DESIGN AND PERFORMANCE ANALYSIS OF A HYDRAULICALLY OPERATED BRIQUETTING MACHINE CASE STUDY OF CASSAVA PEELS

BY

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Declaration

I hereby declare that this project work is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished work were duly referenced in the text.

6/03/2012

ODEY, EJIM OGAR

DATE

Dedication

This work is dedicated to Almighty God for his mercies and abundant grace and love for me, my provider and protector all through the period taken for this project.

I also dedicate this work to millions of Nigerians who cannot afford a good and qualitative education due to abject poverty and helplessness in the midst of plenty.

To President Umaru Musa yar'adua, who until his death was an initiator and an active member in the campaign for education for all, And for setting up a campaign against militancy, granting amnesty and restoring peace in the Niger delta. May his beloved and well cherished soul rest in perfect peace. Amen.

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Ability is of no use if there is no opportunity. In this light, I whole heartedly wish to express my profound gratitude to my father Mr. Christopher Odey Ogar and beloved mother Mrs. Caroline Ikor Ede for their love, support, affection and prayer towards the successful completion of my academic career, I want to use this opportunity to tell my dad that he is the best dad in the world and to my mum that she is the best and sweetest mother in the world.

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Abstract

The current wave of energy consciousness has triggered intense efforts in the search for alternative sources of cooking fuels, including the use of Agricultural by-products like cassava-peels to form briquettes which is substitute of fuel needed for domestic cooking. Cassava peels residues which included slabs, edgings and cut-offs were compressed with binder and without binder, The type of binder used is the gum Arabic, and briquettes produced in this way were assessed. The briquettes were analyzed for compressive strength, volatile matter, carbon content, combustion test, ash content, moisture content and calorific value. The results were subjected to ANOVA and Duncan test. The percentage carbon content in gum Arabic bonded briquettes was slightly higher than in briquettes without binder, with mean values of 87.167 and 85.167% respectively. The result of the moisture content of briquettes with binder and without binder were 5.1 and 4.9% respectively, The calorific value of 7766.39Kcal/kg and 7604.65Kcal/kg was obtained in briquette with binder and without binder respectively. The mean values for the compressive test were 79.625 and 72.875KN for briquette with binder and without binder respectively. The binder significantly influenced durability rating of the briquettes in different samples. Similarly, variations in samples formulation for briquette volatile matter, carbon content, ash and moisture content were significant ($P < 0.05$), All the properties investigated showed that gum Arabic bonded briquettes (with binder) have better physical, mechanical and chemical qualities than unbounded (without binder) briquettes, For quality specification, the best gum Arabic bonded briquette was obtained in sample 1 and sample 2, while the unbounded briquette was obtained in sample 3 This shows that cassava peels are good for production of briquettes with binder.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Renewable fuel briquettes are an environmentally friendly alternative fuel source replacing expensive and depleting fuel sources including firewood, coal, charcoal, liquid propane gas and kerosene. Briquetting is the compaction of loose combustible materials for the purpose of fuel making (Adegoke, 2002). It is a compaction technology in the general category of densification. Densification is a process in which materials are compressed under pressure to form a product of higher bulk density, lower moisture content and uniform size, shape and material properties. There are two ways that compaction can be accomplished with and without a binder. Materials are made to stick together during compression. Otherwise, when the briquette is removed from the mold, it will crumble to pieces. This fastening agent is known as a binder. An example of a good binding agent is cassava starch. In some cases, most commonly under high temperature and pressure, a material can act as its own binder. Wood, for example, becomes plastic and can be briquetted without a binder under such conditions. The idea of briquetting is to use materials that are not otherwise useable due to lack of density, compressing them into a solid fuel of convenient shape that can be burned like wood or charcoal (Olorunnisola, 2007).

According to Ajueyitsi (2002), in the 1830's a Russian inventor F.P Veshniakov, was the first to develop a method of producing hard briquettes from waste wood, charcoal and hard coal. In recent times in Nigeria briquetting has been applied to charcoal, sawdust and of course agricultural by – product like cassava peel, rice husks, groundnut shells, sawdust and Shea butter cake (Adegoke, 2002). Generally briquette processing machines are relatively large, heavy and costly. What is needed is a small, light, simple and cheap press which can be constructed with materials available locally. Olorunnisola (2007) designed and tested a cylindrical briquette extrusion machine using paper waste and coconut husk. He investigated the effect of mixing ratios on the stability of the produced briquettes. Therefore the design and construction of a suitable machine that can compress wood waste and agricultural waste materials into briquette which can be used as fuel would be a solution to the problem of environmental resources conservation.

1.1.1 Cassava peel

Cassava peel is the outer layer of the cassava tuber. Dried peel of cassava root are fed to sheeps and goats, and raw or boiled tubers are mixed into a mash with protein concentrates such as maize, sorghum, groundnut or palm kernel meal and mineral salts for livestock feeding. But recently in developing countries, dried cassava peel have been used for briquetting, it also makes it possible to use waste products such as saw dust, rice husks, maize cobs etc(Ajueyitsi,2002).

1.1.2 Gum Arabic

Gum Arabic or gum acacia is a natural gum made of hardened sap taken from two species of the acacia tree *Acacia senegal* and *Acacia seyal.* Although historically cultivated in Arabia and West Asia, it is harvested commercially from wild trees throughout the Sahel. The *Acacia senegal* is tapped by cutting holes in its bark while the *Acacia sayel's* gum appears on its stem and branches during the prevalence of the dry desert winds. The finest quality of this gum is obtained the *Acacia senegal and the Acacia arabica* which is found in parts of Northern Nigeria (http://pacifier.com/~kthayer/html/Gumarabic.html).

1.1.3 Properties and structure of Gum Arabic

Gum arabic is classed in a group of substances called *arabinogalactan proteins*. In more descriptive terms, it is essentially a polysaccharide, comprised mostly of galactose, arabinose, rhamnose, and glucoronic acid. It also contains a small amount of protein. Gum arabic readily dissolves in water to form highly concentrated solutions that are of relatively low viscosity, which is as a result of the gum's highly branched very compact structure. Gum is quite heterogeneous in nature with at least three discreet components: The first, comprising about 90% of the gum, has a molecular weight of about 250,000 and contains a negligible amount of amino acids. It is suggested by analysts that the structure of this component is globular and highly branched. The second component, making up about 10% of the total, has a molecular weight of 1,500,000, and contains about 10% protein. It is thought to have a structure consisting of five globular lobes of carbohydrate of molecular weight of about 250,000 each, the third component contains 20 – 50% protein located deep in the center of the molecule. It is highly compact with a molecular weight of 200,000. (http://pacifier.com/~kthayer/html/Gumarabic.html)

1.2 Statement of the Problem

1.2.1 Challenges and Remedies of Energy Crisis

In 1973, the Arab/Israel war gave rise to oil embargo that was placed on most European countries by the Arabs. The result of the embargo was a five-fold increase in oil price. This had great effect on the economies of the industrialized nations. Since then, all countries of the world have developed fears that certain source of energy termed 'Non-renewable' may one day run out hence, the need for alternative sources of energy. The industrialized countries reacted with international efforts to find new oil resources, to increase the efficiency with which energy is used and to develop alternative sources of energy. Since the oil crises, considerable progress has been made towards finding new sources of fuel under secure Western control, increasing diversity of supply and improving energy efficiency. The search for oil reveals large and widely spread reserves of natural gas, which rapidly displaced oil in much non-transport uses (Bartholomew *et al.*, 2002).

According to Sambo (2009), Energy is the mainstay of Nigeria's economic growth and development. It plays a significant role in the nation's international diplomacy and it serves as a tradable commodity for earning the national income, which is used to support government development programmes. It also serves as an input into the production of goods and services in the nation's industry, transport, agriculture, health and education sectors, as well as an instrument for politics, security and diplomacy. But the 1973 energy crisis has clearly shown that this will not always be the same, due to the fact that fossil fuels which Nigeria has depended so much on are depleting rapidly and are harder to retrieve. The consequence is that we could be facing an energy crisis in the future if we are not careful today. Another problem is that the fossil fuels that are widely used today are harmful for the environment. The solution to these problems can be resolved by renewable energy. The contribution of energy to Gross Domestic Product (GDP) is expected to be higher when we take into account renewable energy utilization, which constitutes about 90% of the energy used by the rural population (NPC, 1997). Our beautiful planet gives us the opportunity to make proper use of sunlight, flowing water, strong winds, hot spring and bio-resource and convert these into energy. These energy sources are abundant and free to use. Renewable energy is considered a viable solution to the energy challenges of Nigeria especially in the rural areas of the country and to the restrictions posed by the rising cost of conventional or traditional energy.

1.3 Objectives of the Study

a). To design and construct a hydraulically-operated briquetting machine

b). To test the machine for briquette production using cassava peels

c). To carry out analysis of the briquettes

d). To compare with charcoal and wood fuel

1.4 Justification of the Project

It has become more important for developing countries to find low-cost methods of recycling their waste materials. This is especially true if these wastes materials have high energy content that can be converted back into the energy cycle. Briquettes of Agricultural by-products like cassava peel, sawdust, rice husks etc can largely overcome some of the major problems regarding their utilization for energy. The situation in the rural areas of the country is that most end users depend on fuelwood. Fuelwood is used by over 60% of Nigerians living in the rural areas. Nigeria consumes over 50 million metric tonnes of fuel wood annually, a rate, which exceeds the replenishment rate through various afforestation programmes (Sambo, 2009). Sourcing fuel wood for domestic and commercial uses is a major cause of desertification in the arid-zone states and erosion in the southern part of the country. The rate of deforestation is about 350,000 hectares per year, which is equivalent to 3.6% of the present area of forests and woodlands, whereas reforestation is only at about 10% of the deforestation rate (ICCDD, 2000). At this present rate of deforestation, there will soon be a severe shortage of fuel from wood and it is necessary to introduce other sources of cheap and available fuels. An increase in agricultural productivity is associated with increase in agricultural residues supplies which can be converted into high grade energy source with the modern technology known as briquetting. The briquetting of agro-residues is one sure way of fighting climate change and ensure sustainable development due to the fact that it reduces dependence on fossil fuel, use waste products, as well as it reduces pollution which may have resulted in case of dumping (Sambo,2009).

1.5 Scope of the Study

This project work covers the production of briquettes from agricultural by product as well as the design and fabrication of a briquetting machine.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 History of Briquetting

Research and development for briquetting has been going on for several decades, with briquette successfully produced and used across Africa, Asia, and the United States. Biomass densification by means of some form of mechanical pressure to reduce the volume of vegetable matter and its conversion to a solid form which is easier to handle and store than the original material, is called briquetting. Briquetting was first proposed in the 1830's by a Russian inventor F.P Veshniakov, who developed a method of producing hard briquettes from wastes wood charcoal and hard coal (Ajueyitsi, 2002). Many of the developing countries produce huge quantities of agro residues but they are used inefficiently causing extensive pollution to the environment. The major residues are rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks. Sawdust, a milling residue is also available in huge quantity. As a typical example, about 800 tonnes of rice husk ash are generated every day in Ludhiana (Punjab) as a result of burning 2000 tonnes of husk, Erikson and Prior (1990).

Historically, biomass briquetting technology has been developed in two distinct directions. Europe and the United States has pursued and perfected the reciprocating ram or piston press while Japan have independently invented and developed the screw press technology. Although both technologies have their merits and demerits, it is universally accepted that the screw pressed briquettes are far superior to the ram pressed solid briquettes in terms of their storability and combustibility. Japanese machines are now being manufactured in Europe under licensing agreement but no information has been reported about the manufacturing of European machines in Japan (Grover and Mishra, 1996). Worldwide, both technologies are being used for briquetting of sawdust and locally available agro-residues. Although the importance of biomass briquettes as substitute fuel for wood, coal and lignite is well recognized, the numerous failures of briquetting machines in almost all developing countries have inhibited their extensive exploitation. Briquetting technology is yet to get a strong foothold in many developing countries because of the technical constraints involved and the lack of knowledge to adapt the technology to suit local conditions. Overcoming the many operational problems associated with this technology and ensuring the quality of the raw materials used are crucial factors in determining its commercial success (Singh and Khare, 1993). In addition to this commercial aspect, the importance of this technology lies in conserving wood, a commodity extensively used in developing countries and leading to the widespread destruction of forests. Biomass densification, which is also known as briquetting of sawdust and other agro residues, has been practiced for many years in several countries.

According to Grover and Mishra (1996), Screw extrusion briquetting technology was invented and developed in Japan in 1945. As of April 1969, there were 638 plants in Japan engaged in manufacturing sawdust briquettes, known as 'Ogalite', amounting to a production of 0.81 MTY. The fact that the production of briquettes quadrupled from 1964 to 1969 in Japan speaks for the success of this technology. This technology should be differentiated from such processes as the 'Prest-o-log' technology of the United States, the 'Glomera' method in Switzerland and the 'Compress' method in West Germany(http//:www.wikipedia.com) At present two main high pressure technologies: ram or piston press and screw extrusion machines, are used for briquetting. While the briquettes produced by a piston press are completely solid, screw press briquettes on the other hand have a concentric hole which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogeneous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers. Briquettes can be produced with a density of 1.2 g/cm^3 from loose biomass of bulk density 0.1 to 0.2 g /cm^3. These can be burnt clean and are environmentally friendly. Also those advantages that are associated with the use of biomass are present in the briquettes (http://www.rictec.com.sg). With a view to improving the briquetting scene in Nigeria, Inegbenebor (2002) compressed fibrous agricultural and wood waste materials with suitable adhesive into solid fuel briquettes in a compressing machine, which was designed and constructed for this purpose. Nine samples of fibrous waste materials were prepared into different categories: - Category A (100% saw-dust, 100% rice-husk, 50-50% rice-husk/sawdust using starch as adhesive). Category B (100% saw-dust, 100% rice-husk, 50-50% rice-husk/ saw dust using gum arabic as adhesive) and category C (100% saw-dust, 100% rice husk, 50-50% rice-husk/saw dust using bentonite as adhesive). The solid fuel briquettes in category C had the lowest average moisture content of 9.1%, categories A and B solid fuel briquettes had 10.5% and 13.0%, respectively. Results from a water boiling test (WBT), involving comparison of the burning abilities of the solid fuel briquettes and fire wood of the same quantity (200 grams) in boiling 1.5 litres of water showed that the solid fuel briquettes bound with each of the three adhesives; bentonite, gum arabic and starch; boiled water within a period of 14 to 22 minutes, while firewood did so within a period of 22 to 27 minutes. Aris *et al.* (2007) focused on the development of briquettes from oil palm waste to enhance its utilization as fuel. The reuse of waste material reduces operation costs, negative environmental effects and dependency on conventional fuels. Several aspects of improvement to the physical properties as well as energy content were taken into account in the study. A total of eight tests were conducted for different ratios of shell, fibre and binder mixtures as well as varying the type of binder material used. Varying briquette pressing pressures were also considered in these tests. Results show good physical properties in terms of durability, impact and compressive strength for a 36:54:10 ratio by mass of fibre, shell and waste paper briquette with 5.7% ash and 5.24% moisture content. The gross calorific value of 22.4 MJ/kg indicates good energy content of the briquette. The briquette pressing pressure of 159 MPa was used after discovering that it had an outright positive effect on almost all physical and energy components for all combinations tested. Olorunnisola (2007) designed and tested a cylindrical briquette extrusion machine using paper waste and coconut husk. He investigated the effect of mixing ratios on the stability of the produced briquettes. Deiena *et al.* (2004) studied the use of grape moist as a binder to obtain activated carbon briquettes of good mechanical and surface properties. Okonkwo *et al.* (2007) examined the calorific value, sulphur percentage and boiling water duration test on groundnut shell, maize cob and rice husk made into pellets through the process of densification. Rice husk gave 17.35 kJ/kg, maize cob 16.16 kJ/kg and 17.35 kJ/kg for groundnut shell calorific values and 5.23%, 4.25%, 6.0% respectively for sulphur content. For boiling 2 litres of water, it took them 15 minutes, 13 minutes and 10 minutes respectively, while Purvis and Graig (1998) treats a small scale biomass fired turbine power plant.

2.2 Briquetting System

The briquetting process is the conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store. The idea of briquetting is to use materials that are otherwise not usable due to a lack of density, compressing them into a solid fuel of a convenient shape that can be burned like wood or charcoal. The briquettes have better physical and combustion efficiency of existing traditional furnaces. In addition to killing all insects diseases, they reduce the risk of fire in the countryside, (Grover and Mishra, 1996).

According to Ajueyitsi (2002), Briquettes were discovered to be an important source of energy during the First and Second World Wars for heat and electricity production using simple technologies. One of the recommended technologies is lever operating press (mechanical or hydraulic press). Briquetting allows ease of transportation and safe storage of wastes as they have a uniform shape and are free of insects and disease carriers.

2.3 Advantages of briquetting

The advantages of briquetting are:

1. Gets rid of insects
2. Decreases the volume of waste
3. Efficient solid fuel of high thermal value
4. Low energy consumption for production
5. Protects the environment
6. Provides job opportunities
7. Less hazardous.

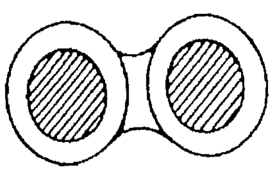
2.4 Fundamental Aspect of Briquetting

2.4.1 Pressure Compaction

Biomass densification represents a set of technologies for the conversion of biomass into a fuel. The technology is also known as briquetting and it improves the handling characteristics of the materials for transport, storing etc. According to Grover and Mishra (1996), this technology can help in expanding the use of biomass in energy production, since densification improves the volumetric calorific value of a fuel, reduces the cost of transport and can help in improving the fuel situation in rural areas. Briquetting is one of several agglomeration techniques which are broadly characterized as densification technologies. Agglomeration of residues is done with the purpose of making them more dense for their use in energy production. Raw materials for briquetting include waste from wood industries, loose biomass and other combustible waste products. On the basis of compaction, the briquetting technologies can be divided into:

1. High pressure compaction
2. Medium pressure compaction with a heating device
3. Low pressure compaction with a binder.

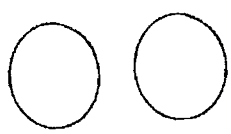
In all these compaction techniques, solid particles are the starting materials. The individual particles are still identifiable to some extent in the final product. Briquetting and extrusion both represent compaction i.e., the pressing together of particles in a confined volume. If fine materials which deform under high pressure are pressed, no binders are required (Pietsch, 1991). The strength of such compacts is caused by Van der Waals' forces, Valence forces, or interlocking. Natural components of the material may be activated by the prevailing high pressure forces to become binders. Some of the materials need binders even under high pressure conditions. Fig.2.1 shows some of the binding mechanisms.



Hardening binders

Highly **viscous binders**

Adsorption layers



Molecular forces

(Van der waal's forces)

Fig.2.1. Binding mechanisms (Pietsch, 1991)

2.4.2 Binding Mechanisms of Densification

In order to understand the suitability of biomass for briquetting, it is essential to know the physical and chemical properties of biomass which also influence its behaviour as a fuel. Physical properties of interest include moisture content, bulk density, void volume and thermal properties. Chemical characteristics of importance include the proximate and ultimate analysis, and higher heating value. The physical properties are most important in any description of the binding mechanisms of biomass densification. Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area. In the case of biomass the binding mechanisms under high pressure can be divided into adhesion and cohesion forces, attractive forces between solid particles, and interlocking bonds (Pietsch, 1991). High viscous bonding media, such as tar and other molecular weight organic liquids can form bonds very similar to solid bridges.

According to Pietsch (1991), adhesion forces at the solid-fluid interface and cohesion forces within the solid are used fully for binding. Lignin of biomass or wood can also be assumed to help in binding in this way. Finely divided solids easily attract free atoms or molecules from the surrounding atmosphere. The thin adsorption layers thus formed are not freely movable. However, they can contact or penetrate each other. The softening lignin at high temperature and pressure conditions form the adsorption layer with the solid portion. The application of external force such as pressure may increase the contact area causing the molecular forces to transmit high enough which increases the strength of the bond between the adhering partners. Another important binding mechanism is Van der Waals' forces. They are prominent at extremely short distances between the adhesion partners. This type of adhesion possibility is much higher for powders. Fibres or bulky particles can interlock or fold about each other as a result forming interlocking or form-closed bonds, (Grover and Mishra, 1996). To obtain this type of bond, compression and shear forces must always act on the system. The strength of the resulting agglomerate depends only on the type of interaction and the material characteristics.

2.5 BRIQUETTING TECHNOLOGIES

2.5.1. Screw Press and Piston Press Technologies

High compaction technology or binderless technology consists of the piston press and the screw press. In a screw extruder press, the biomass is extruded continuously by a screw through a heated taper die. In a piston press the wear of the contact parts e.g., the ram and die is less compared to the wear of the screw and die in a screw extruder press (Pietsch, 1991). The power consumption in the former is less than that of the latter. But in terms of briquette quality and production procedure screw press is definitely superior to the piston press technology. The central hole incorporated into the briquettes produced by a screw extruder helps to achieve uniform and efficient combustion and, also, these briquettes can be carbonised. At present, screw press and piston press technologies are becoming more important commercially. As the piston press technology is comparatively older than the screw press technology, more piston presses are operating today in most developing countries of the world. The lack of basic research to improve the piston press and the manufacturers' inability to understand the technology are the two prime reasons why these presses are not performing satisfactorily on a commercial basis. Entrepreneurs face many problems due to frequent wear in the ram and the die. The life of the ram has been observed from 33 to 300 hours (Singh and Khare, 1993). It consists of a fly wheel that operates a piston, which presses the material through a tapered die where the briquette is formed. But piston presses have not been successful due to a lack of understanding of the characteristics raw material which in turn affects machine design parameters like flywheel size and speed, crank shaft size and piston stroke length. The feeding mechanism also needs to be perfected, in this case according to the bulk density of the raw material (Eriksson and Prior, 1990). While an appropriate technology is important for briquetting, the compaction characteristics of biomass also play a significant role.

2.5.2 Hydraulic piston press

The hydraulic piston press is different from the mechanical piston press in that the energy to the piston is transmitted from an electric motor via a high pressure hydraulic oil system. This machine is compact and light. This machine can tolerate higher moisture content than the usually accepted 15% moisture content for mechanical piston presses. Pelletizing is closely related to briquetting except that it uses smaller dies (approximately 30 mm) so that the smaller products are called pellets. The pelletizer has a number of dies arranged as holes bored on a thick steel disc or ring and the material is forced into the dies by means of two or three rollers. The two main types of pellet presses are: flat and ring types (Eriksson and Prior, 1990). The flat die type features a circular perforated disk on which two or more rollers rotate. The ring die press features a rotating perforated ring on which rollers press onto the inner perimeter.

Some of the technical features of both types are given below:

Table 2.1: Features of pellet presses (Eriksson and Prior, 1990)

	Flat type	Ring type
Disk diameter (mm)	300 - 1500	250 - 1000
Track surfaces of rollers (cm^2)	500 - 7500	500 - 6000

Large capacity pelletizers are available in the range of 200 kg/h to 8 ton/h. Thus, pellet press capacity is not restricted by the density of the raw material as in the case of piston or screw presses. Power consumption falls within the range of 15-40 kWh/ton.

2.5.3 Compaction Characteristics of Biomass and Their Significance

In order to produce good quality briquettes, feed preparation is very important. Feed parameters are discussed in this section, as these play a practicable role in briquetting technology. For densification of biomass, it is important to know the feed parameters that influence the extrusion process. For different briquetting machines, the required parameters of raw materials like their particle size, moisture content and temperature are different. These are discussed below.

2.5.4 Effect of particle size

Particle size and shape are of great importance for densification. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component gives the best results. Although the screw extruder which employs high pressure (1000 - 1500 bar), is capable of briquetting material of oversized particles, the briquetting will not be smooth and clogging might take place at the entrance of the die resulting in jamming of the machine (Grover and Mishra, 1996). The larger particles which are not conveyed through the screw start accumulating at the entry point and the steam produced due to high temperature (due to rotation of screw, heat conducted from the die and also if the material is preheated) inside the barrel of the machine starts condensing on fresh cold feed resulting in the formation of lumps and leads to jamming. That is why the processing conditions should be changed to suit the requirements of each particular biomass. Therefore, it is desirable to crush larger particles to get a random distribution of particle size so that an adequate amount of sufficiently small particles is present for embedding into the larger particles. The presence of different size particles improves the packing dynamics and also contributes to high static strength (Ludwig, 1994). Only fine and powdered particles of size less than 1 mm are not suitable for a screw extruder because they are less dense, more cohesive, non-free flowing entities.

2.5.5 Effect of moisture

The percentage of moisture in the feed biomass to extruder machine is a very critical factor. In general, it has been found that when the feed moisture content is 8-10 %, the briquettes will have 6-8% moisture (Sen, 1987). At this moisture content, the briquettes are strong and free of cracks and the briquetting process is smooth. But when the moisture content is more than 10%, the briquettes are poor and weak and the briquetting operation is erratic. Excess steam is produced at higher moisture content leading to the blockage of incoming feed from the hopper, and sometimes it shoots out the briquettes from the die (Grover and Mishra, 1996). Therefore, it is necessary to maintain an optimum moisture content. In the briquetting process water also acts as a film type binder by strengthening the bonding in briquettes. In the case of organic and cellular products, water helps in promoting bonding by Van der Waals' forces by increasing the true area of contact of the particles. In fact, the surface effects of water are so pronounced that the success or failure of the compaction process solely depends solely upon the moisture content of the material.

According to Sen (1987), the right amount of moisture develops self-bonding properties in lignocellulosic substances at elevated temperatures and pressures prevalent in briquetting machines. It is important to establish the initial moisture content of the biomass feed so that the briquettes produced have moisture content greater than the equilibrium value, otherwise the briquettes may swell during storage and transportation and disintegrate when exposed to humid atmospheric conditions.

2.5.6 Effect of temperature of biomass

By varying the temperature of biomass the briquette density, briquette crushing strength and moisture stability can be varied. In a screw extruder, the temperature does not remain constant in the axial direction of the press but gradually increases. Internal and external friction causes local heating and the material develops self-bonding properties at elevated temperatures. It can also be assumed that the moisture present in the material forms steam under high pressure conditions which then hydrolyses the hemicellulose and lignin portions of biomass into lower molecular carbohydrates, lignin products, sugar polymers and other derivatives, (Grover and Mishra, 1996). These products, when subjected to heat and pressure in the die, act as adhesive binders and provide a bonding effect.

According to Grover and Mishra (1996), the addition of heat also relaxes the inherent fibers in biomass and apparently softens its structure, thereby reducing their resistance to briquetting which in turn results in decreased specific power consumption and a corresponding increase in production rate and reduction in wear of the contact parts. However, the temperature should not be increased beyond the decomposition temperature of biomass which is around 300 °C.

2.5.7 Effect of temperature of the die

The distinctive feature of a screw type briquetting machine is that heat is applied to the die 'bush' section of the cylinder. This brings about two important operational advantages. The machine can be operated with less power and the life of the die is prolonged. Further, the surface of the briquette is partially carbonized or torrified to a dark brown color making the briquette resistant to atmospheric moisture during storage. The temperature of the die should be kept at about 280-290 °C If the die temperature is more than the required one, the friction between the raw material and the die wall decreases such that compaction occurs at lower pressure which results in poor densification and inferior strength, (Grover and Mishra, 1996). Conversely, low temperature will result in higher pressure and power consumption and lower production rate.

2.5.8 Effect of external additives

The briquetting process does not add to the calorific value of the base biomass. In order to upgrade the specific heating value and combustibility of the briquette, certain additives like charcoal and coal in very fine form can be added. About 10-20% char fines can be employed in briquetting without impairing their quality, (Grover and Mishra, 1996). Further, only screw pressed briquettes can be carbonized. When carbonized with additives in the briquette to make dense char coal, the yield is remarkably increased. However, depending upon the quality of charcoal and coal powder, various formulations can be evolved for optional results. In piston press technology the effect of particle size and moisture content is similar to that of the screw press. But in this case preheating of raw material is not employed and the die is not heated. In fact the die needs cooling for smooth briquetting.

2.6. Unit Operations

The above factors illustrate that biomass feed preparation is very important and forms an integral part of the briquetting process. The unit operations of the piston press and the screw press are similar except where the latest development in screw press technology has been adopted, i.e., where a preheating system has been incorporated to preheat the raw material for briquetting to give better performance commercially and economically to suit local conditions, (Grover and Mishra, 1996). In the present piston press operating briquetting plants, the biomass is briquetted after pre processing the raw material, but no preheating is carried out. Depending upon the type of biomass, three processes are generally required involving the following steps.

A. Sieving - Drying - Preheating - Densification - Cooling - Packing

B. Sieving - Crushing - Preheating - Densification - Cooling - Packing

C. Drying - Crushing - Preheating - Densification - Cooling - Packing

When sawdust is used, process A is adopted. Process B is for agro- and mill residues which are normally dry. These materials are coffee husk, rice husk, groundnut shells, cassava peel etc. Process C is for materials like bagasse, coir pith (which needs sieving), mustard and other cereal stal (Grover and Mishra, 1996).

CHAPTER THREE

3.0 MATERIAL AND METHODS

This chapter presents the design analysis, procedure for briquetting cassava peels, test procedure of cassava peel briquette, comparison with other samples (charcoal and fuel wood), combustion test and analysis of cassava peel, charcoal and fuel wood.

3.1 DESIGN CONSIDERATION AND MATERIAL SELECTION

Economy is the basis of any good design hence material used were carefully selected so as to serve the specific purpose for which they were meant, while at the same time considering cost.

The properties of the materials must include resistance to corrosion because corrosion may contaminate the briquette material hence adding unwanted property to the material.

Materials like stainless steel, brass, and grey cast iron have better advantage over others but for availability and economic reasons, galvanized mild steel was chosen for this project.

3.2 Various Components of the Briquetting Machine

3.2.1 Briquetting Chamber

This unit is used for compressing and moulding of the briquette. It is made up of the following;

i. 4 cylinders 40mm diameter each where the biomass materials are fed for compaction. Based on the diameter of the cylinder, the assumed diameter of the briquette is 40mm and height of 50mm.

ii. 4 pistons 38.50mm diameter each. Assumption based on the diameter of the cylinders.

iii. A top cover, 30mm thick.

3.2.2 Piston Base

This is a c-sectioned bar that transfers the pressure produced by the hydraulic jack to the pistons for compressing and molding of the briquette material.

3.2.3 Frame

The briquetting machine has four angle bars on which the briquetting chamber is hanged, it also guides the to and fro movement of the "C" section bar as it is been pushed up and down by the hydraulic jack. It also serves as a base for the briquetting chamber.

3.2.4 Hydraulic Jack

This is the lift unit which raises the "C" section bar, pressurizing the bio materials fed to the cylinders in briquetting chamber from the "C" section bar through the connecting rods to the pistons; finally pressurize the materials against the briquetting chamber cover.

3.2.5 Base

This is a flat metal plate that provides support to the machine; it is on this plate that the hydraulic jack is placed. The machine weight lies on this part of the machine.

3.3 Design Analysis and Calculations

3.3.1 Assumptions:

Cylinder diameter = 40mm

Cylinder length = 95mm

Briquetting Chamber cover thickness = 20mm

The distance between each cylinder = 5mm

Piston diameter = 38.5mm

Piston length = 10mm

3.3.2 Choice of Hydraulic jack Capacity

Using charcoal and fuel wood from Shea butter tree as standard for comparing the briquettes, the maximum force of compaction of charcoal and fuel wood deducted from the compressive test is 20kN and 60kN respectively. For briquette to burn longer and more effectively than charcoal and fuel wood, its maximum compaction force has to be more than that of fuel wood and charcoal. Therefore choosing a compaction force of 80kN for the briquette,

Tonnage Capacity of Hydraulic Jack (C) is given as;

$$C = \frac{F}{1000g}$$

Where;

C = Tonnage capacity of hydraulic jack

F = Compaction force of the briquette

g = gravitational force = $9.8m/s^2$.

$$= \frac{80000}{(1000 \times 9.8)}$$

= 8.16tonnes

The size of jack used is 10 tones which is the nearest size of jack available.

3.3.3 Determination of Cylinder Thickness

Using the equation;

$P_a D = 2tS$ (Khurmi and Gupta)

Where

P_a = maximum pressure on the cylinder wall= the compacting pressure $= \frac{F}{A}$

D = internal diameter of the cylinder = 40mm = 0.04m

S = tensile strength of the material (mild steel) = $430 \times 10^6 N/m^2$ (Khurmi and Gupta, 2008)

t = thickness of the cylinder.

F = maximum force

A = surface area of the piston base

From above, a hydraulic jack of 10tonne was chosen for this project which was designed to carry a maximum load of 10000kg.

F = mg

$= 10000 \times 9.8 = 98000N$

Surface area of the piston base $= l \times b$

l = Length of the piston base = 100mm

b = Breadth of the piston base = 120mm

$A = 100 \times 120 = 12000mm^2 = 0.012m^2$

$= 0.012m^2$

$P_a = \frac{F_t}{surface\ area}$

$= \frac{98000}{0.012}$

$= 8.167 \times 10^6 N/m^2 = 8.167 N/mm^2$

Therefore

$8.167 \times 10^6 \times 0.04 = 2 \times 430 \times 10^6 \times t$

$2546160 = 860 \times 10^6 t$

$t = \frac{326680}{860 \times 10^6}$

$t = 0.00038m = 0.38mm$

From the above calculation, the minimum cylinder thickness is 0.38mm but for safety and availability of material, a thickness of 3mm will be used for this design.

3.3.4 Calculation of Maximum Shear Stress in the cylinder

To calculate the maximum shear stress produced in cylinder.

Using the equation

$\tau_{max} = \frac{P_a d}{8t}$

Where,

d = diameter of the cylinder

P_a = pressure required for compaction

t = minimum cylinder thickness

τ_{max} = Maximum shear stress produced in the cylinder

Where, $P_a = 8.167 N/mm^2$

$d = 40mm$

$t = 3mm$

$\tau_{max} = \frac{8.167 \times 40}{8 \times 3} = 13.61\, N/mm^2$

Based on the above calculations, we can conclude that it is safe to use the parameters used in the calculation of the cylinder for fabrication since the maximum shear stress acting in the cylinder is less than the allowable shear stress.

3.3.5 Calculation of cylinder volume

The cylinders volume is calculated in order to know the value of agricultural waste that it will contain in each batch operation. It can be calculated using equation below

$V = \frac{\pi}{4} d^2 l$

Where, V = volume of cylinder

d = diameter of cylinder = 40mm

l = length of cylinder = 95mm

$\therefore \quad V = \frac{\pi \times 40^2}{4} \times 95$

$V = 119380.52mm^3$ or $1.1938052 \times 10^{-4}\ m^3$

To get the total volume of the cylinders, we multiply the value of V by four (number of cylinders)

Therefore the volume of the cylinders = $119380.52\ mm^3 \times 4 = 477522.08mm^3$

3.3.6 Determination of the Compression Ratio

Let the distance travelled by the piston to compress the briquette material to height of 50mm be "S"

Therefore, S = height of cylinder− designed height of briquette

Height of cylinder = 95mm

Designed height of briquette = 50mm

$S = 95 - 50 = 45mm$

The displacement volume (V_d) = $\frac{\pi}{4} d^2 S$

$$V_d = \frac{3.142 \times 40^2}{4} \times 45$$

$$= 56548.67mm^3$$

And total volume (V) = displacement volume (V_d) + compression volume (V_c)

$V_c = V - V_d$

$$= 119380.52 - 56548.67 = 62831.85mm^3$$

$\therefore$ Compression ratio (r_c) $= \frac{V}{V_c}$

$= \frac{119380.52}{62831.85} = 1.9$

3.3.7 Determination of Thickness of Briquette Cover

From equation

$t = \sqrt[3]{\frac{KFb^2}{E\delta^2}}$ (Khurmi and Gupta, 2008)

Where

t = thickness of the plate

k = constant depending on its length and breadth

F = concentrated load

δ = Maximum displacement

E = modulus of elasticity of the plate

$K = \frac{b}{a}$

b = breadth of the plate = 120mm

a = length of the plate = 100mm

$\therefore \quad K = \frac{120}{100} = 1.2$

If the maximum deflection $\delta = 0.3$mm (Assumed)

$E = 220 \times 10^3\ N/mm^2$ (Khurmi and Gupta)

$F = 98000N$

$$\therefore \quad t = \sqrt[3]{\frac{1.2 \times 98000 \times 120^2}{220000 \times 2^2}} = 12.44mm$$

3.3.8 Spring Design

After the compression or compaction of the briquetting material to produce briquette by the hydraulic jack through the pistons, the formed briquettes are collected at the top of the briquetting chamber by removing the briquetting chamber cover and further jack the hydraulic jack lever till the briquettes is out of the briquetting chamber.

Two helical tensile springs are used to pull back the hydraulic jack lever to its normal height or length once the hydraulic jack valve is released or opened.

Let;

The normal height of the hydraulic jack (height before jacking the lever) be = the free length of the spring = 200mm.

The maximum distance travelled by the hydraulic jack = maximum deflection of the spring = 100mm

Diameter of the spring wire (d) = 3mm (assumed)

Spring index = 5 (assumed)

3.3.8.1 Determination of Number of Active Turns of the Springs

Free length of spring = $n \times d + \delta_{max} + (n-1) \times 1$ (Khumi and Gupta)

Where

n = number of active turns

d = diameter of spring wire = 3mm

δ_{max}= maximum deflection of spring =100mm

$\therefore 200 = 3n + 100 + (n-1) \times 1$

$200 = 4n + 100 - 1$

$200 - 99 = 4n$

$$n = \frac{101}{4} = 25.25$$

Number of turns of coil = 25 turns

3.3.8.2 Determining the Mean Diameter of the Spring

Spring index = $\frac{D}{d}$ = 5

Where;

D = mean diameter of the spring

d = diameter of spring wire = 3mm

Therefore,

D = 5d

$= 5 \times 3 = 15mm$

3.3.8.3 Pitch of Coil

Pitch of coil $= \frac{free\ length}{n-1}$

$$= \frac{200}{25-1} = \frac{200}{24} = 50mm$$

Pitch of coil = 50mm

3.3.9 Power Requirement

The power required for the compression and molding of briquettes can be classified as listed below

i. Power required to compress the briquetting material.

ii. Power required to drive the hydraulic pump

The summation these different power components give the total power requirement by the machine.

Let

P_t = total power requirement of the machine

P_c = power required to compress the briquette material

P_h = power required to drive the hydraulic pump

Total power (P_t) = P_c + P_h

3.3.9.1 Power Required to Compress the Briquette Material (P_c)

P_c = W/T (Rajput, 2006)

Where

W = work done by hydraulic jack in compression

= mg × d

m = maximum load capacity of hydraulic jack 10 ton (10000kg)

d = maximum distance travelled by jack = 100mm (0.1m)

g = acceleration due to gravity = $9.8 m/s^2$

T = compressing time = 5 minutes = 300 seconds

$W = 10000 \times 9.8 \times 0.1 = 9800 Nm$

$P_c = \frac{9800}{300} = 32.67 Nm/s$

$P_c = 32.67 Nm/s$

3.3.9.2 Power Required to Drive Hydraulic Pump (P_h)

P_h = W/T

$W = F \times d$

Where;

W = work done by hydraulic jack in compression

F = minimum force applied on hydraulic pump lever = $40N$ (Assumed)

d = length of hydraulic pump lever= $0.25m$

T = compression time= 5minutes= 300 seconds

$W = 40 \times 0.25 = 10Nm$

$P_h = \frac{10}{300} = 0.033Nm/s$

$P_t = P_c + P_h$

$= 32.67 + 0.033 = 32.703 Nm/s$

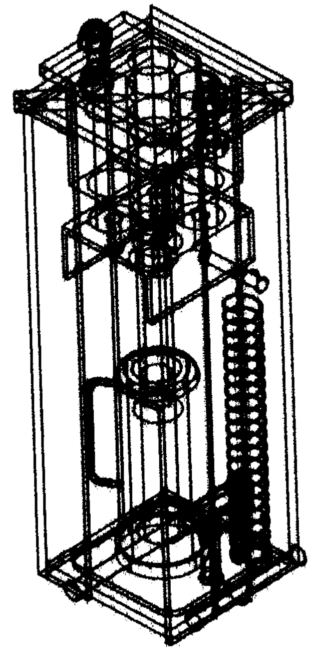
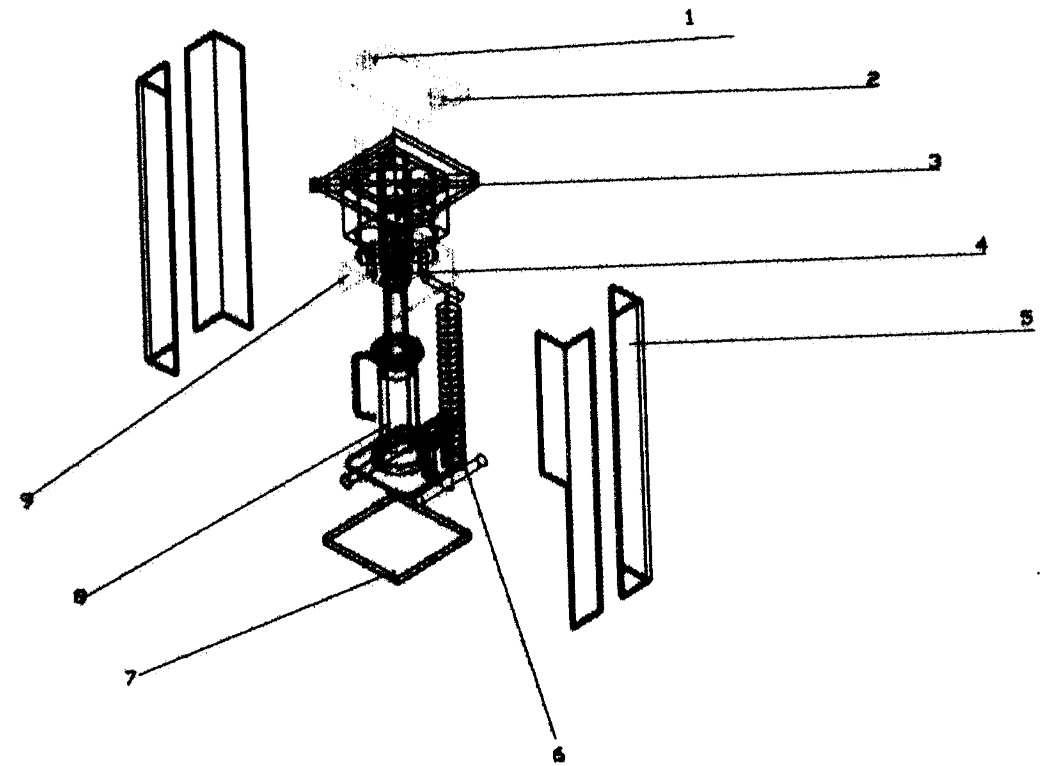


Fig. 3.1 Isometric View of Briquetting Machine

ALL DIMENSION IN MM.

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA.			
ISOMETRIC VIEW OF A BRIQUETTING MACHINE			
DRAWN BY:	[illegible] 2006/24035EA		
DESIGNED BY:	[illegible] 2006/24035EA		
CHECKED BY:	DR. [illegible]	SIGNED	
APPROVED BY:	DR. [illegible]	SIGNED	
DATE:	NOVEMBER 2011	SYMBOL	[illegible]



S/N	PART
1	[illegible]
2	TOP COVER
3	BRIQUETTING CHAMBER
4	PISTON
5	FRAME
6	SPRING
7	BASE
8	HYDRAULIC JACK
9	PISTON BASE

ALL DIMENSION IN MM.

Fig. 3.3 Exploded View of Briquetting Machine

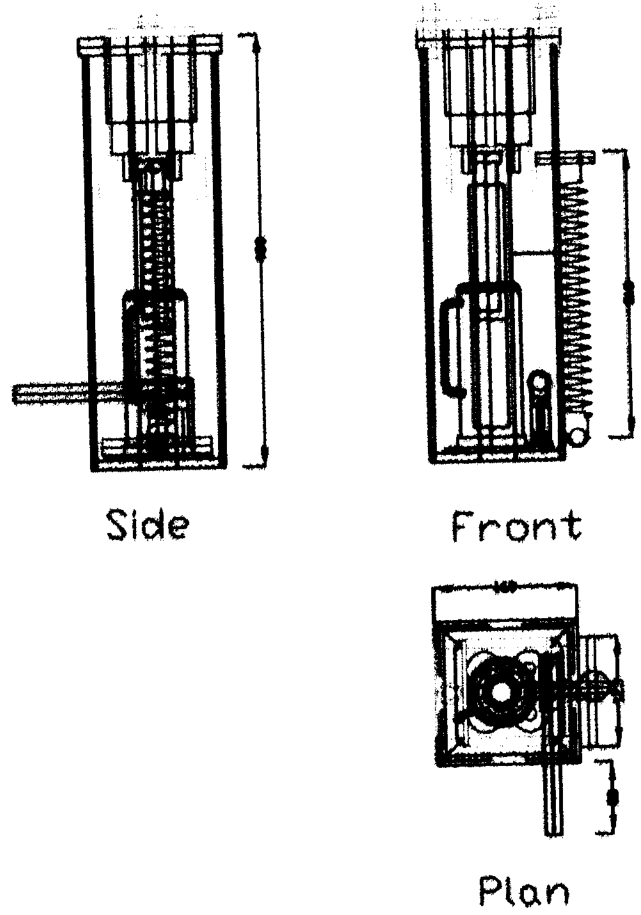
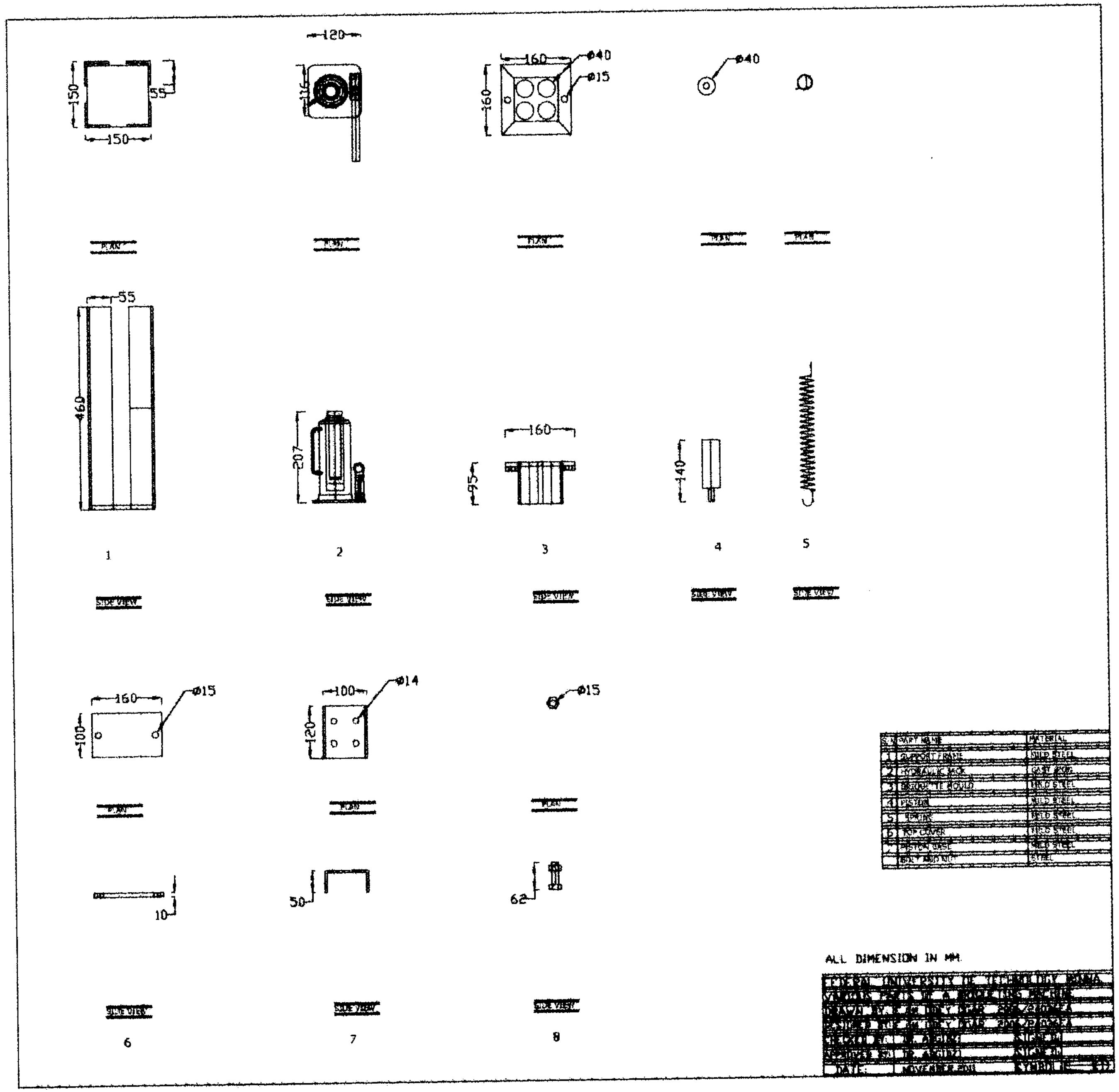


Fig. 3.4. Orthographic view of Briquetting Machine

ALL DIMENSION IN MM.

FEDERAL UNIVERSITY OF TECHNOLOGY MINNA.			
ORTHOGRAPHIC VIEW OF A BRIQUETING MACHINE			
DRAWN BY:	EJIM ODEY OGAR 2006/24036EA		
DESIGNED BY:	EJIM ODEY OGAR 2006/24036EA		
CHECKED BY:	DR. ADGIDZI	SIGNED:	
APPROVED BY:	DR. ADGIDZI	SIGNED:	
DATE:	NOVEMBER,2011	SYMBOL	



150
55
PLAN
120
116
160
Ø40
Ø15
55
460
207
95
140
1
2
3
4
5
SIDE VIEW
100
Ø14
PLAN
10
50
62
6
7
8
S/N PART NAME MATERIAL
1 SUPPORT FRAME MILD STEEL
2 HYDRAULIC JACK CAST IRON
3 BRIQUETTE MOULD MILD STEEL
4 PISTON MILD STEEL
5 SPRING MILD STEEL
6 TOP COVER MILD STEEL
7 PISTON BASE MILD STEEL
8 BOLT AND NUT STEEL
ALL DIMENSION IN MM.
DATE:

3.4 Description and Principle of Operation of the Briquetting Machine.

The manually operated briquetting machine fabricated at central workshop, FUTMinna was used for compression and molding of different agricultural by- products into a solid cylindrical shaped briquette fuel. The machine is equipped with a top cover with dimension 100mm × 160mm which is 10mm thick, the top cover has a handle with two holes on both sides which allows the bolt and nut to be screwed against the cover as shown in the diagram below, a briquetting chamber consisting of four cylinders welded close to each other and inside a rectangular metal plate, four flat bars are welded round the four cylinders at top end of the cylinders, the briquetting chamber could produce four briquettes in a batch operation, four pistons of diameter 38.5mm and length of 100mm each are fitted inside each cylinders of the briquetting chamber. This compresses the briquette materials against the briquetting chamber cover with the help of the piston base which is screwed on the top of the jack. The piston base is a "C" sectioned bar where the pistons are screwed, four angle bars on which the briquetting chamber is hanged, a hydraulic jack which is the main source of power is screwed to the base of the machine, a hand lever is attached to the jack for pumping the jack as shown in the plate below.

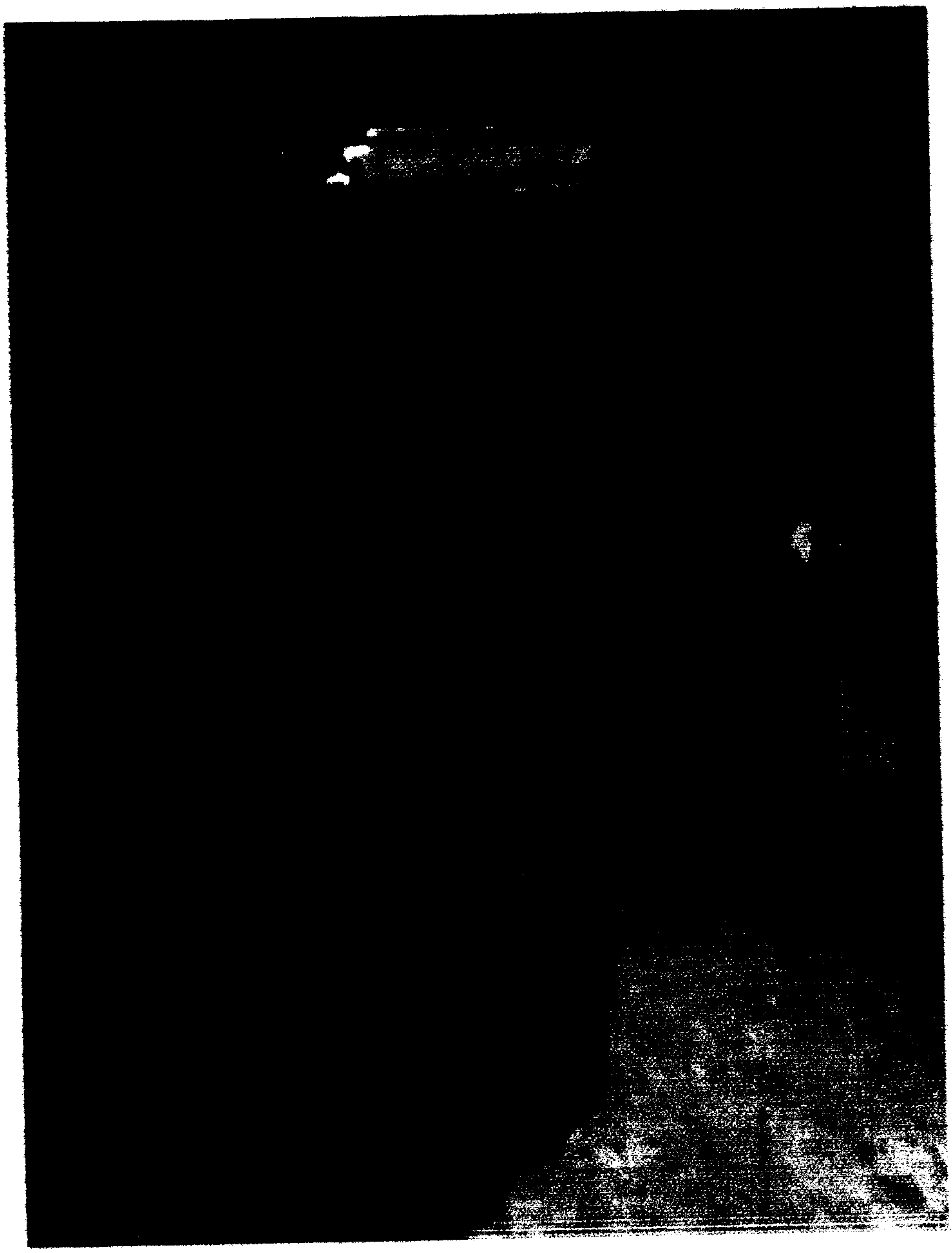


Plate 3.1: Pictoral view of the briquetting machine

3.4.1 Principle of Operation of the Machine

The agricultural by-products (briquetting materials) are fed into the briquetting chamber with the help of a funnel, the briquetting chamber is covered and screwed with the top cover, and the hydraulic jack is pumped using the hand lever. This jacks the piston up to compress the briquette material through the piston base against the top cover, the jack is pumped continuously until the hand lever can no longer move, the compressed material is allowed for 10 minutes on the machine. The top cover is unscrewed after compaction; and the formed briquette is extracted by further jacking up of the hydraulic jack after unscrewing and removing the top cover.

3.5 Material Selection

The factors that guided the material selection were:

i) The material availability

ii) The ability of the material to withstand stress without failure under the different loading conditions.

iii) The cost of the material.

iv) The ability to use the available manufacturing technology to process the materials.

3.6 Procedures for Briquetting of Cassava peels

3.6.1 List of Materials

i) Cassava peels (dry)

ii) Gum Arabic as binder

3.6.2 List of Equipments Used

i) A stopwatch was used during the experiment to record the timing of the different stages of the test

ii) Weighing balance

iii) Crucible

iv) Water bucket

v) Electric heater for boiling water

vi) Stainless pan for proper mix

vii) Hydraulic briquetting machine for compaction

viii) Aluminium cooking pot

ix) A manual compressing test machine

3.6.3 Selection of Agricultural By-Product Binder for Briquetting

Binders are substances that are suitable for holding substances or materials together by surface attachment based on their cohesive and adhesive properties. Considering the availability and combustible characteristics of gum Arabic, it was selected and used as binder in this project.

3.6.4 Procedure for Briquetting of Cassava peel (Without Binder)

Cassava peels collected from a processing plant were dried under the sun for three days. After which they were pounded to reduce the particle size. The reduced particle size was sieved, using a sieve of 1.8mm diameter to get fine particles of equal size. After which the fine particle cassava peels were weighed and fed into the four cylinders of the briquetting chamber of the fabricated hydraulically operated briquetting machine, the cylinders were filled to the brim. The four cylinders with cassava peel particles were covered with the top cover and screwed. The cassava peel particles were compressed by applying pressure on the hydraulic jack using the hand lever till it can no longer jack further. The compressed cassava peel particles were allowed to stay under pressure for 10 minutes before unbolting and removing the top cover. After compaction, the formed briquettes were collected by gradual application of pressure to the hydraulic jack to collect the briquettes at the top of the machine. The extracted briquettes were dried under sun for six days. After drying, they were packed and conveyed to the laboratory for test.

Plate 3.2 Briquettes of cassava peels without binder

3.6.5 Procedure for Briquetting of Cassava peel with Binders (Gum Arabic)

The gum Arabic was pounded and sieved to reduce the particle size, About 20 grams of the fine structured gum was dissolved in 0.2 litres of hot water at a temperature of 100°C. It was stirred vigorously to achieve uniform mix and form gum gel. The fine particle cassava peels which was sieved with a 1.8mm sieve was mixed with the gum gel at temperature range of 80°c to 100°C ; they were stirred vigorously to achieve uniform mix. The mixture was fed into the briquetting chamber of the hydraulically operated briquetting machine and compressed. After compaction, the formed briquette was collected by gradual application of pressure at the hydraulic jack. The extracted briquette was allowed to dry under sun for some days before they were conveyed to the laboratory for test.

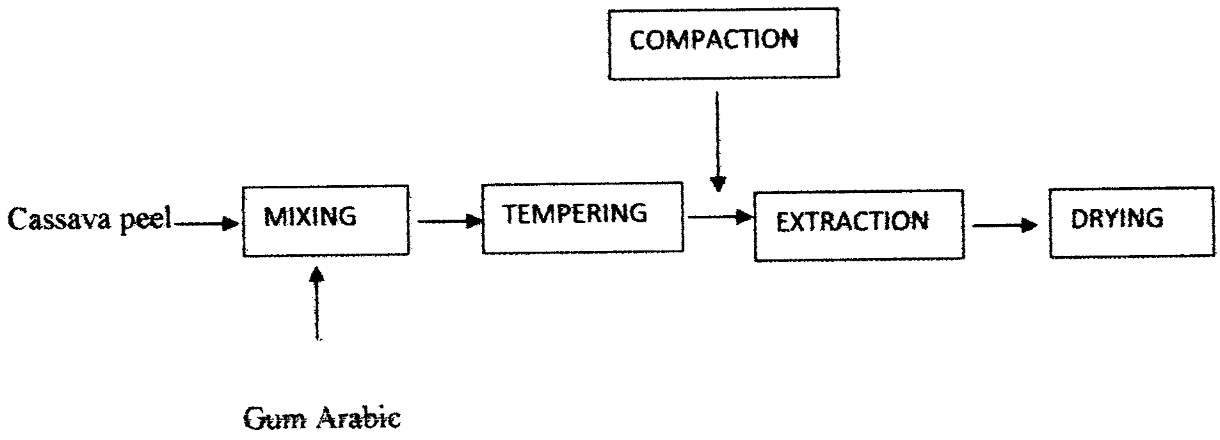


Fig.3.1: Briquette production sequence.

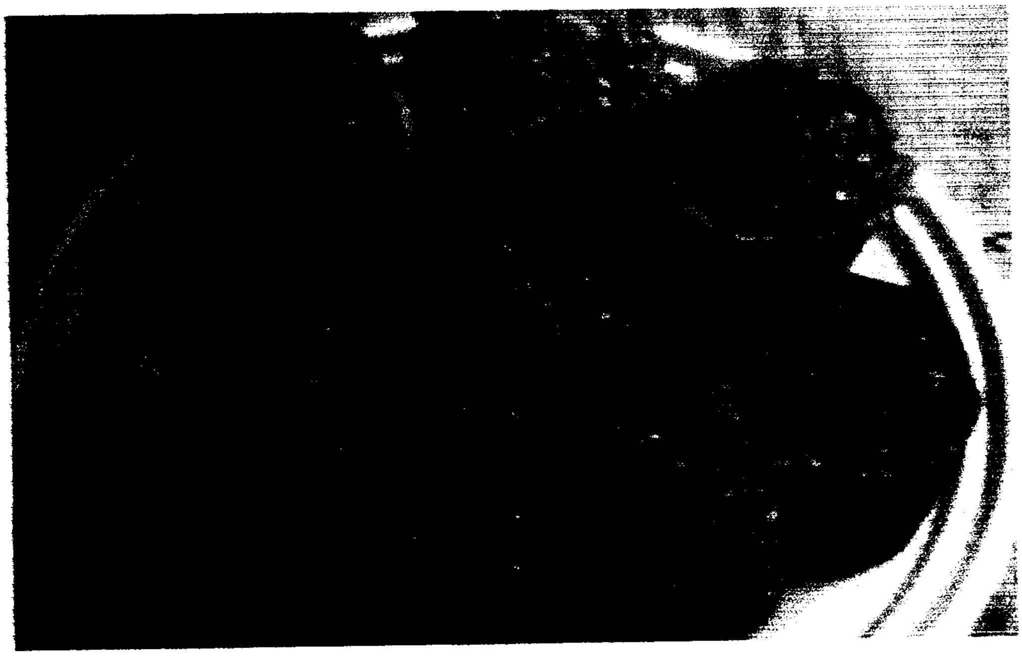


Plate 3.3: Briquettes of cassava peels with binder

3.7 Briquetting Technology Used

The briquetting technology used in this project is the hydraulic piston press technology. The biomass material or briquette material is compressed against the cover of the briquetting chamber by a piston moving up and down of which the motion is controlled by a hydraulic jack.

3.8 Test procedures of briquettes from cassava peels

3.8.1 Compressive test

The compressive strength was determined using a manual compressive test machine of weight 126kg with a model mark of C90. The machine which is hydraulically operated is equipped with a die gauge, an upper base, and a lower base with a hand lever attached to the side of the compressing machine. During the test, the samples were placed on the machine and the upper base was lowered with the aid of the hand lever so that it forces the sample against the lower base of the machine, this was continued until the sample can no longer withstand the pressure exerted on it by the upper base of the machine. The point at which the sample can no longer withstand the pressure is the point of failure. At this point the sample would either crack or divide into parts. Readings are then taken on the die gauge, which indicate the compressive strength of the sample. The readings taken are presented on table 4.3 and 4.4 for briquettes with binder and without binder respectively. Each experimental sample was replicated at least four times, this process was repeated for charcoal, fuel wood, and briquette samples and the results were subjected to simple statistical analysis.

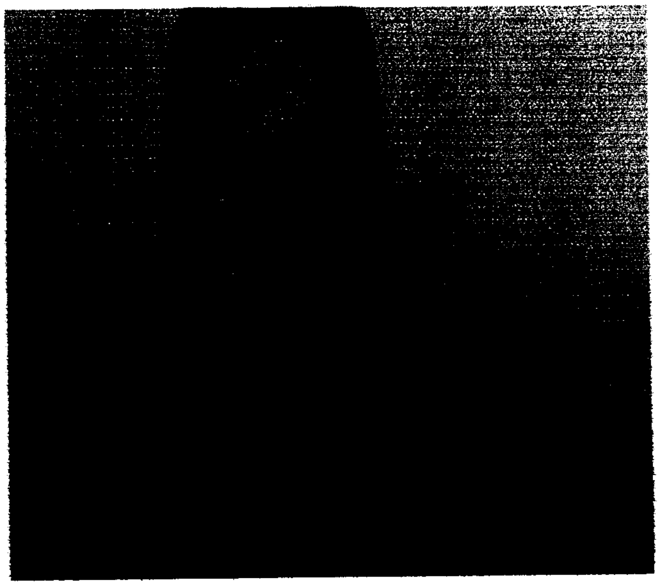


Plate 3.4: Pictorial view of the compressive test machine

3.8.2 Burning Efficiency

The burning test was carried out using the various briquettes replicates to test for the burning capacity and the burning efficiency, There are different method of water boiling test to be carried out, they are percentage Heat Utilized (PHU), Specific Fuel Consumption (SFC). The specific fuel consumption was determined by

Adekunle (2004)

$$S.F.C = \frac{Mass\ of\ briquette\ burnt}{Mass\ of\ water\ boiled}$$

$$S.F.C = \frac{Mi - Mf}{Mw - Mp}$$

Where,

M_i = initial mass of briquette before burning, (kg)

M_f = Final mass of briquette after burnt, (kg)

M_w = Mass of pot and water, (kg)

M_p = Mass of pot, (kg)

3.8.3 Moisture Content

The moisture content was determined by heating about 20g of the samples to 105°C for four hours and calculating the loss in weight as percentage. The formula given below was used to calculate the moisture content of the samples. Moisture content = $\frac{W_2 - W_3}{W_3 - W_1} X100$

Where;

W_1 = weight of container

W_2 = Weight of container + wet sample

W_3 = Weight of container + dry sample

3.8.4 Ash content

The ash content was determined by heating at 500°C about 20g (0.02kg) of the powdered sample for fifteen minutes in the muffle furnace to burn off the carbonaceous matter and for complete combustion. During the test, a container of weight 0.02569kg was labeled W_1, the weight of container plus sample before burning W_2, and the weight of container plus sample after burning W_3. The respective values were then substituted into the formula given below to calculate for the percentage ash.

Ash content = $\frac{W_3 - W_1}{W_2 - W_1} X100$

Where;

W_1 = Weight of container

W_2 = Weight of container + sample before heating

W_3 = Weight of container + sample after heating

3.8.5 Volatile matter Determined

The volatile matter was determined by heating about 20g (0.02kg) of the air dried sample exactly for 7 minutes in a crucible of weight 0.02569kg at a steady temperature of 925°C in muffle furnace. The container was labeled W_1, Weight of container plus sample before heating W_2, Weight of container plus sample after drying W_3. The loss in weight was calculated as a percentage minus percentage moisture to get the percentage volatile matter, as given in the formula below. Volatile matter = $\frac{W_3 - W_1}{W_2 - W_1} X100 - \%Moisture$

Where;

W_1 = Weight of container
W_2 = Weight of container + sample before heating
W_3 = Weight of container + sample after heating
The percentage moisture has been calculated in the previous section.

3.8.6 Carbon content

The sum total of the percentages of the volatile matter, moisture and ash subtracted from hundred gives the percentage of fixed carbon.

Carbon content = 100 – (%volatile matter + %moisture + %ash)

3.8.7 Calorific value

The calorific value of a fuel is the amount of energy liberated by burning a unit mass. It is one of the important properties of a fuel on which its efficiency is judged. During this test, the moisture content, volatile matter, and ash content of the samples were determined in Mechatronics Laboratory II of Agricultural and Bio-resources Engineering Department. The moisture content was determined by heating a known mass of the air dried samples to 105°C for four hours in the oven and calculating the loss in weight as percentage. The volatile matter was determined by heating a known mass of the air dried sample exactly for seven minutes in a silica crucible at a steady temperature of 925°C in a muffle furnace. The loss in weight calculated as percentage minus percentage moisture gives the percentage volatile matter. The ash content was determined by heating at 500°C about 20g of the powdered sample for fifteen minutes in the muffle furnace to burn off the carbonaceous matter and observing when the colour turns completely black for complete combustion. The weight of the residue remaining in the crucible corresponds to the ash content of the sample, which is reported on percentage basis. The sum total of the percentages of volatile matter, moisture and ash subtracted from hundred gives the percentage of fixed carbon. The percentage carbon was substituted into the formula given below to calculate the calorific value of the samples.

According to Gouthal (1989)

Calorific value = $147.6C + aV$ (Gouthal, 1989)

Where;

C = % of carbon

V = Volatile matter

a = Constant depending on V

Table 3.1 shows Test procedure for cassava peels briquettes

Table 3.1: Test Procedure for cassava peels briquette

Test	Heat Treatment	Duration	Temperature	Description
Moisture content	Oven dried	4 hours	105°C	The weight of crucible and Briquette samples were taken and recorded W_1 and W_2 respectively. Briquette samples were placed inside a crucible and left inside the oven for the time duration. After which it was brought out and weighed W_3.The loss in weight is calculated as percentage.
Ash Content	Muffle furnace	15mins	500°C	Crucible was weighed and recorded W_1. About 20g of the sample was presented in powdered form. Crucible plus sample was weighed and recorded W_2. It was heated to burn of the carbonaceous matter. After which it was brought out and weighed W_3. The weight of the residue remaining in the crucible is the ash content reported on percentage basis.

Volatile matter	muffle furnace	7mins	925°C	about 20g of the sample was Presented in powdered form crucible was weighed and recorded W_1.crucible plus sample was weighed and recorded W_2. It was heated at specified temperature. The loss in weight was calculated as percentage subtracted from percentage moisture.
Combustion test	briquette-fuelled furnace	4:15secs	100°C	The combustion test was carried out by determining the specific fuel consumption. Briquette sample before burn-ing was weighed and recorded M_i. The weight of pot was Taken and recorded M_p. About 0.5litres of water plus mass of pot was taken and recorded M_w. The values were then substituted into formula to get the specific fuel consumption.
Carbon content	-	-	-	The sum total of the per-centages of volatile matter, moisture and ash subtracted

				from hundred gives the percentage of fixed carbon.
Calorific value	-	-	-	The calorific value was determined by substituting known values of percentage carbon and volatile matter into the following equation given by Gouthal, calorific value = 147.6C + aV
Compressive test	-	-	-	During the test, the samples were placed on the compressive machine and the upper base was lowered with the aid of the hand lever so that it forces the sample against the lower base of the machine. This was continued until the sample can no longer withstand the pressure exerted on it by the upper base of the machine. At this point, the sample would either crack or divide into parts. Readings are then taken on the die gauge, which indicate the compressive strength of the sample.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Result

The mass of briquette with binder and mass of briquette without binder before burning and after burnt are shown in table 4.1 and table 4.2 respectively.

Table 4.1: The Mass of Briquette with binder before burning and mass of briquette after burnt.

Sample No.	Mass of briquette before burning (kg)					Mass of briquette after burnt (kg)				
	Y_1	Y_2	Y_3	Y_4	$\bar{Y}$	Y_1	Y_2	Y_3	Y_4	$\bar{Y}$
1	0.09384	0.09379	0.09438	0.09388	0.09397	0.089	0.090	0.089	0.087	0.089
2	0.09345	0.09334	0.09337	0.09335	0.09338	0.087	0.086	0.087	0.090	0.088
3	0.08957	0.08954	0.08956	0.08955	0.08956	0.080	0.085	0.082	0.086	0.083

Table 4.2: The Mass of briquette without binder before burning and mass of briquette after burnt

Sample No.	Mass of briquette before burning (kg)					Mass of briquette after burning (kg)				
	Y_1	Y_2	Y_3	Y_4	$\bar{Y}$	Y_1	Y_2	Y_3	Y_4	$\bar{Y}$
1	0.04802	0.04795	0.04810	0.04806	0.04803	0.044	0.042	0.040	0.043	0.042
2	0.04974	0.04968	0.04970	0.04972	0.04971	0.042	0.043	0.045	0.043	0.043
3	0.04992	0.04981	0.04990	0.04994	0.04991	0.046	0.044	0.045	0.043	0.044

The Physical, mechanical and chemical properties of briquettes with binder and without binder are shown in Table 4.3 and 4.4 respectively

Table 4.3(a): Physical, mechanical and chemical properties of briquettes with binder

Sample	Ash content (%)					Carbon content (%)					Calorific Value (Kcal/Kg)				
No.	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$
1	3.6	3.5	3.6	3.4	3.5	86.5	86.8	86.5	87.3	86.8	7748.4	7762.6	7745.5	7803.6	7765.03
2	3.5	3.8	3.5	3.6	3.6	87.7	87.6	88.1	87.7	87.8	7764.2	7738.2	7776.4	7776.4	7763.8
3	3.9	3.6	3.8	3.6	3.7	86.7	87.7	86.4	86.9	86.9	7769.4	7746.4	7744.8	7770.8	7757.9

Table 4.3(b): Physical, mechanical and chemical properties of briquettes with binder

Sample	Volatile matter (%)					Compressive test (KN)					Moisture content (%)				
No.	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$
1	4.3	4.5	4.3	4.3	4.4	84	75	80	82.5	80.4	5.5	4.9	5.5	5.4	5.3
2	3.6	3.7	3.9	3.7	3.7	82	78.5	80.5	90	82.5	4.7	4.9	5.0	4.9	4.9
3	4.4	4.3	3.7	4.5	4.2	85	70	85	95	83.8	5.2	4.8	5.3	5.2	5.1

Table 4.4(a): Physical, mechanical and chemical properties of briquettes without binder

Sample	Ash content (%)					Carbon content (%)					Calorific Value (Kcal/Kg)				
No.	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$
1	5.9	6.0	5.9	5.8	5.9	86.5	86.9	86.8	86.6	86.7	8061.2	7590.8	7582.6	7611.2	7711.45
2	6.2	5.9	5.8	5.9	6.0	85.2	85.5	85.1	85.4	85.3	7541.4	7566.0	7563.2	7587.8	7564.6
3	5.9	6.1	5.9	6.3	6.1	83.1	83	85.2	82.4	83.4	7525.3	7531.0	7541.4	7553.7	7537.9

Table 4.4(b): Physical, mechanical and chemical properties of briquettes without binder

Sample	Volatile matter (%)					Compressive test (KN)					Moisture content (%)				
No.	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$	Y_1	Y_2	Y_3	Y_4	$\hat{Y}$
1	3.1	3.2	3.4	3.1	3.2	80	85.5	65	75	76.4	4.2	4.1	4.3	4.2	4.2
2	3.7	3.9	3.7	3.9	3.8	75	60	80.5	65	70.1	4.9	5.0	4.9	5.1	5.0
3	5.0	3.7	5.1	5.3	4.8	75	60	75	78.5	72.1	6.2	4.8	5.9	6.1	5.8

The Physical, mechanical and chemical properties of Shea butter wood and charcoal are shown on table 4.5 and 4.6 respectively,

Table 4.5: Physical, machanical and chemical properties of fuelwood (Shea butter)

Batch No.	Moisture content (%)	Carbon content (%)	Ash content (%)	Compressive test (%)	Volatile matter (%)	Calorific value (Kcal/Kg)	Burning efficiency
Y_1	5.0	80.0	3.0	55	5.0	7400	0.0279
Y_2	6.5	79.6	4.8	50	6.4	7485	0.0478
Y_3	5.3	82.3	3.6	65	4.8	8315	0.0492
Y_4	6.0	85.5	3.5	65	5.0	7600	0.0550
$\bar{Y}$	5.7	81.85	3.7	75	5.3	7700	0.0449

Table 4.6: Physical, mechanical and chemical properties of charcoal (Shea butter)

Batch No.	Moisture content (%)	Carbon content (%)	Ash content (%)	Compressive test (%)	Volatile matter (%)	Calorific value (Kcal/Kg)	Burning efficiency
Y_1	5.0	82.0	5.0	20	4.8	8500	0.0586
Y_2	5.3	80.5	5.8	20	4.5	8544	0.0489
Y_3	4.5	80.0	6.0	20	5.0	8603	0.0934
Y_4	4.8	84.5	5.3	20	4.4	8540	0.0942
$\bar{Y}$	4.9	81.8	5.5	20	4.7	8547	0.0738

4.1.1 Material and Labour cost

The cost of a component is usually influenced by its component design, manufacturing techniques and method and the material used in making the component. The cost of fabrication of the machine is grouped into three, namely:

i. Material cost

ii. Labour cost

iii. Overhead cost

4.1.2 Material cost

The material cost is tabulated below.

Table 4.7 Breakdown of the material cost

s/no	Material/Part	Quantity	Unit Price(₦)	Amount(₦)
1.	75× 75 × 5mm Angle bar	4	300	1200
2.	"C" sectioned bar	2	500	1000
3.	40mm pipe, 95mm in length	4	125	500
4.	38.5mm hollow shaft, 100mm in length.	4	300	1200
5.	15mm shaft, 120mm in length.	4	200	800
6.	Bolt & nuts	2	350	700
7.	Spring	1	500	500
8.	10 tons hydraulic jack	1	3500	3500
9.	Flat bar	1	1200	1200
10.	6mm flat plate	1	300	300
Total				**10900**

4.1.3 Labour cost

Labour cost involves the cost of the machining, cutting, welding and painting. It is taken as 20% of the material cost.

Therefore,

Labour cost = $\frac{20}{100} \times 10900 =$ ₦2180

4.1.4 Overhead cost

The overhead cost includes cost incurred during construction such as transportation, lubrication, as well as other consumables. It is taken at 20% of the material cost.

Overhead cost = $\frac{20}{100} \times 10900 =$ ₦2180

Therefore the total cost = 10900 + 2180 + 2180 = ₦15260

4.1.5 Cost of Producing Briquette

The briquettes were produced using the fabricated briquetting machine, cassava peel and gum Arabic as binder. The machine produces four briquettes in a batch production within 30 minutes, in an hour; the machine will produce eight briquettes.

If the briquetting machine works for 10 hours in a day, it will produce a total of $8 \times 10 = 80$ briquettes/day. If the machine has a life span of 10 years (120 months), therefore, about = $\frac{15260}{120} =$ ₦127.17 of the machine is consumed every month

Table 4.8 shows the list, quantity and cost of the inputs needed for the production of briquettes using the fabricated briquetting machine for a month (30 days)

Table 4.8 Breakdown of production cost of briquette/month

INPUTS	QUANTITY	UNIT COST (₦)	COSTS (₦)
Materials:			
• Cassava peel	10 bags	200	2000.00
• Gum Arabic	7.5 mudus	700	5250.00
Equipment (Briquetting machine)	1 machine	15260	127.17
Direct Labour	A worker	10000	10000.00
Overheads			5000.00
TOTAL COST OF PRODUCTION			**22377.17**

Therefore

Total cost of production per month = ₦22377.17

Total cost of producing 80 briquettes per day = $\frac{22377.17}{30}$ = ₦745.91

Total cost of producing a briquette = $\frac{745.91}{80}$ = ₦9.32

Therefore, price tag for a briquette is ₦10

4.1.6 Material Selection

The choice of a particular material depends on the materials that meet design specifications which were obtained from calculations, the following factors were taken into consideration when selecting the materials;

- **Material properties:** The yield strength of the material selected must correspond to or be greater than that used in the design analysis and calculations.
- **Deteriorative properties:** Such as resistance to oxidation, corrosion or weathering were also considered and are taking care of by painting of the finished work.
- **Manufacturing characteristics:** This includes the material ability to be welded and machined, as most joints are to be made by welding.
- **Cost:** Material cost and manufacturing cost were considered. Relatively cheap materials when compared to other engineering materials that meet the design constraints were considered during selection.
- **Aesthetic properties:** Considering these parameters listed above and the design calculations done, mild steel plates were used for the base plate, pressure plate, top plate and other components were made from mild steel.

4.1.7 Statistical analysis for Physical, mechanical and chemical properties of briquettes with binder

The physical, mechanical and chemical properties of briquettes with binder were presented in table 4.3. The moisture content, carbon content and volatile matter showed statistical significant difference ($P<0.05$) while compression strength, calorific value, ash content and combustion test did not show any significant difference ($P<0.05$). The compressive strength of the briquette with binder ranged from 78.750 – 80.375kN. The lowest compressive strength of briquette was 78.750kN while the highest compressive strength was 80.375kN and the grand mean was 79.625kN. The moisture content of the briquette with binder ranged from 4.850% – 5.325%. The moisture content of briquette was lowest at sample 2 which was 4.850%, the highest moisture content of the briquette with binder was 5.325%. The combustion test for briquette with binder ranged from 0.055 – 0.059. The lowest combustion test was 0.055, while the highest combustion test value was 0.059. The ash content of the briquette with binder ranged from 3.525% – 3.725%. The lowest ash content was 3.525%, while the highest ash content value was 3.725%. The carbon content of the briquette with binder ranged from 86.800% – 87.775%. The lowest carbon content was 86.800%, while the highest carbon content value was 87.775%. The volatile matter of briquette with binder ranged from 3.775% – 4.350%. The volatile matter of the briquette with binder was lowest in sample 2 which was 3.775% while the highest volatile matter was recorded at 4.350%. The calorific value for briquette with binder ranged from 7757.850Kcal/Kg – 7777.525kcal/kg. The lowest calorific value was 7757.850kcal/kg at sample 3 while the highest calorific value was 7777.525kcal/kg.

Table 4.7: **Statistical analysis for Physical, mechanical and chemical properties of briquettes with binder**

Samples	Compressive test (KN)	Moisture Content(%)	Combustion Test	Ash Content(%)	Carbon content (%)	Volatile Matter(%)	Calorific Value (Kcal/Kg)
sample 1	$80.375^{a}\pm1.97$	$5.325^{a}\pm0.14$	$0.055^{a}\pm0.01$	$3.525^{a}\pm0.05$	$86.800^{a}\pm0.18$	$4.350^{a}\pm0.05$	$7777.525^{a}\pm13.14$
sample 2	$79.750^{a}\pm0.92$	$4.850^{a}\pm0.05$	$0.059^{a}\pm0.01$	$3.600^{a}\pm0.07$	$87.775^{a}\pm0.11$	$3.775^{b}\pm0.08$	$7763.800^{a}\pm9.00$
sample 3	$78.750^{a}\pm3.75$	$5.150^{ab}\pm0.11$	$0.055^{a}\pm0.01$	$3.725^{a}\pm0.08$	$86.925^{b}\pm0.28$	$4.200^{a}\pm0.17$	$7757.850^{a}\pm7.09$
Grand mean	79.625 ± 1.32	5.108 ± 0.08	0.056 ± 0.00	3.617 ± 0.04	87.167 ± 0.16	4.108 ± 0.09	7766.392 ± 5.82

Mean ± Standard error mean (S.E.M)

a, b, c Mean values in the same column followed by different superscript are significantly different from one another ($P<0.05$)

4.1.8 Statistical analysis for Physical, mechanical and chemical properties of briquettes without binder

The physical, mechanical and chemical properties of briquettes without binder were presented in table 4.8 The moisture content, carbon content and volatile matter showed statistical significant difference ($P<0.05$). The compression strength, calorific value, ash content and combustion test did not show any significant difference ($P<0.05$). The compressive strength of the briquette without binder ranged from 70.125KN – 76.375kN. The lowest compressive strength of briquette was 70.125kN while the highest compressive was 76.375kN and the grand mean of compressive strength was 72.875kN. The moisture content of the briquette without binder ranged from 4.175% – 5.750%. The moisture content of briquette was lowest at sample 1 which was 4.175%, the highest moisture content of the briquette without binder was 5.750%. The combustion test for briquette without binder ranged from 0.055% – 0.058%. The lowest combustion test was 0.055%, while the highest combustion test value was 0.058%. The ash content of the briquette without binder ranged from 5.900% – 6.050%. The lowest ash content was 5.900%, while the highest ash content value was 6.050%. The carbon content of the briquette without binder ranged from 83.425% – 87.775%. The lowest carbon content was 83.425%, while the highest carbon content value was 87.775%. The volatile matter of briquette without binder ranged from 3.200% – 4.775%. The volatile matter of the briquette without binder was lowest in sample 1 which was 3.200% while the highest volatile matter recorded was 4.775%. The calorific value for briquette without binder ranged from 7537.850kcal/kg 7711.450kcal/kg. The lowest calorific value was 7537.850kcal/kg at sample 3 while the highest calorific value was 7711.450kcal/kg.

Table 4.8: **Statistical analysis for Physical, mechanical and chemical properties of briquettes without binder**

Samples	Compressive test (KN)	Moisture Content(%)	Combustion Test	Ash Content(%)	Carbon content(%)	Volatile Matter(%)	Calorie Value (Kcal/Kg)
Sample 1	$76.375^{a}\pm4.36$	$4.175^{c}\pm0.03$	$0.058^{a}\pm0.01$	$5.900^{a}\pm0.04$	$86.775^{a}\pm0.15$	$3.200^{b}\pm0.71$	$7711.450^{a}\pm1.17$
Sample 2	$70.125^{a}\pm4.66$	$4.950^{b}\pm0.05$	$0.055^{a}\pm0.01$	$5.950^{a}\pm0.09$	$85.300^{b}\pm0.09$	$3.800^{b}\pm0.05$	$7564.600^{a}\pm9.49$
Sample 3	$72.125^{a}\pm4.13$	$5.750^{a}\pm0.32$	$0.054^{a}\pm0.01$	$6.050^{a}\pm0.10$	$83.425^{c}\pm0.61$	$4.775^{a}\pm0.36$	$7537.850^{a}\pm6.25$
Grand Mean	$72.875^{a}\pm2.42$	4.958±0.21	0.056±0.00	5.967±0.04	85.167±0.44	3.925±0.22	7604.633±13.19

a, b, c Mean values in the same column followed by different superscript are significantly different from one another ($P<0.05$)

Mean ± Standard error mean (S.E.M)

4.2 DISCUSSION OF RESULT

The results of the moisture content for briquette with binder and without binder were 5.108% and 4.958% respectively. The moisture content were in agreement or close to the value (5.7% and 4.9%) obtained from the control samples, Shea butter wood and charcoal respectively. The results of the volatile matter presented in Table 4.7 and Table 4.8 show that briquette bonded with gum Arabic type and briquette without binder had a marked effect on the volatile matter of briquettes with P values of 0.002 and 0.013 respectively (Appendix I). The percentage volatile matter in gum Arabic bonded briquettes was higher than that obtained in briquettes without binder. The volatile matter of gum Arabic bonded briquette increased from 3.775% to 4.775%, while it increased from 3.200% to 4.350% in briquette without binder. The values for volatile matter in briquette with binder and briquette without binder of different samples (i.e. sample 1 – 3) were close to the values (5.3% and 4.7%), which are values obtained from Shea butter wood and charcoal respectively, Although, some of the values obtained in this research fall within the 3.500% – 9.8% range obtained in briquettes produced with binder and without binder. In terms of quality specification, the low volatile matter recorded implies that the briquettes might not be easy to ignite, but once ignited they will burn smoothly with clean flame without smoke. The fuels related to smokeless grade are known to contain no more than 20% volatile substances (Ivanov *et al.*, 2003).

The percentage carbon content in gum Arabic bonded briquettes was slightly higher than in briquettes without binder, with mean values of 87.167% and 85.167% respectively (Table 4.7 and 4.8) these carbon content values were almost the same with carbon content of Shea butter wood and charcoal with values of 81.9% and 81% respectively. The highest percentage carbon content of 87.775% was obtained when the cassava peel and gum Arabic blended in sample 2 which was in contrast to 86.775% obtained in briquettes without binder. The difference in value obtained could be attributed to the difference in compressed densities and compressive strength of the two briquette types. Nevertheless, the percentage carbon content obtained was within the 84.7% - 90.9% range obtained in briquettes with binder and without binder. It is expected that the high percentage of carbon content and its smokeless flame will enhance the heat value and combustion duration of the briquette. When the percentage ash content of the briquettes was considered, it was discovered that the type of binder used does not significantly influence the ash content of the briquette (P = 0.149) Appendix I and it was close to the value obtained from Shea butter charcoal (P value of 0.144). The ash content of 5.967% obtained in briquette without binder was higher than the 3.617% value obtained in gum Arabic-binded briquette. The lowest ash content in gum Arabic and briquettes without binder were obtained in both samples 1 of with binder and without binder briquettes. The low ash recorded is a reflection of the high heating value obtained in the two briquette types. Similar low percentage ash content has been reported for briquettes from oil palm biomass (Nasrin *et al.*, 2008) and briquettes from lignite with biobinders (Ivanov *et al.*, 2003). Ash content in the briquette normally causes an increase in the combustion remnant in the form of ash, thereby lowering the heating effect of the briquette.

The grand mean combustion test was 0.056% and 0.056% for briquettes with binder and briquettes without binder respectively. These combustion test values were close to the values obtained from Shea butter wood and charcoal which are 0.0449 And 0.0738 respectively . The central hole in the centre of cylindrical briquettes provides an insulated combustion zone resulting in less heat transfer by radiation to the surroundings from this surface. This produces higher temperatures within the hole compared to the outer briquette surface which is in contact with the atmosphere. The steeper temperature gradients result in an increased rate of heat transfer into the solid at this surface, a heat wave moves inside the solid,

rapidly increasing its temperature. The result is a faster rate of pyrolysis compared to the outer briquette surface which is exposed to the atmosphere. This increased rate in pyrolysis in the central hole region compared to the outer surface explains the deviation of the burn rate cylindrical briquettes (Chaney *et al.*, 2007).

Calorific value is one of the most important combustion properties for determining the suitability of a material as fuel. It gives the indication of the quantity of fuel required to generate a specific amount of energy. The summation of the previous tests was reflected in the heating value. The slightly higher heating value of 7766.392Kcal/kg obtained in gum Arabic bonded briquette compared to 7604.63Kcal/kg obtained in briquette without binder. This could be attributed to its higher compressed density, volatile matter, carbon content and low ash content. Variation in briquettes with binder and without binder was discovered to significantly influence the heating values of the briquettes. These values were almost closed to 7700Kcal/kg obtained in Shea butter wood. In terms of quality specification, this shows that an excellent fuel briquette can be produced from the cassava peel and the fact that the materials used *i.e.* the press, mould and binders are cheap and require low technology, and make the production cost-effective.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The physical, mechanical and chemical properties of the briquettes were found to be influenced by the binder used. In terms of quality specification, the gum Arabic bonded briquette was better than unbounded briquettes. The results obtained on the physical, mechanical and chemical properties show that both binder types can produce high quality charcoal briquette with high durability rating and heating value. The moisture content, carbon content and volatile matter showed statistical significant difference ($P<0.05$) while compression strength, caloric value, ash content and combustion test did not show any significant difference ($P<0.05$).

5.2 RECOMMENDATION

For further research work on this project, the following recommendations are important;

1. It is recommended that other source of powering the machine should be explored and considered.
2. That different binders should be used in the production of briquettes as this may improve the fuel quality of the briquettes.
3. That different sizes and shape of briquettes should be considered to get better surface area and therefore make the drying process faster.

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APPENDICES

APPENDIX I

Statistical Analysis of briquettes with binder and without binder

ANOVA for Briquette with binder

Oneway

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
ompr_stre gth	1	4	80.3750	3.94493	1.97247	74.0977	86.6523	75.00	84.00
	2	4	79.7500	1.84842	.92421	76.8087	82.6913	78.00	82.00
	3	4	78.7500	7.50000	3.75000	66.8158	90.6842	70.00	85.00
	Total	12	79.6250	4.58320	1.32305	76.7130	82.5370	70.00	85.00
loisture	1	4	5.3250	.28723	.14361	4.8680	5.7820	4.90	5.50
	2	4	4.8500	.10000	.05000	4.6909	5.0091	4.70	4.90
	3	4	5.1500	.23805	.11902	4.7712	5.5288	4.80	5.30
	Total	12	5.1083	.28749	.08299	4.9257	5.2910	4.70	5.50
ombustion	1	4	.055100	.0202270	.0101135	.022914	.087286	.0300	.0744
	2	4	.058650	.0167433	.0083716	.032008	.085292	.0345	.0732
	3	4	.055400	.0182598	.0091299	.026345	.084455	.0357	.0755
	Total	12	.056383	.0167866	.0048459	.045718	.067049	.0300	.0755
sh_conten	1	4	3.5250	.09574	.04787	3.3727	3.6773	3.40	3.60
	2	4	3.6000	.14142	.07071	3.3750	3.8250	3.50	3.80
	3	4	3.7250	.15000	.07500	3.4863	3.9637	3.60	3.90
	Total	12	3.6167	.14668	.04234	3.5235	3.7099	3.40	3.90
arbon_co ent	1	4	86.8000	.35590	.17795	86.2337	87.3663	86.50	87.30
	2	4	87.7750	.22174	.11087	87.4222	88.1278	87.60	88.10

	3	4	86.9250	.55603	.27801	86.0402	87.8098	86.40	87.70
	Total	12	87.1667	.58049	.16757	86.7978	87.5355	86.40	88.10
olatile_matter	1	4	4.3500	.10000	.05000	4.1909	4.5091	4.30	4.50
	2	4	3.7750	.15000	.07500	3.5363	4.0137	3.60	3.90
	3	4	4.2000	.33665	.16833	3.6643	4.7357	3.70	4.40
	Total	12	4.1083	.32322	.09330	3.9030	4.3137	3.60	4.50
alorie	1	4	7.7775E3	26.29339	13.14670	7735.6863	7819.3637	7748.40	7803.60
	2	4	7.7638E3	18.00963	9.00481	7735.1427	7792.4573	7738.20	7776.40
	3	4	7.7578E3	14.17169	7.08584	7735.2997	7780.4003	7744.80	7770.80
	Total	12	7.7664E3	20.14513	5.81540	7753.5921	7779.1913	7738.20	7803.60

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Compr_strength	Between Groups	5.375	2	2.688	.107	.900
	Within Groups	225.688	9	25.076		
	Total	231.062	11			
Moisture	Between Groups	.462	2	.231	4.642	.041
	Within Groups	.447	9	.050		
	Total	.909	11			
Combustion	Between Groups	.000	2	.000	.045	.956
	Within Groups	.003	9	.000		
	Total	.003	11			
Ash_content	Between Groups	.082	2	.041	2.371	.149
	Within Groups	.155	9	.017		
	Total	.237	11			
Carbon_content	Between Groups	2.252	2	1.126	6.964	.015
	Within Groups	1.455	9	.162		
	Total	3.707	11			
Volatile_matter	Between Groups	.712	2	.356	7.320	.013
	Within Groups	.437	9	.049		
	Total	1.149	11			
Calorie	Between Groups	814.512	2	407.256	1.004	.404
	Within Groups	3649.578	9	405.509		
	Total	4464.089	11			

Post Hoc Tests

Homogeneous Subsets

Compr_strength

Duncan

Factor	N	Subset for alpha = 0.05 1
3	4	78.7500
2	4	79.7500
1	4	80.3750
Sig.		.671

Means for groups in homogeneous subsets are displayed.

Moisture

Duncan

Factor	N	Subset for alpha = 0.05 1	2
2	4	4.8500	
3	4	5.1500	5.1500
1	4		5.3250
Sig.		.090	.296

Means for groups in homogeneous subsets are displayed.

Combustion

Duncan

Factor	N	Subset for alpha = 0.05
		1
1	4	.055100
3	4	.055400
2	4	.058650
Sig.		.801

Means for groups in homogeneous subsets are displayed.

Ash_content

Duncan

Factor	N	Subset for alpha = 0.05
		1
1	4	3.5250
2	4	3.6000
3	4	3.7250
Sig.		.069

Means for groups in homogeneous subsets are displayed.

Carbon_content

Duncan

Factor	N	Subset for alpha = 0.05	
		1	2
1	4	86.8000	
3	4	86.9250	
2	4		87.7750
Sig.		.671	1.000

Means for groups in homogeneous subsets are displayed.

Volatile_matter

Duncan

Factor	N	Subset for alpha = 0.05	
		1	2
2	4	3.7750	
3	4		4.2000
1	4		4.3500
Sig.		1.000	.361

Means for groups in homogeneous subsets are displayed.

Calorie

Duncan

Factor	N	Subset for alpha = 0.05
		1
3	4	7757.8500
2	4	7763.8000
1	4	7777.5250
Sig.		.219

Means for groups in homogeneous subsets are displayed.

ANOVA for Briquette without binder

Oneway

Descriptives

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
ompr_str ngth	1	4	76.3750	8.71182	4.35591	62.5125	90.2375	65.00	85.50
	2	4	70.1250	9.31285	4.65642	55.3062	84.9438	60.00	80.50
	3	4	72.1250	8.25000	4.12500	58.9974	85.2526	60.00	78.50
	Total	12	72.8750	8.38593	2.42081	67.5468	78.2032	60.00	85.50
oisture	1	4	4.1750	.05000	.02500	4.0954	4.2546	4.10	4.20
	2	4	4.9500	.10000	.05000	4.7909	5.1091	4.90	5.10
	3	4	5.7500	.64550	.32275	4.7229	6.7771	4.80	6.20
	Total	12	4.9583	.75373	.21758	4.4794	5.4372	4.10	6.20
ombustio	1	4	.057900	.0171569	.0085785	.030600	.085200	.0402	.0804
	2	4	.054600	.0148459	.0074229	.030977	.078223	.0374	.0672
	3	4	.054125	.0130531	.0065265	.033355	.074895	.0390	.0692
	Total	12	.055542	.0137816	.0039784	.046785	.064298	.0374	.0804
sh_conte	1	4	5.9000	.08165	.04082	5.7701	6.0299	5.80	6.00
	2	4	5.9500	.17321	.08660	5.6744	6.2256	5.80	6.20
	3	4	6.0500	.19149	.09574	5.7453	6.3547	5.90	6.30
	Total	12	5.9667	.15570	.04495	5.8677	6.0656	5.80	6.30
arbon_co ent	1	4	86.7250	.15000	.07500	86.4863	86.9637	86.60	86.90
	2	4	85.3000	.18257	.09129	85.0095	85.5905	85.10	85.50
	3	4	83.4250	1.22304	.61152	81.4789	85.3711	82.40	85.20

	Total	12	85.1500	1.55417	.44865	84.1625	86.1375	82.40	86.90
latile_mer	1	4	3.2000	.14142	.07071	2.9750	3.4250	3.10	3.40
	2	4	3.8000	.11547	.05774	3.6163	3.9837	3.70	3.90
	3	4	4.7750	.72744	.36372	3.6175	5.9325	3.70	5.30
	Total	12	3.9250	.78291	.22601	3.4276	4.4224	3.10	5.30
lorie	1	4	7.7114E3	233.47653	1.16738	7339.9367	8082.9633	7582.60	8061.20
	2	4	7.5646E3	18.97718	9.48859	7534.4031	7594.7969	7541.40	7587.80
	3	4	7.5378E3	12.49333	6.24667	7517.9703	7557.7297	7525.30	7553.70
	Total	12	7.6046E3	46.15448	13.19116	7511.7712	7697.4955	7525.30	8061.20

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Compr_strength	Between Groups	81.500	2	40.750	.530	.606
	Within Groups	692.062	9	76.896		
	Total	773.562	11			
Moisture	Between Groups	4.962	2	2.481	17.342	.001
	Within Groups	1.288	9	.143		
	Total	6.249	11			
Combustion	Between Groups	.000	2	.000	.074	.929
	Within Groups	.002	9	.000		
	Total	.002	11			
Ash_content	Between Groups	.047	2	.023	.955	.421
	Within Groups	.220	9	.024		
	Total	.267	11			
Carbon_content	Between Groups	21.915	2	10.957	21.185	.000
	Within Groups	4.655	9	.517		
	Total	26.570	11			
Volatile_matter	Between Groups	5.055	2	2.528	13.480	.002
	Within Groups	1.687	9	.187		
	Total	6.743	11			
Calorie	Between Groups	69889.927	2	34944.963	1.905	.204
	Within Groups	165082.520	9	18342.502		
	Total	234972.447	11			

Post Hoc Tests

Homogeneous Subsets

Compr_strength

Duncan

Factor	N	Subset for alpha = 0.05
		1
2	4	70.1250
3	4	72.1250
1	4	76.3750
Sig.		.360

Means for groups in homogeneous subsets are displayed.

Moisture

Duncan

Factor	N	Subset for alpha = 0.05		
		1	2	3
1	4	4.1750		
2	4		4.9500	
3	4			5.7500
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Combustion

Duncan

Factor	N	Subset for alpha = 0.05
		1
3	4	.054125
2	4	.054600
1	4	.057900
Sig.		.743

Means for groups in homogeneous subsets are displayed.

Ash_content

Duncan

Factor	N	Subset for alpha = 0.05
		1
1	4	5.9000
2	4	5.9500
3	4	6.0500
Sig.		.226

Means for groups in homogeneous subsets are displayed.

Carbon_content

Duncan

Factor	N	Subset for alpha = 0.05		
		1	2	3
3	4	83.4250		
2	4		85.3000	
1	4			86.7250
Sig.		1.000	1.000	1.000

Carbon_content

Duncan

Factor	N	Subset for alpha = 0.05		
		1	2	3
3	4	83.4250		
2	4		85.3000	
1	4			86.7250
Sig.		1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

Volatile_matter

Duncan

Factor	N	Subset for alpha = 0.05	
		1	2
1	4	3.2000	
2	4	3.8000	
3	4		4.7750
Sig.		.082	1.000

Means for groups in homogeneous subsets are displayed.

Calorie

Duncan

Factor	N	Subset for alpha = 0.05
		1
3	4	7537.8500
2	4	7564.6000
1	4	7711.4500
Sig.		.117

Means for groups in homogeneous subsets are displayed.