DEVELOPMENT OF A LOW COST BIOMASS BRIQUETTING MACHINE FOR RURAL COMMUNITIES

BY

AWOLOKUN IWALEWA OMOTOYOSI

(MEE/12/0856)

DISSERTATATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF B.ENG DEGREE IN MECHANICAL ENGINEERING

TO

MECHANICAL ENGINEERING DEPARTMENT, FACULTY OF ENGINEERING,

FEDERAL UNIVERSITYOYE EKITI, EKITI STATE

NOVEMBER, 2017

CERTIFICATION

This is to certify that this project was carried out by AWOLOKUN IWALEWA OMOTOYOSI, a student of Mechanical Engineering, Faculty of Engineering, Federal University Oye Ekiti, Ekiti State.

DR OYELARAN O.A ……………………………, 07/11/17

PROJECT SUPERVISOR **SIGNATURE AND DATE**

DR ADELEKE …………………………… 20/02/2018

HEAD OF DEPARTMENT **SIGNATURE AND DATE**

PROF. ABOLARINWA ……………………………

EXTERNAL SUPERVISOR **SIGNATURE AND DATE**

DECLARATION

I hereby declare that this thesis titled "Design and Development of a Low Cost Briquetting Machine for Rural Communities" was done by me, AWOLOKUN IWALEWA OMOTOYOSI with matriculation number MEE/12/0856 and submitted to the Department of Mechanical Engineering, Federal University Oye Ekiti in partial fufilment for the award of Bachelor (B.ENG) degree in Mechanical Engineering. The information derived from the literature has been appropriately acknowledged in the text and a list of references provided.

AWOLOKUN IWALEWA OMOTOYOSI ....

(STUDENT) **SIGNATURE AND DATE**

DEDICATION

I dedicate this project to the Almighty God, my guardian and my strength who kept me throughout the time the project was carried out.

ACKNOWLEDGEMENTS

My endless gratitude goes to God who provided and gave me much support, wisdom, understanding and strength to complete this project. To Him be the all the glory.

Much appreciation to my wonderful, caring, and lovely parents, Mr and Mrs Awolokun. Thanks for the motherly support and advices. May God continue to bless you (Amen).

A big thank you to my supervisor, Dr O.A Oyelaran who encouraged and directed me throughout the time project was carried out. God will continue to strengthen you sir.

To my friends and well-wishers, thank you for your advices and support. May God never leave you (Amen).

ABSTRACT

The decrease in availability of fuel wood and rise in prices of fossil fuels in Nigeria calls for considering alternative sources of energy for domestic and industrial use. This project was carried out in order to design and develop a low cost briquetting machine for rural communities. It involves the modification of hand use in producing briquettes by employing the use of hydraulic jack, moulds, pistons etc. This method is faster and easier. The agricultural residue used was 80% sawdust and a mixture of 5% ash and 15% of cassava waste as binder. Performance characteristics were evaluated based on the compressive test, durability test, water boiling test for cold and hot start done. The calorific value of 15,774 kJ/kg was given. Analysis between sawdust and firewood was done, which showed that sawdust briquette is healthier and economical.

TABLE OF CONTENTS

CHAPTER FIVE

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND STUDY

Briquetting technology is one of the renewable sources of energy that was devised to address problems regarding global warming, energy crisis, as well as solid waste management. Studies like that of Kaliyan and Morey (2009) show that varying the compression parameters during briquetting such as temperature and pressure affects the characteristics of the output briquettes such as combustion performance and durability. The need for alternative sources of energy has been a sensitive issue for the past years. In the Philippines, the harnessing and utilization of renewable energy has been a significant part of the government's strategy to supply the energy needs of the country (Department of Energy 2011a). Biomass is essentially a plant material, ranging from algae to wood, in form. However, agricultural residues such as, rice husks, coffee husks, sawdust, straws, sugar cane waste, etc. are considered sources of biomass for energy production. These abundant supplies of waste products (coconut husks, corn husks, saw dust, etc.) can undergo processes such as direct combustion, gasification, or liquefication, for energy production. The situation of rural areas in developing nations is shockingly bad as far as energy is concerned. Electricity is less affordable in most rural communities, the usage of energy has been for cooking and heating applications mostly.

Cooking gas which is another source of energy for household heating purposes is also out of their reach. Njenga et al. (2009) reported that kerosene and charcoal are by far the most commonly used sources of cooking fuel in rural communities. They further added that shortage of low cost sources of energy has resulted in families abandoning traditional foods that require long time cooking.

Others have resulted to using unhealthy materials as source of energy such as plastics, with potential negative health impacts, Obi (2013).

In Nigeria, kerosene has become a scarce commodity and when available is usually very expensive. Kerosene is being distributed to the people by the NNPC or Oil dealers at a very high rates which put the poor in a very difficult situation, less consideration is given to the people living in the rural areas. Due to deforestation, Wood is also out of reach and less available. Women in the rural areas spend most of their time to gather woods for cooking and heating purposes, which can be used as a source of energy. Hood (2010) reported that the unsustainable harvesting of wood fuel from forest has led to enhanced desert encroachment and has contributed to environmental degradation witnessed in terms of climate change manifestation. It is clear that now more than ever, alternative fuels need to be found. Beyea et al. (1991) expressed the view that biomass has the potential of meeting the additional energy demand of urban and industrial sectors, thereby making a significant contribution to the economic advancement of developing countries. Most rural communities have more agricultural residues which are pure source of energy. This brings an advantage to them because less transportation and low cost of fuel can be gotten.

For good hygiene and to avoid bad health issues, biomass densification can be employed. Biomass densification represents technology for converting agricultural residues into solid fuel with or without binders in order to improve the handling characteristics of the material for transportation, storage, and usage. The technology includes briquetting, pelletizing and agglomeration, Obi (2013). In this project, Biomass briquetting is used. Briquetting is the process of transforming a granular or powdery substance into a larger, more convenient size. According to Maglaya and Biona (2010), briquetting increases the homogeneity of the mixture, allowing a more uniform and controlled combustion performance. Another factor that is essential and affects the production of the briquettes is pressure and temperature. Under high pressure and temperature, the natural binding components in the biomass (starch, protein, lignin, and pectin) materials are squeezed out of the particles, aiding in the inter-particle bonding. The current briquetting industry in the other countries has gone a long way. In Germany, a plantation is situated wherein their machines are automated and can be easily operated. Their production is of large-scale basis and supplies the country with briquettes for energy consumption (RUF Briquetting Machinery 2008).

The constraint in the advancement of biomass briquetting in Africa and in developing nations generally, is the development of appropriate briquetting technology that suits the local condition; both in terms of the briquetting press itself for local manufacture and the briquettes. The failure of these machines have been attributed to some factors which include inappropriate or mis-match of technology; technical difficulty and lack of knowledge to adapt the technology to suit local conditions; excessive initial and operating cost of the machines; and the low local prices of wood fuel and charcoal. Hood (2010) stated that the more replicable, appropriate, cost effective, locally available, easy to make, environment friendly and culturally fitting a technology is for the briquetting of biomass, the higher its chance of success. A number of machines have been developed for the production of biomass briquettes both in the developed and developing nations, but none of these machines would produce briquettes at a low enough cost to compete with the common source of fuel: wood fuel. Some of the machines that do exist in the rural areas are either gender unfriendly, or having poor production capacity and briquette quality, and its densification process rely on human strength. The need at the moment in the densification of biomass in developing countries is the development of an appropriate briquetting machine suitable to the local communities. A efficient, cost effective and easy to duplicate technology should be developed specifically for rural communities, for biomass to make a notable impact as fuel.

1.2 Aims and Objectives

The aim and of this study is to provide a preferable type of fuel or source of energy from waste biomass (Saw Dust) which is cheap, environmental friendly and readily available. This will be achieved through the following objectives:

- To design and fabricate a low cost biomass briquetting machine
- To test the machine using sawdust as a source of energy and a binder (cassava waste), for performance evaluation

1.3 Scope of Study

This study examines the production of usable fuels from biomass through the design of a briquetting machine. The study includes:

- The production of briquettes for rural communities for domestic utilization.
- To check for durability, compressive strength and combustion properties

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BIOMASS

Biomass can be defined as renewable organic materials that contains energy in a chemical form that can be converted to fuel. It includes the residues from agricultural operations, food processing, forest residues, municipal solid wastes and energy plantations. The use of biomass residues and wastes (for chemical and energy production) was first seriously investigated during the oil embargo of the 1970s. (Biomass Briquetting in Sudan, 2010)

In recent years the use of biomass as a source of energy became of great interest world-wide because of its environmental advantages. The use of biomass for energy production, biofuels, has been increasingly proposed as a substitute for fossil fuels. Biomass can also offer an immediate solution for the reduction of the CO_2 content in the atmosphere. It has three other main advantages: firstly, its availability can be nearly unlimited, secondly it is locally produced and thirdly the fact that it can be used essentially without damage to the environment. In addition to its positive global effect by comparison with other sources of energy, it presents no risk of major accidents, as nuclear and oil energy do (Biomass Briquetting in Sudan, 2010). Due to their heterogeneous nature, biomass materials possess inherently low bulk densities, and thus, it is difficult to efficiently handle large quantities of most feed stocks. Therefore, large expenses are incurred during material handling (transportation, storage, etc.). Very often, of all the factors considered, transportation presents the second highest cost, next to capital recovery. It was also noted that transportation costs of field residues will increase with the increasing size of a conversion facility. In order to combat the negative handling aspects of bulk biomass, densification is often required. The process of compaction of residues into a product of higher bulk density than the original raw material is known as densification or briquetting (Biomass Briquetting in Sudan, 2010).

Densification has aroused a great deal of interest in developing countries all over the world in recent years as a technique of beneficiation of residues for utilization as energy source. (Biomass Briquetting in Sudan, 2010). Biomass briquetting provides additional income to farmers, creates jobs and possibly rural development - it can serve social and economic functions as well. (Biomass Briquetting in Sudan, 2010)

2.2 BIOMASS BRIQUETTING

O.A. Oyelaran (2015) said that agricultural waste which is produced in millions of tons per year is one of the most viable alternatives to replace wood as a source of energy and the some of the factors to be considered that affect briquetting are effects of particle size, preheating of biomass feedstock, pressure/density relationship and effects of moisture content. Shakya, et al (2005) stated that agricultural residues like ground nut shells, straws, tree leaves, grass, rice and maize husks, banana leaves and sawdust can be used for briquette making. Although some materials burn better than others, the selection of raw material is usually most dependent in what is easily available in the surrounding area of where the briquettes are made. The briquettes can consist of a blend between several different raw materials. However, to use agricultural residues efficiently for energy production, a detailed knowledge of its physical and chemical properties are required. These properties, more specifically average and variation in elemental compositions, are also essential for modeling and analyzing of energy conversion processes.

Tropical Development and Research Institute (1983) suggested from a survey in 1979, worldwide, that "about 250million tons of sawdust and over 400million tons of other wood residues were produced". The report also noted that about 60% of this material arose in developing countries and whereas in the USA up to 80% of this waste was utilized, in developing countries large quantities of these materials remain unused. DahamShyamalee, et al (2015) found that the Biomass briquettes are often used as an energy source for cooking purpose and in some industries like bricks and bakery. The briquettes are produced by densification of waste biomass using various processes.

Vogler (1986) technically assesses some simple sawdust briquetting techniques in which various attempts have been made to devise methods by which people in rural areas can use sawdust to make briquettes. The simplest idea, for areas where dung is shaped by hand and sun dried for use as fuel, is that the dung cake will burn longer if wood ash is added. He found that most efforts have been devoted to making simple briquetting machines.

Lardinois and Klundert (1993) stated that the use of organic waste as cooking fuel in both rural and urban areas is not new. In seventeenth century England, the rural poor often burned dried cow dung because of acute shortage of wood fuel due to widespread deforestation. And they went further saying that during the two world wars, households in many European countries made their own briquettes from socked newspaper and other combustible domestic waste using simple lever operated press.

2.3 BRIQUETTES BINDER

Emerhi, E. A. have found that the best briquette was produced when sawdust was mixed with starch as a binder, comparing the three binding agents (starch, cow dung and wood ash). He mixed sawdust with the binder in ratio of 70:30 for cow dung and wood ash and 70:15 of starch. The sawdust was mixed in a ratio 50:50 for each briquette combination produced. Combustion related properties namely percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of the briquettes were determined.

Olawale et al., (2014) have tested effect of starch and gum arabic as binders in the combustion characteristics of briquette prepared from sawdust of different ratios were investigated. Briquettes of sawdust were produced by mixing with different binders and agglomerate using starch paste and gum arabic. The mixture was compressed at 110kN using manually operated hydraulic briquette machine and sun dried. The calorific value, the volatile matter and flame temperature were determined. Results showed that the briquette formed using starch as a binder performed better in all aspect than the gum arabic. Adegoke (2001) explained, that results of a recent study in the Mechanical Engineering Department of the Federal University of Technology, Akure, have shown that sawdust mixed with certain biomass materials of appropriate grain sizes and in certain proportions have improved calorific values. This mixture of the sawdust and the biomass materials are compressed using a specially developed briquetting machine and the briquettes dried either directly in the sun or in an oven. When burned in internally lined stoves, heat a loss to the environment is much reduced, a lot of cooking energy is obtained from a relatively small amount of the sawdust briquettes.

Bello (2005) carried out a research project in processing of agricultural residues into briquettes as fuels for cooking purposes in the department of agricultural engineering, Ahmadu Bello University, Zaria in which she produced briquettes from agricultural residues using gum Arabic as her binder and evaluated their performance characteristics based on fuel efficiency, cooking efficiency, boiling time and fuel consumption rate respectively. Her briquettes were produced using a manual hand press used in making coal briquettes in Amil Nigeria Limited in Kaduna State. Eriksson and Prior (1990) stated that binding agent is necessary to prevent the compressed material from springing back and eventually returning to its original form. This agent can either be added to the process or, when compressing ligneous material, be part of the material itself in the form of lignin. Lignin, or sulphuric lignin, is a constituent in most agricultural residues. It can be defined as a thermo plastic polymer, which begins to soften at temperatures above 100°C and is flowing at higher temperatures. The softening of lignin and its subsequent cooling while the material is still under pressure is the key factor in high pressure briquetting. It is a physico-chemical process related largely to the temperature reached in the briquetting process and the amount of lignin in the original material.

Lardinois and Klundert (1993) suggested that the raw material of a briquette must bind during compression; otherwise, when the briquette is removed from the mould, it will crumble. Improved cohesion can be obtained with a binder but also without, since under high temperature and pressure, some materials such as wood bind naturally. A binder must not cause smoke or gummy deposits, while the creation of excess dust must also be avoided. Two different sorts of binders may be employed. Combustible binders are prepared from natural or synthetic resins, animal manure or treated, dewatered sewage sludge. Non-combustible binders include clay, cement and other adhesive minerals. Although combustible binders are preferable, non-combustible binders may be suitable if used in sufficiently low concentrations. For example, if organic waste is mixed with too much clay, the briquettes will not easily ignite or burn uniformly. Suitable binders include starch (5 to 10%) or molasses (15 to 25%) although their use can prove expensive.

Wright (1911) said that briquettes could be produced without the aid of external binders in the presence of high temperature and pressure, during which the lignin present in the biomass acts as natural binder. However, briquettes could be produced with binding material in which case the biomass is compressed with binders usually under low temperature and pressure to improve the mechanical and sometimes the combustion properties of the briquette. Binders are substances of organic or inorganic composition that have ability to, after mixing with biomass for briquette manufacturing, link, solidify and connect particles of briquette material, giving briquettes form and satisfactory mechanical properties (Mitic et al., 2006). Furthermore, binders of organic and inorganic origin are currently equally used for briquette manufacturing processes with a tendency of more significant utilization of organic ones. Addition of inorganic binders tends to change the chemical composition of indurated briquettes but organic binders do not affect the chemical composition of fired briquettes to a large extent as they burn or volatize (Mohamed et al., 2004). Binders improve the mechanical characteristic of the biomass and produce a more durable product. They also help reduce wear in production equipment and increase abrasion-resistance of the solid fuel. During the pelletizing process for example, starch not only acts as a binder, but also as a lubricating agent, helping to ease the flow of materials through the die. Paper could be used as a binder in biomass densification. The papers are usually soaked in water, allowing them to ferment and then hand-mashed into slurry before it is mixed with the biomass to produce solid shaped briquettes. It has been observed that the paper solution when used as a binder in the production of fuel briquettes helps in reducing the smoke generated when these briquettes are combusted. It should be noted however that almost any resinous or tarry matter may be used as binding material for making briquettes (Mukherjee, 1940). The following binders have been used in experimental work:

Organic adhesives – flour, molasses, polyvinyl-alcohol, paper pulp, dextrin, paraffin, starch paste, carboxyl-methyl cellulose, modified glucosans, sulfide gelatin, semicellulose, sodium silicate, bone glue, bitumen, coal tar, resin, asphalt. Inorganic adhesives – gypsum, clay, water glass, cement, concrete and lime. Banerjee (2008) and Mohamed et al. (2004) identified some key requirements for the use of any material as a binding agent in the manufacture of briquettes. They are:

1. It should give adequate green strength to survive crumbling due to handling, transportation, abrasion and impact.

2. It should impart impact and abrasion strength to avoid crumbling and disintegration at elevated temperature.

3. Binder should be cheap and widely available.

4. Binder should be consistent with the chemical. (Obi 2013)

2.4 EXISTING BRIQUETTING TECHNOLOGIES

Fernando, (2002), developed a technology for small scale briquetting, oriented to briquetting agricultural waste and basically all kinds of burnable wastes. He achieved very interesting and exciting results in his aim to find an alternative to the costly extruder machine. He designed and operated his own machine based on the very principle of the world wide known CINVA RAM machine, for producing compressed earth blocks. With a pressure of around 3 – 7 MPa using a lever to apply a compressive force through a piston he pressed the biomass into a briquette, shaped like an ordinary 6cm x 13cm x 24cm brick.

2.4.1 Earth Rams

Presses currently in use for making stabilized earth blocks might be modified to make briquettes. The Combustaram, similar to the CINVA-Ram and Tersaram, is commercially available or can be manufactured locally, see figure 4 below. The lever arm is put in the open position, feed stock is poured into the molds and the lever is then quickly pushed up, over the top of the press, and down. This movement positions the lever over the top of the press and compresses the briquettes on the downward stroke. Obi (2013)

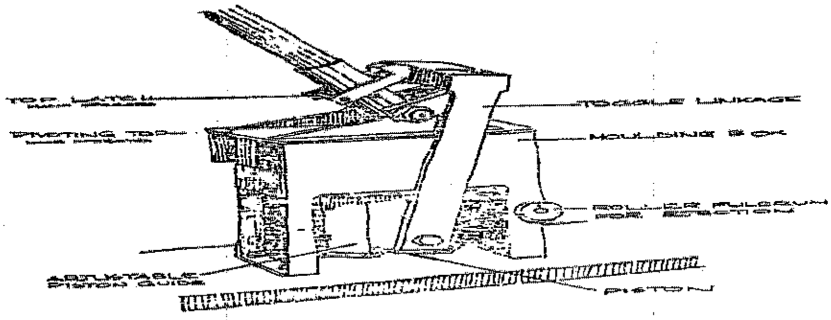

Figure2.1: The Combustaram Source: Davies (1985)

2.4.2 Tube-Presses

Metal or plastic pipe provides a good briquetting mould since it produces cylindrical briquettes.

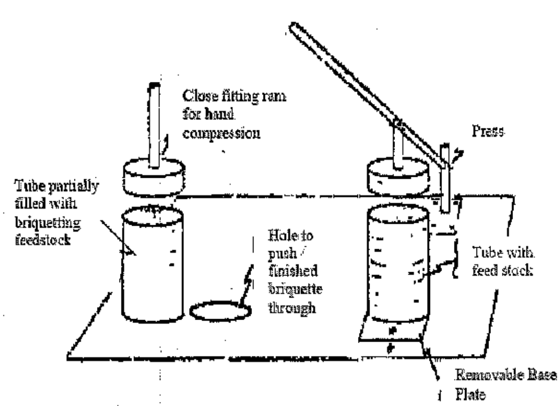

Figure2.2: Tube Presses Source: Davies (1985)

2.4.3 Heat Die Extrusion Screw Press

The heat die extrusion screw press is an industrial machine for producing briquettes. It consists basically of an electric motor, a hopper, a die heater and muff, and the screw which densifies the raw material. The electric motor drives the briquetting screw, which is housed inside the die, through a V-belt and pulley arrangement. Biomass raw material is fed to the screw through the hopper. The electric die-heater softens the lignin in the raw material as it passes through the die which acts as a binding material. A smoke trapping system traps and removes the smoke from the vicinity during the briquetting process. Besides the cost of the investment, the machine has a cost for the electricity consumed.

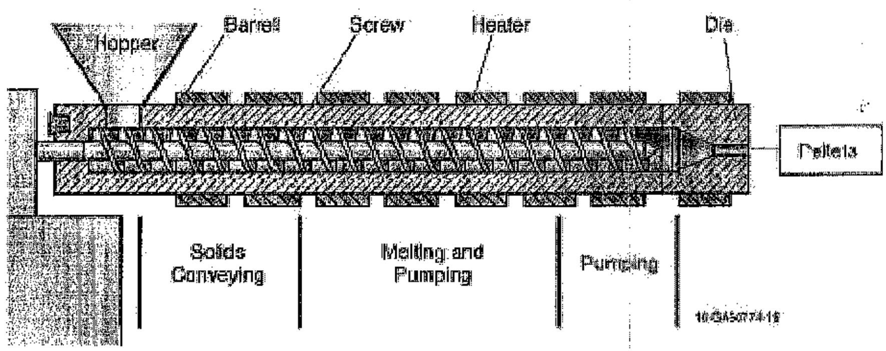

Figure2.3: Typical screw extruder Source: Tumuluru et al. (2010a)

2.4.4 Piston Press

Figure 1.5 shows a typical piston press that produced briquettes. These machine works best with dry (15% moisture content maximum) cellulose material, which is fed into a compression chamber (Sani I.F 2008). A reciprocating piston then forces the material through a tapered die to form a long briquette. Typically, flywheel drive machines produce between 300kg and 500kg of briquettes per hour.

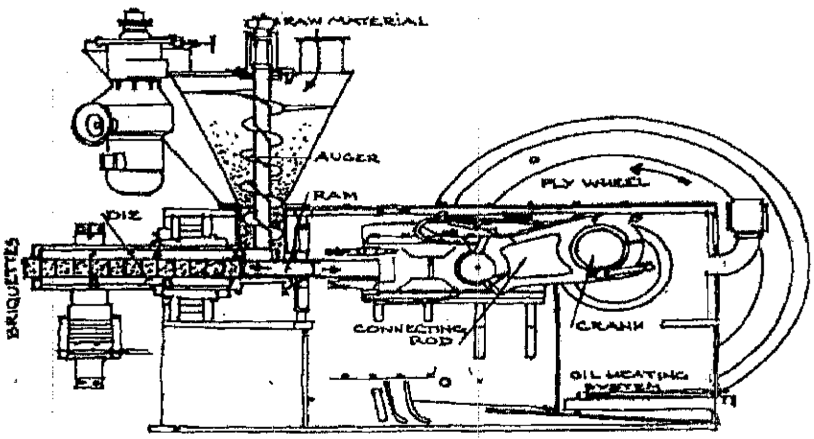

Figure 2.4: Piston Press

Source: Bhattacharya et al, (1984)

2.5 USE OF BIOMASS

Figure1.4 shows the level of use of the different biomass conversion technologies to energy. Household energy, mainly for cooking, heating and drying, are the most widely available technology. Biomass cook stoves, for instance, have hundreds of versions all around the world. Gasification and pyrolysis have most technologies in the demonstration stage. These technologies are concentrated in Europe, USA, Japan and India. Bio-oil and bio-chemical applications are mostly in the research and development stage.

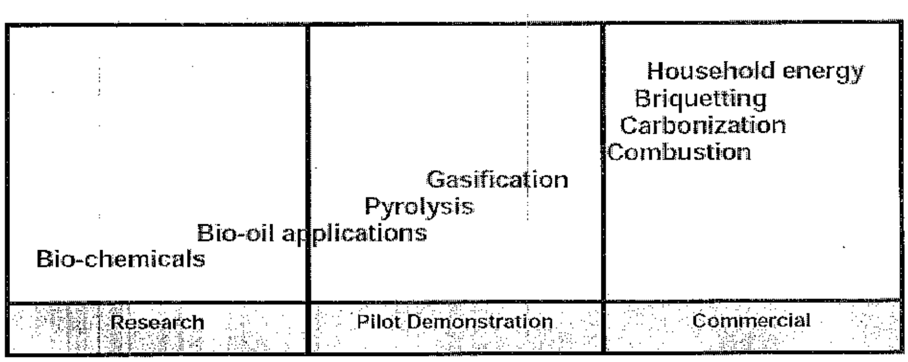

Figure2.5: Level of use of different biomass conversion processes

Source: UNEP (2009)

2.6 FACTORS AFFECTING BIOMASS BRIQUETTING

As reported by Tumuluru et al. (2010a), the quality of densified biomass depends on a number of process variables, like die diameter, die temperature, pressure, usage of binders, and preheating of the biomass mix. Shaw (2008) in his studies on densification of biomass demonstrated how process variables (die temperature, pressure, and die geometry), feedstock variables (moisture content, particle size, and shape) and biomass composition (protein, fat, cellulose, hemicellulose, and lignin) play a major role in the quality of densified biomass. Some of the process variables are discussed below.

2.6.1 Process variables

2.6.1.1 Temperature

Hall and Hall (1968) and Hood (2010) found that for a given moisture content, the pressure required to obtain a certain density of biomass is reduced by the addition of heat in the die and the heat also increases both strength and moisture stability. Also, high temperature conditioning of the raw materials reduces resistance of the material against an applied load for densification and increases briquette durability (Hill and Pulkinen, 1988; Mani et al., 2003; Sokhansanj et al., 2005). Smith et al. (1977) in their study concluded that the expansion of the briquettes was less when the die temperature was between 90 and 140°C. It is suggested that biomass material be heated when it can be incorporated into the briquetting process otherwise binding agents should be used to increase the bonding strength.

2.6.1.2 PRESSURE

Pressure plays an important rôle in the quality of briquettes made from biomass material. Butler and McColly (1959) observed that the density of pellets is proportional to the natural logarithm of the applied pressure, that is, an increase in pressure significantly increases density. This is because the solid particles approach each other closely resulting in stronger bonding. Singh and Singh (1982) showed that the higher the value of applied compressive load, the better the durability and compaction efficiency of paddy straw briquette. Yaman et al. (2000) recommended that briquetting pressure should be selected at an optimum value that influences the mechanical strength of the briquette by increasing plastic deformation.

However, above an optimum briquetting pressure, fractures may occur in the briquette due to sudden dilation (Tumuluru et al., 2010a). Ndiema et al. (2002) reported that for a given die size and storage condition, there is a maximum die pressure beyond which no significant gain in cohesion (bonding) of the briquette can be achieved. Demirbas et al. (2004), in their article on compaction of biomass waste materials observed that increasing the pressure from 300 to 800 MPa, with about 7% moisture (wet basis), increases the density sharply from 0.182 to 0.325g/ml, and then the densities slightly rise to 0.405 g/ml. The applied pressure in the densification of biomass is proportional to the resulting density of the produced pellet or briquette.

2.6.1.3 RETENTION OR DWELL TIME

The quality of briquettes is significantly influenced by the retention or dwell time of the material in the die during densification (Tabil and Sokhansanj, 1996a). Al-Widyan et al. (2002) found that retention time between 5 and 20 seconds did not have a significant effect on Olive cake briquette durability and stability. At lower densification pressures, Li and Liu (2000) found that the hold time for Oak sawdust had more effect than at higher pressures. At the highest pressure of 138 MPa, the effect of hold time became negligible and they also observed that the holding time had little effect on the expansion rate. According to Tumuluru et al. (2010a), it appeared that hold times greater than 40 seconds had a negligible effect on density of briquettes. Furthermore, a 10-second hold time could result in a 5% increase in log density whereas at holding times longer than 20 seconds, the effect diminished significantly. Oladeji (2010) in his study of fuel characterization of briquettes produced from two species of corncob, observed a dwell (holding) time of 120 seconds.

2.6.1.4 DIE GEOMETRY

The die geometry refers to the size and shape of the die and their effects on the amount of biomass that can be briquetted or pelletized. It has been reported that for a constant mass of material, the density of the densified biomass is greater for smaller diameter chambers at a given pressure (Butler and McColly, 1959; Olaoye et al., 2003). This is an indication of easy facilitation of the interlocking potential of the biomass particles under the applied pressure. Tabil and Sokhansanj (1996a) concluded that the durability of the densified biomass significantly improves when a smaller die with higher length/diameter (L/D) ratio is used. This view is supported by Hill and Pulkinen (1988) who indicated that an L/D ratio between 8 and 10 is ideal for making high quality pellets. Furthermore, Heffiner and Pfost (1973) evaluated the effect of three die sizes, 4.8 × 44.5, 6.4 × 57.2, and 9.5 × 76.2mm, on durability, finding that the pellets produced on the smallest die have the best durability values. It is therefore important in the design of briquette making machine, to utilize a die with large L/D ratio for high density and durable briquettes.

2.6.1.5 BINDER TO BIOMASS RATIO

Olaoye et al. (2003) observed that the durability of briquettes using different die diameters was dependent on the mix ratio of the binding agent. Die diameters of 25, 50 and 75 mm produced best briquette at about 7:3 mix ratio of mush to sludge (binding agent). The best durable briquettes were however obtained at 7:3 mix ratio (palm oil mush to sludge ratio) using a 75 mm diameter mould yielding a 96.5% durability, 496kg/m3 density briquettes. A durability rating of 80 – 90 should be considered "good" and 90 or above "very good" (Waelti and Dobie, 1973). It was also reported that the mix ratio also affects the bulk density of the briquette as it varies linearly with increase in the binding agent. Mohamed et al. (2004) also reported that as the amount of binding agent, in this case starch increases, the dropping damage resistance and bulk density of both green and dried briquettes increase. This is due to the increase of plasticity of the briquettes, because of the fact that the starch is a colloidal material having a higher surface area. It was noted that increase in water added to the mixture also follows the same trend as the binder but the formation of muddy mixture due to excess addition of water reduces both the durability and density of the briquettes.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Materials

Suitable materials and equipment were used for good performance of the briquetting machine. The machine fabricated, is a manually operated briquetting. The machine was fabricated at workshop at Ikole town in Ekiti state. It is cost effective and the material used is a mild carbon steel which has high strength, good ductility and moderate hardness. It has good machinability to be formed into shape and is readily available in the market. The binding agent used was cassava starch. It is cheap, available in much quantity and efficient. Cassava starch prevents the breaking of the briquettes. The sawdust was collected from a sawmill in Ikole-Ekiti, Ekiti state.

Some of the materials used are;

- Galvanized Pipe
- Mild steel
- Paint and Thinner

The equipment used are;

- Arc welding machine and Electrodes
- Hydraulic Jack

3.2 Machine Description

The briquette making machine consists of the following components as shown in (Figure3.1 and Plate 1).

3.2.1 Hydraulic jack

The machine is hydraulically operated. The hydraulic jack provides the mechanical force that moves the piston up, thereby compressing the material in the compression chamber. The hydraulic jack is connected to a base frame at the bottom and a plate carrying the piston at the top.

3.2.2 Frame

The frame is made from mild steel plates of low carbon steel. Steel plates are very useful in the fabrication of briquetting machines. They were also used in the fabrication of other component of the briquetting machine, such as, the cylinder head cover, the pressure plate and the base plates.

3.2.3 Pistons

The pistons are used to transfer energy from the hydraulic jack to the compression chamber. The pistons tops were of lesser diameter when compared to the internal diameter of the cylinders; this is to allow free movement of the piston and also to create room for fluid to escape during compression.

3.2.4 Compression cylinders

This is the enclosure where compression takes place. It consists of twenty-five cylinders held together in an enclosure. Each cylinder has its own piston which transfers the compressive pressure at the bottom through the pistons to the briquette materials inside the cylinders. It also serves as a mould since the briquettes are forced to shape of the cylinders.

3.3 Mode of operation of the machine

The agricultural waste (sawdust) is mixed thoroughly with the binding material (starch). The hydraulic jack is lowered with the aid of a relief valve. The top cover of the briquetting machine is opened for the agricultural waste already mixed with the binder to be fed into the cylinder. The cover is then put back in place and closed. The valve is then closed and the handle is inserted into the pump lever and actuated until the maximum. It is then allowed for 3 to 5 min for the water to drain in order to enable the briquette to become well compacted. The top cover is opened and the pump is further actuated to push the briquettes up for easy removal. The wet briquettes are gently removed and placed on a tray and dried under the sun. The whole process is repeated for a new batch of briquettes to be produced.

3.4 Design and Fabrication of Briquetting Machine

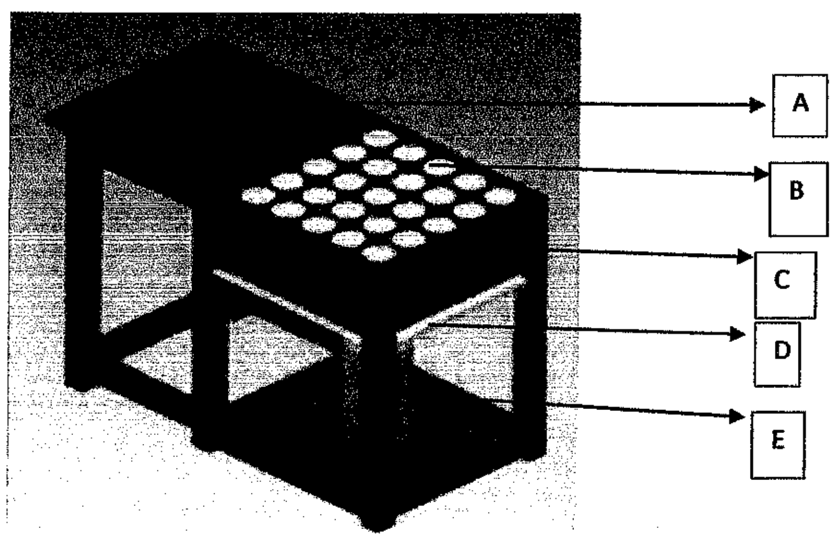

Figure 3.1 The Biomass Briquetting Machine

This is a manually operated biomass briquetting machine which was designed and constructed (Figure 3.1). The briquetting machine consist of 25 molds each having a depth of 50mm and an internal diameter of 20mm welded to a 4mm flat mild steel plate at the top and bottom and positioned vertically over equal number of pistons. The pistons were made such that there was a clearance of about 2mm between the piston head and the mold walls so that water will escape during compaction. The opposite ends of the rods were welded on a flat metal plate of 6mm thickness which rests on a 16-ton capacity hydraulic jack. The jack drives the pistons in and out of the molds during operation.

A flat metal plate(A), 10 mm thick, was hinged to the mould box (B) to cover the open ends of the moulds during compaction; and opened up during ejection of the briquettes from the moulds. The moulds, the hydraulic jack(E) and other parts of the machine were all supported by a frame (C) made of angle bars. The vertical motion of the moulds, and the ejection of compressed briquettes from the moulds were effected through a number of pistons (D) by the manual operation of the hydraulic jack. The hydraulic jack rests on a plate (F) welded to the frame of the machine. By this arrangement, the force from the hydraulic jack is centrally applied to the metal plate bearing the moulds. The machine was fabricated using mild steel and angle bars. Different views with detailed dimension of the machine are given in Figure 3.2 and 3.3

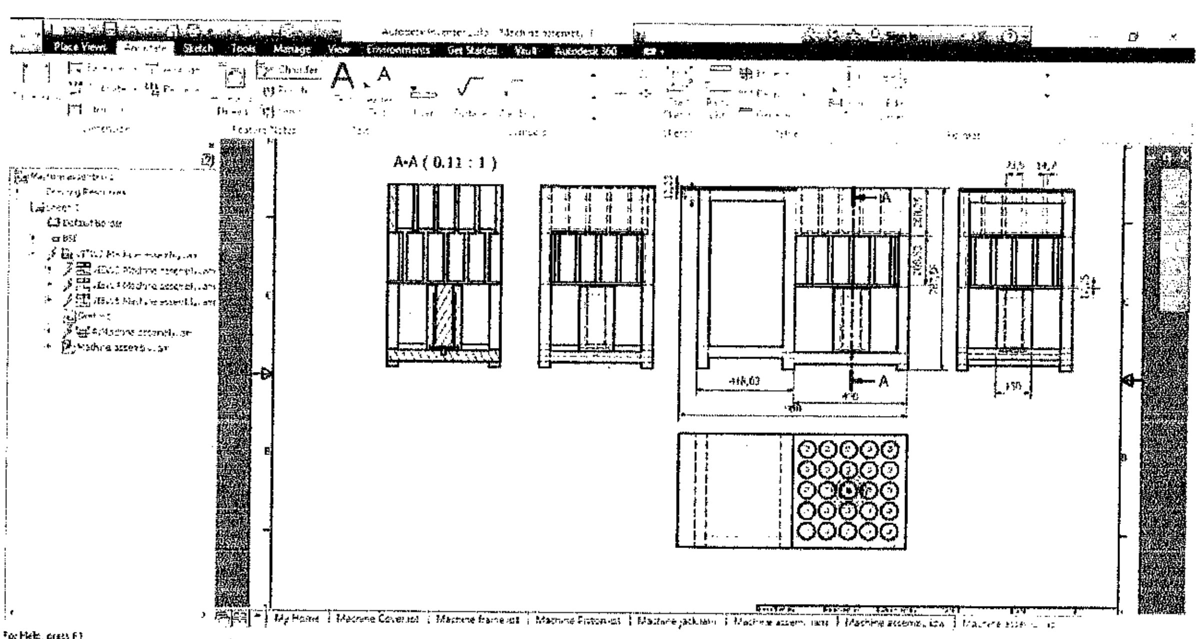

Figure 3.2: Orthographic view of the briquetting machine

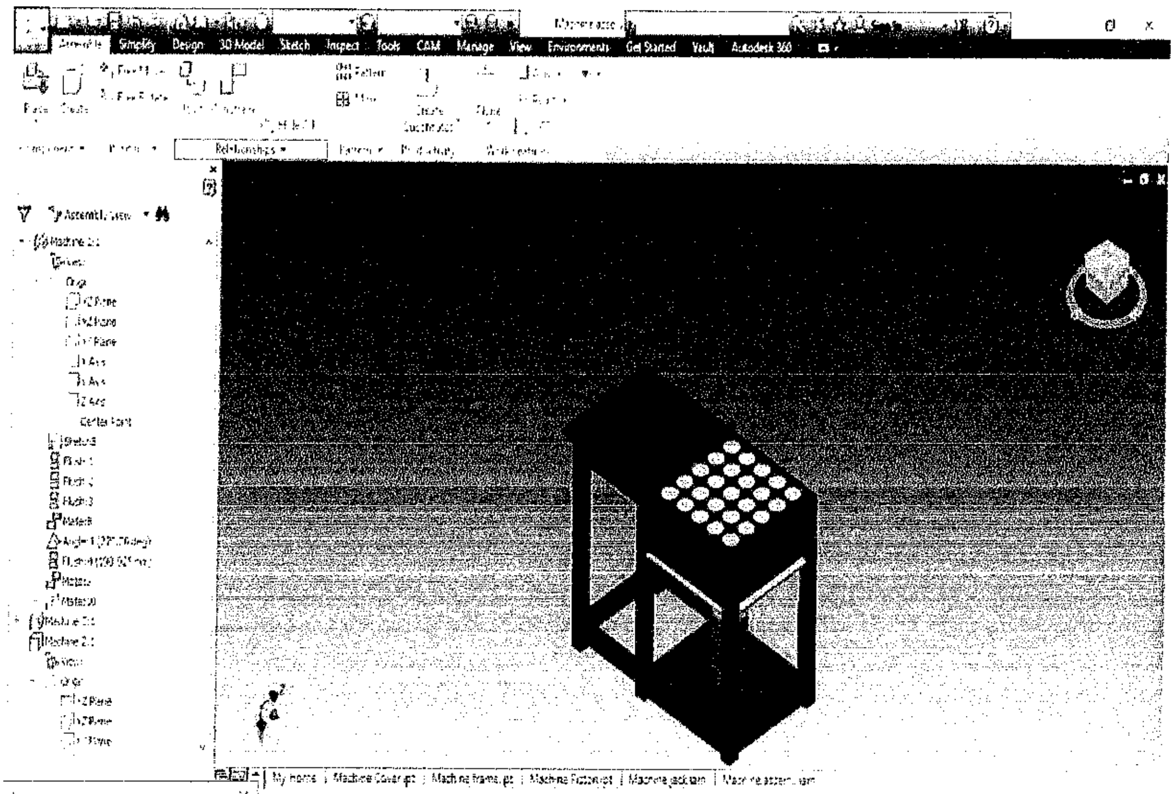

Figure 3.3: The full view of biomass briquetting machine using Autodesk Inventor

3.4 Design of material elements and selection

Determination of maximum shear stress in the cylinder

The internal walls of the cylinders would be subjected to pressures due to the compressive action of the pistons against the materials inside them. Therefore, in order for the cylinders to withstand the shear stress that would be generated at the walls of the cylinders, appropriate thickness of the materials (for the construction of the cylinders) has to be selected. For this design that the maximum design pressure required is less than 20 MN/m, a thin cylinder is used. In order to determine the expected thickness of the cylinder, the circumferential and longitudinal stresses were first determined as follows (Rajput, 2006).:

(i) Circumferential Stressσ_c $= \frac{Toatal\ pressure}{Resisting\ section} = \frac{Pdl}{@tl}$ (1)

Where, c = Circumferential stress, l = length of the shell, d = diameter of the shell t = thickness of the shell, P = intensity of internal pressure

(ii) Longitudinal stress

Considering the same cylindrical shell subjected to the same internal pressure, the cylinder also has a tendency to split into two pieces due to internal pressures. The longitudinal stress was determined as reported by Rajput

(2006).

Longitudinal stress$\sigma_1 = \frac{Total\ pressure}{Resisting\ section} = \frac{\frac{\pi}{4}(d)^2 P}{\pi dt} = \frac{Pd}{4t}$ (2)

Where, P= intensity of internal pressure, d= Diameter of the cylinder, t = Thickness of the cylinder wall

Maximum shear stress (τ_{max}) = $\frac{\sigma_c - \sigma_1}{2}$ (3)

Substituting$\sigma_c = \frac{Pd}{2t}$and $\sigma_1 = \frac{Pd}{4t}$, $\tau_{max} = \frac{\frac{Pd}{2t} - \frac{Pd}{4t}}{2} = \frac{Pd}{2t}$

i.e. $\tau_{max} = \frac{Pd}{2t}$ (4)

Where, σc = Circumferential stress, σl = Longitudinal stress, P = Intensity of internal pressure d = Diameter of the cylindrical shell, t = Thickness of the cylindrical shell

Thickness of cylinder wall

It is observed that the circumferential stress is greater the longitudinal stress, the thickness of the cylinder wall was obtained as reported by Rajput, (2006) and is given as $\sigma_c > \sigma_1$

$$\sigma_c = \frac{Pd}{2t} \qquad (5)$$

But, since σ_c cannot exceed the permissible tensile stress (σ_1)

$$\text{i.e. } \sigma c \leq \sigma_t \text{ , } \frac{Pd}{2t} \leq \sigma_c \text{ } t \geq \frac{Pd}{2\sigma_t} \qquad (6)$$

Determination of change in cylinder volume due to pressure

The cylinder is bound to experience change in volume due to the combined actions of both circumferential and perpendicular forces. This is expressed in form of volumetric strain as follows: The volumetric strain (e_v) = Algebraic sum of net strains in all axes.

$$e_v = \text{net longitudinal strain} + 2 \text{ x net circumferential strain} = e_v = e_1 + 2e_c \qquad (7)$$

$$\text{Direct strain due to } \sigma_c = \frac{\sigma_c}{E} = \text{ and Direct strain due to } \sigma_1 = \frac{\sigma_1}{E} \qquad (8)$$

Net circumferential strain (e_c) = Direct strain – Lateral strain due to direct strain

$$\text{i.e. } e_c = \frac{\delta cl}{d} = \frac{\sigma_c}{E} - \mu \frac{\sigma_l}{E} \, e_c = \frac{Pd}{2tE} \left(1 - \frac{\mu}{2}\right) \qquad (9)$$

Where,

Direct Strain due to Circumferential Stress, $\sigma_c = \frac{\sigma_c}{E}$,

Direct strain due to lateral stress, $\sigma_l = \frac{\sigma_l}{E}$

Net longitudinal strain (e_l) = Direct strain – Lateral strain due to direct strain $\frac{\sigma_c}{E}$

$$e_l = \frac{\sigma_l}{l} = \frac{\sigma_l}{E} - \frac{\mu \sigma_c}{E} \qquad (10)$$

$e_l = \frac{Pd}{4tE}(1-2\mu)$ (11)

The volumetric strain (e_v) = $e_l + 2e_c$ (12)

But, $e_l = \frac{\delta V}{V} = [\frac{Pd}{4tE}(1-2\mu) + 2 \times \frac{Pd}{2tE}(1-\frac{\mu}{2})] \times V = \frac{PdV}{2tE}\left(\frac{E}{2} - 2\mu\right)$ (13)

Where, l = Length of the cylinder, V = Volume of the cylinder, E = Young's modulus for cylinder material, μ = Poisson's ratio.

Determination of the mean breaking stress of the piston rod

This was computed in order to apply appropriate force that would yield tolerable stress on pistons (Rajput, 2006). Assuming the crippling load (P_c) = $\sigma_c A$

Where, σ_c = Maximum likely compressive stress, A = Sectional area

From Euler's equation $P_{euler} = \frac{\pi^2 El}{l_e^2} \frac{\pi^2 EAk^2}{l_e^2}$ (14)

Where, = Euler's equation for critical load, E = Modulus of elasticity, I = Least moment of inertia of section of the rod, le = Equivalent length of the rod, A = Area of cross section of the rod, k = Least radius of gyration

Note I=Ak^2

From Rankine hypothesis

$\frac{1}{P} = \frac{1}{P_c} + \frac{1}{P_{Euler}}$ (15)

Substituting $\frac{1}{P} = \frac{1}{\sigma_c A} + \frac{1}{\pi^2 EA(\frac{R}{l_e})^2}$

$$P \frac{\sigma_c A}{1+a(\frac{l_E}{k})^2} = \quad (16)$$

Where, $= \frac{\sigma_c}{\pi^2 E}$, l_e, $\frac{l}{2}$since both ends are fixed.

Determination of the equivalent length of the piston rod

The determination of the permissible length of the pistons is necessary in order to avoid failure in form of deformation or breakage. By equating Euler and Rankine formulae

$$P_{Euler=P}\text{P} \quad (17)$$

$$\sigma_{cAl_e^2} - \frac{\pi^2 Elal_e^2}{k^2} = \pi^2 El \quad (18)$$

Since I =AK^2

$$l_\varepsilon = \left(\frac{\pi^2 Ek^2}{\sigma_c - \pi^2 E\alpha}\right)^{\frac{1}{2}} \quad (19)$$

Determination of the thickness of the bottom plate

This is necessary in order to select the appropriate thickness that would be able to bear the applied load. The bottom plate can be assumed to be clamped at the four corners and the centre is subjected to concentrated loading from the base of the hydraulic jack. The thickness of the bottom plate is given by the formula;

$$t = \sqrt[E]{\frac{KFb^2}{E\delta^2}} \quad (20)$$

Where, t = thickness of the plate, δ = maximum displacement, F = concentrated load K = constant depending on its length and breath, b = breath of the plate a = length of the plate, E = modulus of elasticity of the plate

Mechanical Efficiency = $\frac{Output}{input} \times 100$

3.5 Construction of the machine

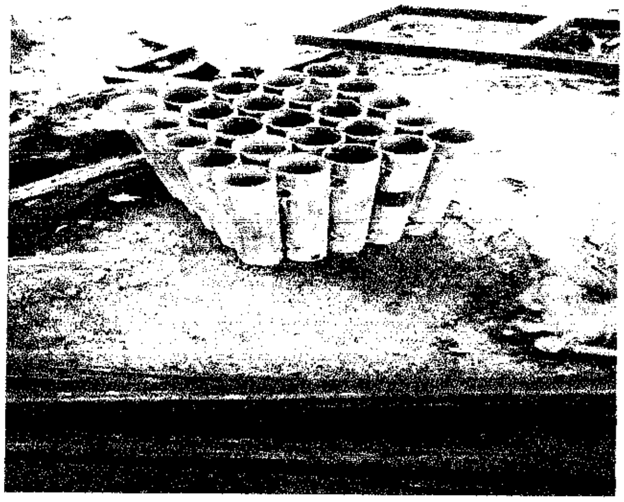

Plate3.1: mould box

The machine contains 25 moulds, each of mm length and a mm external diameter galvanized pipe. The moulds were cut with a cutting disc and ground to ensure a uniform and level height. The 5mm spacing between the 25 circles of the moulds were marked and joined using arc welding machine . All the 25 moulds was set straight with the aid of a spirit level and a try square.

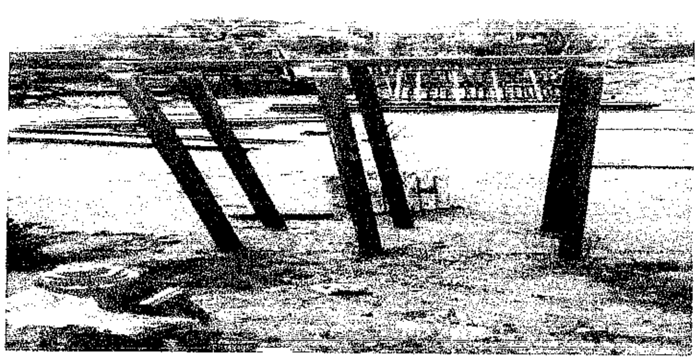

Plate3.2: Frame under construction

The frame is the member that supports the mould box, the jack, mould cover and the pistons with the base plate was constructed with a mm angle bars. The frame was made up of six 762mm long vertical stands which support the weight of all the parts of the machine and also support the dynamic load that the jack would exert during compaction of the biomass material. Eight mm long angle bars,were welded horizontally between the six vertical bars at the top and down of the pressure side and also held with six mm angle bars at the side which would support the mould cover when opened. Four mm long bars was welded at mm from the top, which serves as a support for the mould box, it also have another two angle bars welded at distance of mm from the top which serves as a seat for the under plate. The mould cover, mm thick plate was welded to the frame with the aid of two hinges which were welded to the frame.

The machine requires equal number of pistons as the number of moulds to produce all the 25 briquettes required. The pistons are made up of mm long, 12mm rod and a 3mm plate . The pistons was constructed by positioning each rod and welded on a plate.. A plate, 4mm thick and mm × mm size was cut and 25 holes of 1inch diameter with a clearance of about 0.5mm was centered in accordance with the centers of the moulds. The pistons was inserted in the holes of the moulds on the base plate and welded upright to ensure easy and free movement of pistons in the moulds during operation.

Plate3.3: Frame under construction

Plate3.4: Frame and mould box after construction

3.6 Sample Preparation The sawdust was mixed with the cassava waste used as a binder and ash. The binding ratio used is ratio 75:15:5

Plate3.5: Briquettes produced

3.7 Compressive Test

This is used to determine the compressive strength of materials or the maximum force or load a material can withstand. This test was carried out using the fuel sample of the produced briquettes and a compressive test machine (model C90). The machine consists of a hydraulic jack, a load measuring gauge and a dial gauge. The material was placed in-between two plates of the machine and pressure applied to the hydraulic jack lever which pushed one of the plate upward as it compresses the materials against the second plate until the material starts to fail. The readings on the pressure gauge and dial gauge were recorded (Thomas et al., 2006).

3.8 Durability Test

The durability test was carried out according to Oyelaran et al., [2014] method, where the briquettes were dropped from a height of 1.85 m on a flat steel plate four times. This gave an indication of the ability of the briquette to withstand mechanical handling,

$$\text{Durability is equal to} = \frac{\text{Material weight in plate after 4 drops}}{\text{Initial weight of materials}} \times 100$$

3.9 The Calorific Value

Leco AC-350 Oxygen Bomb Calorimeter interfaced with a microcomputer was used to assess the heat values of the produced briquettes. Two grams of the briquettes was measured and the screw mould bracket was used to re-mould the briquette to the appropriate calorimeter bucket size. Ten (10) ml distilled water was poured into the bomb and the industrial oxygen cylinder was connected to the bomb and the valves were opened and bomb was filled slowly at pressure range of 2.5 – 3.0 Mpa for a minute. The bomb was placed inside a canister bracket containing the distilled water and the bomb lid was covered. The switch was turned on and the microcomputer was set for the determinations which automatically calibrate and measure the energy values and display the values on the screen for recording after feeding the necessary data on the briquettes. The data and result of the experiment are displayed. [Oyelaran O.A., 2014].

Calorific Value = 18,774 kJ/kg

3.10 The Water Boiling Test (WBT)

What is interesting about the energy content of a briquette is how much of the energy in the briquette that can be actually be utilized. If the same test is carried out on each briquette and firewood, a good evaluation can be made. The test is known as the Water Boiling Test and it will be used for assessing the briquettes with each other. The modified version of the WBT, which was developed for the Shell Household Energy Programme based on the procedures proposed by VITA and Baldwin was used in this work (Oyelaran et al, 2015). It consists of three phases.

(a) The first phase began with the stove at room temperature and using a pre-weighed bundle of wood to boil a measured quantity of water in a standard pot. Next the boiled water is replaced with a fresh pot of cold water to perform the second phase of the test.

(b) In the second phase which is the high power test with hot start, water is boiled beginning with a hot stove in order to identify differences in performance between a stove when it is cold and when it is hot.

(c) The third phase which is the simmering test, the second phase test is continued using a pre-weighed bundle of wood, simmering the water at just below boiling for a measured period of time (45 minutes).

The same procedure is repeated on the samples of briquettes made with the various sawdust and binder varied proportions. Fuel samples of similar size of average dimension 193mm x 37mm x 45mm were used for the test in order to minimize variation due to fuel differences. This size is in accordance to Olle and Olof (2006) who states that: the type and size of fuel can affect the outcome of the stove performance tests. In order to minimize the variation that is potentially introduced by variations in fuel characteristics VITA (1985) recommends taking the following precautions:

(i) Use only wood that has been thoroughly air-dried. Drying is accelerated by ensuring wood is stored in a way that allows air to circulate through it.

(ii) Different sizes of wood have different burning characteristics. While stove users may not have the ability to optimize fuel size, use only similar sizes of wood to minimize this source of variation throughout the world.

Due to the lack of adequate turn - down ability of the three stones stove to maintain a desired temperature without the fire going out, the minimum amount of fuel sample necessary to keep the fire from dying completely was used.

The fuel sample outputs to be analyzed include:

A. Thermal efficiency: This is the ratio of the work done by heating and evaporating water to the energy of the fuel consumed. This is given by (Prasad et al, 1983).

B. Burning Rate: This is a measure of the rate of wood consumption while bringing the water to a boil. It is calculated by dividing the equivalent dry wood consumed by the time of the test (Prasad et al, 1983).

C. Specific fuel consumption: This is a measure of the amount of wood required to produce one gram of boiling water or maintain one gram of boiling water within 3°C of the boiling point (Prasad et al, 1983).

Nomenclature

Pe = Dry mass of pot (g)

Pi = Initial mass of pot and cold water (g)

Pf = Final mass of pot and hot water (g)

Wr = Water remaining at the end of water boiling test (g)

Wv = Water vaporized

fm = Mass of fuel (kg)

Ti = Initial temperature of water (°C)

Tf = Final temperature of water (°C)

fi = Initial mass of fuel (g)

ff = Final mass of fuel (g)

fm = Mass of fuel that was used to bring the water to boil (g)

fd = Equivalent dry wood consumed (g)

Cw = Specific heat capacity for water (J/g°C)

ΔT = Temperature difference in water boiling test (°C)

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Compressive Test

The results of the compressive strength of the biomass samples as well as the average compressive strength of the samples are shown in Table 4.1.

Table4.1: Results of compressive test

Sample	Compressive strength (kN/m^2)
1	0.96
2	0.96
3	0.95
Average	0.957

Compressive strength is one of the most important characteristics of a briquette that determines the stability and durability of the briquette. From Table 4.1, the average compressive strength of the briquettes is 0.957 kN/cm

4.2 Durability Test

The durability percentage of the biomass samples and the average durability percentage of the samples are shown in Table 4.2. The durability rating of the samples differs at each level. The durability rating of each samples are 92%, 91%, 94% respectively.

Table4.2: Results of durability test

	Durability Rating (%)
1	92
2	91
3	94
Average	92.33

Durability is a measure of the briquettes ability to withstand destructive forces such as compression, impact, and shear during handling and transportation. The production of fines or dust during handling, transport, and storage would create health hazard and inconvenient environment for the workers. There is no limit for the production of fines in place. However, Karunanithy et al., wrote that fines up to 5% (by weight) would be an acceptable level and greater than 5% would reduce storage capacity and create problems in flow characteristics. Depending upon the values researchers has classified the durability into high (> 0.8), medium (0.7-0.8), and low (< 0.7) . From Table4.2, the mean durability of the briquettes is 92.33% which is higher than 84.4% reported by Wamukonya and Jenkins, for sawdust and wheat straw briquettes. On the basis of durability, the briquettes meet the requirement for a good briquette.

4.3 Calorific value

The mean calorific value of the briquettes was found to be 18,774 kJ/kg. The energy value obtained for this work meets the minimum requirement of calorific value for making commercial briquette (>17,500 J/g) (Oyelaran et al, 2016). They can therefore produce enough heat required for household cooking and small-scale industrial cottage applications. The results of the calorific value of the briquettes compare well with the results of the heating value of rice husk briquette 12,600 kJ/kg (Musa, 2007); cowpea 14,372.93 kJ/kg; and soy-beans-12,953 kJ/kg (Enweremadu, et al., 2004)

4.4 Results for water boiling test

Table4.3: Experimental Results of Water Boiling Test one (Cold Start) for Fuel Samples

Time (min)	Saw dust Briquette Temp. (°C)	Firewood Temp. (°C)
0	21.0	22.0
2.5	40.0	45.0
5.0	52.0	54.0
7.5	65.0	66.0
10.0	74.0	74.0
12.5	82.0	82.0
15.0	89.0	88.0
17.5	97.0	93.0
20.0		97.0

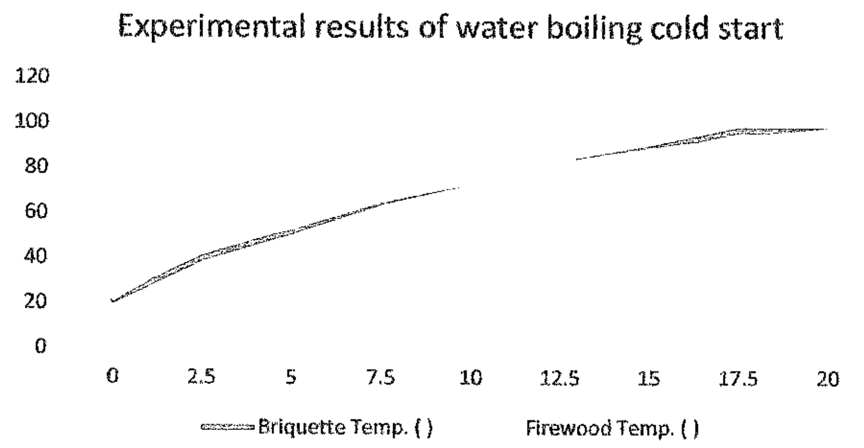

Figure 4.1: Experimental Results of Water Boiling Test one (Cold Start) for Fuel Samples

Table4.4: Experimental Results of Water Boiling Test 2 (Cold Start) for Fuel Samples

Time (min)	Saw dust Briquette Temp. (°C)	Firewood Temp. (°C)
0	22.0	23.0
2.5	43.0	45.0
5.0	58.0	57.0
7.5	66.0	69.0
10.0	76.0	81.0
12.5	86.0	90.0
15.0	91.0	97.0
17.5	97.0	

Table4.5: Experimental Results of Water Boiling Test 3 (Cold Start) for Fuel Samples

Time (min)	Saw dust Briquette Temp. (°C)	Firewood Temp. (°C)
0	21.0	23.0
2.5	43.0	41.0
5.0	54.0	53.0
7.5	63.0	67.0
10.0	74.0	79.0
12.5	83.0	89.0
15.0	91.0	97.0
17.5	97.0	

Table4.6: Experimental Results of Water Boiling Test one (Hot Start) for Fuel Samples

	Saw dust Briquette Temp. (°C)	Firewood Temp. (°C)
0	21.0	23.0
2.5	45.0	47.0
5.0	60.0	64.0
7.5	71.0	80.0
10.0	77.0	85.0
12.5	87.0	93.0
15.0	93.0	97.0
17.5	97.0	
20.0	97.0	

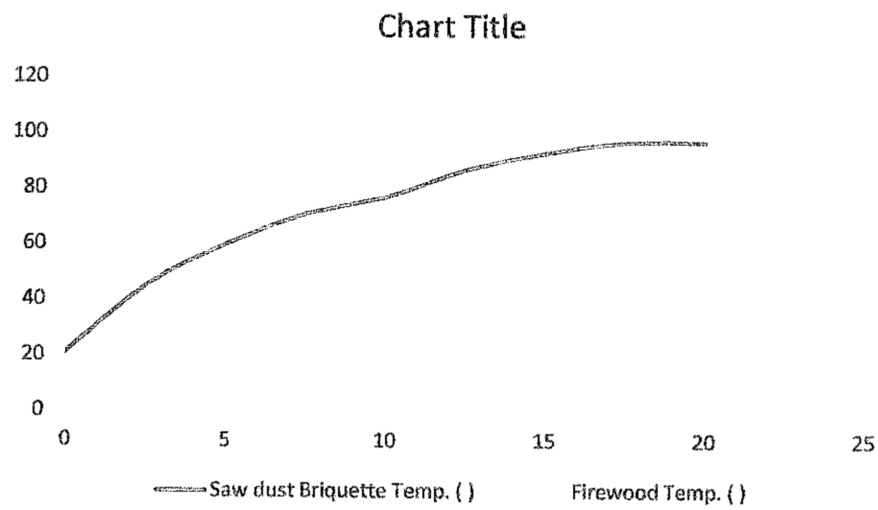

Figure 4.2 Experimental Results of Water Boiling Test one (Hot Start) for Fuel Samples

Table4.7: Water Boiling Test Values for Firewood

	Cold Start	Hot Start	Simmering
fi	0.70	0.80	0.70
ff	0.20	0.30	0.55
Pi	2.00	2.00	2.00
Pf	1.90	1.85	1.40
fm	0.50	0.50	0.65
Δ°C	0.075	0.075	0.150
fd	0.425	0.425	0.500
Ti	21,5°C	22.00°C	97°C
Tf	97°C	97°C	94°C
ΔT	75.5°C	74°C	-3°C

Table4.8: Water Boiling Test Values for Sawdust Briquette

	Cold Start	Hot Start	Simmering
fi	0.70	0.70	0.70
ff	0.55	0.55	0.35
Pi	2.00	2.00	1.90
Pf	1.80	1.90	1.40
fm	0.15	0.15	0.35
Δ°C	0.10	0.10	0.20
fd	0.15	0.20	23
Ti	22	23	97
Tf	97	97	94
ΔT	75	74	-3

4.5 Result of Average Fuel Samples Boiling Point Time and Simmering Duration

Table4.9 Result of Average Fuel Samples Boiling Point Time and Simmering Duration

Sample	**Boiling time cold start (minutes)**	**Boiling time hot start (minutes)**	**Boiling time simmering start (minutes)**
V	28.05	19.20	45
Z	14.80	13.05	45

The values obtained during the water boiling test for the fuel samples were used to plot a graph of temperature against time as shown in Figure 4.1 and 4.2. Repeating the test with a hot stove Figure 4.2 helps to identify differences in performance of the briquettes when the stove is hot or cold.

From the plotted graphs it was observed that the briquettes have the fastest rate of boiling water in both cases, Provision of adequate heat for the time necessary is an important quality of any solid fuel (Oyelaran et al. 2015). The results of water boiling test showed that the time required for each set of briquettes to boil an equal volume of water The burning rate (how fast the fuel burns) and the caloric value (how much heat released) are two combined factors that controlled the water boiling time. This explained why briquettes was able to boil water faster than firewood even when the latter burns faster than the former.

4.6 Average Values of Thermal Efficiency of Fuel Samples

Table4.10 Average Values of Thermal Efficiency of Fuel Samples

Fuel samples	High Power (cold)	High Power (hot)	Low Power (simmering)	Total	Average
Saw dust briquette	16.92	15.40	13.88	46.20	15.70
Fire wood	11.70	13.00	12.17	36.87	12.29

The efficiency of the briquette is 15.70 while for fire wood is 12.29 it is observed that the cooking efficiency of the briquettes is better than that of wood used. This value compared well with the values obtained in the thermal fuel efficiency of cashew shell briquette of 15.5% (Sengar et al. 2012), red mangrove wood and firewood 23.55 and 21.31% respectively (Davies et al, 2013). Prasad and Verhaart (1983) also reported thermal fuel efficiencies for sawdust and rice husk ranged between 19.97 and 21.64%, and 26.20 and 27.27% respectively.

4.7 Average Values of Burning Rate of Fuel Samples

Table4.11 Average Values of Burning Rate of Fuel Samples

Fuel samples	High Power (cold)	High Power (hot)	Low Power (simmering)	Total	Average
Saw dust briquette	1.16	1.25	0.69	3.10	1.03
Fire wood	2.17	1.77	0.98	4.92	1.64

The average burning rates as shown in Figure 4.11 of the various fuel samples were estimated using equation 2 with data obtained from the WBT. The average burning rates values for all five fuel samples at high power (cold start), high power (hot start) and low power (simmering). The burning of the briquettes was steady and it produced red hot charcoal. Comparison of the performance between the average burning rates of

The Burning rate of the briquette in this research is 1.03 while for wood is 1.64 kg/hr. The results elucidated with that reported by Islam et al (2014) of briquette from Coir Dust and Rice Husk Blend which varies between 0.789 - 0.945 kg/hour. 3.6 Average specific consumption for fuel samples.

4.8 Average Values of Specific Fuel Consumption of Fuel Samples

Table4.12 Average Values of Specific Fuel Consumption of Fuel Samples

Fuel samples	High Power (cold)	High Power (hot)	Low Power (simmering)	Total	Average
Saw dust briquette	0.19	0.20	0.43	0.82	0.27
Fire wood	0.27	0.31	0.54	1.12	0.37

The average specific fuel consumption as shown in Figure 4.12 of the fuel samples were estimated using equation 3 with data obtained from the WBT. The average specific fuel consumption values for briquette and wood samples at high power (cold start), high power (hot start) and low power (simmering). The average specific fuel consumption of the briquettes is 0.27 J/g while that of wood is 0.37 J/g.

Nature of the Flame

Nature of the flame colour of a burning fuel gives an indication of the quality of heat and the cleanliness of the flame. A blue flame indicates a clean and high quality heat. On the other hand, yellow flame indicates a low quality heat with soot deposits. During the water boiling test, the colour of the flame was pale blue which signifies complete combustion and high heating efficiency and for wood, the colour of the flame was pale yellow with smoke.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

The goal to design and construct a briquetting machine was achieved. It had limitations. Separation of the briquettes from the moulds after compression was difficult, it had to be done with care to avoid damages on the briquettes. The high cost of the parts and workmanship was due to the machine, been a project, a lot of materials were wasted and great attention had to be given to the construction to get it working and achieve its aim. The briquetting machine could go for half the cost in producing it; eighteen thousand hundred only (=N=18,000) if bought. In spite of its limitation, in separating the briquettes from the mould, it gives better result because it offers production of more briquettes within the same time.

RECOMMENDATIONS

1. Means of removing the briquettes from the mould should be improved instead of using hand
2. The height of mould should be reduced to produce more stabilized briquettes to avoid breakages.
3. A mixture of combined rice straw and other residues should be formed into briquette and investigate if it could have improved performance.
4. An alternative cheaper binder which will produce finer output briquettes should be source for.

REFERENCES

Adegoke, C.O. (1999). A Preliminary Investigation of Sawdust as High Grade Solid Fuel. Nigerian Journal of Renewable Energy. Vol. 9. Pp. 103

Adegoke, C.O. (2001). Waste to Waste; Sawdust Briquettes as Case Study. Paper Presented at the Mechanical Division of Nigerian Society of Engineers Conference. Ibadan

Barnard, C. (1985). The use of Agricultural Residues as Fuel. AMBIO; XIV: 4 – 5.

Bello, A.W. (2005), Processing of Agricultural Residues into Briquettes as Fuel for Cooking Purposes. BSc Project. Department of Agricultural Engineering. Ahmadu Bello University. Zaria.

Bhattacharya, S.C. et al. (1984). Densification of Biomass Residues in Asia. Bioenergy 84, Volume III. Elsevier Applied Science Publishers

DahamShyamalee, et al, "Evaluation of different binding materials in forming biomass briquettes with sawdust", International Journal of Scientific and Research Publications, Volume 5, Issue 3, March 2015.

Davis, M. C. (1985). Understanding briquetting. Technical paper, No. 31. Published by Volunteers in Technical Assistance (VITA). ISBN: 0-86619-233-6 Virginia USA.

Emerhi, E. A., "Physical and combustion properties of briquettes produced from sawdust of three hardwood species and different organic binders", Advances in Applied Science Research, Vol.2, pp. 236-246, 2011.

Eriksson S, Prior M (1990). The Briquetting of Agricultural Wastes for Fuel, FAO, Agriculture and consumer protection Department, Rome pp 10-25.

Erikson, S.; M. Prior; (1990). Briquetting of agricultural wastes for fuel FAO Environment and Energy Paper 11 Rome, Italy.

Hood AH (2010). Biomass Briquetting in Sudan: A Feasibility Study. Women's Refuge Commission pp 100-120.

L. Wamukonya, B. Jenkins, Durability and relaxation of sawdust and wheat-straw briquettes as possible fuels for Kenya, Biomass and Bioenergy. 8(3) (1995) 175-179. doi:10.1016/0961-9534(95)00016-Z

Islam, H., Hossain, M. & Momin, A. (2014). Development of Briquette from Coir Dust and Rice Husk Blend: An Alternative Energy Source, Int. Journal of Renewable Energy Development 3 (2) 2014: 119-123

Lardinois, I and Klundert, A. (1993). Organic Waste Options for Small – Scale Resource Recovery. Waste Consultants. The Netherlands.

Obi, O.F (2010). Development of an Appropriate Biomass Briquetting Machine, Department of Agricultural and Bio Resources Engineering, University of Nigeria, Nsuka.

Olaoye, et al (2003). Effects of die diameter, mix ratio and compressive force on briquetting of oil palm mush. Nigerian Journal of Technological Development, Vol. 3: 27 – 37.

Olawale J. et al, "Effect of Starch and Gum Arabic Binders in the Combustion Characteristics of Briquette Prepared from Sawdust", International Journal of Scientific & Engineering Research, Volume 5, Issue 3, March-2014.

Oyelaran, O.A (2015). The effect of storage on some properties of groundnut shell biomass briquettes. *Journal of renewable energy and environment,* JREE: Vol. 1, No. 2,36-40

Oyelaran, O.A, et al, Effects of Binding Ratios on Some Densification Characteristics of Groundnut Shell Briquettes. Iran. J. Energy Environ. 5(2) (2014) 167-172. doi: 10.5829/idosi.ijee.2014.05.02.08

Oyelaran, O.A. Development of a motorized biomass fuel briquetting machine [dissertation]. Abeokuta: University of Agriculture; 2014.

Oyelaran, O.A, et al (2015) Performance Evaluation of the Effect of waste paper on Groundnut Shell Briquette. *Int. Journal of Renewable Energy Development,* 4(2),95-101, dx.doi.org/10.14710/ijred.4.2.95-101

Olle, F. & Olof, N. (2006). Biomass Briquettes in Malawi, Degree Project, Department of Management and Engineering, Institute of Technology, Linkoping University, Malawi.

Prasad, K, Krishna, K, & Verhaart, P. (1983) Wood heat for cooking, Indian Academy of Sciences, Bangladesh. Macmillan Indian Press.

P. Sah, B. Singh, U. Agarwal, Compaction behaviour of straw. J. Agr. Eng.-India 18(1) (1981) 89-96.

Sani, I.F (2008) design, construction and experimental evaluation of the products of a low cost briquette machine for rural communities in Nigeria, Department of Mechanical Engineering, Faculty of Engineering, Ahmadu Bello University, Nigeria.

Sengar, S. H., Mohod, A. G., Khandetod, Y. P., Patil, S. S. & Chendake A. D. (2012). Performance of Briquetting Machine for Briquette Fuel International Journal of Energy Engineering, 2(1): 28-34 DOI: 10.5923/j.ijee.20120201.05

Tabil, L. G. and Sokhansanj, S. (1996a). Process conditions affecting the physical quality of Alfalfa pellets. American Society of Agricultural Engineers, 12(3), 345 – 350.

Thomas JU, Sung KL, Charles GJ (2006). Column Compression Strength of Tubular Packaging Forms Made from Paper Journal of Testing and Evaluation. Vol. 34, No. 6 Paper ID JTE100030 Available online at: www.astm.org.

UNEP (2009). Converting waste agricultural biomass into a resource - Compendium of technologies. United Nations Environmental Programme, Division of Technology, Industry and Economics, International Environmental Technology Centre Osaka/Shiga, Japan.

VITA. (1985) Testing the Efficiency of Wood – Burning Cook Stoves: International Standards, Volunteers in Technical Assistance, Virginia, USA

Vogler. J. (1986). Understanding Wood Wastes as Fuel. Technical Paper No. 46. Published by Volunteer in Technical Assistance (VITA). ISBN: 0-86619-260-3

Waelti, H. and Dobie, J. B. (1973). Culpability of rice straw as affected by the various binders. Transaction of ASAE 16(2): 380 – 383.