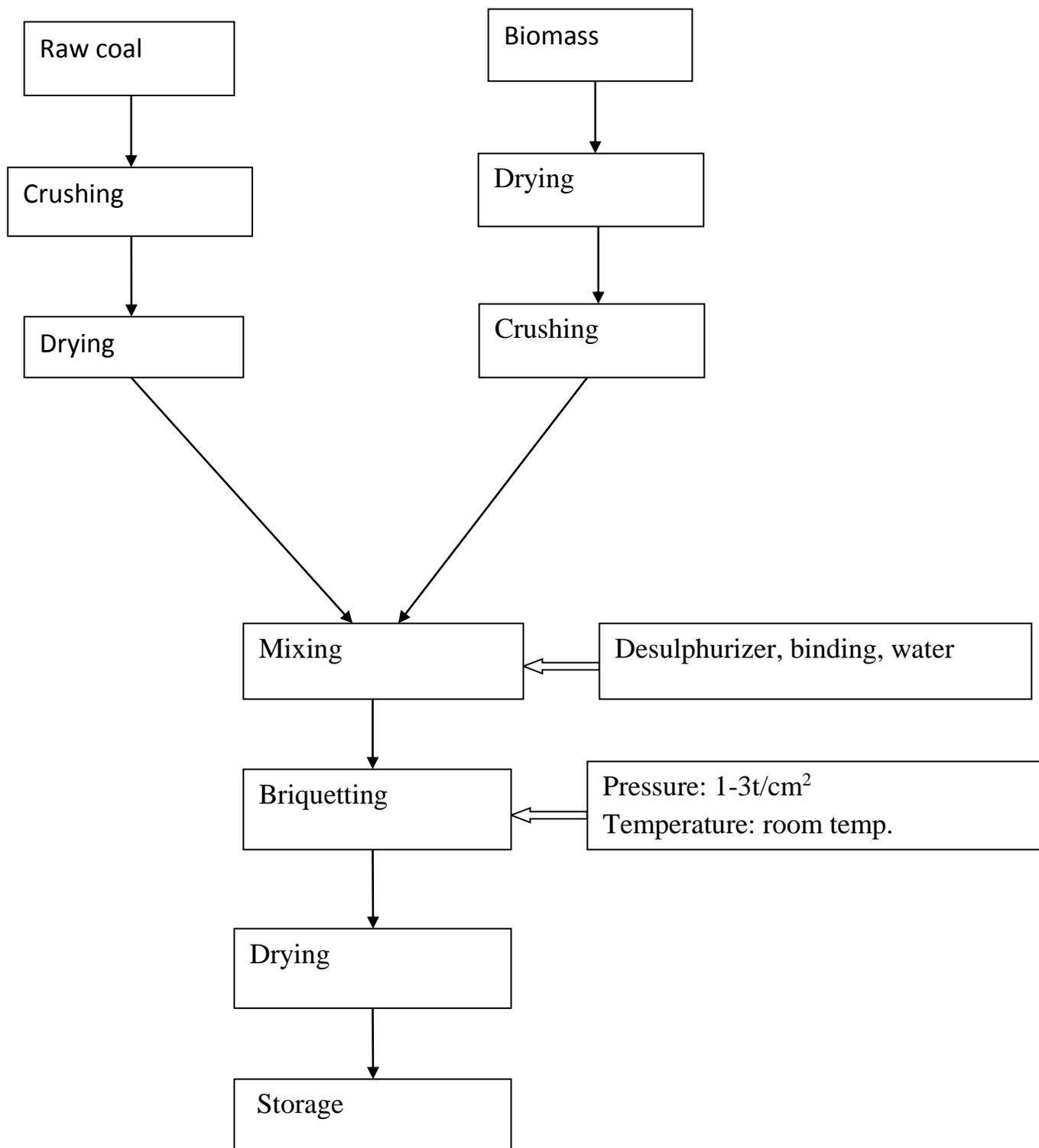
5. Bio-coal briquettes are usually produced near the consumption centers and supplies do not depend on erratic transportation from long distance.

Based on these facts, bio-coal can replace the following conventional fuels that are used in mass quantities: diesel, kerosene, furnace oil, fire wood, coal, lignite, etc.

### **2.3.4 Production Process of Bio-Coal Briquette**

The production process of bio-coal briquette is very simple and cost effective. The raw materials; coal and biomass are pulverized to a size of approximately 3mm, and then dried. Research showed that 0-5mm is the optimum particle size of the raw materials for a briquette. The dried pulverized materials, a desulphurizing agent and binder are mixed together in appropriate proportions and are compressed with briquette machine into a designed shape. The type of briquetting machine determines the shape and size of the briquette. Some briquette machines have small mould while some have relatively larger mould. For a large mould, there is always a facility which creates holes in the briquettes when formed. These holes are necessary for efficient combustion of the briquette. It allows for proper flowing of air needed to maintain the combustion.

In this production process, high temperature is not required. The process is simple, safe and does not require skilled operating technique. Hence the process can easily be adopted and sustained in Nigeria. Fig.1 shows the basic process flow for bio-coal production.



**Fig 1: The basic flow process for bio-coal production.**

### 2.3.5 Preparation of other types of Briquettes

As it has been mentioned earlier, briquette is a kind of solid smokeless fuel produced by compressing pulverized raw materials under high pressure at ambient or elevated temperature. The raw materials are generally coal and biomass of various forms. The name given to any fuel briquette depends on the materials of which it was made. For instance, common briquettes: charcoal briquettes, biomass briquettes and coal briquettes are prepared as follows:

**Charcoal briquettes:** Charcoal briquette is a common type of briquette made by compressing pulverized wood charcoal with a binder. However, other activator such as sodium nitrate is added as an accelerant.

**Biomass briquettes:** Biomass briquette is made from agricultural wastes. It is a renewable source of energy. Lignin and cellulose are the two major compounds of biomass. The lignin distributed among cellulose determines the structural strength of biomass. Lignin is a non-crystallized aromatic polymer with no fixed melting point. When heated to 200-300°C, lignin melts and liquefies. When pressure is applied in this case, the method lignin glues the cellulose together; hence the biomass is briquetted when cooled. This method of production of biomass briquette is based on lignin plasticization mechanism. However, biomass briquette can also be produced at room temperature by the application of another briquetting technique; in that case binder is used.

**Coal briquette:**Coal briquettes are made by compressing finely divided coal particles. The coal is dried, crushed into appropriate particle sizes. Binder desulphurizing agents are added, and then the material is compressed into briquette. Also, coal briquette can be produced by first carbonizing the coal before

it is used. During the carbonization, some of the volatile components of the coal are driven off.

## **2.5 Coal**

Coal was formed by the remains of vegetable that were buried under ground million of years ago under great pressure and temperature in the absence of air. Coal is a complex mixture of compounds composed mainly of carbon, hydrogen and oxygen with small amounts of sulphur, nitrogen, and phosphorus as impurities.

## **2.6. Biomass Resources of Nigeria**

Biomass is organic non-fossil material of biological origin. The biomass resources of Nigeria can be identified as wood, forage, grasses and shrubs, animal waste, and waste arising from forest, agricultural, municipal and industrial activities as well as aquatic biomass. Generally, biomass can be converted into energy either by thermal or biological process.

Biomass energy resources base in Nigeria is estimated to be about 144 million tonnes per year. Nigeria has about 71.9 million hectares of land considered to be arable and grasses of different kinds are among the major agricultural purposes. The potential for the use of biomass as energy source in Nigeria is very high. This can be explained from the fact that about 80% of Nigerians are rural or semi-urban dwellers and they depend solely on biomass for their energy source. Biomass may be used directly as energy source for heating or are better converted to a cleaner fuel source. For-instance, conversion of wood into charcoal and biomass based briquettes is always encouraged. Other energy sources that are got from biomass include: biogas, biodiesel and bio-ethanol etc. All these energy sources have been shown to have better combustion performance and are more environmental friendly than direct combustion of biomass.

However, owing to the fact that firewood is the energy choice of the rural dwellers and the urban poor, pressure is mounted on the forest in search of fuel wood while on the other hand, vast majority of other biomass resources in form of agricultural wastes are wasted either deliberately or inadvertently. Meanwhile, researches have proved that this category of biomass resources can be converted to better fuel sources compared to fire wood, and at the same time, act as pollution control measures.

### **2.6.1 Bio-coal briquette:**

They are briquettes formed by blending coal with vegetable matter (biomass), and then treating with desulphurizing agent ( $\text{Ca}(\text{OH})_2$ ), using an amount corresponding to the sulphur content in the coal. When high pressure is applied in the briquetting process, the coal particles and fibrous vegetable matter in the bio-briquette strongly intertwined and adhere to each other, and do not separate from each other during combustion (<http://www.nedo.go.jp/sekitan/cc.eng-pdf/2-3c3pdf>).

### **2.6.2 Charcoal:**

Types of charcoal are: wood charcoal, sugar charcoal, and animal charcoal. They are produced by burning wood, sugar and animal refuse (blood, bones), respectively in limited supply of oxygen. Wood charcoal is a common fuel source used by some people. It is a cleaner fuel source than fuel wood. In fact, analysis shows that transition from fuel wood to charcoal would have been a best option for reducing exposure to indoor pollution but such transition could lead to even more severe environmental degradation and fuel scarcity as more wood is needed per meal using charcoal compared to fuel wood.

## **2.7 Starches as a Binder**

Starch is a white granule organic chemical compound that occurs naturally in all green plants. The percentage of occurrence varies with plant and in different parts of the same plant. The natural function of the starch is to provide a reserve food supply for the plant. Starch can be extracted from many kinds of plants, only a few plants can yield starch in commercial quantities. Such plants are maize, potato, rice, sorghum and cassava, etc.

Cassava plants are the major source of starch. The plant thrives in the equatorial region between the tropics of capricorn, and as well it thrives very well in Nigeria. There are many varieties of cassava plants of which two varieties-bitter and sweet varieties are widely grown for the purpose of manufacturing of starch. They contain high content of starch which ranges from 12-33%. A typical composition of the cassava root is moisture (70%), starch (24%), fiber (2%), protein (1%) and other substance including materials (3%).

When starch is cooked, it gelatinizes to form viscous solution with water. The starch granules begin to swell as they are heated in water until they absorb most of the water and starch paste which differs in clarity, texture and gelling strength is formed. Cassava starch has numerous industrial uses. They are used as an additive in cement to improve the setting time. It is used to improve the viscosity of drilling moulds in oil wells. It is used to seal the walls of bore holes and prevent fluid loss. It is used in the main raw material in glue and adhesive industries. In briquetting industries, it is widely used as a binder. Briquette produced using starch as the binder is easily ignitable and burns with less ash deposit.

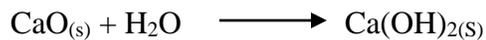
### 2.7.1 Binders used in the production of bio-coal briquettes:

Binders are substances, organic or inorganic, natural or synthetic, that can hold (bind) two things or something together. Two types are combustible and non-combustible binders.

Combustible binders are binders that support combustion and can burn. Examples are starch, petroleum residues, molasses, cottonseed oil etc. Non-combustible binders are binders that cannot support combustion examples are clay, cement, limestone, etc. Starches have proved very satisfactory as binders.

### 2.7.2 Calcium Hydroxide

Calcium hydroxide is also known as slaked lime, hydrated lime, slake lime or picking lime. It is a chemical compound with the formula,  $\text{Ca(OH)}_2$ . It is a white powder or colourless crystal. Commercially, it is produced when calcium oxide ( $\text{CaO}$ ) (also known as quick lime or lime) is mixed with water. This process is known as slaking of lime.



Naturally, calcium hydroxide occurs in mineral form called portlandite. Portlandite is a relatively rare mineral known from some volcanic, plutonic, and metamorphic rocks. It has also been known to arise in burning of coal dumps.

Quicklime is a white solid obtained when limestone (calcium trioxocarbonate (iv)) is heated to a very high temperature, about  $900^\circ\text{C}$ .



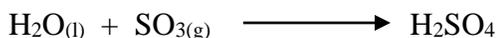
In Nigeria, calcium hydroxide is expected to be very cheap and available in abundance because there is large deposit of limestone in the country and besides, the production of calcium hydroxide is a simple process. Many investigations have shown that calcium hydroxide is an effective sulphur fixation agent (Desulphurizing agent) for production of briquettes.

### 2.7.3 Environmental issues.

Coal contains carbon, hydrogen, sulphur, and other minerals. When coal is burnt, carbon, hydrogen and sulphur react with oxygen in the atmosphere to form carbon (iv) oxide, water and sulphur (iv) oxide. The sulphurdioxide can react with more oxygen to form sulphur trioxide, SO<sub>3</sub>.



The SO<sub>3</sub> dissolves readily in water droplets in the atmosphere to form an aerosol of sulphuric acid which falls as rain.



When inhaled, the sulphuric acid aerosol is small enough to be trapped in the lung tissues, where they cause severe damage. Acid rain destroys vegetation and forest as well as life in the sea, lake, ocean, streams, etc. Also, CO<sub>2</sub> is produced when coal is burnt. The total quantity of CO<sub>2</sub> released by the human activities of deforestation and burning of fossil fuel is 6-7 billion metric tonnes per year. Carbon (iv) oxide causes global warming and depletes the ozone layer.

Bio-coal briquette contains less percentage of coal than in coal briquette (since there is partial substitution of coal with biomass). Hence, there will be lesser emission of carbon, sulphur, dust, etc, into the environment.

In order to reduce the emission of these gases into the environment, lime based products such as  $\text{Ca}(\text{OH})_2$  can be incorporated into the mixture to fix the pollutants to the sandy ash, or the coal can be carbonized.

Since the use of bio-coal briquettes will reduce cutting down of trees for the purpose of using them as fire wood, briquette technology can serve as global warming countermeasure by conserving forest resources which absorbs  $\text{CO}_2$ , through provision of bio-coal briquettes.

#### **2.7.4 Groundnut shell as an appropriate residue for the production of bio-coal briquette.**

Groundnuts, *Arachis hypogea*, are legumes whose fruits are formed underground; each fruit or nut usually contains two or three seeds, enclosed by the shell. It is one of most important annual cash crops grown in West Africa. In Nigeria, the crop is grown mainly in Kano State, but also in the Sokoto, Bornu and Kaduna States.

Groundnuts require rich, light, sandy loam soils, since such light soils allow the ovary to push easily into the soil, making harvesting easier. It requires annual rainfall of 80-120cm, abundant sunshine and fairly high temperatures. These conditions are obtained in the savanna areas.

Groundnuts are propagated by seed. Planting is done with the early rains in March-April in South, and May-June in the North. Groundnuts reach maturity in 4-5 months. In wetter areas, groundnuts are harvested in August, while in the drier savannah, harvesting is done in October-November. Harvested pods are spread on concrete floors or plat forms to dry. They are beaten with sticks or pounded or

using threshing machine to remove the shells. This is called shelling or decortications machine to remove the shells. The seeds are separated from the shells by winnowing or using a shelling machine. The seeds are further dried and packed in jute bags, while the shells are dried and kept (Akinyosoye, 1993).

Groundnuts are normally baked before eating. Groundnut oil is used in cooking and also in the manufacture of margarine and soap. It is also used in canning sardines. The solid portion which remains after the oil is extracted is used in the manufacture of biscuits and for animal feed in the form of groundnut cake. This cake is richer in protein than other cake such as palm kernel and coconut cakes. Groundnuts may be crushed and used as a fodder crop or ploughed into the soil as organic manure. It is a most useful rotational crop since it enriches the soil with nitrogenous material. Groundnut shell is obtained after the groundnut seeds have been removed from the pod. Hence, it is an agro residue.

### **2.7.5 Analysis of groundnut shell**

Table 1: Chemical composition of groundnut shell.

Constituent	Percentage
Cellulose	65.7
Carbohydrate	21.2
Protein	7.3
Mineral	4.5
Lipids	1.2

### **2.7.6 Uses of groundnut shell.**

Groundnut shell is used as fuel, for manufacturing coarse boards, cork substitutes, etc. Groundnut shell can also be grounded and mixed with feed, to be used in feeding livestock. A recent experiment carried out, showed that groundnut shell can be used as partial replacement of ordinary Portland cement. In the experiment, the ash analysis of the groundnut shell was carried out, and it was observed that the constituents in groundnut shell (which was given in the table above) have cement properties that would be beneficial to the concrete.

Groundnut shell, when ground is an appropriate agro waste for the production of bio-coal briquettes, since it burns smoothly and very fast when it is dried.

#### **The aim of the research:**

The aim of the research work is to investigate the effect of the use of groundnut shell on the properties of coal briquettes.

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.0 MATERIALS AND METHOD**

##### **3.1 Materials and their sources:**

- i. Coal: Sub-bituminous coal was obtained from Onyeama mine, Enugu, Enugu State.
- ii. Groundnut shell: This was obtained from Ogbete market, Enugu (i.e. cooked groundnut shell) from eat cooked groundnut.
- iii. Cassava starch: This was bought from Ogbete market, Enugu.
- iv. Calcium hydroxide was bought from a chemical shop in Enugu, Enugu State.

##### **3.2 Apparatus used for the experiment:**

1. Triple beam balance, model: MB-2610g.
2. Manually hydraulic briquetting machine.
3. Bunsen burner.
4. Muffle furnace.
5. Desiccator.
6. Thermometer.
7. Stop watch.

8. Electrically operated hammer milling machine.
6. Mortar and pestle.
7. Basin.
8. Aluminum kettle (2litres).
9. 1000ml plastic basin.
10. Crucibles / aluminum pans.
11. Conical flask (250ml, 500ml, etc).
12. Burette.
13. Atomic Absorption spectrophotometer. Buck scientific model 210 VGP.
14. Measuring cylinder (1000ml, 500ml, and 100ml).
15. Analytical balance, sensitive to 0.1mg.
16. Meter rule.
17. Volumetric flasks (250ml).
18. Filter paper.
19. Sieves

### **3.3 Reagent used for the experiment.**

1. Calcium hydroxide.
2. Hydrochloric acid.

3. Nitric acid.
4. Hydrofluoric acid.
5. Distilled water.
6. Phenolphthalein indicator.
7. Methyl orange indicator.

### **3.4 Preparation of materials:**

Coal: The coal from Onyeama mine was crushed and ground to fine powder using an electrically operated hammer milling machine. The coal powder obtained after grinding was sieved to obtain coal of particle size 1mm in diameter.

### **3.5. Determination of the colour and texture of the raw materials:**

The colour and texture of the raw materials were determined using physical method. A small quantity of each material was placed in a petri dish. They were closely looked at to observe their colour, and felt with the fingers to observe their texture.

#### **3.5.1 Determination of the chemical composition of the raw materials**

Digestion of the samples (Aqua regia method):

0.2g of the ground samples was weighed into a crucible. 10mls of aqua regia (prepared by mixing conc. HCl and HNO<sub>3</sub> at a ratio of 3:1) was added into the

crucible and 5mls of hydrofluoric acid was added. The whole mixture was thoroughly stirred using a spatula. The crucible was properly covered and put into an oven set at 100°C for 2hrs, after which the sample got digested. It was allowed to cool down. The mixture was transferred using a funnel into a 250ml volumetric flask. The crucible was rinsed with distilled water and then poured into the volumetric flask. The content of the volumetric flask was made up to 250ml mark of the volumetric flask. A portion of the mixture was then sent for AAS analysis.

### **3.5.2 Proximate analysis of the raw materials:**

#### **a. Determination of the moisture content of the raw materials.**

An aluminum pan of known weight was put in a drying oven for 3hrs at 105°C. The aluminum pan was put in a desiccator to cool down. The aluminum pan was reweighed and the weight was noted. Then 1g of the sample was measured out. The sample and aluminum pan were put in a drying oven set at 105°C and was left for 6hrs. The pan and its contents was removed and put in a desiccator, allowed to cool to room temperature and reweighed. This was repeated until the weight after cooling was constant within 0.3mg. This was recorded as the final weight.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight of sample} - \text{final weight of sample}}{\text{Initial weight of sample}} \times 100$$

#### **b. Determination of the volatile matter in the samples:**

Volatile matter is defined as those products, exclusive of moisture, given off by a material as gas or vapour. The volatile matter of the sample was determined using

the Meynell method. The residual dry sample from moisture content determination was preheated at 300°C in a furnace for 2hrs to drive off the volatiles. The resulting sample was further heated at 470°C for 2hrs (just before the materials turns black i.e. before it ashes).

Volatile matter = weight of residual dry sample – weight of dry sample after heating

$$\text{Volatile matter (\%)} = \frac{\text{loss in weight due to removal of volatile matter}}{\text{Weight of sample taken}} \times 100$$

**c. Determination of the ash content of the raw materials**

1g of a 105°C dried test sample was measured and heated in a furnace at 590°C, and left in a desiccator to cool down to room temperature, and weighed. This was repeated for 1hr interval until the weight was constant. This weight was recorded as the final weight of the ash.

$$\text{Ash content (\%)} = \frac{\text{weight of ash}}{\text{Initial weight of dried sample}} \times 100$$

**d. Determination of the carbon content of the raw materials.**

Carbon content refers to the percentage of carbon present in a particular sample. The carbon content was determined using the Walkey-Black method. About 0.005-0.1g of the sample was weighed into a 500ml conical flask. 1ml of 1M K<sub>2</sub>CrO<sub>7</sub> was added into the flask, followed by 20ml of concentrated H<sub>2</sub>SO<sub>4</sub> (this is to digest the

sample so that the organic component in the sample will breakdown). The mixture was allowed to cool down for about 20 minutes. 200mls of distilled water was added to dilute the mixture. Then a pinch of NaF was added (to give a clear end point). 1ml of diphenylamine (this serve as an indicator) was also added into the flask. The mixture was shaken thoroughly, and titrated with 1M FeSO<sub>4</sub>. The colour changes from purple to dirty green.

#### **e. Determination of the fixed carbon content of the raw materials**

Fixed carbon represents the quantity of carbon that can be burnt by a primary current of air drawn through the hot bed of a fuel (Moore and Johnson, 1999).

The fixed carbon content of the samples was calculated using the following relation:

Fixed carbon content (%) = 100 – (moisture content (%) + volatile matter (%) + Ash content (%)).

### **3.6 Bio-coal briquette formulation.**

Bio-coal briquettes were formulated using different percentages of groundnut shell and coal. The ratio of coal to biomass made were 100:0, 90:10, 85:15, 80:20, 75:25, 70:30. The quantity of the calcium hydroxide used was 20% of the whole briquette as shown in Table 2.

---

**Table.2: Bio-coal briquette formulation.**

---

Raw materials	100:0	90:10	85:15	80:20	75:25	70:30
Starch (g)	70	70	70	70	70	70
Coal (g)	280	252	238	224	210	196
Biomass (g)	0	28	42	56	70	84
Ca(OH) <sub>2</sub> (g)	14.0	12.6	11.9	11.2	10.5	9.8
Water (ml)	250	250	250	250	250	250

---

**Procedure:**

A specific quantity of starch, biomass, coal and Ca(OH)<sub>2</sub> were weighed out using a triple beam balance into a 100ml plastic basin. They were mixed thoroughly until a homogenous (uniform) mixture was obtained. A measured quantity of water was added to give a paste that can agglomerate. The briquetting moulds of the hydraulic press briquette moulder were filled with mixture, making sure that the moulder plates were inserted first. The lid of the moulder was closed and the mixture was briquetted by applying pressure on the hydraulic jack. This action moves the movable part of the mould up to the immovable part (the lid), causing the mixture in the mould to be compressed, and it agglomerate into a briquette. This manual hydraulic press briquette machine can exert pressure up to 10 MPa.

### **3.6.1 Characterization of the bio-coal briquettes samples:**

The moisture and ash content was determined using the procedure used in the raw materials.

### **3.7 Determination of Ignition Time**

Ignition time is the time taken for a flame to raise the briquette to its ignition point. The briquette samples were ignited at the edge of their base with a cigarette lighter adjusted to give a steady light. The time taken for each briquette sample to catch fire was recorded as the ignition time of the sample. The test was repeated twice for each sample and the average time taken.

### **3.8 Determination of Density**

Density is a physical property of briquettes. It is defined as structural packing of the molecules of the substance in a given volume. Since the briquettes are cylindrical of equal diameters (3.90cm), the various height of each was measured using veneer calipers. The volume was evaluated using  $\pi r^2 h$ . The density was computed as the ratio of mass to the volume of the briquette.

$$\text{Density (g/cm}^3\text{)} = \frac{\text{Mass (g)}}{\text{Volume (cm}^3\text{)}}$$

### 3.9 Determination of compressive strength of the briquette samples

The compressive strength is the force required to crush or break a material. It determines how the briquettes can be handled. A briquette sample with a good compressive strength can easily be transported, packed, and handled.

The compressive strength of the briquette samples was determined using a compressive strength testing machine Model 2914. This machine is 1000kN capacity capable of compressing non-metallic materials. It is powered by electricity, but hydraulically operated. The length and width of the specimen was measured and recorded. The machine was switched from the mains and allowed to warm up for about 3 mins. The samples was then put on the movable bed, and the control lever applied upward to bring contact between the upper fixed bed and the movable lower bed on which the samples was sitting. The reading was taken immediately crack was noticed in the specimen, an indication that the specimen has been compressed. The value of the reading recorded from the machine is the compressive force or test force. The compressive strength of the samples was calculated using the formula below. The unit is given by N/mm<sup>2</sup>

Compressive strength = compressive force/ test force (Ft)

$$\text{Compressive strength} = \frac{\text{compressive force/ test force (Ft)}}{\text{Cross sectional area of the sample (Ac)}}$$

Where cross sectional area = length × width.

### **3.7 Water boiling tests of the briquette samples**

The time taken for a definite quantity of briquette sample (100g) to boil a specific quantity of water. This will indicate the briquette sample that will cook food faster. 1litre of water was poured into a kettle and the briquette samples were ignited in a briquette stove. The time taken for a briquette sample to boil the water was noted and recorded.

## CHAPTER FOUR

### 4.0 RESULT AND DISCUSSION

#### 4.1 Colour and texture of the raw materials

The results of the colour and texture of the materials obtained by physical observation are shown in Table 3.

**Table 3: Colour and texture of the materials.**

Sample	Coal	Groundnut shell
Colour	Black	Light brown
Texture	Fine	Relatively fine

Since coal is black, the colour of the biomass will not have any effect on the briquettes produced. The groundnut shell has the same texture with coal and it is compatible with coal.

## 4.2 Chemical composition of the materials.

The results of the chemical composition of the materials obtained using AAS are shown in Table 4.

**Table 4: Chemical composition of the materials**

Cations	Coal (%)	Groundnut shell (%)
Ca <sup>2+</sup>	0.115	0.651
Mg <sup>2+</sup>	0.020	ND
Al <sup>3+</sup>	0.074	0.029
Na <sup>+</sup>	0.126	0.203
K <sup>+</sup>	0.081	0.323
Cu <sup>2+</sup>	0.028	0.043
Zn <sup>2+</sup>	0.073	0.004
Mn <sup>2+</sup>	0.089	0.041
Pb <sup>2+</sup>	0.338	0.188
Ni <sup>2+</sup>	0.242	0.031
Cr <sup>3+</sup>	0.305	ND
As <sup>+</sup>	0.129	0.003
S	0.93	0.007

N.D = Not detected

From Table 4, the values of some of the elements are higher in coal than groundnut shell. During combustion some of these elements will be deposited in the ash. Therefore, it is expected that the ash content of coal will be higher than that of the

groundnut shell. Also, it can be seen that the percentages of As and Pb which are toxic pollutants are higher in coal than in groundnut shell. The sulphur content of coal is 0.93%, compared to 0.007% of groundnut shell respectively. Therefore coal has tendency of emitting sulphur (iv) oxide into the atmosphere than the others during combustion.

### 4.3 Analysis of the materials

Proximate analysis: The results of proximate analysis of the materials are shown in Table 5.

**Table 5: Proximate analysis of the materials.**

Parameter	Coal	Groundnut shell
Moisture content (%)	6.10	10.30
Volatile matter (%)	23.00	54.70
Ash content (%)	14.00	6.00
Fixed carbon	56.90	29.00
Carbon content	64.30	26.00

From Table 5, it can be seen that groundnut shell has higher moisture content than coal.

From literature, the moisture content of biomass should be as low as 10-15% so that there will be complete combustion of the briquettes (Maciejewska *et al.*,

2006) Low moisture content of biomass also helps in their storage (prevents rotting and decomposition).

It can also be seen clearly from the table that groundnut shell has the higher value of volatile matter than coal. From literature, the volatile matter content of biomass is usually higher than that of coal.

The ash content results show that coal has the higher ash content value than groundnut shell. 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 (Maciejewska *et al.*, 2006).

As expected, the carbon content of coal is higher than that of groundnut shell as shown in the Table 5

#### **4.4 Effect of biomass on the moisture content of the briquette samples**

The effect of biomass on the moisture content of the briquette samples are indicated in Table 6. The moisture content of the briquette without biomass (control) is 6.00%. For the groundnut shell-coal briquettes; the moisture content decreases from 10% - 15% and increases from 20% - 30%.

**Table 6: Results of the moisture content of the briquettes:**

Biomass load (groundnut shell)	Moisture content (%)
0%	6.00
10%	5.50
5%	5.50
20%	6.50
25%	7.50
30%	7.00

#### **4.5. Effect of biomass on the ash content of the briquette samples**

The effect of biomass on the ash content of the briquette samples are indicated in Table 7. The ash content of the briquette without biomass (control) is 11.7%. The value of the ash content decreases from 10% - 15% and increases from 20% - 30%.

**Table 7: Ash content results**

Groundnut shell load	Weight of ash (g)	Ash Content (%)
0%	0.117	11.7
10%	0.129	12.9
15%	0.123	12.3
20%	0.116	11.6
25%	0.112	11.2
30%	0.091	9.1

N/B: Weight of sample used = 1g.

**Table 8: Effect of biomass on the density of the briquette samples**

Biomass load (groundnut shell)	Density $\times 10^2$ (kg/m <sup>3</sup> )
0%	10.0
10%	9.5
15%	9.3
20%	9.2
25%	9.1
30%	9.0

From the results in Table 8, it can be seen that the density of the samples increase with increase in biomass load and this will help for easy transportation of the sample.

**Table 9: Effect of biomass on the ignition time of the briquette samples**

Biomass load (groundnut shell)	Ignition time(mins)
0%	18
10%	15
15%	13
20%	11
25%	10
30%	8

The results in Table 9 show that ignition time of the sample decrease with increase in biomass load.

From the compressive strength results in Table 10. Biomass reduces the compressive strength of the briquettes. The 0% biomass sample has the highest compressive strength value, and this is due to the fact that there is no biomass in it, hence the coal particles are closely packed together. The higher the biomass load the lower the compressive strength.

**Table 10: Compressive strength results.**

<b>Groundnut shell load</b>	<b>Compressive strength N/mm<sup>2</sup></b>
0%	1.31
10%	1.14
15%	1.08
20%	0.98
25%	0.93
30%	0.83

#### **4.6. Effect of biomass on the water boiling test.**

The effects of biomass on the water boiling test are indicated in Table 11. The time required for the briquettes to boil a specific quantity of water (i.e. 1litre). The time it takes to boil 1litre of water with 100g of coal briquette (control) is 18mins. It takes longer time to boil water with bio-briquette which in turn decrease from

10%-25%( 10%>15%>20%>25%) while 30% is smaller than the control. The lesser value of the control may be due to the higher calorific value of the coal which produces higher heat energy, hence the lesser the time required to boil water.

**Table 11: Water boiling test results.**

<b>Groundnut shell load (%)</b>	<b>Time (mins)</b>
0%	18
10%	24
15%	22
20%	20
25%	19
30%	12

## **CONCLUSION**

From the results of the tests and analyses, the following conclusions can be drawn on the possibility of using groundnut shell as biomass in the production of bio coal briquettes. The raw materials consist of many cations and the bio coal briquettes take less time to boil water, cook food than coal briquette under similar conditions, burn smoothly with very little generation of smoke and harmful gases, are easier to ignite, have low ash content than coal briquettes.

Although bio-coal briquettes have lower compressive strength than coal briquette, which will make their storage, handling and transportation difficult. This can be taken care of by increasing the quantity of binder used, as we increase the percentage of biomass so that the particles will be bound properly together by the binding agent.

## REFERENCES

- Akinyosoye, J. (1993). *Tropical Agriculture for Senior Secondary Schools*. London: Macmillan Publishers Ltd.
- Bhattacharya, C. (1985). *Dandified Biomass in Thailand: Potential Status and Problems*. Elsevier Applied Science, Vol. 34 (23). Pp. 255-259.
- Eapetu, O.P. (2000). Management of Energy from Biomass. *Nigeria Journal of Engineering Management*, Vol. 7 (17) Pp. 789-793.
- Ezzati, M., & D.Kammen, M. (2001). *An Exposure-Response Relationship for Acute Respiratory Infection as a Result of Exposure to Indoor Air Pollution from Biomass Combustion in Kenya*. Kenya: Maxwell Printing Press.
- Hayami, H. Y., Kojima T., & K. Yoshioka, K. (2001). *Bio-coal briquettes and Planting trees as an experimental CDM*. China: Kong Youg Publications.
- Jekayinfa, S. O., & Omisakin, O. (2005). *The energy potentials of some Agricultural wastes as local Fuel materials in Nigeria*. Agricultural Engineering International (CIGR). *Journal of Scientific Research and Development*, Vol. 9. (14). p.10.
- Jekayinfa, S. O., & Scholz, V. (2009). *Potential Availability of Energetically Usable Crop Residues in Nigeria*. Lagos: Ola and Sons Ltd.
- Joe O. C. (2007). Kingsford Charcoal Ingredient; California Barbecus Association website of all about charcoal. California: Middle Press Intl.
- Maciejewska, A., Veringa, H., Sanders, J., & S.Peteve, D. (2006). Co-firing of Biomass With Coal Constraints and Role of Biomass. *International Journal of Biomass and Constraint*, Vol. 79. (34). Pp. 786-789.
- Mangena, S. J. & Cann, V. (2007). Binderless Briquetting of Some Selected South Africa Prime Cooking. *International Journal of Health Maintenance*, Vol. 71. (45). Pp. 300-312.
- Mohammad, S. B. (2005). *Bio-coal Briquette Cleaner, Affordable and Sustainable Fuel to Indonesia*. Indonesia: Hulk-up Press.
- Moore, W., & Johnson, D. (1999). *Procedures for the Chemical Analysis of Wood and Wood Products*. Madison, U.S. Forest Products Laboratory. U.S.A: Department of Press.
- Onuegbu, T. U. (2010). Improving Fuel Wood Efficiency in Rural Nigeria: (A Case of Briquette Technology). *International Journal of Chemistry in Nigeria*. Vol. 3 (4) Pp. 35-39.

- Onuegbu, T., Uzoma, F., & Ikechukwu, M. K. (2010). Enhancing the properties of coal Briquette using spear grass. *Leonardo Journal of Sciences*, Vol. 9. (17). Pp. 47-58.
- Onuegbu, T.U., Ogbu, I.M., Ilochi, N.O., Okafor, I., Obumselu, O. F., & Ekpunobi, U.E. (2010b). *Enhancing the Efficiency of Coal Briquette in Rural Nigeria using Pennisetum Purpurem*. Vol. 4. (3) Pp. 299-304.
- Onuegbu, T. U., Ilochi, N. O., & Okafor I. (2006). Preparation of Environmentally Friendly Bio Coal Briquette from Ground nut Shell and maize cob biomass waste. *Comparative Effect of Ignition time and water boiling Studies*, Vol. 4. (4) Pp. 110-118.
- Patomsok, W. (2008). *Density Equation of Bio-coal Briquette and Quantity of Maize Cob*. Thailand: Sample Express Inc.
- Schirnding Y. Von., & Bruce, N. (2002). *Addressing the Impact of Household Energy and Indoor Air Pollution on the Health of the Poor: Implication for Policy Action and Intervention Measures*. Washington D C: Multi-In Press.
- Smith K, T. F., & Samet, U. (2000): *Indoor Air Pollution in Developing Countries and Acute Respiratory Infection in Children*. Thorax: London Express Inc.
- Somchai, O. B., Kunchana, O., & Duangporn, T. (1988). *Desulfurization of Coal Briquettes by Lime Department of Chemical Technology*. Thailand: Chulalongkorn University Press.
- Wilfred, F., & C. Martin, P. (1980). *Fuels and Fuel Technology*. New York: Pera-Gamon Publishing Company.