CONSTRUCTION OF A MOULDER AND FABRICATION OF BRIQUETTE FROM BIOMASS MATERIALS (PAPER, CORNSTALK AND BAGASSE) FOR USE IN CLEAN STOVES

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BEING A DISSERTATION SUBMITTED TO THE DEPARTMENT OF PHYSICS, FACULTY OF SCIENCE, BAYERO UNIVERSITY, KANO, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc.) DEGREE IN PHYSICS

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DECLARATION

I hereby declare that this work **"CONSRUCTION OF A MOULDER AND FABRICATION OF BRIQUETTE FROM A BIOMASS MATERIALS (PAPER, CORNSTALK AND BAGASSE) FOR USE IN CLEAN STOVES"** is a product of my own research efforts under the supervision of Prof. A. O. Musa and has not been presented anywhere for the award of a degree or certificate. All sources have been duly acknowledged.

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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write up of it were carried out by Surajo Namadi (SPS/13/MPY/00010) under my supervision.

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APPROVAL PAGE

This dissertation "**CONSTRUCTION OF A MOULDER AND FABRICATION OF BRIQUETTE FROM BIOMASS MATERIAL (PAPER, CORNSTALK AND BAGASSE) FOR USE IN CLEAN STOVES**" has been examined and approved for the award of Master of Science (M.Sc.) degree in Physics.

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DEDICATION

This dissertation is joyfully dedicated to my parents; Alh. Muhammad A. Bangaje and Late Khadijatu Bello Harka and the entire members of my family.

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ABBREVIATIONS AND SYMBOLS

ASTM	American Society of Testing and Material
WHO	World Health Organization
UNEP	United Nation Environmental Programme
FAO	Food and Agricultural Organization
CHP	Combined Heat Power
D_o	Outside diameter
D_i	Inside diameter
ρ	Density
L	Length
Kg	Kilogram
m	Meter
CV	Calorific Value
GCV	Gross Calorific Value
HHV	High Heating Value
FC	Fixed Carbon
VM	Volatile Matter
AC	Ash Content
n	Number of minutes between ignition time and attainment of maximum temperature
A_f	Area occupied by the main frame
L_f	Length of the main frame
b_f	Breadth of the main frame
A_m	Cross sectional area of the briquette moulder
b_m	Breadth of the moulder
L_m	Length of the moulder
L_h	Length of the handle
T_h	Torque produced by the handle
M_p	Mass of an average person

M_{cs} Mass of the carbon steel metal

F_{cs} Force produced by the carbon steel metal

GI Galvanized Iron

Kg Kilogram

R_D Relaxed density

M_D Maximum density

RC Radiation Correction

M_b Mass of the Benzoic acid

CV_b Calorific value of the Benzoic acid

t Corrected temperature rise

^0C Degree Celsius

IP Ignition Period

T_{max} Maximum Temperature

ABSTRACT

This research work was carried out to produce briquette from biomass materials (paper, cornstalk and bagasse) as an alternative to wood charcoal using a designed and fabricated hand-press briquette moulder capable of producing five briquettes at a time. Six different mixtures of briquette (100%Paper, 100%Cornstalk, 100%Bagasse, 50%Paper + 50%Cornstalk, 50%Paper + 50%Bagasse and 50%Cornstalk + 50% Bagasse) were produced using Tapioca starch as a binder. After briquetting, the physical properties of the produced briquettes were determined by direct measurements and calculations, the proximate analysis were performed in accordance with ASTM analytical method and the average results show that; the percentage volatile matter of the dried briquettes was found in the range of 80.05%–92.01%, ash content in the range 5.32%–19.32% and fixed carbon in the range of 0.34%–5.25%. The average maximum and relaxed densities of the briquettes ranged from 578.85kg/m^3–1011.48kg/m^3 and 213.64kg/m^3–315.57kg/m^3 respectively. With the aid of Cussons-Bomb calorimeter the calorific value of the produced briquettes varies from 12045.45J/g–17009.22J/g with the maximum value observed for sample 3. The average results for the relaxation and density ratios of the produced briquette were 2.68–3.71 and 0.27–0.37 respectively. Results from different tests show that the briquettes made from sample 3(100%Bagasse) were the best quality fuels among their counter-parts.

CHAPTER ONE

GENERAL INTRODUCTION

1.0 INTRODUCTION

Energy is the engine of economic development of any country; its rate of consumption is a major indicator of the rate of economic growth. It is central to the development of the World's economy and environmental quality, providing power needed for industrial production, transportation and agriculture. Energy is important for the provision of essential services for the well-being of humanity like heating, lighting and refrigeration (UNEP, 2000). Energy resources are classified broadly into non-renewable energy and renewable energy. The non-renewable are fossils fuels such as Coal, Petroleum Oils and Natural Gas, while the renewable energy include Hydropower, Geothermal, Biomass, Solar, Wind, Tidal and Wave energies. Their production and consumption give rise to environmental human health and safety problems which the industrialized countries are capable of minimizing more than the developing countries (Stedman and Hodgkinson, 1990).

The large scale use of fossil fuel energy led to better quality of life; however it has also created many problems. Perhaps the most serious of these are the harmful effect on the environment and climate change which both have consequences on pollution which maltreat human health. However, it is now clear that the era of non-renewable energy resources is gradually coming to an end, oil, natural gas and coal will all be depleted. Energy problem is very serious and the main objective is how to find solution to match the demand and supply of energy sources. Therefore the need for conserving energy and developing alternative energy source is a must.

Biomass refers to non-fossil biodegradable organic material from plant, animal and microbial origin. Biomass materials include products, by-products, residues and wastes from agricultural and forestry activities; non-fossil and biodegradable fractions from municipal and industrial wastes. Classical examples are trees, grasses, agricultural crops, agricultural wastes, wood waste and their derivatives, bagasse, municipal solid waste, waste paper, waste from food processing as well as aquatic plants and algae animal wastes (Demirbas, 2010). Biomass is the third global primary energy source after coal and oil and is set to become an important contributor to the world energy (Sugumaran and Seshadri, 2010). Biomass resources are considered renewable as they are naturally occurring and when properly managed, may be harvested without significant depletion of their sources. Biomass is plentifully available in the rural regions; it is already being used by the rural people as a major source of energy, mainly in cooking food which constitutes almost over 90% of the total energy consumption.

In Nigeria, the huge volume of agricultural waste generated annually, coupled with the decreasing availability of wood fuel has necessitated concerted effort to look for efficient ways of harnessing these waste for energy generation. Agricultural waste is an ideal source of charcoal. Direct combustion of raw agricultural waste as fuel feedstock has some obvious disadvantages including difficulty in controlling the burning rate of the biomass, difficulty in mechanized feeding supply, low heat density, difficulty in stock handling and transportation as well as large storage requirements. Most of these problems are associated with the low bulk density of the agricultural waste. One approach to checkmate these setbacks and efficiently utilize agricultural wastes as fuel is by their densification to produce charcoal briquettes (Zubairu and Gana, 2014).

Briquette is a block of flammable matter that can be used as a fuel to start and maintain a fire. Briquettes are produced through a process known as briquetting. This process involves the densification of loose biomass residues, such as sawdust, straw, rice husk etc, into high density solid blocks that can be used as a fuel. Common types of briquettes are charcoal and biomass briquettes. Biomass briquettes (including pellets, which are very small briquettes) replace fossil fuels or wood for cooking and industrial processes. They are cleaner and easier to handle, and cut greenhouse gas emissions.

The process of briquetting involves the compression of a biomass material into a solid product of any convenient shape that can be utilized as fuel just like the use of wood or charcoal. This conversion of combustible materials found in the waste stream was found to be a better way of turning waste into wealth (Adegoke, 2002). In addition, if briquettes are produced at low cost and made conveniently accessible to consumers, it could serve as supplement to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for the latter two. Hence, these materials which were of low density prior to being converted into briquettes are compressed to form a product of higher bulk density, lower moisture content and uniform size and shape.

Briquetting is the process of compaction of residues into a product of higher density than the original raw materials, it is also known as densification (Kaliyan and Morey, 2009). Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use and relatively smaller space requirement for storage (Kaliyan and Morey, 2009). Therefore, briquetting of biomass can be considered for its economics, cleanliness, reliability and ease of operation. As it has been used for domestic heating in cooking stove and furnace with a lower volume of smoke and ash content compared to conventional biomass.

1.1 BIOMASS AND ITS POTENTIALS

Biomass is simply a material made from biological organisms that can be burned to produce heat energy. One advantage of biomass is that it can be made from agricultural waste and forestry residuals; another is that, biomass is incredibly abundant on many farmlands and much of what could be used as an energy source is currently burned off in fields and unutilized. Using agricultural waste and forestry residuals as energy sources will create a new market for farmers and other independent craftsmen who acquire stockpiles of agricultural waste as a by-product of their trade. Farmers can generate more revenue for themselves while providing a more greener and sustainable form of energy to society. Since farmers will be gaining a new market, they would also be less dependent upon a productive crop yield from year to year and less affected by droughts or other unforeseen environmental occurrences.

The revenue generated from biomass will help smaller, independently-owned farms to sustain a profitable business in times of distress. Due to such an abundance of agricultural waste, biomass would be expected to remain cheap in its raw, unprocessed form and to be a sustainable form of energy. This sustainability may allow many nations to be energy independent and, as a result, to be able to re-allocate funding in budgets to other areas of concern.

1.2 STATEMENT OF THE RESEARCH PROBLEM

The use of agro-residues in-efficiently leads to the environmental problems of erosion, deforestation and desertification. Direct burning of loose biomass in conventional grates is associated with very low thermal efficiency and widespread air pollution which has been associated with a wide spectrum of health effects ranging from eye irritation to death.

Overcoming the use of loose biomass material is paramount to establishing and enduring synergy between house hold energy use and environmental degradation. Briquetting, which is one of the ways densification of biomass has been achieved, can be considered for its economic reliability and ease of operation. Briquetted biomass can also be used to solve air pollution caused from inefficient burning of loose biomass.

1.3 AIM AND OBJECTIVES OF THE RESEARCH

This study is aimed at fabricating briquettes from a constructed moulder using biomass materials to serve as an alternative to wood charcoal which provide much needed source of cheap fuel that is economical and cleaner in burning.

The objectives of this study are:

- To produce briquettes from abundant biomass and urban wastes using a hand-press briquette moulder primarily designed for household or small-scale level of production as alternative source of energy.
- To determine the physical and combustion properties of the briquette produced from the various biomass materials.
- To determine the quality of briquettes produced based on their physical dimensions and heating value/calorific value.

1.4 JUSTIFICATION

Bio-fuel briquettes for utilization as energy source for domestic and industrial heating processes can significantly reduce emissions of air pollutants, deforestation, desertification and enhance research on the development and application of alternative and cost-effective energy sources which will make a significant contribution to improving national energy efficiency, optimised profit as well as enhance rural development goals and global competitiveness for Nigerian industries. Some biomass materials which are currently thrown away or burned in our farmlands can certainly contribute in prospective and diagnostic studies regarding the use of renewable energies especially solid bio-resources and enhance research for changing waste to wealth in many sector of national economy.

1.5 SIGNIFICANCE OF THE RESEARCH

The conversion of biomass and urban wastes is an environmental way of recycling them into useful fuel briquettes to help reduce the dependence of the households on charcoal, a still commonly used fuel for cooking in the country. Less dependence in the use of charcoal would mean less cutting down of trees which have an impact on the depletion of forest resources, harmful effect on the environment and climate change which have consequences on pollution that detriment human health. The conversion of biomass into briquettes may become a viable business enterprise and a source of income for farmers thereby providing the populace with a new and cheap alternative source of cooking energy.

1.6 SCOPE OF THE RESEARCH

This study focused on fabrication of briquettes from three biomass materials [sugarcane peals (baggase), corn stalk and waste paper] for use as fuels in clean stoves with the use of hand-press briquette moulder primarily designed for household or small-scale level of production as alternative source of energy. The biomass residues were chosen for their suitability in fabrication of the briquette for household and by the use of tapioca starch as a binder which is readily available in the northern part of the country.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

This chapter contains the history of briquetting, review of the existing literature based on biomass, major elements that make up the biomass which include cellulose, hemicelluloses, lignin and protein, briquetting process as well as briquetting machine. This review also include the physical and thermal properties of the briquetted fuel which include the compressive strength, moisture content, briquette density, compaction ratio, density ratio, shatter and tumbling resistance, calorific value or heating value, percentage of the volatile matter, ash content as well as the percentage fixed carbon contents.

2.1 HISTORY OF BRIQUETTING

Briquetting is the densification of loose biomass material. Fuel briquettes emerged as a significant business enterprise in the 20th century. In the 1950s, several economic methods were developed to make briquettes without a binder where multitude of factories throughout the world produced literally tens of millions of tons of usable and economic material that met the household and industrial energy needs (Lardinois and Klundert, 1993). During the two World Wars, households in many European countries made their own briquettes from soaked waste paper and other combustible domestic waste using simple lever-operated presses. Today's industrial briquetting machines, although much larger and more complex, operate on the same principle (Lardinois and Klundert, 1993). According to FAO (1990), briquetting could be categorized into five main types depending on the types of equipment used; piston presses, screw presses, roller press, pelletizing, manual presses and low pressure briquetting. Densified biomass is acquiring increasing importance because of the growing domestic and industrial applications for heating, combined heat and power (CHP) and electricity generation in many countries. In countries such as Austria, Denmark, Netherlands and Sweden, for example, it is becoming a major industry with pellets traded internationally.

In Austria, the production of pellets in 2002 was 150,000 tons but with the rapid expansion of small-scale pellets heating systems, it was expected to reach 0.9 Mt/year by 2010 (Hood, 2010). In Europe this potential has been estimated at around 200Mt/year and is increasing continuously because advances in technology allow the densification of biomass to be more competitive, driven by high demand. There has been briquetting projects in many African countries such as Nigeria, Zimbabwe, Tanzania, Uganda, Kenya, Sudan, Rwanda, Niger, Gambia, Ethiopia and Senegal, though not all of these are still functional. The raw materials most commonly briquetted in Africa are coffee husks and groundnut shells while sawdust and cotton stalks are also used to a limited extent (Hood, 2010).

2.2 THE BIOMASS

The totality of the earth's living matter that is derived from the process of photosynthesis either directly or indirectly is termed the BIOMASS. Biomass exists on the planet in a thin surface layer called the biosphere. The biosphere accounts for a fraction of the mass of planet earth but holds an enormous storehouse of energy, this store of energy has its heart, the Sun. The source is being continually replenished. Energy radiates from the sun at the rate of some 1026 watts. Roughly 98% of the energy emitted into space is conveyed by radiation of wavelengths between 250nm and 3000nm. About 50% of this energy is between 350nm and 750nm. Only a small fraction of the Sun's emitted radiation reaches the Earth. At a specific location on the surface of the planet, the insolation is dependent on such factors as the latitude, season, time of day, cloud cover and atmospheric pollution. This all has a marked influence on earth's climate and hence the biological primary production.

2.2.1 Pre-processing of biomass residues

Before briquetting, biomass material often needs to be broken down in size. Depending on the residue, in a rural setting this might involve chopping, crushing and hammering the material by hand or using hammer mills, hand cranked devices or a pestle and mortar (Stanley, 2003). This process can potentially consume a large amount of energy, and therefore the most suitable method for the individual situation needs careful consideration. For some materials this step might be less energy intensive than for others (Cosgrove, 1985). For example, residues such as rice husks, peanut shells, maize-milling residues and waste papers require minimum chopping and pounding to break them down, compared to harder materials such as palm nut shells.

2.3 ELEMENT OF BIOMASS

There is a wide variety of biomass, and composition is also diverse. Some primary components are cellulose, ligning, hemicellulose, starch and proteins. Trees mainly consist of cellulose, hemicellulose and ligning and so herbeceous plant, although the component percentage differs. Different kinds of biomass have different components: grain have much starch, while livestock waste has many proteins.

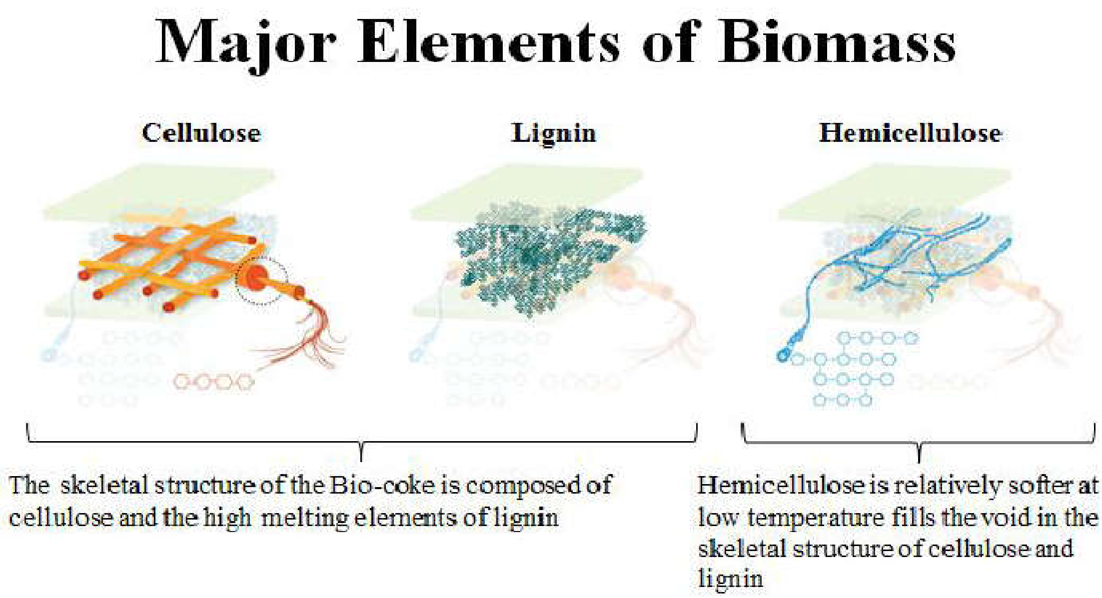


Figure 2.1: Major element of biomass (William, 2012).

2.3.1 Cellulose ($C_6H_{10}O_5$)

Cellulose is the major constituent, comprising roughly 50% of weight with a high molecular weight polymer. Cellulose is a long chain of linked sugar molecules that gives wood its extraordinary strength. Cellulose forms crystalline micro fibrils that are surrounded by amorphous cellulose inside the cell (Chen *et al.*, 2004). The structural integrity of cellulose is due to hydrogen bonding that occurs between glucose monomers. Cellulose is considered to be an abundant source of carbon in biomass. For hot pressing of wood material, Zandersons *et al.* (2004) concluded that the strength of the binding depends on converting cellulose to an amorphous state.

2.3.2 Hemicellulose ($C_5H_8O_4$)

Hemicelluloses are polymeric units that are comprised of simple sugar molecules. Hemicelluloses differ from celluloses as it yields several types of sugar when reacted with acids. Hemicellulose found in the cell wall is more of a heteropolysaccharide, which is a combination of many sugars other than simple glucose. Its amorphous structure is due to branching and it is more easily hydrolyzed than cellulose, or it can be dissolved in alkali solution. Some researchers believe that natural bonding may occur due to the adhesive degradation products of hemicellulose (Tumuluru *et. al,* 2010).

2.3.3 Lignin $C_9H_{10}O_3(OCH_3)$

Lignin is a random network polymer with a variety of linkages based on phenyl-propane units (Zandersons *et al*., 2004). While its structure is complex, lignin is derived from two amino acids, phenylalanine and tyrosine, both of which contain aromatic rings. The lignin molecule provides complements of the structural properties of cellulose, such as acting as glue to the cellulose fibers. The presence of lignin in plant materials helps to form pellets without binders; for example, Van Dam *et al*. (2004) reported that lignin exhibits thermosetting properties at working temperatures of >140°C and acts as intrinsic resin in binder less board production. Hence, lignin is the component that permits adhesion in the wood structure and acts as a rigidifying and bulking agent (Anglès *et al.*, 2001).

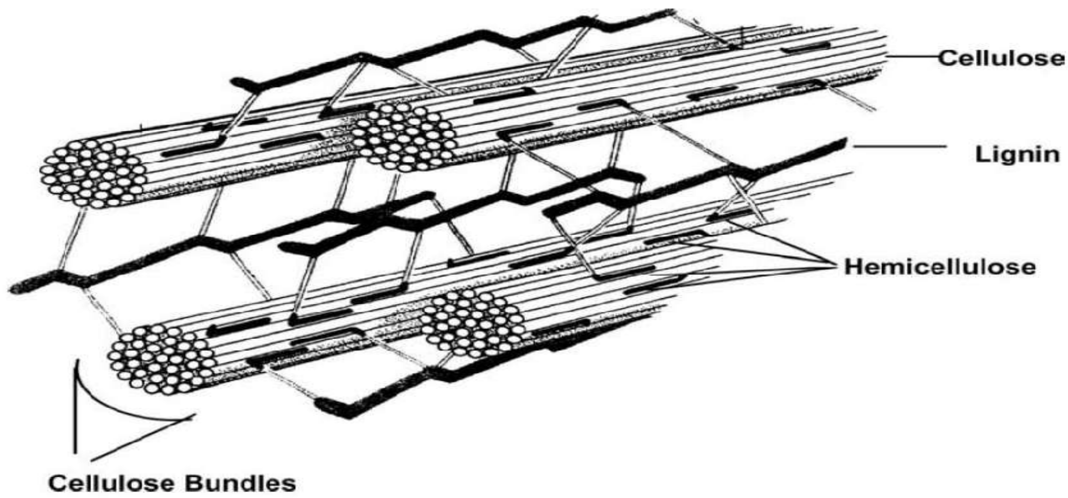


Figure 2.2: Arrangement of Cellulose, Hemicellulose, and Lignin in Biomass.
(Murphy and McCarthy., 2005).

2.3.4 Proteins

Proteins are macromolecular compounds in which amino acids are polymerized to a high degree. Properties differ depending on the kinds and ratios of constituent amino acids, and the degree of polymerization. Proteins are not a primary component of biomass, and account for a lower proportion than the previous three elements.

2.4 ATTRIBUTES OF BIOMASS RESIDUES FOR BRIQUETTING

Even if there are sufficient residues for briquetting to be considered feasible, there are other factors that must be considered, and problems that need to be overcome before the widespread adoption of these wastes as a fuel substitute becomes possible. Apart from its availability in large quantities, it should have the following characteristics:

2.4.1 Low moisture content

Moisture can influence the ease and degree of compacting of coal briquettes. According to the "capillary" theory, when coal powder is subjected to pressure, water from the capillary is exuded at a certain point and coats the surface of particles, hence improving the intimacy of contacts. When pressure is removed, not all the water is reabsorbed in the capillaries and a surface adsorbed layer remains which maintain the close contact between the particles (Rhys

Jones, 1963). The "capillary" theory implies optimum moisture content. This is because sufficient moisture must be held in the capillaries for some to be exuded during compacting. In contrast, there must not be so much water that an excessive amount is left between the particles after the release of pressure (Rhys Jones, 1963). It was found that the relaxed density, D, can be expressed as a function of moisture content, m_w, according to the relation proposed by O'Dogherty and Wheeler, 1984 given by

$$D = a \quad ^{-cm_{w},} \quad \text{..} \quad (2.1)$$

where a and c are empirical constant.

2.4.2 Ash content and composition

Biomass residues normally have much lower ash content (except for rice husk with 20% ash) but their ashes have a higher percentage of alkaline minerals, especially potash (Grover and Mishra, 1996). The ash content of different types of biomass with lower ash content will not show any slagging behaviour of the biomass.

Generally, the greater the ash content the greater the slagging behaviour. But this does not mean that biomass with lower ash content will not show any slagging. The mineral composition of ash and their percentage combined determine the slagging behaviour. Below is a table which shows the ash content of some biomass materials.

Table 2.1 Ash content of some biomass materials

Biomass	Percentage (%) Ash content	Biomass	Percentage (%) Ash content
Corn cob	1.2	Coffee husk	4.3
Saw dust	1.3	Cotton shell	4.6
Soya bean stalk	1.5	Ground nut shell	5.1
Baggase	1.8	Bean straw	10.2
Tea waste	3.8	Rice husk	22.4

(Source: Food and Agriculture organization of the United Nation Bangkok April, 1996).

2.5 BRIQUETTING

Briquetting is the process of compaction of residues into a product of higher density than the original raw materials. It is also known as densification (Kaliyan and Morey, 2009). The handling characteristics of material for packaging, transportation and storage are also improved (Stout and Best, 2001). If produced at low cost and made conveniently accessible to consumers, briquettes could serve as compliments to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both (Wilaipon, 2008).

Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleanliness, convenience in use and relatively smaller space requirement for storage (Kaliyan and Morey, 2009). The briquettes are normally cylindrical or rectangular in shape. Wilaipon, 2008, described briquetting as a process of compaction of residues into a product of higher density than the original material.

2.5.1 Need for Briquetting

A huge quantity of agricultural residues and a major part of it is consumed world-wide in traditional uses (such as fodder for cattle, domestic fuel for cooking, construction material for rural housing, industrial fuel for boilers, etc.). The direct burning of agricultural residues in domestic as well as industrial applications is very inefficient. Moreover, transportation, storage and handling problems are also associated with their use (Pallavi, *et al*. 2013).

One of the approaches that are being actively pursued worldwide towards improved and efficient utilization of agricultural and other biomass residues is their densification in order to produce pellets or briquettes (Li and Liu, 2000). Briquetting is the process of conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of application. The biomass briquette is a fuel consisting of biomass, such as agricultural waste or waste paper, bound together and compressed into small pieces approximately 5 to 15cm. Briquette-making can serve as cottage industry in areas where these bio-wastes are in abundance (Ilavsky and Oravec, 2000).

2.5.2 Physical Properties of Briquette

The physical properties of briquettes include compressive strength, moisture content, briquette density, compaction ratio, density ratio, shatter resistance, tumbling resistance/durability and are discussed as follows;

2.5.2.1 Compressive Strength

Compressive strength is the maximum crushing load that the briquette can withstand during handling, transportation, storage and firing. Charbonnier and Visman (1959) used the Komarek Greaves compression strength test, under controlled conditions, to test the strength of the pillow-shaped briquettes manufactured from bituminous coal and petroleum asphalt. The authors recommended that the temperature of the briquettes during the test be virtually the same as the average temperature during transportation and storage.

2.5.2.2 Moisture Content

In the briquetting process, water acts as a film-type binder by strengthening and promoting bonding via van der Waal's forces by increasing the contact area of the particles. As a general rule, the higher the moisture content, the lower the density of the pellet/briquette. Demirbaş (2004) found that increasing the moisture content (7-15%) of pulping rejects and spruce wood sawdust resulted in stronger briquettes. Mani and co-workers (2006) reported that corn stover of a low moisture (5–10%) resulted in denser, more stable and more durable briquettes than high moisture stover (15%). The moisture content of a biomass sample can be calculated by using the formula

$$\text{Percentage Moisture Content } (\%M_c) = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \text{ .... } (2.2)$$

where,

W_1 = Weight of empty dish, g

W_2 = Weight of dish + sample before drying, g

W_3 = Weight of dish + sample after drying, g.

2.5.2.3 Briquette density

The material density of biomass can vary enormously, from around $100 kg/m^3$ for light dry straw, to over $2000 kg/m^3$ for highly compressed biomass fuels. It is a factor largely determine by the fuel manufacture and the higher the density of the fuel the greater the energy density. For a stoked fire, this therefore influences the ratio of energy input per unit volume into a cook-stove's combustion chamber. The fuel briquette's density will affect its bulk thermal properties: the thermal conductivity will be reduced as the density is decreased (increased fuel porosity), but the lower the density, the less heat is required for a specific volume of fuel to reach the ignition temperature. As a result the ignition time, and the rate of thermal decomposition will be affected. According to (Khokan, 2013), the cross sectional area of the cylindrical briquette sample can be calculated using the following formula:

$$\text{Cross-sectional area, } A = \frac{\pi({D_o}^2 - {D_i}^2)}{4} \ (cm^2) \quad \ldots\ldots\ldots\ldots (2.3)$$

where,

D_o = Outside diameter

D_i = Inside diameter

The Briquette density can be calculated using the following equation

$$\text{Density, } \rho = \frac{W}{AL} \quad \ldots\ldots\ldots\ldots (2.4)$$

where,

ρ = density, g/cm^3

W = weight, g

A = cross-sectional area of briquette (cm^2), and

L = length, cm.

2.5.2.4 Bulk density (kg/m^3)

Bulk density is an important parameter for storage and transportation purposes. Pellets or briquettes with higher density are preferred as fuel because of their high energy content per unit volume and slow burning property (Kumar *et al*. 2009). Bulk density of pellets or briquettes greatly depends upon processing conditions, like temperature, moisture content, particle size, and pressure. High temperatures and lower moisture content favor high density products. Smaller particle size produces denser products (Tumuluru *et al.* 2010).

According to Birwakar *et al* (2014), the Bulk density of biomass can be calculated by the use of the following formula:

$$\text{Bulk density} = \frac{\text{Mass of Biomass Sample (kg)}}{\text{Volume of Measuring Cylinder } (\text{m}^3)} \quad \text{............ (2.5)}$$

2.5.2.5 Compaction ratio

The compaction ratio can be defined as the ratio of the maximum density (the compressed density of the briquette immediately after ejection from the briquetting machine) to the initial density (density of the residue before compressing in the briquetting machine). It can be expressed mathematically as: .

$$\text{Compaction Ratio (C.R)} = \frac{\text{Maximum Density}}{\text{Initial Density}} \quad \text{............................ (2.6)}$$

2.5.2.6 Density ratio

The density ratio of the briquettes can be defined as the ratio of the relaxed density to the maximum density. The relaxed density which is also known as the spring back density is the density of the briquette obtained after the briquette has remained stable and is simply calculated as the ratio of the briquette's mass to the new volume. Mathematically as (Oladeji, 2012):

$$\text{Density Ratio (D.R)} = \frac{\text{Relaxed Density}}{\text{Maximum Density}} \quad \text{.................................. (2.7)}$$

2.5.2.7 Shatter resistance

The hardness of the briquettes can be determined in accordance with the shatter indices described by Sotannde *et al.* (2010). The briquette samples were dropped repeatedly from a height of one meter and above onto a metal base. The fraction of the briquette that remained was used as index of briquette durability in percentage. The briquette with known weight and length was dropped on RCC floor or concrete floor from the height of one meter and above. The weight of disintegrated briquette and its size was noted down. The percentage loss of material was calculated. The shatter resistance of the briquettes can be calculated by using the following formula (Ghorpade, 2006).

$$\text{Percentage weight loss} = \frac{W_1 - W_2}{W_1} \times 100$$

Shatter resistance = 100 - % weight loss …………………… (2.8)

where,

W_1 = Weight of briquette before shattering, g

W_2 = Weight of briquette after shattering, g

2.5.2.8 Tumbling resistance

The tumbling resistance test is used for testing the durability of briquetted fuel. A metallic box was used for the test. Briquetted sample of known weight was taken in the box and covered with lid. The box was thoroughly shaken for 15 minutes. Then weight loss in the briquettes was noted and the tumbling resistance can be determined by using the equation below (Tayade *et al.*, 2010).

$$\text{Percentage weight loss} = \frac{W_1 - W_2}{W_1} \times 100$$

Tumblance resistance = 100 - % weight loss ……………… (2.9)

where,

W_1 = Weight of briquette before tumbling, g

W_2 = Weight of briquette after tumbling, g

2.5.2.9 Resistance to water penetration

It is the measure of percentage of water absorbed by a briquette when immersed in water. The percentage water gained and resistance to water penetration can be calculated by equation below (Tayade *et al,* 2010).

Percentage of water gained by briquette = $\frac{W_2 - W_1}{W_1} \times 100$

% resistance to water penetration = 100 - % weight gained …….. (2.10)

where,

W_1 = Initial weight of briquette, g

W_2 = Final weight of briquette, g

2.5.3 Proximate analysis of the Briquette

The important proximate analysis of briquettes includes the calorific value, volatile matter, ash content and fixed carbon, (Senger *et al.,* 2012).

2.5.3.1 Calorific Value (CV)

The calorific value (or heating value) is the standard measure of the energy content of a fuel. It is defined as the amount of heat evolved when a unit weight of fuel is completely burnt and the combustion products are cooled to 298K (BSI, 2005). When the latent heat of condensation of water is included in the calorific value it is referred to as the gross calorific value (GCV) or the higher heating value (HHV). The higher calorific value of solid fuel using the bomb calorimeter experiment can be determined by the equation below (Birwakar *et al*., 2014):

Calorific value (kcal/kg) = $\frac{(W+w)\times(T_2 - T_1)}{X}$ …………………….. (2.11)

where;

W = Mass of water placed in the calorimeter, g

w = Water equivalence of the apparatus, g

T_1 = Initial Temperature of water in the calorimeter, °C

T_2 = Final Temperature of water in the calorimeter, °C

X = Mass of the fuel sample

The calorific value (heat of combustion) of a sample may be broadly defined as the number of heat units liberated by a unit mass of a sample when burned with oxygen in an enclosure of constant volume. The heat energy measured in a bomb calorimeter may be expressed either as calories (cal), British thermal units (Btu) or Joules (J). One calorie equals 4.1868 absolute Joules, and is roughly equivalent to the heat energy required to raise the temperature of one gram of water one degree Celsius at 15°C.

2.5.3.2 Volatile Matter

The volatile matter represents the components of carbon, hydrogen and oxygen present in the biomass that when heated turn to vapour, usually a mixture of short and long chain hydrocarbons. It is determined by heating a dried ground sample of biomass in an oven at 900℃ for 7 minutes (BSI, 2009). The amount of volatile matter in the biomass can be calculated as percentage of the weight loss of the sample.

$$\text{Volatile Matter, V.M (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.12)$$

where;

W_1 = Initial weight of the briquette dry sample, g

W_2 = Final weight of the dry briquette sample after heating in the furnace for 7minutes, g

In almost all biomass, the amount of volatile matter is higher than in bituminous coal. Biomass generally has a volatile content of around 70-86% of the weight of dry biomass as compared to coal, which contains only about 35% volatile matter. Consequently, the fractional heat contribution of the volatiles is more for biomass (Demirbas, 1999).

2.5.3.3 Ash Content

Ash is the non-combustible component of biomass and the higher the fuel's ash content, the lower its calorific value. It is both formed from mineral matter bound in the carbon structure of the biomass during its combustion, and is present in the form of particles from dirt and clay introduced into the fuel during harvest, transport and processing.

The ash content can be determined by heating a dry sample of biomass in an open crucible in a furnace at 900°C.

$$\text{Ash Content AC (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.13)}$$

where;

W_1 = Weight of empty crucible, g

W_2 = Weight of crucible + Sample taken, g

W_3 = Weight of crucible + weight of ash left in crucible, g.

Depending on the type of biomass, the ash content can vary between 0.8% for groundnut shells, for example, to as high as 23% for rice husks (Demirbas, 1999).

2.5.3.4 Fixed Carbon

After the volatiles and moisture have been released, ash and fixed carbon remain.

The relative proportion of volatiles, moisture, fixed carbon and ash are often quoted for biomass fuels. The percentage of fixed carbon is normally determined

by difference from the other quantities (Demirbas, 1999), and is given by:

$$\text{Fixed Carbon FC (\%)} = 100 - (\%AC + \%VM) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2.14)}$$

where:

AC = Ash Content

VM = Volatile Matter.

2.6 BRIQUETTING MACHINE

Briquette machines have been in existence and used for sawdust and waste materials in Europe, Asia, and America (Kishimoto, 1969). Inegbenebor, 2002, developed a five (5) tones capacity briquetting machine for compressing agricultural and wood waste that can produce six briquettes at a time. In developing countries like Nigeria, the direct burning of loose agro waste residues like rice husk, palm kernel shells, and groundnut shells in a conventional manner is associated with very low thermal efficiency, loss of fuel and widespread air pollution. When they are made into briquettes, these problems are mitigated, transportation and storage cost are reduced and energy production by improving their net calorific values per unit is enhanced (Grover and Mishia, 1996). The briquetting machine will help minimize the environmental hazard and it is hoped to be useful for small and medium scale briquette manufacturers.

According to Osarenwinda 2012, the manually briquetting machine designed to produce (20) Briquette at a time covers a total area which pressure act given by the equation:

$$P = n \times \frac{\pi}{4} d^2 \text{ .... } (2.15)$$

where;

d = diameter of moulding die

π = 3.142

n = number of moulding die

The briquetting machines can be divided into: high pressure compaction, medium pressure compaction assisted by a heating device and low pressure compaction with a binding agent. The physical properties (moisture content, bulk density, void volume and thermal properties) of the biomass are the most important factors in the binding process of biomass densification. The densification of biomass under high pressure results in mechanical interlocking and increased adhesion/cohesion (molecular forces like van der Waal’s forces) of the solid particles, which form intermolecular bonds in the contact area. Additives of high viscous bonding media (binders), such as tar, molasses and other molecular weight organic liquid can form bonds very similar to solid bridges.

2.6.1 High and Medium Pressure Compaction

High and medium pressure compaction normally does not use any additional binder. Normally, the briquetting process bases either on screw press or piston press technology. For the Screw Press Compression, the Biomass is extruded non-stop by the screw through a hot and taper block. For Piston Press Compression method, the hardness at the touch part like at the compress and block part is less compared with screw and block for Screw Press type. From quality aspect, the briquetting and production procedure for Screw Press is better when compared with Piston Press type.

2.6.2 Screw Press

In a screw press, the biomass is extruded continuously through a heated tapered die. The quality of the extruded logs and the production processes of a screw press are superior to piston press technology. However, compared to the wear of parts of a piston press, like the ram and a die, screw press parts need more maintenance. In the screw press, the raw material from feed hopper is conveyed and compressed by a screw. These presses produce denser and stronger briquettes compared with piston press. There are basically three types of screw presses:

(1) Conical screw press

(2) Screw press with heated die and

(3) Extruder.

2.6.2.1 Conical screw press

Conical screw press Produce denser and stronger briquettes compared to piston presses. A rotating die head extrudes the material through a perforated matrix to produce briquettes of diameter of 2.5 cm .A knife cuts the densified product to a specified length (Dutta, 2007).

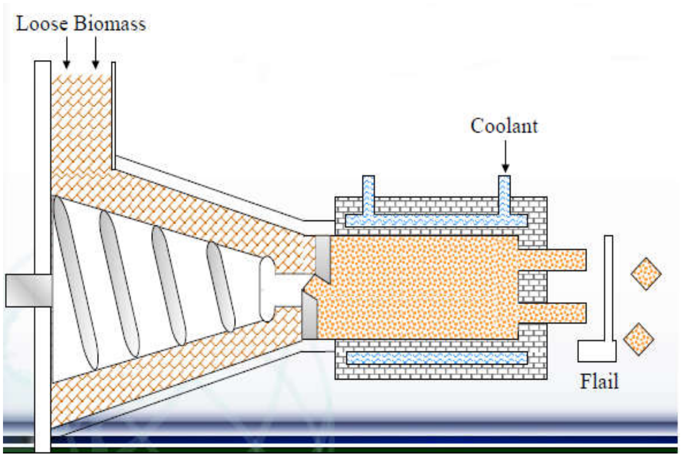


Figure: 2.3 Conical screw press (Dutta, 2007).

2.5.2.2 Screw press with heated die

In screw presses, material is fed continuously into a screw, which forces the material into a cylindrical die. This die is often heated to raise the temperature to the point where lignin flows.

2.6.2.3 Extruder

During screw extrusion, the biomass material moves from the feed port through the barrel and compacts against a die with the help of a pressure made by rotating screw. This process causes friction from the shearing of biomass. The purpose of using an extruder performing compaction is to bring the smaller particles closer. Therefore, the forces acting between the particles go stronger and provide more strength to the densified material. If the die is tapered the biomass becomes more compacted and if the heat produced within the system is not enough for the material to reach a pseudo plastic state for smooth extrusion, we can provide extra heat to the extruders from outside the system using band or tape heaters (Payne, 1978).

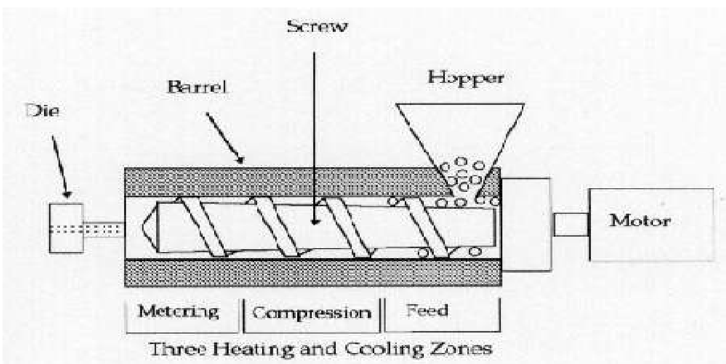


Figure: 2.4 Diagram of an extruder (Grover and Mishra, 1996).

The advantages of screw press densification are:

- The output is continuous and its size is uniform, it shows an easy ignition and combustion.
- The machine runs very smoothly without any shock load.
- The machine is lighter than the piston press (Steven and Verbe, 2004).

The disadvantages include:

- The parts and the oil used in it are free from dust or raw material contamination. Wear of the screw and die is the main problem.
- The power requirement of the machine is higher than the piston press (Payne, 1978).

2.6.3 Piston Press

The piston presses are usually long channel which aim to keep the shape of the briquettes while cooling. Piston presses punch the feed material into a die with very high pressure, either mechanically by a reciprocating ram powered by a massive flywheel, or by a hydraulically driven piston. Thereby, the mass is compressed and forms a very dense briquette. Some modern (hydraulically operated) machines apply pressure not only in longitudinal but also in radial direction.

2.6.4 Low Pressure Compaction

Low pressure briquetting needs a binding agent to assist the formation of bonds between the biomass particles. There are various binding agents in use which can be divided into two main groups: organic binders which include; Molasses, coal tar, bitumen, starch. And inorganic binders which comprises clay, cement, lime, sulphite liquor, etc.

During the compaction process the briquettes are brought into shape without giving them substantial strength. Only after subsequent curing steps (drying/burning) the briquettes will develop the required strength and stability.

CHAPTER THREE

MATERIALS AND METHOD

3.0 INTRODUCTION

This chapter gives detail explanation of the materials used as well as the methods followed in obtaining the data for the current study. The processes involved in the chapter include; design consideration of the briquette moulder, description of the parts the moulder contained, construction of the briquette moulding machine and lastly step by step method of the briquette production processes.

3.1 MACHINE DESIGN

The manual briquette machine was designed to produce five (5) briquettes at a time. The moulder consists of three basic parts thoroughly designed and fabricated as shown in the diagram below;

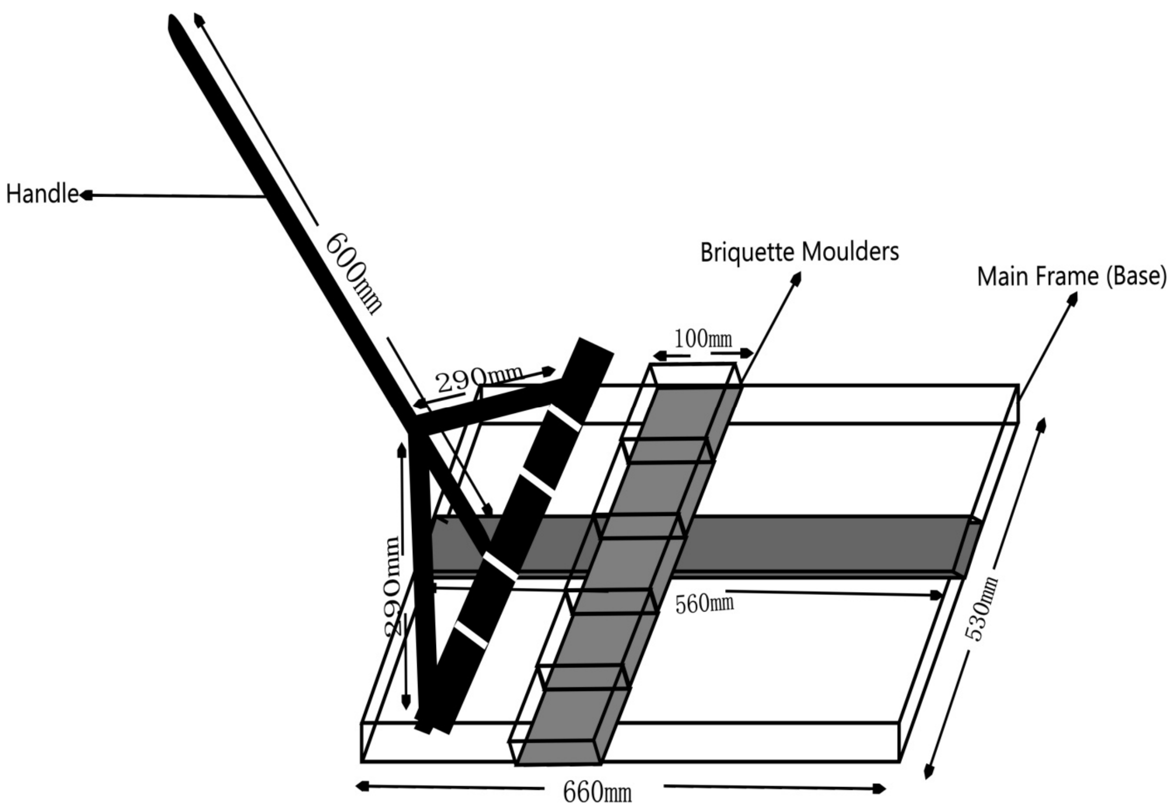


Figure 3.1: Schematic drawing showing dimensions of the designed briquette moulder.

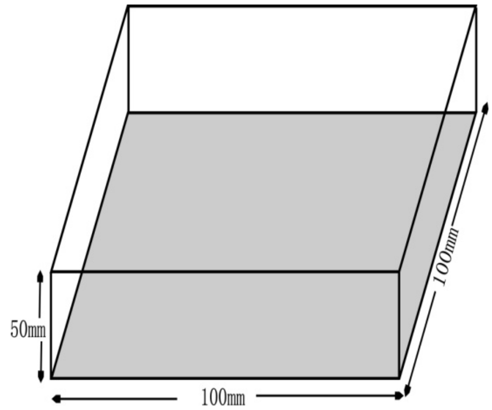


Figure 3.2: Schematic drawing of briquette moulder.

The three parts of base/frame, molding dies and handle are described below.

3.2 DESCRIPTION OF THE MACHINE PARTS

The manual briquetting machine consists of three main parts:

i. The Main frame (Base)
ii. The Briquette Moulders
iii. The Handle.

3.2.1 The main Frame (Base)

The main frame is the base plate of the machine that supports the compaction pressure as provided from the handle. It was made from a black hollow pipe 50mm×50mm of various lengths welded together to produce a rectangular shape of dimension 660mm×530mm. The major function of the main frame (base) is it serves as a chamber where the briquette compression processes occur. It also houses and supports the other parts the machine contained.

The area occupied by the main frame (A_f) of the briquetting machine is given by

$A_f = L_f \times b_f = 660mm \times 530mm = 0.318m^2$

3.2.2 Briquette Moulders

The Briquette moulders was made from a flat bar of 50mm height and thickness 5mm.The flat bar was cut into sizes of different lengths and welded together to produce five symmetrical moulders connected on both sides.

The shape of the moulder is a rectangle with an area given by;

$$A_m = L_m \times b_m \quad \ldots\ldots (3.1)$$

where;

A_m= Cross sectional area of the briquette moulders

L_m= Length of a the briquette moulders = 530mm = 0.53m

b_m= breadth of the moulders = 100mm = 0.10m

Hence, the area over which the pressure acts is given as

$A_m = 0.53\text{m} \times 0.10\text{m} = 0.053\text{m}^2$

3.2.3 The Handle

The handle is one of the essential parts of the machine that maneuvers the movement of the upper part which enclosed the moulders. The machine handle was made from 1inch galvanized iron (GI) pipe with a length of 600mm welded at the centre of the upper mould cover and was braced with two similar galvanized iron pipes of length 290mm each.

Assuming an average person can apply a force intermittently with the arm

Mass of an average person (Olle and Olof, 2006) is m = 50kg

The torgue produced by the handle T_h is given by

$$L_h = {}^{T_h}/_{M_P} \quad \ldots\ldots (3.2)$$

where;

L_h= Length of the handle = 600mm = 0.6m

Therefore,

$T_h = L_h \times M_P = 0.6\text{m} \times 50\text{kg} = 294.3\text{Nm}$

The mass of the carbon steel metal placed on the upper mould cover of the machine during compaction M_{CS} = 38.60kg with a length L_{CS} = 25cm and breadth B_{CS} = 10cm

The force produced by the metal is given as;

$F_{CS} = M_{CS} \times g = 38.60\text{kg} \times 9.81\text{m/s}^2 = 378.67\text{N}$

Hence, the pressure applied by the carbon steel metal to the moulding cavities of the machine is given by;

$P = {}^{F}/_{A} = {}^{378.67\text{N}}/_{0.025\text{m}^2} = 15146.80\text{N/m}^2$

3.3 BRIQUETTING MACHINE CONSTRUCTION PROCESSES

The construction of the briquette moulding machine and processes took place at Kabiru Abubakar Technical Services at Janguza Town, along Gwarzo road, Kano. The Construction was carried out using locally available materials. The available necessary equipments used in the construction of the briquette moulding machine and their functions are described in the table below;

Table 3.1 Construction Processes

S/N	MATERIALS	DESCRIPTION/FUNCTION
1.	Vices	Mechanical device use to secure or hold a work-piece to allow work to be performed on it. It has two parallel jaws, one fixed and the other movable, threaded in and out by a screw and lever.
2.	Oxygen-acetylene cylinder	This contains oxyacetylene welding fuel gasses and is used to weld and cut metals respectively. It is commonly used to permanently join mild steel.
3.	Measuring Tape	A flexible ruler consists of ribbon of cloth, plastic fiber glass or metal strip with linear measurement markings for taking measurements.
4.	Tri-Square	A metal working tool used for marking, measuring a piece of

		wood and measuring the accuracy of a right angle.
5.	Hack saw	A fine tooth saw, originally and principally for cutting metal.
6.	Electric hand grinder	Also called angle grinder is a powerful ball bearing motor that provides smooth running power to tackle the hardest metal cutting, shaping and slag removal.
7.	Electric Welding machine + electrode	Arc welding with coated electrodes is a manual process where the heat source consists of electric arc. When the arc strikes between the coated electrode and the piece to be welded, it generates heat which causes rapid melting of both the base material and electrode.
8.	Black Paint	Used for painting the constructed moulder.

3.3.1 Main Frame Construction

The main frame of the machine was constructed using 50mm × 50mm black hollow pipe. It was constructed by cutting the black hollow pipe into five (5) pieces. Two pairs each of 530mm and 660mm and one pair of 560mm which was placed at the centre of the machine. The various sizes of the black hollow pipes were joined together to produce a base frame as shown by the diagram below.

Plate I: Construction of Base Frame

3.3.2 Moulding Cavity

The Moulding cavity of the briquette moulder was constructed using mild steel flat bar of height 50mm and thickness 5mm. The flat bar was cut into sizes 100mm × 50mm (2pieces) and 100mm×50mm (6pieces). Five symmetrical moulding cavities with a rectangular shape connected on both side were produced and used to contain the prepared mixture of biomass for compaction. Each moulder is 100mm long, 100mm wide and 50mm high with a cutting allowance giving a total length of 540mm.

The figures below show the briquette moulding cavities under construction.

Plate II: Mild steel Flat bar cutting

Plate III: Briquette moulders under construction

3.3.3 Top and Bottom Mould Cover

Top and Bottom mould cover were created using 2mm thick mild steel plate. The 2mm thick plate was cut into a size of 550mm×120mm and attached to the main frame to serve as the briquette's bedrock at the bottom. The same size of the plate was also attached to the handle to serve as a cover plate covering the moulding cavities and compresses the material during compaction.

3.3.4 The Handle

The machine handle was constructed using 25mm diameter galvanized iron (GI) pipe. The iron was cut into pieces of size 600mm (1pieces) and 280mm (2pieces) and welded together. The machine handle is used to maneuver the movement of the upper part of the moulder.

3.3.5 The Hinges

Hinges are the mechanical bearing that connects two solid objects together; typically allowing only a limited angle of rotation between them. Hinges were mounted on top of the black hollow pipe of the main frame and connected to a galvanized iron pipe (GI) of the handle for easy rotation. They are placed in such a manner to have a very low contact stress and not carry any form of load. For their maintenance, they are lubricated with grease.

The diagrams in plate IV and V below show the briquette moulder under and after the construction processes:

Plate IV: Briquette moulding machine under construction

Plate V: Constructed Briquette moulder

3.4 BRIQUETTE PRODUCTION

Briquette production processes usually starts with the collection of biomass residues from the fields or farmlands, sun-drying in order to reduce the moisture content of the biomass, size reduction by shredder or choppers, mixing with the required and appropriate binding agent, residues compaction into the briquetting machine and lastly drying of the compressed residue to form a solid briquette that can serve as an alternative to wood charcoal.

3.4.1 Materials

The materials used in the production of the briquettes include;

- **Baggase:** The fibrous residue of the sugarcane stalk after the extraction of sugar.
- **Cornstalk:** The residue remains after the corn was harvested and has no value rather than to become organic residue that decompose in the field before the next planting season.
- **Waste paper:** An incredible versatile substance made from naturally occurring plant fibers called cellulose derived from wood, rags or grasses and drying them into flexible sheets. The waste papers used in this research are mostly computer print-out papers.
- **Tapioca starch:** Tapioca starch which is made from cassava flour and was used as a binding agent to enhance the compactness of the biomass materials and prevents them from disintegrating.
- **Water.**

3.4.2 Materials preparation and briquettes production processes

3.4.2.1 Sorting

The collected biomass samples were initially screened from stones and other impurities that may inhibit proper briquette production. All unwanted materials or large size of biomass were removed to ensure that all feedstock’s are of the required sizes for the process.

3.4.2.2 Crushing

Biomass crushing machine was used to grind the sorted biomass waste-like materials (Bagasse, Cornstalk and Paper). Under this process, the biomass materials were chopped and crushed into small pieces of sizes 2mm-8mm with 10-20% powdering components so as to enhance their workability and compactness.

The diagrams below show the crushing processes of different biomass materials using biomass crushing machine.

Plate VI: Crushing of cornstalk

Plate VII: Waste paper crushing

Plate VIII: sugarcane peals (Bagasse) under crushing

3.4.2.3 Starch preparation and Mixing

Cassava starch (Tapioca) was prepared by combining 0.5litre of cold water with 0.25kg of cassava flour and mixed in a pot of boiling water. When the water was boiling, the cassava flour with water mixture was gradually stirred until it was slightly lumpy and rather viscous. After cooling, 20% by weight of starch was poured into a container containing slightly wetted 100% of paper (sample 1) and were mixed thoroughly with bare hands (for about 2-4minutes) until almost every particle of the paper is attached with the binder. The same procedure was repeated with subsequent treatments; sample 2 (100%Cornstalk), sample 3 (100% Bagasse), sample 4 (50%Paper +50% Cornstalk), Sample 5 (50% Paper +50%Bagasse) and sample 6 (50%Cornstalk+50% Bagasse).

3.4.2.4 Compaction and Drying

At this stage, the prepared mixture of the biomass residue and starch was poured into the moulding cavities of the constructed briquette moulder and was slightly compacted by closing down the mould cover of the machine handle. The pressure created on the mixtures depends on the control and power of the machine user. The pressure was created by placing the carbon steel metal of mass 38.60kg on top of the mould cover which enclosed the moulders for a dwell time of 15minutes after which it was removed.

Plate IX: Biomass mixtures loaded into the moulding cavities of the moulder.

The compressed biomass mixtures were ejected and placed on a tray and sun-dried for fourteen days (2weeks). Briquette production and drying took place from 21st Dec, 2015 to the first week of January 2016.

Plate X: Sun drying of the produced briquettes

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 INTRODUCTION

This chapter present the results obtained from the determination of the physical properties of the briquette which includes; Maximum/Relaxed densities, Relaxation ratio, Density ratio and Shatter resistance. It also present and discussed the results obtained for the determination of proximate analysis of the briquette comprising percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of the briquette mixtures.

4.1 DETERMINATION OF BRIQUETTE PHYSICAL PROPERTIES

The physical properties of the briquettes examined in this study were limited to Maximum density, relaxed density, relaxation ratio and density ratio. The results were therefore discussed according to the values obtained. One of the major indices for accessing the combustion, handling characteristics and ignition behaviour is density. Tables 4.1 and 4.2 below show the results obtained for maximum and relaxed density of the briquettes fabricated.

Table 4.1: Maximum density of briquetted fuel

Sample(s) Serial N0.	Sample(s) mixtures	Weight of the wet briquette (kg)	Volume of the wet briquette (m^3)	Maximum Density of the Briquette $\mathbf{M_D}$ (kg/m^3)
1.	100% Paper	0.4046	0.0004	1011.48
2.	100% Cornstalk	0.3023	0.0004	755.65
3.	100% Bagasse	0.3354	0.0004	838.55
4.	50% Paper + 50% Cornstalk	0.3017	0.0004	754.20
5.	50% Paper + 50% Bagasse	0.2971	0.0004	742.65
6.	50% Cornstalk + 50% Bagasse	0.2315	0.0004	578.85

Table 4.2 Relaxed density of the briquette fuel

Sample(s) Serial N0.	Sample(s) mixtures	Weight of the dry briquette (kg)	Volume of the dry briquette (m^3)	Relaxed Density of the Briquette $\mathbf{R_D}$ (kg/m^3)
1.	100% Paper	0.11045	0.00035	315.57
2.	100% Cornstalk	0.08332	0.00039	213.64
3.	100% Bagasse	0.08136	0.00036	226.00
4.	50% Paper + 50% Cornstalk	0.08706	0.00037	235.30
5.	50% Paper + 50% Bagasse	0.08848	0.00036	245.78
6.	50% Cornstalk + 50% Bagasse	0.08407	0.00039	215.56

From table 4.1 above, the maximum densities of the briquettes obtained varied from 578.85kg/m^3 for sample 6 (50% Cornstalk + 50% Bagasse) to 1011.48kg/m^3obtained for sample 1 (100% Paper). These values are within the range of 600kg/m^3 and above as recommended by Gilber *et al.*, (2009). Consequently, the values obtained for the relaxed densities ranged from 213.64kg/m^3 for sample 2 (100% Cornstalk) to 315.57kg/m^3 for sample 1 (100% Paper).

The maximum and relaxed density of the briquette obtained in this study are well compared and considered acceptable with that of corn cob briquettes with maximum and relaxed densities values ranging from 533kg/m^3 to 981kg/$m^3$and 307kg/m^3 to 417kg/m^3respectively (Oladeji and Enweremadu, 2012), and 214.17kg/m^3 to 421.05kg/$m^3$for the relaxed densities of sawdust briquettes (Nasiru *et al.*2015). The briquettes will not crumble during transportation and storage because the values obtained for the densities are quite high.

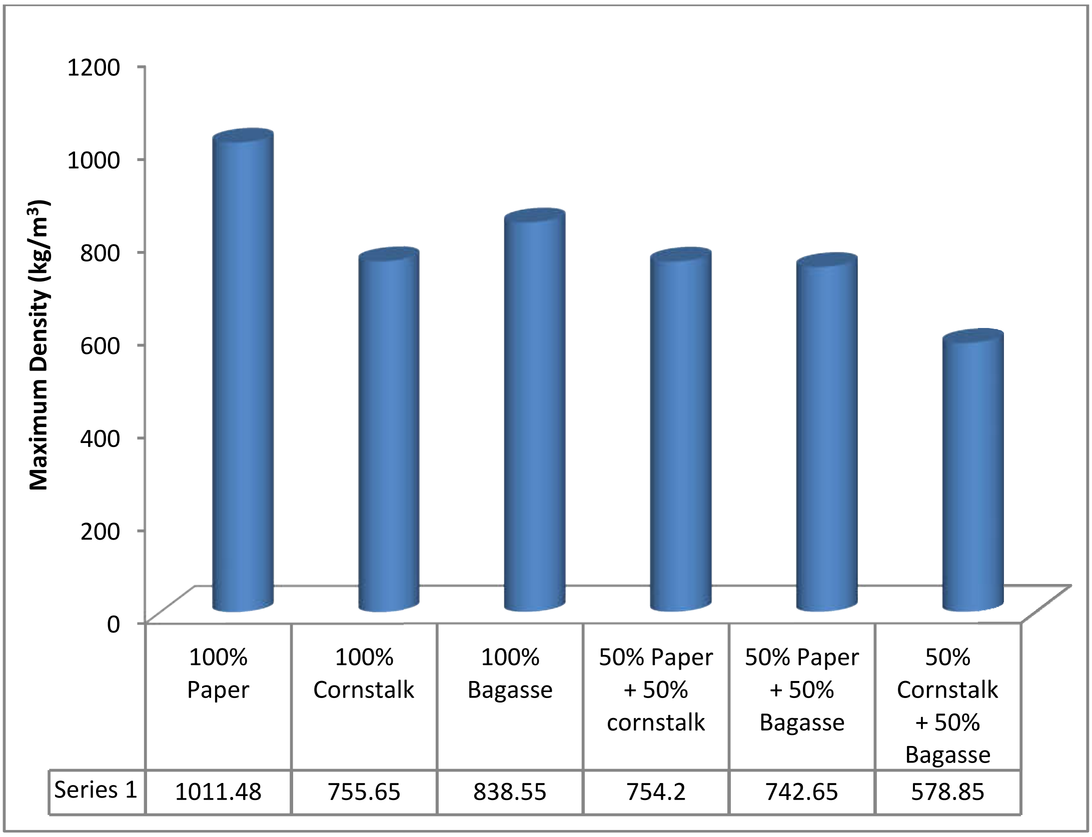


Figure 4.1: Maximum density of the briquetted fuel.

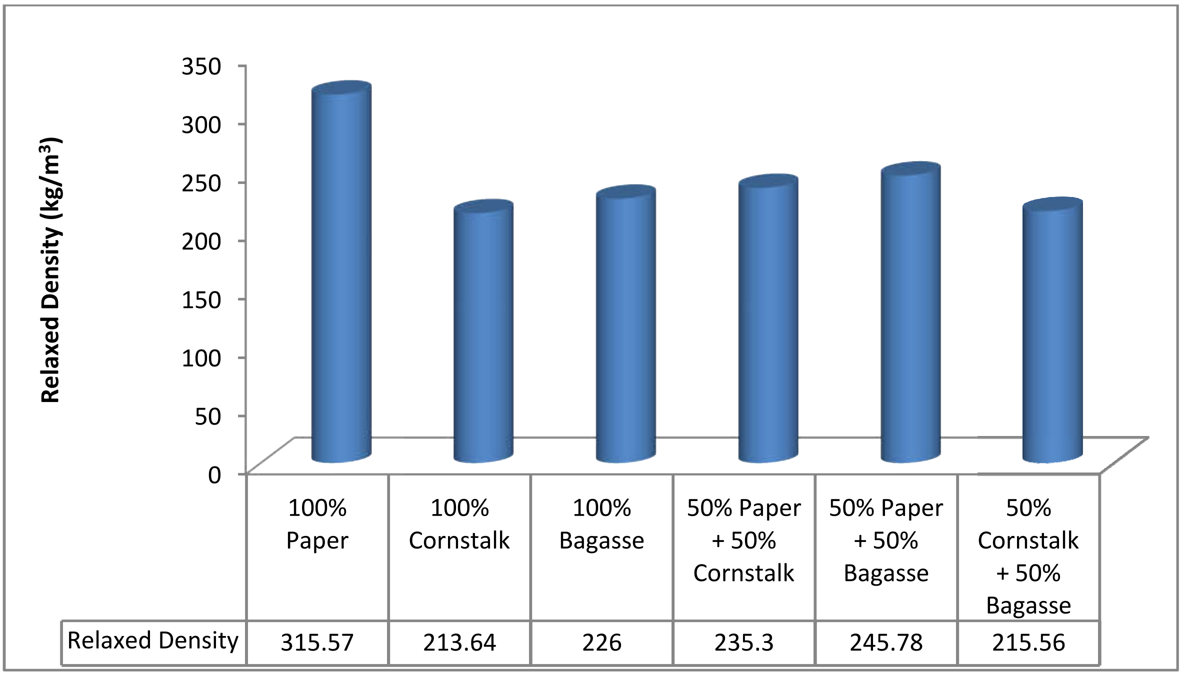


Figure 4.2: Relaxed density of the briquetted fuel

The maximum and minimum relaxed density values were respectively observed at sample 1 (100% Paper) with 315.57kg/m^3 and sample 2 (100% Cornstalk) with 213.64kg/m^3 implying that the briquettes can be easily handled and transported.

Table 4.3: Relaxation ratio R_R and Density ratio D_R of the briquetted fuel

SampleSerial N0.	Sample(s) mixtures	Maximum Density of the Briquette $\mathbf{M_D}$ (kg/m^3)	Relaxed Density of the Briquette $\mathbf{R_D}$ (kg/m^3)	Relaxation ratio $\mathbf{R_R = M_D/R_D}$	Density ratio $\mathbf{D_R = R_D/M_D}$
1.	100% Paper	1011.48	315.57	3.21	0.31
2.	100% Cornstalk	755.65	213.64	3.54	0.28
3.	100% Bagasse	838.55	226.00	3.71	0.27
4.	50% Paper + 50% Cornstalk	754.20	235.30	3.21	0.31
5.	50% Paper + 50% Bagasse	742.65	245.78	3.02	0.33
6.	50% Cornstalk + 50% Bagasse	578.85	215.56	2.68	0.37

As shown in table 4.3, the corresponding values for the Relaxation ratios were 3.21, 3.54, 3.71, 3.21, 3.02 and 2.68 for sample 1, 2, 3, 4, 5 and 6 respectively. These values are compared favourably well as they are close to the values obtained by Obi *et al.*, (2013) for sawdust briquette 2.887 and 2.86 for corncobs (Oladeji and Enweremadu, 2012).

Consequently, the density ratio varied from 0.27 to 0.37 for the briquetted fuel in this study. And the results are compared well with notable biomass residue like coconut fibre, palm fibre and peanut shells with density ratio of 0.71, 0.41 and 0.25 respectively (Chin and Siddique, 2000).

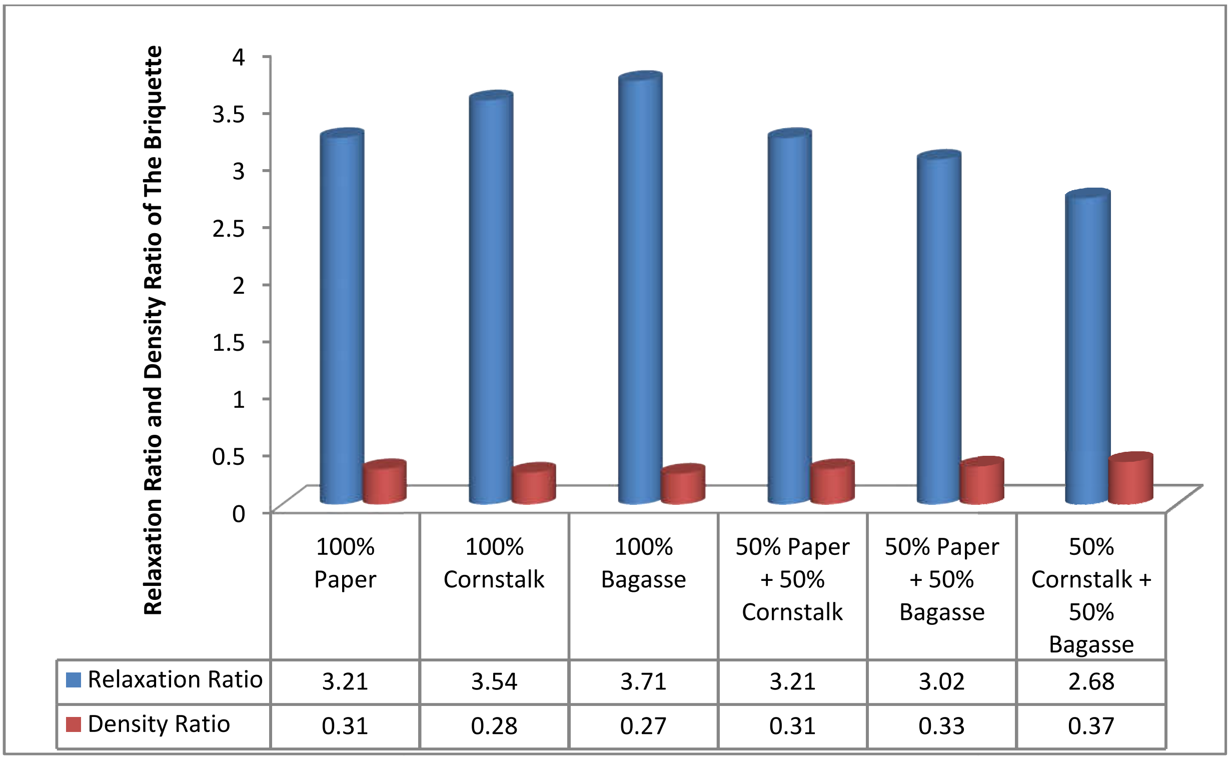


Figure 4.3: Density and Relaxation ratio of the briquetted fuel.

Shatter resistance test for the produced briquettes was determined in accordance with shattered index described by sotande *et al.*, (2010). The briquette were dropped repeatedly from a height of 1.5meter onto a concrete floor, the fraction of the briquette remained was used as index of briquette durability in percentage.

Table 4.4: Shatter resistance test for the briquetted fuel

Sample Serial N0.	Sample(s) mixtures	Weight of the briquette before shattering in (g), $\mathbf{W_1}$	Weight of briquette after shattering in (g), $\mathbf{W_2}$	Percentage Loss	% Contents remaining after shatter
1.	100% Paper	110.45	109.61	0.76	99.24%
2.	100% Cornstalk	83.32	80.38	3.53	96.47%
3.	100% Bagasse	81.36	75.50	7.20	92.80%
4.	50% Paper + 50% Cornstalk	87.06	82.31	5.46	94.54%
5.	50% Paper + 50% Bagasse	88.48	86.70	2.01	97.99%
6.	50% Cornstalk + 50% Bagasse	85.43	74.70	12.56	87.44%

As shown in table 4.4 above, the maximum average shatter resistance was found to 99.24% in sample 1 (100% Paper), seconded by 97.99% of the sample 5 (50%Paper + 50% Bagasse) and sample 6 (50% Cornstalk + 50%Bagasse) recorded the least with 87.44%.

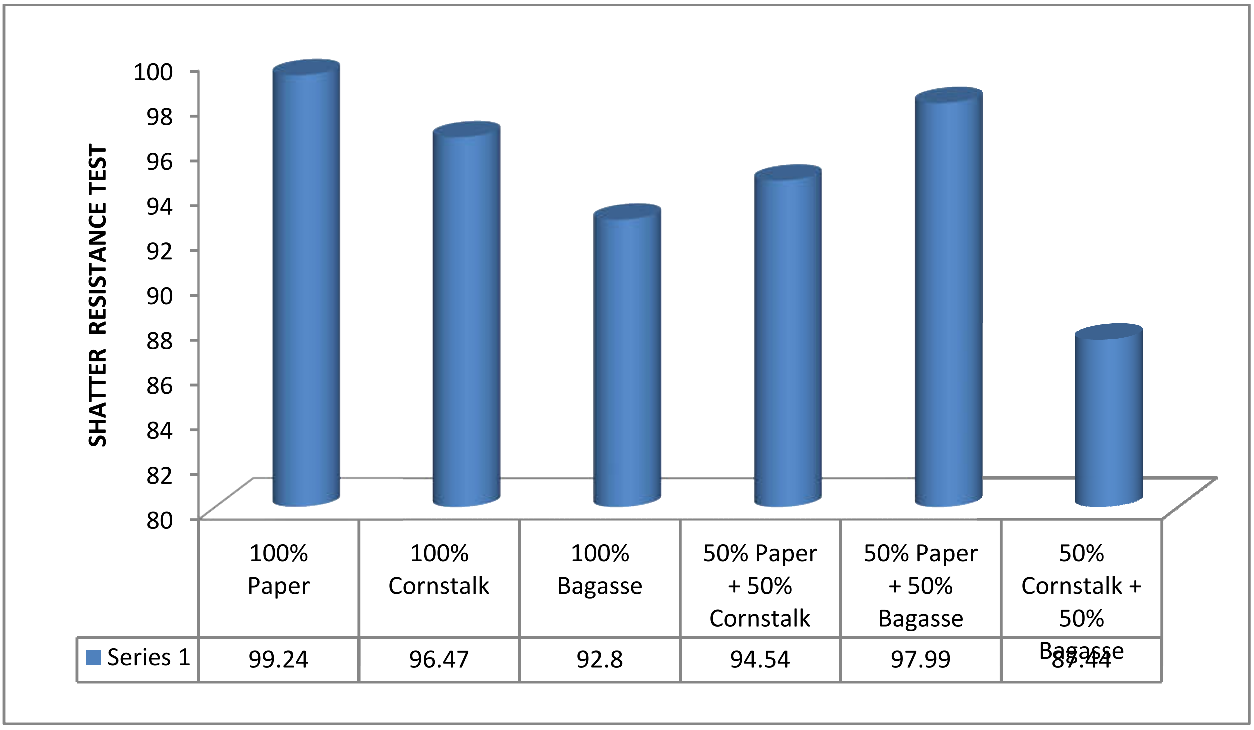


Figure 4.4: Shatter resistance of the briquetted fuel.

The results recorded are nearly in agreement with the values 92.80% to 95. 23% for sole briquette and 77.27% to 96.26% for the combined briquette (Jyoti *et al.*,2010). High shatter resistance value indicates that briquette can withstand high shock and impact resistance, and as such sample 1 (100%Paper) was more suitable for transportation and handling.

4.2 DETERMINATION OF BRIQUETTE PROXIMATE ANALYSIS

The proximate analysis of the briquette is a standardized procedure that gives an idea of the bulk components that make up a fuel. The procedures of the ASTM Standard D5373-02(2003) was adopted to obtained the percentage volatile matter (%VM), percentage ash content (%AC) and percentage fixed carbon (%FC), and their corresponding result are shown in table 4.5.

Table 4.5: Proximate analysis of the briquetted fuel

Sample Serial N0.	Sample(s) mixtures	Percentage Volatile Matter (%VM)	Percentage Ash Content (%AC)	Percentage Fixed Carbon (%FC)
1.	100% Paper	81.52	16.44	2.04
2.	100% Cornstalk	82.47	17.19	0.34
3.	100% Bagasse	92.01	5.32	2.67
4.	50% Paper + 50% Cornstalk	80.05	19.32	0.63
5.	50% Paper + 50% Bagasse	84.31	11.45	4.24
6.	50% Cornstalk + 50% Bagasse	80.11	14.64	5.25

Table 4.5 above gives the average values recorded for the percentage volatile matter; percentage ash content as well as the percentage fixed carbon. The percentage volatile matter ranged from 80.05% to 92. 01% with the lowest and highest value observed for samples 4 (50% Paper + 50% Bagasse) and 3 (100%Bagasse) respectively. These values are in agreement with notable biomass residues like corncobs, groundnut shell and yam peels with 86.53, 88.49 and 82.87 respectively (Oladeji, 2012), and 91.69 for sawdust briquette (Obi *et al.*, 2013).

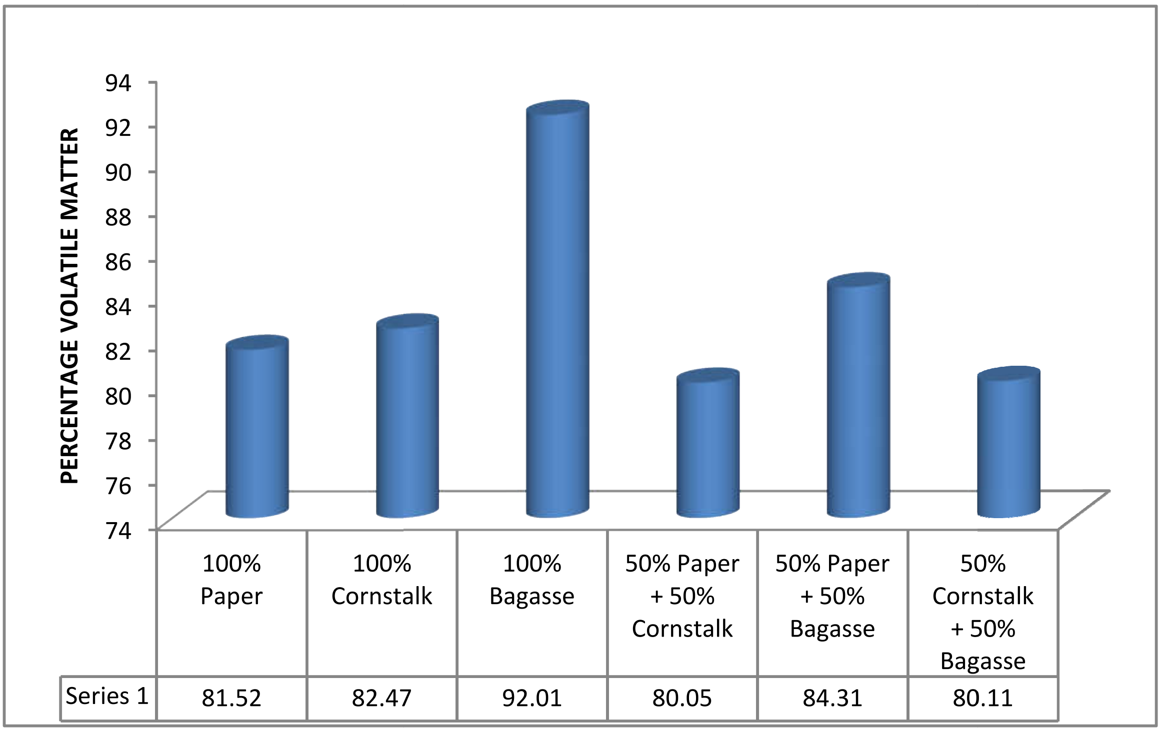


Figure 4.5: Percentage volatile matter of the briquetted fuel.

Consequently, the average values obtained for the percentage of ash content varied from 5.32 to as much high as 19.32, with 16.44, 17.19, 5.32, 19.32, 11.45 and 14.64 for sample 1, 2, 3, 4, 5 and 6 respectively. These values are in agreement with those found to exist within the range of values obtained for soybean 6.58% (Khardiwar *et al.*, 2013) and sawdust 19.45% (Obi *et al.,* 2013).

The low ash content indicates that it is suitable for thermal utilization and higher ash content in a fuel usually leads to lower calorific value (Efomah and Gbabo, 2015).

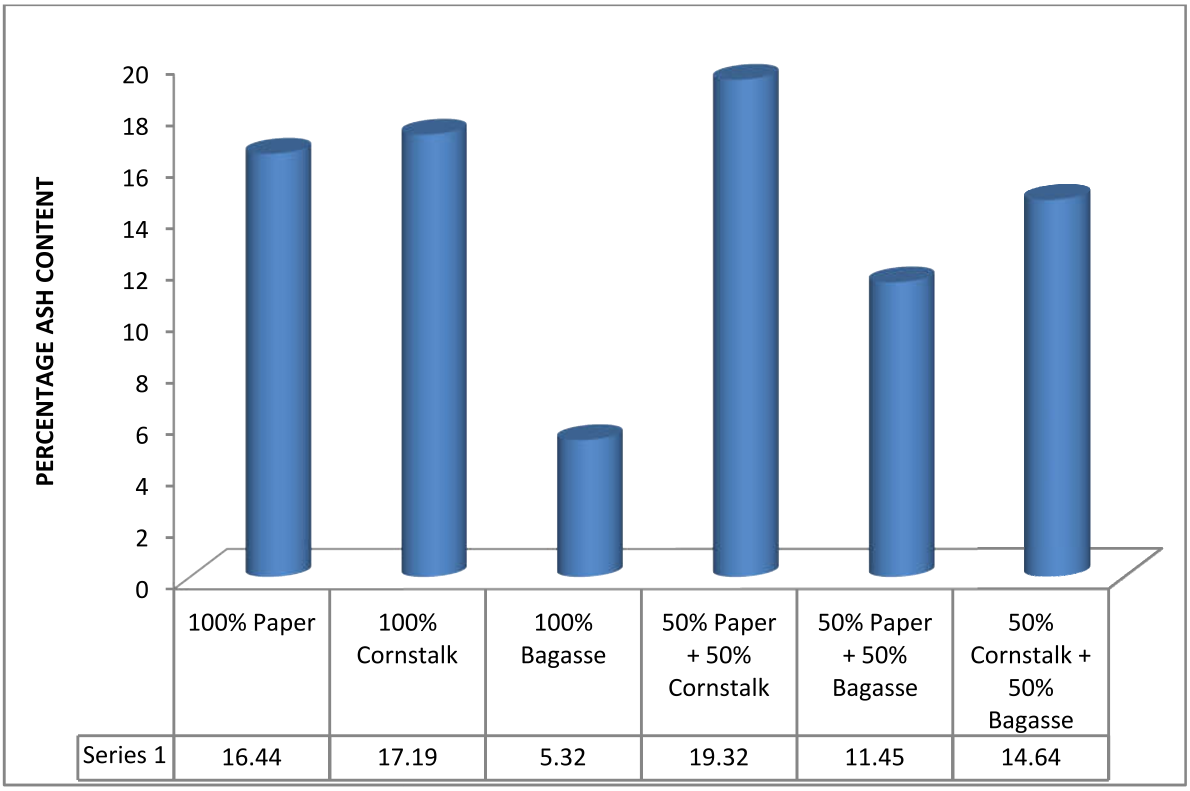


Figure 4.6: Percentage ash content of the briquetted fuel.

The fixed carbon of the fuel is the percentage of carbon available for char combustion. As reported in table 4.5 above, the average percentage of the fixed carbon in this study ranged from 0.34 to 5.25 which are closer to the range of values 2.57, 3.29 and 3.29 obtained by Oladeji, (2012) for cassava peels, Yam peels and Groundnut shell respectively.

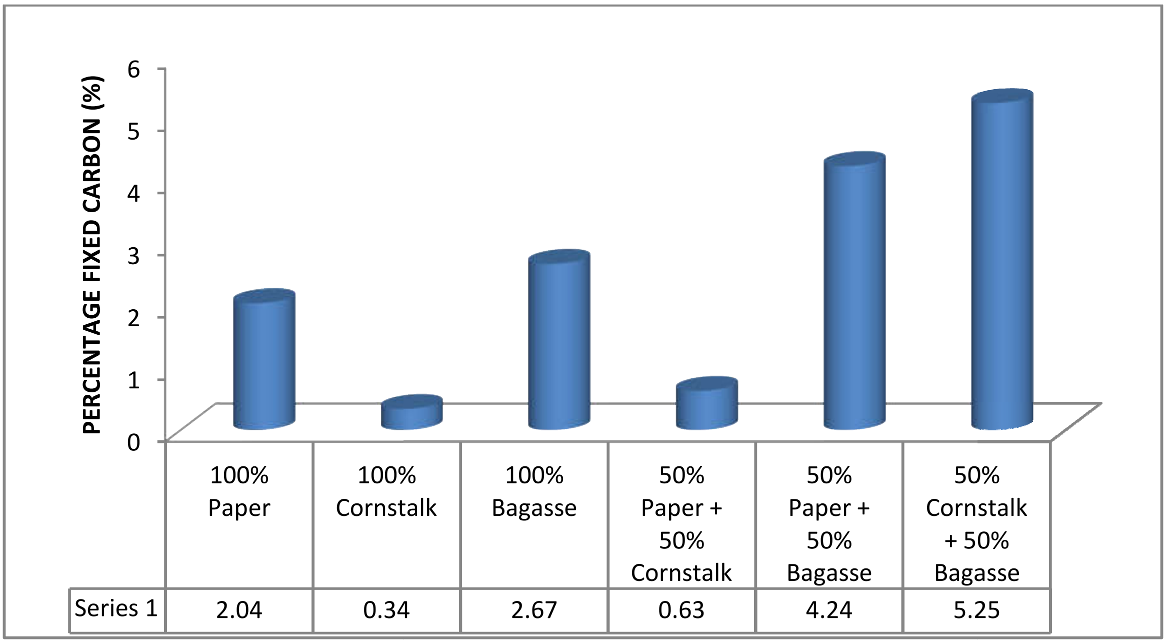


Figure 4.7: Percentage fixed carbon of the briquetted fuel.

4.3 CALORIFIC VALUE TEST AND RESULTS

The calorific value of the briquette samples was determined using Cussons-bomb calorimeter in the Thermodynamic/Fluid laboratory of Mechanical Engineering department of Bayero University, Kano.

4.3.1 Materials used for the calorific value test

The materials used in carrying out the calorific value test includes; Cussons bomb calorimeter, Beckman thermometer (0 to 6℃) and magnifying eye piece, crucibles, vice; for bomb holding, spanners, oxygen cylinder, digital weighing balance, syringe(50ml), cotton thread, ignition fuse wire, stop watch and 0.50/0.51g of the briquette sample.

4.3.2 Test procedure

The briquette samples to be tested were ground into very small fine particles, clean and empty crucible was weighed using digital weighing balance and later filled with 0.50g/0.51g of the briquettes sample. The Cussons bomb calorimeter was cleaned before starting and 10ml of distilled water was pipette into the bomb.

A fuse wire of length 6cm was connected across the terminals of the bomb along with some cotton thread linked with the fuel samples placed into the crucible. The bomb was carefully closed using the vice and spanner and connected to the oxygen cylinder were it was charged carefully with oxygen up to about 25atms.

2000ml of the distilled water was added into the calorimeter vessel and the bomb was carefully submerged into it and checked to ensure no oxygen leakage. The Beckman thermometer and stirrer were arranged so that they do not touch the bomb or the vessel, the stirrer was then switched on. Having the stirrer running successfully and the temperature was noticed to be rising steadily, a series of reading at one minute interval was taken for 3minutes and then ignited. The one minute reading was continued until the temperature passed through the maximum and temperature started dropping for about three minutes.

The bomb was then removed, inserted in the vice and the pressure was release slowly and uniformly over a period of one minute by unscrewing the bomb. The bomb was opened, observed for proper combustion, rinsed out, cleaned and dried. The same procedure was repeated for all the various samples. Below is the table for temperature readings with time of the bomb calorimeter test for fuel the samples and the benzoic acid.

Table 4.6: Temperature readings with time of the bomb calorimeter test for the fuel samples.

Time (Minutes)	100% Paper Briquettes Temp. (°C)	100% Cornstalk Briquettes Temp. (°C)	100% Bagasse Briquettes Temp. (°C)	50% Paper + 50% Cornstalk Briquettes Temp. (°C)	50% Paper + 50% Bagasse Briquettes Temp. (°C)	50% Cornstalk + 50% Bagasse Briquettes Temp. (°C)	Benzoic Acid Temp. (°C)
0	2.922	2.345	1.875	2.372	2.168	2.839	3.185
1.	2.885	2.340	1.865	2.356	2.165	2.840	3.140
2.	2.905	2.328	1.895	2.361	2.165	2.842	3.155
3.	2.912 IP	2.342 IP	1.912 IP	2.370 IP	2.160 IP	2.845 IP	3.164 IP
4.	3.055	2.478	1.969	2.518	2.263	2.908	3.142
5.	3.318	2.689	2.278	2.665	2.558	3.082	3.889
6.	3.410	2.860	2.438	2.780	2.652	3.212	4.105
7.	3.481	2.902	2.540	2.852	2.762	3.290	4.212
8.	3.530	2.955	2.612	2.877	2.795	3.338	4.315
9.	3.555	2.990	2.668	2.900	2.821	3.360	4.379
10.	3.572	3.012	2.690	2.922	2.840	3.378	4.402
11.	3.588	3.029	2.705	2.932	2.860	3.390	4.432
12.	3.592	3.042	2.715	2.940	2.866	3.398	4.445
13.	3.598	3.046	2.722	2.942	2.870	3.400	4.455
14.	3.600	3.048 } T_{max}	2.728	2.943 T_{max}	2.871 T_{max}	3.402	4.460
15.	3.600	3.048	2.731	2.940	2.870	3.405	4.461 T_{max}
16.	3.601 T_{max}	3.045	2.732 } T_{max}	2.938	2.869	3.408 T_{max}	4.460
17.	3.600	3.041	2.732	2.932	2.865	3.405	4.458
18.	3.599	3.039	2.729			3.402	4.455
19.	3.598		2.727			3.400	
20.			2.726				

The calorific value can be calculated for the fuel sample as analyzed below (Cussons G, 1974);

Radiation correction RC = $nV` + \left[\frac{-V + V`}{2}\right]$ .... (4.1)

where;

n = Number of minutes between the ignition time and attainment of maximum temperature.

$V`$ = Rate of temperature fall in degrees per minute at the end of the test

V = Rate of temperature rise in degrees per minute at the beginning of the test

The actual temperature rise T_{rise} during the test is given by

$$T_{rise} = T_{max} \quad T_{min} \text{ ………………………………..….. (4.2)}$$

where;

T_{max} = maximum temperature attained during the test

T_{min} = Initial temperature at the ignition point (IP) of the test

Corrected temperature rise (t) during the test is given by = RC + T_{rise}

And the water value W of the apparatus can be calculated using the equation below;

$$W = \frac{M_b \times CV_b}{t} \text{ ……………….……………………….. (4.3)}$$

where;

M_b = Mass of the benzoic acid

CV_b = Calorific value of the benzoic acid

Hence, the calorific value of the fuel sample can be determine by the equation (4.4) below

$$CV = \frac{t \times W}{M_s} \text{ .... (4.4)}$$

Using equations 4.1 to 4.4 with the data obtained from the bomb calorimeter test given in table 4.6, the calorific values of the fuel samples were summarized in table 4.7 and figure 4.8 respectively.

Table 4.7: Calorific value of the briquette samples

Sample(s) Serial N0.	Samples mixtures	Calorific value of the fuel samples (J/g)
1.	100% Paper	14074.69
2.	100% Cornstalk	14641.97
3.	100% Bagasse	17009.22
4.	50% Paper + 50% Cornstalk	12313.35
5.	50% Paper + 50% Bagasse	14998.54
6.	50% Cornstalk + 50% Bagasse	12045.45

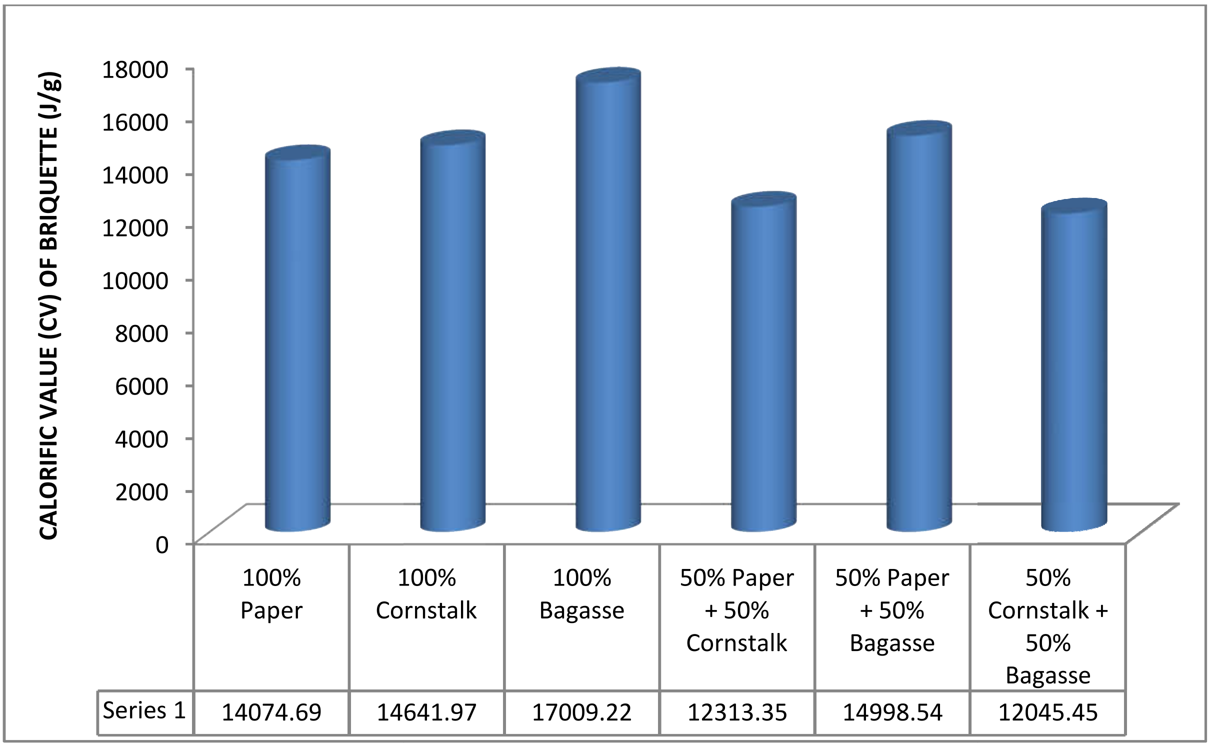
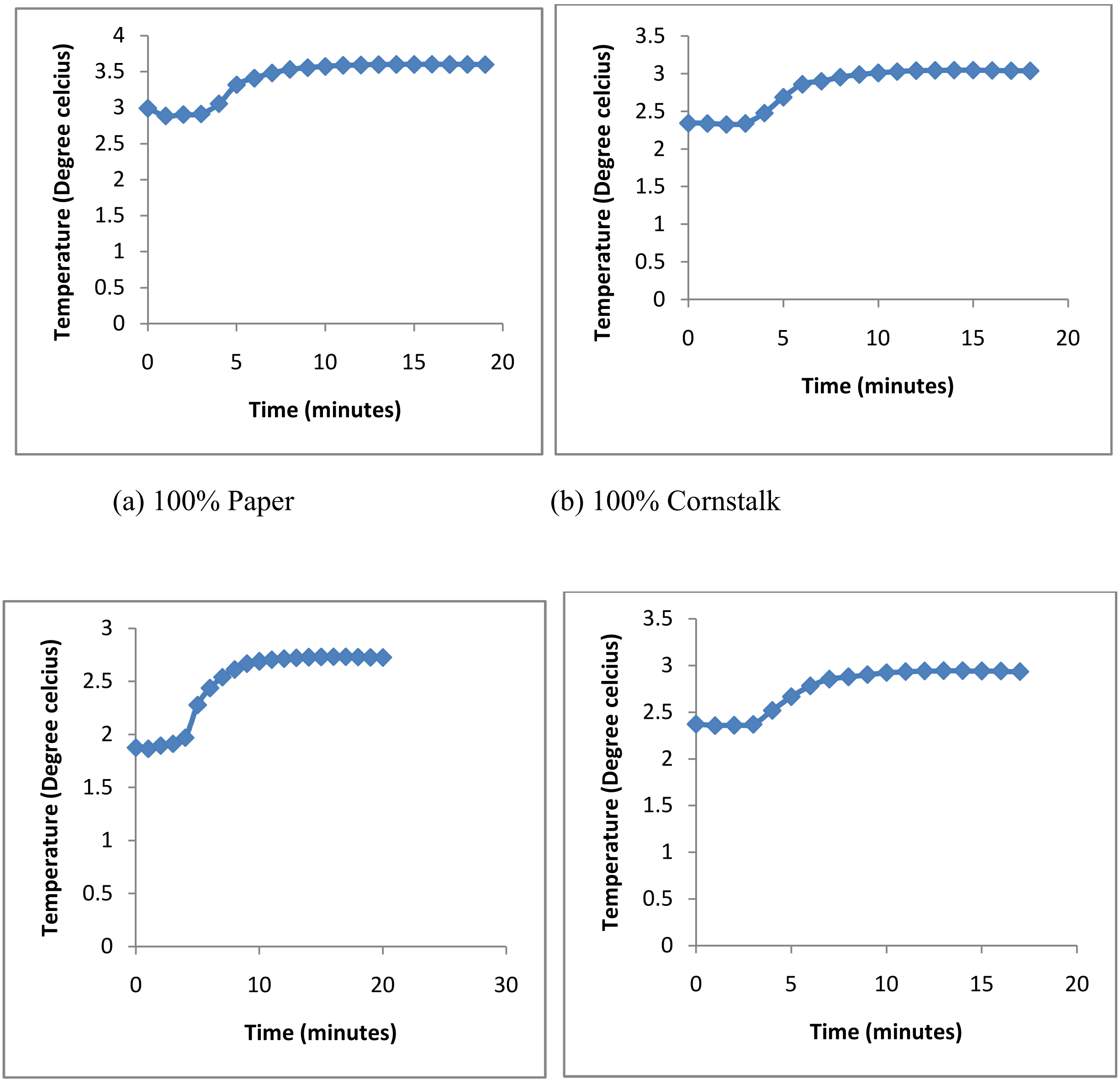


Figure: 4.8: Results of calorific value of the briquetted fuel

The maximum calorific value in this study was observed in the briquette sample 3 (100%Bagasse) with 17009.45J/g and the minimum value was obtained in briquette sample 6 (50%cornstalk + 50% bagasse) with value 12045.45J/g. These values obtained agree well with the values obtained for cassava peel- 12765kj/kg, yam peel - 17348kj/kg (Oladeji and Oyetunji, 2013) and soybean + sawdust – 14713.79kj/kg (Jyoti, 2010).

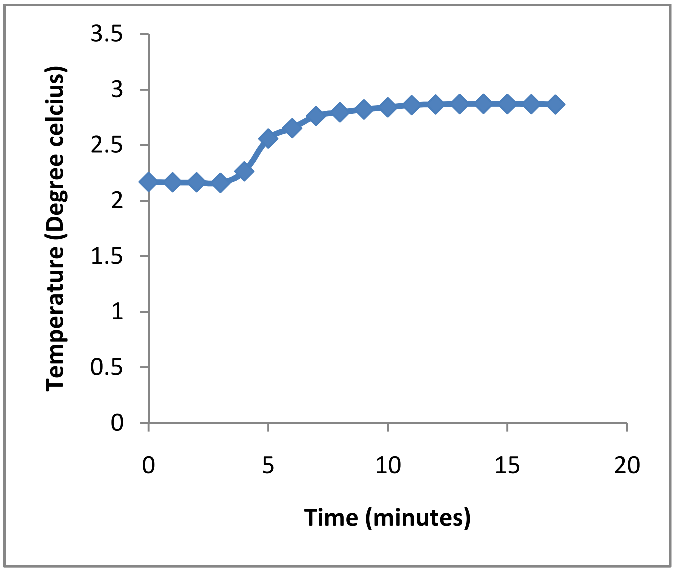
These energy values (Table 4.8) are sufficient enough to produce heat required for household cooking and small scale industrial applications.

Below are the results for the temperature against time of the Bomb calorimeter test for the fuel samples and benzoic acid.

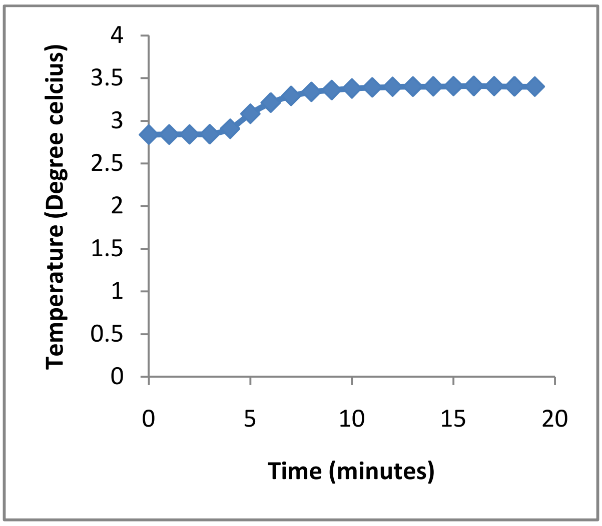


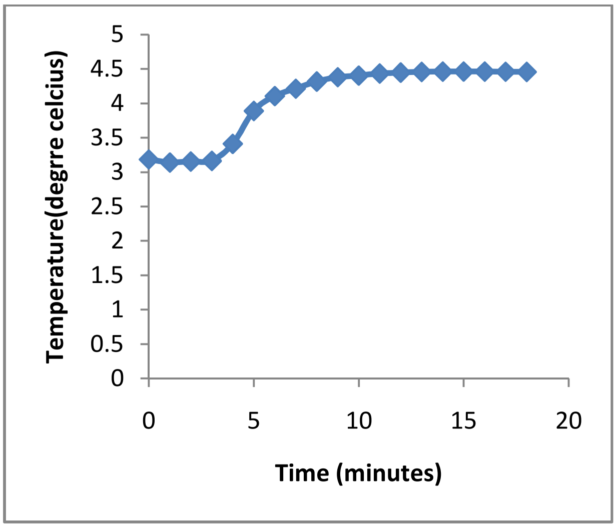
(a) 100% Paper (b) 100% Cornstalk

(c) 100% Bagasse (d) 50% Paper + 50% Cornstalk



(e) 50% Paper + 50% Bagasse





(f) 50% Cornstalk + 50% Bagasse (g) Benzoic acid

Figure 4.9 (a-g): Graphs of the temperature against time of the bomb calorimeter test of the fuel samples and benzoic acid.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

The overriding objective of this thesis was to produce briquette from biomass materials (Paper, Sugarcane Bagasse and Cornstalk) to serve as an alternate to wood charcoal using a designed and fabricated hand-press briquette moulder. This low pressure briquetting process could provide a simple means for people with limited equipment and resources of upgrading residues that might otherwise go to waste.

This research also examined the physical and combustion characteristics of briquette produced from waste paper, sugarcane bagasse, cornstalk and combination of their 50% mixtures.

5.2 CONCLUSION

There is presently a large world-wide interest in biomass briquettes as a renewable energy source, because it does not negatively affect the environment. Based on the experimental analysis and findings of this study, the following conclusions can be made;

- A hand-press briquette moulder suitable for the production of biomass briquettes on a small scale was designed, constructed and used in the production of biomass briquettes using a waste paper, cornstalk, sugarcane bagasse and their mixtures.
- The briquettes produce from all the biomass mixtures will not crumble during transportation and storage because the values obtained for the relaxed densities are sufficient enough and the briquettes with higher densities were observed to have higher stability.
- The energy value (calorific value) of the briquette ranges between 12045.45J/g and 17009.22J/g are sufficient enough to produce heat required for house hold cooking and small scale industrial applications.

- Briquette production can be a viable business enterprise and source of income: Members of the community engaging on the job can become experts in recycling waste products to wealth, thereby providing the populace with new and cheap alternative source of cooking energy.
- From the six mixtures of briquettes produced and analyzed in this study, briquette sample 3 (100%Bagasse) recorded the highest Calorific value of 17009.22J/g, and with the lowest ash content 5.32%, a maximum density of 838.55kg/m^3, a shatter resistance of 92.80% and appears to be the best briquette among its counter-parts. Other mixtures which shows positive attributes include sample 1 (100%Paper), sample 2 (100%Cornstalk) and sample 5 (50%Paper + 50%Bagasse).

5.3 RECOMMENDATIONS

Based on the findings and conclusions of the study, the following are the recommendations made for further studies;

- Determination of the machine capacity using other types of biomass and with different binding agent and level, alongside the heating value, physical and proximate analysis of the produced briquettes.
- Performance evaluation of the briquette produced from the machine should be tested on the clean stove.
- Designing and constructing more effective ways of extruding the briquette from the mould instead of using bare hands.
- Manual operation of the machine should be shifted to mechanical means for better compaction and faster operation.

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