DESIGN, CONSTRUCTION AND EXPERIMENTAL EVALUATION OF THE PRODUCTS OF A LOW COST BRIQUETTE MACHINE FOR RURAL COMMUNITIES IN NIGERIA

BY

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AHMADU BELLO UNIVERSITY, ZARIA.

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JULY, 2008

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY IN PARTIAL FULFILLMENT FOR THE AWARD OF MASTER OF SCIENCE IN MECHANICAL ENGINEERING

DEPARTMENT OF MECHANICAL ENGINEERING

AHMADU BELLO UNIVERSITY, ZARIA.

NIGERIA

JULY, 2008

DECLARATION

I declare that this thesis entitled, "**DESIGN, CONSTRUCTION AND EXPERIMENTAL EVALUATION OF THE PRODUCTS OF A LOW COST BRIQUETTE MACHINE FOR RURAL COMMUNITIES IN NIGERIA"** is a record of my own research work. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

SANI, ITODO FIDELIS	____________	____________
Name of Student	SIGN	DATE

CERTIFICATION

This project entitled **DESIGN, CONSTRUCTION AND EXPERIMENTAL EVALUATION OF THE PRODUCTS OF A LOW COST BRIQUETTE MACHINE FOR RURAL COMMUNITIES IN NIGERIA** by SANI ITODO FIDELIS meets the regulations governing the award of the degree of Master in Science of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is joyfully dedicated to my beloved parents, Mr. and Mrs. A. Sani, for their love, care, guidance, counsel, prayers and encouragement.

It is also dedicated to my brother, Reuben Sani, my sisters, Hauwa Sani, Mrs. Ajuma Isah and Mrs. Christiana Adaji, for their prayers and encouragement.

Above all, to the Almighty God whose grace has seen me through this course.

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NOMENCLATURE

P_h = Pressure transmitted on material surface (N/m^2)

P_{cr} = Critical load causing rupture on screw (m^4)

P_t = Pitch of thread (mm)

P_{min} = Minimum pressure required by material (N/m^2)

P_b = Bearing pressure of nut (N/m^2)

P_{max} = Maximum pressure load produced (N/m^2)

P_e = Dry mass of pot (g)

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

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

P = Level of significance

W = Axial load (N)

W_a = Axial load from minimal pressure (N)

W_{max} = Maximum axial load from available screw (N)

W_b = Actual axial load from available screw (N)

w = Deflection (mm)

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

W_v = Water vaporized

M_{max} = Maximum bending moment

M_h = Force applied by an average person (N)

M_x = Moment about x – axis

M_f = Mass of fuel (Kg)

M_w = Mass of water (2900g)

M_c = Mass of 80mm of cotton thread (0.0035g)

M_{fw} = Mass of 50mm of fuse wire (0.0023g)

M_θ = Water equivalent of calorimeter (475g)

M_{cap} = Mass of capsule (g)

MS_t = Treatment mean squares

MS_ε = Error mean squares

M.S = Mean of Squares

m = Mass of an average person (Kg)

d_h = Handle diameter (mm)

d_m = Mean screw diameter (mm)

d_1 = Root screw diameter (mm)

d_2 = Nominal screw diameter (mm)

d_b = Diameter of bolt (mm)

d_1' = Minimal screw thread root diameter (mm)

D..F = Degree of freedom

S = Ultimate shear strength (N/m^2)

Sc = Specific fuel consumption

SS_t = Treatment sum of squares

SS_T = Total sum of squares

SS_ε = Error sum of squares

S.S = Sum of squares

A_a = Area over which pressure is applied (m^2)

A_1 = Bearing area of one thread (m^2)

A_2 = Projected area of nut (m^2)

L_h = Length of Handle (mm)

L_s = Screw length (mm)

L = Lead of Thread (mm)

T_h = Torque on screw thread (Nm)

T_i = Initial temperature of water (^oC)

T_f = Final temperature of water (^oC)

τ = Torsional shear stress (N/m^2)

τ_{max} = Maximum shear stress (N/m^2)

t = Value form the t-table

t_p = Thickness of plate (mm)

F_t = Tangential force necessary to turn the screw (N)

f_i = Initial mass of fuel (g)

f_f = Final mass of fuel (g)

f_m = Mass of wood that was used to bring the water to boil (g)

f_d = Equivalent dry wood consumed (g)

F = Freedom

$C_{p.w}$ = Specific heat capacity for water (4.2J/g^{o}C)

C_c = Specific heat capacity of cotton (17539J/g)

C_{fw} = Heat value for fuse wire (1402.243J/g)

C_{cap} = Heat value of capsule (18836J/g)

H = Height of nut (mm)

H_f = Calorific value of fuel (KJ/Kg)

H_L = Latent heat of evaporation of water (2260J/g)

Q_f = Heat liberated by fuel (KJ)

Q_{w+c} = Heat absorbed by water and calorimeter (KJ)

σ_u = Ultimate tensile strength of material (N/m^2)

σ_n = Direct stress (N/m^2)

$\sigma_{1,2}$ = Principal stress (N/m^2)

σ_{max} = Maximum bending stress (N/m^2)

R = Normal reaction between Screw and Nut (N)

R_b = Burning rate

r = Number of block (Number of test)

$\Delta\theta$ = Temperature rise in calorimeter (^{o}C)

ΔT = Temperature difference in water boiling test (^oC)

ΔC = Weight of fuel ash (g)

B.M = Bending moment (Nm)

Π = pi

N = Factor of Safety

c = Width over which pressure is applied (mm)

Ø = Friction angle

μ = Coefficient of friction

θ = Thread helix angle

k = Number of treatment (Fuel samples)

E = Modulus of Elasticity (N/m^2)

I = Moment of inertia (m^{-4})

b = Length of cover plate (mm)

D = Flexural rigidity of plate

g = Acceleration due to gravity ($9.81m/s^2$)

η = Thermal efficiency

ABSTRACT

The decreasing availability of fuel wood, coupled with the ever rising prices of kerosene and cooking gas in Nigeria draws attention to consider alternative sources of energy for domestic and cottage level industrial use in the country. This research work was conducted to design and construct a low cost briquette machine for rural communities in Nigeria. It involved the modification of the existing CINVA RAM press and evaluation of the products produced. Selected agricultural residues (i.e. rice straw and rice husk), saw dust residue of softwood and a combination of 50% rice husk + 50% saw dust by weight with 30% optimum cassava starch by weight as binder were used to produce briquettes. Performance characteristics were evaluated for the briquettes produced based on average fuel efficiency, burning rate and specific fuel consumption. Calorific value of 16,577KJ/Kg was obtained for rice straw briquette, 14,396KJ/Kg for rice husk briquette, 15,547KJ/Kg for sawdust briquette, 17,529KJ/Kg for 50% rice husk + 50% saw dust briquette and 12,378KJ/Kg for firewood (*Parkia biglobosa*). The average fuel efficiency, burning rate and specific fuel consumption values of 10.68%, 1.10Kg/hr, 0.3g/g, 22.42%, 0.83Kg/hr, 0.13g/g, 15.40%, 1.03Kg/hr, 0.26g/g, 18.52%, 0.93Kg/hr, 0.16g/g and 12.29%, 1.62Kg/hr, 0.36g/g were obtained for rice straw briquette, rice husk briquette, saw dust briquette, 50% rice husk + 50% saw dust briquette and firewood respectively. Statistical analysis using the least square differences in comparison to each of the fuel samples average performances showed that rice husk briquette had the most outstanding thermal performance.

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CHAPTER ONE

INTRODUCTION

Approximately 2000 million people world wide; most rural people and many urban as well, all depend on wood fuels as their main or sole source of energy to cook their food and keep warm. Nine-tenths of all the wood harvested annually is used for energy; "it accounts for over two-thirds of total energy consumption in 24 tropical countries of which 16 are least-developed countries" (Rodas, 1981).

The demand for fuel wood is expected to have risen to about $213.4x10^3$ metric tones, while the supply would have decreased to about $28.4x10^3$ metric tones by the year 2030 (Adegbulugbe, 1994).

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

Table 1.1: Nigeria's renewable energy resources

Energy Source	Capacity
Hydropower, large scale	10,000MW
Hydropower, small scale	734MW
Fuel wood	13,071,464 hectares (forest land)
Animal waste	61 million tones/yr
Crop Residue	83 million tones/yr
Solar Radiation	3.5 – 7.0 kW/m2-day
Wind	2-4 m/s (annual average)

Source: ECN (2005)

1.1 Statement of Problem

As wood fuel supplies diminish, the people who depend on wood fuels are suffering increase in physical or economic burdens in maintaining even a minimal daily fuel supply. The use of firewood and misuse of the existing energy resources (agricultural residues) is creating human and environmental crisis in developing countries which is resulting in deforestation. Traditionally, wood in form of fuel wood, twigs and charcoal has been the major source of renewable in Nigeria, accounting for about 51% of the total annual energy consumption; the other sources of energy include natural gas (5.2%), hydroelectricity (3.1%), and petroleum products (41.3%) (Akinbami, 2001).

In many developed and developing countries, the forest covers at least 25% of the total land area, the minimum level required by international standard. The first indicative forest inventory project completed in Nigeria in 1977 put reserved forest at approximately 10% of the total land area. Between 1976 and 1990, deforestation proceeded at an average rate of 400,000 ha. per annum, in 1981-1985 at 3.48% while in 1986-1990 it was 3.57% including some forest reserves. The FAO concluded that if this rate was maintained, the remaining forest in Nigeria would disappear by the year 2020. The degradation and depletion of the forest reserve base has major effects on other sectors of the economy. The disappearance of forest cover leads to erosion, soil degradation and unfavorable hydrological changes (Government of Nigeria, 1997).

The decreasing availability of fuel wood, coupled with the ever rising prices of kerosene and cooking gas in Nigeria, draw attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country (Olorunnisola, 2007). Such energy sources should be renewable and should be accessible to the poor. As rightly noted by Stout and Best (2001), a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria. This should, of necessity, be characterized by a departure from the present subsistence energy level usage which is based on decreasing firewood resources, to a situation where human and farming activities would be based on sustainable and diversified energy forms.

The realization that deforestation and wood fuel shortages are likely to become pressing problems in many countries has turned attention to other types of biomass fuel. Agricultural residues are, in principle, one of the most important of these. They arise in large volumes and in the rural areas which are often subject to some of the worst pressures of wood shortage (Eriksson and Prior 1990). If one or more efficient method of using the abundant agricultural and wood residues could be developed on a large scale the energy situation could be sustainable and the deforestation problem could be controlled.

The lack of capital among most house holds in the rural communities makes it difficult to move from either firewood or charcoal, to a more advanced energy sources where small initial capital investment can be used. Hence, the substitute of these fuels requires a minimal capital investment, be as cheap and accessible as charcoal and firewood. At the same time be environmentally sustainable.

1.2 Agricultural and wood residues

Large quantities of agricultural and wood residues are generated yearly in developing countries but they are neither managed nor utilized efficiently. Agricultural residues which are freely available are often discarded or burned as wastes. They occur in large amounts and have the potential to be an important industrial input for fuel production in briquette forms, particle board and straw board for furniture making, biogas fuel, gasification, biomass combustion, ruminant feeding, absorbent for industrial effluents treatment, grain storage structure and regulation/reduction of geothermal temperature.

The procedures for manufacturing these products are described briefly below;

1.2.1 Particle board and straw board production.

Wood residues resulting from furniture making industries or stalks like cotton stalks after harvesting cotton are either grounded into particles for particle board or steam heated to breakdown the residues into fibers for medium density fiberboard, then dried to lower moisture content. After the fiber is dried, it is blended with wax, a synthetic resin such as urea formaldehyde, and other addictives, and formed into mats. The mats are processed in large presses that use heat and pressure to cure the resin and form the products into sheets or boards. Primary finishing steps of particle and medium density fiber board include cooling or hot stacking, grinding, trimming/cutting and sanding. Secondary steps include fooling, painting, laminating and edge finishing. Straw boards are made from straw and bagasses, which undergo the same production procedure as particle board production. They are used for making doors, furniture and cabinets (Gary and Rajiva, 2001).

1.2.2 Biogas production by anaerobic decay of organic materials.

Anaerobic reactors are generally used for the production of methane biogas, from manure (human and animal waste) and agricultural residues. They utilize mixed methanogenic bacterial cultures which are characterized by defined optimal temperature ranges for growth. These mixed cultures allow digesters to be operated over a wide range i.e. above 0^oC up to 60^oC. When functioning well, the bacteria convert about 90% of the feedstock energy content into biogas containing about 55% methane, which is a readily useable energy source for cooking and lighting. Fig.1 below shows the route path of biogas energy production.

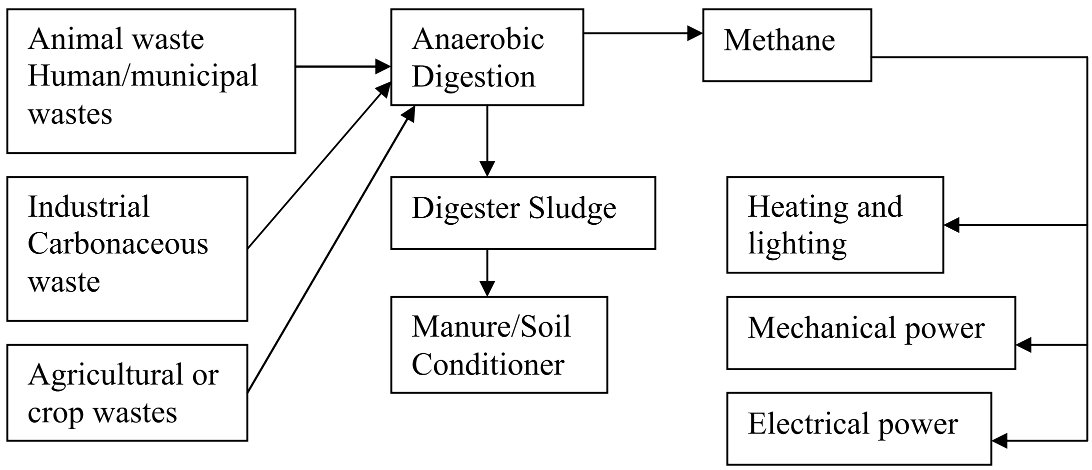

Figure 1: Biogas energy route Source: Elizabeth, et al, (1999)

1.2.3 Gasification.

Gasification is the process involving the burning of biomass fuels (human, animal and agricultural wastes) at very high temperatures with a limited supply of oxygen so that the burning process is only partially completed (Elizabeth et al, 1999). High temperatures and a controlled environment lead to virtually all the raw materials being converted to gas. This takes place in two stages. In the first stage, the biomass is partially combusted to form producer gas and charcoal. In the second stage, the carbon dioxide (CO_2) and water (H_2O) produced in the first stage is chemically reduced by the charcoal, forming carbon monoxide (CO) and hydrogen (H_2). The composition of the gas is 18% to 20% H_2 gas equal portion of CO, 2% to 3% methane (CH_4), 8% to 10% CO_2 and the rest nitrogen. These stages are spatially in the gasifiers. Gasifiers require temperature of about 800^{o}C and is carried out in closed-top or open top gasifiers. These gasifiers can be operated at atmospheric pressure or higher. The producer gas can be burned directly in processes which normally use oil fired boilers. It can be burned in ovens, kilns and driers to replace fuels otherwise, used in this equipment. The gas can also be cleaned and used to run an engine for generating electricity.

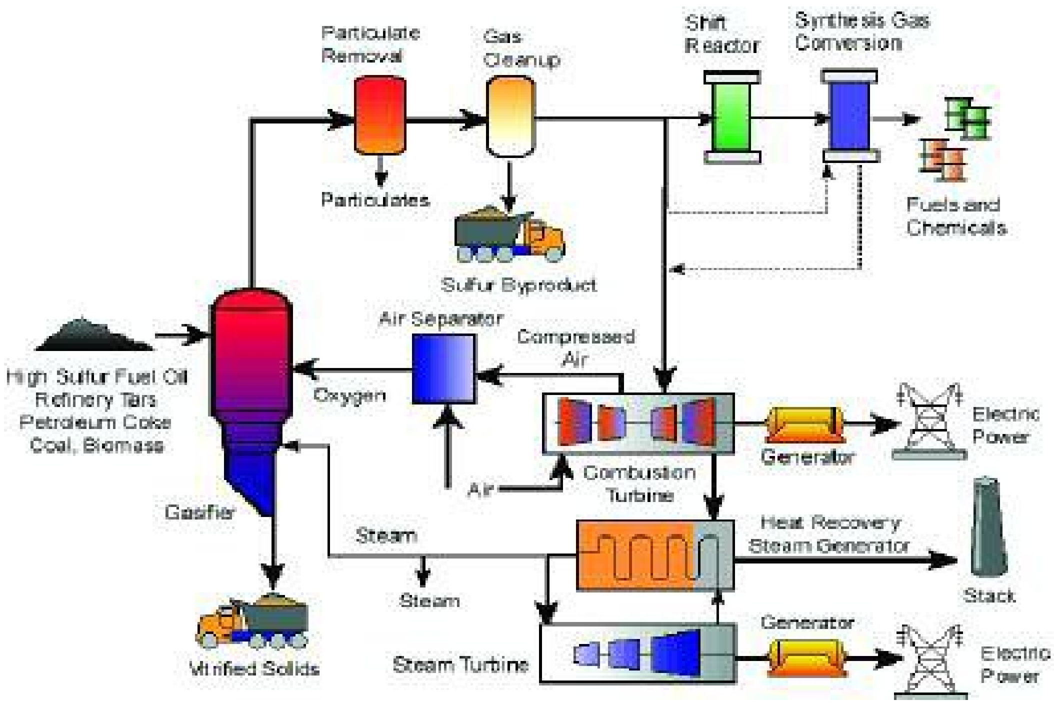

Figure 2: Gasification process. Source: Vannbush, (2006)

1.2.4 Biomass Combustion.

Biomass fuel (agricultural residue) is burned in a furnace or boiler. The heat is used to produce high pressure steam. This steam is introduced into a steam turbine where it flows over a series of aerodynamic turbine blades, causing the turbine to rotate. The turbine shares a common shaft with an electric generator so as the steam flows it causes the turbine to rotate, the electric generator is turned and electricity is produced. Also it can be used to produce hot water for goods processing.

1.2.5 Briquetting.

This involves the densification process of loose organic materials, such as rice husk, sawdust and coffee husk aiming at improving handling and combustion characteristics. There are two principal methods of briquetting, with or without a binder. The binder technology is used where low pressure presses are employed to produce briquette. Binders are added to this process to improve mechanical strength and also allow dry materials to be briquetted using low pressure techniques as simple block presses or extrusion presses. The binderless technology is a high pressure technique which produces briquettes from fine dry particle size materials without a binder being added. Three types of press are commonly used. Piston press, pelletizers and screw extrusion presses. Briquettes are burned the same way as wood and can be used directly in open fires, gasifiers, boilers, furnaces and kilns.

1.2.6 Ruminant Feeding.

Fibrous agricultural residues such as rice straw, sugarcane tops, cassava leaf, soyabean-straw, peanut vines and sweet potato vines are important component of the feed base for ruminant livestock particularly in areas where land grazing is limited and pasture growth is seasonal (Dixon, 1985).

1.2.7 Construction of village level grain storage structure.

Agricultural residues could be used to construct village level grain storage structure, called rhumbu which may be thatched, mud or underground pit. Thatched rhumbus are commonly found in the north-Eastern parts of Nigeria. They are cylindrical in shape with floors made of wooden grass stems or fibers and overhanging conical roof made with straws or grass. The structure normally is supported on low wooden structure or by stones. The wall is provided with tension rings in two or three positions using local rope material. Mud rhumbus are found in Zaria and Sokoto towns in Nigeria. They are circular in cross section and supported on stone pieces or pillars which are about 25-50cm above the ground. The floor is made of wood and plastered with mud; the roof is conical and made of thatch. Underground pits are found in the Sahel part of the Sudan savanna Zone where water table is low. The pit is either round or square is 2-3m deep and 1.5-3m in diameter or square. The pit is lined with straw mat (Zare) with corn husk padding or insulation is provided at the bottom of the pit, it is covered with a polyethylene or metal sheet, then a layer of husk and finally with layers of laterite (Olumeko and Igbeka, 1996).

1.2.8 Regulation and reduction of geothermal temperature.

In animal structures agricultural residues such as groundnut shells, maize husk or sawdust of 6mm particles are spread on the floors of poultry houses, horse stables and goat/sheep pens to serve as an absorbent material to keep the structure dry and the animals away from cold floors.

1.3 Justification of Research

The abundantly available agricultural and wood residues can efficiently be used for resolving energy problems to a significant extent by adopting proper measures.

Olorunnisola (2002) states that of the various types of biomass processing technologies that are being considered, and for which there are currently potentially viable local markets for in the country, which include biomass combustion, gasification and briquetting/pelletizing it is evident that none of these alternatives can compete with the low capital investment that is required; with the briquetting technology. Several kinds of agricultural residues can be utilized properly by densifying loose residues to produce a compact product of different sizes. Briquetting is essentially a mechanical process requiring investment in equipment and training to ensure a product of reasonable quality that will perform the task for which it is intended. Russell, (1997) considered that briquetting is often seen as a relatively high-cost high-pressure technology, and that it is possible to use a low-cost low-pressure technique to produce acceptable briquettes.

For rural communities the most suitable briquetting methods are those which are based on available waste and building materials. The manufacturing should be done in locally made hand operated presses and the briquettes held together mainly by a binder.

- Briquette making saves trees and prevents problems like soil erosion and desertification by providing an alternative to burning wood for heating and cooking.
- Briquetting substitutes agricultural waste like hulls, husk, corn stocks, grass, leaves and other garbages for a valuable resource.
- Briquetting engenders many micro enterprise opportunities making the presses from locally available materials, supplying materials, supplying materials and making the briquettes, selling and delivering the briquettes.
- The availability of briquette as an alternative fuel to replace firewood can also improve the living conditions of the rural women and children, who spend most of their time collecting firewood instead of engaging in other income generating activities or attending school.

1.4 Existing Briquetting Techniques

1.4.1 Wu-Presser

The Wu-presser was developed by the Washington University. It is constructed from either metal or wooden parts as shown in figure 3 below.

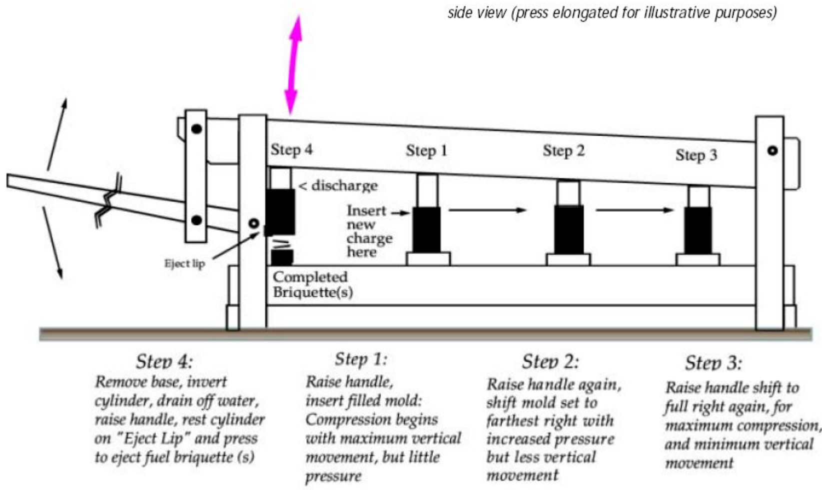

Figure 3: The Wu-presser Source: Legacy Foundation (2003)

The Wu-presser presses briquettes in three steps shown in the illustration above. Each step will press with increasing pressure. This takes advantage of the non-linear force to distance property of briquetting pressing.

1.4.2 Earth Rams

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

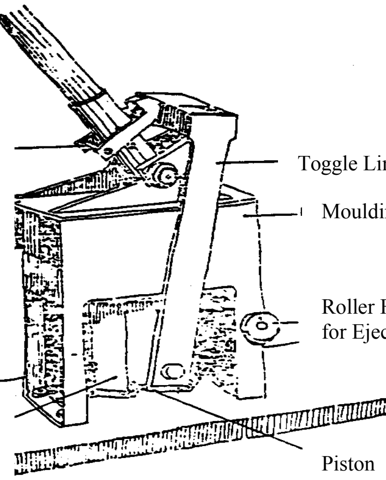

Figure 4: Combustaram Source: Davies (1985)

The lever is then moved back to the original position and again pushed down, thus forcing the briquettes out of the molds. Finished briquettes are set in the sun to dry. The process requires at least two workers.

1.4.3 Tube-Presses

Metal or plastic pipe provides a good briquetting mould since it produces cylindrical briquettes. The tube press, illustration shown in Figure 5 below,

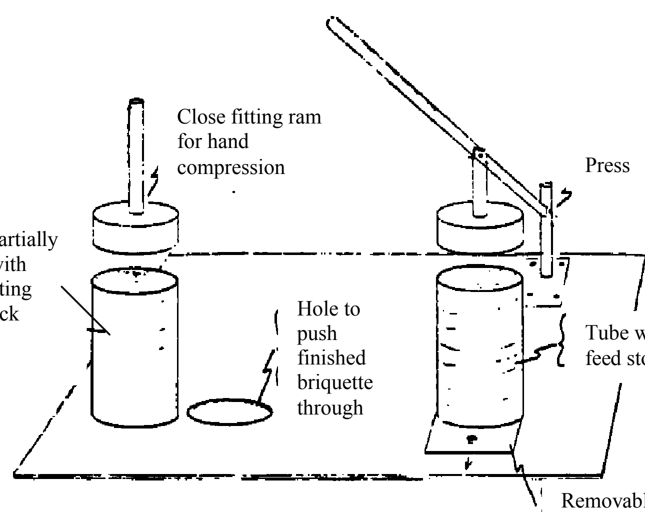

Figure 5: Tube Press Source: Davies (1985)

consist of a tube mounted vertically on a platform and a close fitting ram used for compaction. The basic design can be varied considerably, as the figure indicates. Feed stock is poured into the tube and compressed with the ram. The tube is then positioned over a hole (or a slide is removed) below the tube exposing a hole and the briquette is pushed through. Briquettes are then dried in the sun before storage and use.

1.4.4 Screw Presser

The screw presser makes briquettes in upright cylinders. The raw material is compressed by lowering a metal disc which is moved vertically by a screw that is turned by hand. The screw press is most commonly made of metal as shown in figure 6 below.

Figure 6: Screw presser in use. Source: Olle and Olof (2006)

1.4.5 Hydraulic Press

These machines operate by hydraulic pressure acting upon a piston that extrudes the material through a longitudinal die. The machine operates rather slowly which minimizes the wave rates. However, they operate at much lower pressures and the briquette quality is of lower density. They are typically used for low outputs of 40kg/hr but can be made to achieve up to 80kg/hr.

1.4.6 Piston Press

These machine works best with dry (15% moisture content maximum) cellulose material, which is fed into a compression chamber. A reciprocating piston then forces the material through a tapered die to form a long briquette as shown in figure 7 below. Typically flywheel drive machines produce between 300kg and 500kg of briquettes per hour.

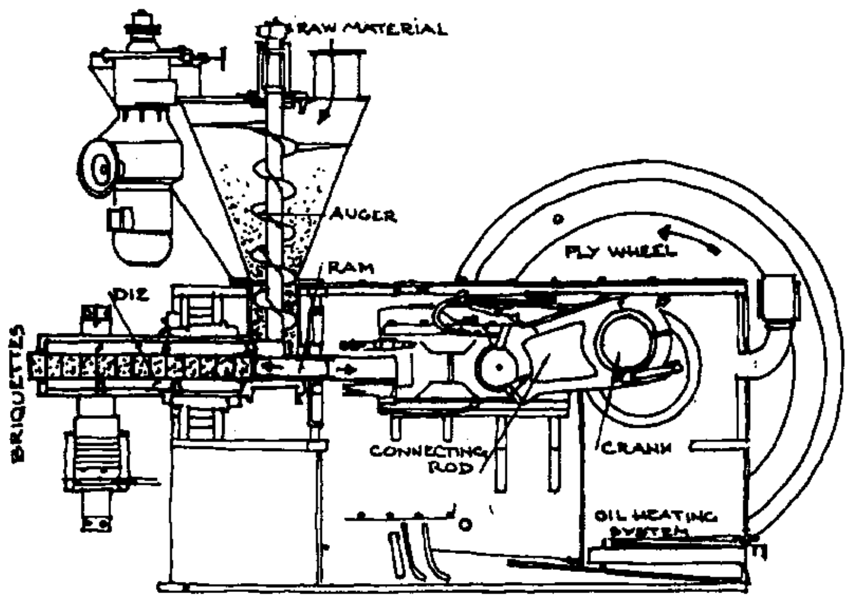

Figure 7: Piston Press Source: Bhattacharya et al, (1984)

The machine can achieve a service life of between 500 hours and 1000 hours using relatively clean material such as sawdust. Use of agricultural wastes containing high levels of silica (sand) will reduce the operating hours considerably. The initial cost of this type of machine is high and the briquettes are prone to breaking.

1.4.7 Pelletizer

Pellet presses have dies with small diameter (usually about 30mm). The machine has a number of dies arranged as holes bored in a thick steel disk or ring. The material is forced into the dies by means of a ram, perpendicular to the centerline of the dies. The main force applied results in shear stresses in the material which often is favorable to the final quality of the material. The pellets are cut to lengths normally about one or two times the diameter (Eriksson and Prior, 1990). Pelletizers can produce up to 1000kg of pellets per hour but require high initial capital investment and high energy input.

1.4.8 Heat Die Extrusion Screw Press

The heat die extrusion screw press is an industrial machine for producing briquettes (see figure 8 below). It consists basically of an electric motor, a hopper, a die heater and muff, and the screw which densifies the raw material.

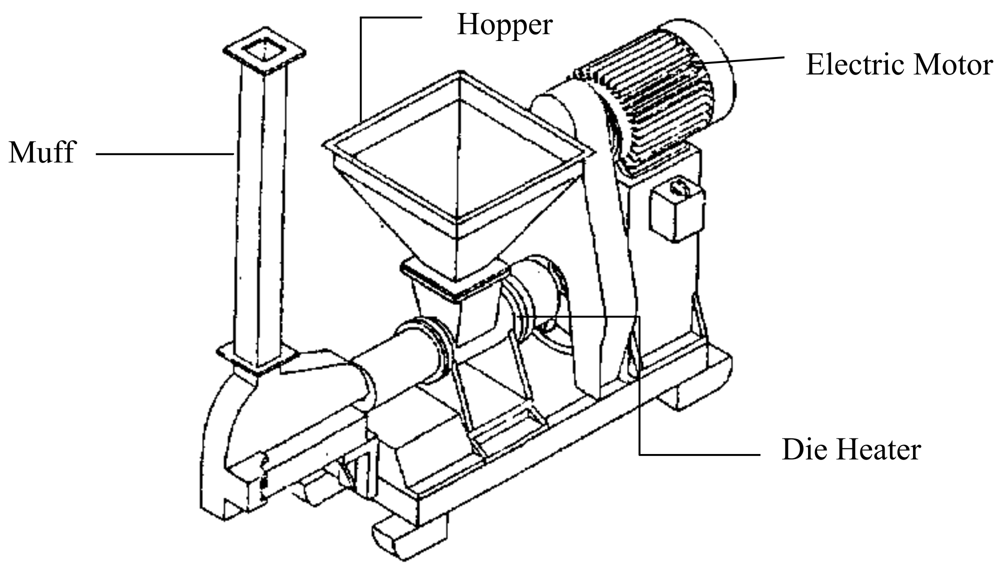

Figure 8: Heated die extrusion screw press Source: Bhattacharya et al, 1984

The electric motor drives the briquetting screw, which is housed inside the die, through a V-belt and pulley arrangement. Biomass raw material is fed to the screw through the hopper. The electric die-heater softens the lignin in the raw material as it passes through the die which acts as a binding material. A smoke trapping system traps and removes the smoke from the vicinity during the briquetting process. Besides the cost of the investment, the machine has a cost for the electricity consumed. Another cost is the screw that gets worn and has to be replaced frequently.

1.5 Objectives of study

The objective of this project is to:

- Design and construct a simple, low cost briquette machine which can be used in rural communities.
- Test the design briquette machine using selected agricultural residues (sawdust, rice husk, rice straw) with cassava starch as binder.
- Evaluate the calorific value of briquetted residues.
- Compare calorific value and performance with firewood.

CHAPTER TWO

LITERATURE REVIEW

According to Grover and Mishra (1996), briquetting is one of the 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 includes 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 heating device,
3. Low pressure

Eriksson and Prior (1990), stated that if the material is compacted with low to moderate pressure (0.2-5MPa), then the space between particles is reduced. Increasing the pressure will at certain state particular to each material, collapse the walls of the cellulose constituent (primary structural component of plant cell walls), thus approaching the physical, or dry mass, density of the material. The pressures required to achieve such high densities are typically in excess of 100MPa.

2.1 Research and Development Efforts in the Use of Agricultural Residues as Energy Source for Cooking Purpose Using Low Cost Technique

Russell (1977) carried out a study of a simple briquette making technique which was developed in Sri Lanka to produce corrugated briquette sheets made from coir. A small amount of binder, lime, is mixed with the wet coir which is then placed into a tobacco bailing box in alternate layers between sheets of corrugated metal until the box is full. Pressure is exerted on the layers, pressing water out of the material and also helping a chemical reaction to occur between the coir and the binder. After the briquettes have been formed it requires drying for a number of days before being used. The resulting briquettes can be cut easily or broken along the corrugation to produce small logs.

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

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

Kartha and Leach (2001) carried out a study using modern bioenergy to reduce rural poverty. Good results were obtained by adapting presses for bricks or earth blocks in briquetting wood and agricultural wastes.

Adegoke (2001) pointed out, that results of a recent study in the Mechanical Engineering Department of the Federal University of Technology, Akure, have shown that sawdust mixed with certain biomass materials of appropriate grain sizes and in certain proportions have improved calorific values. This mixture of the sawdust and the biomass materials are compressed using a specially developed briquetting machine and the briquettes dried either directly in the sun or in an oven. When burned in internally lined stoves, heat a loss to the environment is much reduced, a lot of cooking energy is obtained from a relatively small amount of the sawdust briquettes.

The Forest Products Research and Development Institute (2002) second prize winner in the mechanical inventions category in 1984 developed a carbonizer, simple, low-cost machine. It has a rectangular trough, hopper, charcoal receiver, swing-type metal plate cover and fire box. The briquetting machine is a simple energy- and money-saving device used in converting charcoal fines from sawdust, rice hull, coconut coir dust and other carbonaceous fine materials into charcoal briquettes for industrial uses. It consists of molds, plungers, top sliding platen, common lever, fulcrum, steel plates where the molds are welded, with a casing assembly.

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

Inegbenebor (2002) compressed fibrous agricultural and wood waste materials with suitable adhesive into briquettes in a compressing machine, which was designed and constructed for this purpose. Nine samples of fibrous waste materials were prepared into different categories: - (100% saw-dust, 100% rice-husk, and 50-50% rice-husk/sawdust), using starch as adhesive for category A, while category B employs gum Arabic as adhesive and category C used bentonite as adhesive. The 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 1.5liters of water. Results showed that the solid fuel briquettes bound with each of the three adhesives; boiled water within a period of 14 to 22 minutes. While, firewood boiled the same quantity of water within a period of 22 to 27 minutes. The open flame test showed that the solid fuel briquettes bound with starch burnt with bluish yellow flame with little black smoke. The solid fuel briquettes bound with gum Arabic and bentonite burnt with yellow flame with moderate black smoke.

Olorunnisola (2004) carried out, a study involving experimental production of briquettes from chopped rattan strands mixed with cassava starch paste. Samples of rattan strands of mixed species (Laccosperma secundiforum and Eresmopatha macrocarpa) were collected from a furniture workshop in Ibadan, Oyo State, Nigeria. The strands, having an average moisture content of 12% and an average dimension of 630 mm (length) by 4.0 mm (width) and 1.8 mm (thickness), were reduced to 25 mm (length) by 4.0 mm (width) and 1.8 mm (thickness) particles by manual shearing. They were subsequently mixed with cassava starch at six proportions by weight, i.e. 50%, 100%, 150%, 200%, 250%, and 300%. It was observed that the minimum proportion by weight of cassava starch required for briquette formation was 200%. Compression experiments were performed using a simple tabletop closed - end die piston press fitted with both a pressure and a dial gauge. It was concluded that stable briquettes could be formed from rattan strands mixed with cassava starch paste.

Bello (2005) carried out a research project in processing of agricultural residues into briquettes as fuels for cooking purposes in the department of agricultural engineering, Ahmadu Bello University, Zaria in which she produced briquettes from agricultural residues using gum Arabic as her binder and evaluated their performance characteristics based on fuel efficiency, cooking efficiency, boiling time and fuel consumption rate respectively. Her briquettes were produced using a manual hand press used in making coal briquettes in Amil Nigeria Limited in Kaduna State.

Murugappa Chettiar Research Centre (2005) is carrying out a research project based on income generation through biomass charcoal briquetting work being implemented at Kanathur and Thiruvidanthai villages in India where casuarinas leaf litter is available abundantly as waste biomass. The moisture, ash, volatile matter and fixed carbon content and biochemical properties of the biomass viz; cellulose, hemicellulose, lignin, crude fiber, content have been estimated. The selected biomass has been carbonized at different temperatures ranging from $200^{o}C$ to $400^{o}C$ and the charcoal yield determined. Also, a hand operated biomass briquetting mould, have been fabricated with locally available materials to prepare the charcoal briquettes for its ultimate analysis.

Energy Commission of Nigeria and United Nations Development Programme (2005) stated that several machines have been developed in Nigeria for briquettes production, including a single cylinder extrusion machine that transforms rice, millet and sawdust husk to briquettes at 13kg of briquettes/hour. There are, however, only two small-scale companies in Nigeria situated in Ogun and Kaduna states which produce and market sawdust briquettes. The locally produced briquette has 6 to 7 times more energy content per kg than un-briquetted biomass. Today, most work on biomass briquetting is confined to University Research and Development centers.

Olorunnisola (2007) undertook a study to investigate the properties of fuel briquettes produced from a mixture of a municipal solid waste and an agricultural residue, i.e., shredded waste paper and hammer milled coconut husk particles. Briquettes were manufactured using a manually-operated closed – end die piston press (see plate I) at an average pressure of 1.2×10^{3} N/m^2 using four coconut husk: waste paper mixing ratios (by weight), i.e., 0:100; 5: 95; 15: 85; and 25: 75. Results obtained showed that briquettes produced using 100% waste paper and 5:95 waste paper-coconut husk ratios respectively exhibited the largest (though minimal) linear expansion on drying. While the equilibrium moisture content of the briquettes ranged between 5.4 % and 13.3%, there was no clearly discernible pattern in equilibrium moisture content variation with increase in coconut husk content. A reciprocal relationship was observed between compressed/relaxed density and relaxation ratio of the briquettes. The mean durability rating of all the briquettes exceeded 95%. It was concluded that stable briquettes could be formed from waste paper mixed with coconut husk particles.


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Plate I: Manually operated briquetting machine

An industrial visit was made to the only present existing briquetting plant in Nigeria (AMIL Nigeria Limited) located in Kaduna state in April 2007, to study their production process. A tour of the plant showed that two well known existing processes are used in their production. The automated, heat die screw extrusion press for densifying sawdust, rice straw and corn stalks into carbonated briquettes without the use of binders. The present worth of the equipment was said to cost five million naira (#5million). The other process is a manual hand press, consisting of a round hollow cavity with twelve (12) plungers which is controlled by a foot lever for compacting of coal dust with clay as binder to form coal briquettes. Due to the erratic energy supply in the country with the cost of running a generator to power the plant, along with miscellaneous expenses and staff salary compared to the income generated from the sales of briquettes produced, the company had been running at a great loss which has made it to fold up for over a year. Plate II and III show the types of briquette produced by AMIL Company.

Plate II: carbonated sawdust briquette.

Plate III: coal dust briquette.

2.2 Review of Previous Research Work on Briquette making Raw Materials

Maih et al (1999) conducted a study on rice husk briquettes at Sylhet, Khulna and Dinaj Pur districts of Bangladish in order to identify the problems and prospects of using the briquettes as an alternative fuel for cooking. Rice is the staple food for the people of

Bangladish. The total annual production of paddy is about 28million tonne (FAO, 1992) and about 20% of this (5.6million tonne) is rice husk. The study also concluded that to prevent environmental hazards caused by rapid deforestation activities, rice husk briquettes may be introduced as an alternative fuel which is smoke free, less hazardous, high calorific value and comparatively cheap.

Shakya, et al (2005) stated that agricultural residues like ground nut shells, straws, tree leaves, grass, rice and maize husks, banana leaves and sawdust can be used for briquette making. Although some materials burn better than others, the selection of raw material is usually most dependent in what is easily available in the surrounding area of where the briquettes are made. The briquettes can consist of a blend between several different raw materials. However to use agricultural residues efficiently for energy production, a detailed knowledge of its physical and chemical properties are required. These properties, more specifically average and variation in elemental compositions, are also essential for modeling and analyzing of energy conversion processes Table 1 below shows the analysis of some agricultural residues.

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

Another important characteristic is its ability to bond together, when compressed. For these reasons fibre-rich materials are good.

2.3 Review of Previous Research Work on Residue Energy Potential

Tropical Development and Research Institute (1983) suggested from a survey in 1979, worldwide, that "about 250million tons of sawdust and over 400million tons of other wood residues were produced". The report also noted that about 60% of this material arose in developing countries and whereas in the USA up to 80% of this waste was utilized, in developing countries large quantities of these materials remain unused.

Eriksson and Prior (1990) technically assessed that one of the major world crops, rice, has about 25% of the crop in the form of husk which amounts to about 100 million tons of residue. On a smaller scale, world production of groundnuts is about 10 million tons of which about 45% is shell. In general though there are crops with both higher and lower residue yields, it is reasonable to assume that about 25% of any dry agricultural feedstock is a residue.

Larry (1993) reported that the U.S. Forest Service estimates national forest wastes at, one billion dry tons. In Minnesota alone, 7.2 million tons of wood residues are available every year for fuel. Hennepin County in Minnesota (part of the seven-county metropolitan Twin Cities area) produces almost 5,000 tons per day of burnable paper garbage. This waste could be effectively converted to briquette fuel that would provide 80 billion Btus of heat energy daily. This 80 billion Btus of daily untapped heat energy is equivalent to that produced by 500,000 gallons of fuel oil, which, at $.90 per gallon, would cost $450,000 per day, or $3.15 million per week.

A Study by Wanamukonya and Jenkins (1994) highlighted the potential of briquette biomass as a potential fuel to be utilized in Kenya. Biomass burning accounts for 85% of Kenya's energy consumption, growing demand and lack of resources have created the need for alternative energy resources. This study found the utilization of waste from over 400 sawmills through the briquetting process could supply about 63,000 tons of combustible material to help toward growing energy demands.

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

European Biomass Industry Association (2000) produced a newsletter that disseminated information on biomass (agricultural residues) resources as potentially the world's largest and most renewable energy source, with an annual terrestrial biomass yield of 220 billion oven-dry tonnes. In the European Union (EU), biomass currently supplies 3.5 percent of energy, representing 45 million tonne. Looking ahead to 2010-2015, the possible energy supply from biomass in the EU is estimated at 130 million tonne.

2.4 Review of Previous Studies on Binding of Briquettes

Reineke (1964) carried a research into the binding action of some agricultural residues and came out with the finding that granular materials require no added binder because they are self bonding when briquetted at elevated temperatures. At temperatures above the minimal plastic temperature (325^{o}F for wood), the elastic strains set up in the material under briquetting pressure are completely relieved and the particle surfaces come together into intimate contact. Cohesion of the interfaces, interlocking of broomed out fibrous parts of the particles, and a possible adhesion of the heat softened lignin (the natural bonding agent between the wood fibers), all contribute to a binding action that imparts satisfactory strength to briquettes after they have cooled under pressure.

Eriksson and Prior (1990) stated that binding agent is necessary to prevent the compressed material from springing back and eventually returning to its original form. This agent can either be added to the process or, when compressing ligneous material, be part of the material itself in the form of lignin. Lignin, or sulphuric lignin, is a constituent in most agricultural residues. It can be defined as a thermo plastic polymer, which begins to soften at temperatures above 100°C and is flowing at higher temperatures. The softening of lignin and its subsequent cooling while the material is still under pressure is the key factor in high pressure briquetting. It is a physico-chemical process related largely to the temperature reached in the briquetting process and the amount of lignin in the original material.

Lardinois and Klundert (1993) suggested that the raw material of a briquette must bind during compression; otherwise, when the briquette is removed from the mould, it will crumble. Improved cohesion can be obtained with a binder but also without, since under high temperature and pressure, some materials such as wood bind naturally. A binder must not cause smoke or gummy deposits, while the creation of excess dust must also be avoided. Two different sorts of binders may be employed. Combustible binders are prepared from natural or synthetic resins, animal manure or treated, dewatered sewage sludge. Non-combustible binders include clay, cement and other adhesive minerals.

Although combustible binders are preferable, non-combustible binders may be suitable if used in sufficiently low concentrations. For example, if organic waste is mixed with too much clay, the briquettes will not easily ignite or burn uniformly. Suitable binders include starch (5 to 10%) or molasses (15 to 25%) although their use can prove expensive.

2.5 Review of Research Work on Calorific Values of Some Briquettes

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

Table 2.1: Calorific Value and Ash Content of Various Fuels

Material	Ash Content %	Higher Calorific Value MJ/kg (oven dry)	Material	Ash Content %	Higher Calorific Value MJ/kg (oven dry)
Alfalfa straw	6.0	18.4	Olive pits	3.2	21.4
Almond shell	4.8	19.4	Pigeon pea stalks	2.0	18.6
Cassava stem	-	18.3	Rice straw	-	15.2
Coconut shell	0.8	20.1	"	19.2	15.0
Coconut husk	6.0	18.1	Rice husks	-	15.3
Cotton stalks	17.2	15.8	"	16.5	15.5
"	3.3	17.4	"	14.9	16.8
Groundnut shells	-	19.7	Soybean stalks	-	19.4
"	4.4	20.0	Soybean stalks	-	19.4
Maize stalks	6.4	18.2	Sunflower straw	-	21.0
"	3.4	16.7	Walnut shells	1.1	21.1
Maize cobs	1.5	18.9	Wheat straw	-	18.9
"	1.8	17.4	"	8.5	17.2

Source: Barnard, (1985)

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

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

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

Source: Krist and Wentink, (1985)

Eriksson and prior (1996) acknowledged that of the most important characteristics of a fuel is its calorific value, that is the amount of energy per kg it gives off when burned. Although briquettes, as with most solid fuels, are priced by weight or volume, market forces will eventually set the price of each fuel according to its energy content. However, the production cost of briquettes is independent of their calorific value as are the transportation and handling costs. They went further stating that the calorific value can thus be used to calculate the competitiveness of a processed fuel in a given market situation. There is a range of other factors, such as ease of handling, burning characteristics etc, which also influence the market value but calorific value is probably the most important factor.

Review of previous research works carried out to provide the rural communities with a briquetting machine revealed that most of the low cost low pressure briquette machines focused on producing a single briquette in one operation. None of these machines have been successful in the market because of their low output with time spent in producing briquettes which cannot compensate for the demand for energy (firewood) in the rural homes. Use of briquettes in Nigeria is zero because of the cost of imported briquetting machines and adequate research work not conducted in the country to find alternative machines.

Above all, the need to identify a technology which can be successful in the Third world marginalized communities; like Nigeria, where the high pressure mechanized process have not been successful, infrastructure is weak, supply of raw material is inconsistent in quantity and the market populations are widely dispersed over areas which are difficult to access brought about this project. This project is aimed at re-designing the most popular existing low cost low pressure technology (Cinva Ram Press) to produce multiple briquettes in one operation, in order to meet the demand for fuel in the rural community, to save trees and prevent soil erosion. Having in mind that the machine can be produced in the areas of local need by local citizen, with no technical skills and the community would have little cash flow and the local market would be price driven in their fuel price decision.

CHAPTER THREE

MACHINE DESIGN AND CONSTRUCTION PROCESSES

3.1 Material

When selecting materials for a machine, first consideration is what materials are suitable for the product, the way the product will be made, method of construction and cost are all vital elements. The material selected for construction of this briquette press is medium carbon steel of 0.3% carbon which has high strength, good ductility and moderate hardness. It has good machinability to be formed into shape and is readily available in the market. These are properties suitable for a press material. In the design approach it is ensured that the stress level is below the yield point ($456 x 10^6 N/m^2$) to ensure safety. My design was done based on the following consideration and analysis.

3.2 Design Considerations

The manually operated briquetting screw press is designed to the following specifications;

(i) Pressure to be applied should be within a range of 0.2MPa and 10MPa on the material,

(ii) Base ram area (A_b) = 104mm x 266mm,

(iii) Torque handle for screw thread = 1000mm.

The screw briquette press is a modification of the CINVA-RAM press use for making building blocks. It is modified to produce ten pieces of stabilized briquettes of 260mm long, 48mm wide and 48mm thick with a vertical hole of 10mm diameter passing through the central axis of the briquette length.

The basic screw press design has the power to magnify input forces to compact materials using only a factor of the force ordinarily needed. The goal in this design is to design an efficient briquetting screw press capable of compacting within a pressure of 0.2MPa to 10MPa. The press will be manually operated and have at least 40mm compression stroke from the bottom and 100mm from the top. The design will be transportable, storable and have a removable handle see drawing no.1.

3.3 Description of Parts and Functions

The Screw briquette press consists of three main parts;

(i) The main frame and the mould,

(ii) The base ram,

(iii) The connecting link mechanism and power screw.

3.3.1 The Main Frame and Mould

This main frame is made from 75mm x 10mm flat bars and 50mm x 50mm angle bars of various length all welded together to produce a rectangular shape of dimension 620mm x 386mm x 224mm. The upper parts of the frame that form the mould is made from a 10mm thick mild steel plate formed into a box shape.

3.3.1.1 Function

The mould has the following functions;

(i) The chamber where the compression of the material occur,

(ii) It gives the press its essence,

(iii) It affords the briquettes its basic three dimensional shape.

3.3.2 The Base Ram

The base ram is made of 8mm thick mild steel plate. It carries 10 rods of 10mm diameter and 268mm length, which are used to make holes through the briquettes.

3.3.2.1 Function

The base ram plate acts as;

(i) The piston during the compression process,

(ii) It is used to eject the briquettes from the mould.

3.3.3 The Connecting Link Mechanism and Power Screw

The connecting link is made of 75mm x 12mm flat bar. It serves as a mechanism for converting a relatively small force into heavy pressure. The power screw is a mechanism used in transmitting force/pressure.

3.3.3.1 Function

(i) Compression: pushes the base ram plate for an upward stroke, this transmits an enormous force which facilitates compaction of the material.

(ii) Ejection; to remove the briquette from the mould.

3.4 Design Analysis

In any compacting operation, the compression force which is the axial load (w) is given by (Abbott, 1984)

$$P_a = \frac{W_a}{A_a} \text{-----------------} 3.1$$

3.4.1 The Handle

This is the mechanism through which torque is applied to turn the screw thread. Assuming a person can apply an average of M_h(N) intermittently with the arm;

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

$$L_h = \frac{T_h}{M_h} \text{ - - - - - - - - - - - - - - } 3.2$$

$$B.M = \frac{d_h^3 \sigma_u \pi}{32N} \text{ - - - - - - - - - - - - - - } 3.3$$

$$d_h = \sqrt[3]{\frac{32NB.M}{\pi \sigma_u}} \text{ - - - - - - - - - - - - - } 3.4$$

Factor of safety for power screws (Robert,1992) is N = 3.

3.4.2 The Thread Shaft (Square Thread)

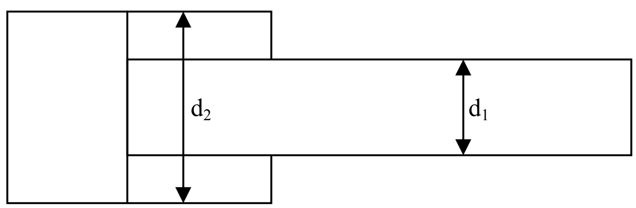

Figure 9: Thread Shaft

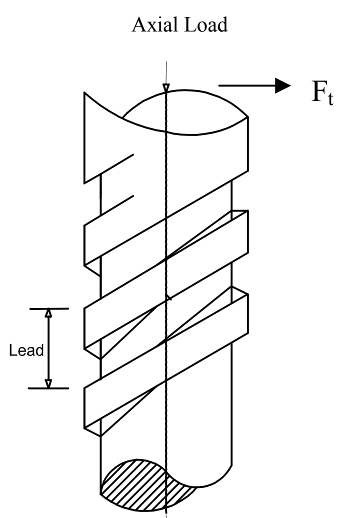

Figure 10: Single Start Thread

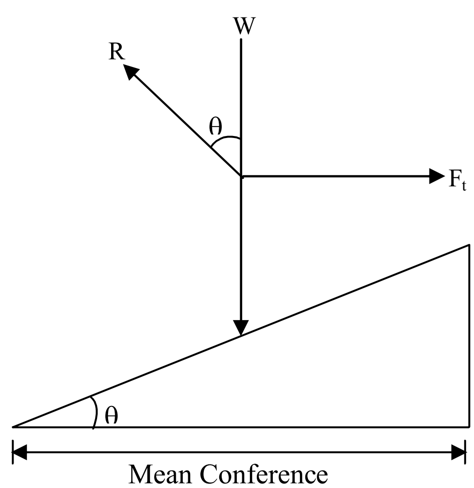

Figure 11: Representation of one revolution of the inclined plane

The thread shaft carries the axial load due to compression pressure and a torsional load due to the frictional movement.

For pure compression (Patel and Panda, 1968), an estimate of screw root diameter can be made from.

$$W_{\max} = \frac{\pi d_1^2 \sigma_u}{4N} ----------3.5$$

From fig. 10,

$$d_m = \frac{d_1 + d_2}{2} ---------- 3.6$$

From fig. 11,

$$\phi = \tan^{-1} \mu ---------- 3.7$$

Coefficient of friction between thread and nut for square thread screw (Robert, 1992) is μ = 0.5

$$\tan\theta = \frac{Lead}{MeanCircmference}$$

$$\tan\theta = \frac{L}{\pi d_m} ----------3.8$$

Like all screw threads, square thread is in effect an inclined plane wrapped round a cylinder. The effort is applied in a direction at right angles to the direction of the load. Problems involving the square thread such as the lifting/compressing mechanism can be calculated using the equation.

$$F_t = W_b \tan(\theta + \phi) ----- -- 3.9$$

Torque applied to turn the screw;

$$T_h = F_t \times \frac{d_m}{2} ---------- 3.10$$

The maximum stress in the screw may be estimated by considering load and torque on bear cylinder.

Torsional shear stress;

$$\tau = \frac{16T_h}{\pi d_1^3} ------------- 3.11$$

Direct shear;

$$\sigma_n = \frac{4W_b}{\pi d_1^2} ------------ -3.12$$

The principal stresses are given as;

$$\sigma_{1,2} = \frac{1}{2}\left[\sigma_n \pm \sqrt{\sigma_n^2 + 4\tau^2}\right] ---- 3.13$$

The maximum shear stress is given as;

$$\tau_{\max} = \frac{1}{2}\sqrt{\sigma_n^2 + 4\tau^2} ------- 3.14$$

When the screw is longer than 8 times the root diameter it must be considered as column. Long columns are dealt with using the Euler equation.

From the Euler's formula of critical load for slender column of uniform cross section (Spotts, 1988)

$$P_{cr} = \frac{\pi^2 \mathrm{EI}}{L_s^2} ------------- 3.15$$

3.4.3 Bearings

Bearings are devices that allow part of a machine to turn smoothly. The bearings to be used for the support are determined by the diameter of the shaft that will pass through its bore. Friction between moving parts cannot be eliminated entirely, but it can be reduced effectively by using some form of ball bearings. Ball bearings are mounted on both ends of the pivot shaft to easy rotation. The bearings are placed in such a way to have very low contact stress and not to carry any form of load in this design. The bearings are lubricated with grease.

3.4.3 **Nut**

Sufficient bearing surface must be provided between threads of screws and nuts to prevent the bearing pressure from being too high.

$$A_1 = \pi/4 \left(d_2^2 - d_1^2\right) ---------- 3.16$$

If H represents the height of the nut, then area available (Jegede, 1999);

$$A_2 = \frac{HA_1}{P_t} -------------- 3.17$$

Load = project area x bearing pressure

$$W = A_2 P_b --------------- 3.18$$

3.4.5 The Cover Plate

The cover plate covers the mould and it acts as a piston which compresses the material in the mould.

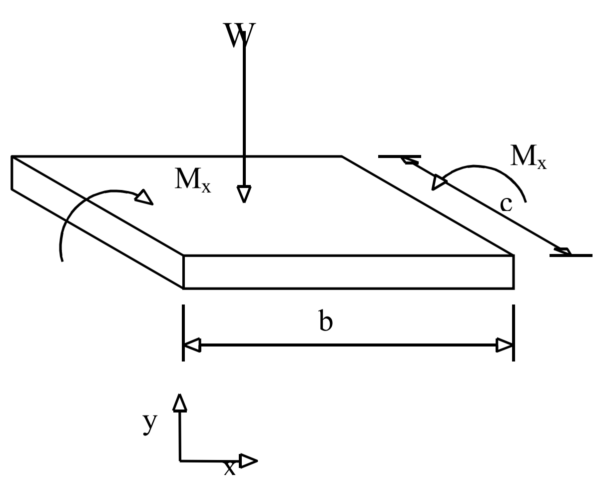

Figure 12: Cover Plate

Bending of the plate takes place in one direction only i.e. x – direction as shown in figure 12. From the equation of deflection and associated boundary conditions, minimum thickness of required cover plate can be obtained as (Jegede 1999)

$$\frac{d^4 w}{dx^4} = \frac{W_b}{D} ----------------3.19$$

Boundary condition

$$\frac{w}{x}\Big|_{x=0} = w\Big|_{x=b} = \frac{dw}{dx}\Big|_{x=0} = \frac{dw}{dx}\Big|_{x=b} = 0$$

Maximum bending moment (M_{max}) is given as;

$$M_{\max} = \frac{5W_b b^2}{12} --------------3.20$$

$$\sigma_{\max} = \frac{M_{\max} \, {}^{t_b}\!/_2}{\left(\frac{1}{12}\right) t_b{}^3} = \frac{5W_b b^2}{2t_b{}^2} --------3.21$$

$$t_b = \sqrt{\frac{5W_b b^2 N}{2\sigma_{\max}}} --------------3.22$$

3.4.6 Coupling Bolt for Installation

Force to be resisted by frame foot is equal to the torsional force of the shaft which is transformed into static load by the bearing during operation and is equal to the axial load (w). This force will be transmitted to the number of bolts used to hold the frame rigidly in position. Number of bolts required = 4

Force on each bolt = ${}^{W_b}\!/_4$ ----------3.23

Let d_b = diameter of each bolt,

$$d_b = \sqrt{\frac{4W_b N}{4\pi s}} ---------------3.24$$

3.5 Design Calculations

S/N	Initial Data	Calculations	Results
1	**The Handle**		
	L_h = 1000mm = 1m m = 50kg	Assuming a person can apply an average force of M (N) intermittently with the arm. M = mg = 50 x 9.81 =490.5N $L_h = T_h / M_h$ $T_h = L_h M_h$ = 1 x 490.5 = 490.5Nm	T_h = 490.5Nm
	$\sigma_u = 456 \times 10^6 \, N/m^2$ N = 3	The handle diameter is given by (equation 3.3) $d_h = \sqrt[3]{\frac{32 \times T_h \times N}{\pi \times \sigma_u}}$ $= \sqrt[3]{\frac{32 \times 490.5 \times 3}{\pi \times 456 \times 10^6}}$ $= 0.02798m$ $= 32mm$	d_h = 32mm
2	**The Screw** a = 0.266m c = 0.104m	Area over which pressure is applied $A_a = a \times c$ = 0.266m x 0.104m = 0.027664m^2	A_a = 0.028m^2

		$W_a = P_{min}A_a$	
	$P_{min} = 0.2 \times 10^6 N/m^2$	$= 0.2 \times 10^6\ N/m^2 \times 0.028\ m^2$	
		$= 5{,}600N$	$W_a = 5{,}600N$
		From equation 3.5	
	$\sigma_u = 456 \times 10^6\ N/m^2$	$d_1' = \sqrt{\frac{4W_a N}{\sigma_u \pi}}$	
	N = 3	$= \sqrt{\frac{4 \times 5600 \times 3}{456 \times 10^6 \times \pi}}$	
		$= 6.849 \times 10^{-3}\ m$	$d'_1 = 7mm$
		From calculation d'_1 = 6.8mm is the minimal screw thread root diameter required to apply the minimal pressure of $0.2 \times 10^6 N/m^2$ over the design area choice of screw thread would be larger than calculated d_1 to give more pressure for compression.	
		Available screw thread has d_1 = 46mm, d_2 = 48mm, L_s = 7mm which would be used for compression.	
		Maximum axial load from available screw thread.	
		From equation 3.5	
	d_1 = 46mm		
	d_2 = 48mm	$W_{max} = \frac{\pi d_1^2 \sigma_u}{4N}$	

		$= \frac{\pi \times (0.046)^2 \times 456 \times 10^6}{4 \times 3}$ $= 252{,}609N$ From equation 3.6 $d_m = \frac{d_1 + d_2}{2}$ $= \frac{46mm + 48mm}{2}$ $= 47mm$	W_{max} = 253,000N d_m = 47mm
	μ = 0.15 L = P_t = 7mm T_h = 490.5Nm d_m = 47mm $\phi = 8.53^0$ $\theta = 2.71^0$	From equation 3.7 $\phi = \tan^{-1} \mu$ $= \tan^{-1} 0.15$ $= 8.53^0$ From equation 3.8 $\tan\theta = \frac{L}{\pi d_m}$ $\tan\theta = \frac{7}{\pi \times 47}$ $\tan\theta = 0.0474$ $\theta = \tan^{-1} 0.0474$ $\theta = 2.71^0$ Axial load produced by available handle is (equation 3.10) $T_h = W_b \times \frac{d_m}{2} \tan(\theta + \phi)$	$\phi = 8.53^0$ $\theta = 2.71^0$

	$W_b = 105KN$ $A = 0.028m^2$	$490.5 = W_b \frac{0.047}{2} \tan(2.71 + 8.53)$ $W_b = 105{,}028N$ Maximum pressure which can be produced (equation 3.1) $P_{max} = \frac{W_b}{A_a}$ $= \frac{105 \times 10^3}{0.028}$ $= 3.75 \times 10^6 N/m^2$ Torsional shear stress (equation 3.11) $\tau = \frac{16T_h}{\pi d_1^3}$ $= \frac{16 \times 490.5}{\pi \times 0.046^3}$ $= 25.66 \times 10^6 N/m^2$ Direct stress (equation 3.12) $\sigma_n = \frac{4W_b}{\pi d_1^2}$ $= \frac{4 \times 105 \times 10^3}{\pi \times (0.046)^2}$ $= 63.2 \times 10^6 N/m^2$ Principal stress (equation 3.13) $\sigma_{1,2} = \frac{1}{2}\left[\sigma_n \pm \sqrt{\sigma_n^{\ 2} \pm 4\tau_n^2}\right]$	$W_b = 105{,}000N$ $P_{max} = 3.75 \times 10^6 N/m^2$ $\tau = 25.7 \times 10^6 N/m^2$ $\sigma_n = 63.2 \times 10^6 N/m^2$

		$= \frac{1}{2}\left[63.2 \pm \sqrt{63.2^2 \pm 4(25.7)^2}\right]$ $\sigma_1 = \frac{1}{2}[63.2 \pm 81.46]$ $\sigma_2 = \frac{1}{2}[63.2 \pm 36.77]$ $\sigma_1 = 72.33 \times 10^6 N/m^2 or - 9.13 \times 10^6 N/m^2$ $\sigma_2 = 50 \times 10^6 N/m^2 or 13.22 \times 10^6 N/m^2$ Maximum stress (equation 3.14) $\tau_{max} = \frac{1}{2}\sqrt{\sigma_n^2 + 4\tau^2}$ $= \frac{1}{2}\sqrt{63.2^2 + 4(25.7)^2}$ $= 40.73 \times 10^6 \; N/m^2$ Stress are within safe limit Buckling load (equation 3.15) $P_{cr} = \frac{\pi^2 EI}{L_s^2}$ The screw is shorter than 8 times the root diameter, so it is not considered as a column.	$\sigma_1 = 72.33 \times 10^6 N/m^2 or$ $-9.13 \times 10^6 N/m^2$ $\sigma_2 = 50 \times 10^6 \; N/m^2 or$ $13.22 \times 10^6 N/m^2$ $\tau_{max} = 40.73 \times 10^6 N/m^2$
	L_s = 300mm d_1 = 46mm		
3	**The Nut** d_1 = 0.046m d_2 = 0.048m	From equation 3.16 available thread area of screw is given by $A_1 = \frac{\pi}{4}\left(d_2^2 - d_1^2\right)$	

	H = 30mm P_t = 7mm	$=\frac{\pi}{4}\left(0.048^2-0.046^2\right)$ $=1.48\times10^{-4}m^2$ From equation 3.17 area of the nut is given by $A_2=\frac{HA_1}{P_t}$ $=\frac{30\times1.48\times10^{-4}}{7}$ $=6.34\times10^{-4}m^2$ Bearing pressure on nut as given by equation 3.18 $P_b=W_b/A_2$ $=\frac{105\times10^3}{6.34\times10^{-4}}$ $=165.61\times10^6 N/m^2$ Within safe limit	$A_2=6.34\times10^{-4}m^2$ $P_b=165.61\times10^6 N/m^2$
4	**<u>Cover Plate</u>** b = 0.124m $\sigma = 456 \times 10^6 N/m^2$ $W_b = 105 \times 10^3 N$	Thickness of cover plate (equation 3.22) $t_b=\sqrt{\frac{5W_b b^2 N}{2\sigma_u}}$ $=\sqrt{\frac{5\times105\times10^3\times0.124^2\times3}{2\times456\times10^6}}$ $=5.15\times10^{-3}m$ $=5.15mm$	$t_b=5mm$

5	**Coupling Bolt** $W_b = 105 \times 10^3 N$ $S = 380 \times 10^6 N/m^2$ $N = 3$	The diameter of the coupling bolt from equation 3.24 is $d_b = \sqrt{\frac{4W_bN}{4\pi S}}$ $= \sqrt{\frac{4 \times 105 \times 10^3 \times 3}{4 \times \pi \times 380 \times 10^6}} = 0.0162\,\text{m}$	$d_b = 16mm$ $= M20\ size$

3.6 Construction of Machine

Construction of the briquette screw press was carried out at JODA steel engineering works, line Zomo along Samaru road. The construction was carried out using the available necessary equipments such as the Oxygen-acetylene gas to cut the plates that are thicker than 4mm, drilling machine to bore holes, measuring tape to take measurements, tri-square to check the angles, hack saw for cutting, vice for holding the work piece, electric hand grinder for leveling cuts and welding machine with electrodes to join the parts. And the construction was done to specification as in the drawings.

Construction details are shown on drawing numbers 1 to 44.

Table 3.1 Construction Processes

S/No.	Component	Material	Construction Process	Equipments Used
1	Frame	Mild steel angle iron (50mmx50mm) Flat bar (10mmx75mm)	It was constructed by cutting the angle iron and flat bar into various sizes and joining them together as specified in drawing 4 to 12.	Measuring tape, vice, hacksaw, welding machine, electrodes, tri-square and drilling machine.
2	Mould	10mm thick mild steel plate	The plate was cut into two sizes of 104mmx344mm and	Measuring tape, tri-square, steel ruler, Oxygen-

			286mmx344mm and joined together as specified in drawings no. 13.	acetylene gas, lighter welding machine and electrodes.
3	Cone Rod with Base	8mm thick mild steel plate. 10mm diameter mild steel rod of 1000mm (4pieces).	It was constructed by cutting a 8mm plate into a size of 104mm by 266mm and 10 holes of 10mm bore. The steel rods were cut into 10pieces of 268mm, one end of all the 10 pieces were grind and they were assembled as specified in drawings no. 14 to 17.	Measuring tape, tri-square, steel ruler, Oxygen acetylene gas, lighter, welding machine, electrodes, vice, hacksaw, drilling machine and hand grinder.
4	Pressure Plate	6mm thick mild steel plate	The plate was cut into a size of 104mm by 266mm and 10 holes of 11mm were bored through as specified in drawings no. 18.	Hack saw, measuring tape, drilling machine and hand grinder.
5	Mould Cover	10mm thick mild steel plate.	The 10mm thick plate was cut into a size of	Vice, Oxygen-acetylene gas,

		6mm thick mild steel plate. 4mm mild steel plate. 25mm internal diameter galvanized pipe of 2mm thick. 72mm internal diameter steel pipe of 6mm thick.	124mm by 286mm. The galvanized pipe was cut into 10pieces of 100mm lengths. The 4mm plate was cut into 2pieces of size 10mm by 15mm. The 6mm plate was cut into 10pieces of size 46mm by 46mm and 12mm holes bore through each of them. 15mm length was cut out of the steel pipe to house a ball bearing. All the cut out pieces were joined together as specified in drawings 19 to 25	lighter, hack saw, tri-square, measuring tape, drilling machine, welding machine and electrodes.
6	Connecting Linkage	12mm by 75mm flat bar	The flat bar was cut into various appropriate lengths and joined together as specified in drawings 26 to 29.	Hack saw, vice, measuring tape, welding machine and electrodes.
7	Base Ram	8mm thick mild	The plate was cut into	Measuring tape,

		steel plate.	appropriate various sizes and joined together as specified in drawings no 30 to 36.	tri-square, Oxygen-acetylene gas, lighter, welding machine and electrodes
8	Mould divider	4mm thick mild steel plate	The mild steel plate was cut into four sizes of 104mm by 260mm and a groove cut along their axis up to their mid point. A 260mm by 266mm size was also cut and four grooves cut through from one end of the 266mm length up to its mid point and the cut plates interlocked and joined together. as in drawings no. 37 to 40	Hack saw, Oxygen-acetylene gas, lighter, measuring tape, welding machine, electrodes and tri-square.
9	Handle	25mm diameter mild steel rod	The steel rod was cut into a length of 400mm and 0.5mm turned from	Lathe machine, hack saw, vice and measuring

			one end through a length of 300mm on the lathe machine as specified in drawing no. 41.	tape.
10	Pivot Shaft	25mm diameter mild steel rod	224mm was cut out of the mild steel length and 2holes of 5mm drilled through close to the two ends as in drawing no. 42.	Hack saw, measuring tape, vice and drilling machine.
11	Ejection Shaft	18.75mm diameter mild steel rod	A length of 244mm was cut from the 18.75mm diameter rod as in drawing no. 43.	Hack saw, measuring tape, and vice
12	Screw Thread Shaft	48mm outer diameter mild steel square thread	From a purchased square thread of outer diameter, 7mm pitch, thread length of 300mm and shaft length of 100mm a hole of 25mm was bore through 50mm from the shaft end as in drawing no. 44.	Drilling machine

3.7 Pallets (Aluminum Foil)

Aluminum foils used in printing press were obtained in the size of 300mm by 500mm and cut into rectangular sizes of 146mm by 260mm with a scissors. The cut pieces (ten in number) were folded into a U-shape at 48mm from the shorter edges along the both longer sides see Plate IV.

Plate IV: Aluminum Foil (pallet)

3.8 Coupling of Components

The mould was placed on the frame; the edges of the mould were properly aligned with that of the frame and weld together. The two bushings were weld to the outer surface hole of the base ram, one on each side to avoid rocking of the ram during operation and the cone rod base plate was weld onto the surface of the base ram and edges grind with a hand girder. The base ram whole unit was placed into the mould by holding the rods with cane when lifting. Two (205) ball bearing were placed to face the base ram hole, one on each side from outside the frame with the two girders on the frame acting as railing for the bearing. The connecting linkage was placed over the mould and frame with its holes in-line with that of the bearings and the base ram. Holding the connecting linkage in the vertical position the coupling shaft was passed through the holes and a 5mm concrete nail was force fitted into the coupling shaft. The 75mm outer diameter nut which was purchased along with the screw thread shaft was placed in the gap at the top end of the connecting linkage and weld to the connecting linkage, and then the screw thread shaft was screwed through the nut see plate V.

Plate V: Fully assembled briquetting press

3.9 Method of Operating the Briquette Press

The machine is bolted to a plank of wood 1000mm x 300mm x 250mm through the holes on the base of the frame and raised on a floor of height 100mm and area 1000mm by 1000mm or bolted to a concrete floor prepared for the press usage.

3.9.1 Filling Mould with Material

In the vertical position, the screw thread handle is pulled back to rest the connecting linkage against the ejecting shaft. Aluminum foils used by printing press are cut and folded into the shape of each sections of the mould to act as pellets. The prepared residue is filled into the mould and rammed slightly with a 18.75mm plastic pipe, making sure that the corners are properly filled see Plate VI and VII.

Plate VI: Mould before filling

Plate VII: Filling mould with prepared residue

3.9.2 Compression Stroke

The mould is covered and the screwed thread brought back to the vertical position over the cover. With the handle the screwed thread is turned to align into the cover bearing to push down the cover and pull up the base ram through the connecting linkage until full compression is achieved, see Plate VIII and IX.

Plate VIII: Position for compression

Plate IX: Inside mould after compression

3.9.3 Ejection Stroke

The screw thread is swung back over the mould to the same position as during filling. The mould cover is removed and the screw thread is depressed further by pulling and jerking the connecting linkage with the screw thread handle until the briquette is completely out of the mould and connecting linkage is held in this ejection position until the briquettes are removed from the press. The briquettes are separated from the mould divider with the aluminum foils acting as pallets using a flat steel plate or an old steel ruler and dried in the sun, see Plate X to XII.

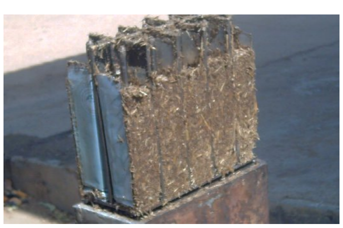

Plate X: Ejected briquettes

Plate XI: Removing Briquette from divider

Plate XII: Briquettes drying in the sun

3.9.4 Maintenance and Repair

- The inside of the mould, pressure plate, mould divider, aluminum foils and under surface of the cover must be kept clean after each day's operation.
- All moving parts and wearing parts (rollers, screw thread and roller guide on frame) should be well lubricated with heavy oil or grease to insure smooth operation and cut down on wears.
- The pins which secure the pivot shaft, base ram, connecting linkage and rollers should be replaced when broken by the largest nail available.

3.10 Briquette Production

3.10.1 Material

The materials used in the production of the briquettes include;

- Rice husk
- Rice straw
- Saw dust
- Cassava starch
- Water

3.10.2 The Binder: Cassava Flour

Cassava flour is made from a tropical root crop cassava. The crop is quite robust, it can be easily grown in infertile soil, and additionally can withstand drought and other climatic changes. When boiled with water, cassava flour can be made into a porridge-like food product. In its cooked state, cassava flour makes an excellent, combustible binder. The binding by starch occurs after drying.

3.10.3 Preparation and Production of Briquettes from Residues

Residues of sawdust, rice husk and rice straw were used in the production of briquettes. Dried rice straws were obtained from the field and pounded in a mortar with a pestle then crushed with bare hands to smaller size and sieved through a 5mm sieve to suitable, smaller and uniform size, see Plate XIII.

Plate XIII: Crushed Rice Straw

Samples of one (1) kilogram of rice husk, rice straw, saw dust, combine 0.5kg fine sawdust and 0.5kg rice husk were, each, measured into separate bowls and labeled A,B,C and D respectively. In a bowl, 0.5litre of cold water was combined to 0.25kg of cassava flour and mixed in a pot of 2.5litre of boiling water. When the water was boiling, the cassava flour with water mixture, was gradually stirred in. The temperature of the stove heating the mixture was kept constant throughout the process and the mixture continuously stirred for 5 to 10 minutes, until it was slightly lumpy and rather viscous.

The cooked starch was poured into bowl ‘A’ containing the rice husk residue and mixed thoroughly with bare hands, until the mixture had a thick consistency that feels moist, but does not easily flow. Some of the mixture was formed into a ball that holds its shape without falling apart indicating the correct amount of starch binder was added. The same binder preparation and material mix process was carried out on samples B, C and D. The fabricated briquetting press was used in the production of the briquettes with the folded Aluminum foils inserted into each of the mould cavities. The mixed residue was filled into the mould cavities and ram slightly with an 18.75mm PVC pipe to compress and make sure the corners were properly filled. The mould cover was placed over the residue, compressed, ejected and dried on a flat surface or platform in the sun.

Production and drying of the briquettes was done during the harmattan season. It took a maximum of seven days to achieve a constant dry weight during drying. Plate XIV to XVII shows the briquette types produced.

Plate XIV: Rice Straw Briquette

Plate XV: Rice Husk Briquette

Plate XVI: 50% Saw Dust + 50% Rice Husk Briquette

Plate XVII: Saw Dust Briquette

CHAPTER FOUR

TESTS AND RESULTS

4.1 Tests

4.2 Determination of Calorific Value

The calorific value for the briquettes samples and firewood sample were determined using a Mahler – cook bomb calorimeter in the heat transfers laboratory of Mechanical Engineering department in Ahmadu Bello University Zaria.

4.2.1 Equipments used for the Calorific value test

(i) Mahler – cook bomb calorimeter and accessories.

(ii) Oxygen cylinder in mobile trolley with valves and pressure gauge assembly for changing the bomb.

(iii) Special vice and spanner.

(iv) Thermometer 0 – 100^{o}C by 0.1^{o}C and magnifying eye piece.

(v) Stanton balance model CB3

(vi) Empty gelatin capsules

(vii) Pipette (1ml)

(viii) Cotton thread

(ix) Stop clock

(x) Ignition fuse wire

4.2.2 Test Procedure Carried Out

a. Pieces of each of the various briquettes and of firewood were ground and sieved through a 250μm sieve.

b. Five empty gelatin capsules were measured on the balance then various samples of the sieved introduced into the lower half of the capsules and covered immediately and weighed.

c. The bomb calorimeter interior was cleared before starting and 1ml of distilled water pipetted into the bomb.

d. The gelatin capsule with the sample was uncovered.

e. A length of 6cm fuse wire was folded into two and the folded end placed into the capsule, then re-covered back with the two wire ends outside the capsule.

f. The two wire ends were connected across the terminals of the bomb along with some cotton thread and the capsule set into the crucible.

g. The bomb was carefully closed using the special vise and spanner, then connected to the oxygen bottle and charged with oxygen carefully up to 25 to 30 atms.

h. 2900gms of water at temperature $3^{o}C$ below room temperature was added to the calorimeter vessel and the bomb submerged into it, without the electrical terminals in it. The bomb was carefully put in place, the electrical connections made and checked to ensure no oxygen leakage.

i. The thermometer and stirrer were arranged so that they do not touch the bomb or the vessel then the stirrer switched on.

j. When the temperature was noticed to be rising steadily and the stirrer had been running for at least 2minutes, a series of readings at one minute interval were taken for 5 minutes. At the end of the 5 minutes, the firing circuit was closed for two seconds and the bomb isolated for 20 seconds.

k. The one minute reading was continued until the temperature passed through the maximum and the temperature started dropping.

l. After five minutes, five temperatures drop reading were taken, the bomb was removed, inserted in the vise and the pressure released slowly and uniformly over a period of one minute by unscrewing the check value short distance and pressing down.

m. The bomb was opened, observed for proper combustion, rinsed out, cleaned and dried. This test procedure was carried out for all the various samples

The calorific value was calculated for the fuel samples as analyzed below;

Heat energy liberated by the fuel (Adegoke 1999) is given by:

$$Q_f = M_f H_f \qquad 4.1$$

Heat absorbed by water and calorimeter (Institute of Petroleum, 1960) is given as:

$$Q_{w+c} = (M_w + M_\theta) C_w \Delta\theta = M_f H_f + \text{losses} \qquad 4.2$$

The energy equation used to determine the calorific value is given below.

$$(M_w + M_\theta) C_w \Delta\theta = M_f H_f + M_c C_c + M_{fw} C_{fw} + M_{cap} C_{cap} \qquad 4.3$$

Where;

$$M_f H_f = (M_w + M_\theta) C_w \Delta\theta - M_c C_c - M_{fw} C_{fw} - M_{cap} C_{cap}$$

The readings obtained from the bomb calorimeter test in appendix B was used to plot graphs of temperature against time for all the fuel samples to determine the temperature differences, in figure 13 to 17.

Sixty percent (60%) of the temperature rise for each curve, which is between the time of ignition and the time at which the temperature rise became a maximum was calculated and marked to cut the curves toward the maximum temperature in a vertical position. Tangential lines were drawn from the curve of the temperature rise and temperature fall to touch the 60% line drawn. From the points in which the lines met each other horizontal lines were drawn to touch the vertical axis of the graphs and readings of the temperatures were made to obtain the actual temperature rise from the graphs for the fuel samples according to Gary (2002).

4.3 The Water Boiling Test (WBT)

4.3.1 Introduction

What is interesting concerning the energy content of a briquette is how much of the energy in the briquette that can be actually be used. If the same test is performed on each briquette and firewood, a good comparison can be made. The test is called the Water Boiling Test and it will be used for comparing:

- The briquettes with each other
- The briquettes with firewood

The modified version of the WBT, which was developed for the Shell Household Energy Programme based on the procedures proposed by VITA (1985) and Baldwin (1987) was used in this work. It consists of three phases.

1) In the first phase, I began with the stove at room temperature and using a pre-weighed bundle of wood to boil a measured quantity of water in a standard pot. I then replaced the boiled water with a fresh pot of cold water to perform the second phase of the test.
2) In the second phase which is the high power test with hot start, water is boiled beginning with a hot stove in order to identify differences in performance between a stove when it is cold and when it is hot.

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

This third step simulates the long cooking of legumes or pulses that is common.

4.3.2 Equipments used in the Boiling Water Test

- Thermometer (0 – 100^{o}C range)
- Scale of 10kg capacity and 10gram accuracy
- Timer (Digital stop clock)
- Pot of diameter 18cm, 10cm deep and water holding capacity of 2.5kg
- 1.7litres of clean water for every test
- Dust pan for transferring ash
- Metal tray to hold ash for weighing
- Heat resistant gloves
- Air dried fuel samples

4.3.3 Variables

4.3.3.1 Fuel Samples

Fuel samples of similar size of average dimension 260mm x 50mm x 50mm were used for the test in order to minimize variation due to fuel differences. This size is in accordance to Olle and Olof (2006) who states that: the type and size of fuelwood can affect the outcome of the stove performance tests. In order to minimize the variation that is potentially introduced by variations in fuel characteristics VITA (1985) recommends taking the following precautions:

- Use only wood that has been thoroughly air-dried. Drying is accelerated by ensuring wood is stored in a way that allows air to circulate through it.
- Different sizes of wood have different burning characteristics. While stove users may not have the ability to optimize fuel size, use only similar sizes of wood to minimize this source of variation throughout the world.

The central hole in the briquettes helps the air to pass through, which makes the combustion much more efficient. The wood species used for this experiment as firewood was *Parkia biglobosa.*

4.3.3.2 Stove

For this test the 3-stone open fire which is the most widely used within most homes was used. The stove consists of three stones placed on the ground, forming at the edges a triangle, which holds the pot 14cm above the ground. Underneath the pot fuel wood is pushed in from different angles.

4.3.3.3 Pot

Aluminum pot of 300g, weight, 18cm diameter, and 10cm depth of capacity 2.5kg was used for the test. Before the test, the pot was scrubbed clean, both inside and outside. It was dried before each test.

4.3.3.4 Lid

The water boiling tests were conducted without a lid. This was in accordance with Baldwin (1987) who states that lid should not be used for the WBT because it does not affect the transfer of heat from the stove to the pot and it has little impact on the result of the test.

4.3.3.5 Power Control

Due to the lack of adequate turn - down ability of the 3-stone stove to maintain a desired temperature without the fire going out, the minimum amount of fuel sample necessary to keep the fire from dying completely was used in all the test.

4.3.3.6 Environment

I carried out the test during the harmattan period of the year indoor.

4.4 Experimental Phases Process

4.4.1 Phase 1: High Power (Cold start)

a. The timer was prepared, but not started until the fire was started.

b. The empty pot was placed on the scale and water was filled into the pot $^2/_3$ full to give the total weight of the pot and water together as 2kg. The weight of the pot with the water was recorded.

c. A thermometer was placed into the pot to take the initial water temperature and recorded.

d. Pre-measured recorded fuel sample was placed in the stove and fire was started using kerosene as the starting material.

e. As the fire was started the pot containing the water was placed on the stove.. The timer was started and readings of the water temperature were taken at two and half minutes intervals.

f. The fire was controlled by means of bringing the water in the pot rapidly to boil without waste of the fuel used.

g. When the water in the pot reached the boiling temperature as shown by the thermometer, rapidly the following were done:

(i) The time the water in the pot reached the local boiling point was recorded along with the temperature.

(ii) All fuel sample were removed from the stove and the flames extinguished by blowing the ends and knocking all loose ash off the ends of the fuel into the container for collecting the ash for weighing.

(iii) The unburnt fuel, removed from the stove was weighed and the weight recorded.

(iv) The pot with hot water was weighed and the weight recorded.

(v) The ash from the stove was extracted and weighed with the ash knocked off the fuel and the weight recorded.

The second phase of the test, high power (hot start) was continued within 10 minutes after the completion of the first test high power (cold start) on the same stove.

4.4.2 Phase 2: High Power (Hot start)

a. The timer was reset, but not started until the fire was started.

b. The pot was refilled with 1.7kg of fresh cold water which was $\frac{2}{3}$ full of the pot to give a total weight of the pot and water together as 2kg. The weight of the pot with water and water's initial temperature were recorded.

c. The fire was rekindled using kerosene.

d. As the fire was started the pot was placed on the stove with the water. The timer was started and readings of the temperature were taken at every two and half minute intervals.

e. When the boiling temperature was reached, the following were done rapidly:

(i) The unburnt fuels were removed from the fire and the loose ash knocked into the stove. The unburnt fuels were weighed and returned into the stove immediately. The weight was recorded.

(ii) The water temperature was taken and recorded.

(iii) The pot with the water was weighed and returned on the stove and the weight recorded.

4.4.3 Phase 3: Low Power (Simmering)

The hot start high power test was continued with the flame reduced and the water simmered for additional 45minutes at a temperature between $3^oC – 4^oC$ below the boiling temperature using minimal amount of fuel. When the 45minutes was reached, the following were done rapidly:

a. All fuel sample were removed from the stove and the flame extinguished by blowing on the ends and knocking all loose ash off the ends of the fuel into the container for collecting the ash for weighing.
b. The un-burnt fuel, removed from the stove was weighed and the weight recorded.
c. The pot with water was weighed and the weight recorded.
d. The ash from the stove was extracted and weighed with the ash knocked off the fuel and the weight recorded.

4.5 Analysis

4.5.1 Definition of terms

$f_m = f_i – f_f$ - 4.4

$f_d = f_i – f_f - \Delta C$ - 4.5

$W_v = P_i – P_f$ - 4.6

$W_r = P_f - P_e$ - 4.7

$\Delta\theta = t_f - t_i$ - 4.8

$\Delta T = T_f - T_i$ - 4.9

The fuel sample outputs to be analyzed include:

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

$$\eta = \frac{C_{p.w} \times (p_i - p_e) \times (T_f - T_i) + H_L \times (p_i - p_f)}{f_m \times H_f} \text{ - - - - - - - - 4.10}$$

R_b - Burning Rate: This is a measure of the rate of wood consumption while bringing the water to a boil. It is calculated by dividing the equivalent dry wood consumed by the time of the test.

$$R_b = \frac{f_m}{t_f - t_i} \text{ - 4.11}$$

SC- Specific fuel consumption: This is a measure of the amount of wood required to produce one gram of boiling water or maintain one gram of boiling water within 3^oC of the boiling point.

$$SC = \frac{f_d}{p_f - p_e} \text{ - 4.12}$$

4.5.2 Statistical Analysis

The statistical tool used for the analysis of this work is the analysis of variance based on the two way classification method with the t -distribution and F-distribution table at 5% and 1% significance level in appendix O, P and Q respectively. This statistical tool was used to compare the briquette samples thermal efficiency, burning rate and boiling time with that of firewood and among themselves in order to determine whether there is any significant difference in their average performance values.

4.5.3 Analysis of Variance (ANOVA)

The total variation is partitioned into two sources of variation-treatment and experimental error variation. The relative size of the two variations is used to indicate whether the observed difference among experimental values is significant or due to chance.

The observed difference is said to be significant if the treatment variation is sufficiently higher than the experimental error variation (Rao et al, 1966).

The ANOVA table is a useful means of analysis of variance. Table 4.1 below shows a format of the ANOVA table.

Table 4.1: The ANOVA table

Source of variation	D.F	S.S	M.S	F
Treatment (fuel sample)	k – 1	SS_t	$\frac{SS_t}{(k-1)} = MS_t$	$\frac{MS_t}{MS_\varepsilon}$
Error	(r - 1)k	SS_ε	$\frac{SS_\varepsilon}{(r-1)k} = MS_\varepsilon$	
Total	kr-1	SS_T		

The treatment mean squares MS_t and the error mean square MS_ε each gives an independent unbiased estimate of the population variance. This is true only if the means are equal i.e. if the null hypothesis is true. But if the null hypothesis is false, the treatment mean square will be larger than the error mean square. This ratio of treatment mean square to error mean square, enable one to determine if there are differences between the treatments (fuel samples). Thus, by comparing the computed F-value, to the tabled F-value, I can reject or accept the null hypothesis at a given significant level.

If the calculated F-value in the ANOVA table is greater than the critical value from the F-table, the null hypothesis of equal means is rejected at a given significant level. Otherwise, I fail to reject.

Once the null hypothesis is rejected, it becomes necessary to compare means using any of the following methods: Least Significant Difference (LSD) and Duncan's multiple range test.

Least Significant Difference (LSD) was used in this experiment. It is defined by

$$LSD = t\sqrt{\frac{2MS_{\varepsilon}}{n}} \text{ - } 4.13$$

A comparison is made between any two means and the LSD value. If it is larger, then the means are significantly different at a given significant level.

The preliminary data and calculations obtained from the evaluation of the fuel samples during the Water Boiling Test are given in appendix D to N and table 4.2 to 4.8 respectively.

4.6 Calorific value of fuel samples

Using equation 4.3 with the data obtained from the bomb calorimeter test given in appendix A and temperature rise values obtained from figure 13 to 17 the calorific values of the fuel samples were estimated and summarized in table 4.2, using the procedure in appendix C. These values were used to evaluate the performance parameters of the fuel samples in terms of efficiency, burning rate and specific fuel consumption and represented with bar charts in appendix S.

4.6.1 Average Thermal Efficiency for Fuel Samples

The average thermal efficiencies of the various fuel samples were estimated using equation 4.10 with data obtained from the WBT in appendix I to N, for high power (cold start), high power (hot start) and low power (simmering) which can be seen in table 4.3.

Analysis of variance (ANOVA) for the average thermal efficiencies distribution of the fuel samples are shown in table 4.4. Comparison of the average thermal efficiencies of each the briquettes with the least square difference value (0.3) computed in table 4.4, showed that rice husk briquette (22.42%) with the highest thermal efficiency was significantly different from rice straw briquette (10.68%) and firewood (12.29%). This difference was highly significant at P = 0.01. However, this difference there was not significant from sawdust briquette (15.40%) and 50% rice husk + 50% saw dust briquette (18.52%), because the difference between the average thermal efficiencies of the briquettes was less than the least square difference value. Also, 50% rice husk + 50% saw dust briquette (18.52%) showed that there was significant difference from rice straw briquette (10.68%) and fire wood (12.29%). This difference was significant at P = 0.5.

4.6.2 Average Burning Rate for fuel samples.

The average burning rates values for all five fuel samples at high power (cold start), high power (hot start) and low power (simmering) and their means are shown in table 4.5.

The analysis of variance (ANOVA) for the average burning rate of the fuel samples is shown in table 4.6.Comparison of the performance between the average burning rate of the briquettes with the least square difference value (0.68) computed and analyzed in table 4.6, showed that rice husk briquette (0.83kg/hr) with the lowest burning rate was significantly different from fire wood (1.62kg/hr). This difference was significant at P =

0.05. However, not significantly different from 50% rice husk + 50% sawdust briquette (0.93kg/hr), sawdust briquette (1.03kg/hr) and rice straw briquette (1.10kg/hr). Since, the differences between the average burning rate of the briquettes were less than the least square difference value.

4.6.3 Average Specific Consumption for Fuel samples

The average specific fuel consumption for all five fuel samples at high power (cold start), high power (hot start) and low power (simmering) and their means are shown in table 4.7.

The analysis of variance (ANOVA) for the average specific fuel consumption of the fuel samples is shown in table 4.8. Comparison of the performance between the average specific fuel consumption of the briquettes with the least square difference value (0.21) computed and analyzed in table 4.8 showed that rice husk briquette (0.13g/g) with the lowest specific fuel consumption was significantly different from fire wood (0.36g/g). This difference was significant at P = 0.05. However, not significantly different from 50% rice husk + 50% sawdust briquette (0.16g/g), sawdust briquette (0.26g/g) and rice straw briquette (0.30g/g). Since, the differences between the average burning rates of the briquettes were less than the least square difference value.

4.6.4 Boiling Time

Readings of the values for the water boiling test in Appendix I to N for the various fuel samples were used to plot a graph of temperature against time as shown in figure 18 to 23. From the plotted graphs it was observed that 50% rice husk + 50% saw dust briquettes had the fastest rate of boiling water, followed by rice husk briquette. The time in which the local boiling temperatures were attained during the Water Boiling Test for each of the fuel samples along with their simmering durations are shown in table 4.9.

Table 4.2: Bomb Calorimeter Test Results of Fuel Samples

Fuel Samples	Fuel Sample Weight (g)	Temperature rise (^{o}C), $\Delta\theta$	Calorific Value (KJ/kg)
Rice straw Briquettes	0.1325	0.2950	16,577
Rice husk Briquettes	0.1325	0.2650	14,396
Saw dust Briquettes	0.0988	0.2500	15,547
50%rice husk + 50% sawdust briquettes	0.1140	0.2850	17,529
Firewood	0.1643	0.2950	12,378

Table 4.3: Average Values of Thermal efficiency of Fuel Samples

Fuel samples	High power (cold)	High power (hot)	Low power (simmering)	Total	Mean
Rice straw briquettes %	11.33	10.43	10.27	32.03	10.68
Rice Husk briquettes %	24.60	25.39	17.26	67.25	22.42
Saw dust briquettes %	16.91	15.39	13.90	46.20	15.40
50% rice husk + 50% saw dust briquettes %	20.92	21.06	13.59	55.57	18.52
Firewood %	11.70	13.10	12.07	36.87	12.29

Table 4.4: Analysis of variance for thermal efficiency of fuel samples

Source	D.F	S.S	M.S	F	$F_{(0.05)}$	$F_{(0.01)}$	$LSD_{(0.05)}$	$LSD_{(0.01)}$
Fuel sample	4	320.23	80.06	5.29	3.48	5.99	0.21	0.30
Error	10	151.42	15.14					
Total	14	471.65						

Table 4.5: Average Values of Burning Rate of Fuel Samples.

Fuel samples	High power (cold)	High power (hot)	Low power (simmering)	Total	Mean
Rice straw briquettes (kg/hr)	1.07	1.39	0.85	3.31	1.10
Rice Husk briquettes (kg/hr)	0.90	1.00	0.58	2.48	0.83
Saw dust briquettes (kg/hr)	1.15	1.26	0.69	3.10	1.03
50% rice husk + 50% saw dust briquettes (kg/hr)	1.23	0.96	0.60	2.79	0.93
Firewood (kg/hr)	2.16	1.75	0.95	4.86	1.62

Table 4.6: Analysis of Variance for Burning Rate of Fuel Samples

Source	D.F	S.S	M.S	F	$F_{(0.05)}$	$F_{(0.01)}$	$LSD_{(0.05)}$	$LSD_{(0.01)}$
Fuel sample	4	1.13	0.28	2.00	3.48	5.99	0.68	0.97
Error	10	1.39	0.14					
Total	14	2.52						

Table 4.7: Average Values for Specific Fuel Consumption of Fuel Samples

Fuel samples	High power (cold)	High power (hot)	Low power (simmering)	Total	Mean
Rice straw briquettes (g/g)	0.23	0.25	0.41	0.89	0.30
Rice Husk briquettes (g/g)	0.09	0.08	0.22	0.39	0.13
Saw dust briquettes (g/g)	0.18	0.20	0.41	0.79	0.26
50% rice husk + 50% saw dust briquettes (g/g)	0.11	0.06	0.31	0.48	0.16
Firewood (g/g)	0.26	0.29	0.52	1.07	0.36

Table 4.8: Analysis of Variance for Specific Fuel Consumption of Fuel Samples

Source	D.F	S.S	M.S	F	$F_{(0.05)}$	$F_{(0.01)}$	$LSD_{(0.05)}$	$LSD_{(0.01)}$
Fuel sample	4	0.11	0.03	2.14	3.48	5.99	0.21	0.30
Error	10	0.14	0.014					
Total	14	0.25						

Table 4.9: Results of Fuel Samples Boiling point Time and Simmering Duration

Fuel samples		Boiling Time (minutes) Cold start	Boiling Time (minutes) Hot start	Boiling Time (minutes) Simmering
Rice straw briquettes	Test 1	29.07	19.08	45
	Test 2	23.39	21.58	45
	Test 3	24.50	22.00	45
Rice Husk briquettes	Test 1	19.20	13.30	45
	Test 2	14.10	13.05	45
	Test 3	14.08	12.58	45
Saw dust briquettes	Test 1	17.18	16.00	45
	Test 2	16.10	16.03	45
	Test 3	16.05	15.59	45
50% rice husk + 50% saw dust briquettes	Test 1	10.40	15.30	45
	Test 2	11.00	12.15	45
	Test 3	10.35	10.58	45
Firewood	Test 1	12.12	18.10	45
	Test 2	15.36	15.58	45
	Test 3	17.06	18.17	45

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 Introduction

The briquette screw press performs the function for which it was designed. It works based on the principle of the Cinva ram machine to compress residues into briquette form. When the machine was tested to produce briquettes it produced satisfactory briquettes. The products were tested to determine their performance. The overall conclusion can be shown that briquettes can be used as alternative fuel to firewood.

5.2 Performance of the Briquetting Screw Press

The designed screw briquetting press performed well in compacting of the selected residue samples into the desired shapes. It was discovered that the aluminum foils which act as pallets for the briquettes could be used for up to a week before they are due for a change. But if the constructed mould and cover dimensions are not in conformity with the drawing details it would cause constant damages to the aluminum foils, which would call for replacement frequently and add to the cost of briquette production. With two workers an average of 240 to 320 briquettes can be produced a day (eight working hours) if proper/careful removal of the briquettes are done to reduce the number of briquettes damaged by crumbling.

In a study involving experimental production of briquettes from chopped rattan strands mixed with cassava starch paste Olorunnisola (2004), obtained a minimum proportion of 200% by weight of cassava starch for briquette formulation using a simple table top close - end die piston press. Whereas, in this research, for every one kilogram of each residue a minimum proportion of 30% cassava starch was required for satisfactory binding of the briquettes using the designed briquetting press.

5.3 Performance of Fuel Samples

5.3.1 Rice Straw Briquettes

Briquetting the prepared rice straw residue into the required shape took 20minutes for one compression, ejection to removal cycle. Separating the briquettes from the mould and pallet while wet was easy. The shape was retained without crumbling, cracks and breakages. Less starch binder was used in comparison with other residues.

The calorific value 16,577KJ/kg from the bomb calorimeter test performed on the rice straw briquette was found to be 8.3% higher than its residue value 15,300KJ/kg given by Barnard (1985) in table 2.2. It was observed that there was significant drop in the average thermal efficiency of the rice straw briquette (10.68%) when compared to firewood (12.29%), the average burning rate of the rice straw (1.10kg/hr) with specific fuel consumption (0.30g/g) was discovered to be lower than that of firewood average burning rate (1.62kg/hr) with specific fuel consumption (0.36g/g). But it was discovered from the ANOVA table that it had no significance compared to firewood.

The rice straw briquette burnt slowly with whitish smoke producing high ash quantity.

From the Water Boiling Test plot of temperature versus time in figures 19 to 24 it was observed that the rice straw briquettes took the longest time to boil the measured quantity of water to its local boiling point.

5.3.2 Rice Husk Briquettes

Briquetting the prepared rice husk material into shape took an average of 25minutes for the production cycle process. During the production there was little difficulty in the separation of the briquettes from the divider. A lot of care had to be taken to remove the briquettes for drying because in the process some broke, some crumbled at the edges and some developed cracks while, those that were not affected came out perfect. The briquettes had to be left to dry on the pallets for two hours before they could be turned over for the pallets to be removed, unlike that of the rice straw which came off immediately after separation from the divider.

The calorific value of 14,396KJ/kg obtained for the rice husk briquette from the bomb calorimeter test was found to be 0.4% less than mean calorific value obtained by Krist and Wentink (1985) as 14,450KJ/kg in table 2.2.

From the water boiling test, result of the average thermal efficiency of 22.42% with a burning rate of 0.83kg/hr and specific fuel consumption of 0.13g/g for the rice husk briquette showed that it had a better performance than that of firewood of average thermal efficiency of 12.29% with a burning rate of 1.62kg/hr and specific fuel consumption of 0.36g/g. The ANOVA result showed the rice husk briquette to be significant in replace of firewood. The water boiling time observed between 13 to 16minutes was in the same range with what was obtained by Inegbenebor (2002) as 14 to 22minutes. The burning of the briquette was rapid and steady with little white smoke.

From the Water Boiling Test the plot of temperature versus time in figures 19 to 24 showed that the rice husk briquettes had the second fastest rate of bringing the measured quantity of water to its local boiling point obtained as 96°C.

5.3.3 Saw Dust Briquettes

Briquetting the prepared saw dust material into shape took an average of 25minutes for the production cycle process. During the production there was little difficulty in the separation of the briquettes from the divider. A lot of care had to be taken to remove the briquettes for drying because in the process some got broken, some crumbled at the edges and some developed cracks while, those that were not affected came out perfect. The briquettes had to be left to dry on the pallets for two hours before they could be turned over for the pallets to be removed.

The calorific value of 15,547KJ/kg obtained from the bomb calorimeter test with an average thermal efficiency of 15.40%, burning rate of 1.03kg/hr and specific fuel consumption of 0.26g/g for the saw dust briquette from the water boiling test showed that it had a better performance than that of firewood of average thermal efficiency of 12.29% with a burning rate of 1.62kg/hr and specific fuel consumption of 0.36g/g. But from the ANOVA result it was discovered not to be significant in comparison to firewood. The water boiling time observed between 15 to 17minutes was in agreement with what was obtained by Inegbenebor (2002) as 14 to 22minutes. The burning of the briquette was very rapid and steady with little white smoke and it produced red hot charcoal.

From the Water Boiling Test the plot of temperature versus time in figures 19 to 24 showed that the saw dust briquettes takes a longer time to boil the same quantity of water when compared to Rice straw, 50% Rice husk + 50%Saw dust briquettes and firewood.

5.3.4 50% Rice Husk + 50%Saw Dust Briquettes

Briquetting of the prepared mixture into shape was quite easy and it took an average of 20minutes for the production cycle process. In the separation of the briquettes from the divider the cracks, crumbling and breakages were less.

The calorific value of 17,529KJ/kg obtained was the highest of the samples. From the water boiling test result of the average thermal efficiency of 18.52% with a burning rate of 0.93kg/hr and specific fuel consumption of 0.16g/g for the briquette showed that it had a better performance than that of firewood of average thermal efficiency of 12.29% with a burning rate of 1.62kg/hr and specific fuel consumption of 0.36g/g. From the ANOVA result it was discovered to be significant to replace firewood. The water boiling time observed between 10 to 13minutes was not in range with what was obtained by Inegbenebor (2002) as 14 to 22minutes. The burning of the briquette was rapid, steady with very little white smoke and it produced red hot charcoal.

From the Water Boiling Test the plot of temperature versus time in figures 19 to 24 showed that 50% Rice husk + 50%Saw dust briquettes had the fastest rate of bringing the measured quantity of water to a local boiling point as compared to the other fuel samples.

Charts summarizing the fuel samples performance parameters can be seen in Appendix S.

Table 5.1 Bill of Quantity

S/N o	Material	Dimensions (mm)	Quantity	Cost =N=
1	10mm Plate	820x580	1	3000.00
2	8mm Plate	530x390	1	1500.00
3	6mm Plate	260x210	1	600.00
4	4mm Plate	800x260	1	1500.00
5	1m, 1" Galvanized pipe	1000 length	1	500.00
6	1m, 10mm rod	1000 length	5	800.00
7	Printing Aluminum Foil	300x500	5	50.00
8	10mm Flat bar	3500 length	1	3000.00
9	2"x2" Flat bar	3500 length	1	3000
10	3m, 12mm Flat bar	2,150 length	1	3500.00
11	Power Screw	300 length	1	600.00
12	Three Quarter Shaft	224 length	1	80.00
13	1" Shaft	624 length	1	250.00
14	205 Bearing		2	100.00
15	207 Bearing		1	50.00
16	Workmanship + Painting			15,000.00
17	**Total Cost**			**33,280**

CHAPTER SIX

Summary, Conclusion and Recommendation

6.1 Summary

This research into briquette production for rural communities is a broad and challenging task. This research sought to design a local low cost briquetting press to produce briquettes with selected residues and determine their performance. The variation in the briquette performance was investigated.

The popular known CINVA-RAM press use in making earth ram bricks was considered and modified to a suitable briquette machine press. Briquettes were produced from rice husk, rice straw, saw dust and combination of saw dust and rice straw using starch as binder. Calorific values of the produced briquettes were determined using the bomb calorimeter and their performance was determined using the Water Boiling Test (WBT). For the WBT three tests were carried out on each of the four types of briquette and firewood using the open three stone stove. The test consisted of three phases i.e. high power (cold start), high power (hot start) and low power (simmering) as recommended by VITA (1985) and Baldwin (1987) to cater for variabilities.

Readings of the tests were taken down and analyzed to determine thermal efficiency, burning rate and specific fuel consumption of the briquettes compared to firewood under the same test. These readings were analyzed statistically using Analysis of Variance (ANOVA) and Least Significant Difference (LSD) to determine their significance compared to firewood and performance compared to each other. These results were discussed.

6.2 Conclusion

The set goal: design and construction of a briquetting machine was achieved, it was not without limitation. Separation of the briquettes from the divider after compression was not straight forward as expected, it had to be done with care to avoid damages on the briquettes. The high cost of the parts and workmanship was due to the machine, been a project, a lot of materials were wasted and great attention had to be given to the construction to get it working and achieve its aim. The briquetting machine could go for half the cost in producing it; sixteen thousand six hundred and forty naira only (=N=16,640) if commercialized. In spite of it's limitation, in separating the briquettes from the mould, it is imperative that what has been achieved so far out weighs most existing design of this kind, because it offers production of more briquettes within the same time with others which produce one briquette at a time.

Among the briquette types produced rice husk briquette proved to be the most outstanding. It had the highest average thermal efficiency (22.42%), the lowest average burning rate (0.83kg/hr) and the lowest average specific fuel consumption (0.13g/g), which was significantly better than that of firewood in the three stone open fire stove.

The cost of the machine is within the reach of a lot of families in the rural communities and if commercialized the cost could go for far less the price of production in this project. This machines design if set in production can be used to address the issue of deforestation in the country and provide jobs to youths in the communities.

6.4 Recommendation

The following recommendations are suggested:

1) Designing a more effective way of removing the briquettes from the mould instead of using the aluminum foils as pallets.
2) The height of mould should be reduced to produce more stabilized briquettes.
3) Performance of these residue briquettes produced from these press should be tested on other popular stoves such as the metal stoves and clay stoves.
4) A mixture of combined rice straw and other residues should be formed into briquette and investigate if it could have improved performance.
5) An alternative cheaper binder which will produce finer output briquettes should be source for.

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APPENDICES

Appendix A

Weight of Fuel Samples for Bomb Calorimeter Test

Measurement	Rice straw briquettes	Rice husk briquettes	Saw dust briquettes	50%rice husk + 50% sawdust briquettes	Firewood
Weight of empty capsules (g)	0.1014	0.1032	0.1026	0.1044	0.1085
Weight of capsule + sample (g)	0.2339	0.2353	0.2014	0.2184	0.2728
Weight of Sample (g)	0.1325	0.1321	0.0988	0.1140	0.1643

Appendix B

Temperature Readings with Time of Bomb Calorimeter Test for Fuel Samples

Time (minute)	Rice Straw Briquettes Temp.(^oC)	Rice Husk Briquettes Temp.(^oC)	Saw Dust Briquettes Temp.(^oC)	50% Saw Dust + 50% Rice Husk Temp.(^oC)	Firewood Temp.(^oC)
0	2.35	2.80	1.13	1.08	1.80
1	2.36	2.80	1.13	1.10	1.84
2	2.37	2.80	1.14	1.10	1.85
3	2.38	2.80	1.14	1.11	1.87
4	2.39	2.81	1.15	1.12	1.88
5	2.40	2.81	1.15	1.13	1.90
6	2.41	2.81	1.15	1.14	1.91
7	2.50	2.91	1.25	1.14	1.91
8	2.56	2.98	1.31	1.15	2.02
9	2.60	3.00	1.34	1.16	2.08
10	2.65	3.03	1.36	1.27	2.12
11	2.66	3.04	1.37	1.35	2.15
12	2.67	3.05	1.38	1.38	2.17
13	2.68	3.05	1.39	1.39	2.18
14	2.69	3.06	1.40	1.40	2.18
15	2.70	3.06	1.40	1.42	2.18
16	2.70	3.06	1.40	1.43	2.18
17	2.70	3.06	1.40	1.45	2.18
18	2.70	3.06	1.40	1.47	2.18
19	2.69	3.06	1.40	1.47	2.18
20	2.69	3.06	1.40	1.48	2.17
21	2.68	3.05	1.39	1.50	2.17
22	2.67	3.05	1.39	1.50	
23	2.67	3.04		1.50	
24	2.67	3.04		1.49	
25				1.48	
26				1.48	

Appendix C

Sample Calculation for Determining Calorific Value for Fuel Samples Using

Rice Straw Briquette Sample

Temperature rise, $\Delta\theta$ for rice straw briquette from figure 13 was obtained as $0.295^{o}C$ and tabulated in table 4.2.

Using the value of $\Delta\theta$ obtained in table 4.2 and the value of the fuel sample weight obtained in appendix A, the calorific value of the briquette sample can be calculated using equation 4.3 as:

$$H = \frac{(M_w + M_\theta)C_w\Delta\theta - M_c C_c - M_{fw}C_{fw} - M_{cap}C_{cap}}{M_f}$$

$$H = \frac{(2900 + 475)4.2 \times 0.295 - (0.0035 \times 1{,}7539) - (0.0023 \times 1{,}402.2) - (0.1014 \times 18{,}836)}{0.1325}$$

$$H = 16{,}577 KJ / kg$$

Appendix D

Water Boiling Test Values for Rice Straw Briquettes

	COLD START	HOT START	SIMMERING
f_i	0.65 0.70 0.50	0.70 0.80 0.80	0.80 0.70 0.70
f_f	0.25 0.20 0.05	0.25 0.30 0.30	0.10 0.05 0.05
P_i	2 2 2	2 2 2	1.90 1.85 1.85
P_f	1.85 1.90 1.85	1.90 1.85 1.85	1.40 1.40 1.35
f_m	0.40 0.50 0.45	0.45 0.50 0.50	0.60 0.65 0.65
ΔC	0.100 0.075 0.100	0.100 0.075 0.100	0.200 0.150 0.200
f_d	0.300 0.425 0.350	0.350 0.425 0.400	0.400 0.500 0.450
T_i	21.0 21.5 21.0	20.5 22.0 22.0	96 96 96
T_f	96 96 96	96 96 96	92 92 92
ΔT	75 74.5 75	75.5 74 74	- 4 - 4 - 4
η	13.16 9.12 11.70	10.3 10.5 10.5	11.10 9.30 10.40
R_f	0.83 1.28 1.10	1.42 1.39 1.36	0.80 0.87 0.87
SS_c	0.19 0.27 0.23	0.22 0.27 0.26	0.36 0.45 0.43

Appendix E

Water Boiling Test Values for Rice Husk Briquettes

	COLD START	HOT START	SIMMERING
f_i	0.70 0.65 0.60	0.70 0.65 0.60	0.70 0.65 0.60
f_f	0.45 0.40 0.40	0.45 0.45 0.40	0.25 0.20 0.20
P_i	2 2 2	2 2 2	1.90 1.85 1.90
P_f	1.80 1.90 1.90	1.90 1.85 1.90	1.40 1.40 1.40
f_m	0.25 0.25 0.20	0.25 0.20 0.20	0.45 0.45 0.40
ΔC	0.10 0.10 0.10	0.10 0.10 0.10	0.20 0.20 0.20
f_d	0.15 0.15 0.10	0.20 0.10 0.10	0.25 0.25 0.20
T_i	22 23 23	23 23 24	96 96 96
T_f	96 96 96	96 96 96	93 93 93
ΔT	74 73 73	73 73 72	- 3 - 3 - 3
η	27.19 20.17 25.89	20.71 29.82 25.67	17.13 15.40 19.27
R_f	0.78 1.06 1.85	1.12 0.92 0.95	0.60 0.60 0.53
SS_c	0.10 0.09 0.07	0.13 0.06 0.06	0.23 0.23 0.38

Appendix F

Water Boiling Test Values for Saw Dust Briquettes

	COLD START	HOT START	SIMMERING
f_i	0.65 0.60 0.70	0.50 0.60 0.60	0.65 0.70 0.65
f_f	0.30 0.30 0.40	0.15 0.25 0.20	0.10 0.20 0.10
P_i	2 2 2	2 2 2	1.90 1.85 1.90
P_f	1.85 1.85 1.90	1.90 1.85 1.90	1.35 1.35 1.40
f_m	0.35 0.30 0.30	0.35 0.35 0.30	0.55 0.50 0.55
ΔC	0.05 0.05 0.05	0.05 0.05 0.05	0.1 0.1 0.1
f_d	0.30 0.30 0.25	0.30 0.35 0.30	0.45 0.40 0.45
T_i	21 22 22	22 21 22	96 96 96
T_f	96 96 96	96 96 96	93 93 93
ΔT	75 74 74	74 75 74	- 3 - 3 - 3
η	16.04 18.56 16.14	13.83 16.04 16.29	12.90 14.29 12.98
R_f	1.22 1.12 1.12	1.31 1.31 1.15	0.73 0.67 0.67
SS_c	0.19 0.27 0.13	0.19 0.23 0.19	0.43 0.38 0.41

Appendix G

Water Boiling Test Values for 50% Saw Dust + 50% Rice Husk

	COLD START	HOT START	SIMMERING
f_i	0.60 0.40 0.40	0.45 0.50 0.45	0.50 0.60 0.60
f_f	0.4 0.2 0.15	0.25 0.30 0.25	0.05 0.15 0.15
P_i	2 2 2	2 2 2	1.90 1.90 1.90
P_f	1.90 1.85 1.85	1.90 1.90 1.90	1.40 1.45 1.40
f_m	0.20 0.20 0.25	0.20 0.20 0.20	0.45 0.45 0.45
ΔC	0.05 0.05 0.05	0.05 0.05 0.05	0.10 0.10 0.10
f_d	0.15 0.15 0.20	0.10 0.10 0.10	0.35 0.35 0.35
T_i	22.5 23.0 24.0	24 23 24	96 96 96
T_f	96 96 96	96 96 96	93 93 93
ΔT	73.5 73 72	72 73 72	- 3 - 3 - 3
η	21.36 24.49 16.90	28.08 28.08 28.08	14.07 12.64 14.07
R_f	1.15 1.09 1.45	0.78 0.99 1.13	0.60 0.60 0.60
SS_c	0.09 0.10 0.20	0.06 0.06 0.06	0.32 0.30 0.32

Appendix H

Water Boiling Test Values for Firewood

	COLD START	HOT START	SIMMERING
f_i	0.8 0.7 1.0	1.0 0.8 0.8	0.8 0.8 0.8
f_f	0.20 0.20 0.55	0.55 0.25 0.30	0.05 0.10 0.10
P_i	2.0 2.0 2.0	2.0 2.0 2.0	1.90 1.85 1.85
P_f	1.90 1.90 1.90	1.90 1.85 1.85	1.35 1.40 1.40
f_m	0.60 0.50 0.45	0.45 0.55 0.50	0.75 0.70 0.70
ΔC	0.1 0.1 0.1	0.05 0.05 0.05	0.15 0.15 0.15
f_d	0.50 0.40 0.35	0.40 0.50 0.45	0.60 0.55 0.55
T_i	22 24 25	25 25 24	96 96 96
T_f	96 96 96	96 96 96	93 93 93
ΔT	74 72 71	71 71 72	- 3 - 3 - 3
η	10.1 11.9 13.1	13.1 12.4 13.8	13.2 11.5 11.5
R_f	2.97 1.95 1.58	1.49 2.12 1.65	1.00 0.93 0.93
SS_c	0.31 0.25 0.22	0.25 0.32 0.29	0.57 0.39 0.39

Appendix I

Experimental Results of Water Boiling Test One (Cold start) for Fuel Samples

Time (min)	Rice straw Briquette Temp. (^oC)	Rice husk Briquette Temp. (^oC)	Saw dust Briquette Temp. (^oC)	50%Saw dust + 50%Rice husk mixture Briquette Temp. (^oC)	Firewood Temp. (^oC)
0	26.5	22.0	21.0	24.5	22.0
2.5	39.0	42.0	41.0	50.0	45.0
5.0	51.0	54.0	52.0	68.0	54.0
7.5	55.0	65.0	64.0	84.0	65.0
10.0	62.0	73.0	74.0	93.0	73.0
12.5	69.0	80.0	82.0	96.0	80.0
15.0	72.0	87.0	89.0	95.0	87.0
17.5	80.0	92.0	96.0	96.0	92.0
20.0	84.0	96.0			96.0
22.5	89.0				
25.0	93.0				
27.5	95.0				
30.0	96.0				

Appendix J

Experimental Results of Water Boiling Test 1 (Hot start) for Fuel Samples

Time (min)	Rice straw Briquette Temp. (^{o}C)	Rice husk Briquette Temp. (^{o}C)	Saw dust Briquette Temp. (^{o}C)	50%Saw dust + 50%Rice husk mixture Briquette Temp. (^{o}C)	Firewood Temp. (^{o}C)
0	20.5	24.0	22.0	24.0	23.0
2.5	43.0	49.0	48.0	47.0	49.0
5.0	64.0	63.0	59.0	62.0	65.0
7.5	72.0	80.0	70.0	70.0	79.0
10.0	82.0	86.0	78.0	78.0	87.0
12.5	88.0	96.0	85.0	87.0	94.0
15.0	92.0	96.0	94.0	95.0	96.0
17.5	94.0		96.0	96.0	
20.0	96.0				

Appendix K

Experimental Results of Water Boiling Test 2 (Cold start) for Fuel Samples

Time (min)	Rice straw Briquette Temp. (^oC)	Rice husk Briquette Temp. (^oC)	Saw dust Briquette Temp. (^oC)	50%Saw dust + 50%Rice husk mixture Briquette Temp. (^oC)	Firewood Temp. (^oC)
0	21.5	23.0	21.0	23.0	23.0
2.5	43.0	41.0	41.0	47.0	41.0
5.0	54.0	53.0	52.0	65.0	53.0
7.5	61.0	67.0	64.0	85.0	67.0
10.0	70.0	79.0	74.0	93.0	79.0
12.5	78.0	89.0	82.0	96.0	89.0
15.0	82.0	96.0	89.0		96.0
17.5	89.0		96.0		
20.0	93.0				
22.5	95.0				
25.0	96.0				

Appendix L

Experimental Results of Water Boiling Test 2 (Hot start) for Fuel Samples

Time (min)	Rice straw Briquette Temp. (^oC)	Rice husk Briquette Temp. (^oC)	Saw dust Briquette Temp. (^oC)	50%Saw dust + 50%Rice husk mixture Briquette Temp. (^oC)	Firewood Temp. (^oC)
0	23.0	24.0	21.0	23.0	23.0
2.5	40.0	47.0	45.0	45.0	47.0
5.0	59.0	63.0	60.0	67.0	63.0
7.5	70.0	79.0	71.0	86.0	79.0
10.0	78.0	85.0	77.0	91.0	85.0
12.5	83.0	93.0	87.0	96.0	93.0
15.0	87.0	96.0	93.0		96.0
17.5	93.0		96.0		
20.0	95.0				
22.5	96.0				

Appendix M

Experimental Results of Water Boiling Test 3 (Cold start) for Fuel Samples

Time (min)	Rice straw Briquette Temp. (^oC)	Rice husk Briquette Temp. (^oC)	Saw dust Briquette Temp. (^oC)	50%Saw dust + 50%Rice husk mixture Briquette Temp. (^oC)	Firewood Temp. (^oC)
0	21.0	23.0	22.0	24.0	23.0
2.5	38.0	44.0	43.0	49.0	44.0
5.0	49.0	56.0	57.0	68.0	56.0
7.5	58.0	69.0	66.0	85.0	69.0
10.0	69.0	80.0	75.0	94.0	80.0
12.5	74.0	90.0	86.0	96.0	90.0
15.0	80.0	96.0	91.0		96.0
17.5	89.0		96.0		
20.0	93.0				
22.5	95.0				
25.0	96.0				

Appendix N

Experimental Results of Water Boiling Test 3 (Hot start) for Fuel Samples

Time (min)	Rice straw Briquette Temp. (^oC)	Rice husk Briquette Temp. (^oC)	Saw dust Briquette Temp. (^oC)	50%Saw dust + 50%Rice husk mixture Briquette Temp. (^oC)	Firewood Temp. (^oC)
0	23.0	24.0	22.0	24.0	24.0
2.5	43.0	49.0	45.0	47.0	49.0
5.0	60.0	63.0	59.0	68.0	63.0
7.5	70.0	80.0	71.0	85.0	80.0
10.0	76.0	86.0	79.0	90.0	86.0
12.5	88.0	96.0	87.0	96.0	96.0
15.0	89.0		93.0		
17.5	92.0		96.0		
20.0	95.0				
22.5	96.0				

APPENDIX O

The *t*-Distribution: Fractiles

v \ p	0.975	0.995	0.9995	0.95	0.99	0.999	0.60	0.70	0.75	0..80	0.90
1	12.706	63.657	636.619	6.314	31.821	318.309	.325	.727	1.000	1.376	3.078
2	4.303	9.925	31.598	2.920	6.965	22.327	.289	.617	.816	1.061	1.886
3	3.182	5.841	12.924	2.353	4.541	10.213	.277	.584	765	.978	1.638
4	2.776	4.604	8.610	2.132	3.747	7.173	.271	.569	.741	.941	1.533
5	2.571	4.032	6.869	2.015	3.365	5.893	.267	.559	.727	.920	1.476
6	2.447	3.707	5.959	1.943	3.143	5.208	.265	.553	.718	.906	1.440
7	2.365	3.499	5.408	1.895	2.998	4.785	.263	.649	.711	.896	1.415
8	2.306	3.355	5.041	1.860	2.896	4.507	.262	.546	.706	.889	1.397
9	2.262	3.250	4.781	1.833	2.821	4.297	.261	.543	.703	.883	1.383
10	2.228	3.169	4.587	1.812	2.764	4.144	.260	.542	.700	.879	1.372
11	2.201	3.106	4.437	1.796	2.718	4.025	.260	.540	.697	.876	1.363
12	2.179	3.055	4.318	1.782	2.681	3.930	.259	.539	.695	.873	1.356
13	2.160	3.012	4.221	1.771	2.650	3.852	.259	.538	.694	870	1.350
14	2.145	2.977	4.140	1.761	2.624	3.787	.258	.537	.692	.868	1.345
15	2.131	2.947	4.073	1.753	2.602	3.733	.258	.536	.691	.866	1.341
16	2.120	2.921	4.015	1.746	2.583	3.686	.258	.535	.690	.865	1.337
17	2.110	2.898	3.965	1.740	2.567	3.646	.257	.534	.689	.863	1.333
18	2.101	2.878	3.922	1.734	2.552	3.610	.257	.534	.688	.862	1.330
19	2.093	2.861	3.883	1.729	2.539	3.579	.257	.533	.688	.861	1.328
20	2.086	2.845	3.850	1.725	2.528	3.552	.257	.533	.687	.860	1.325
21	2.080	2.831	3.819	1.721	2.518	3.527	.257	.532	.686	.859	1.323
22	2.074	2.819	3.792	1.717	2.508	3.505	.256	.532	.686	.858	1.321
23	2.069	2.807	3.767	1.714	2.500	3.485	.256	.532	.685	.858	1.319
24	2.064	2.797	3.745	1.711	2.492	3.467	.256	.531	.685	.857	1.318
25	2.060	2.787	3.725	1.708	2.485	3.450	.256	.531	.684	.856	1.316
26	2.056	2.779	3.707	1.706	2.479	3.435	.256	.531	.684	.856	1.315
27	2.052	2.771	3.690	1.703	2.473	3.421	.256	.531	.684	.855	1.314
28	2.048	2.763	3.674	1.701	2.467	3.408	.256	.530	.683	.855	1.313
29	2.045	2.756	3.659	1.699	2.462	3.396	.256	.530	.683	.854	1.311
30	2.042	2.750	3.646	1.697	2.457	3.385	.256	.530	.683	.854	1.310
40	2.021	2.704	3.551	1.684	2.423	3.307	.255	.529	.681	.851	1.303
60	2.000	2.660	3.460	1.671	2.390	3.232	.254	.527	.679	.848	1.296
80	1.990	2.639	3.416	1.664	2.374	3.195	.254	.527	.678	.846	1.292
100	1.984	2.626	3.390	1.660	2.364	3.174	.254	.526	.677	.845	1.290
∞	1.960	2.576	3.291	1.645	2.326	3.090	.253	.524	.674	.842	1.282
2 sided test	5%	1%	0.1%	10%	2%	0.2%	deciles and quartiles				
1 sided test	2.5%	0.5%	0.05%	5%	1%	0.1%					
	Levels of significance										

Source: Roa et al

Note: 1. v represents the degree of freedom.

2. For any given p in the top row, the table provides the value of t_p such that the probability of t being less than t_p is equal to p. For p<0.5; $t_p = -t_{(1-p)}$, $t_{0.50}$ being zero always.
3. For obtaining a critical value of $|t|$ for a two-sided or of t for upper-sided test refer to the entry corresponding to the chosen level of significance indicated in the last row, and the relevant degrees of freedom. For one-sided tests using the lower tail, the critical value is the same as that for the upper tail with the sign changed.

Appendix P

5 PER CENT POINTS OF THE F-DISTRIBUTION

ν_1=	1	2	3	4	5	6	7	8	10	12	24	∞
ν_1=1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	241.9	243.9	249.0	254.3
2	18.5	19.0	19.2	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.5	19.5
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.79	8.74	8.64	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	5.96	5.91	5.77	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.74	4.68	4.53	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.06	4.00	3.84	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.64	3.57	3.41	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.35	3.28	3.12	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.14	3.07	2.90	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	2.98	2.91	2.74	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.85	2.79	2.61	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.75	2.69	2.51	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.67	2.60	2.42	2.21
14	4.60	4.74	3.34	3.11	2.96	2.85	2.76	2.70	2.60	2.53	2.35	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.54	2.48	2.29	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.49	2.42	2.24	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.45	2.38	2.19	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.41	2.34	2.15	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.38	2.31	2.11	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.35	2.28	2.08	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.32	2.25	2.05	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.30	2.23	2.03	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.27	2.20	2.00	1.74
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.25	2.18	1-98	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.24	2.16	1.96	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.22	2.15	1.95	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.20	2.13	1.93	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.19	2.12	1.91	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.18	2.10	1.90	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.16	2.09	1.89	1.62
32	4.15	3.29	2.90	2.67	2.51	2.40	2.31	2.24	2.14	2.07	1.86	1.59
34	4.13	3.28	2.88	2.65	2.49	2.38	2.29	2.23	2.12	2.05	1.84	1.57
36	4.11	3.26	2.87	2.63	2.48	2.36	2.28	2.21	2.11	2.03	1.82	1.55
38	4.10	3.24	2.85	2.62	2.46	2.35	2.26	2.19	2.09	2.02	1.81	1.53
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.08	2.00	1.79	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	1.99	1.92	1.70	1.39
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.91	1.83	1.61	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.83	1.75	1.52	1.00

Source Rao et al (1966)

Appendix Q

1 PER CENT POINTS OF THE F-DISTRIBUTION

v_1 =	1	2	3	4	5	6	7	8	10	12	24	∞
v_1 =1	4052	5000	5403	5625	5764	5859	5928	5981	6056	6106	6235	6366
2	98.5	99.0	99.2	99.2	99.3	99.3	99.4	99.4	99.4	99.4	99.5	99.5
3	34.1	30.8	29.5	28.7	28.2	27.9	27.7	27.5	27.2	27.1	26.6	26.1
4	21.2	18.0	16.7	16.0	15.5	15.2	15.0	14.8	14.5	14.4	13.9	13.5
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.05	9.89	9.47	9.02
6	13.74	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.87	7.72	7.31	6.88
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.62	6.47	6.07	5.65
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.8	5.67	5.28	4.86
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.26	5.11	4.73	4.31
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.85	4.71	4.33	3.91
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.54	4.40	4.02	3.60
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.30	4.16	3.78	3.36
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.10	3.96	3.59	3.17
14	8.86	6.51	5.56	5.04	4.70	4.46	4.28	4.14	3.94	3.80	3.43	3.00
15	8.86	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.80	3.67	3.29	2.87
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.69	3.55	3.18	2.75
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.59	3.46	3.08	2.65
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.51	3.37	3.00	2.57
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.43	3.30	2.92	2.49
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.37	3.23	2.86	2.42
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.35	3.27	2.80	2.36
22	7.95	5.72	4.82	4.39	3.99	3.76	3.59	3.45	3.26	3.18	2.75	2.31
23	7.88	5.66	4.76	4.26	3.94	3.71	3,54	3.41	3.21	3.07	2.70	2.26
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.17	3.03	2.66	2.21
25	7.77	5.57	4.68	4.18	3.86	3.63	3.46	3.32	3.13	2.99	2.62	2.17
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.09	2.96	2.58	2.13
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.06	2.93	2.55	2.10
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.03	2.90	2.52	2.06
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.00	2.87	2.49	2.03
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	2.98	2.84	2.47	2.01
32	7.50	5.34	4.46	3.97	3.65	3.43	3.26	3.13	2.93	2.80	2.42	1.96
34	7.45	5.29	4.42	3.93	3.61	3.39	3.22	3.09	2.90	2.76	2.38	1.91
36	7.40	5.25	4.38	3.89	3.58	3.35	3.18	3.05	2.86	2.72	2.35	1.87
38	7.35	5.21	4.34	3.86	3.54	3.32	3.15	3.02	2.83	2.69	2.32	1.84
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.80	2.66	2.29	1.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.63	2.50	2.12	1.60
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.47	2.34	1.95	1.38
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.32	2.18	1.79	1.00

Source Rao et al (1966)

APPENDIX R

GRAPHS

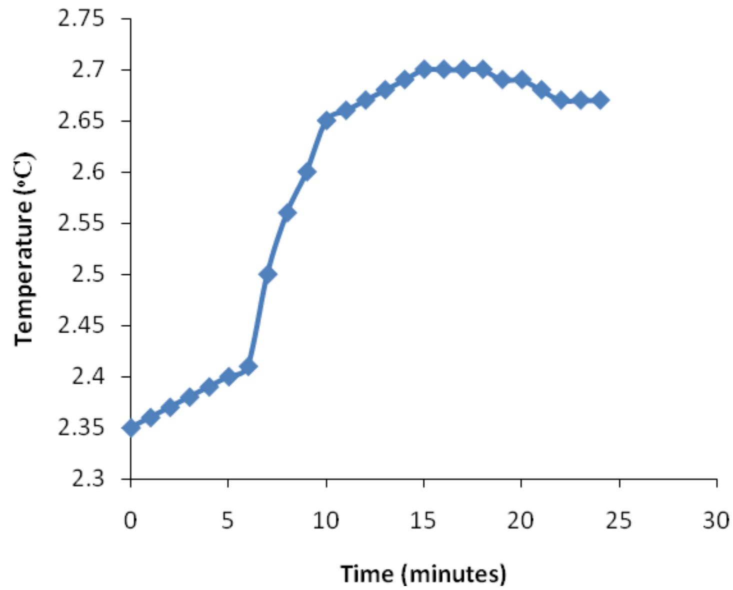

Fig 13: Temperature versus Time graph for Bomb Calorimeter Test of Rice Straw Briquette

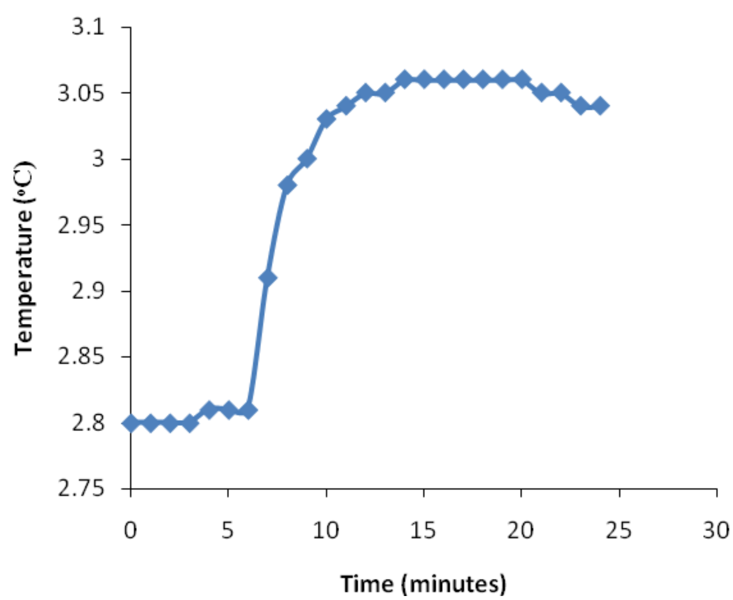

Fig 14: Temperature versus Time graph for Bomb Calorimeter Test of Rice Husk Briquettes

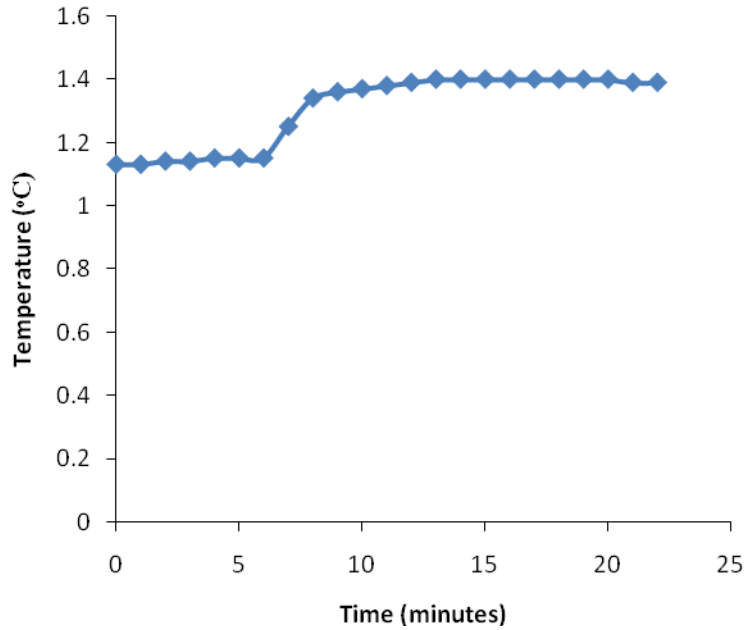

Fig 15: Temperature versus Time graph for Bomb Calorimeter Test of Sawdust Briquette

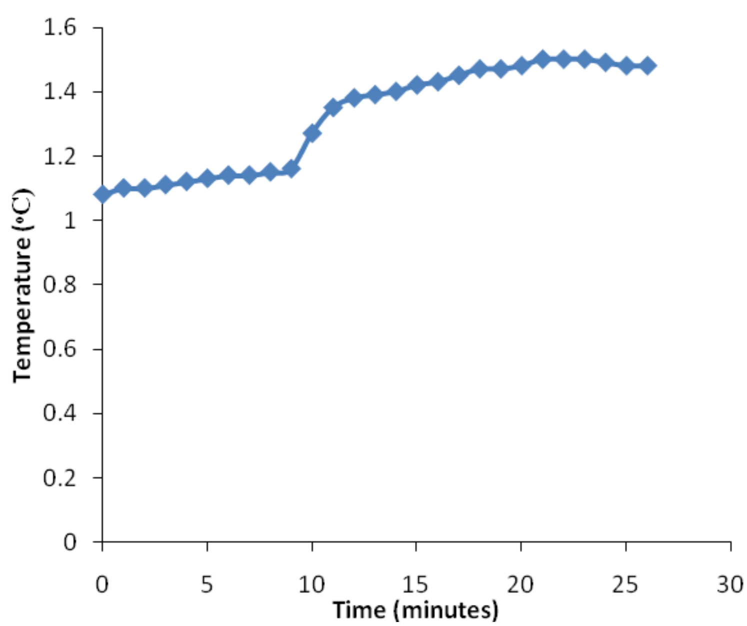

Fig 16: Temperature versus Time graph for Bomb Calorimeter Test of 50% Saw dust + 50% Rice husk

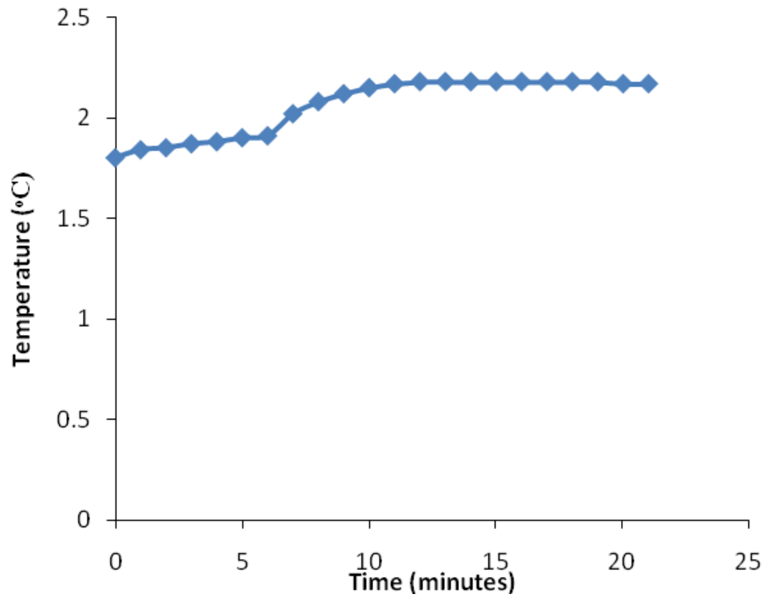

Fig 17: Temperature versus Time graph for Bomb Calorimeter Test of Firewood

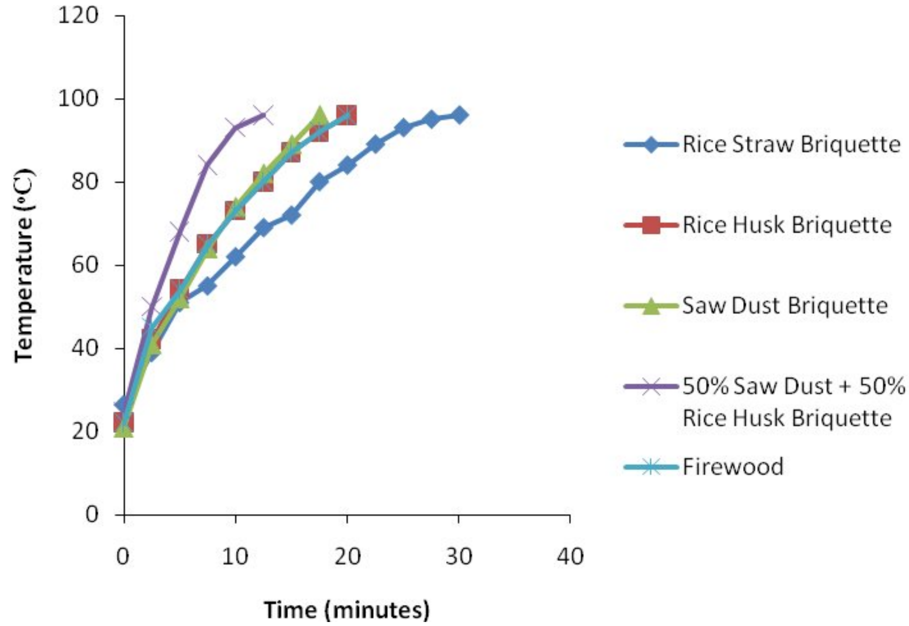

Fig 18: Graph of Water Boiling Test 1 (cold start) of fuel samples

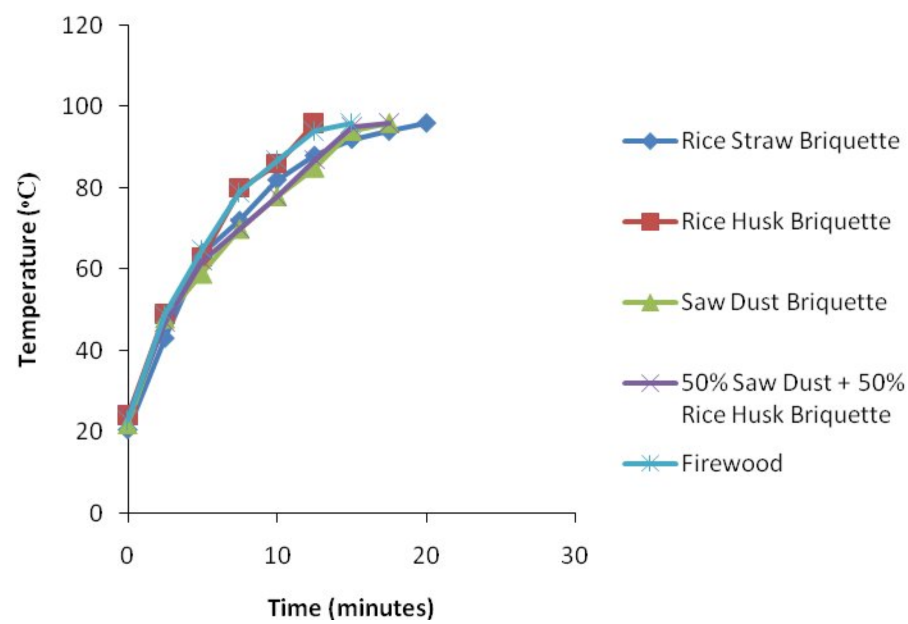

Fig 19: Graph of Water Boiling Test 1 (hot start) of fuel samples

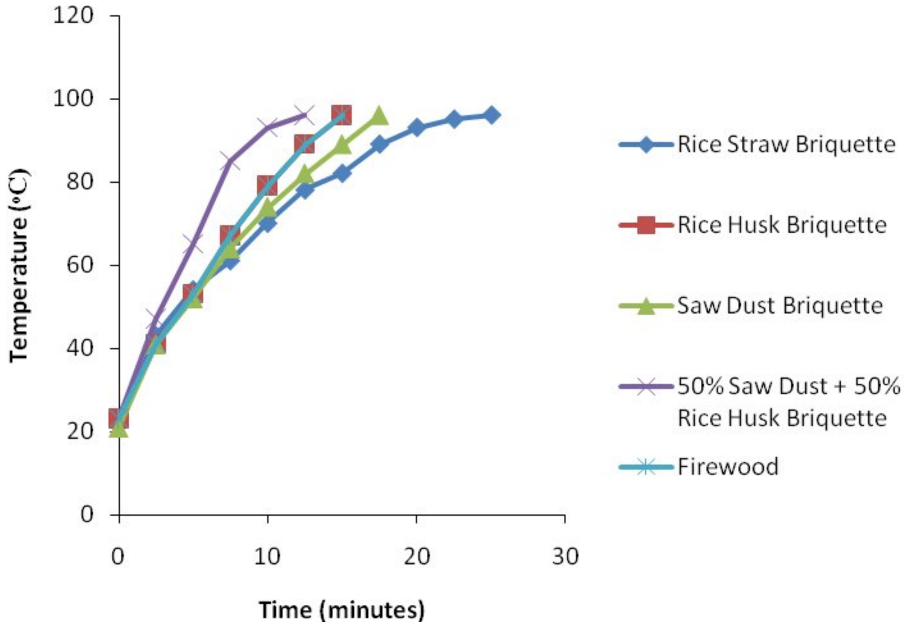

Fig 20: Graph of Water Boiling Test 2 (cold start) of fuel samples

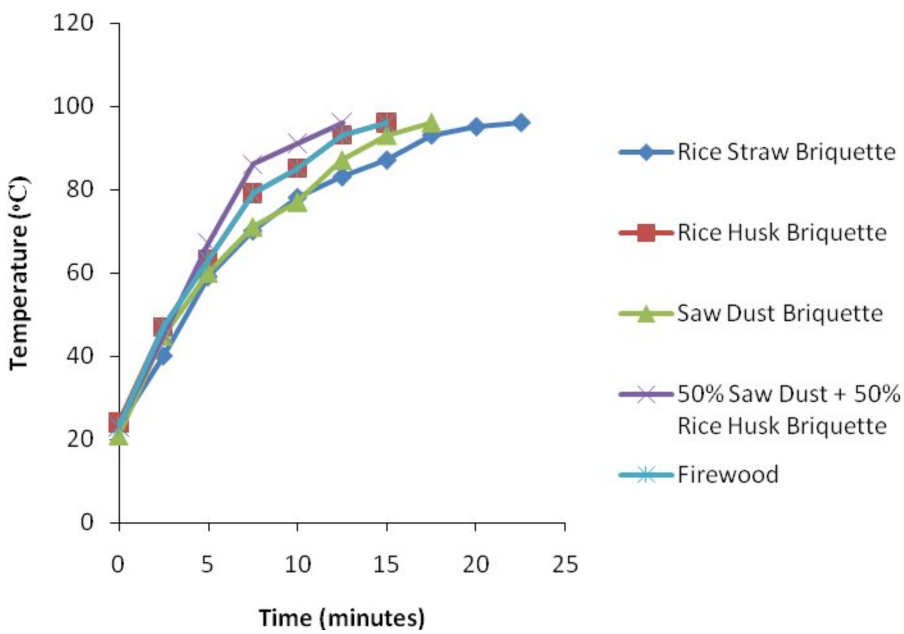

Fig 21: Graph of Water Boiling Test 2 (hot start) of fuel samples

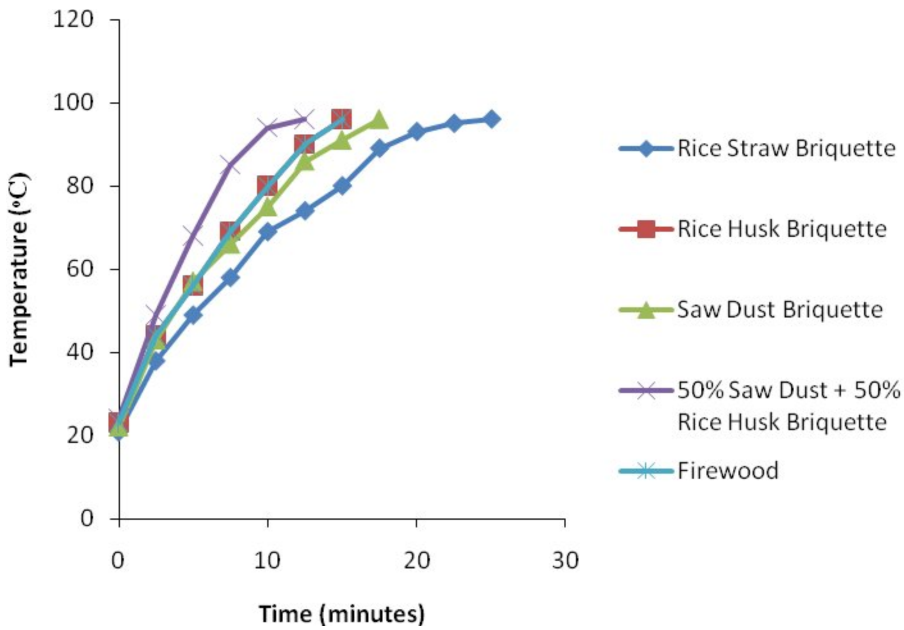

Fig 22: Graph of Water Boiling Test 3 (cold start) of fuel samples

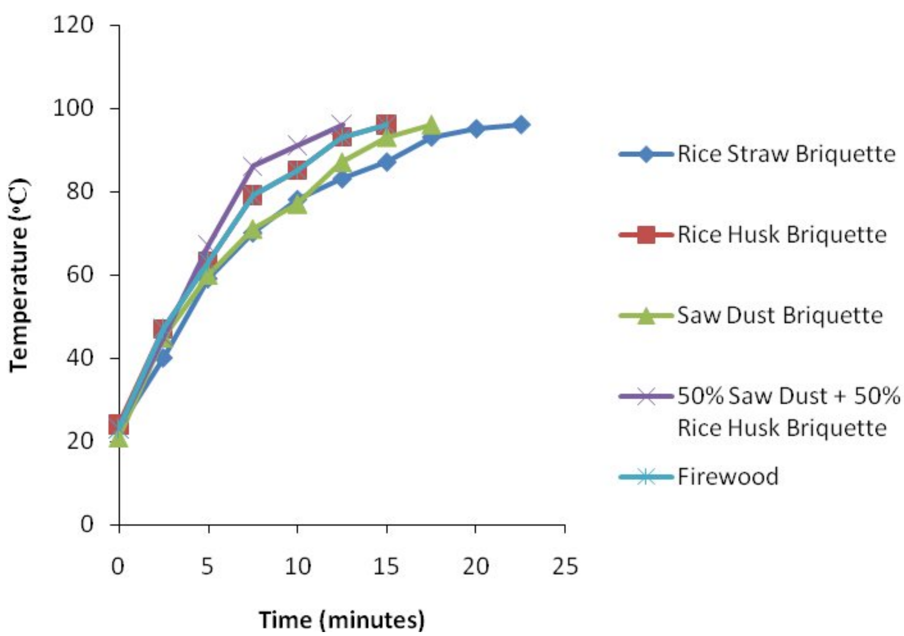

Fig 23: Graph of Water Boiling Test 3 (hot start) of fuel samples

Appendix S

Charts of Fuel Performance

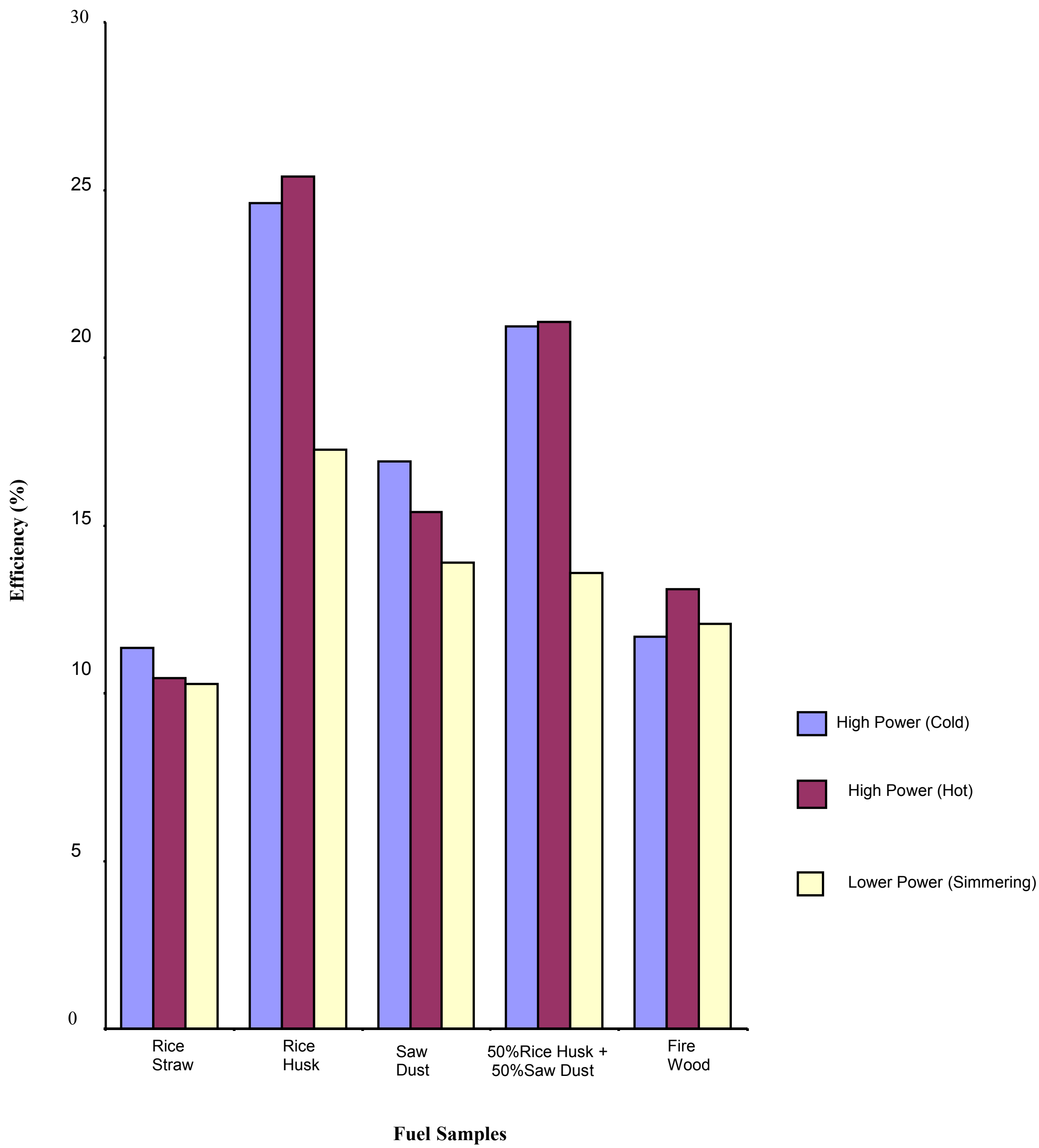

Figure 24: Thermal Efficiency of Fuel Samples (%)

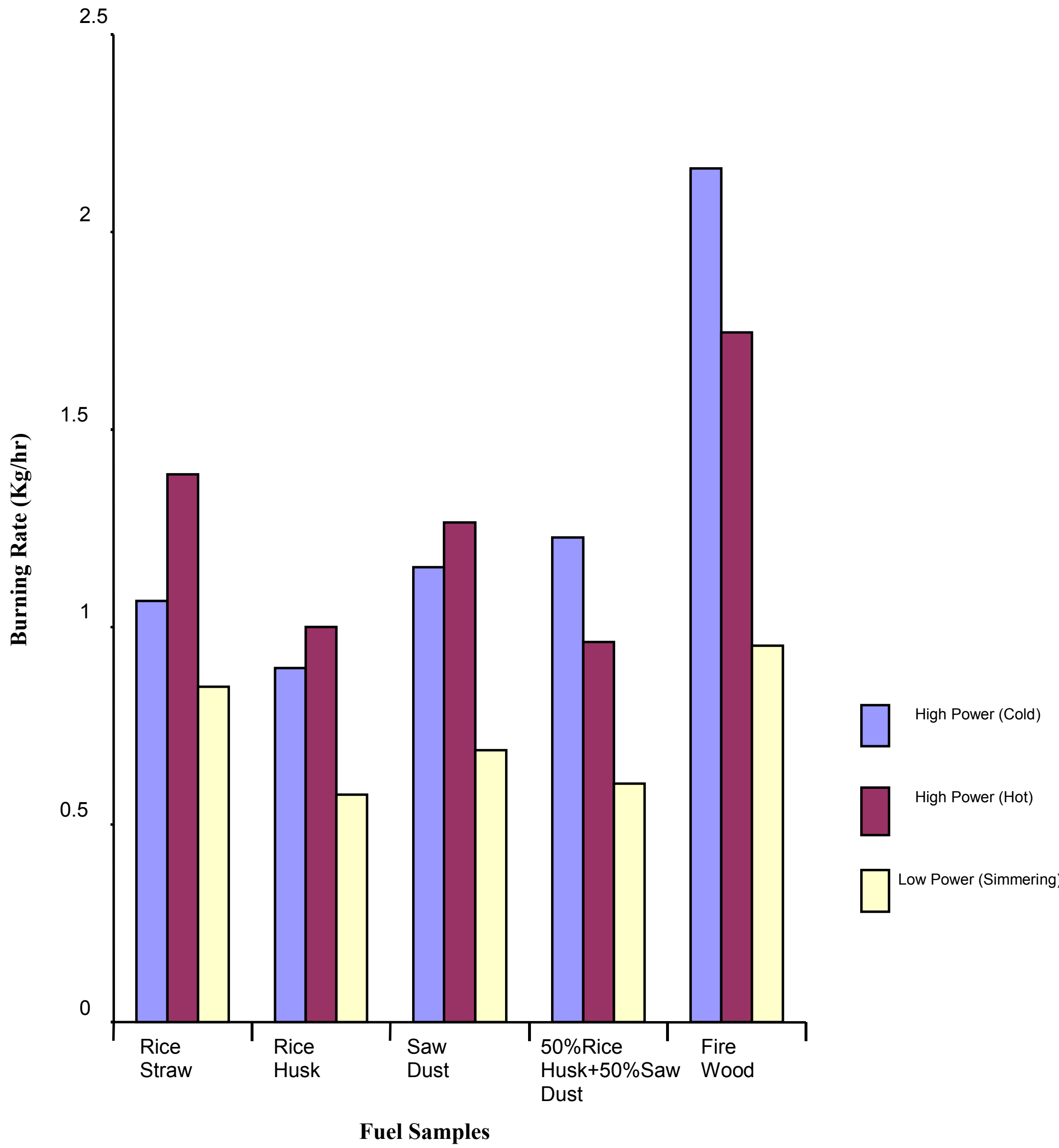

Figure 25: Burning rate of Fuel Samples (Kg/hr)

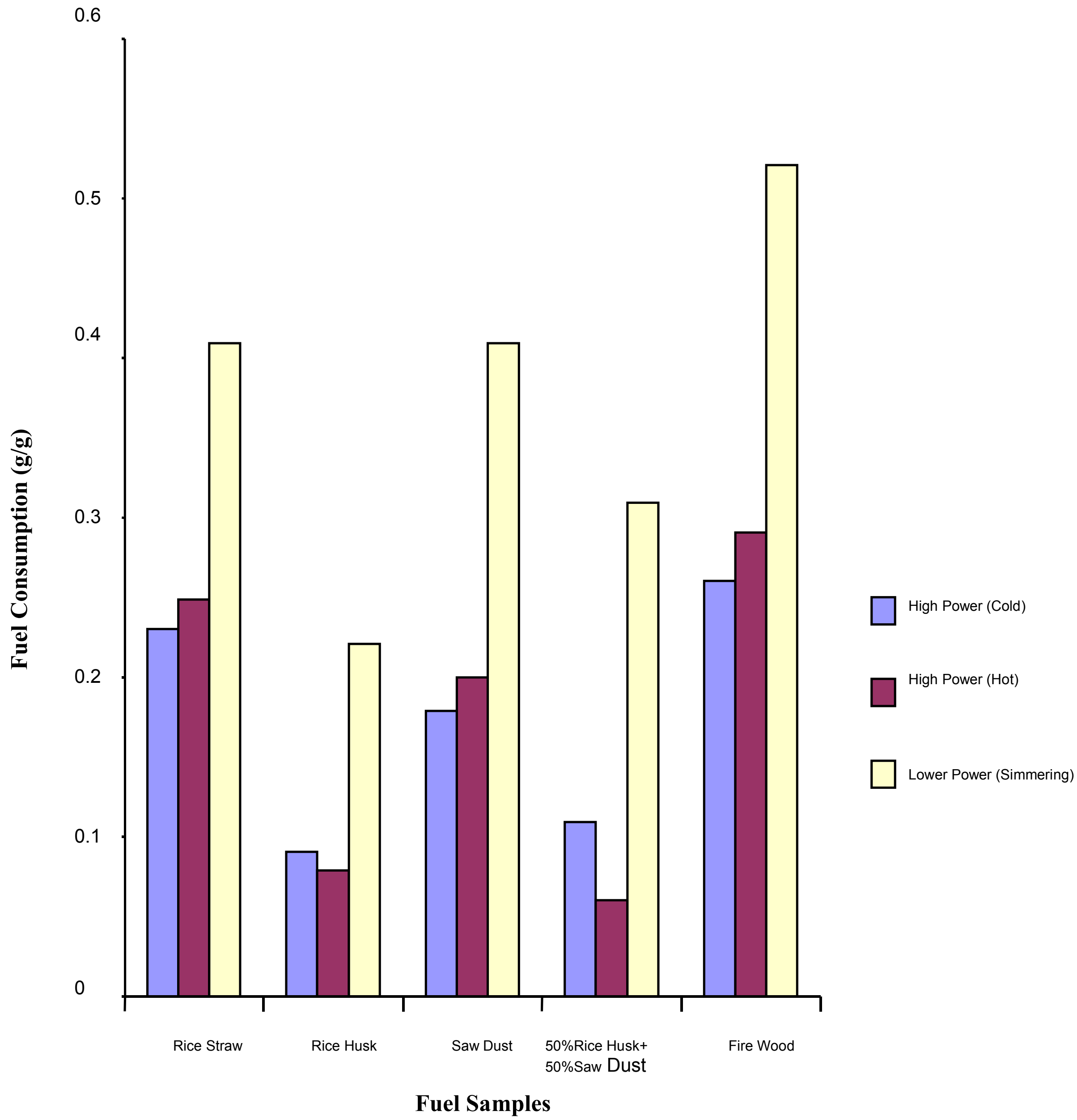

Figure 26: Fuel Consumption (g/g) of Fuel Samples

WORKING DRAWINGS OF BRIQUETTING SCREW PRESS (DRAWING NO. 1 – 44)

ALL DIMENSIONS IN MILLIMETRES