DEVELOPMENT OF A LOW COST BIOMASS BRIQUETTING MACHINE FOR RURAL COMMUNITIES

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CERTIFICATION

This is to certify that this project was carried out by OJO OMOLARA DAMILOLA with the matriculation number MEE/12/0866 a student of mechanical engineering. Faculty of Engineering, Federal University OyeEkiti.

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DECLARATION

I hereby declare that this thesis has not been submitted for a degree to any other university and that it is entirely my own work and all help has been appropriately acknowledged.

OJO OMỌLARA DAMILOLA

……………………………………

STUDENT

DEDICATION

I dedicate this project to God Almighty, my entire family, and my supervisor.

ACKNOWLEDGEMENT

I am very obliged to those who have contributed massively to the success of my project and academic career with the Federal university oye-ekiti, Ekiti. My special thanks goes to my project supervisors Dr.Adeleke, and Dr. Oyelaran, who were able to direct me through their advice, time devotion, careful review And helpful suggestion in writing this report on this work. In the same line, I appreciate my parents who sacrificed all in Order to bring me all to this level in my educational lives. I also thank my Sister Tomilola Ojo and all my friends for their needed moral and financial supports.

ABSTRACT

The demand for energy is becoming a critical challenge for the world as the population continues to grow. This calls for Sustainable energy production and supply such as renewable energy technologies. Renewable energy technologies are safe sources of energy that have a much lower environmental impact than conventional energy technologies. In this paper, the sawdust briquette machine is designed. Sawmill waste is a big problem especially in urban cities in Nigeria. These wastes are burnt openly which is causing environmental pollution. The wastes can be converted to wealth thereby providing jobs for many unemployed citizens. This paper deals with the design and fabrication of a briquetting machine, the machine is successfully tested and briquettes has been produced using cassava starch as binder and Ash. The sawdust and cassava starch briquettes are produced by manually operated piston press with the use of hydraulic jack. The strength of briquettes is investigated by the compression, combustion, durability tests and also the water boiling test, the cassava starch is blended with the sawdust and Ash in the ratio of 80:15:5 (sawdust: cassava starch: Ash). This study shows that sawdust, Ash with cassava starch as binding agent has considerably increased the strength of the briquettes.

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1. INTRODUCTION

1.1 Background of the study

The population of the world continues to grow, the demand for energy is becoming critical challenge for the world's energy leaders (Christoph Frei, 2012). Global energy consumption has about doubled in the last three decades of the past century. Biomass briquetting is the densification of loose biomass material to produce compact solid composites of different sizes with the application of pressure. Briquetting of residues takes place with the application of pressure, heat and binding agent on the loose materials to produce the briquettes. Two different types of densification technologies are currently in use. The first, called pyrolizing technology relies on partial pyrolysis of biomass, which is mixed with binder and then made into briquettes by casting and pressing. The second technology is direct extrusion type, where the biomass is dried and directly compacted with high heat and pressure. Setting up the briquette production unit raw material should be locally available.

The raw materials for biomass briquetting can be:

• Agricultural residues (husks, cob, stalks, leaves, stems, shells, sticks).

• Invasive plants.

• Waste from bio-product industries like sawmills, plywood industries, furniture factories.

Life is a continuous process of energy conversion and transformation. The accomplishment of civilization has largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity (Pallavi, et al. 2013). Thus, access to energy is necessary to sustain human life and to achieve overall economic, social and environmental aspects of human development. It is generally acknowledged that burning of fossil fuels and deforestation are major contributors to anthropogenic climate change. Biomass from plants can serve as an alternative renewable and carbon-neutral raw material for the production of energy (Tumuluru, et al. 2010).

In Nigeria, the Energy Commission of Nigeria, (2005) recently reported that Nigeria's fossil led economy is under severe pressure and gave data of potential renewable energy for utilization including crop residue as shown in table 1.1 below.

TABLE 1.1: NIGERIA'S RENEWABLE ENERGY RESOURCES

S/N	ENERGY SOURCE	CAPACITY
1.	Hydropower, large scale	10,000MW
2.	Hydropower, small scale	734MW
3.	Fuel wood	13,071,464 hectares (forest land)
4.	Animal waste	61 million tones/yr
5.	Crop Residue	83 million tones/yr
6.	Solar Radiation	3.5 – 7.0 kW/m2-day
7.	Wind	2-4 m/s (annual average)

Source: ECN, 2005

There is scarcity of energy and there is the need to source for alternative form of energy, which is different from convectional types. The worldwide inevitability of oil depletion, instability in world petroleum market (apparently due to the instability in the Middle-East and the unrest in the Niger-Delta area of Nigeria) and the hazardous emissions from petroleum-based fuels are serious problems besetting continued utilization of fossil fuels. For example, Nigeria imports about 80% of her domestically consumed refined fuel resulting in incessant increase in fuel prices and its attendant civil unrest. However, most countries of the world, Nigeria inclusive has abundant supplies of biomass resources particularly agro-forestry residues and municipal solid wastes, whose potentials can be fully tapped for energy generation (Jekayinfa and Scholz, 2009). Also, the problem of agricultural residues disposal is posing challenge to the farmers and to the general public as these residues constitute a nuisance to the environment as well as an eyesore to the public. Therefore, if these wastes could be used to generate energy, it would be a welcomed solution to the problem of waste pollution, disposal and control (Oladeji, 2012.). One of viable and promising technologies by which these wastes can be converted to biomass energy is through the process of briquetting (Wilaipon, 2008).

1.2 Problem statement

Solid waste management is one of the major problems in Nigeria. This is not only found in the urban areas but also at the rural areas. The major waste generated at the rural areas is agricultural waste or residue (crop by-product). Despite this level of waste generation fuel for heating, cooking and other purposes is a huge problem; hence the rural people rely on wood fuel and charcoal. The realization that deforestation and wood fuel shortages are likely to become serious problems in Nigeria has turned attention to other types of biomass fuel.

Agricultural residues are, in principle, one of the major sources. They arise in large volume and in the rural areas which are often subject to some of the worst pressures of wood shortage. The use of briquetting for conversion of agricultural residues is comparatively recent, however, and has only been taken up in developing countries in the last few years. Main agricultural residues that are produced are paddy chaff, coconut dregs, hay, groundnut skin, saw dust and press cake, palm nut shell, maize cob and cotton stem. There is also bio waste as wood dust. This wood dust is produced in big scale. Beside the problem of transportation, storage and operation, open burning of this bio waste with traditional style without control can cause critical air pollution. The impact of agricultural waste on the environment depends not only on the amounts generated but also on the disposal methods used. Some of the disposal practices pollute the environment. The potential threat posed by climate change, due to high emission levels of greenhouse gases (CO_2 being the most important one), has become a major stimulus for renewable energy sources in general. When produced by sustainable means, biomass emits roughly the same amount of carbon during conversion as is taken up during plant growth. The use of biomass therefore does not contribute to a buildup of CO_2 in the atmosphere (McKendry, 2002). Hence the need at the moment in the densification of this agricultural waste in developing countries is the development of an appropriate briquetting machine suitable to the local communities. For biomass to make a significant impact as fuel for rural communities, it is imperative that an efficient, cost effective and easy to duplicate technology is developed specifically for rural communities.

1.3 Main Objectives

The main objective of this study is to design, construct and test a briquetting machine.

1.4 Aim and objectives

- To provide a preferable type of fuel or source of energy or waste biomass (sawdust)

The specific objectives are to:

- Design and construct a simple low cost briquetting machine which can be used in rural communities.
- To test the briquetting machine using agricultural residue (saw dust) with cassava starch as binder for performance evaluation.

1.5 Project Justification

Densification of agricultural residues and wood waste into briquettes can provide a relatively high-quality alternative source of second generation biofuel, especially now that wood fuel resources are scarce and are not encouraged. Olaoye et al. (2003) stated that the uncontrolled cutting of wood for fuel and charcoal for domestic and industrial uses is now a serious problem in Nigeria and semi-arid ecosystems. This trend could be attributed to the lack of suitable machines for the conversion of available biomass into fuel. Felfli et al. (2011) is of the opinion that the installation of briquetting machines in biomass production areas is unusual due to lack of appropriate technologies. Densification of biomass requires energy and as Hood (2010) rightly stated, the amount and type of energy used has a large impact on the economic viability of the technology. Furthermore, present technologies have caused many people to preconceive the idea that densification costs more energy than it produces. In Nigeria for example, the availability of biomass resource is a reality but the required technology to harness the resource is the missing link in its production and utilization (Olaoye, 2001). A machine as this would help close up the gap between production and utilization of sawdust, rice husk and other agricultural wastes and residues with the capability of opening up new commercial possibilities for briquetting beyond household use.

1.6 Scope and Limitation of the Study

The production of biomass briquetting machine for rural areas of poor and developing countries is of central interest in this study.

- The study is focused on the development and test evaluation of a simple biomass briquetting machine suitable for the production of fuel briquettes in rural areas for domestic and micro-enterprise utilization. The machine is not intended for the production of biomass briquettes for industrial purposes.
- The biomass samples to be used in the testing of the machine is limited to sawdust.
- To determine the durability, compression, combustion properties and water boiling test (WBT) of the briquettes produced.

CHAPTER 2

LITERATURE REVIEW

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, the 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 200 Mt/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 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).

The history of residue briquetting in Africa is largely one of single projects in various countries which have usually not been successful (FAO, 1990). A survey carried by FAO, (1990) showed that many briquetting plants in East Africa have been faced by outright failures while others have had their operations marred by problems. According to this survey, it was difficult to find a single agency-funded briquetting project which had been commissioned and was operating fully satisfactorily. The reasons that seemed to explain this failure included; inappropriate or mis-specified ordering of briquetting machinery, non-availability and high cost of the briquetting machines' spare parts, poor projects' planning and implementation where free supply of raw materials was assumed, low local prices of firewood and charcoal which inhibited the marketing of briquettes and unacceptability of briquettes in the household sector due to their ignition difficulties and smoke generation which caused indoor pollution, little involvement of the private sector and early withdrawal of donor as well as lack of government financial support.

The main generalization that can be made about briquetting in Africa is that it has often proved difficult to sell briquettes against the competitive price of wood or charcoal and the very high capital cost of the briquetting plants. In order to produce cheap biomass briquettes for the household sector, the general trend nowadays in Africa is towards low pressure or manual briquetting. The Legacy Foundation is taking the lead in promoting the technology in Africa. Production is mainly based on women's groups to produce their family needs and excess briquettes could be sold to generate income (Eriksson and Prior, 1990).

Therefore, the aim of this paper was to make comprehensive review of biomass briquetting, its technology and fundamental principles. The advantages as well as its drawbacks were also examined along with the factors that can influence biomass briquetting.

Briquetting of biomass is a relatively new technology in most African countries but there exist a number of different commercial briquetting technologies in Asia, America and Europe. The expansion of the use of biomass as an alternative source of energy for heating applications depends basically on three factors: residue availability for briquetting, adequate technologies and the market for briquettes. reported that although the importance of biomass briquette as a substitute fuel for wood is widely recognized, the numerous failures of briquetting machines in almost all developing countries have inhibited their extensive exploitation.

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 miss-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.

The use of biomass as an alternative energy source would reduce the dependence on fossil fuels. Country like Nigeria has large quantities of agricultural and forestry residues, e.g. rice husk, rice straw, saw dust, bagasse, coconut shell, peanut shell, etc. Traditionally, a part of residues is put to various non-energy usage as roofing material, cattle feed, raw materials for paper mills etc. A part of the residues is also used for energy production, while the remainder finds no practical use and wasted. The residues found in variety of forms have high moisture content and low bulk density. As a result, a low heat release per unit volume and hence high transportation and storage costs when used in natural form. So utilization of these residues as fuel in its original form is often not feasible. The process of densifying biomass shows promise of providing a dry uniform easily stored and conveniently shipped fuel from the wide variety of residues produced in agriculture, forestry and food processing. Therefor the development of simple and effective design of briquetting system for agricultural wastes and residues would be of much importance.

Briquettes are the modern development of biomass fuel. So traditional stoves are not efficient enough to burn it properly. Therefore, while introducing briquetting technology in a country, it would be important to introduce clean and efficient briquette stoves as well in order to avoid promotion of efficient briquette stoves produced by local artisans.

2.2 DIFFERENT DESIGN OF BRIQUETTING MACHINE

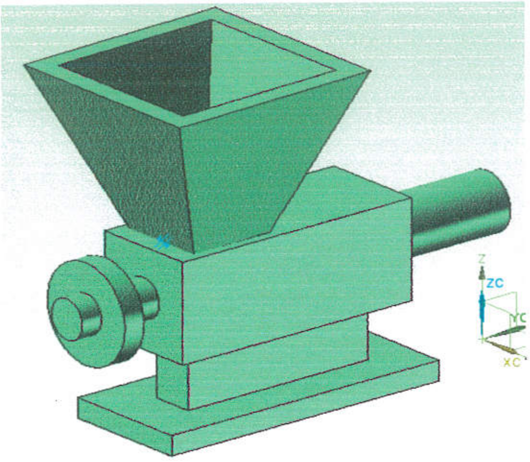

Fig 2.1 screw press

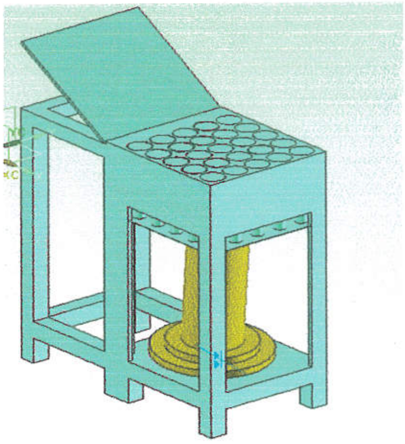

Fig 2.2 Piston press

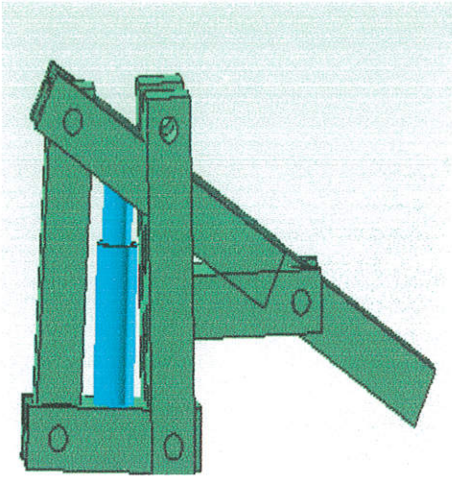

Fig. 2.3 lever arm press

2.3 Research and Development of Agricultural Residues as Energy Source for Cooking Purpose Using Low Cost Technique

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. Adegoke (2001) pointed out, 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 loss to the environment is much reduced, a lot of cooking energy is obtained from a relatively small amount of the sawdust briquettes. Kartha and Leach (2001) carried out a study using modern bioenergy to reduce rural poverty. Good results were obtained by adapting presses for bricks or earth blocks in briquetting wood and agricultural wastes. 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.

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. Olle and Olof (2006) stated that lot of different materials can be used for briquette making, for example agricultural residues like ground nut shells, straw, tree leaves, grass, rice and maize husks and banana leaves. It is also possible to use already processed materials such as paper, saw dust and charcoal fines. Although some materials burn better than others, the selection of raw material is usually most dependent on what is easily available in the surrounding areas of where the briquettes are made. They further stated that, briquette can consist of a blend between many different raw materials. The inflammability is not the only thing that matters when the raw material is being selected.

Center for Environment and Development in Africa (1997) reported that the timber trade in southern Nigeria is highly commercial with over 500 saw mills. Sapele, a coastal town in Delta State is the centre of the timber trade and has over 70 sawmills. The Africa timber and plywood company, Sapele, is the biggest wood industry in Nigeria. There is also the Epe Sawmill located at Epe on the shores of the Lekki lagoon. All this sawmills generate large amount of saw dust waste which are not utilized efficiently. 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 worldwide 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.

Shyamalee 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. In this study manual densification of saw dust was tested with three different binding agents; dry cow dung, wheat flour, and paper pulp. The samples with cow dung as binding agent failed with mould detaching and minimum required binder percentage for other two binders for successful forming were found to be 30%. 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 110 kN 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.

2.4 RESEARCH WORK ON CALORIFIC VALUES OF SOME BRIQUETTES

Barnard (1985) gave an indication of the variations of ash content and calorific value for a number of agricultural residues as shown in table 2.1 and said there were discrepancies in the calorific values from different sources, probably due to inaccurate testing procedures.

Table 2.1 calorific value and ash content of various fuels

Material	Ash content %	High calorific value MJ/kg (oven dry)	Materials	Ash content %	High calorific value MJ/kg (oven dry)
Cassava stem	-	18.3	Olive pits	3.2	21.4
Coconut shell	0.8	20.1	Pigeon pea stalks	2.0	18.6
Coconut husk	6.0	18.1	Rice straw	-	15.2
Alfalfa straw	6.0	18.4	"	19.2	15.0
Maize stalks	6.4	18.2	Rice husks	-	15.3
"	3.4	16.7	"	16.5	15.5
Groundnut shells	-	19.7	Soybean stalks	-	19.4

Source: Barnard, (1985)

Krist and Wentink (1985) gave ultimate analysis and the proximate analysis of some typical briquettes as shown in table 2.2.

Table 2.2 Typical Ultimate analysis of briquetted fuels by weight (%)

Material	H	C	O	Ash	Calorific Value (net) MJ/kg
Rice husk	5.50	40.4	34.5	19.8	15.1(13.8)
Corn Stover	6.05	47.1	43.5	3.40	18.6(17.2)
Cotton stalk	5.99	47.1	43.9	3.16	19.0(17.2)
Coffee husks	5.10	47.8	36.0	8.90	18.6(17.5)
Cow dung	5.18	31.6	37.8	19.3	11.4(10.2)

Source: Krist and Wentink, (1985)

2.5 PREVIOUS STUDIES ON BINDING OF BRIQUETTES

Reineke (1964) carried a research into the binding action of some agricultural residues and came out with the finding that granular materials require no added binder because they are self-bonding when briquetted at elevated temperatures. At temperatures above the minimal plastic temperature (325oF for wood), the elastic strains set up in the material under briquetting pressure are completely relieved and the particle surfaces come together into intimate contact. Cohesion of the interfaces, interlocking of boomed out fibrous parts of the particles, and a possible adhesion of the heat softened lignin (the natural bonding agent between the wood fibers), all contribute to a binding action that imparts satisfactory strength to briquettes after they have cooled under pressure. According to Eriksson and Prior (1990), several biomass briquetting projects have been implemented in Kenya. Both direct briquetting and carbonization/ briquetting were tried on a commercial basis but due to the high cost of biomass briquettes compared with firewood, none of the plants was able to continue production.

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.

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

Equipment

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).

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.

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.

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.

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

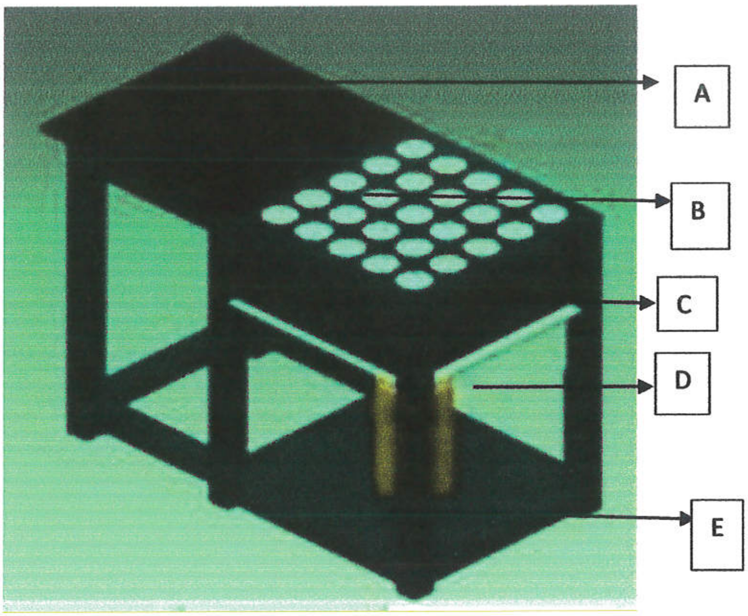

Figure 3.1 The Biomass Briquetting Machine

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 50.mm and an internal diameter of 20mm welded to a 6mm 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

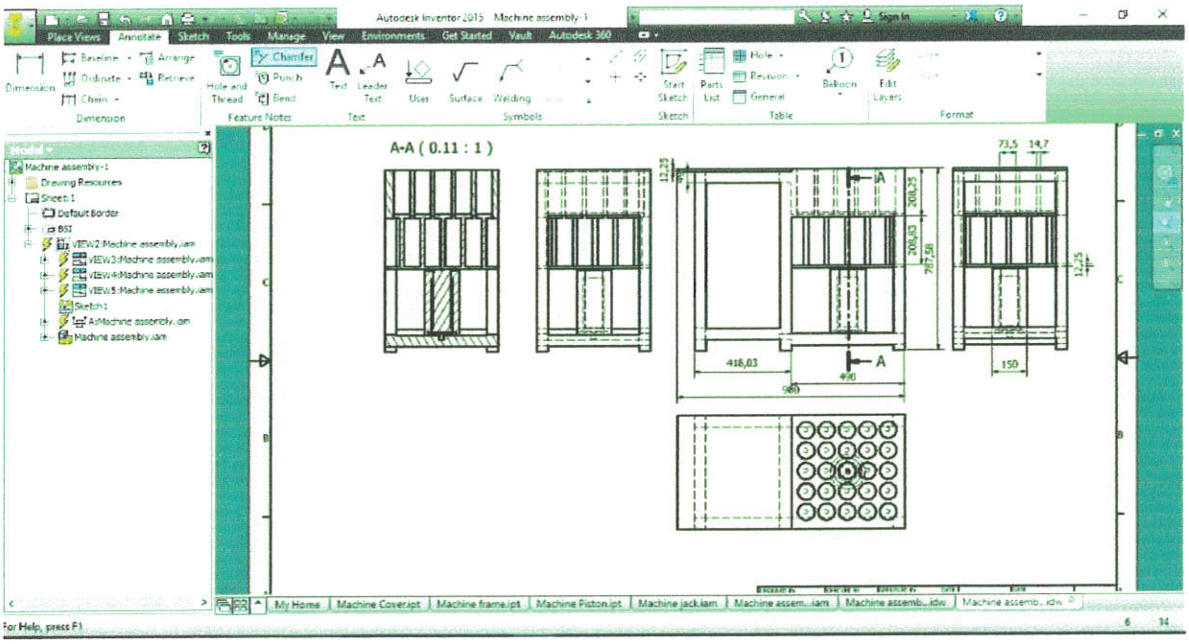

Figure 3.2: Orthographic view of the briquetting machine

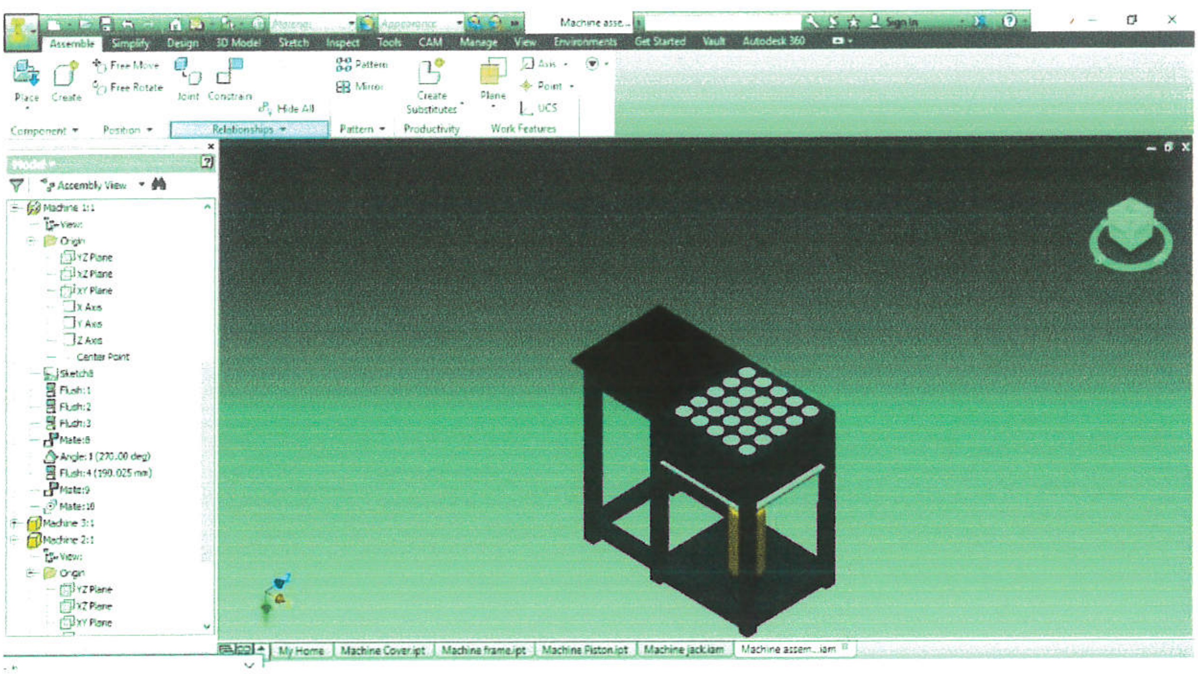

Figure 3.3: Full View Of Biomass Briquetting Machine Using Autodesk Inventor

3.5 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 Stress$\sigma_c = \frac{Toatal\ pressure}{Resisting\ section} = \frac{Pdl}{@tl}$ (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 as shown in (Figures 4a and b), the cylinder also has a tendency to split into two pieces due to internal pressures as shown in (Figure 5). The longitudinal stress was determined as reported by Rajput (2006).

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

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

Maximum shear stress $(\tau_{max}) = \frac{\sigma_c - \sigma_1}{2}$ (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 (Figure 6) was obtained as reported by Rajput, (2006) and is given as$\sigma_c > \sigma_1$

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

But, since$\sigma_c$cannot exceed the permissible tensile stress (σ_1)

i.e. σc $\leq \sigma_t$, $\frac{Pd}{2t} \leq \sigma_c$ t $\geq \frac{Pd}{2\sigma_t}$ (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= net longitudinal strain + 2 x net circumferential strain =$e_v = e_1 + 2e_c$ (7)

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

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

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

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

$e_l = \frac{Pd}{4tE}(1 - 2\mu)(11)$ (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 $P_{euler} = \frac{\pi^2 El}{l_\epsilon^2} \frac{\pi^2 EAk^2}{l_\epsilon^2}$ (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 $\frac{1}{P} = \frac{1}{\sigma_c A} + \frac{1}{\pi^2 EA(\frac{R}{l_\epsilon})^2}$

P $\frac{\sigma_c A}{1+a(\frac{l_\epsilon}{k})^2}$= (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

$$P_{Euler=PP} \tag{17}$$

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

Since I =AK^2

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

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 center is subjected to concentrated loading from the base of the hydraulic jack. The thickness of the bottom plate is given by the formula;

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

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 $= \frac{\text{Output}}{\text{Input}} \times 100$

3.6 Construction of the machine

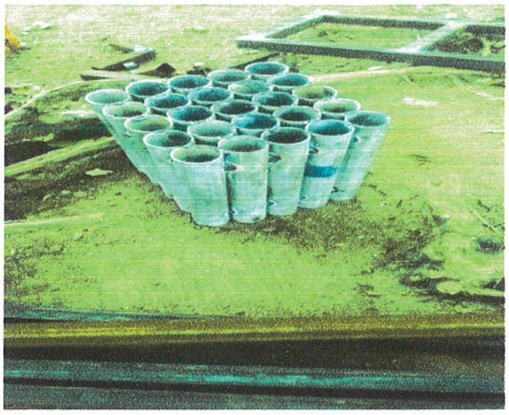

Plate3.1: mould box

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.

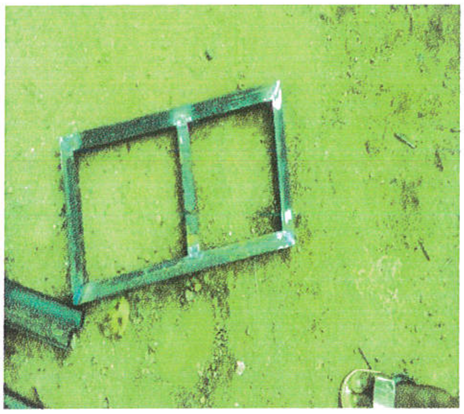

Plate3.3: Frame under construction **Plate3.4: Frame and mould box after construction**

3.7 Sample Preparation

The sawdust was mixed with the cassava waste used as a binder and ash. The binding ratio used is ratio 80:15:5

Plate3.5: Briquettes produced

PHYSICAL

3.8 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).

3.9 Durability

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,

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

3.10 Calorific Test

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 on computer screen (Oyelaran O.A., 2014).

Calorific value = 18.774KJ/Kg

3.11 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 Programmed 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 3oC of the boiling point (Prasad et al, 1983).

3.12 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

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^2.

Table4.2: Results of durability test

Sample	**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 Table 4.2, 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.

Fig 3.4: Experimental Results of Water Boiling Test one (Cold Start) for Fuel Samples

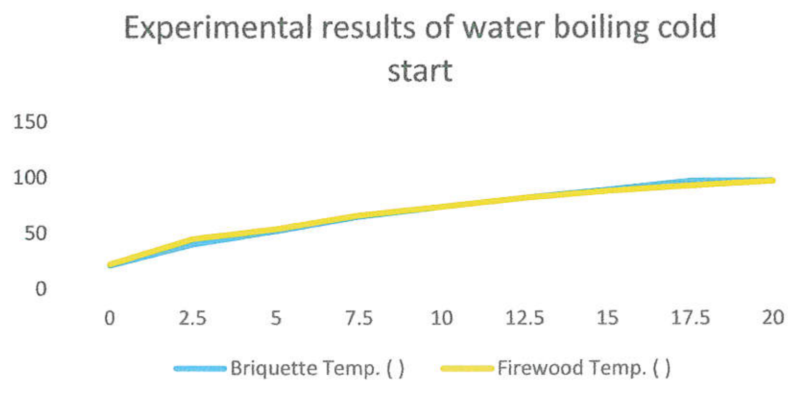

Table 4.3: Experimental Results of Water Boiling Test one (Cold Start) for Fuel Samples

Time (min)	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
0	89.0	88.0
17.5	97.0	93.0
20.0	97.0	97.0

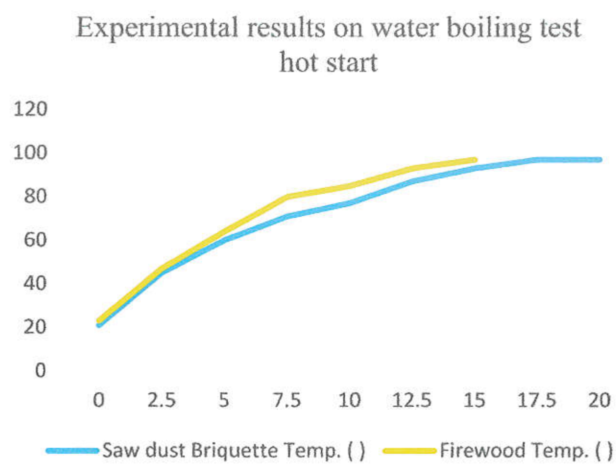

Fig 3.5 Experimental Results of Water Boiling Test one (Hot Start) for Fuel Samples

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

Time (min)	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	

4.5: 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
17.5	91.0	97.0
17.5	97.0	

Table4.6: 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	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	

Table.4.7 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

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)
Sawdust	28.05	19.20	45
Firewood	14.80	13.05	45

4.3 Boiling time

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 Table 4.9. Repeating the test with a hot stove 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.

4.4 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.

4.5 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 3 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. 6 Average Values of Specific Fuel Consumption of Fuel Samples

Table 4.12 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 Table 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

4.7 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)

4.8 Nature of the Flame

Nature of the flame color 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 color of the flame was pale blue which signifies complete combustion and high heating efficiency and for wood, the color 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.