CHARACTERISATION OF FUEL BRIQUETTES

FROM *Gmelina arborea (Roxb)* SAWDUST AND MAIZE COB PARTICLES USING *Cissus populnea* GUM AS BINDER

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ABSTRACT

Large quantities of agricultural and mill residues which are generated annually in Nigeria constitute environmental health hazards. Densification of these residues which is a major way of converting them to high quality fuel has not been adequately studied in Nigeria. The objective of this study was to develop and evaluate a system for briquetting and combusting *Gmelina arborea* sawdust and maize cob particles.

Gmelina arborea Sawdust (GS) was obtained from a small-scale sawmill in Ibadan while maize cobs were obtained from Oja – Oba market, Ibadan and milled. Moisture Contents (MC) and Bulk Densities (BD) of GS and Maize Cob Particles (MCP) were determined. Gum extracted from *Cissus populnea* stems was evaluated for its suitability as binding agent for fuel briquettes. The viscosity of the crude gum powder was determined at concentrations of 1-10 % (w/v). A manual briquetting machine and a briquetting stove were developed and evaluated. Briquetting of the GS and MCP was done at gum concentrations of 1-30 % (w/w) and pressure levels of 1.5-5.0MPa using 0.6 mm fine and 1.18 mm coarse particles. Briquette stability was measured in terms of linear expansion with time (1-10080 minutes) while the Compressive Strength (CS), Durability Index (DRI) and Water Resistance Index (WRI) were determined in accordance with ASABE standards. Briquette burn rate and thermal efficiency of the stove were determined using the standard water boiling test. Data were analysed using ANOVA.

The MC and BD of GS (10.0 % and 150.0 kg/m^3) were higher than those of MCP (9.0 % and 134.0 kg/m^3). The gum yield of *C. populnea* was 1.40±0.05 % at 12.60±0.02 % MC. There was positive correlation between gum concentration and viscosity (R^2=0.958). The piston press type briquetting machine produced 50.0 mm diameter and 60.0 mm long hollow cylindrical briquettes and gave a maximum through-put of 0.6 kg/h. The combustion chamber of the clay-lined steel stove accommodated a maximum of 5 briquettes. Minimum gum contents required for durable briquette production were 10.0% and 15.0% for GS and MCP respectively. Increase in binder concentration enhanced the linear expansion of both *Gmelina arborea* Sawdust Briquette (GSB) and Maize Cob Briquette (MCB) with the increase more pronounced in the MCB than GSB. There was significant difference ($p<0.001$) in the CS and WRI of the briquettes whereas there was no significant difference ($p>0.05$) between the DRI values. The strongest and most durable briquettes were obtained using fine particle size at a pressure of 1.5 MPa and 25.0% gum content. The burning rate of GSB was 0.800±0.003 kg/h while that of MCB was 1.000±0.018 kg/h. There was no significant difference ($p > 0.05$) in their burn rate values. However, it took more time to boil one litre of water with GSB (22-24 min) than MCB (16-18 min). Maximum thermal efficiency of the stove was 38.0 %.

Cissus populnea gum was suitable for the production of briquettes from *Gmelina* sawdust and maize cob particles. However, *Gmelina arborea* Sawdust Briquettes were stronger and more durable but less efficient in combustion than Maize Cob Briquettes.

Keywords: Biomass residues, Briquettes, *Cissus populnea*, Briquette stove.

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DEDICATION

To God almighty and Christ Jesus, the Son of the Living God, my Lord and Saviour that has made me His ambassador to the nations;

To my parents, Deacon S.A. Oyedemi and Mrs. R.O. Oyedemi who are the architects of my Education;

To my darling wife, Dasola Oyedemi and our children: Adetola, Temiloluwa, Iyinoluwa and Abimifoluwa;

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NOTATIONS

The following symbols are used in this thesis.

Symbol	**Description**	**Unit**
D	Relaxed density	kg/m^3
P	Pressure	MPa
Nc	Cauchy number	–
b	Porosity index	–
V	ram speed	mm/s
r	compression ratio (Y/Yo)	–
A	material constant (Ko/Yo)	–
Ko	initial bulk modulus	MPa
Yo	initial charge density	kg/m^3
MC	Moisture Content	%
BD	Bulk Density	kg/m^3
MCP	Maize Cob Particles	
GS	*Gmelina arborea* Sawdust	
CS	Compressive Strength	kN/m^2
DRI	Durability Index	%
WRI	Water Resistance Index	h
IEA	International Energy Agency	
ASABE	American Society of Agricultural and Biological Engineers	
ECN	Energy Commission of Nigeria	
toe	Tonnes of Oil Equivalent	
scf	Standard Cubic Feet	
odt	Oven Dried Tonnes	

CHAPTER ONE

INTRODUCTION

1.1 Preamble

Worldwide, there are energy crises resulting from increasing population, improved standard of living and industrialization. The industrialized nations are worried because the future supplies of commercial energy, most of which is derived from petroleum and natural gas have become very uncertain. Without the supply of adequate quantities of commercial energy these countries cannot maintain high levels of productivity and high standard of living. The developing nations are worried because the target of higher level of productivity and reasonable standard of living for its people will not be achievable if petroleum supplies become restrictive or more expensive. Therefore there has been an increased interest in the search for alternative energy all over the world especially in the last four decades (Akor, 2003). The use of fossil fuel is being discouraged because of its associated green house gases that contribute to global warming.

In Nigeria, despite the huge petroleum resources, there is periodical scarcity of kerosene that forces people to look for alternatives such as wood fuel for rural dwellers and charcoal for some urban dwellers. Increasing use of wood fuel results in desertification and consequent soil erosion and ecological problems. The Federal Government in 1992, set up a Presidential Task Force on Alternative to Fuel Wood, in realization of increasing desertification and deforestation in the country. The Task Force recommended sawdust briquette, solar energy and biogas as viable renewable energy alternative (Akinbami *et al.*, 2003).

1.2 Biomass Energy Resources in Nigeria

Biomass resources in Nigeria include animal waste, agricultural and wood residues and fuel wood. Fagbenle *et al.* (1998) estimated the biomass energy reserve of Nigeria to be 9.1 x 10^{12} MJ (Table 1.1). According to Akinbami (2001), biomass mainly in the form of wood fuel (charcoal and firewood) is the major source of fuel energy in Nigeria accounting for about 50.45% of the total energy consumed. The other sources are natural gas, 5.22%; hydroelectricity, 3.05% and petroleum products, 41.28%. Fuel wood is also a major source of income in the rural areas and its importance has been accentuated by the high poverty level, the unreliable supply and often unaffordable price of kerosene.

Table 1.1: Estimate of Nigeria's Primary Energy Resources

Resource	Total Reserve	Proven Reserve	Source
1. Crude oil	230 mt	71.0 mt	Odukwe & Enibe (1988)
	16 x 10^9 bbl	-	Sharma & Sharma (1991)
	2300 mt	89.3 mt	Davidson & Ogunlade (1992)
2. Natural gas	4670 x $10^9 m^3$	2830 x 10^9 m^3	Odukwe & Enibe (1988)
	3000 x 10^9 m^3	-	Sharma & Sharma (1991)
	2500 x 10^9 m^3	18.2 x 10^9 m^3	Davidson & Ogunlade (1992)
3. Coal	1300 mt	300 mt	Odukwe & Enibe (1988)
	9.35 x 10^8 mt	3.67 x 10^8 mt	Sharma & Sharma (1991)
	1302 mt	-	Davidson & Ogunlade (1992)
4. Hydro	11 000 MW	1376 MW	Odukwe & Enibe (1988)
	12 400 MW	1320 MW	Davidson & Ogunlade (1988)
5. Biomass	-	9.1 x 10^{12} MJ	Odukwe & Enibe (1988)
	-	1.1834 x 10^{12} MJ	Davidson & Ogunlade (1992)

Mt = million ton; 1 bbl = 0.13 tons of oil equivalent

Source: Fagbenle and Karayiannis, 1994.

According to Adegbulugbe (1994), Nigeria's forestry resources could be depleted within fifty years. Wood projection balance up to the year 2030 (Table 1.2) indicates that it will be increasingly difficult to meet the demand for wood products from the current capacity of the country's forest resources.

1.2.1 Agricultural Residues

Nigeria is still an agrarian based country with about 59.5% of her labour force of about 44.6million (and 21.1% of the entire population of 126 million) engaged in agriculture (N.B.S, 2006). Large quantities of cotton, groundnut, sugarcane, rubber, palm, maize, millet, sorghum, rice and wheat etc., are grown in the country resulting in the production of varied residues including cotton and maize stalks, groundnut and coconut shells, coconut and rice husks, maize cobs and rice straw. Added to these are municipal and industrial waste products such as waste paper (Olorunnisola, 2004). These residues are available as free and are potential environmentally friendly energy source. They are generated on farms and in agricultural process industries, but the form and concentration varies both within regions and between industries. Although large amounts of agricultural residues are produced in Nigeria each year, their contribution towards meeting national energy demand has remained rather low due to inefficient and unplanned use. According to Wilaipon (2002), when used in their raw state, agro residues are often bulky, dirty during handling and storage. They have lower energy value when used for direct combustion. Maize and vegetables are common subsistence crops grown in most parts of Nigeria. Maize, millet, sorghum, rice and groundnut are produced commercially on a large scale. Rice is grown on a large scale in both the Northern and Eastern parts of Nigeria. In Oyo State, the study area, maize has the single largest acreage of the major crops grown in the state with 183.77 acreage land cultivated in 2009 (OYSADEP, 2010).

1.2.2 Mill Residues

In Nigeria, the sawmill industry has continued to increase over the decades as the demand for lumber (sawn wood) continues to rise. Saw-milling industries in Nigeria increased from 64 in 1960 to about 2,700 in 1993 (Badejo, 2001). The industry is characterized by a number of small-scale saw-milling outfits strategically located around urban centres mainly in the South Western and South Eastern parts of Nigeria (Ogunsanwo, 2001).

Mill operators regularly generate large quantities of wood wastes. According to Badejo and Giwa (1985), an estimated volume of about 1.72 million m^3 of wood waste was generated in

Table 1.2: Projected Future Demand, Supply and Balance of Wood Products in Nigeria (1000 m^3)

Product	**YEAR**		
	1990	**2010**	**2030**
FUEL WOOD			
Demand	73,949	133,403	213,444
Supply	82,026	45,469	28,418
Balance	8078	-87,933	-185,025
POLES			
Demand	1678	3027	4844
Supply	1435	795	497
Balance	-243	-2232	-4346
SAW LOGS			
Demand	3992	7202	11,522
Supply	3482	1930	1206
Balance	-510	-2232	-10,316
VENEER WOOD			
Demand	395	713	1140
Supply	162	90	56
Balance	-233	-623	-1084
PULPWOOD			
Demand	227	409	654
Supply	724	401	251
Balance	497	-8	-403

Source: Adesina et al. (1990).

Nigerian sawmills in 1981. This volume had increased to 2.32 million m^3 by 1988 (Badejo, 1990) and 3.87 million m^3 by 1993 (Owonubi and Badejo, 2001).

It is estimated that annual generation of sawdust in the country is 1.8 million tonnes per year (Adegoke *et al,* 2011). A study by Food and Agricultural Organization concluded that 65% of all the wood entering the sawmills in less-industrialized countries (LICs) ends up as residues (Mahin, 1991). The wastes generated are so large that they constitute menace to the industry itself and the environment. For instance, the sawdust from sawmills pile up forming large heaps, which disturb activities within the mills. In some areas in Lagos metropolis, sawdust and other wood wastes are dumped into waterways into which they leach their extractives, thereby causing water pollution (Ogunsanwo, 2001). Some of the wood wastes are used as cooking fuel or combined with diesel fuel in a boiler to generate steam, for bedding in animal housing etc. Large quantities of wood wastes not utilized are eventually burnt in open air as disposal measure (Wamukonya and Jenkins, 1995).

Burning of sawdust is a nuisance to the environment and it creates harmful effects on man, animals and crops. Compared to using solid wood as fuel, sawdust is a good substitute in terms of heat content (Resh, 1981). When available in adequate quantities, sawdust can be successfully converted into heat energy. Fuwape (1984) recommended *Gmelina arborea* (Roxb) sawdust species generated as wastes in pulp and paper industries in Nigeria as supplementary fuel in Nigerian mills. There are plantations of *Gmelina arborea* in pulp wood industries at Iwopin, Jebba and Oku-Iboku. It is also planted in the belt regions in the Northern part of Nigeria.

However, since sawdust is a very loose and light material, handling, transportation and storage could be problematic. Compaction minimizes the problems and turns the material to a good fuel for domestic cooking, bakery furnaces, brick kilns and steam boilers. Briquetting is therefore an effective approach for using residues efficiently. According to Akor (2003), briquettes come second in the energy content only to fossil fuels, but first among renewable fuel sources (Table 1.3).

Table 1.3: Heating Value and Density of Some Selected Fuels

Fuel	Higher Heating Value (MJ/kg)	Density (kg/m^3)
Wood Briquette	23.00	980
Petrol	45.31	845
Diesel	39.55	898
Wood	22.16	450

Source: Akor (2003).

1.3 Aims and Objectives of the Study

The main goal of this study was to develop and evaluate a system for briquetting and combusting *Gmelina arborea* sawdust and maize cobs.

The specific objectives of this study are:

i. To investigate the possibility of producing Maize cob and *Gmelina* sawdust briquettes using *Cissus populnea* Guild Perr *(Ogbolo)* gum as a binder.

ii. To design and fabricate an appropriate briquetting machine that can be used to produce a doughnut shaped briquette or cylindrical briquettes with central holes.

iii. To design an improved stove to burn the briquettes.

iv. To determine the influence of processing and material variables such as particle size, binder concentration and applied pressure on the physical, mechanical and combustion characteristics of the briquettes.

1.4 Significance of the Study

The important factors that are considered in the choice of a material as a feedstock for fuel briquette include availability of material at low or no cost and the heating values; other important factor is the density of fuel because the specific gravity of a fuel affects the quantity of heat per unit volume and the rate of ignition (Lucas and Fuwape, 1984).

(1) Maize is one of the common subsistence crops grown in most parts of the country. It is grown in large scale in both Western and Northern parts of the country and it is one of the five major crops produced in Oyo State, Nigeria. Of the five major crops cultivated in Nigeria i.e. maize, sorghum, groundnut, cowpea/beans, cocoyam and rice (National Bureau of Statistics, 2006), the ones that are easily amenable to briquetting are maize, rice and groundnut wastes.

Of the crops amenable to briquetting, maize has the highest productivity of the major crops in Nigeria (Fig. 1.1). Maize production increased from 6.29 million tons in 1993 to 11 million tons in 2006. Maize is the crop with the highest productivity in Oyo State (Fig 1.2). Maize production increased from 224.09 metric tons in 1999 to 225.8 metric tons in 2009 (Table 1.4). . From the energy point of view, maize cob has a calorific value of 18.9 MJ/kg in contrast to rice husk whose calorific value is (15.3 – 16.8 MJ/kg). Maize cob seems to have a higher heat content value compared to other crop residues (Table 1.5). From the energy and availability point of view, maize cobs seem to be the best crop waste for briquetting in the study area.

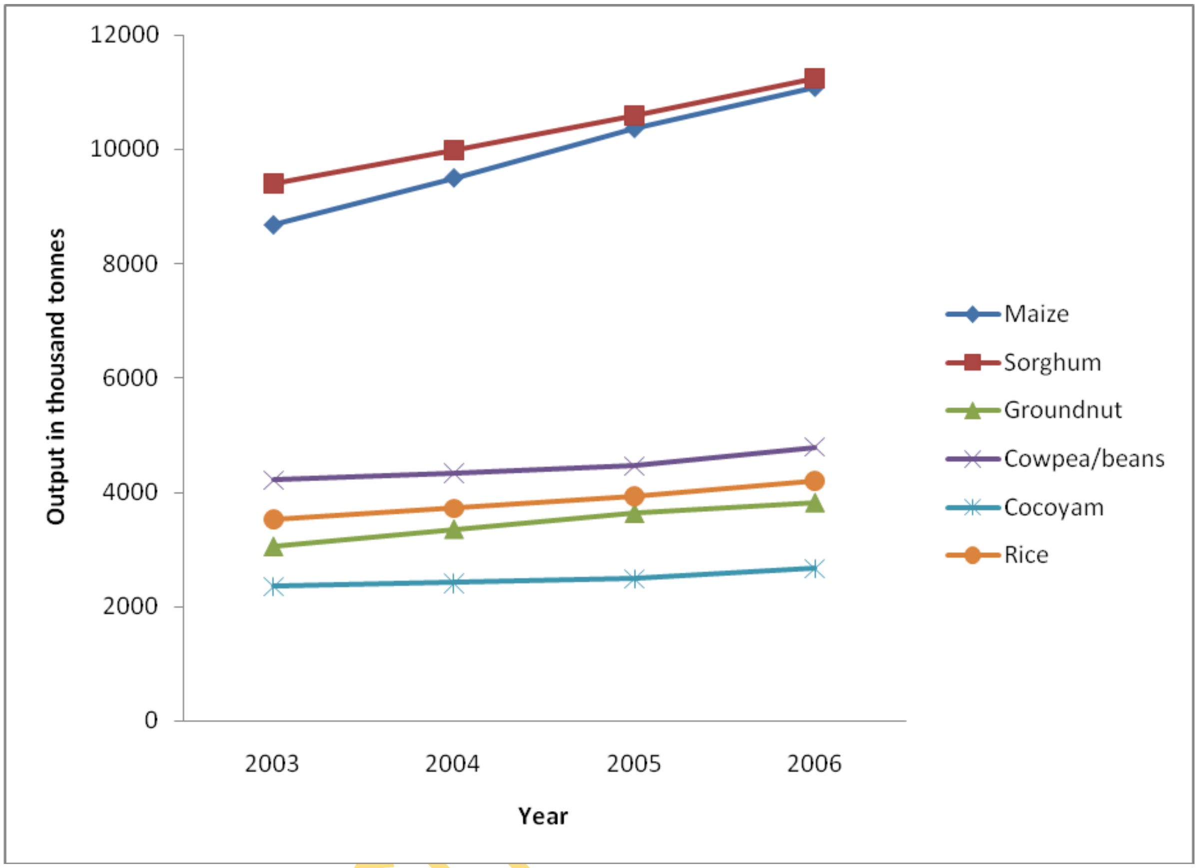

Figure 1.1: Estimated Output of Major Crops in Nigeria (2003-2006)

Source: National Bureau of Statistics (2006).

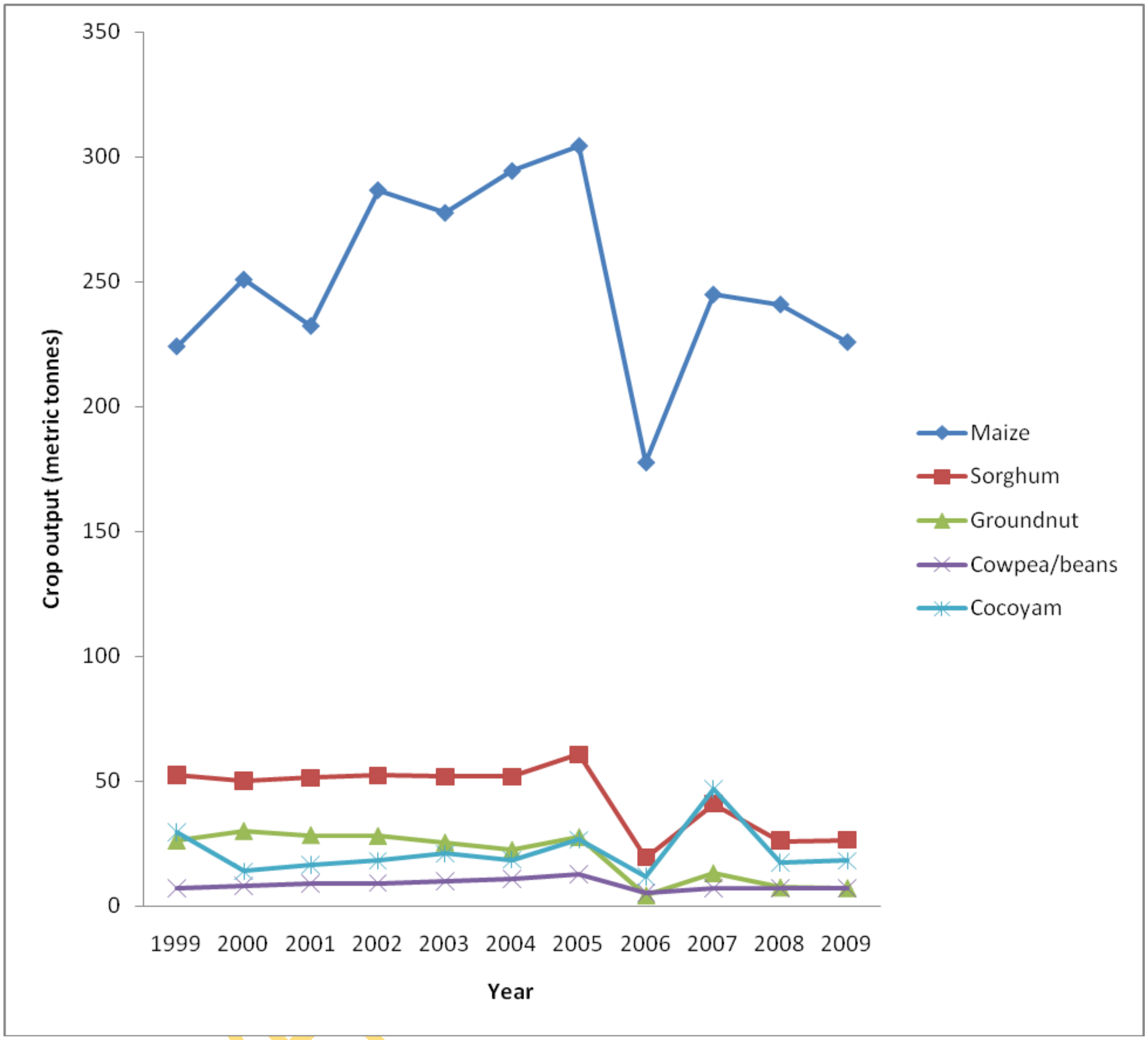

Figure 1.2: Outputs of Major Crops in Oyo State (1999-2009)

Source: Oyo State Agricultural Development Programme, Ibadan (2010).

Table 1.4: Production of Major Crops in Oyo State (metric tonnes)

CROP	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Cassava	949.50	20.30	1,116.71	1,209.14	1,325.76	1,555.31	2,380.67	1,139.38	1488.33	1496.94	1561.4
Yam	966.40	80.00	1,015.71	1,037.72	959.94	808.65	1,033.46	387.54	792.85	695.47	713.9
Maize	224.09	250.75	232.24	286.46	277.4	294.13	304.14	177.66	244.8	240.79	225.8
Sorghum	52.41	50.00	51.28	52.27	51.64	51.7	60.58	19.31	40.78	26.02	26.3
Groundnut	26.14	30.00	28.33	28.05	25.40	22.45	27.54	4.26	13.14	7.48	7.2
Cowpea/beans	7.11	7.80	8.81	9.01	9.82	10.47	12.52	5.10	6.90	6.92	7.0
Cocoyam	29.38	13.65	16.24	17.92	20.77	18.29	26.33	11.48	46.72	17.17	17.9
Rice	0.94	-	-	-	-	-	-	-	-	-	-
Mellon	8.21	9.03	9.54	9.73	11.65	8.39	10.62	1.34	3.09	2.11	2.3
Okro	21.89	22.00	22.47	23.89	31.79	23.69	29.03	15.15	34.95	34.99	36.7
Soya bean	4.01	5.30	4.03	4.65	5.66	0.81	4.80	0.12	0.27	0.27	0.3
Pepper	25.64	27.00	28.50	31.19	33.94	31.46	36.90	15.26	32.30	21.6	22.8
Sweet potato	39.81	46.30	44.06	50.71	46.97	48.13	54.36	1.10	34.48	25.12	26.9
Millet	-	-	-	-	0.04	0.10	-	0.99	1.31	1.33	-
Tomato	47.87	49.72	53.42	54.74	36.46	31.86	46.61	13.91	27.48	27.73	29.7
Vegetable	1.03	1.24	1.51	1.52	1.76	0.20	2.45	-	-	-	-
Pigeon pea	0.22	-	0.14	0.19	0.77	0.44	0.46	-	0	0.10	-

Source: Oyo State Agricultural Development Programme, Ibadan (2010).

Table 1.5: Calorific Value and Ash Content of Various Fuels

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

Source: Barnard (1985).

If an availability factor of residue to product ratio of 0.27 is used for maize as reported by Lars (2004), maize cobs estimate in the country can be put at 3.0 million tonnes per year. It is therefore not surprising that maize cobs litter the streets, drainage channels and market places in the urban and rural areas of the country at different stages of decay especially in the harvesting season spanning February to September (Olorunnisola, 1999a). Converting maize cobs to fuel briquettes should help reduce their nuisance.

(2) *Gmelina arborea* can be found in abundance in almost all sawmills in Ibadan metropolis where it constitutes a nuisance and environmental hazard. *Gmelina arborea* has a mean higher heating value of 24046.8 KJ/kg (Fuwape, 1984) and ash content of 1.5% (Onuorah, 1999). From the point view of availability of *Gmelina arborea* sawdust residues in industries and mills and its higher heating value and low ash content. It is the preferred wood species as feedstock for briquetting in this study

(3) The commonest binder used for briquetting in Nigeria is cassava starch obtained from tubers of cassava. However cassava tubers are eaten as food and this will make its use as adhesive competitive. With the increasing diversification and expansion of the use of cassava as outlined in the presidential initiative on cassava production and export in 2002 (N.B.S, 2006), there is the need to develop alternative adhesive to cassava starch. The *Cissus populnea* plant already being explored as a potential adhesive in the pharmaceutical industry, grows in forests and farms in Oyo State, particularly in Ido Local Government of Ibadan municipality as climbing plant and weeds. It can therefore be explored as an adhesive in briquette production.

(4) As observed by Wamukonya and Jenkins (1995) for the briquetting industry to be successful in the less industrialized countries, the equipment should consist of locally designed simple, low-cost machines as most of the conventional briquetting presses are very expensive and not within the reach of household users and majority of the poor local farmers. Very few screw – press briquetting machine that produces hollow shaped briquettes are in the country and none is ever reported to be in use in Oyo State. The proposed machine is to produce cylindrically shaped briquettes with central holes to enhance combustion efficiency of briquettes.

(5) The Federal Government of Nigeria Energy policy (ECN, 2007) stipulates the promotion of improved efficiency in the use of fuel wood by the development of efficient wood stoves. The improvement of the efficiencies and performances of existing improved wood stove is recommended (ECN, 2006). The use of three stone wood stove is common in our society. It is highly inefficient with a low efficiency of 5-10%. The firewood requirements for cooking is relatively high because most of the heat energy does not reach the pot as only about 5-10% of the fuel wood heating/energy value reaches the pot (Danshehu and Sama, 2006)

1.5 Justification for the Study

(1) The use of briquette fuel as a substitute or supplement to fuel wood will reduce the high rate of deforestation and desertification and consequent soil erosion and flooding in sub-Saharan Africa, especially the Northern Parts of Nigeria. Its use will reduce reliance on fuel wood by households and small scale industries.

(2) Every year, millions of tons of agricultural and forestry residues are generated. This biomass includes agro-industrial by-products and animal refuse. The conversion of these wastes to briquettes will both reduce pollution problems in the environment and is a waste recycling process with potential of converting wastes in Nigeria to wealth.

(3) The ever increasing prices of petroleum products in Nigeria with attendant periodical scarcity necessitates a shift of policy to an alternative sustainable fuel for which briquette fuel is one.

(4) The application of a new binder, *Cissus populnea* gum could be a suitable alternative to cassava starch, the most commonly used binder for briquette production, which has an increasing competitive use both in agricultural and industrial applications.

(5) There are plants that grow as weeds or wild in Nigerian forests which have remained underutilized commercially. One of these plants is *Cissus populnea* which is either burn off as weed or are cut off as they grow as climbing plants in most parts of Oyo State. The development of *Cissus populnea* gum from the *Cissus* plant is a means of converting the weed plant or underutilized plant to something of economic value.

(6) Some of the existing binders including, palm oil sludge have one disadvantage or the other; ranging from high cost and high toxicity, bad odour, low shelf and pot life and also production of smoky briquettes.

(7) The development of an intermediate briquetting press is justified as it is simple, low cost and easy to maintain in contrast to the more expensive motorized presses that are not within the affordable reach of the low and medium level income earners and local entrepreneurs.

(8) The dominant traditional three-stone wood stove technology used in the country has very low thermal efficiency (5-10%), high indoor pollution tendency with its associated health hazard to users.

(9) The thermal heat transfer to the pot and combustion efficiency of the proposed stove is to be improved and therefore a tool for energy efficiency and rural energy management in the country.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Energy Situation in Nigeria

Nigeria is endowed with a rich energy resource base. An overview of the reserves of depletable and renewable energy sources in Nigeria is given in Table 2.1. It is West African's only significant oil producer and a member of the Organization of Petroleum Exporting Countries (OPEC) and a net energy exporting country. The country also possesses the seven largest reserves of crude oil and the ninth largest natural gas reserve in the world (Energy commission of Nigeria; 2007). Associated and non associated natural gas reserves are in the ratio 53:5; 46:5.

The potential in using modern renewable energy alternatives to traditional fuel wood in Nigeria has been recognized. In the year 1992, the Presidential Taskforce on Alternatives to Fuel wood recommended sawdust briquette, solar energy and biogas as viable renewable energy alternatives (Akinbami et al, 2003).

Prior to the 1960s, energy utilization constituted very predominantly, of non-commercial energy namely fuel wood, charcoal, agricultural wastes and residues as well as solar radiation. The major commercial fuel was coal which was used by the railways and for power generation (ECN, 2007). Only modest contributions came from other commercial fuels such as petrol and diesel (from petroleum products) and electricity (from coal and diesel generators).

The structure of energy utilization has drastically changed since then. By 2000, out of total primary energy consumption of 65.2 tonnes of oil equivalent (toe), natural gas accounted for 59.75% followed by non-commercials (21.49%), petroleum products (17.73%) and hydropower (1.03%). Coal contribution had declined to an insignificant level. Table 2.2 shows the percentage consumption levels and structure of the consumption of the major energy resources over the years (1989 – 2005).

Over the period 1989 – 2005, the share of non-commercial energy fluctuated within the range of 30 – 40%. The supply of petroleum resources in the country is characterized by a complex of limitations which include the unending conflict in the Niger Delta Area; the perennial corruption in the oil sector and the epileptic nature and inadequate number of refineries, importation of refined petroleum products and over dependence on a single source of

Table 2:1: Nigeria's Energy Reserves/Capacity as at December 2005.

ENERGY SOURCE	RESERVES
Crude Oil	36.5 billion barrels
Natural Gas	187.44 trillion scf
Tar Sands	30 billion barrels of oil equivalent
Coal & Lignite	Over 4 billion tonnes
Large Hydropower	11,250MW
Small Hydropower	3,500MW
Fuel wood	13071,464 Hectares
Animal Waste	61 million tonnes/yr
Crop Residue	83millions tonnes/yr
Solar Radiation	3.5 – 7.0KWh/m^3 –day
Wind	2 – 4m/s at 10m height

Source: Energy Commission of Nigeria, 2007.

1 barrel of oil = 0.136 tonnes of oil.

100m^3 of natural gas = 0.857 toe

1 Tonne of coal = 0.697 toe

1000 kwh (primary energy) = 0.223 toe.

Table 2.2: Energy Consumption of Primary Energy Resources (%).

Year	Coal	Nat. Gas	Pet. Product	Hydropower	Non-Commercial
1989	0.16	21.77	31.10	10.98	35.99
1990	0.14	21.88	30.79	10.12	37.07
1991	0.19	21.87	32.25	9.52	36.23
1992	0.16	15.55	36.12	15.76	32.41
1993	0.01	20.76	30.47	15.42	33.34
1994	0.03	23.09	26.33	15.66	34.89
1995	0.04	25.55	25.09	8.93	40.38
1996	0.04	28.92	28.29	6.53	36.22
1997	0.04	30.88	23.44	6.79	38.85
1998	0.02	31.94	26.28	5.71	36.05
1999	0.02	33.67	23.88	5.70	36.73
2000	0.02	34.17	23.51	4.90	37.40
2001	0.02	43.26	22.30	4.34	30.09
2002	0.01	57.95	18.18	0.94	22.91
2003	0.01	57.24	18.62	1.11	23.03
2004	0.00	60.01	17.53	1.05	21.40
2005	0.00	59.75	17.73	1.03	21.19

Source: ECN (2007).

energy (Umar, 2011). The prices of fossil fuels especially petrol, kerosene and diesel have been on the increase since 1973 when the Nigerian Government began to comply with the full recommendations of the International monetary fund for the full withdrawal of oil subsidy (as seen from Tables 2.3 and 2.4). The continual increase in the pump price of fossil fuel has aggravated the wood scarcity and depletion of forests in the country. The effect is felt more by the rural dwellers and the low income class. Commercial electricity is generated mainly from hydropower, steam plants and gas turbines in Nigeria. The annual consumption of electricity has increased very rapidly over the last three decades from 1,273 GWh in 1970 to 13,700 GWh in 2001 (ECN, 2007).

This however represents a suppressed demand caused by inaccessibility to the national grid and the inadequacies of the electricity supply. One consequence of this is that various industries and other consumers have installed generators with total electrical power capacity estimated to be at least 50% of the installed capacity of the national grid. According to Ugwuoke et al (2008), outside the major cities and towns in Nigeria, there are very little electrification in other regions of the country and where they exist, the supply is usually epileptic and very unreliable. The energy supply infrastructure has remained inadequate in meeting the growing demand of the economy (ECN, 2005).

2.2 Biomass Energy

Biomass energy is an indirect form of solar energy. By means of photosynthesis; plants deposit some of the solar energy as a mass in their bodies. When biomass is burnt, this energy is released (Yaman et al, 2001). Biomass is either burnt directly or processed to take advantage of its energy content. Biomass energy is derivable from trees, grasses, agricultural crops and their derivatives, as well as animal wastes (Adegoke et al 2011). The biomass may be used as solid fuel or converted to biogas.

The estimated biomass resources of Nigeria are given in Table 2.5. Biomass fuels with prospect in Nigeria include: wood, biogas, liquid fuels from biomass (or alcohols) and briquettes. In Nigeria, the rural populace depends to a large extent on traditional sources of energy, mainly fuel wood, charcoal, plant residues and animal wastes. This class of fuel constitutes about 50% of total energy consumption in the country (ECN, 2005).

Table 2.3: Historical Prices of Petroleum Products in Nigeria

Product		1973	1979	1986	1990	1991	1993	1994	1998	2000	2000	2002	2003	% Change	
										(Initial)	(Final)			30-yr	Latest
Petrol	PMS	0.095	0.153	0.395	0.51	0.6	3.25	11	20	30	22	26	40	42,005	53.85
Diesel	AGO	0.088	0.11	0.295	0.35	0.5	3	9	19	29	21	26	38	43,082	46.15
Kerosene	DPK	0.08	0.105	0.105	0.15	0.4	2.75	6	17	27	17	24	38	47,400	58.33
Fuel Oil		0.026	0.054	0.19	0.3	0.5	2.5	9	12.5	12.5	12.5	-	-		
$1 =150Naira		0.658	0.596	4.537	8.038	9.91	22.33	21.89	21.89	88	88	127	127	19,204	
Petrol	$/litre	0.144	0.257	0.087	0.063	0.061	0.146	0.503	0.914	0.341	0.25	0.205	0.315	118	53.85
	$/gallon	0.546	0.971	0.329	0.24	0.229	0.55	1.9	3.454	1.289	0.945	0.774	1.191	118	53.85

PMS - Premium Motor Spirit (Petrol or Gasoline)

AGO - Automotive Gas Oil

DPK - Dual Purpose Kerosene

Source: Daily Times of Nigeria, June 23, 2003.

Table 2.4: Historical Crude Oil Prices

Year	Crude oil price ($/barrel)	Year	Crude oil price ($/barrel)
1946	1.63	**1979**	25.10
1947	2.16	**1980**	37.42
1948	2.77	**1981**	35.75
1949	2.77	**1982**	31.83
1950	2.77	**1983**	29.08
1951	2.77	**1984**	28.75
1952	2.77	**1985**	26.92
1953	2.92	**1986**	14.44
1954	2.99	**1987**	17.75
1955	2.93	**1988**	14.87
1956	2.94	**1989**	18.33
1957	3.14	**1990**	23.19
1958	3.00	**1991**	20.20
1959	3.00	**1992**	19.25
1960	2.91	**1993**	16.75
1961	2.85	**1994**	15.66
1962	2.85	**1995**	16.75
1963	2.91	**1996**	20.46
1964	3.00	**1997**	18.64
1965	3.01	**1998**	11.91
1966	3.10	**1999**	16.56
1967	3.12	**2000**	27.39
1968	3.18	**2001**	23.00
1969	3.32	**2002**	22.81
1970	3.39	**2003**	27.69
1971	3.60	**2004**	37.66
1972	3.60	**2005**	50.04
1973	4.75	**2006**	58.30
1974	9.35	**2007**	64.20
1975	12.21	**2008**	91.48
1976	13.10	**2009**	53.48
1977	14.40	**2010**	69.85
1978	14.95	**2011***	87.48
		2012	102.06

1Barrel=159 litres
Source: http://inflationdata.com/inflation/inflation_rate/historical_oil_prices_table.asp
*www.ioga.com/Special/crudeoil_Hist.htm (accessed 28 Jan., 2012)

Table 2.5: Estimated Biomass Resources of Nigeria.

Resource	Quantity (million tonnes)	Energy Value ('000 MJ)
Fuel wood	39.100	531.00
Agro waste	11.244	147.70
Sawdust	1.800	31.43
Municipal Solidwaste	4.075	

Source: Sambo, 2009.

Biomass mainly in the form of wood fuel is the major source of fuel energy in Nigeria accounting for about 50% of the national primary energy consumption (Tembe et al, 2010). It is the most important non-commercial fuel.

Over 90% of the Nigerian population is made up of rural dwellers who do not have access to modern energy sources (Ugwuoke et al 2008). Over 95% of these rural dwellers use firewood (Idumah et al, 2011). Compared with the costs of petroleum product, fuel wood is cheaper than any commercial fuel substitute. Wood in some instances is converted into charcoal which is used as a substitute to fuel wood in some urban areas.

Fuel wood and charcoal are used largely for heating, boiling and cooking. They are also used in cottage industries for generating heat for production of tobacco, brick tiles, sugar, bread and other processed food items (Izekor and Modugu, 2011). Recent studies reveal that Nigeria produces about one million tonnes of charcoal annually, out of which 80% are consumed in cities (Tembe et al 2010).

However, deforestation from fuel wood extraction remains one of Nigeria's top three environmental problems, which directly affect over 84 million Nigerians mostly through declining fuel wood supplies (Amusa et al 2010). In meeting the rapidly increasing demand, fuel wood traders cut down indiscriminately, ten of hundreds of square kilometers of standing forests accounting for more than half of the 9.6 million hectares of rain forest belt in the south of the country.

Recent studies (Table 2.6) have shown that the demand for fuel wood and charcoal is far greater than the supply. In 1990, the supply of wood for fuel wood was greater than the quantity demanded. But in 2000 and 2010, there were deficits of about 1217200m^3 and 250000m^3 respectively, indicating shortage of wood availability. The demand of wood was projected to be over 954487000m^3 by the year 2010 while the supply was about 682927000m^3 showing a deficit of about 27156000m^3. The current demand for wood in the country has therefore outstripped the sustainable level of supply.

Table 2.6: Demand and Supply of wood for fuel-wood and charcoal (1000m^3)

Year	Demand	Supply
1990	73949	82026
2000	83521	71349
2010	88138	63099

Source: Tembe *et al* (2010)

Fuel wood use and indiscriminate tree felling promotes deforestation, soil erosion, desert encroachment and global warming. In view of the above reasons, the National Energy master plan (ECN, 2007) advocated that:

(i) The use of wood as a fuel should be de-emphasized in the nation's energy mix

(ii) Alternative energy sources to fuel wood should be promoted. Non-fuel wood biomass energy resources should be harnessed and integrated with other energy sources. This includes solar, biogas, and other alternative technologies to fuel wood.

(iii) The development of improved stoves with higher thermal efficiencies (20 – 40%) in contrast to the traditional three – stone wood stove with very low efficiency of the order of (5–10%) should be intensified.

(iv) Establishment of fuel wood lots (energy farms) using fast growing plant species and the annual tree planting programme should be promoted to increase the availability of fuel wood and reduce the deforestation rate (ECN, 2007).

2.3 Briquetting

Briquetting can be regarded as an attempt to link up two large and complex worlds together: agriculture and fuel supply to generate energy supply that can be of use to mankind (Adegoke et al, 2010). It is the densification of loose biomass, such as rice husk, maize cobs and sawdust into solid fuel, aimed at improving handling and combustion characteristics.

The use of agricultural and wood residues could have an appreciable impact in a country, which is suffering badly from fuel wood shortages (FAO, 1990). The average world production of wood residues comprised 250 million tonnes of sawdust, 200 million tonnes of bark and over 400 million tonnes of crooked log (FAO, 1990). It is estimated that about 55% of wood biomass processed in the saw-mills in Nigeria end up as mill residues. (Adegoke and Fuwape, 2008).

Briquettes may be produced in various shapes such as circular, rectangular (Plate 2.1), cylindrical hollow cylindrical, spherical, cuboid, prismatic (Seth et al, 1994). The diameter may range from 25 – 100mm while the length may range from 40 – 400mm.

Briquettes are distinguished from pellets by their size. Pellets typically have a length of 5 to 30mm, compared to briquettes which can range from 30mm to 200mm in diameter and between 50mm to 400mm in length (British Standard Institution, 2004; Olorunnisola, 2004). Besides the normal domestic cooking, briquettes are used in rural industries, such as small-scale foundries, bricks, kilns

Plate 2.1 Briquettes of different shapes and sizes

Source: www.google.com

and bakeries. Based on heating value, locally produced briquettes using sawdust as feedstock at Briquette Industries Limited, Ota, Ogun State, Nigeria had 6 to 7 times more energy content per kg than the loose biomass not briquetted (ECN, 2005). Equally the heating flame and temperature obtained in cooking process are better when compared with other renewable energy fuels.

Briquettes have the following advantages as a fuel:

i. It helps convert waste to useful fuel.
ii. They are easier to transport than the original material.
iii. They burn evenly and steadily giving a longer lasting fire.
iv. They have low ash content which means reduced environmental pollution. Ash problem associated with the use of wood is eliminated.
v. When carbonized they are smokeless. They are eco-friendly and improve health by providing a cleaner burning fuel.
vi. They have a high calorific value than the original waste. Thermal values are 16 – 28 MJ/kg.
vii. It helps to reduce deforestation and desertification by being a substitute to wood. (Bhattacharya *et al*, 2002)

Briquetting of biomass has been a widely used technology since the 19th century (Blesa et al 2003a). The industry was significant in the early part of the 20th century in Europe and USA especially on remote farms. The production of briquettes decreased during the1960s to 1970s as the agglomerates were not able to compete with fuels such as oil fractions and natural gas (Blesa et al 2003b). Recently there has been a renewed interest in this process to produce smokeless fuels for domestic use in view of the present environmental concerns in the world.

Briquettes are widely used in Asia and Europe. There are producers of densified fuels located in at least six European countries i.e. Austria, Spain, Sweden, Italy, the Czech Republic and Norway (Oberber and Thek, 2004). A 2007 estimate suggested about 250 operating plants in India, producing approximately 750,000 tonnes of briquettes per year (Schweizer, 2012). The demand for briquette fuel is increasing especially in South India. Various international agencies such as the FAO, UNDP, ESCAP, and UNIDO have assisted in the sponsorship of technology development and transfer of biomass briquette (Grover, 1995). Briquetting technology is yet to get a strong foothold in many developing countries because of the technical constraints involved and the lack of knowledge to adapt the technology to suit local conditions (Grover and Mishra, 1996).

ECN (2007) report advocated the efficient use of agricultural residues and human wastes as energy sources to reduce health hazards arising from combustion of biomass fuels. Despite the positive disposition of the Government towards briquetting technology, it is still not a popular technology in Nigeria. According to ECN report (2005), there exists only a couple of industries in Kaduna and Ogun states, involved in the production and marketing of briquettes in Nigeria. The report attributed the low patronage of the fuel to unpopularity and lack of technological awareness of briquette production and machinery. Except in few research and tertiary institutions, the development and utilization of briquetting technology is negligible.

Briquetting business can be in two scales: the small village producers, making briquettes for themselves and other local families, and a larger scale briquette manufacturer producing sufficient quantities for local industries and commercial businesses. There have been a number of successful briquetting rural cottage industries established around the globe in developing countries notably by the Legacy Foundation in America who have designed appropriate technology equipment for rural briquetting system and trained up entrepreneurs to set-up small scale businesses (Legacy, 2003). These enterprises have multiple benefits as they generate rural employment and income; eliminate disposal problems associated with large quantities of agro-residues waste and provides alternative to wood fuel, thereby reducing impact on forests.

2.4 Technology of Briquetting

Abakr and Abasaeed (2006) classified briquetting machine into three types depending on the die pressure range. They are:

(i) Low pressure briquetting machine ($0 < P < 5$MPa): This requires the addition of binding material at room temperature. It is considered to be the most suitable type of machine for carbonized agro waste. They are used for briquetting due to the lack of the lignin material as a result of carbonization process and due to the low energy requirement for this type of machine.

(ii) Medium Pressure Briquetting Machine (5MPa $< P <$ 100 MPa): This type of machine requires in most cases the use of an additional heat source to melt the internal lignin content of the feedstock and eliminate the use of an additional binder.

(iii) High Pressure Briquetting Machine ($P <$ 100MPa): This type is suitable for the residues of good lignin content. At this high pressure the temperature rises to about 200 – 250°C, which is sufficient to fuse the lignin content of the residue, which acts as binder and so, no need of any additional binding material.

Historically, biomass briquetting technology has been developed in two distinct directions. Europe and the United States have pursued and perfected the reciprocating ram/piston press while Japan has independently invented and developed the screw press technology (Grover and Mishra, 1996).

The screw – type briquetting press is a popular densification method suitable for small-scale applications in developing countries. The raw material from the hopper is conveyed and compressed by a screw in screw press briquetting (Bhattacharya et al, 2002). Briquettes are extruded continuously by a screw through a taper die, which is externally heated to reduce friction (Grover and Mishra, 1996). In screw-presses shown in Figure 2.1; material is fed continuously into a screw, which forces the material into a cylindrical die; this die is often heated to raise the temperature to the point where lignin flow occurred.

Pressure builds up smoothly along the screw rather than discontinuously under the impact of

If the die is not heated then the temperature may not rise sufficiently to cause lignin flow and a binding material may have to be added. This can be molasses, starch or some other cheap organic material (Eriksson and Prior, 1990). It is also possible to briquette carbonized material in a screw press but with this type of machine, the lignin is destroyed so a binder has to be employed. Some low-pressure piston machines may also require the use of binders. If the die is heated then the temperature is normally raised to 250 – 300°C, which produces a good quality briquette provided the initial moisture is below 15%. The briquettes from screw machines are often of higher quality than those from piston units. They are less likely to break along natural fracture lines. Screw presses are usually sized in the range 30 – 100kg/cm though larger machines are available. Their maintenance cost is usually relatively high because of the considerable wear on the screws, which have to be rebuilt rather frequently (Granda et al, 2002).

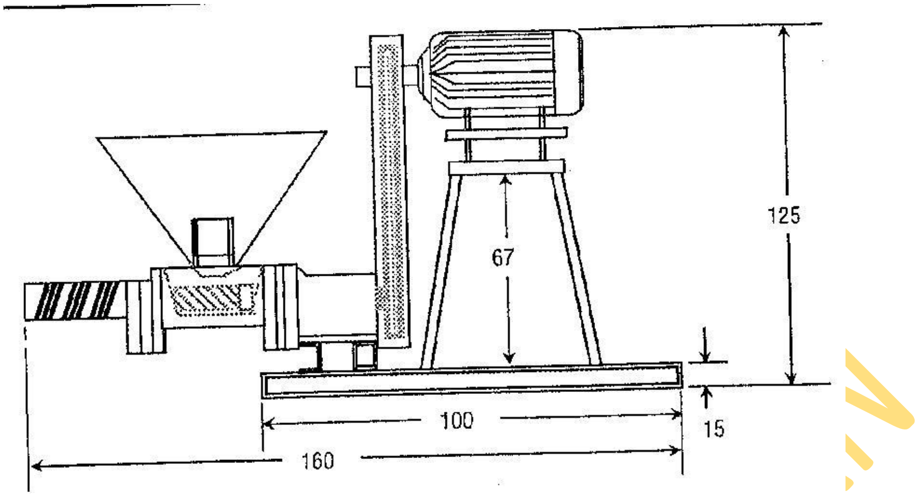

Figure 2.1a: Heated die screw press type briquetting machine (Dimensions are in cm)

Source: Bhattacharya et al., (2002).

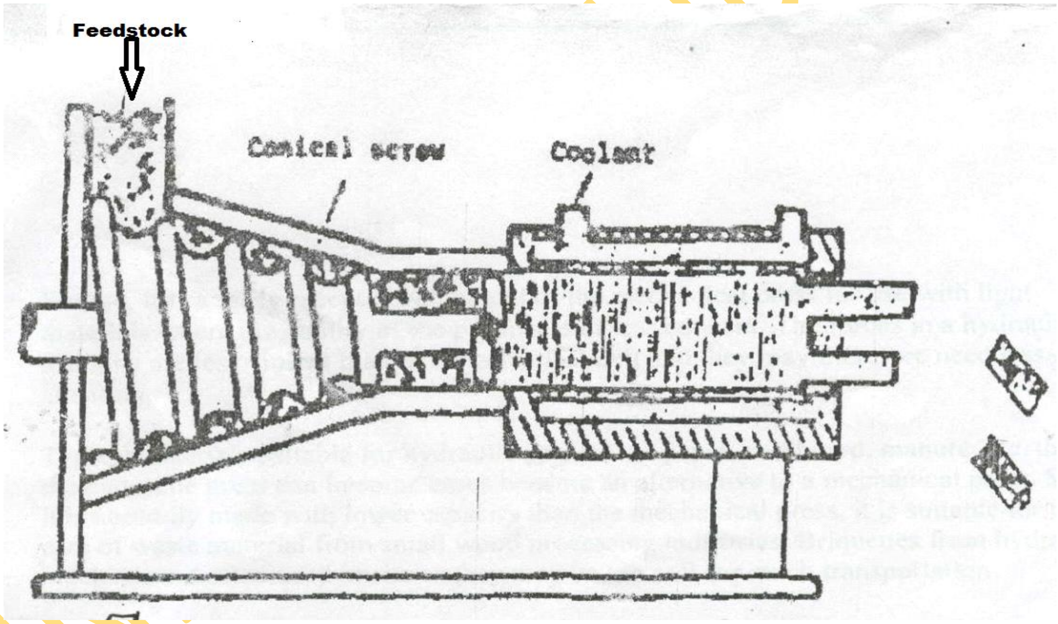

Figure 2.1b: Screw Press Briquetting Machine

Source: Eriksson and Prior (1990).

Piston presses are driven either by mechanical means from a massive flywheel via a crankshaft or hydraulically (Figure. 2.2). The machines usually range in capacity from 0.45 to 0.3t/h, whilst hydraulic machines normally have capacities up to 0.25t/h. Piston presses generally produce hard and dense briquettes while hydraulic presses, which work at lower pressures, produce briquettes, which are less dense and are sometimes soft and friable (Eriksson and Prior, 1990). Typical materials suitable for hydraulic presses are paper, cardboard, manure etc.

Though the hydraulic press can in some cases become an alternative to a mechanical press, it is suitable for briquetting waste material from small wood processing industries. Such briquettes from hydraulic machines are often used on site as they may be too soft for much transportation.

With the piston press technology, biomass is punched or pushed (corresponding to impact or hydraulic technology, respectively) into a die by a reciprocating ram or plunger at high pressure: In both cases, application of high pressure increases the temperature of the biomass and existing lignin in the biomass is fluidized and acts as a binder (Granda *et al*, 2002). In a piston press the wear of the contact parts e.g. the ram and die is less compared to the wear of the screw and die in a screw extruder press. The power consumption of the piston press is less than that of the screw – press. In terms of briquette quality and production procedure screw – press is definitely superior to the piston press technology. The central hole incorporated into the briquettes produced by a screw extruder helps to achieve uniform and efficient combustion and also these briquettes can be carbonized. Table 2.7 shows a comparison between a screw extruder and a piston press. The merits and demerits of hydraulic/piston presses are:

- Ease of use and low maintenance
- Low power consumption
- Densification of low quality residues like cotton, paper, wet sawdust.
- Low product density, friability and production.
- Carbonization of the outer layer is not possible because briquettes are brittle.
- The moisture content of the raw material should be less than 12% for the best results.

The merits and demerits of the screw press (Granada *et al*, 2002, Grover and Mishra 1996) are:

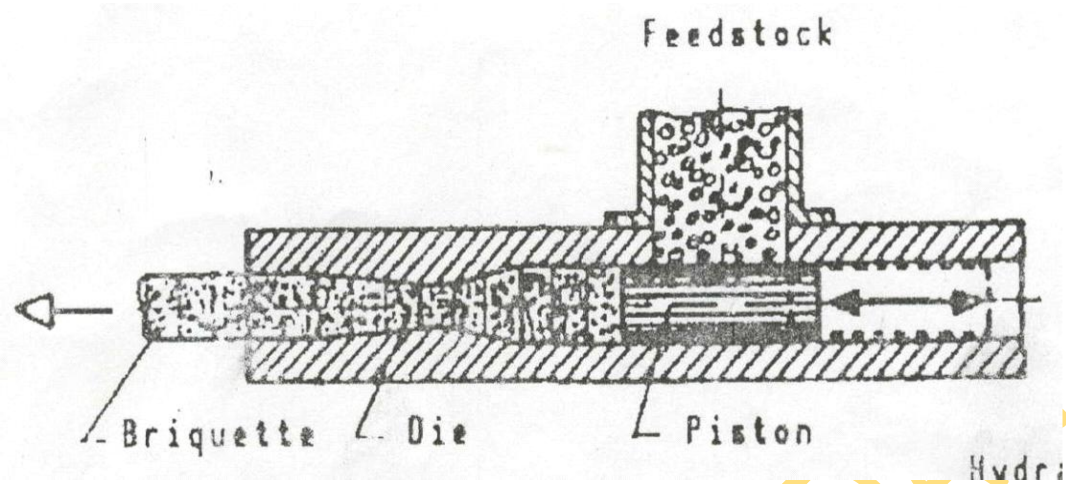

Figure 2.2a: Piston Press Briquetting Machine

Source: Eriksson and Prior (1990).

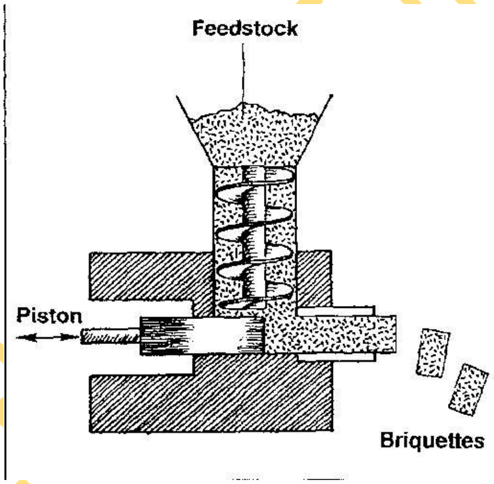

Figure 2.2b: Schematic Diagram of Basic Piston Press

Source: Arnold (2003).

Table 2.7: Comparison of a Screw Extruder and Piston Press

	Piston Press	**Screw extruder**
Optimum moisture content of raw material	10 – 15%	8 – 9%
Wear of contact parts	Low in case of ram and die	High in case of screw
Output from the machine	In strokes	Continuous
Power consumption	50 kWh/ton	60 kWh/ton
Density of briquette	1 – 1.2 gm/cm^3	1 – 1.4gm/cm^3
Maintenance	High	Low
Combustion performance of briquettes	Not so good	Very good
Carbonization to charcoal	Not possible	Makes good charcoal
Suitability in gasifiers	Not suitable	Suitable
Homogeneity of briquettes	Non-homogeneous	Homogeneous

Source: Grover and Mishra (1996).

- The output is continuous and the briquette is uniform in size.
- The outer surface of the briquette is partially carbonised facilitating easy ignition and combustion. This also protects the briquettes from ambient moisture.
- A concentric hole in the briquette helps in combustion because of sufficient circulation of air.
- The machine runs very smoothly without any shock load.
- The machine is light compared to the piston press because of the absence of reciprocating parts and flywheel
- The machine parts and the oil used in the machine are free from dust or raw material contamination.
- The power requirement of the machine is high compared to that of piston press.

Piston presses have not been as successful as the screw presses and are not performing satisfactorily on a commercial basis due to a lack of understanding of the characteristics of raw material which in turn affects machine design parameters like flywheel size and piston stroke length, also the feeding mechanism needs to be perfected according to the bulk density of the raw material. Manual presses have the advantage of being able to handle wet wastes, which cannot be utilized with mechanical presses. Since they cannot however, be made to generate sufficient pressure to break down cell walls, they cannot produce densified briquettes.

The Asian Institute of Technology developed a unique briquetting press which includes one complete heated die, screw-press biomass briquetting system and three gasifier stoves which can use biomass briquettes as fuel (Moral et al, 2005).

In Nigeria, several machines have been developed for briquetting. An extrusion machine that transforms rice and millet husk and sawdust with a through put of 13kg of briquettes per hour has been developed at Sokoto Energy Research Centre, Usman Dan Fodio University, Sokoto (ECN, 2005). A sawdust briquetting machine (screw press) was developed at Obafemi Awolowo University, Ile-Ife. The machine has press barrel screw-shaft, bearing assembly, nozzle or die and 4kW electric of 10kg/hr of sawdust, rice husk and groundnut shells briquettes with 17.8MJ calorific value and 67.94% burning efficiency. The Centre for Industrial Studies (CIS) of the Abubakar Tafawa Balewa University (ATBU), Bauchi in collaboration with the Raw-Material Research and Development Council (RMRDC), Abuja has developed a briquetting machine with a through put of 40kg/hr. The machine features include: four pistons and cylinders, a hopper with four feedholes table, cover and locking device and a crank arrangement as the major operating parts. At present the technology is mostly limited to research institutes, universities and other tertiary institutions in Nigeria.

The University of Ibadan Mission Research Team in 2005 developed a manually operated briquetting machine with 12 rectangular moulds as shown in Plate 2.2. The design is based on the piston technology principle. It is incorporated with twelve moulds each measuring 12 ×12 ×10cm.

2.5 Production Variables Influencing Biomass Briquetting

A number of production variables affect the briquetting process and the properties of the briquettes produced. These include temperature, pressure, dwell time, compaction velocity, die diameter and briquette size and shape.

2.5.1 Temperature

Curing of briquettes can be done in an oven in order to improve their physical properties. After curing, the briquettes are ready for handling to be stored or burnt. Blesa *et al.* (2003c) produced briquettes from blends of low-rank coal and olive stone using molasses as binder and observed that the curing temperature of 200°C in 2 hr was the optimum treatment to produce quality briquettes with the highest mechanical strength. The curing conditions provide to the briquettes a uniform morphology and a development of carboxylic structures. The structures produced contribute to the formation of hydrogen bonds to stabilize briquettes (Blesa *et al.*, 2003a).

2.5.2 Pressure

Al-Widyah and Al-Jalil (2001) produced briquettes at four levels of maximum axial pressure (15, 25, 35 and 45MPa), four levels of material moisture (20, 25, 30 and 35% w. b.), and four levels of hold time (5, 10, 15 and 20s). They found out that durability of briquettes was acceptable at maximum pressures (P_{max}) and hold time applied, but at lower moisture content, briquettes possessed poor durability regardless of P_{max} and hold time. For the ranges of their study, 15MPa and 30 to 35% MC (w. b.) with a hold time of 5s were considered optimum.

Maximum density is the ultimate density attained under a given maximum stress in the die. Maximum density increases with maximum pressure levels (P_{max}). According to Al-Widyah and Al-Jalil (2001), the briquette maximum density at the P_{max} levels of 45, 35 and 25MPa were 1256, 1250 and 1245kg/m^3 respectively. At these P_{max} levels, briquette experienced about 14% reduction in density immediately upon unloading and ejection from the die.

It was also observed by Singh and Singh (1982) that a compressive force of 300kg/cm^2 was adequate to convert paddy straw mixed with binder into satisfactory briquettes. O’Dogherty and

Plate 2.2: Manual Briquette Machine Produced by University of Ibadan Mission Research Team (Igbeka *et al,* 2005)

Wheeler (1984) conducted experiments on the compression of straw in closed dies. At densities of 250 kg/m^3 the wafers were durable and could be formed at pressure of 12 – 30MPa. Sethi *et al.* (1994) classified briquetting techniques into two groups: high and low-pressure techniques. There is need for very high power i.e. 18.75-26.25kw to densify briquettes without binding material. There is no need for any external binding material. The lignin of biomass itself acts as binder. But in low-pressure techniques, there is need for some binding material like molasses, starch, bentonite clay, cow-dung, Cerdex 265, sodium silicate etc.

Bruhn (1985) prepared pellets from a mixture of hay and clay and studied the effects of pressure on the density and durability of pellets. The density of pellet varied from 800.95 to 961.14kg/m^3 at 562.48 to 703.10kg/cm^2 pressure range. Sudhagar *et al.* (2004) conducted experiments on the compression of corn stover in a closed die. Corn stover was compacted at three levels of pressure (5, 10, 15MPa) and at three moisture content levels (5, 10, 15% w. b.) to produce briquettes. They concluded that briquette durability increased with increase in pressure and moisture content (5% and 10%). However, it reduced at higher pressure (15MPa) due to high feed moisture and surface cracks.

Wamukonya and Jenkins (1995) produced durable briquettes form shavings and sawdust at a pressure of 75MPa without the use of a binder. Olorunnisola (2004) observed that minimum pressure required for production of rattan briquette was 14MPa at all levels of cassava starch incorporation as binder.

2.5.3 Hold (Dwell) Time

This is defined as the period during which a dynamic process remains halted in order that another process may occur. It is the time programmed to elapse before a briquette is extruded from the die. According to Olorunnisola (2004), minimum pressure and dwell time required for briquette formation have significant implications for equipment design. Al-Widyah and Al-Jalil (2001) observed that hold time of 5s was optimum value for olive cake compaction.

Wamukonya and Jenkins (1995) produced briquettes from wood waste, wheat straw and their blends at moderate pressure of 75MPa without a binder with the sample compressed over a 5s hold time. Faborode (1989) investigated the compression of agricultural residues at eleven levels of moisture content (wet basis) ranging from 6 to 40%, using a 53mm die, two charge density levels of 61.4 and 85.8kg/m^3, a constant ram speed of 9.2mm/s, a pressure hold-time of 5s and maximum pressure of 5MPa.

2.5.4 Compaction Velocity

Increasing the ram speed during the compression process does not affect the critical density. It is evident however, that increasing the speed V increases the Cauchy number (N_C) in proportion to the square of the speed as given by the formula:

$$N_C = \frac{V^2 r}{A} e^{-b(r-1)}$$ (Faborode and O'Callaghan, 1987)…………………………..[2.1]

N_C = Cauchy number

b = porosity index

V = ram speed

r = compression ratio (Y/Y_o)

A = material constant (K_o/Y_o)

Y = compressed density (kg/m^3)

Y_o = initial density (kg/m^3)

K_o = initial bulk modulus (MPa)

2.5.5 Die Diameter

O'Dogherty and Wheeler (1984) reported that the pressure required to form a wafer of given density increased exponentially with die diameter. This is because there is less relaxation of the straw as the die size becomes smaller and therefore, a denser wafer can be formed in a smaller die. For a particular die size, the relaxation ratio is not significantly affected by the maximum pressure. The compressive force required to achieve a chosen relaxed density increased in proportion to die diameter raised to a power between 2.6 and 3.0. This exponent resulted from both the increase in die area and the increase in pressure required with increasing diameter.

2.5.6 Briquette Size and Shape

Dobie (1960) stated that shapes of a wafer affect its density and handling characteristics. He gave the optimum length-to-diameter ratio as 1.0. The shape and diameter of briquettes influence combustion speed (Tabares *et al.*, 2000). Square or rectangular briquettes have a greater weight loss due to combustion starting at the corners and then taking on a cylindrical form. Briquettes with larger diameter tend to have slower combustion. They concluded that the behaviour of briquettes could be predicted and modified by varying the manufacturing conditions (mainly the diameter factor) and the raw material chosen (mainly the fixed carbon factor), this being the principal factor that determines the weight characteristics during combustion.

Olle and Olof (2007) stated that the size of the briquette has an influence on the stove used, since it must be able to fit into the combustion chamber. According to them, there is a common type of briquette called the "doughnut" shaped briquette; which has a cylindrical shape with a hole in the middle. Legacy Foundation (2003) stated that the central hole in doughnut briquette increases the combustion efficiency of the briquette when and if it is burnt properly. The hole also creates a draft through the central hole, similar to that of a chimney, which gives a clear path for good air – flow from underneath the briquette. The hole therefore encourages rapid drying, easy ignition, and highly efficient burning due to the draft and the insulated combustion chamber which it creates.

2.6 Feedstock and Material Variables Influencing Briquetting

2.6.1 Raw Material

A number of raw material variables affect the briquetting process and the properties of the briquettes produced. These include moisture content, particle size, type of binder and binder to feedstock ratio (Paulrud and Nilsson, 2001).

2.6.2 Moisture Content

The significant influence of the moisture content on the compression and relaxation behaviour of a material was confirmed by Faborode (1989). He observed that the initial bulk modulus of wafer and the critical density of compression decrease with increasing moisture content while the material porosity index increases. For barley straw, the practical limit of moisture beyond which wafer formation was no longer possible corresponds to the fibre saturation point and this was found approximately to be in the region of 22% wet basis.

Yaman *et al.* (2000) noted that an increase in the moisture content of biomass paper mill waste used for briquetting from 9% to 15%, results in an increase in shatter index and a decrease in compressive strength. When the moisture content was reduced to 5%, shatter index and compressive strength were affected negatively. Sudhagar *et al.* (2003) conducted experiments on the production of corn stover briquettes with a piston cylinder with three pressures (5, 10, 15MPa) at three moisture content levels [5, 10, 15% (w.b.)] to produce briquettes. They observed that corn stover produced highly dense, more stable and durable briquettes at low moisture levels (5 and 10%) than at high moisture level of 15%. Combination of high moisture content and pressure was not favourable to the quality of the corn stover briquettes. An increase in corn stover moisture content considerably decreased the briquette density even at high pressures.

According to Sudhagar *et al.* (2004), the maximum briquette density of about 950kg/m^3 was observed in the moisture range of 5–10%. High moisture, more surface-cracks and axial expansion was observed on the briquettes. Smith *et al.* (1977) also observed that wheat straw briquettes tend to expand at high pressure and moisture levels. They concluded that optimal moisture content exists for each feedstock to produce high briquette density and strength. Grover and Mishra (1996) recommended low feed moisture content (8 and 10%) for biomass materials to produce strong and crack-free briquettes.

2.6.3 Particle Size

Paulrud and Nilsson (2001) observed during experimental production of briquettes from spring-harvested reed canary grass that coarser fraction (20mm – 40mm) resulted in briquettes with lower bulk density and consequently a lower fuel rate per hour. The coarser particle size also decreased the ability for the ash to fall off the briquettes and this increases the content of unburned matter inside the briquette. Singh and Singh (1982) also concluded that density, bulk density and durability increased with a decrease in particle size of straw used for production.

2.6.4 Type of Binder

There are three types of binders according to Komarek (2004). They are:

i. Matrix binders which help the briquette achieve structural strength by embedding the particles in a continuous pattern;
ii. Film binders which act as a glue to bond the surface of particles
iii. Chemical binders, which depend upon chemical reactions occurring between the components of the binder.

When briquetting with binders, mixing adds another variable to briquette quality by increasing the strength of the agglomerates (Komarek, 2004). Some materials act as binders while others act as lubricants and some act both as binder and lubricant. Lubricants decrease the coefficient of friction between individual particles or between the surfaces of the agglomerates and the rolls that form them. Proper mixing can minimize costs by allowing the use of less binder. Over mixing, however, can make the material too wet or gummy (Komarek, 2001).

The addition of a binder to briquetting materials is necessary to prepare briquettes with adequate mechanical properties under low pressure systems (Blesa *et al.*, 2003c). The authors noted that increased quantity of molasses as binder in low rank coal and biomass briquettes enhanced their mechanical performance. Blesa *et al.* (2001) and Chemplex (2004) listed binders already used for coal to include:

i. Starch
ii. Molasses
iii. Asphaltite
iv. Humic acid or humates
v. Petroleum bitumen
vi. Lignin
vii. Sulphite liquor from pulp and paper mill
viii. Bagasse
ix. Molasses / H_3PO_4

Previous studies (Olorunnisola, 2004; Husain *et al.*, 2002 and NEDA, 2004) recommended cassava starch as a binder because it is cheap and readily available in the local market. It has high bonding strength. However, cassava as a plant has multiple applications/competitive uses in the agricultural industry. In the production of paddy husk briquettes, Sethi *et al.* (1994) used a combination of cow-dung and molasses in proportions (25: 10), (15:15), (10:25) percent, with chopped straw.

Blesa *et al.* (2003b) used molasses and humates in the preparation of smokeless fuel briquettes prepared from blends of a low rank coal and biomass, which was pyrolysed at 600°C. Crude oil was used as a binding agent in the production of rice husk briquettes in Pakistan (Abdul *et al.*, 1999).

2.6.5 Binder to Feedstock Ratio

Traditionally, the selection of coals, binders and additives has been based on both experience and rudimentary test (Blesa *et al.*, 2003c). Blesa *et al.* (2001) examined among other factors in briquetting of coal, the influence of the binder / additive ratio. Briquettes were prepared from chopped rattan strands and starch was used as a binder in the proportions by weight of 50%, 100%, 150%, 200%, 250% and 300% (Olorunnisola, 2004). It was observed that minimum proportion by weight of cassava starch required for briquette formation was 200%. A minimal decrease in the average compression density was observed with increase in binder content. Briquette stability also increased with increase in binder proportions.

Ajayi and Lawal (1997) used palm-oil sludge as binder at six levels of sludge proportions of the total weight of mixtures - they were 0, 10, 20, 30, 40 and 50% with three briquetting pressures (12.7, 16.9 and 21.2MPa) and three hold times (5, 10 and 15 minutes). They observed that heating values increased with an increase in sludge proportions. Singh and Kashyap (1983) formed briquettes from paddy husk by using the proportion of molasses and sodium silicate between 10% and 25% in ground paddy husk. The density of the briquettes varied from 0.902 to 1.364g/cm^3.

Sethi *et al.*, 1994 formed briquettes by using a combination of molasses and cow dung mixed with ground paddy husk. It was observed that:

i. Moisture content increased with increase in molasses proportion.
ii. Density of briquettes increased with an increase in the percentage of molasses but decreased with an increase in percentage of cow-dung.
iii. The standard deviation from the mean for the diameter increased with the decrease in the percentage of molasses added and increased with an increase in the percentage of cow-dung.

Singh and Singh (1982) prepared briquettes from paddy straw and binders such as molasses, sodium silicate and a mixture of molasses and sodium silicate. They used binder in the ratio of 10, 15, 20 and 25% of the weight of the paddy straw. They concluded that molasses were superior over other binders used. It was observed that density, bulk density and durability increased with an increase in compressive load, and quantity of binder but decreased with particle size of the straw. The burning efficiency was also found to depend on the type of binder used. For molasses, the burning efficiency was 70%. Adegoke et al (2010) observed that high starch (binder) content has significant effect on the burning rate and heating value of charcoal briquettes. The authors observed that the higher the binder content, the higher the calorific values of briquette produced.

2.7 ***Cissus populnea*** **Plant**

Cissus populnea (*Ogbolo*) is a strong woody liana, 8 – 10m long and 7½ cm diameter, dispersed generally throughout Africa from the Coast to the Sudanian and Sahelian woodland, Senegal to North and South Nigeria, and across Africa to Sudan, Abyssinia and Uganda (Burkill, 1980). It is a tropical plant belonging to the family *Ampelidacea*. It is a tall woody climber (Plate 2.3) that may grow up to eight meters tall. The stem is up to about 10cm in girth at the base and has copious sap. The stem when cut pours out clean sticky liquid. It grows on the beds of valleys and its surroundings. It is widely found in savannah regions of Northern Nigeria, in some parts of Western Nigeria especially in Oyo, Osun, Ogun and Ondo states. It is cultivated by cutting the plant. It has a natural tendency of retaining water. It therefore remains fresh throughout the dry and rainy seasons. It is a gel forming plant.

Plate 2.3: *Cissus populnea* Stem (Plant)

Source: www.*herbaria.plants.ox.ac.uk*

All parts of the plants are mucilaginous yielding a viscid sap which when freshly cut from stems is sometimes drunk and used to adulterate honey (Burkill, 1980).

The Yorubas in Western part of Nigeria refer to this plant as *Ogbolo.* It is used as a medicinal plant to improve genital erection in male, to improve *spermatogenesis* and as appetite stimulant. The roots are used by the Yorubas to treat sore breasts in women at childbirth and as a (male) coital adjunct or *aphrodisiac.* The plant is ascribed with fetish/magical power. Yorubas invoke it to keep calamity away from one's head. Bedik of South East Senegal consider the liana to be a hunter's charm. A stem decoct, with *Alchornea cordifolia* is used for treating veneral disease and the viscid solution is used along with other veneral herbal remedies. The Igala and Idoma people of Benue state call it *Ohoho*, they used the mucilage from the stem as a thickener in broth. Mucilage from the stems and fruits is commonly used in soups. The Ibos in Northern part of Anambra state call it *Ukoho* and also use the mucilage from the root as a thickener in broth. In Northern Nigeria, it is known as *Dogomia, Dafara* or *Lodo,* it is used for rope in thatching as binding material for hut roofs, as it is resistant to termite. The plant together with the milky juiced *Pergularia tomentosa,* is given to cows by the Fulani to increase milk production. The root is used in parts of Nigeria as an arrow-poison antidote. The plant forms an ingredient in complex yellow fever and jaundice remedies.

An enema prepared from the juice of the leaves is used for toothache and epileptic fits. A leafy decoction is said to cause a rapid clearance of intestinal parasites like worms. A leaf infusion is drunk in the early morning for womb pains during pregnancy in Ivory Coast (Irvine, 1961).

Other medicinal uses of *Cissus populnea* are as follows:

- The pulped young roots and leaves are effective when applied to oedemas.
- The root is used for boils and infected wounds in Ivory Coast (Kone et al, 2004).

Apart from the herbal properties, the plant has binding properties. Sap from the liana is used in Senegal to smear over the walls of houses to confer a smooth surface. The sap is also mixed with cattle-dung and earth in building adobe huts for the same effect. Mucilage derived from the root bark or by maceration of the liana mixed with mud is similarly used in Nigeria as a sort of cement known as *laso*, for lining dye-pits, mud-walled interiors and beaten floors (Burkill, 1980). The bark is fibrous. It is used in Sudan and in Ubangi to make cordage. Strips of the liana serve as binding material for hut-roofs. They are said to be termite proof.

Some evaluation studies have been carried out on *Cissus populnea* because of its use by traditional medical practitioners. Balami and Bangudu (1991) investigated the mucilage obtained as a pharmaceutical expedient in tablet formulation. Salami (2002) evaluated the suspending property of the gum, while Adeleye (2005) evaluated the mucilage of the plant as a binder in paracetamol tablet formulation. Kone *et al*. (2004) confirmed the antibacterial potency of the root of *Cissus populnea*. Iwe *et al*. (2004) investigated the physicochemical properties of *Cissus* Gum powder extracted with edible starches.

Since the *Cissus populnea* plant is widely distributed across the country and can be cultivated at low cost, it is logical to investigate its use as a binder in briquette production, more so that cassava starch which is a common binder has multiple uses in food, agriculture and allied industries.

2.8 *Gmelina arborea (Roxb)* Sawdust Species

Gmelina arborea is a member of family Verberneaceae and was introduced into Nigerian forestry in 1929 due to its fast growth rate, ease and cheapness of plantation establishment and early returns (Fuwape, 1985). There are plantations of G *arborea* for pulp wood production near Nigerian Paper Manufacturing Company, Iwopin, Ogun State (at J4, 5000 ha; Oluwa; 3940 ha); Nigerian Newsprint Manufacturing Company, Oku-Iboku, Cross River State (at Awi, 5130 ha, Eket, 680 ha, Obom Itiat, 1870 ha, Edondon, 2060 ha, Orira, 200 ha and Ikom, 2,010 ha) and National Paper Mill, Jebba, 560ha (Fuwape, 1984). G. *arborea* is also planted in many fuel wood plantations as well as in shelter belt regions in the Northern part of the country. In derived savannah zone, the growth rate of 84m^3/ha was recorded while growth rate was 252m^3/ha in deep soil after 12 years in the forest zone. An average annual increment of 7 to 25.2m^3/ha was recorded for savannah site and 31.5m^3/ha for high forest (Fuwape, 1985).

The average higher heating values of various parts of G. *arborea* (Roxb) are (Fuwape, 1985)

Heart wood - 22, 542.11KJ/kg
Sapwood - 24, 713.29 KJ/kg
Bark - 23, 357.03 KJ/kg
Branch - 24, 114.13 KJ/kg
Leaves - 24, 543.93 KJ/kg

The grand mean higher heating value of the wood was 24, 046.8 KJ/kg. Average higher heating value using Dulong Petit's equation was 16, 240.25 KJ/kg. According to Akachakwu (1993), the mean gross calorific value for *Gmelina* plantations at Oluwa Forest Reserves, near Ondo was 22,102 KJ/kg. This value is close to the values for the tree species generally regarded as good source of energy for domestic cooking and industrial use. The ash content of *G. arborea* is 1.5% while its higher heating value otherwise known as Gross Calorific value is 22,554 kJ/kg (Onuorah, 1999).

Of the sawdust of *Gmelina arborea*, *Triplochiton Scleroxylonand* and *Khaya ivorensis* wood species experimented for charcoal briquettes; the *Gmelina arborea* species had the highest calorific value of 33796.80kcal/g (Adegoke et al, 2010). According to the authors, the calorific value is in proportion to the percentage of fixed carbon present in the fuel wood as carbon supports combustion. *G. arborea* charcoal briquette has a percentage carbon of 49.04% which was higher than the values of the other wood species. They concluded that sawdust of *G. arborea* and *Khaya ivorensis* would be good for heat generation for domestic cooking and industrial purposes. Ash content of G. *arborea* charcoal briquette was estimated as 4.03% at 40% starch binder incorporation.

G. arborea sawdust is particularly plenteous in almost all mills in Ibadan metropolis. It is the main wood species processed into logs at the challenge sawmills in Ibadan.

2.9 Maize Cob

Maize (*Zea mays*), known as corn in some countries is the third most important cereal crop after wheat and rice (Alabi, 2008). According to Food and Agricultural Organisation (FAO) 2007 data, 589 million tons of maize was produced world-wide in the year 2005. The United States of America was the largest maize producer having 43% of world production (Oladeji, 2012). Nigeria was the second largest producer of maize in Africa in the year 2006 with 7.5 million tons (NBS, 2006). In Africa, South Africa has the highest production of 11.04 million tons (Adesanya and Raheem, 2009). Maize provides food for humans and animals and serves as a basic raw material for the production of starch, alcoholic beverages, food sweeteners and fuel (FAO, 2007). In Nigeria alone, twenty eight different food items can be prepared from maize (Oladeji, 2012).

Maize cob (or corncob) is the agricultural waste product obtained from maize. Maize is mostly harvested and processed for food, leaving a large quantity of maize cob residue constituting waste on the farm, most of which are flared off in preparation for subsequent farming season, thereby posing health risks to both human and ecology (Oladeji, 2012).

Yield of maize cobs is seldom reported (Martinov *et al*, 2011). Pordesimo (2005) presented the following shares of maize plant parts: 45.9% grain, 27.5% stalk, 11.4% leaf, 8.2% cob and 7.0% husk on a dry matter basis.

Maize cobs may be used as a raw material for many products as well as for ethanol production (Akpan, 2005). Still, their utilization as a fuel for combustion facilities is dominant, especially in rural areas of developing countries. The use of maize cobs as energy source for household heating and process energy is auspicious due to:

- their price which is lower than for other crop residues and fossil fuels and availability on the farm.
- their utilization which do not impact food production and
- their use, which can contribute to better economy of farming and moreover, rural development. (Martinov *et al*, 2011).

The lower heating value of maize cobs has been reported by a couple of authors. Schneider and Hartmann (2006) measured lower heating values of maize cobs for different maturity stages, and obtained a value of 17.2 – 18.1 MJ/kg based on dry matter. According to Wilaipon (2008), the average lower heating value of maize cobs was 14.2MJ/kg but the corresponding moisture content was not reported. A value of 17.4 – 18.9 MJ/kg was reported for Higher Heating Value (HHV) based on dry matter by Barnard (1985). In summary the heating value is comparable with other crop residues and even above average. This value is close to value of agricultural residues regarded as a good source of energy for industrial use and domestic cooking.

Schneider and Hartmann (2006) also measured other characteristics of maize cobs. For mature plants, the contents of elements important for the combustion process were: Chlorine 0.1%, potassium, 0.5%, Phosphorus, 0.08% and nitrogen 0.6%. The ash content was measured to be 1.3% based on dry matter. Zabaniotou and Ioannidou (2008) measured 2.1%. Barnard (1985) gave a value range of 1.5 – 1.8% for ash content based on dry matter. Compared with feedstock such as coconut husk with calorific value 18.1–20.8 MJ/KG and low ash content (3.5 – 6%) which has been successfully briquetted and reported to have burn well (Olorunnisola, 2004, Jekayinfa and Omisakin, 2005); maize cob seems to have a relatively high heating value and low ash content. It is therefore a good feedstock for briquetting.

2.10 Materials Already Briquetted in Different Parts of the World

Different materials have been used as raw materials to produce briquettes all over the world. This ranges from metallic briquettes to bio-briquettes, which includes agro-briquettes. Recently the use of agricultural and forestry wastes as well as industrial by-product has increased in the preparation of fuel briquettes (Blesa *et al.*, 2003b). In Turkey, lignite is blended with biomass samples such as molasses, pine cone, olive refuse, sawdust, paper mill waste and cotton refuse in the production of fuel briquettes (Yaman *et al.*, 2001). Olive oil refuse is ground and briquetted to form firm briquettes without the need of a binder. In Sweden, spring-harvested reed canary grass has been successfully used to produce viable briquettes (Paulrud and Nilsson, 2001).

In Spain, chars obtained from low rank coals and blends (sawdust, straw, olive stone and almond shell) have been used to prepare smokeless fuel briquettes. Woody wastes and agricultural wastes such as barks, sawdust, beet pulp and rice husks have been the biomasses usually used in preparation of coal-blended briquettes (Blesa *et al*., 2001).

In India, paddy straw and rice husk have been used for briquette production (Singh and Singh, 1982). In Malaysia, bio-wastes readily available for briquetting are fibre (from the mesocarp) and shell (from around the kernel) obtained from an industry source of 265 palm mills (Husain *et al.*, 2002). In Kenya, sawdust, blends of wheat-straw and shavings have been successfully briquetted (Wamukonya and Jenkins, 1995). In Sudan, low-pressure carbonized cotton-stalk briquettes are favourable and find a ready market in households and small-scale industries. In Tanzania, sawdust is used and in Ghana, wood-waste briquettes are generally good substitutes for wood in industries, where they fetch a higher price than wood fuel (Wamukonya and Jenkins, 1995). Depending on the quantity and availability of waste, usually the crops with the highest productivity and consequently the highest quantity of waste residue that is amenable to briquetting is used in different African countries: in Rwanda, papyrus is used; in Sudan and Gambia, groundnut shells is used, coffee husks is utilized in Ethiopia, while tomato and cotton straw are used in Zimbabwe (Ebubechukwu, 2000).

Briquetting of agricultural residues is considered where factories such as sugar mills exist in Kenya: wastes of sugar cane stalks obtained from the mills are used as a briquetting raw material (Wamukonya, 1995). Olorunnisola (2004) presented an experimental production of briquettes from chopped rattan strands mixed with cassava starch. Arnold (2003) presented an experimental production of durable briquettes from waste papers, while Wilaipon (2003) carried out experiment on maize cob briquetting using molasses as binder. The durability, relaxation characteristics and water resistance of the briquettes were evaluated.

Demirbas and Sahin (1998) evaluated the characteristics of briquettes from blends of waste paper and wheat straw. Demirbas (1999) upgraded tea waste into durable briquettes. Wilaipon (2009) investigated the briquetting characteristics of banana peel waste using molasses as binder. Jin and Wang (2011) presented the densification characteristics and specific energy requirements for the compression of maize cobs under four pressure levels (10, 12, 14, 16 MPa) and two particle size levels

(2.41 mm, 0.86mm). He reported that finer cob grinds (0.86mm) resulted in higher density and lower specific energy requirement than the coarser cob grinds (2.41mm).

2.11 Previous Studies on Biomass Briquettes in Nigeria

There has been a very few studies on briquetting in Nigeria. Such works include that of Faborode (1988) where the briquetting of water hyacinth was demonstrated. He concluded that a stable briquette can be formed from dried water hyacinth at a pressure of 10MPa and pyrolysis temperature of 230ºC at curing time of about 16minutes. Adekoya (1989) presented the performance of a briquetting machine tested with the following sawdust types: *Arere; Araba; Ire; Ayunre; Afara; Banta* and *Ona*. The crushing strength for briquettes made with each of the sawdust types was determined while that of *Gmelina* sawdust was left out. Ajayi and Lawal (1995) conducted a study on the briquetting of *Opepe* and *Arere* species of sawdust using palm oil sludge as a binder. *Arere* species was recommended as a good raw material for briquetting while *Opepe* species is not a good raw material for briquetting on the account of its poor durability behavior. Ajayi and Lawal (1997) presented the combustion characteristics and heating values of *Arere* and *Opepe* briquettes and concluded that *Arere*, a soft wood produces briquette with higher heating value than Opepe but will require more frequent clearing of the furnace than *Opepe* when used as bio-fuel. This is because the ash content of *Arere* is greater than that of *Opepe*.

Adegoke (1999) produced briquettes from sawdust-blends of the following biomass: palm kernel shell; coconut shell; coconut fiber and charcoal, and concluded that, briquettes from sawdust/palm kernel shell blends have higher calorific values than those of other biomass blends. Akpabio and Danbature (2002) investigated the combustion characteristics of coal / biomass blends briquettes. The biomass includes: maize husk; rice husk and sawdust using starch as the binder but limited their tests to the moisture content, shear-stress, ash content and water boiling test determination of the briquettes while the heating value and burn rate determinations were left out.

Olorunnisola (1999a) investigated the efficiency of two Nigerian cooking stoves in handling maize – cob briquettes. Olorunnisola (2007) examined the production of fuel briquettes from waste paper and coconut husk admixtures. It was concluded that good quality and highly storable/durable briquettes could be produced from a mixture of coconut husk and waste paper and from waste paper only.

Olajide (2011) presented comparative fuel characterisation of briquettes produced from two varieties of maize cobs: white and yellow maize. The compressive strength of white maize and yellow maize were respectively 2.30kN/m^2 and 2.34kN/m^2 while their higher heating values were 19,356KJ/kg and 20,890KJ/kg respectively.

None of the investigators has carried out an in-depth study on maize cob briquettes. For example, Olorunnisola (1999a & b) only reported bulk density and calorific value of maize cob briquette while detailed strength and combustion characteristics were not investigated. Wilaipon (2003) investigated maize cob briquettes using molasses as binder. The durability, relaxation characteristics, impact resistance and water resistance of maize cob bounded with molasses were evaluated but the more important characteristics like water boiling test, heating values and other combustion characteristics were left out.

The investigation of *Cissus populnea* gum as a viable binder in briquette production proposed in this study to solve binder unavailability problem in place of cassava starch is innovative and relevant to the pressing energy problems in Nigeria, a country with a population of about 150 million. No previous in-depth study is reported of briquetting using the gum or extracts of the *Cissus populnea* plant as binder and none have investigated their combustion characteristics. This study is expected to bridge this gap.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Materials

The binder used in this study was *Cissus populnea* gum obtained from the stem of *Cissus populnea* Guild Perr (*Ogbolo*). The plant was collected from *Olokemeji* Forestry Reserves, Ibadan, and authenticated in the Herbarium of Forest Research Institute of Nigeria, Ibadan.

Maize cobs were obtained from *Oja-Oba* Market, Ibadan after which they were air-dried for three weeks at ambient temperature of 30 ± 2^{o}C and relative humidity of 70 ± 5 % to reduce the moisture content before being grinded using a hammer mill powered by 1.5kW electric motor. A 6.20mm screen was used to sieve the particles before further processing. *Gmelina* sawdust, sourced from a saw-mill in Challenge Area of Ibadan was also air-dried for three weeks at ambient temperature of 30 ± 2^{o}C and relative humidity of 70 ± 5 % before sieving into various particle sizes.

3.2 Extraction and Characterisation of *Cissus populnea* Gum

The barks of fresh *Cissus populnea* stems (Plate 3.1) were removed and chopped into pieces, (5-6mm long) and peeled (Plate 3.2). 2kg of the chopped samples were rinsed in water and afterwards steeped into 2 litres of chloroform water double strength (Plate 3.3). The chopped samples were stirred continuously for 10-15 minutes, covered and kept at room temperature for 72 hours. The exudates were then filtered with a sieve to separate dirt or visible fibres from the mucilage (Plate 3.4).

The mucilage was dried in a hot air oven (BS Oven 259, Size 1, Gallenkamp, Germany) at 50°C (Plate 3.5). The dried gum was pulverized using a laboratory blender (Plate 3.6) and then screened (Plate 3.7) through a 60 mesh sieve (250µm). This is the crude gum. The purified gum was obtained by precipitating the mucilage with 95%v/v ethanol. The precipitated gum was then washed with diethyl ether to remove organic matter before oven drying. The powder obtained was passed through 250µm sieve and packed into an airtight bottle. 4kg of *Cissus* stem yielded 56.38g of crude powder gum and 50.14g of purified gum when precipitated with 95% v/v ethanol.

Plate 3.1: *Cissus populnea* Stem

Plate 3.2: Peeling of the *Cissus populnea* Stem

Plate 3.3: Soaking of the *Cissus* Stem in Chloroform Water

Plate 3.4: Sieving of *Cissus* Mucilage

Plate 3.5: Drying of the Mucilage in the Oven

Plate 3.6: Grinding of the Oven-dried Mucilage

Plate 3.7: Sieving of Dried *Cissus* Gum

3.3 Determination of Chemical Composition of *Cissus populnea* Gum

3.3.1 Determination of Protein Content

The protein content was determined using the Association of Official Analytical Chemistry (AOAC) method (1990).

Gum powder (1g) was weighed into a digestion tube and 15ml of concentrated sulphuric acid and 5 kjeldahl tablet were also placed in the tube. The tubes were then placed in a digester pre-set at 410°C and digested for 45minutes. 75ml of distilled water was added to each tube when it has been cooled after digestion to prevent it from caking. Each of the tubes was placed in the distilling unit, with 50ml of 40% NaOH dispensed into it to dilute the solution. The mixture in the tube was further distilled into 25ml of 4% boric acid for 5 minutes. The mixture was then titrated against 0.47M HCl until a grey colour was obtained. A blank sample which was subjected to the procedures was also titrated with 0.47M HCl.

The percentage total nitrogen was computed as follows:

$$\%\ \text{Total Nitrogen} = \frac{(14.01 + S_t - B_t \times M)}{10 \times S_w} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where, S_t= Sample titre, B_t = blank titre, M = Molarity of HCl and S_w=Sample weight

3.3.2 Determination of Percentage Fat Content

The percentage fat was determined using an automated method (Joslyn, 1970). The thimbles were each loaded with 2g of the sample and then plugged with cotton wool. The thimbles were then dried and inserted into the Soxtec HT. Into previously dried and weighed extraction cups; 25ml of solvent was added. The cups were then inserted into the Soxtec HT and extraction was carried out in boiling position for 15 minutes and in “Rinsing” position for 45 minutes. The solvent was evaporated. The cups were released and dried at 100^0C for 30 minutes. The cups were cooled in a desiccator and weighed. The percentage fat was computed thus:

$$\%\ \text{fat} = \frac{(W_3 - W_2)}{W_1} \times \frac{100}{1} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where W_1 is the weight of sample, W_2 is the weight of empty cup and W_3 is the weight of the cup with the extracted oil. Determinations were done in three replicate.

3.3.3 Determination of Crude Fibre

The crude fibre content was determined according to AOAC methods (1990). The defatted sample (1g) was weighed into a 600ml beaker. 100ml Trichloroacetic acid (TCA) reagent (obtained from mixing 500ml glacial acetic acid, 450ml water and 50ml concentrated HNO_3 and then dissolving 20g of tricholoroacetic acid in the mixture) was added. The mixture was then brought to boil and refluxed for 40 minutes, beginning from the time boiling started. The flask was removed, cooled slightly and then filtered. The residue was then washed six times with hot distilled water and once with methylated spirit. The filter paper with the sample was transferred into a porcelain crucible and dried in an oven for 24 hours. After cooling in a dessicator, the sample was weighed (weight A). It was then ashed in a muffle furnace at 600^{o}C for 6 hours. After cooling in a dessicator, it was weighed again (weight B).

The loss in weight during incineration is equivalent to the amount of crude fibre. The percentage fibre was obtained from equation (3.3).

$$\%\ \text{crude fibre} = \frac{A - B}{\text{Weight of sample}} \times \frac{100}{1} \qquad \ldots\ldots\ldots\ldots (3.3)$$

3.3.4 Determination of Starch and Sugar Content

The starch and sugar contents were quantitatively determined using the method described by Dubois *et al*. (1956). 0.02g of starch was weighed into a centrifuge tube and the powder was wetted with 1ml of ethanol. Distilled water (2ml) was then added followed by 10ml of hot ethanol and vortex. This was centrifuged for 10 minutes at 2000rpm. The supernatant was decanted into a test tube and made up to 20ml extract to determine the sugar content. For the assay, 0.8ml of distilled water was added to aliquot (0.2ml) of supernatant followed by 0.5ml of 5% phenol and vortex. Concentrated H_2SO_4 (2.5ml) was added and vortex. The sediment obtained after centrifuging was hydrolyzed with perchloric acid and used to estimate starch content. Phenol-sulphuric reagent was used for colour development and glucose standards were used for estimation of sugar. The resulting mixtures were cooled and read at absorbance of 490nm.

The free sugar content was calculated as:

$$\% \text{ sugar} = \frac{(A - I) \times DF \times V \times 100}{B \times W \times 10^6} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where A is the absorbance of sample, I is the intercept of sample, DF is the dilution factor, V is the volume, B is the slope of the glucose standard curve and W is the weight of the sample.

3.3.5 Determination of Ash Content

The AOAC method (1990) for the determination of ash content was used. The crucible was dried in an oven for 1 hour at 100°C and then placed in a desiccator to cool. It was then weighed. 3g of sample was weighed into empty crucible. The sample was burnt using a hot plate for 1 hour and the sample was placed in the muffle furnace at 550°C for 6 hours (until the weight was constant). It was removed and cooled in a desiccator for 45 minutes and the weight was taken as w_3.

The calculation for percentage ash is

$$\% \text{ Ash} = \frac{w_3 - w_1}{w_2} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

Where w_1 = initial weight of empty crucible

w_2 = sample weight

w_3 = final weight of crucible and sample

3.4 Phytochemical Examination

Preliminary phytochemical screening of *Cissus* gum powder was carried out using standard phytochemical screening procedures as described by Trease and Evans (1983).

Anthraquinone derivatives

Free anthraquinones

Cissus gum powder (1g) was shaken with 5ml chloroform for 5 minutes. The extract was then filtered and the filtrate shaken with an equal volume of 10% ammonia solution. A rose pink colour in the aqueous layer indicates the presence of free anthraquinones.

Combined anthraquinones

Gum sample (1g) was boiled in 2ml of 10% hydrochloric acid for about 5 minutes and filtered while still hot. On cooling, the filtrate was partitioned against equal volumes of chloroform (2 vols). Avoiding vigorous shaking, the lower chloroform layer was transferred into a test tube. 10% ammonia was then added and shaken together. On separation, the aqueous layer was observed for delicate rose pink colouration.

Saponin glycosides

The gum sample (1.9g) was boiled with 10ml distilled water for 10 minutes and filtered while hot. The following tests were performed on the cooled filtrates.

Frothing action

The filtrate was tested for frothing by diluting 2.5ml to 10ml with distilled water and shaken vigorously, and observed for frothing.

Emulsifying property

This was done by adding 2 drops olive oil with vigorous shaking for few minutes observing for formation of stable emulsion.

Cardiac glycosides

Gum sample (1.0g) was extracted with 10ml of 80% alcohol for 5 minutes. The filtrate was diluted with an equal volume of distilled water. Few drops of lead acetate solution was added, shaken together and allowed to stand for 10 minutes after which it was filtered.

The filtrate was extracted with 2 aliquots of chloroform and the chloroform extracts were combined. The combined extracts were divided into 2 portions in evaporating dishes and evaporated to dryness and the residue reserved for Keller-Killiani and Kedde test.

Keller-Killiani test

The test was conducted to detect the presence of 2 deoxy-sugars in the gum sample. A portion of the cooled residue of the chloroform extracts above was dissolved in 3ml ferric chloride reagent and 2ml of the concentrated HCl was poured carefully to form a ring below the acetic acid. The observation of a brown ring or reddish brown at the interface and green colour in the acetic layer indicates the presence of cardiac glycosides.

Kedde test

This is a specific test for unsaturated lactones in the cardenolides. The second dried residue from above was mixed with 1ml of 2% 3, 5 dinitrobenzoic acid in ethanol. The resulting solution was made alkaline with 5% NaOH. The presence of a brown-purple colour indicates the presence of unsaturated lactone ring.

Tannins

Another portion of the sample (1.0g) was boiled with 20ml distilled water for 5minutes, filtered while hot and filtrate cooled. The filtrate was adjusted to 20ml with additional distilled water. The solution (1ml) was shaken and further diluted with distilled water to make up to 5ml after which few drops of 0.1% ferric chloride solution was added to the final solution. A bluish black or greenish colour indicates the presence of tannins.

The aqueous extract of the powdered sample was also boiled with 10% HCl. A red precipitate formed at the bottom indicates the presence of phlobatannins.

Alkaloids

The powdered sample (1.0g) was extracted with 10ml HCl (10%). The pH of the filtrate was adjusted to about 6.7 using 10% ammonia solution. The following test reagents were added to test the presence of alkaloid in each test tube containing 0.5ml filtrate respectively.

- Meyer's reagent (KHgI solution)
- Dragendorff's reagent (KBr solution)
- Wagner's reagent (Iodine in KI solution)
- Picric acid (1%) solution

The formation of coloured precipitate indicates the presence of alkaloids.

Cyanogenetic glycosides

The gum sample (0.5g) was mixed with distilled water and a moist sodium picrate paper was suspended in the neck of the tube by means of a cork. A brick red coloration of the paper indicates a positive result. The tube was placed in boiling water for 30 minutes.

3.5 Physicochemical Characterisation of *Cissus* Gum

3.5.1 Swelling Index

Cissus gum (1.0g) was poured into a 10ml measuring cylinder and the volume occupied was noted (V_1). 9ml of distilled water was added and the dispersion was well shaken. Water was added to make up to 10ml. The dispersion was allowed to stand for 24 hours and the volume (V_2) was noted. The swelling index(S) was calculated from the equation:

$$S = [(V_2 - V_1) / V_1] \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

Three replicates readings were taken and the mean calculated.

3.5.2 Determination of Viscosity of Gum

Viscosity was determined using a homogenous and well blended mixture of gum samples at a room temperature (30 ± 1.00°C) using a Viscometer (8-speed model 800, serial 03-857, Ofite Testing Equipment Inc, Houston, Texas, USA). The spindle was set at 300r.p.m. and 600r.p.m speeds in succession. The viscosity was calculated from the readings.

3.5.3 Determination of pH of the Gum

The pH of the various gum samples of different concentrations was determined in duplicate using a pH meter (Meltler Delta 340, Halstead, England).

3.5.4 Determination of Pot Life

The pot life was determined by the number of days it took the gum solution to get spoilt after it had been prepared from dry powder form. The odour and colouration were the determinants of the spoilage.

3.6 Characterisation of Raw Materials for Briquetting

3.6.1 Determination of Moisture Content

The moisture content of maize cob particles and *Gmelina* sawdust were determined according to ASAE standard S358.2 for forages (ASAE, 1999). A sample of 25g was oven-dried for 24hr at 105.3°C.

The moisture content (MC) reported in percent dry basis was determined by the formulae:

$$MC = \frac{(w_1 + w_2) - w_3}{w_3 - w_1} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

Where,

W_1 = weight of dish and lid in (gm),

W_2 = weight of dish, lid and sample before drying in (gm),

W_3 = weight of dish, lid and sample after drying in (gm)

3.6.2 Determination of Loose Bulk Density

The loose bulk density (BD) of particles was measured using the grain bulk density apparatus which was a container of known self-weight and volume. The container was filled to the brim with the particles and weighed.

The Bulk Density (BD) was calculated as:

$$BD = \frac{\text{Weight of sample (kg)}}{\text{Volume occupied (m}^3\text{)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

3.6.3 Particle Size Distribution

To determine the particle size distribution, 100g of ground feedstock was placed in a stack of sieves arranged from the largest to the smallest opening. The set of sieves with numbers 10, 7, 14, 18, 25 and 36 and with opening sizes 4.75mm, 2.36mm, 1.18mm, 850µm, 600µm, 422µm respectively and a receiver was placed on sieve shaker and sieved for 15minutes. After sieving, the mass retained on each sieve was weighed. Sieve analysis was repeated three times for each feedstock.

3.7 Development of Process Equipment

The two basic equipment required for briquette production and combustion are a briquetting machine and a stove. These were designed and fabricated prior to briquette production.

3.7.1 Manual Briquetting Machine

3.7.1.1 Design Considerations

A hand operated briquetting machine was designed and constructed. The following considerations were proposed for the machine:

(1) The machine was to be designed on the basis of hydraulic piston press technology, which is the simplest technology up to date in Briquette press design.

(2) The design should lead to the development of a low-cost briquetting machine that could be manufactured from locally available raw materials and expertise.

(3) The mould shape would be cylindrical with 10mm hole in the centre of each produced briquette in accordance to the recommendations by Olle and Olof (2007) and Legacy (2003). According to the authors, a central hole increases the burn rate of briquettes as it provides an insulated combustion zone which results in less heat transfer by radiation to the surrounding.

(4) Ease of maintenance: The machine should be easily manufactured by local machinist or skilled welders. Nearly all the components of the machine should be easily detachable from each other to facilitate follow up maintenance.

(5) Strength of materials: In the selection of materials of construction adequate care was taken to ensure that the machine components could withstand the forces in play and the weights and overcome the resistant forces and moments created by the compression forces. Mild steel and alloy steel were used for most parts of the machine components.

(6) Ergonomic considerations. The machine should be designed such that minimum human

energy would be expended in the production of briquettes.

(7) A hydraulic jack of 40 tons should be incorporated into the machine to aid compaction. A pressure transducer to gauge pressure applied was incorporated into the hydraulic jack.

(8) The diameter of the briquette should be 40 – 50mm according to recommendation by Arnold (2003) and Husssain *et al*. (2002).

3.7.1.2 Machine Features

The design drawing of the manual briquetting machine is shown in Appendix 1B. The design calculations are presented in Appendix 1A while the bill of engineering measurements and evaluation is in Appendix 1C. The machine (Plates 3.8 and 3.9) was made up of the following components.

Main Frame

The main frame is the part of the briquetting machine that provides support for the whole machine. The design and choice of the frame materials were based on strength, availability, cost and weldability of the chosen material. The frame was constructed with mild steel of 5.2mm thickness. The overall dimension of the frame is 1300mm X 950mm X 540mm.

At the middle top of the uppermost part of the frame are welded two cross supporting frames also made of 5.2mm thick iron. The longer crossing frame was 950mm x 80mm, while the shorter frame was 540mm x 80mm. The main frame carries plate that seats the assemblies of moulds. About 30mm below the cross supporting frame, welded to the main frame is the piston plate that houses the assembly of pistons. The plate also carries the hydraulic jack.

End Support Shafts

There are two end support shafts, each located at opposite sides of the frame. The shaft was designed to carry both the piston plate and the mould. To the side ends, the piston plates and the mould assembly are fastened slots which make it possible to move each up and down on the end supporting shafts. For the construction of the end supporting shafts alloy steel rod was used. Length of each rod was 690mm and at the upper end of each of the end shaft is a screw length of 150mm. The shaft which runs from the base mould plate was fastened at its upper end to a flat bar made of mild steel with a nut of 35mm inner diameter.

Base Mould Plate

It was constructed with mild steel of 5.2mm thickness. Its dimension is 950mm x 540mm. It was welded rigidly to the mainframe. It seats the mould assembly and the pallet board. It also bears the

Plate 3.8: Modified Manual Briquetting Press

Plate 3.9: Hydraulic Jack (A Pressure Gauge was incorporated)

weight of the piston plate and the applied pressure exerted, through the hydraulic jack during compression of briquettes. Its design was based on strength and weld-ability of chosen material.

Piston Plate

It was constructed with 5.2mm thick mild steel. It is on this plate that the piston assembly was welded. The piston plate was bolted to a slot at each side end. The slots at the end sides enable a to and fro movement of the piston plate on the end support rods – A 22mm bolt end nut (mild steel) was used at each side end to fasten the slot to the piston plate. There are six pistons welded to the piston plate, which form the assembly of pistons.

Mould Assembly

This consists of six cylindrical moulds with angle iron holding the assembly. The mould is the housing in which the residue material to be densified is loaded. It is the chamber where the ground material is compacted before being withdrawn for subsequent drying. An important criteria considered in the design of the mould is the need for a smooth internal bore that would facilitate easy compression of the residue material. To satisfy the stipulated design conditions, a mild steel pipe of 50mm diameter, having thickness of 4.5mm was selected. The mould is used as a die in this machine to produce briquettes.

Piston Assembly

Piston assembly consists of six pistons welded to the piston plate. It is the unit that compresses the residue material fed into the mould. The design of this unit is critical to the operation of the machine, since the degree of compaction of the material depends on the effective pressure applied to the material through the piston face. The force and the pressure considerations involved in the operation of this unit necessitated the choice of a rigid and strong material in the construction. For the power suction, 75mm long mild steel was used; though cast iron was proposed originally, but it was not used due to cost and unavailability of material. The piston was made from 5mm thick mild steel machined into a radius of 22.5mm, and at the upper part of the piston is a rod 75mm long. This is welded to the piston plate.

The pressure exerted on the residue material in the mould through the piston face is provided by the pressure lever.

Piston Return Spring

The two pistons return springs were made of alloy steel. The springs suspend the piston plate and at the same time bear the weight of the hydraulic jack that is at the upper part of the piston plate. The two springs were bolted to the 540mm x 80mm (longer) cross supporting frame at the middle top of the main frame.

Pressure Lever System

This consists of the pressure lever rod and the pressure lever pipe. The pressure lever pipe – which is removable, is a 1000mm long mild steel of thickness 10mm and diameter 50mm while the pressure lever rod is made of mild steel, 230mm x 25mm. The pressure lever transmits torque to the pressure lever rod which is attached to the link bars at each end of the machine. The pressure pipe transmits torque through the pressure rod to the short link bar and this in turn transmits torque to the long link bar (520mm x 60mm x 6mm mild steel) and ultimately to the base mould plate which slides freely on end support shaft via the slots it carries.

3.7.1.3 Fabrication and Operational Principles

Special precautions were taken in welding and machining of the various parts of the machine to ensure smooth introduction of the feedstock into the mould, good compaction of the feedstock and its release from the mould. The joints of the main frame were welded together with an electric welding machine for rigidity. The top of the frame are the two crossing bars welded to it. The lower end of the frame is the base mould plate firmly welded to the ends of the main frame. On the mould assembly sides are two angle iron bars of equal dimension firmly welded to hold the six moulds in an assembly. At the two sides ends of the mould assembly is an iron flange bolted to the moulds. The flange provides a slot position on the side support shafts for the up and down movement of the mould assembly during compression.

The piston plate and the pistons were constructed separately before being assembled to form a unit. The pistons are welded to the piston plate. Alloy steel was used for the end support shafts which were turned on the lathe. At both ends of the mainframe is the end support shaft with its upper part thread made of plain carbon steel with a pitch of 2.5mm. The plate which was bore to a diameter of 30mm at the centre provides the means of attaching the threaded rod on the main frame. The threads on both sides of the end support shafts were done on the lathe. The nuts used on the plate are separately bolted together at each sides of the machine. They were made of mild steel material.

Operational Principles

The compaction unit of the machine consists of assembly of moulds, assembly of pistons, return spring, base mould plate, hydraulic jack, pallet board and the pressure lever systems. Prior to the production of the briquettes, a pallet board is centrally placed below the mould assembly on the base mould plate. Afterwards, the feedstocks such as the maize cob particles and *Gmelina* sawdust which had been thoroughly mixed with binder solution was manually hand fed into the moulds. By manually operating the hydraulic jack centrally placed on the top of the piston plate, the piston assembly moves down with the piston rods compressing the feedstock inside the mould to the desired pressure. The compression by the piston rod is allowed for a dwell time of 5 minutes. Afterwards, the screw nut at the side of the jack was slightly loose and then tightened again, causing the piston assembly to move up a bit.

A push effort exerted by the operator through the pressure lever pipe transmits torque via the short link bar, via the long link bar to the mould assembly and subsequently lifts it up. The mould assembly is moved up until it touches the piston plate. At this juncture, the piston assembly by means of return springs will be raised above the briquettes. Finally, the nut at the side of hydraulic jack is loosed to release the jack pressure completely. The briquettes with the pallet are now taken out for subsequent drying.

3.7.2 Briquette Burning Stove

To be able to evaluate the combustion properties of the briquettes produced with the manual briquetting machine, a domestic stove was developed to burn the briquettes.

3.7.2.1 Design Considerations

The following were the main considerations in the design of the briquette burning stove.

(i) The design should lead to the development of a low cost stove that could be built with locally sourced materials to enhance affordability by low income earners.

(ii) The stove should have improved thermal efficiency. To achieve maximum heat transfer, the fuel-bed-to-pot distance was kept at a distance of 25mm. Light weight material (sheet metal) was selected as the construction material, since it has the tendency of warming up quickly and absorbing minimal heat contrary to mud, bricks and cement which take a long time to warm up and absorb considerable heat in the process (Olorunnisola, 1999).

(iii) The design should be such that smoke is reduced and safety of user is enhanced in such a way that risk of burns and scalds associated with conventional open fire stove is eliminated.

(iv) The stove wall should be lined with clay to reduce heat losses.

(v) The design should incorporate an auxiliary combustion chamber below the main combustion chamber for storage and drying of yet to be used briquettes.

(vi) The specific air requirement of biomass briquettes is about 1.6N/m^3/hour per kWh of heat output. Side entry holes should be in the casing of stoves. Alternatively a hollow cylinder made of a perforated sheet (holes size 3-5mm) having a diameter about 50mm less than the inner diameter of the stove should be placed in the stove chambers over the grate. (Grover and Mishra, 1996). The holes will facilitate the entry of distributed secondary air.

3.7.2.2 Stove Features

The design drawing of the briquette burning stove is shown in Appendix 2B. It is cylindrical in shape (Plate 3.10) and consists of three internal compartments namely: main and auxiliary combustion chambers (plate 3.11) separated by a removable grate, air inlet chamber, and ash pit (Plate 3.12). These and other component parts of the stove are described below.

(i) Combustion Chamber

This is the heart of the stove where the briquettes are burnt. There are two combustion chambers of equal volume 1.148 x 10^{-3}m^3 separated by a removable grate made of 1mm thick sheet metal. The combustion chamber is a 486.7mm x 135mm perforated 1mm thick cylinder (with hole size - 2.5mm) designed to accommodate a minimum of five briquettes of 55mm average height and 50mm average diameter. A screen accommodating 2.5mm diameter holes is also provided at the base of the chamber for air intake up by draft and the passage of the ashes down to the ash pit during combustion. The chamber was also provided with a fuel charge loading door. The briquette loading door has dual role of re-fuelling with briquettes and could be opened to increase airflow into the chamber.

(ii) Air Inlet Chamber

This consists of vents on the cylinder wall of the combustion chamber (Plate 3.13) on the briquette loading door and the air entry space when the stove door is opened. Secondary air draft which can be controlled comes through the briquette loading door and stove doors which are often opened during combustion of the briquettes.

(iii) Pot Stand

The pot stand was designed to carry the weight of the cook pot and its contents. It was placed at the top of the stove. The design and choice of the support material were based on the strength, weld-ability availability, cost and resistance to corrosion. The pot stand was made of mild steel. It had a diameter of 190mm and has three equally spaced 10mm mild steel long attached to its circumference.

Plate 3.10: Briquette Burning Stove

Plate 3.11: Internal Compartment of Briquette Stove

Plate 3.12: Ash Pit of the Briquette Stove

Plate 3.13: Vents on the walls and grates of the Combustion Chambers of Briquette Stove

(iv) Grate

There are two grates in the stove; the fixed grate and the removable grate. Both grates were made of a 1mm thick sheet metal. It is on the grates that the briquettes are loaded. The fixed grate is at the bottom end of the combustion chamber. The removable grate is removed when greater heat intensity is needed and the quantity of briquettes to be burned is more than the capacity of the main combustion chamber. Ash passes through the grate to the ash pit during combustion.

(v) Insulated Stove Wall

This is a wall of insulation of clay lining. It has a thickness of 25mm and covered with a thick sheet metal at its inner and outer walls (Plate 3.14). The cylindrical insulated wall was designed to reduce convective and radiation losses of heat energy from the combustion chamber.

(vi) Removable Ash Collector

This is a light ash tray with a handle to enhance ash removal from the stove during combustion for immediate disposal even when the fire is on. Sheet metal of 1mm thickness was chosen for its construction because of its light weight to enhance portability. The handle, which is 66mm in length and of thickness 3.2mm, is made of mild steel.

(i) The Stove Stand

This is a circular ring of diameter 270mm attached with three mild steel 'L' angle legs at three equal distances around the circumference of the stove (Plate 3.14). The ring and the leg support were all made of 10mm thick mild steel. Each of the 'L' angle length is 9cm high. The stand prevents rusting and heat losses through leakage occasioned by direct contact between the stove bottom and the ground surface.

3.7.2.3 Operational Principles

Fuel briquette is loaded through the briquette loading door (Plate 3.15) or from the top of the stove into the combustion chamber. The briquette pieces are of size D = 50mm and H = 55mm (Plate 3.16). The pieces are placed in upright position such that the inner holes in the briquettes are in upward position. This is to allow a better air draft and more efficient combustion of the briquettes.

If the secondary auxiliary combustion chamber is to be employed for greater heat intensity, the removable grate is removed and briquette fuel is first loaded through the briquette loading door up to the top of the combustion chamber. It is now ignited with some wood log and kerosene.

Plate 3.14: Briquette Stove Showing the Insulated Stove Wall

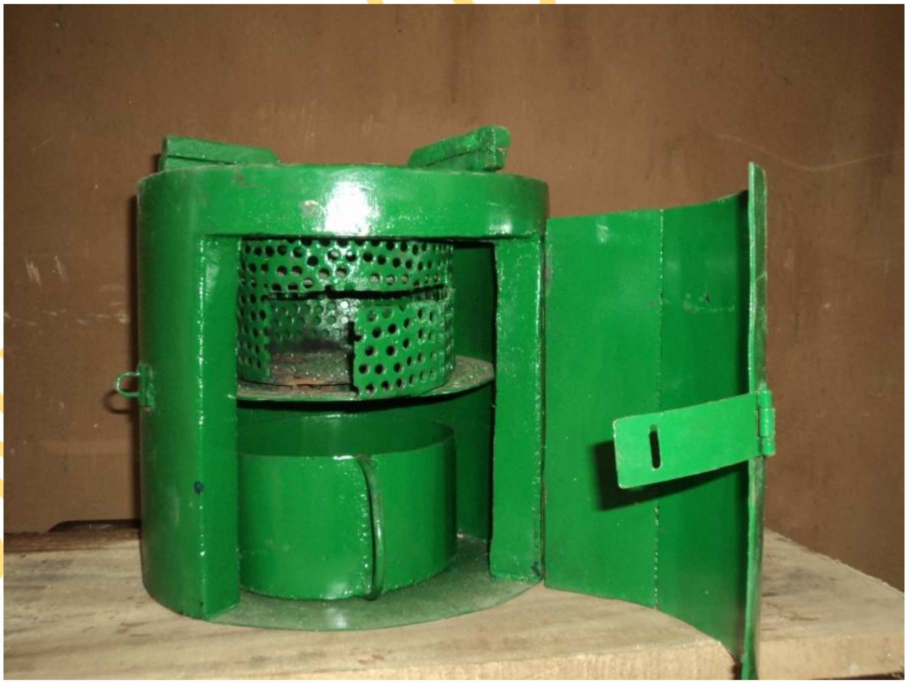

Plate 3.15: Briquette Stove with its Briquette Loading Door Wide Opened

Plate 3.16: Briquette Burning Stove Loaded with Briquettes via the Loading Door

Primary air for combustion is taken through the vents of the combustion chamber while the secondary air is taken through the briquette loading door and the stove doors which are kept partially opened during combustion.

3.8 Briquette Production Process

Gmelina sawdust and maize cobs of particle sizes 1.18mm and 0.6mm as recommended by Husain *et al* (2002) and Akpabio and Danbature (2002) were used. A preliminary study was carried out to investigate the range of pressure that could be used for the densification of sawdust using the manual briquetting machine. It was found out that the maximum pressure that the feedstock could withstand using the machine was 4MPa. Abakr and Abasaeed (2006) reported low pressure briquetting machine (0<P<5MPa**)** with maximum pressure 5MPa, that is considered most suitable for agro waste that requires the addition of binding material for densification. Therefore pre-set pressure loads, of 1.5, 2.5, 3.5MPa were selected.

A hammer mill screen (1.18 mm) was selected because this was a typical coarse particle size at which relatively cohesive briquettes could be formed (Husain *et al.*, 2002; Akpabio and Danbature, 2002) in the compression equipment used. Under the conditions of the study, the lower limit of 0.60mm was selected for contrast purposes.

Cissus populnea binder at concentrations of 1-30% (w/w) of the feedstock were used for briquette production. The binder and the biomass feedstock were manually mixed thoroughly as reported by Singh and Singh (1982), Husain *et al*.(2002), Sethi *et al.(*1994) and Olorunnisola (1999a). Compression of the wet feedstocks was carried out on the manual briquetting machine as shown in Plate 3.17.

Approximately 30g of the selected feedstock was loaded into the mould. The compaction commenced immediately upon filling the mould with feedstock at pre-set pressure loads of 1.5MPa, 2.5MPa,3.5MPa and 5MPa. Preliminary experiments carried out for briquette production on the Manual briquetting machine revealed that stable and durable briquettes were only produced at pressure range 1.5 – 3.5MPa. Beyond the 3.5MPa pressure application, all the binder oouzed out of the feedstock, in the moulds. Preliminary investigation in the use of the machine also revealed that the optimum pressure for briquette production was 1.5MPa. A pressure of 1.5MPa was therefore used for quality evaluation of briquettes in this study.

Plate 3.17: Compression of Briquettes with Manual Briquetting Machine

A lubricant (SAE 30, Mobil) was smeared on the mould and the plunger cylinder fit was such that there was negligible friction between the two components. Once the pre-set pressure was achieved, the plunger was stopped and held in position for 5 minutes. Briquettes were then ejected from the mould.

3.9 Determination of Physical Properties of Briquettes

In order to investigate the influence of processing factors on the physical, mechanical and combustion characteristics of briquettes produced, some standard tests and analysis were carried out. The physical tests include moisture content, loose bulk density and particle size distribution.

3.9.1 Stability

According to Sudhargar *et al*. (2004), stability index is one of the most important criteria for evaluating densified product quality. Stability is the ability of a briquette to maintain its initial dimension and shape after compression in the axial and longitudinal directions. As the pressure is released after compression in mould (or closed cylinder) the briquettes tend to expand. The expansion takes place primarily in the longitudinal direction i.e. in the direction at which force was applied.

To determine dimensional stability, the length of a briquette from each batch production was measured at 1 min, 10 min, 30 min, 60min, 1440min and 10080min after production (Wamukonya and Jenkins, 1995). Length expansions were also taken after three weeks of removal of briquettes from oven. The dimensional changes were taken with a digital vernier caliper. Ten determinations were made.

3.9.2 Density

The density of the briquette was determined by measuring the dimensions using a vernier calliper and weighed by the means of an electronic balance. (Metler PC 440, Zurich, Switzerland). Ten replicates of the sample were tested and the average density reported.

Relaxed Density

The relaxed density is the density of the dry briquettes. The relaxed density was taken after drying to equilibrium moisture content. Ten replicates were made.

3.9.3 Water Resistance Index (WRI)

The water resistance of the briquettes was determined after the method of Yaman *et al.* (2001) by immersing the briquette in a glass container filled with distilled water at room temperature and measuring the time (in hours) required for dispersion in water. Five replications were made.

3.10 Determination of the Mechanical Properties of Briquettes

Yaman *et al*. (2001) and Ajayi and Lawal (1995) showed that the mechanical properties of briquettes can be characterized by two properties: durability index and compression strength. Before testing the strength of the briquettes, the briquettes were stored under ambient conditions for three weeks to stabilize inner tensions affecting the micro structure and the porosity of the briquettes (Yaman *et al*., 2001).

3.10.1 Durability Index

The durability of the briquettes was measured using the ASABE standard method (Wamukonya and Jenkins, 1995). A test sample of three briquettes (approximately 100g) was tumbled for 3 minutes at 13 rev/min in a cage measuring 300mm x 300mm x 457mm with sides made of 6.35mm square wire mesh (Plate 3.18). The fines were separated after tumbling by screening. The weight of the remaining briquette was measured. The durability rating of each type of briquette was expressed as a percentage of the initial weight of the material before tumbling.

It is calculated as follows:

$$\text{Durability (\%)} = \frac{\text{Weight loss(kg)}}{\text{Original weight (kg)}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.8)$$

3.10.2 Compressive Strength

Compression strength test was measured using a Hounsfield Tensiometer (serial number: W4.563, Croydon, England). Load was increasingly applied at a constant rate until the briquette failed by cracking or breaking (Plate 3.19). Compressive strength was read on the scale of the machine at the point of fracture (Plate 3.20). The results were reported as the maximum crushing load, which a briquette can withstand before cracking or breaking. Five determinations were made.

3.11 Determination of Combustion Characteristics of Briquettes

3.11.1 Water Boiling Test

Water boiling test was carried out using: 0.6mm sawdust briquette, 0.6mm maize cob briquette, 1.18mm sawdust briquette and 1.18mm maize cob briquettes (all produced using 15% w/w of *Cissus* gum binder at compression pressure of 1.5MPa). Briquettes were stacked into the stove and 20g of *ogunso* (a locally produced fire-starter made from chaffs recovered during oil palm processing) was placed amidst the fuel charge. It was then lit with a match after the application of 10ml of kerosene to initiate combustion. The fire was allowed to assume steady state combustion. Water (one litre) was put

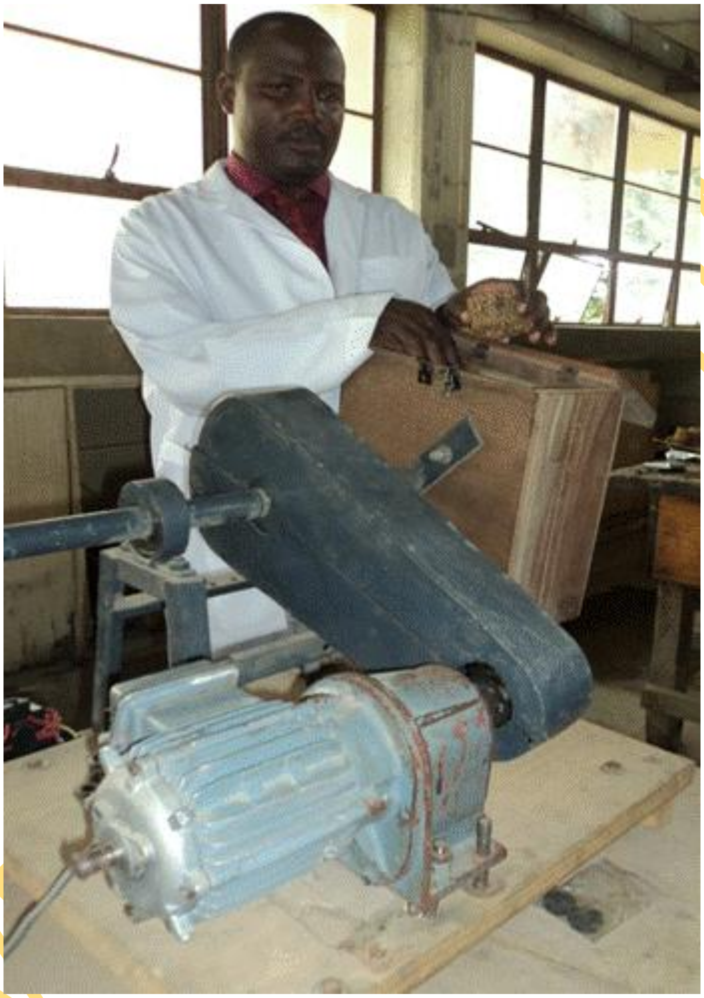

Plate 3.18: Durability Testing Machine

Plate 3.19: Compressive Strength Testing Machine

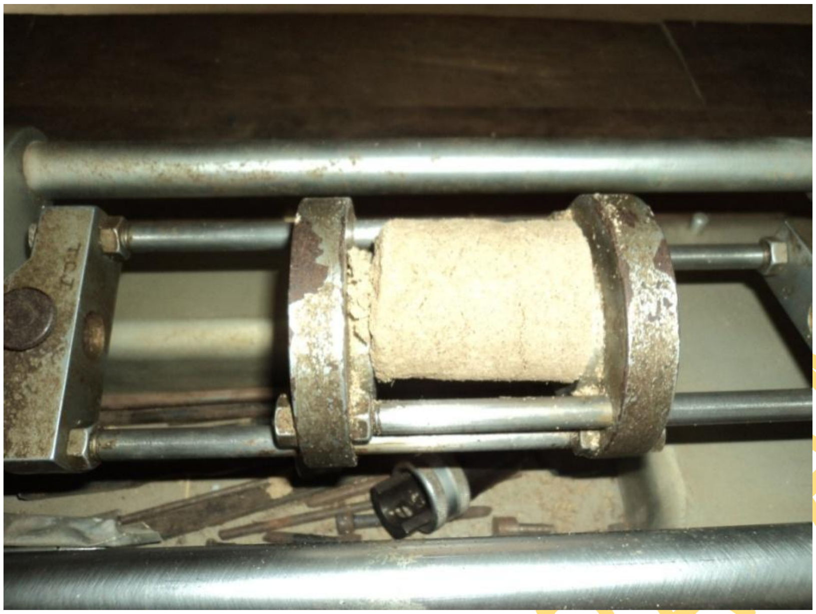

Plate 3.20: Briquette Failure under Compressive Load

in a pre-weighed aluminium pot and the initial temperature of the water was recorded using a mercury thermometer before placing it on the burning stove. The test was conducted at atmospheric pressure and pot opened (Plate 3.21). The subsequent changes in temperature up to boiling point were recorded at 2-minute interval inserted in the opened pot. At the boiling point, the pot was removed from the stove and the fire was immediately put off with the aid of dry sand. The time taken for each set of briquettes to boil 1litre of water were recorded.

The water remaining in the pot and the remnant fuel briquettes were then measured. Determinations were done in three replicates. A comparative test was conducted with two other local stoves; charcoal and wood stoves using the same method as for the briquetting stove. Determinations were done in three replicates.

Burn Rate Determination (B)

The burn rate of the briquettes was calculated using the formula

$$F\left(kghr^{-1}\right)=\frac{100(wi-wf)}{T(100+m)} \qquad \text{……………………..………………..…..(3.9)}$$

Where

F = burn rate in kg/hr

W_i = initial weight of briquette at the start of the test (kg)

W_f = Final weight of briquette at the end of test (kg)

T = Total time taken to burn the briquette (hr)

M = Moisture content of briquette (%)

Thermal Efficiency

Thermal efficiency of the stove is calculated using the approach of Olorunnisola (1999) and Olle and Olof (2007). The thermal efficiency of a stove is given as ή

$$ή = \frac{w_{wi}c_{pw}(T_f - T_i) + (w_{wi} - w_{wf})L}{Fth} \qquad \text{(Olorunnisola, 1999) …..……… (3.10)}$$

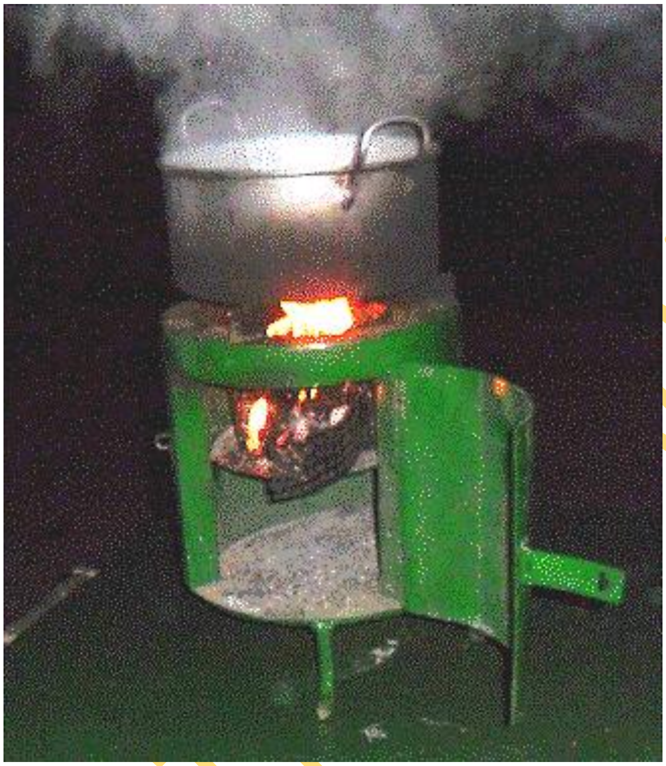

Plate 3.21: Water boiling Test Administered with Briquette Burning Stove at Room Temperature and Pressure

ή = thermal efficiency in percentage

W_{wi} = initial weight of water in pot (kg)

W_{wf} = final weight of water in pot (kg)

C_{pw} = specific heat capacity of water (KJ/Kg°C)

T_f = final temperature of water in pot (°C)

T_i = initial temperature of water in pot (°C)

L = latent heat of vaporization of water at 100°C and 10^5 Pa KJ/Kg

F = burn rate (kg/hr)

h = calorific value of fuel (KJ/Kg)

t = total time taken to burn fuel (hr)

Or alternatively

$$ή = \frac{W_{wi} C_{pw}(T_o - T_i) + M_w evap H_i}{M_f H_f} \times 100$$ (Olle and Olof, 2007)

…..……(3.11)

Where

ή = thermal efficiency in percentage

M_{wi} = mass of water initially in cooking vessel, kg

C_{pw} = specific heat of water, KJ/kg°C

$M_w$evap = mass of water evaporated, kg

M_f = mass of fuel burned, kg

T_0 = temperature of boiling water, °C

T_i = initial temperature of water in pot, °C

H_i = latent heat of evaporation at 100 °C and 10^5Pa, KJ/kg

H_f = calorific value of fuel, KJ/kg

Using

C_{pw} = 4.19 KJ/kg°C

L = 2257 KJ/kg

For the thermal efficiency evaluation of the briquette stove; coal stove and wood stove, maize cob briquettes of 0.6mm feedstock particle size (at 15% w/w concentration and 1.5MPa pressure application) was used for the boiling water test.

3.11.2 Cooking Test

The Controlled Cooking Test (CCT) is meant primarily to compare the performance of an improved stove to a traditional stove in a standardized cooking task (CCT, 2004). The developed briquette stove in this study was compared by means of tests with locally built stoves; charcoal and wood stove. The tests were conducted after the method of (CCT, 2004) and Olorunnisola (1999).

Equal quantities (200g) of rice were placed in three aluminium pots (with covers), each already containing 1000ml of water. The weight of the fuel charge in each stove was noted. A fuel charge of 400g (of 1.18mm maize cob particle 15% w/w concentration at 1.5MPa pressure) was used for each stove. The time taken for cooking rice on each stove was noted. The data collected was used in calculating the specific fuel consumption (SFC). This gives the quantity of fuel required to cook 1kg of a given amount of food for the "standard cooking" task. It is called as a simple ratio of fuel to food:

$$SFC = \frac{\text{Mass of Fuel consumed}}{\text{Total mass of cooked food}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.12)}$$

Total cooking time (T) was also calculated from the data. It is an important indicator of stove performance in the CCT (CCT, 2004). Depending on local conditions and individual preferences, stove users may use these indicators more or less than the fuel consumption indicator.

The time spent in cooking per kilogram (T_R) of cooked food was calculated as

$$T_R = \frac{\text{Total time spent in cooking, T (hr)}}{\text{Total weight of cooked food, w (kg)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.13)}$$

The test was replicated thrice.

3.11.3 Heating Value

The heat of combustion (calorific value or Heat value) of a compound is the standard heat of reaction for complete combustion of the compound with oxygen. The heating value of a material is the most important combustion property for determining the suitability of a material as fuel (Fuwape, 1985).

The terms higher calorific value (HCV) and lower calorific value (LCV) are used respectively, to distinguish the cases in which any water formed is in the liquid or gaseous state.

The two calorific values are related as follows:

$$HCV = LCV + M_m \times H_e \quad \dots\dots\dots\dots\dots\dots \quad (3.14)$$

Where M_m: = mass of water produced per unit mass of fuel

H_e = latent heat of evaporation of water

There are two methods of its determinations: one by calculation based on the chemical composition and the other by actual combustion in a bomb calorimeter. For fuels with complex chemical formular, it is more reliable and simpler to evaluate the heat of combustion by doing a bomb calorimeter test. The International Energy Agency (IEA) according to Obernberger and Thek (2004) gave the empirical equation for the calculation of the gross calorific value as:

$$GCV = 0.3491X_C + 1.1783X_H + 0.1005X_S - 0.0151X_N - 0.1034X_O - 0.0211X_{ash} \quad \dots\dots \quad (3.15)$$

and

$$NCV = GCV(1 - \frac{X_W}{100}) - 2.447 * \frac{X_W}{100} - \frac{X_H}{200} * 18.02 * 2.447(1 - \frac{X_H}{100}) \quad \dots\dots\dots\dots\dots\dots\dots\dots$$

(3.16)

GCV is gross calorific value [MJ/kg (d.b.)]

NCV is net calorific value [MJ/kg (w.b)]

X_W = water content [w% (w.b.)]

X_H and H content wt% (d. b.) from data source.

A bomb calorimeter was used in the determination of the heat values with the briquette ground to a fine powder and oven dried at 212°F.

The calorific value was computed from the equation below:

$$H_C = \frac{(T \times W)}{M_s} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \quad (3.17)$$

M_s = Mass of sample in gram

H_C = Calorific value in calories per gram

Where

W = Energy equivalent of calorimeter in calories per °C temperature rise

T_o = Temperature at firing

T = Temperature Rise = $T_F - T_o$

C = Centimetres of fuel consumed in firing

T_F = Final temperature after temperature has stabilized (about 9 minutes)

e = correction factor in calories for heat of combustion of fuse wire

= $\frac{2.3}{C}$ [when using Parr 45C10 nickel-chromium fuse wire]

W = $\frac{2.7}{C}$ [when using 34B&S gauge iron fuse wire]

Heating value determination for briquettes in this study was carried out using E2K Bomb Calorimeter (Johannesburg, South Africa) at the Nigerian Institute of Science and Laboratory Technology Center, Ibadan. Five determinations were made.

3.12 Statistical Analysis

Statistical Analysis was done to compare the effects of the gum on the briquette properties using the analysis of variance (ANOVA) on computer software IBM SPSS PC Version 20.0 (IBM Software Incorporation, New York, United States of America). At 95% confidence interval, probability, p values less than or equal to 0.05 were considered significant. Pearson’s correlation coefficient was used to determine the relationship between binder concentration and viscosity

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characterisation of the *Cissus Populnea* Gum

4.1.1 Gum Yield

The yields obtained from the crude and purified *Cissus* gum samples on extraction from fresh stems were 1.40 and 1.25% (w/w) respectively. The crude *Cissus* gum is chocolate (dark brown) in colour and without an offensive odour while the purified *Cissus* gum is light brown in colour and odourless.

4.1.2 Chemical Composition of the Gum

The proximate compositions of the crude and purified gums are presented in Table 4.1. The carbohydrate contents of the crude and purified *Cissus* gums were 75.58 and 77.84 % w/w respectively. These values compare favourably with those reported in literature. It is slightly less than the range, 82.31-87.81% reported by Iwe *et al* (2004). It is also slightly greater than 51.9- 68.3% reported by Owofadeju (2009). Glicksman (1982) had noted that carbohydrates are the major components of gums.

The results showed that crude fibre, protein and ash content were higher in the crude than the purified gum. The result also shows that crude gum had the highest amount of non-carbohydrate constituent.

The moisture content of purified gum was 12.89% while that of the crude was 12.57%. Excessive moisture in a material could lead to activation of enzymes and the proliferation of micro-organisms thereby affecting the gum (Iwe *et al*, 2004). The control of relative humidity is therefore important during storage of the gum for optimum shelf-life. The ash content of the crude form was higher than that of purified form. The ash content is an index of mineral contents (Al-Harrassi *et al*, 2012).

4.1.3 Phytochemical Screening of the *Cissus populnea* Gum Samples

The results of the phytochemical screening of the *Cissus* gum samples are presented in Table 4.2. While both purified and crude gum contained saponin, only the crude gum samples contained cardenolides and tannins. Claudius (2006) had observed that tannin is a major component of most plant used for adhesive formulation. The presence of tannin in the crude *Cissus* gum provides a basis to explore it as a resource in locally produced binder or adhesive. Also the purified and the crude gum

Table 4.1 Proximate Composition of Crude and Purified *Cissus populnea* Gum

	% w/w	
Component	**Crude**	**Purified**
Crude Protein	6.76 ± 0.028	5.58 ±0.028
Fat	0.27± 0.000	0.28± 0.000
Ash	2.65±0.014	2.23±0.007
Crude Fibre	2.19±0.014	1.20±0.007
Moisture Content	12.57±0.021	12.89±0.014
Carbohydrate	75.58 ± 0.021%	77.84 ± 0.073%

Table 4.2: Phyto-Chemical Composition of the *Cissus populnea* Gum Powder

Parameter	Crude Gum	Purified Gum
Alkaloids	+	+
Cardenolides	+	-
Anthaquinones	-	-
Saponins	+	+
Tannins	+	-

samples contained alkaloids. Patani (2004) reported the presence of alkaloids in the *Irvingia gabonensis* kernel residue powder binder while Olutayo (2005) also reported the presence of alkaloids in the *Cissus* gum.

4.1.4 Swelling Index

The results of the swelling index of *Cissus* gum with time are presented in Figure 4.1. The aqueous dispersion of purified *Cissus* gum hydrated more than the crude *Cissus* gum giving a colloidal liquid. The crude gum powder hydrated after 24 hours of soaking in distilled water while the purified gum hydrated after 5 hours of soaking. The swelling rate of the purified gum was more than double for the crude gum, for the same period of soaking. After 5 hours of soaking, the swelling index of the crude *Cissus* gum was 185% while that for the purified gum was 464% (Figure 4.1). After 24 hours, the swelling index was 575% for the purified gum while for the crude gum it was 215%. Therefore, *Cissus* gum is hydrophilic and forms a viscous colloidal dispersion or gel when it comes in contact with cold water (Kalu *et al*, 2007).

4.1.5 Viscosity

The results of the effects of gum concentration on the viscosity index are shown in Figure 4.2. There was a positive correlation between the gum concentration and viscosity. The results were found to fit the general equation $V=2.363C - 2.474$ with a correlation coefficient of $R^2 = 0.958$, where: V is the viscosity and C is the concentration. Generally, an increase in the gum concentration resulted in a corresponding increase in the viscosity of the gum irrespective of the form. This finding is in agreement with the results of other studies (Tharp, 1982; Glicksman, 1982; Iwe, 1996; and Iwe *et al*. 2004; Echie and Amalime, 2007). The increase was more pronounced in the purified gum than with crude gum.

This may be attributed to the inter-connective structural difference in the polymers, which was more pronounced in the purified than crude gum. The crude fibres and impurities in the crude gum (Table 4.1) may be responsible for its weaker polymer – polymer cohesion which is known to influence the instinctive properties in the crude gum (Eichie and Okor, 2000).

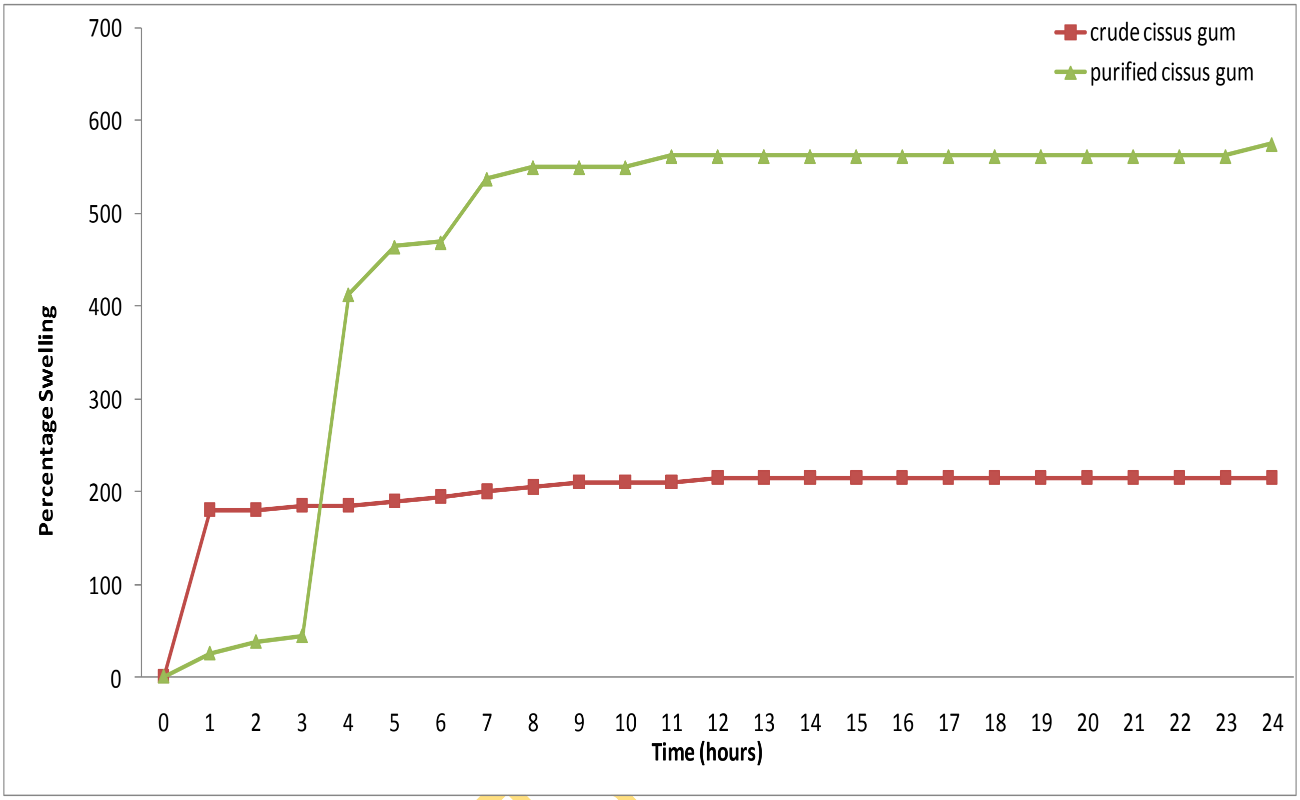

Figure 4.1: Plots of Percentage Swelling Index of *Cissus* Gum against Time

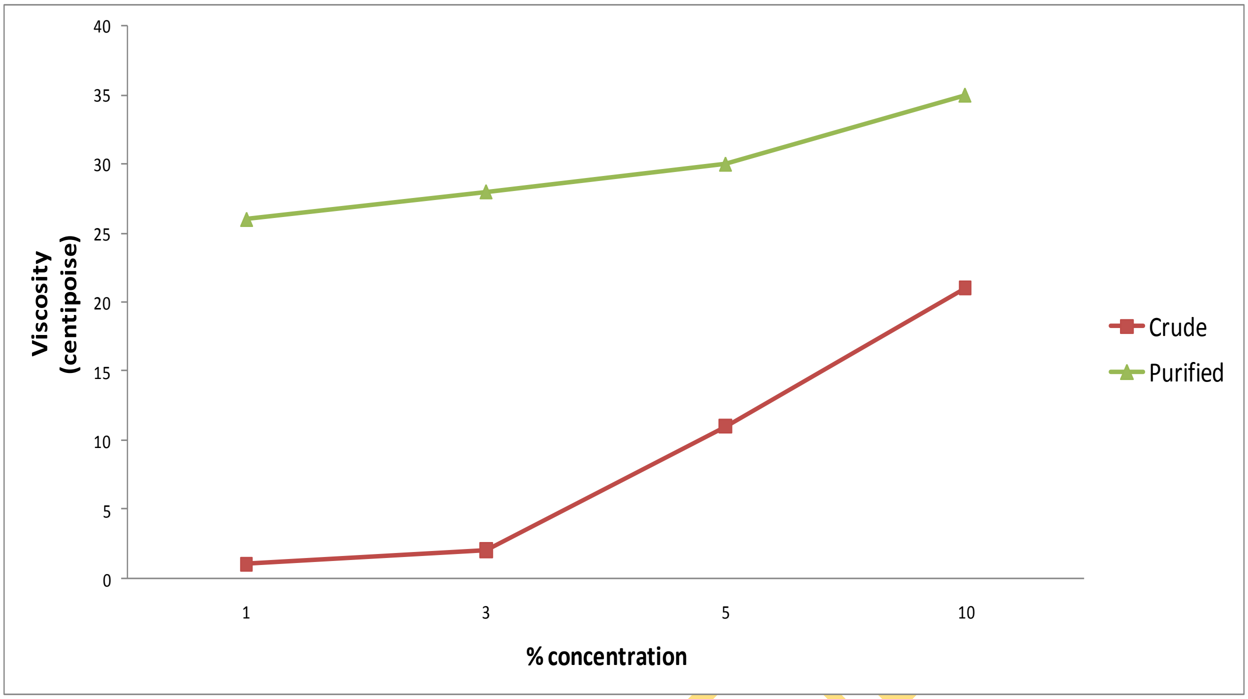

Figure 4.2: Effect of Gum Concentration on Viscosity Index of *Cissus* Gum

4.1.6 pH of the Gum

The pH values of the purified and crude gums are presented in Table 4.3. The pH of both *Cissus* gums were in the acid range (6.5 – 6.8). These pH values compared well with the other gums that have been reported in literature. Cissus gum powdered extracted with the aid of edible starch has a pH value in the range 5.69-6.49. (Iwe *et al* ,2004).

The pH of the polyamine – adhesives formulated with mucuna and African yam bean were 6.3 and 5.5 respectively (Owofadeju, 2009). pH is critical for determining the product shelf life from the view point of microbiological degradation of sensitive ingredients (Iwe *et al*., 2004). Storage stability increases as pH decreases (Glicksman, 1982). Preservation of *Cissus* gum could be by acidification and mild heating (Iwe *et al*. (2004)). The differences in the pH could be due to solute hydration, physicochemical environment and thermodynamic properties of the system (Bell and Lubuza, 1992). The pH decreased with percentage concentration (w/v) in the purified *Cissus* gums but increased with percentage concentration in the crude *Cissus* gum.

4.1.7 Pot Life

The crude and purified *Cissus* gums in solution gave pungent smell after three days of storage in pot at room temperature of 27°C. The colour of both gums in solution changed after three days such that it had to be thrown away due to spoilage. This may be due to microbial action on the gums after exposure to the atmosphere since the pH values of both gums lies within the range (5.5 – 7.0) that encourages microbial growth (Coker and Ehimika, 2005).

4.2 Characterisation of Raw Materials for Briquetting

4.2.1 Physical Properties of Raw Materials.

The sieve analyses of the *Gmelina* sawdust and maize cob particles are presented in Tables 4.4 and 4.5. The greater proportion of the maize cob particles fell within particle size retained on 2.36mm sieve (45.3%), while for the *Gmelina* sawdust, the greater proportion of the particles fell within particle size retained on 1.18mm sieve (35.03%). Shaw (2008) had noted that the particle size distribution has an effect on the briquette quality. Payne (1978) was quoted as stating that a portion of fine to medium particle was required for good briquette quality, but the briquette quality and the efficiency of the commercial briquette traders will not suffer if coarse material was used. The mean moisture contents of *Gmelina* sawdust and maize cob particles were 10.0% and 9.0 % respectively. Both values fall within 8-10% moisture content required to produce strong and crack free briquettes (Grover and Mishra, 1996

Table 4.3: Characterisation of *Cissus Populnea* Gum

	Crude Gum		Purified Gum	
Concentration (% w/v)	**Viscosity (Centipoises)**	**pH**	**Viscosity (Centipoises)**	**pH**
1	1.0	6.46±0.10	26.0	6.80±0.16
3	2.0	6.52±0.15	28.0	6.42±0.20
5	11.0	6.57±0.09	30.0	6.51±0.14
10	21.0	6.82±0.16	35.0	6.49±0.13

Table 4.4 Sieve Analysis of Maize Cob

Sieve sizes (mm)	% by weight	Cumulative (%) by weight
Receiver	10.46	0.00
0.425	4.22	14.68
0.600	7.23	21.91
0.850	8.12	30.03
1.180	24.63	54.66
2.360	45.34	100.00
4.750	0.00	100.00

Mean Loose bulk density of maize cob particles = 134.0kg/m^3

Mean Moisture content of maize cob particles = 9.0%

Table 4.5: Sieve Analysis of *Gmelina* Sawdust

Sieve sizes (mm)	% by weight	Cumulative (%) by weight
Receiver	14.07	0.00
0.425	7.79	21.86
0.600	13.38	35.24
0.850	17.45	52.69
1.180	35.03	87.72
2.360	12.28	100.00
4.750	0.00	100.00

Mean Moisture content of *Gmelina* sawdust = 10.00%

Mean Loose bulk density of *Gmelina* sawdust = 150.0 kg/m^3

and Sudhagar *et al*, 2003).The loose bulk density of *Gmelina* sawdust and maize cobs were 150.0kg/m^3 and 134.0kg/m^3 respectively.

4.2.2 Chemical Composition of the Raw Materials

The proximate composition of *Gmelina* sawdust and maize cob particles is presented in Table 4.6. The ash content of *Gmelina* sawdust was higher than that of maize cob particles. Maize cob particles have eleven times more protein than *Gmelina* sawdust. The higher ash content of the *Gmelina* sawdust implies that **t**here might be more ash removal for *Gmelina* sawdust than maize cob particles when the same quantities of their briquettes are burnt**.**

4.3 Physical Properties of the Briquettes

The mean values of physical dimensions of the hollow cylindrical shaped briquettes produced using 15% w/w of binder and pressure of 1.5MPa level are presented in Table 4.7. Binder concentration of 15% w/w was selected for comparable evaluation in this study because the minimum concentration of binder required to produce stable and durable briquettes was 15% w/w for maize cob particles, though 10% w/w binder concentration was enough for Gmelina sawdust. A pressure application level of 1.5MPa was selected because it was the optimum operating pressure based on preliminary compression experiment carried out on the manual briquetting machine. At 5MPa pressure application and above, all the binder oouzed out of the mould during compression. Therefore, for comparable evaluation of briquettes produced from the two biomass feedstocks, the pressure level was kept constant at 1.5MPa while the binder concentrations were varied.

The pictures of the briquettes at varying concentrations and 1.5MPa pressure are presented in plates 4.1 to 4.8. From the plates it was observed that the Maize cob briquettes were generally longer than Gmelina sawdust briquettes at every level of binder concentration. It was also be observed that the length of both biomass briquettes increased with an increase in the binder concentration. The briquettes were produced in the shape of a regular cylinder with a 10mm diameter hole inside. The mean diameter of all the briquettes was 50.00mm. There was no increase in the diameter after removal of briquettes from the die and subsequent drying. The reason for this is that expansion takes place primarily in the longitudinal direction i.e. the direction in which the load is applied. This conforms to the reports of Adekoya (1989) and Olorunnisola (2007).

Table 4.6: Proximate Composition of *Gmelina* Sawdust and Maize Cob(Mean ± SD, n=3)

	Percentages (%)					
	Protein	**Fat**	**Ash**	**Fibre**	**Moisture Content (dry basis)**	**Carbohydrate**
Maize cob	2.07±0.03	0.68±0.00	4.27±0.02	65.26±0.04	9.10±0.10	17.59±0.10
Gmelina sawdust	0.18±0.01	0.20±0.00	6.58±0.03	68.05±0.07	9.97±0.02	14.83±0.28

Table 4.7 Physical Properties of Briquettes Produced Using 15% w/w *Cissus* Binder Concentration and 1.5MPa Pressure Level (Mean ± SD, n=10).

Feedstock	Particle size (mm)	Mass(g)	Length (mm)	Diameter (mm)	Density (kg/m^3)
Maize cob	0.60	22.10	62.00	50.00±0.01	876 .0±0.10
Gmelina sawdust	0.60	28.20	60.00	50.00±0.00	1005.0±0.20
Maize cob	1.18	20.30	65.00	50.00±0.01	630.0±0.00
Gmelina sawdust	1.18	23.50	62.00	50.00±0.00	840.0±0.00

Plate 4.1: Samples of Maize Cob Briquettes produced from 0.6mm Particle Size, 15%$^{w}/_{w}$ Binder Concentration at 1.5 MPa

Plate 4.2: Samples of Sawdust Briquettes produced from 0.6mm Particle Size, 15%$^{W}/_{W}$ Binder Concentration at 1.5 MPa

Plate 4.3: Samples of Maize Cob Briquettes produced from 1.18mm Particle Size, 20% $^{W}/_{W}$ Binder Concentration at 1.5 MPa

Plate 4.4: Samples of Sawdust Briquettes produced from 1.18mm Particle Size, 20% $^{W}/_{W}$ Binder Concentration at 1.5 MPa

Plate 4.5: Samples of Maize Cob Briquettes produced from 0.60mm Particle Size, 25%$^{W}/_{W}$ Binder Concentration at 1.5 MPa

Plate 4.6: Samples of Sawdust Briquettes produced from 0.60mm Particle Size, 25%$^{W}/_{W}$ Binder Concentration at 1.5 MPa

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Plate 4.7: Samples of Maize Cob Briquettes produced from 1.18mm Particle Size, 25%$^{W}/_{W}$ Binder Concentration at 1.5 MPa

Plate 4.8: Samples of Sawdust Briquettes produced from 1.18mm Particle Size, 25%$^{W}/_{W}$ Binder Concentration at 1.5 MPa

4.3.1 Stability

Figures 4.3 and 4.4 show the change in length of briquettes with time for maize cob and sawdust at particle sizes 0.6mm and 1.18mm respectively. The maize cob briquettes exhibited the largest expansion in length; while the sawdust briquettes exhibited the least expansion. The greater expansion of the maize cob briquettes can be attributed to the fact that maize cob has a relatively lower binding capacity as it contains lower amount of native components, such as the lignin and extractives that enhance particle cohesion (Wamukonya and Jenkins, 1995). Hence, the maize cob briquettes were held together by weak surface-bonds, which weakened as the pressure was released. As evident from Figure 4.4, maximum expansion in the maize cob briquettes took place between the third and the fourth minute, while for *Gmelina* sawdust, it was between the first and the second minute.

The expansion in length of briquettes increased with an increase in the percentage of binder content (Figure 4.5 and Figure 4.6) for both feedstocks. The briquettes produced with 1.18mm particle expanded more than those produced with 0.6mm particle (Figures 4.7 and 4.8), the reason being that there were more spaces between the 1.18mm particles. The bond forces were thus weak, allowing more expansion. The sawdust and the maize cob sbriquettes achieved stability within 30 minutes after removal from the press. This is in agreement with the findings of Osobov (1967); O'Dogherty (1989) and Olorunnisola (2004) that nearly all the expansion of briquettes takes place within 30 minutes.

4.3.2 Briquette Density

The densities of maize cob and sawdust briquettes are presented in Table 4.7. The densities were in the range of 630 -1005.0 kg/m^3. Comparison between the briquettes indicated that the *Gmelina* sawdust briquette had the higher density of the two feedstocks. The average relaxed density of briquettes for 0.6mm maize cob particles was 876.0 kg/m^3, while the density of briquettes for 0.6mm *Gmelina* sawdust particles at 15% w/w concentration was 1005.0kg/m^3. For the 1.18mm maize cob particles, the mean relaxed density of the briquettes was 630.0 kg/m^3 while for 1.18mm *Gmelina* sawdust; it was 840.0kg/m^3. The relaxed density of sawdust briquette was greater than that of maize cob briquette at every level of binder concentration. For all briquettes, the density decreased as the particle size of the feedstock increased. These findings

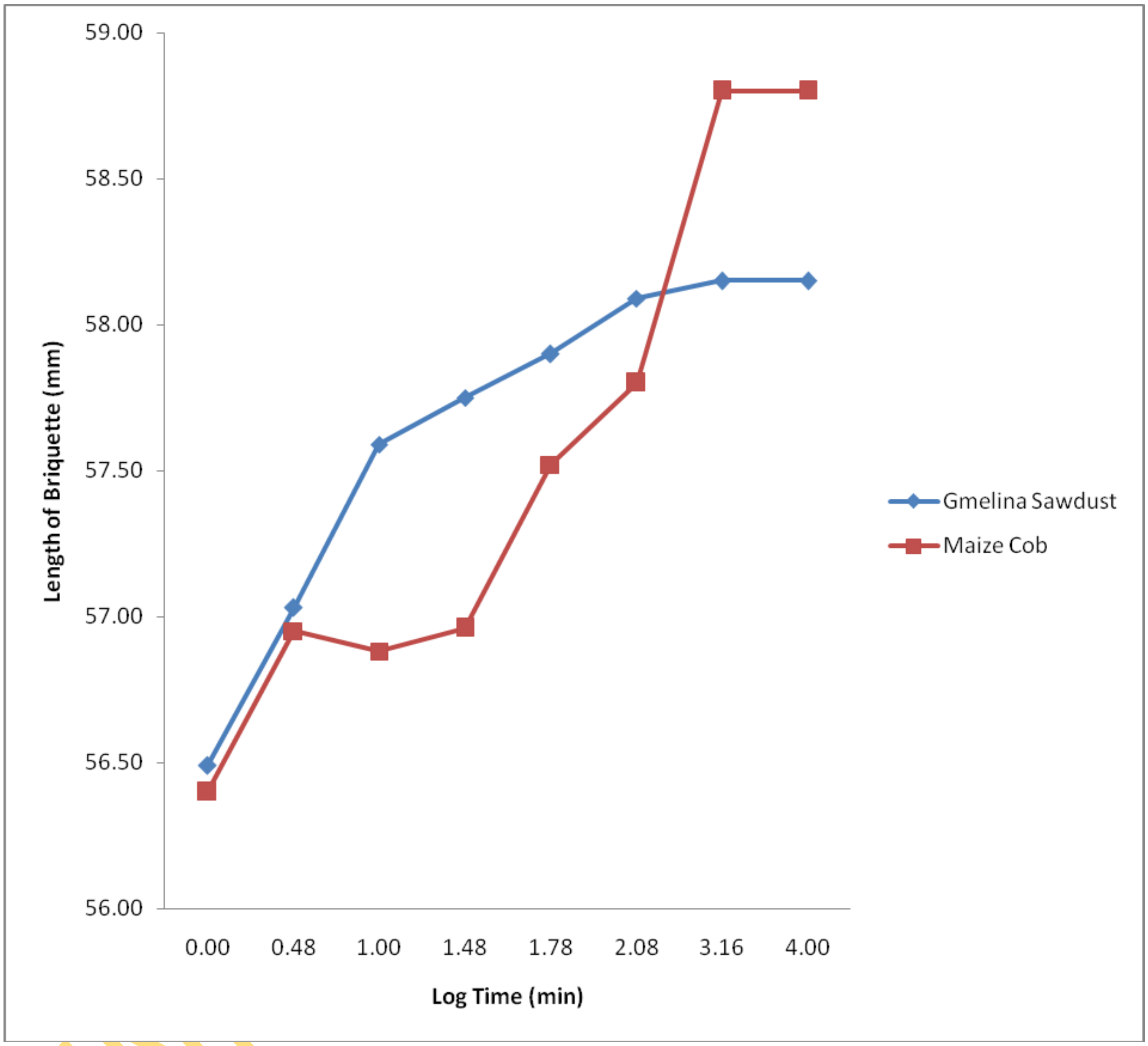

Figure 4.3: Expansion of Briquettes with Time produced from 0.6mm Particle Size of Feedstock, 15% w/w Binder Concentration at 1.5MPa

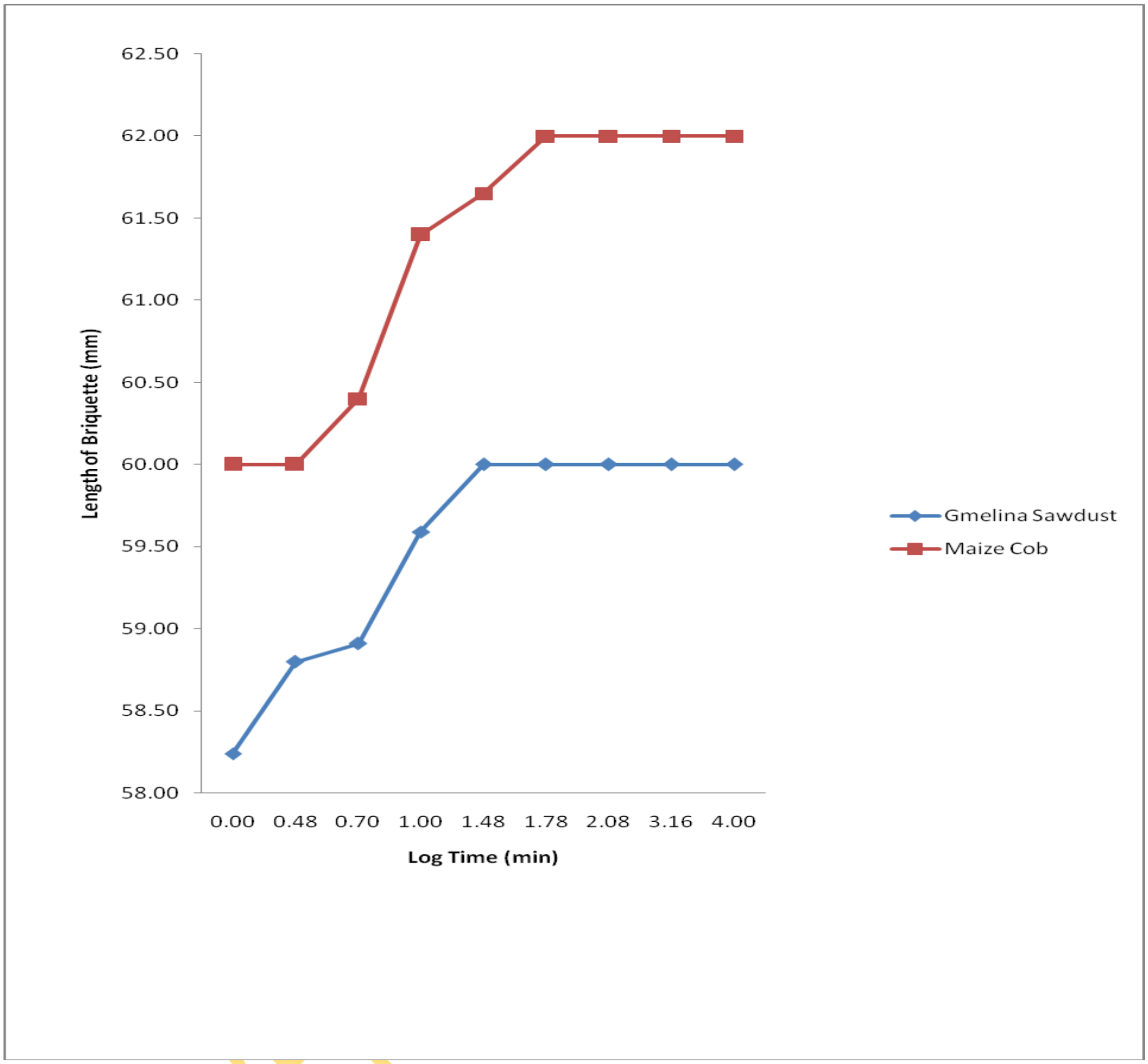

Figure 4.4: Expansion of Briquettes with Time produced from 1.18mm Particle Size of Feedstock, 15% w/w Binder Concentration at 1.5MPa

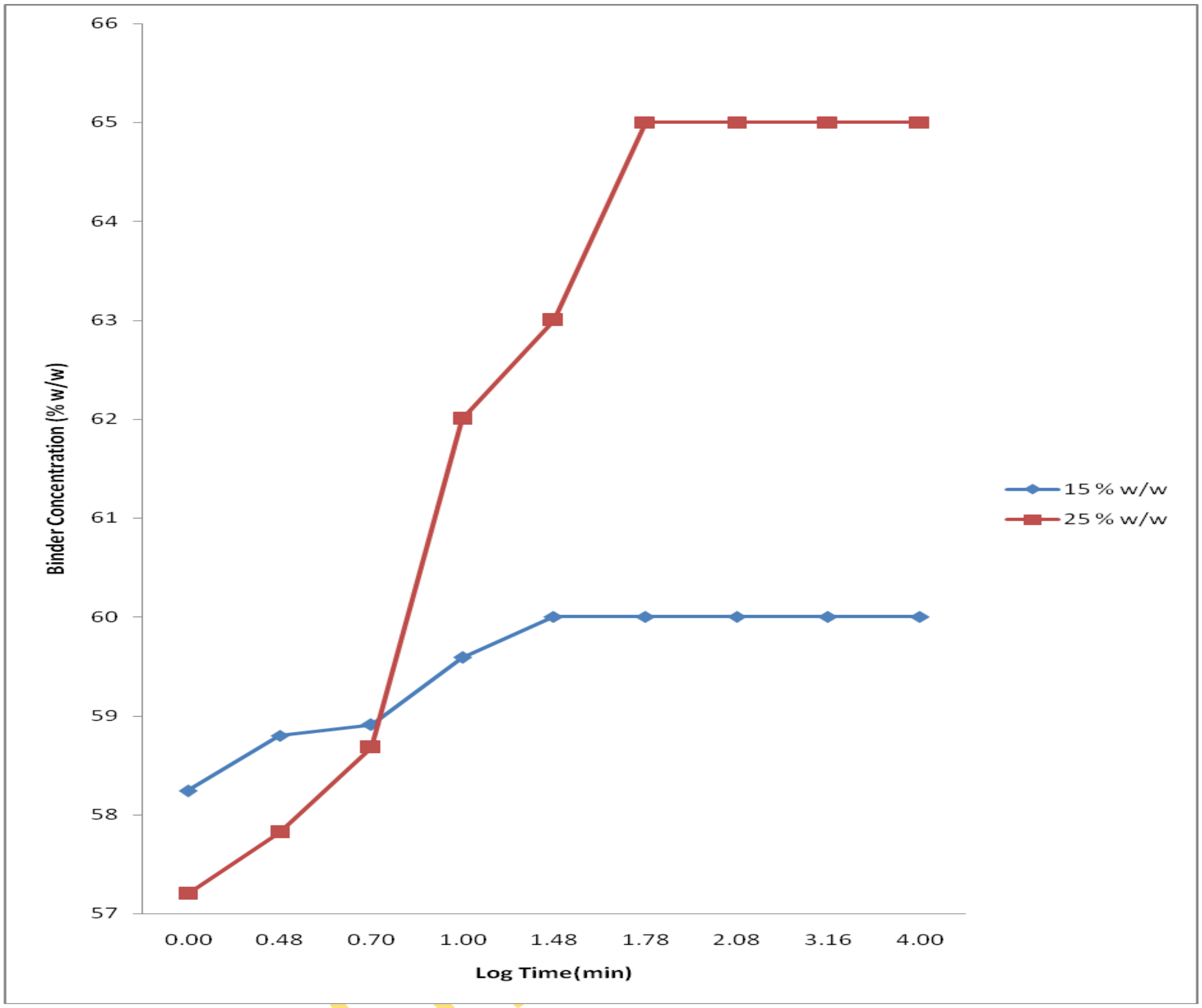

Figure 4.5: Expansion of *Gmelina* Sawdust Briquettes with Time produced from 1.18mm Particle Size of Feedstock, 15% and 25% w/w Binder Concentration at 1.5MPa

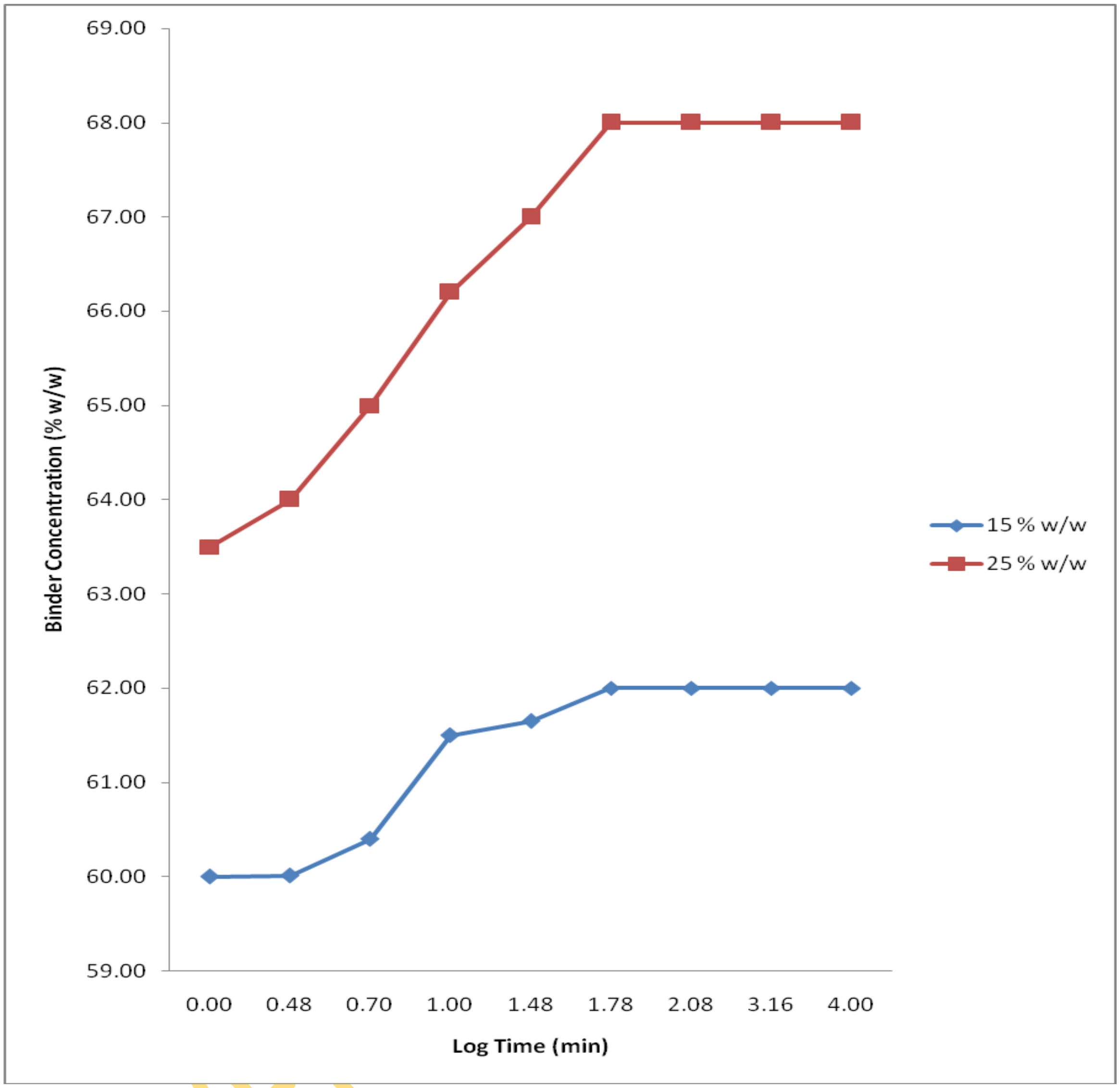

Figure 4.6: Expansion of Maize Cob Briquettes with Time produced 1.18mm Particle Size of Feedstock, at 15% and 25% w/w Binder Concentrations and 1.5MPa

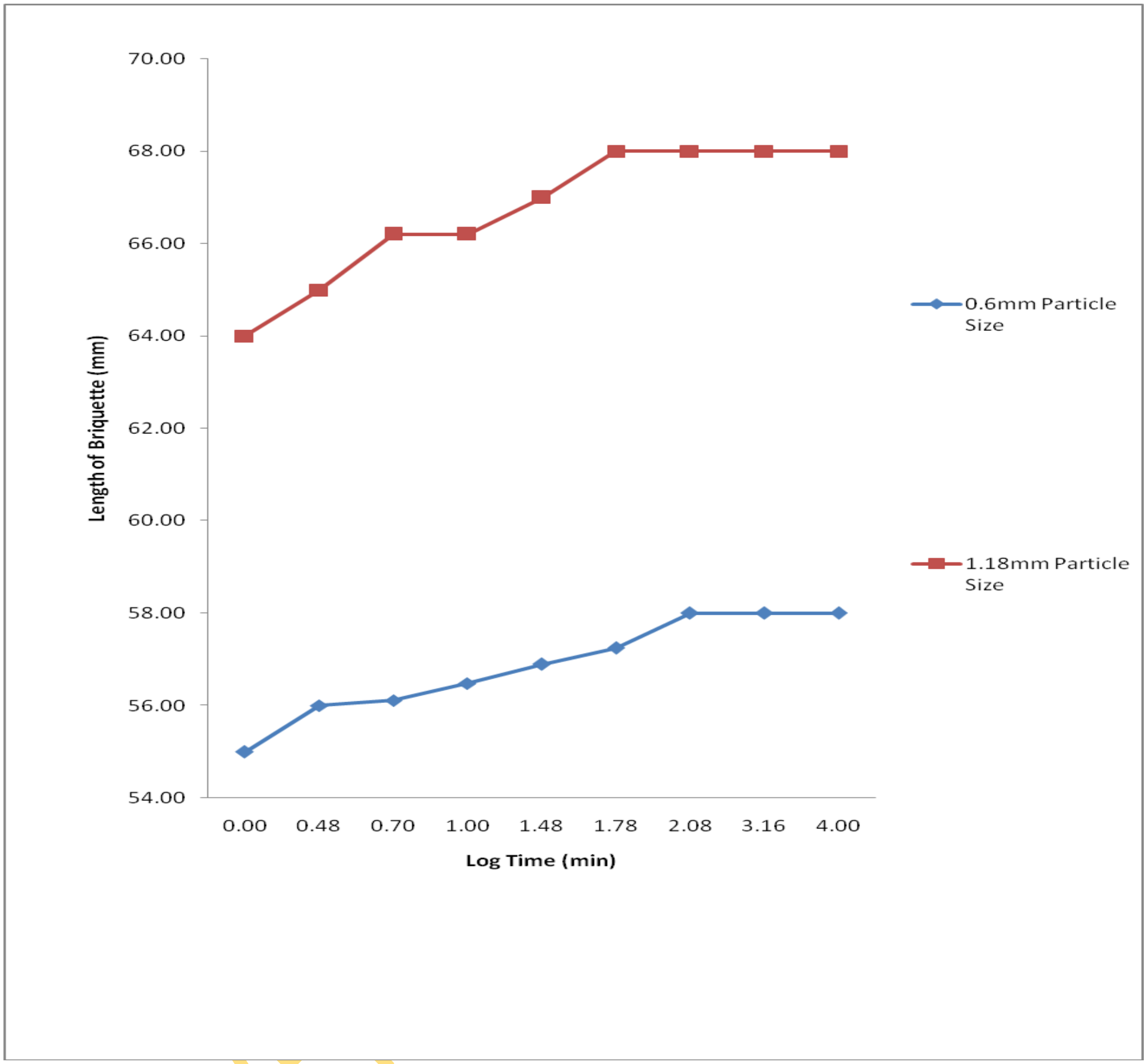

Figure 4.7: Expansion of *Gmelina* sawdust Briquettes with Time produced from 0.6mm and 1.18mm Particle Sizes, 25% w/w of Binder Concentration at 1.5MPa

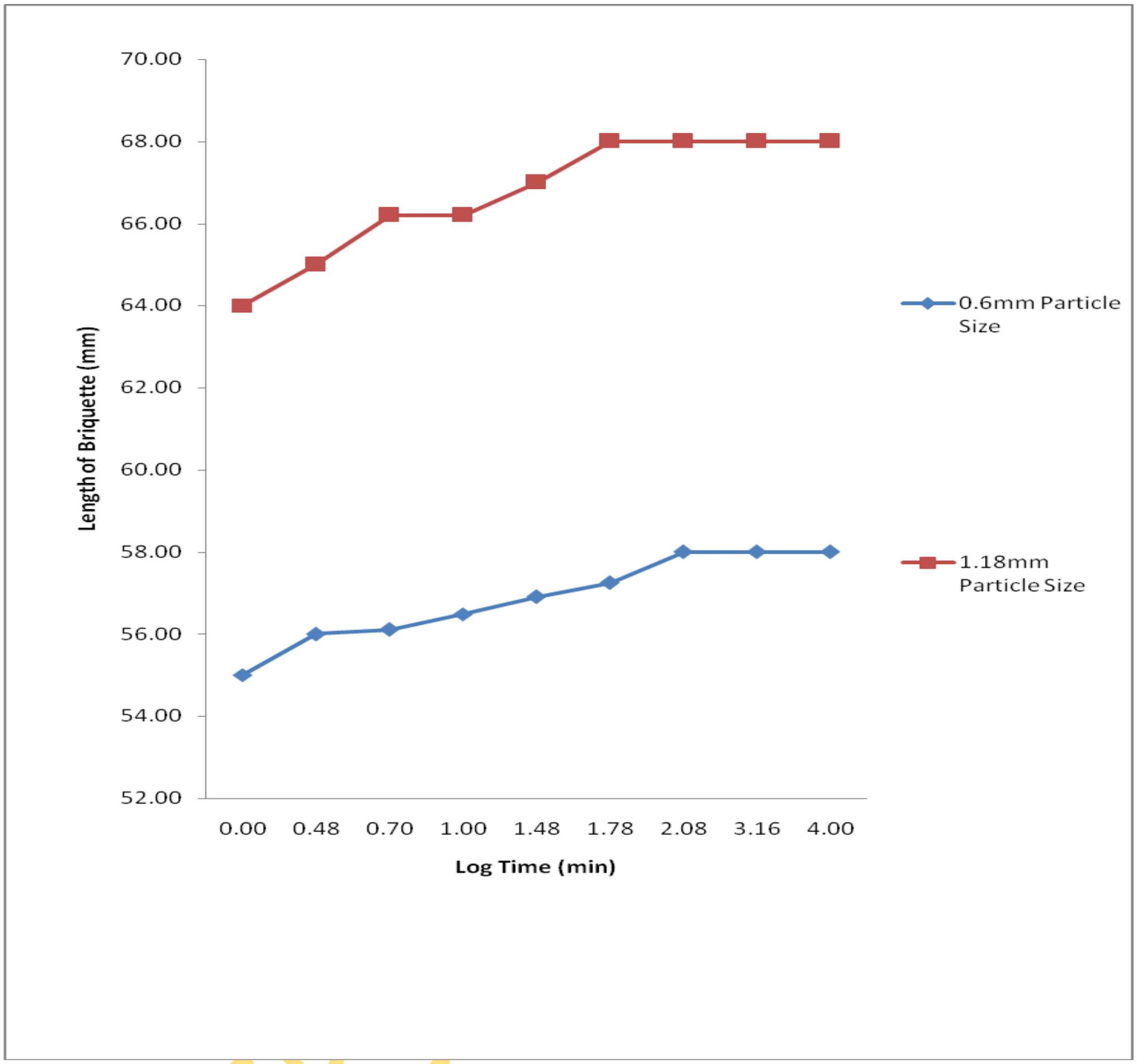

Figure 4.8: Expansion of Maize Cob Briquettes with Time produced from 0.6mm and 1.18mm Particle Sizes, 25% w/w Binder Concentration at 1.5MPa

are in agreement with those of Singh and Singh (1982); Paulrud and Nilsson (2001) and Shaw (2008). The higher densities of the briquettes compared with the densities of the feedstocks showed that they can be more easily handled than the original feedstock (Akor, 2003). Also, storage and handling expenses are reduced (Lucas and Fuwape, 1984).

4.3.3 Water Resistance

The resistance of briquettes against water absorption and disintegration was tested because the binder used was water-soluble. This test is designed to simulate severe weathering conditions, which a fuel might encounter during outdoor storage (Blesa *et al.*, 2001). The water resistance of briquettes at different binder concentrations are presented in Table 4.8. The *Gmelina* Sawdust Briquette (GSB) has a considerably higher water resistance than maize cob briquettes at every concentration level (Table 4.8).

The Water Resistance values of the two biomass briquettes are significantly different (P< 0.001) (Appendix 3A). This is perhaps due to the fact that sawdust has a more fibrous structure than the maize cob which helps it to resist water. Yaman et al (2001) had noted the positive effects of fibrous structure in enhancing water resistance of briquettes. What this finding suggests is that an exposure of the briquettes to a moist environment will have a more devastating effect on the maize cob briquettes than on the *Gmelina* sawdust briquettes. Figures 4.9 and 4.10 show the effects of binder concentration on the water resistance of the briquettes. In general, water resistance of briquettes increased with an increase in binder concentration (Figure 4.9). It is observed (Table 4.8 and Figure 4.10) that water resistance increased with a decrease in particle size of briquette; while the water resistance (WCI) of 0.6mm particle size of *Gmelina* sawdust at 15% w/w binder concentration was 33hr, the corresponding value for that of the 1.18mm particle size, at the same binder concentration was 28hs.

The effect of pressure on the water resistance of briquettes is shown in Figure 4.11. The water resistance increased with an increase in compaction pressure. The results of this finding is in agreement with that of Yaman *et al.* (2000).

4.4 Mechanical Properties of the Briquettes

4.4.1 Durability

Durability index is one of the most important criteria for evaluating densified product quality (Sudhagar *et al.*, 2004). It is a measurement of the briquettes resistance to mechanical action that will affect them when handled and transported. It is determined to simulate or predict the ability of densified product to withstand the impact force and vibration generated during handling

Table 4.8: Quality of Briquettes at Different Binder Concentrations and 1.5MPa Pressure

Feedstock	Particle size (mm)	Binder concentration (% w/w)	Water Resistance (h)	Mean Durability (%)	Mean Compressive strength (kN/m^2)
1.Maize cob	0.6	10.0	0.5	0	0.00
		15.0	2.6	69	2.42
		20.0	3.5	75	2.50
		25.0	4.0	90	2.73
		30.0	4.0	90	2.74
	1.18	10.0	0.2	0	0.00
		15.0	2.2	60	2.30
		20.0	2.5	72	2.40
		25.0	3.4	85	2.58
		30.0	3.4	86	2.60
2. *Gmelina* Sawdust	0.6	10.0	18.0	70	2.60
		15.0	33.0	80	2.80
		20.0	52.0	85	3.20
		25.0	55.0	95	3.60
		30.0	55.0	95	3.60
	1.18	10.0	10.0	60	2.80
		15.0	28.0	75	3.00
		20.0	48.0	82	3.20
		25.0	50.0	89	3.30
		30.0	51.0	89	3.40

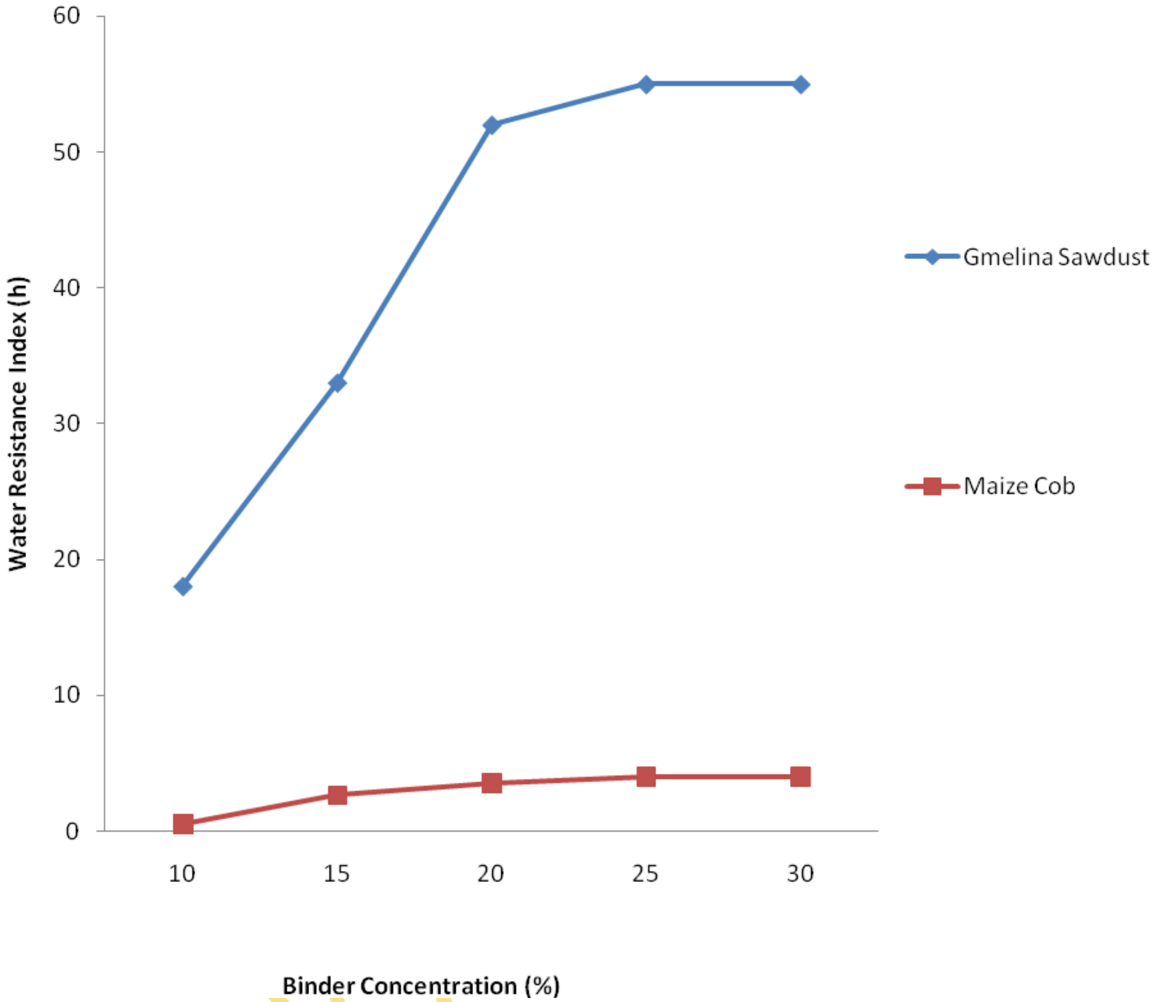

Figure 4.9 Effect of Binder Concentration on Water Resistance of Briquettes produced from 0.6mm Particle Size at 1.5MPa

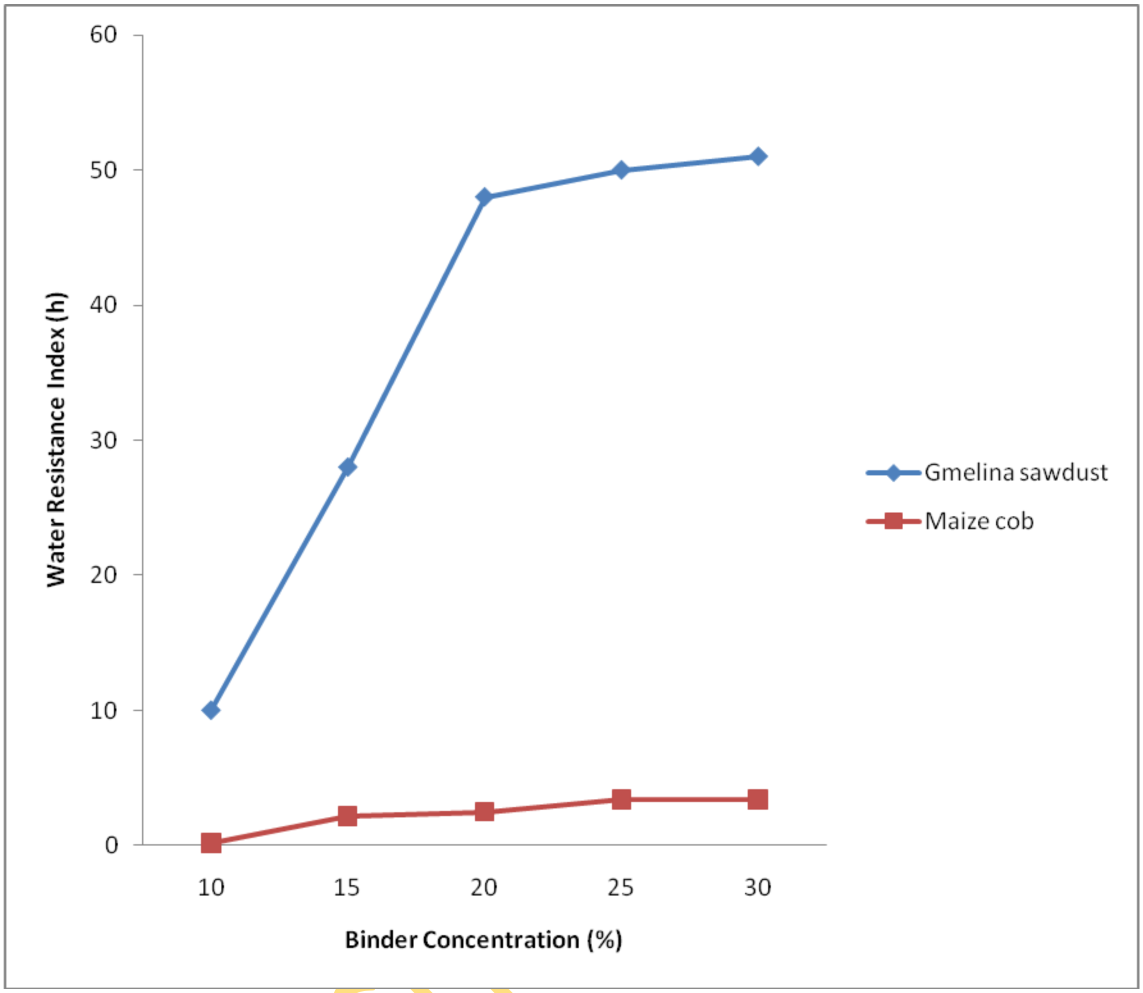

Figure 4.10: Effect of Binder Concentration on Water Resistance of Briquettes produced from 1.18mm Particle Size at 1.5MPa

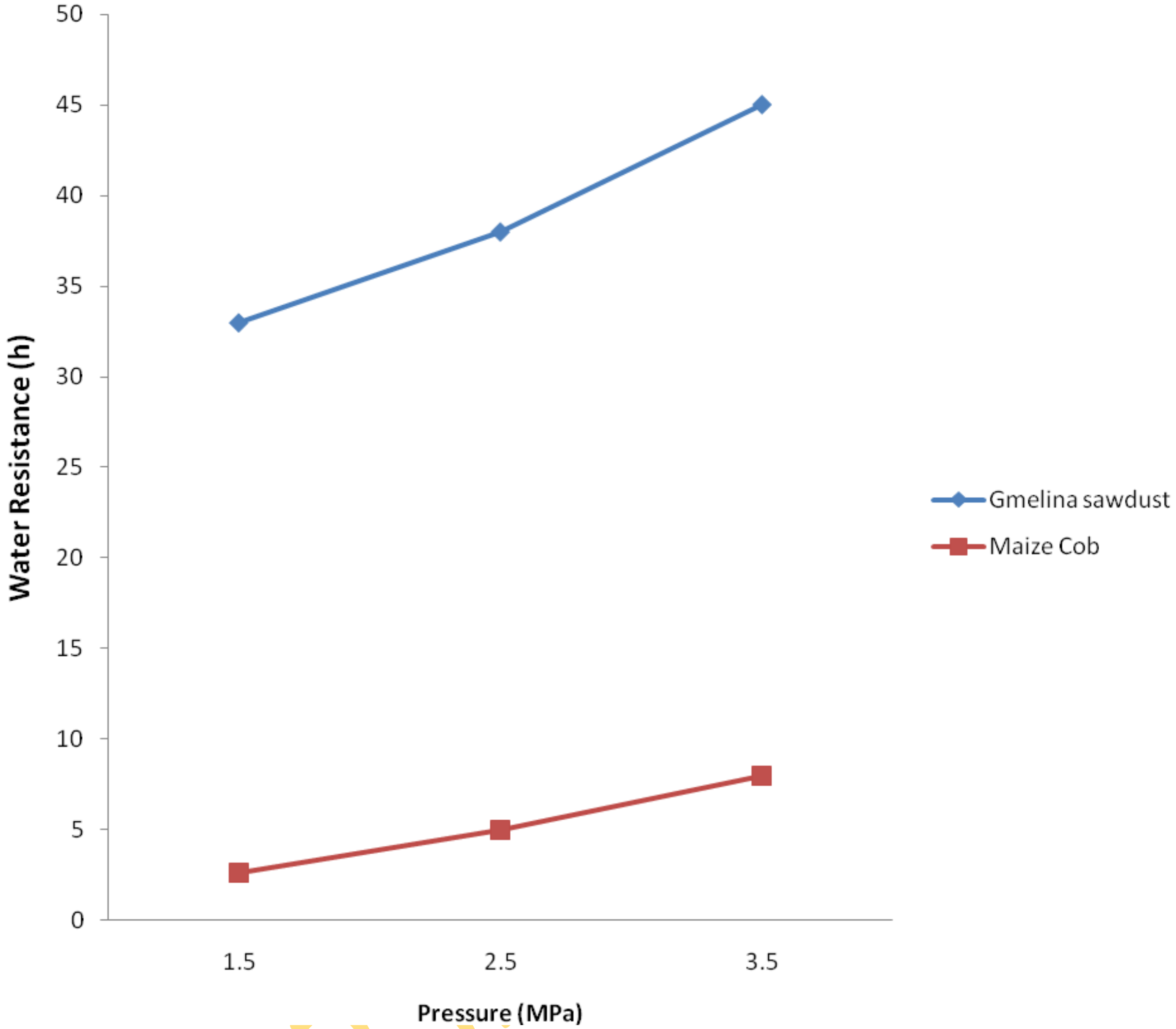

Figure 4.11: Effect of Pressure on Water Resistance of Briquettes produced from 0.6mm Particle Size at 15% w/w Binder Concentration

and transport. Densified products with good durability index are hard enough to be transported by vehicle for considerable distances without degradation.

The mean durability of *Gmelina* sawdust briquettes and maize cob briquettes are presented in Table 4.8. The mean durability of *G.* sawdust briquettes was observed to be higher than that of maize cob briquettes at all concentration levels. This may be due to the higher content of lignin in G. sawdust. However, there was no significant difference ($P < 0.05$) in the durability values of the two briquettes (Appendix 3B). The fibrous structure of *G.* sawdust and maize cob might have enhanced the durability of briquettes (Yaman et al, 2001). Fig. 4.12 shows the effect of increasing binder concentration on the mean durability of briquettes (at 0.6mm particle size and 1.5MPa pressure). Durability increased with an increase in binder concentration. Highest values of durability for *Gmelina* sawdust briquettes and maize cob briquettes were 95% and 90% respectively at 25% binder concentration. Olorunnisola (2007) obtained a durability value of 93%-98% for briquettes from waste paper and blends of coconut husks, while Wamukonya and Jenkins (1995) obtained values of between 82.6 and 88.4. Sudhagar *et al* (2004) obtained durability values in the range of 67-94%.

These values obtained from literature show that 15% w/w of binder concentration will be adequate for briquette production while an optimum durability will be at 25% w/w binder concentration for both feedstocks. From Table 4.8, it is seen that durability decreased with an increase in particle size of feedstock.

The effect of increasing pressure on durability of briquettes is shown in Figure 4.13. It is seen that durability decreased with an increase in the particle size of feedstock (Table 4.8). Durability decreased from 80% at 1.5MP to 60% at 3.5MPa (for *Gmelina arborea* particle size 0.6mm and binder concentration 15% w/w). This trend is not in agreement with Singh and Singh (1982) and Sudhagar *et al* (2004) who reported increased durability with increase in pressure. This negative trend is probably due to the surface cracks that occurred due to the very high load applied on the feedstock through the piston from the 40 tons hydraulic jack. The structure of the maize cob particles reached their plastic limit on the briquetting machine. The briquette crumbled at any load greater than 4MPa. The maximum load ranges in all the other works reported in literature were higher. For example pressure range by Sudhagar et al (2004) was between 5 and 15 MPa.

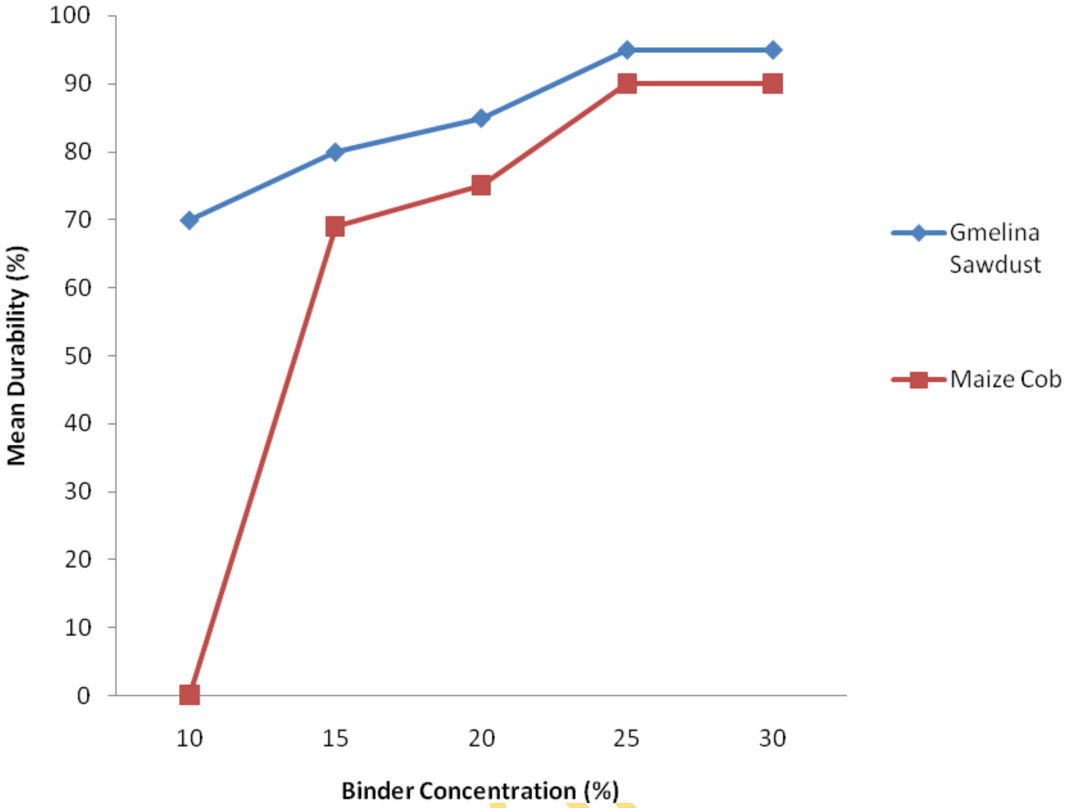

Figure 4.12: Effect of Binder Concentration on the Mean Durability of Briquettes produced from 0.6mm Particle Size at 1.5MPa

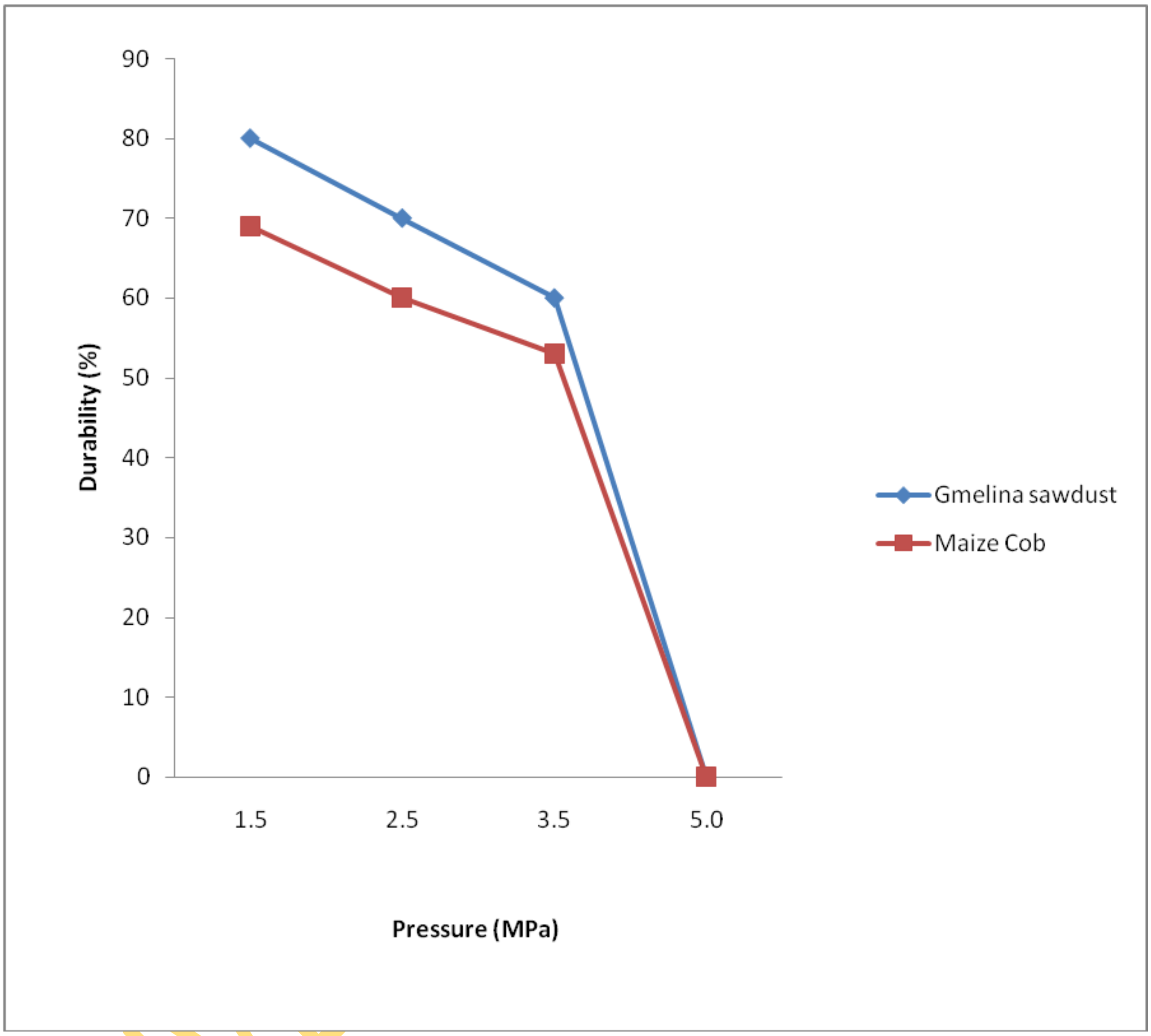

Figure 4.13: Effect of Pressure on Durability Index produced from 0.6mm Particle Size at 15% w/w Binder Concentration

4.4.2 Compressive Strength

According to Blesa *et al* (2001) two of the most important properties required in the preparation of good fuel briquette are compression strength and water resistance. These two properties, according to the authors have been extensively used as the selection criteria for most adequate briquettes and are closely associated with the amount and type of mineral and organic composition of the raw materials. The compressive strength, otherwise known as crushing strength is a criterion of briquette durability (Richard, 1990).

The effect of feedstock material on the compressive strength of briquettes are presented in Table 4.8. *Gmelina arborea* sawdust briquettes have a higher value of compressive strength than the maize cob briquettes. However, there were no significant differences ($P > 0.05$) between the compressive strength of the briquettes prepared using the two materials (Appendix 3C). The *Gmelina arborea* sawdust briquettes generally had a higher compressive strength than maize cob briquettes perhaps because of the morphology of sawdust such as its fibrous texture (Blesa *et al*, 2003a).

The effect of binder concentration on the compressive strength of briquettes is shown in Figure 4.14. In general, an increase in binder concentration resulted in an increase in compressive strength. The compressive strength for *Gmelina arborea* sawdust and maize cob briquettes were 3.6 kN/m^2 and 2.73 kNm^2 respectively at optimum 25% binder concentration. This finding is in agreement with Yaman *et al* (2001) and Ajayi and Lawal (1995).

The compressive strength of the briquettes produced with different particle sizes of feedstock is presented in Table 4.8. It is evident from this Table that briquettes with finer particles (0.6mm) have higher values of compressive strength than the coarse particles (1.18mm) at every concentration level. Compressive strength generally decreased with a decrease in particle size. This could be attributed to the formation of greater number of solid bonds in the smaller particles due to increase in the surface area and the contact points of the particles leading to stronger and more durable briquettes (Paulrud and Nillson, 2001).

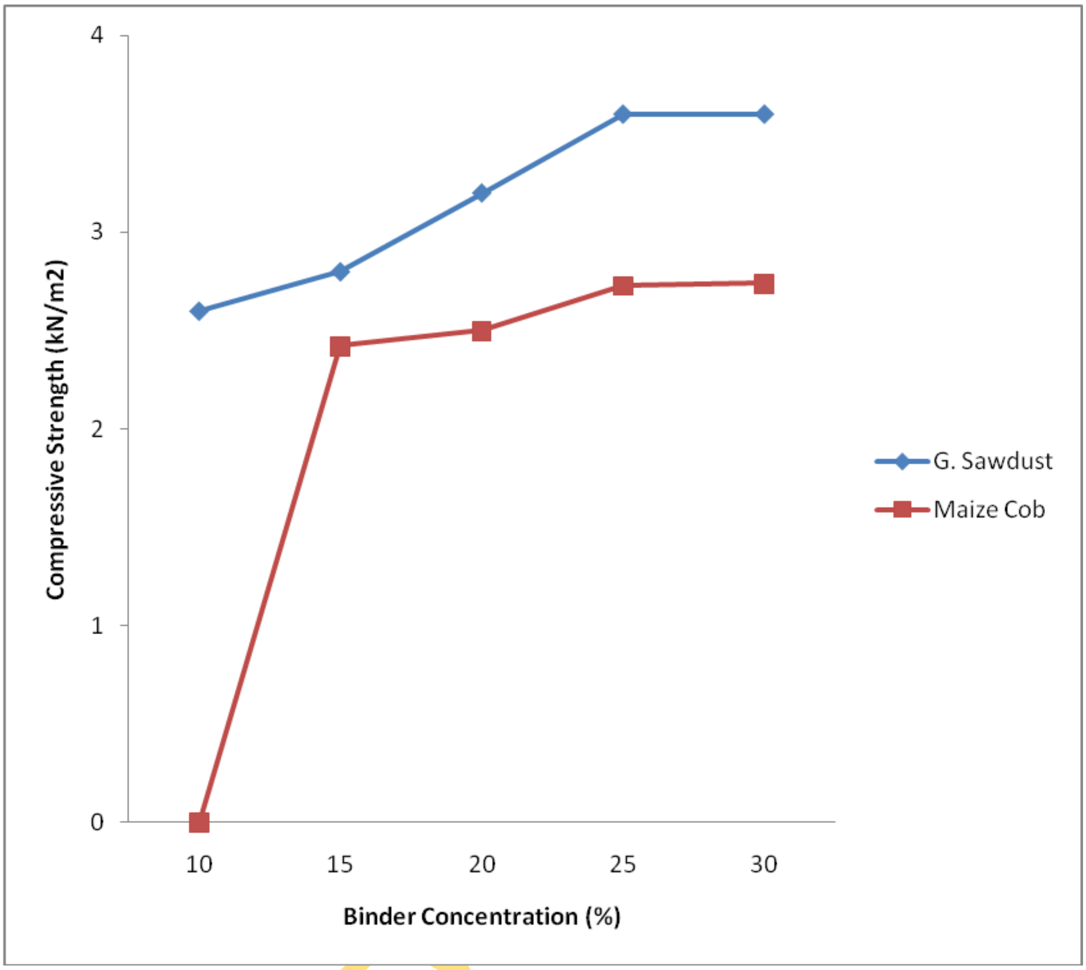

Figure 4.14: Effect of Binder Concentration on Compressive Strength of Briquettes produced from 0.6mm Particle Size at 1.5MPa

The effect of pressure on the compressive strength of briquettes is presented in Figure 4.15. The compressive strength decreased with an increase in pressure. This finding is in agreement with Yaman et al, (2000). At 5MPa, the entire sample crumbled. This finding is in agreement with Yaman et al (2001) and Slobodenka (1997). Compressive strength of maize cob briquettes increased when blended with *Gmelina* sawdust in a preliminary experiment. This possibility could be further explored.

4.5 Combustion Characteristics of the Briquettes

4.5.1 Water Boiling Test

The results of the water boiling tests with the briquette stove are shown in Figure 4.16. The 0.6mm maize cob briquettes took 16minutes to boil 1litre of water while the sawdust briquette took 22 minutes. The rate of mass loss was also higher in the maize cob briquettes than the sawdust briquette. In the same vein it took 18 minutes to boil 1litre of water with 1.18mm maize cob briquette, and 24 minutes for 1.18mm particle size sawdust briquettes to boil the same quantity of water. The time required to boil water increased with the particle size. It took 22 minutes to boil one litre water using 0.6mm sawdust briquette and 24 minutes for the same quantity of water with 1.18mm sawdust briquette. This is also expected as the rate of heat energy expended per time is higher with the smaller particles (0.6mm) than the bigger particles (1.18mm). This is in agreement with observation of Arnold (2003). The burn rate of *Gmelina* sawdust briquette was calculated as 0.80kg/h while that of maize cob was 1.00kg/h. There was no significant difference ($p>0.05$) in their burn rate values (Appendix 3D).

4.5.2 Thermal Efficiency

The thermal efficiency of the briquette stove was compared with that of two other local stoves: charcoal stove and wood stove. The configurations of the two stoves are presented in Table 4.9. The water boiling test result for the three stoves are presented in Figure 4.17. The thermal efficiency of the briquette stove was in the range of 15-38% depending on the heating value of the briquette burnt and the volume of air allowed into the combustion chamber. This figure falls within the values obtained by other workers (Anon, 1988; Kaoma and Kasali, 1994; Olorunnisola, 1999 and Sotannde *et al*, 2010). The briquette stove had a higher thermal efficiency than charcoal and wood stoves as evident in the shorter time required for boiling one litre of water.

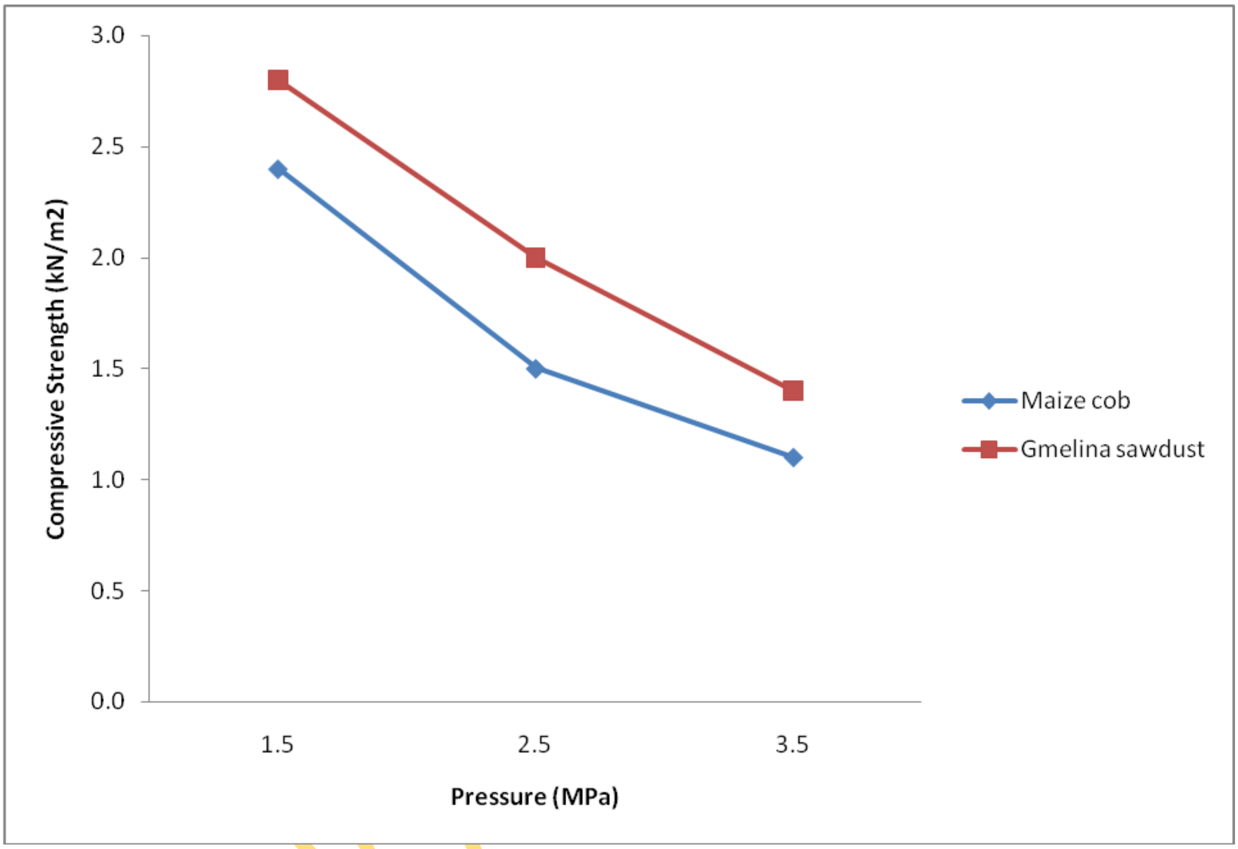

Fig. 4.15: Effect of Pressure on Compressive Strength of Briquettes (produced from 0.6mm Particle Size at 15% Binder Concentration)

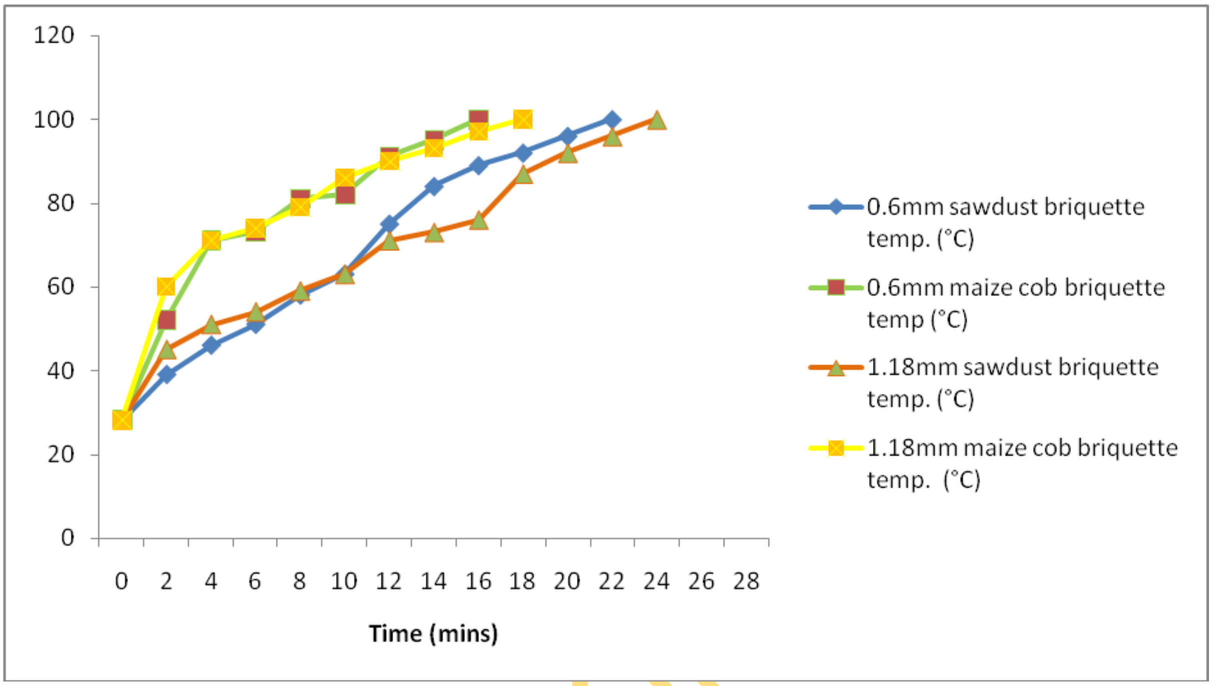

Figure 4.16: Water Boiling Test for Briquettes produced from Particle Sizes 0.6mm and 1.18mm

Table 4.9: Configuration of Local Stoves Used for Comparative Evaluation

Design Parameter	Briquette Stove	Wood Stove	Coal Stove
Weight (kg)	15.050	1.005	1.608
Height (m)	0.255	0.13	0.235
Shape	Cylindrical	Cylindrical	Cylindrical
Material of Construction	Sheet metal (but the pot stand is made of mild steel)	Sheet metal (but the pot stand is made of mild steel)	Sheet metal (but the pot stand is made of mild steel)
Combustion chamber capacity (m^3)	2 .96 x 10^{-3}	4.35 x 10^{-3}	2.54 x 10^{-3}

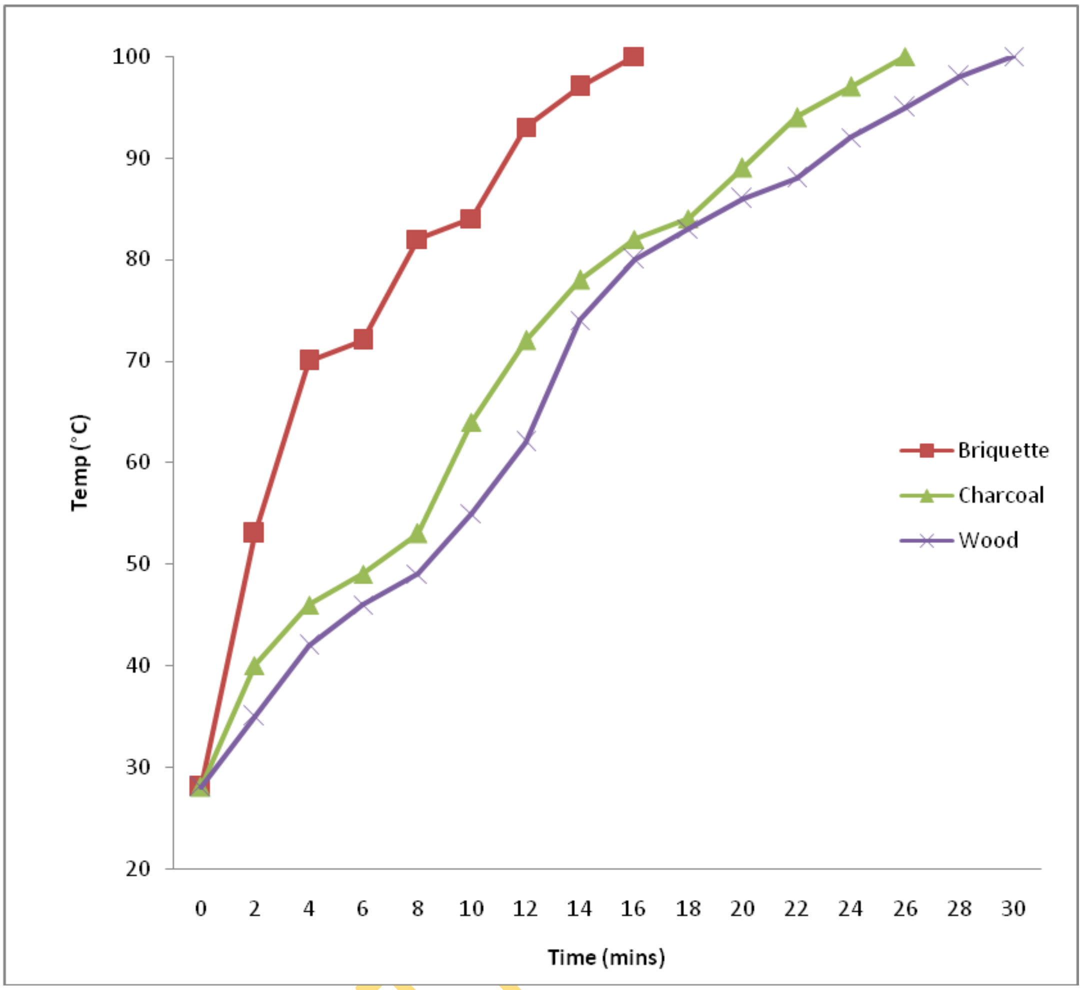

Figure 4.17: Comparison of Water Boiling Tests for Stoves

The higher thermal efficiency of the briquette stove could be accounted for by the following factors:

(i) The air intake was more efficiently controlled in the briquette stove than the other two stoves. This is because of the incorporation of a briquette loading door, through which the air was controlled.

(ii) The lower thermal efficiency of the wood stove can be attributed to the fact that air intake was much greater than in the briquette and charcoal stoves. The flame was not even, therefore it consumed more fuel. The excessive air intake lowered the thermal efficiency.

(iii) Maize cob briquette had lower moisture content, and ash content; therefore it burned more efficiently than the *Gmelina* sawdust with higher moisture content. A notable defect in both the charcoal and coal stoves likely responsible for their lower performance was the lack of effective control of air facilities that was absent. Another defect that may be responsible for their lower performance was the absence of an effective ash disposal facility as obtained in the briquette stove. It is well established that ash accumulation hinders combustion process (Olorunnisola, 1999; Paulrud and Nilsson, 2001).

(iv) These results indicate that the stove rather than the fuel material was responsible for the trend in boiling time duration observed. *Gmelina* sawdust is known to have a higher heat value than maize cob. With this knowledge, one expected that it would burn faster but the result is opposite. It implies therefore that the stove design rather than the fuel type is more important in determining the thermal efficiency of a stove.

4.5.3 Cooking Duration

The controlled cooking test results using the three stoves; briquette (Plate 4.9) charcoal and wood stoves are presented in Table 4.10. It took lesser time to cook rice on the briquette stove than on the other two stoves. It took 25 minutes, 31 minutes and 35 minutes respectively to cook 200g of rice on the briquette, charcoal and wood stoves. The time taken in cooking per kilogram of cooked food varied from 0.43 h/kg for briquette stove to 0.53 h/kg for charcoal stove and 0.6 h/kg for the wood stove.

The time spent in cooking per kilogram of cooked food varied from 0.43 h/kg for briquette stove to 0.53 h/kg for charcoal stove and 0.60 h/kg for the wood stove. This trend is a reflection of the time used in the boiling water for the individual stoves. The higher

Plate 4.9: Briquette Stove Used for Cooking Test

Table 4.10 Controlled Cooking Test Results for Stoves Comparison

S/N	Parameter	Briquette Stove	Wood Stove	Charcoal Stove
1	Cooking duration (Minutes)	25.00	35.00	31.00
2	Time spent in cooking rice per kg of cooked food (h/kg)	0.43	0.60	0.53
3	Specific fuel consumption	0.4	0.6	0.5

efficiency of the briquette stove reflected in shorter time for cooking 200 grams of rice is as explained above.

4.5.4 Specific Fuel Consumption

As shown in Table 4.10, the specific fuel consumption value of the briquette stove (0.4) was less than that of the wood (0.6) and charcoal (0.5) stoves. The practical implication of this result is that lesser quantities briquettes would be required to cook, using the briquette stove. Hence if two fuel products were to attract similar market prices, using the briquette stove could save more money. The specific consumption obtained in this study is close to the value of 0.48 reported by Olorunnisola (1999).

4.5.5 Higher Heating Value

The heating value of a fuel gives an indication of the quantity of fuel to generate a specific amount of energy (Fuwape, 1985). A fuel with a higher heating value will generate more energy for the same quantity of fuel. The results of the higher heating values (HHV) of briquette samples at 0.6mm particle size, 15% w/w binder concentration and 1.5MPa are shown in Table 4.11. For each briquette sample, *Gmelina* sawdust briquette had a higher heating value than maize cob briquette. This was true at all binder concentration levels. The higher heating values ranged from 15.42 MJ/kg to 22.58MJ/kg for *Gmelina* sawdust briquettes, and from 14.25MJ/kg to 15.27KJ/kg for maize cob briquettes. The higher heating values obtained in this study are slightly greater than 22.16MJ/kg reported by Ajayi and Lawal (1997) for the briquettes produced using palm oil sludge, 22.50 MJ/kg reported by Akor (2003) for *Iroko* sawdust briquette and 22.54 kJ/kg obtained for the heart wood of *Gmelina arborea* (Roxb) by Fuwape (1984). The difference in the results might be due to the different species of sawdust used (Ajayi and Lawal, 1997) and the type of binder used (Singh and Singh, 1982). The heating value of maize cob briquette is within the range of 14.1 MJ/kg for maize cob briquette bound with molasses binder (Wilaipon, 2007) and is lower than the values of 19.36 MJ/kg and 20.89 MJ/kg obtained respectively for white and yellow maize cob briquettes reported by Oladeji (2011).

Table 4.11: Heating Values (MJ/kg) of Briquette Samples produced at Varying Concentrations (0.6mm Particle size and 1.5MPa)

Binder	**Higher Heating Values (MJ/kg)**				
% Binder concentration	10	15	20	25	30
Gmelina Sawdust Briquette	15.42	17.41	19.46	21.40	22.58
Maize cob briquette	14.25	14.55	14.67	14.93	15.27

Each value is a mean of five samples

The difference in the results may have been due to variation in the binder use; the species of the maize cob and the method of evaluation of the heating value. In this study, *Cissus populnea* is used as binder whereas he used cassava starch.

Generally, the heating value increased with an increase in binder concentration. For *Gmelina* sawdust briquette, the heating values increased from 15.42MJ/kg at 10% w/w binder concentration to 22.58MJ/kg at 30% w/w binder concentration. In the same vein, the higher heating value of maize cob briquette increased from 14.25MJ/kg at 10% to 15.27MJ/kg at 30% w/w binder concentration. This trend is in agreement with other workers (Ajayi and Lawal, 1997, Singh and Singh, 1982).

4.5.6 Ash Content

The ash content of 0.6mm sawdust briquette was 6.31% while that of maize cob briquettes was 4.44%. This implies there will be need for more clearing of ash pits when *Gmelina* sawdust briquettes are used, than when maize cob briquettes are used. The ash content *Gmelina* sawdust briquette obtained in this study is slightly greater than the range of 4.03 - 4.08% for *Gmelia* sawdust briquettes produced with 35 - 45% w/w concentration of cassava starch reported by Adegoke *et al* 2010. It is also slightly greater than the range 3.35 – 4.45% reported by Sotannde et al (2010) for cassava starch and gum Arabic bonded *Azadirachta indica* sawdust briquettes. It is within the range 3.4 – 6.7 % reported by Ajayi and Lawal (1997) for palm oil sludge bonded *Arere* sawdust briquettes. It is within the range of 2.3 – 7.7% reported by *Tabares et al* 2000 for briquettes from forest and industrial wastes.

The ash content of the maize cob briquette obtained in this study is lower than the value of 1.4% reported by Oladeji (2010). The differences in the results of ash content obtained in this study compared with that of other authors may have been due to the variation in the type and concentration of binders and the species of the feedstock.

The ash content of the biomass briquettes obtained in this study compared favourably with those of good quality and acceptable briquettes reported in literature.

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following are the conclusions of the study on development of systems for briquetting and combusting *Gmelina* sawdust and maize cobs briquettes:

Development of Binder from *Cissus populnea* Plant

(i) Increase in the gum concentration of both crude and purified gums resulted in a corresponding increase in the viscosity of gum. However, the purified *Cissus* gum has a much higher viscosity value than the crude gum at the same percentage. At 10.0% concentration the viscosity of crude gum was 21.0 centipoises while for the purified gum it was 35.0centipoises. About 10.0% concentration (w/v) of the crude gum was considered adequate for briquette production.

(ii) Both the crude *Cissus* gum and purified *Cissus* gum could be used as binder in briquette production from *Gmelina* sawdust and maize cobs. However, the purified gum was more expensive to produce.

Briquetting Machine

(i) A manual briquetting machine with six cylindrical moulds and a 10.0mm hole in the middle was designed and constructed. The production capacity of the machine was 0.576 kg/hour.

(ii) For this low pressure briquetting machine, a pressure of 1.5MPa was found adequate for the densification of both *Gmelina* sawdust and maize cob particles.

Briquette Burning Stove

(i) A briquette burning stove was designed and fabricated with mild steel and lined with clay for insulation. It has two combustion chambers separated by a removable grate each having a volume of 8.8 x 10^2 cm^3. It can accommodate a minimum of 5 briquettes of 5.0cm diameter and 6.5cm height at any given time.

(ii) The maximum thermal efficiency of the briquette burning stove was 38%.

Quality of Briquettes

(i) The minimum concentrations of crude *Cissus* gum required to produce durable briquettes were 10.0% and 15.0% for *Gmelina* sawdust and maize cob particles respectively. More quantity of *Cissus* gum would be required for densification of maize cob particles than *Gmelina* sawdust at the same pressure and particle size of feedstock. It is therefore more economical to densify *Gmelina* sawdust than the maize cobs.

(ii) *Gmelina* sawdust briquette is better than maize cob briquette when durability index, water resistance, compressive strength and heating value are considered. Maize cob briquette performed better in terms of higher burn rate and minimal ash content.

(iii) Briquettes produced from both *Gmelina* sawdust and maize cob particles using the *Cissus* gum burned efficiently in both briquette burning stove and two local stoves; i.e. the charcoal and the wood stoves. Therefore, *Gmelina* sawdust and maize cob briquettes can be combusted in local charcoal and wood stoves.

5.2 Recommendations for Further Work

The following recommendations are made for future research:

(1) An evaluation of curing temperature effects on the mechanical and thermal properties of fuel briquettes from maize cobs and *Gmelina* sawdust should be conducted.

(2) The effects of additives like ash, clay and cow dung on briquettes produced from *Gmelina* sawdust and maize cob particles should be investigated.

(3) Quality attributes of briquettes from fermented maize cobs and sawdust should be investigated.

(4) Additional densification studies are required on *Gmelina* sawdust and blends of other agro-residues. Such biomass feedstocks blends include: sawdust-maize cobs, sawdust-paper, sawdust – coconut husk and sawdust – rice husk.

(5) Investigations into densification equipment is a key to improving the feasibility of briquetting of residues and ensuring maximum efficiency. The manual briquetting machine may be further modified to increase the through-put and produce a higher quality product in the most efficient manner.

5.3 Contributions to Knowledge

The study has made contributions to knowledge in the following areas:

1. Development of a viable binder from a naturally occurring plant of *Cissus populne*a for production of briquettes.
2. Development of intermediate technology equipment for densification of maize cobs and other agro residues.
3. Development of an improved briquette burning stove for household cooking.
4. Characterisation of briquettes produced from *Gmelina* sawdust and maize cob particles using *Cissus populnea* binder in terms of density, durability, compressive strength, water resistance index, heating value and burn rate. These quality attributes assist in the identification of optimum conditions that can guide in the production of quality and acceptable briquettes from *Gmelina* sawdust and maize cobs, especially for entrepreneurs going into its production.

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APPENDIX 1A

DESIGN CALCULATIONS FOR THE MANUAL BRIQUETTING MACHINE

1. Piston Design against Buckling:

For a column with one end fixed and one end free, Euler's equation states that:

Buckling load, $P_C = \frac{4\pi^2 EI}{L^2}$ (Mandal, 2003)

Where P_C = buckling load

E = Young modulus of elasticity

I = Moment of inertia

L = Length of the piston

A circular sectioned mild steel piston of length 80cm was used, while the piston head was made of a circular cross section of $\pi \times (8 \times 10^{-3})^2$ m^2

$$I = \frac{\pi d^4}{64}$$

$$P_C = \frac{4 \times \pi^2 \times 2.02 \times 10^{11} \times \{\frac{\pi \times (8 \times 10^{-3})^4}{64}\}}{75 \times 75 \times (10^{-3})^2}$$

= 7.1152MN

The load applied by 40 tonne hydraulic jack to all the six moulds is

= 40 × 1016.04 × 9.81 × 6 = 2.39N

Since 7.1152 MN is far greater than 2.39MN. It is seen that the piston will not fail by buckling.

2. Mould Design against Failure

The most critical part of the machine is the mould; therefore the mould was designed against failure.

$$P = \frac{F}{A} = \sigma$$

Assuming complete transmission of pressure via the piston surface

P = Pressure
F = Force
A = Area

$$F = 40 \times 1016.04\ \mathrm{N}$$

$$A = \pi \times 0.05^2$$

$$P = \frac{40\ \times 1016.04}{6\ \times\ \pi\ \times 0.05^2}$$

$$= 0.8\mathrm{MPa}$$

This pressure is exerted on the feedstock as well as on the inside of the mould, therefore for failure not to occur in the mould, the calculated stress must be less than the yield stress of the material of the mould i.e. $\sigma_m > \sigma$

$\sigma_m = 220\mathrm{MPa}$ (Hamrock *et al*, 1999)

Since the applied stress 0.8MPa is less than the yield stress (220MPa) of the material. The mould cannot fail during compaction.

3. Design against Compressive Failure

The end support rods, each of length 690mm had 150mm screw at each of the end of the rod. The threaded rod holding the piston plate and the mould assembly is made to move up and down on it when a torque, T is exerted on the press lever rod.

The compressive stress in the nut and the screw is derived as:

$$\sigma c = \frac{W}{\frac{\pi}{4}\left(\frac{d_c + d_p}{2}\right)^2} \quad \text{(Mandal, 2003)}$$

Where

d_p=threaded pitch diameter

Thus

$$\sigma c = \frac{40 \times 1016.04N}{\frac{\pi}{4}\left(\frac{0.035+0.02}{2}\right)^2}$$

$$= 35.395\mathrm{MNm}^{-2}$$

The compressive stress of the alloy steel material from which the nuts and screw were made from is 650MNm^{-2} [Hawkes and Abinett,1990]

Since this value far exceeds the working stress on the screw and the nut, it is evident that they will not fail under working conditions due to compressive stress induced in them.

4. Nut Design against Shear Failure

The shearing stress is the transverse stress due to the bending experienced by the threads on both the screw and the nut on the two end supportive shafts.

Assuming a rectangular cross section for the thread, the transverse shearing stress is given by the relationship:

$$\sigma_v = \frac{3W}{2A}$$

A = cross sectional area of the built-in-end of the threaded beam. Using a screw with root diameter, d_r =2.0mm, and a nut with major diameter, d_0 = 3.5mm

$$\sigma_{v\ screw} = \frac{3W}{2\pi d, nb}$$

$$= \frac{3 \times 60 \times 1016.04}{2 \times \pi \times 2 \times 10^{-3} \times 5 \times 10^{-3} \times 10}$$

b= width of the thread nut at the base = 5mm

n = number of threads in engagement = 10

$$\sigma_{v_{SCREW}} = 179Nm^{-2}$$

While the shearing stress for the nut also is given as

$$\tau_{NUT} = \frac{3W}{2\pi d_0 nb}$$

$$= \frac{3 \times 1016.04 \times 40}{2 \times 3.14 \times 20 \times 10^{-3} \times 5 \times 10^{-3} \times 10}$$

$= 19.41\ MNm^{-2}$

The above calculated shearing stress values indicate that the nut is carrying only 11 percent of the shearing stress value of the screw for any particular axial stress exerted. The selected nut is therefore strong enough to carry the transverse shear stress induced on it and will not fail due to shear action.

5. Bearing Pressure

This is the crushing stress between the surface of the screw and the contacting surface of the nut. It is given in the relation:

$$\sigma_B = \frac{W}{\pi d_m hn}.$$

Where

σ_B = bearing pressure, Nm^{-2}

d_m= mean screw thread diameter, m

W = load, N

h = depth of threads, m

n = number of threads in arrangement

Thus

$$\sigma_B = \frac{40 \times 1016.04}{\pi \times 0.2 \times 1 \times 10^{-3} \times 10}$$

$$= 6.4\text{Nm}^{-2}$$

Since this value is less than the permissible bearing pressure in the nuts selected, the threads of the nut and the screw are capable of withstanding the bearing stresses.

6. Design against Failure Due to Bearing Stresses

The bearing stress is induced in the thread of the nut and the screw. Its magnitude is critical to the maximum load that can be supported by the thread. The stress is estimated by treating the thread as a short cantilever beam with a built-in end at the root diameter.

The section modulus, Z of the loaded section is given by the relation:

$$\frac{1}{Z} = \frac{\pi d_m n b^2}{6} \Rightarrow 1$$ [Hamrock, *et al*, 1999]

Where b = width of the thread nut at the base

Maximum bending moment = M = $\frac{Wh}{2} \Rightarrow 2$

The bending stress equation is

$$\sigma_B = \frac{MZ}{I} \Rightarrow 3$$

Substituting (1) and (2) into (3), the bending stress equation is:

$$\sigma_B = \frac{3Wh}{\pi d_m n b^2}$$

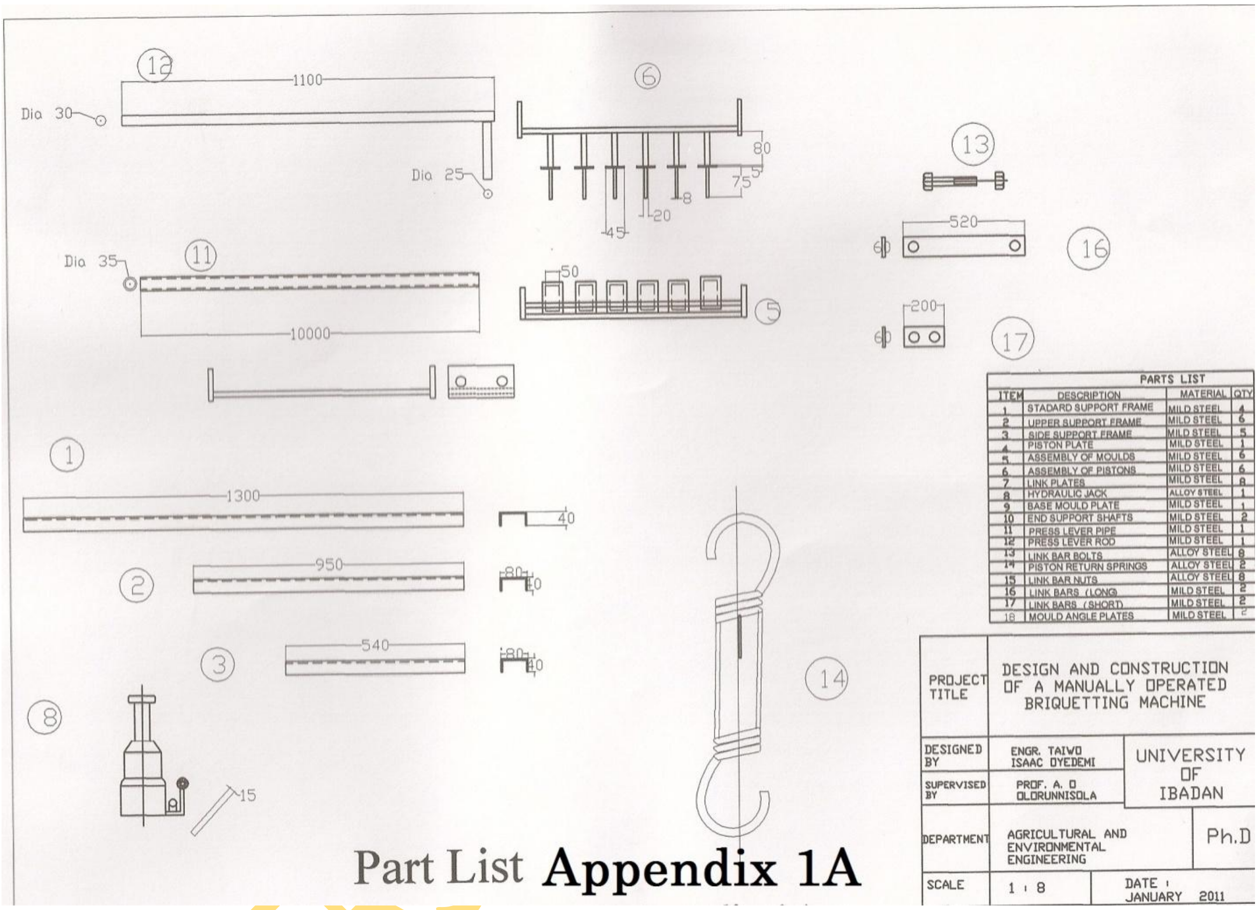
Thus the bending stress on the screw and nut thread is

$$\sigma_B = \frac{3 \times 40 \times 1016.04 \times 1 \times 10^{-3}}{\pi \times 0.2 \times 10\,(5 \times 10^{-3})^2}$$

$$= 0.776\text{MNm}^{-2}$$

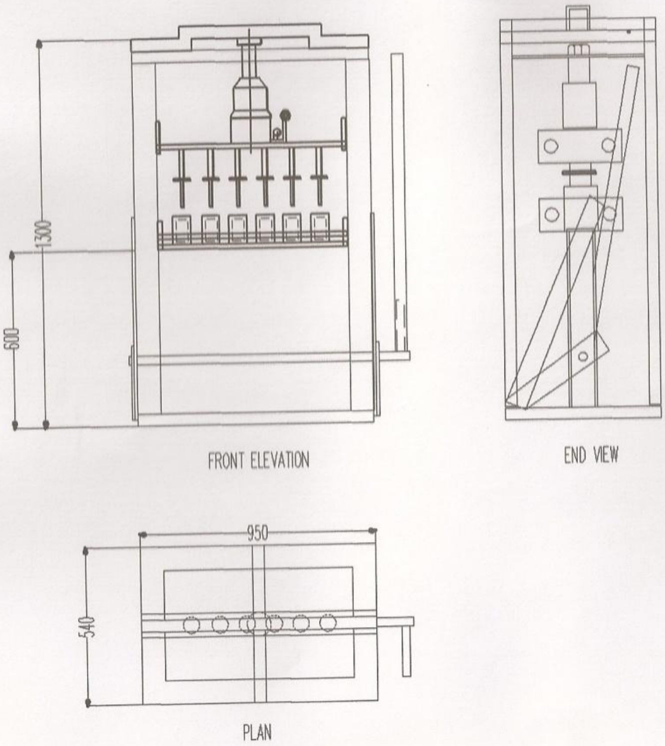
APPENDIX 1B

AUTOCAD DRAWING OF MANUAL BRIQUETTING MACHINE



PARTS LIST			
ITEM	DESCRIPTION	MATERIAL	QTY
1	STADARD SUPPORT FRAME	MILD STEEL	4
2	UPPER SUPPORT FRAME	MILD STEEL	6
3	SIDE SUPPORT FRAME	MILD STEEL	5
4	PISTON PLATE	MILD STEEL	1
5	ASSEMBLY OF MOULDS	MILD STEEL	6
6	ASSEMBLY OF PISTONS	MILD STEEL	6
7	LINK PLATES	MILD STEEL	8
8	HYDRAULIC JACK	ALLOY STEEL	1
9	BASE MOULD PLATE	MILD STEEL	1
10	END SUPPORT SHAFTS	MILD STEEL	2
11	PRESS LEVER PIPE	MILD STEEL	1
12	PRESS LEVER ROD	MILD STEEL	1
13	LINK BAR BOLTS	ALLOY STEEL	8
14	PISTON RETURN SPRINGS	ALLOY STEEL	2
15	LINK BAR NUTS	ALLOY STEEL	8
16	LINK BARS (LONG)	MILD STEEL	2
17	LINK BARS (SHORT)	MILD STEEL	2
18	MOULD ANGLE PLATES	MILD STEEL	2

PROJECT TITLE	DESIGN AND CONSTRUCTION OF A MANUALLY OPERATED BRIQUETTING MACHINE		
DESIGNED BY	ENGR. TAIWO ISAAC OYEDEMI	UNIVERSITY OF IBADAN	
SUPERVISED BY	PROF. A. O OLORUNNISOLA		
DEPARTMENT	AGRICULTURAL AND ENVIRONMENTAL ENGINEERING		Ph.D
SCALE	1 : 8	DATE : JANUARY 2011	



PARTS LIST			
ITEM	DESCRIPTION	MATERIAL	QTY
1	STADARD SUPPORT FRAME	MILD STEEL	4
2	UPPER SUPPORT FRAME	MILD STEEL	6
3	SIDE SUPPORT FRAME	MILD STEEL	5
4	PISTON PLATE	MILD STEEL	1
5	ASSEMBLY OF MOULDS	MILD STEEL	6
6	ASSEMBLY OF PISTONS	MILD STEEL	6
7	LINK PLATES	MILD STEEL	8
8	HYDRAULIC JACK	ALLOY STEEL	1
9	BASE MOULD PLATE	MILD STEEL	1
10	END SUPPORT SHAFTS	MILD STEEL	2
11	PRESS LEVER PIPE	MILD STEEL	1
12	PRESS LEVER ROD	MILD STEEL	1
13	LINK BAR BOLTS	ALLOY STEEL	8
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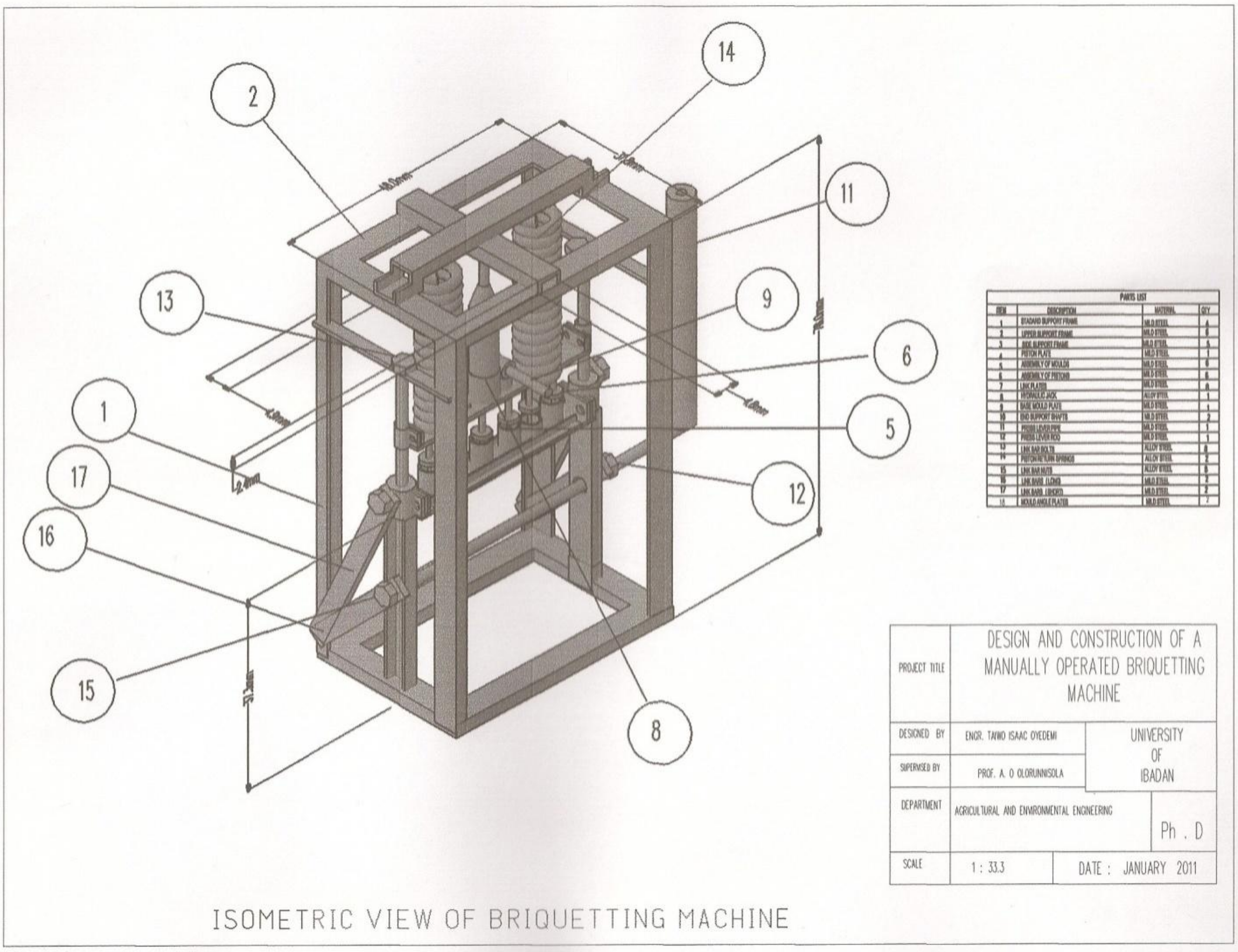
DEPARTMENT	AGRICULTURAL AND ENVIRONMENTAL ENGINEERING	Ph . D
SCALE	1 : 33.3	DATE : JANUARY 2011



PARTS LIST			
ITEM	DESCRIPTION	MATERIAL	QTY
1	STANDARD SUPPORT FRAME	MILD STEEL	4
2	UPPER SUPPORT FRAME	MILD STEEL	6
3	SIDE SUPPORT FRAME	MILD STEEL	5
4	PISTON PLATE	MILD STEEL	1
5	ASSEMBLY OF MOULDS	MILD STEEL	6
6	ASSEMBLY OF PISTONS	MILD STEEL	6
7	LINK PLATES	MILD STEEL	6
8	HYDRAULIC JACK	ALLOY STEEL	1
9	BASE MOULD PLATE	MILD STEEL	1
10	END SUPPORT SHAFTS	MILD STEEL	2
11	PRESS LEVER PIPE	MILD STEEL	1
12	PRESS LEVER ROD	MILD STEEL	1
13	LINK BAR BOLTS	ALLOY STEEL	8
14	PISTON RETURN SPRINGS	ALLOY STEEL	2
15	LINK BAR NUTS	ALLOY STEEL	8
16	LINK BARS (LONG)	MILD STEEL	2
17	LINK BARS (SHORT)	MILD STEEL	2
18	MOULD ANGLE PLATES	MILD STEEL	2

PROJECT TITLE: DESIGN AND CONSTRUCTION OF A MANUALLY OPERATED BRIQUETTING MACHINE
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Ph . D
SCALE: 1 : 33.3
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ISOMETRIC VIEW OF BRIQUETTING MACHINE

APPENDIX 1C

BILLS OF ENGINEERING MEASUREMENTS AND EVALUATION FOR MANUALLY OPERATED BRIQUETTING MACHINE

ITEMS	DESCRIPTION	QUANTITY	UNIT RATE/₦	AMOUNT(₦)
1	LINK BAR (LONG)	2	3000	6,000
2	LINK BAR (SHORT)	2	2000	4,000
3	PISTON RETURN SPRING	2	3000	6,000
4	LINK BAR NUT	4	500	2,000
5	LINK BAR BOLT	4	125	500
6	PRESSURE LEVER ROD	1	3000	3,000
7	PRESSURE LEVER PIPE	1	400	400
8	SUPPORT SHAFT	2	3500	7,000
9	HYDRAULIC JACK	1	15000	15,000
10	LINK PLATES	8	500	4,000
11	ASSEMBLY OF PISTONS	6	500	3,000
12	PISTON PLATE	1	5000	5,000
13	BASE MOULD PLATE	1	5000	5,000
14	ASSEMBLY OF	6	500	3,000

	MOULDS			
15	MOULD ANGLE SUPPORT	2	2000	4,000
16	SIDE SUPPORT PLATE FRAME	5	2000	10,000
17	FRONT SUPPORT FRAME	4	3000	12,000
18	PALLET BOARD	40	070	2,800
19	WORKMANSHIP		10000	10,000
	TOTAL			**(₦102,700)**

APPENDIX 2A

DESIGN CALCULATIONS FOR THE BRIQUETTE BURNING STOVE

1. Designing for the combustion chamber

Diameter of briquette = 40-50mm (Arnold, 2003)

Hussain *et al,* [2002] recommended ‘d’ for briquette, d = 40-60mm

$$d = 50mm$$

$$h = \frac{d}{0.75}$$

d = 0.75h, where h = height of briquette

$$h = \frac{50}{0.75} = 67mm$$

The choice of material for the combustion chamber was based on availability, relative cheapness, thermal conductivity, and weldability. Sheet metal was selected for the fabrication of this part. Design consideration is to be able to burn a minimum of five briquettes at a time in the combustion chamber.

$$\frac{\pi D^2}{4} = \frac{5 \times (\pi \times 50^2) \times 67}{4}$$

Minimum diameter, D of the combustion chamber that satisfies the above calculated volume capacity requirements is given as

$$D = \sqrt{(5 \times 50^2)} = 111.8mm$$

D for chamber was chosen as D_i = 150mm and D_0 = 155mm, which is more than 111.8mm. This is okay for the combustion chamber.

Area of combustion chamber = 0.0176m^2

Since the height of the combustion chamber is 65cm.

Total volume of the two combustion chambers = 2 × 0.001148m^3 = 0.002296m^3

2. For the design of the insulated wall: the materials considered for insulation are fibre, glass, wool, clay and silk. While fibre, glass, wool and silk are not readily available,

clay is therefore the most preferable because of its lower heat conduction.

Calculation of insulation thickness required is given by the equation:

$$q = h_1(T_1 - T_2) = V\Delta T = \frac{Q}{A}$$ [Rajput,2003]

Where V = overall heat transfer

$$V = \frac{1}{\frac{d_{x1}}{k_1} + \frac{d_{x2}}{k_2}}$$ [Rajput,2003]

$d_x = 20mm$

A thickness of 25mm is chosen. The distance between the lining wall and the combustion chamber = 33mm.

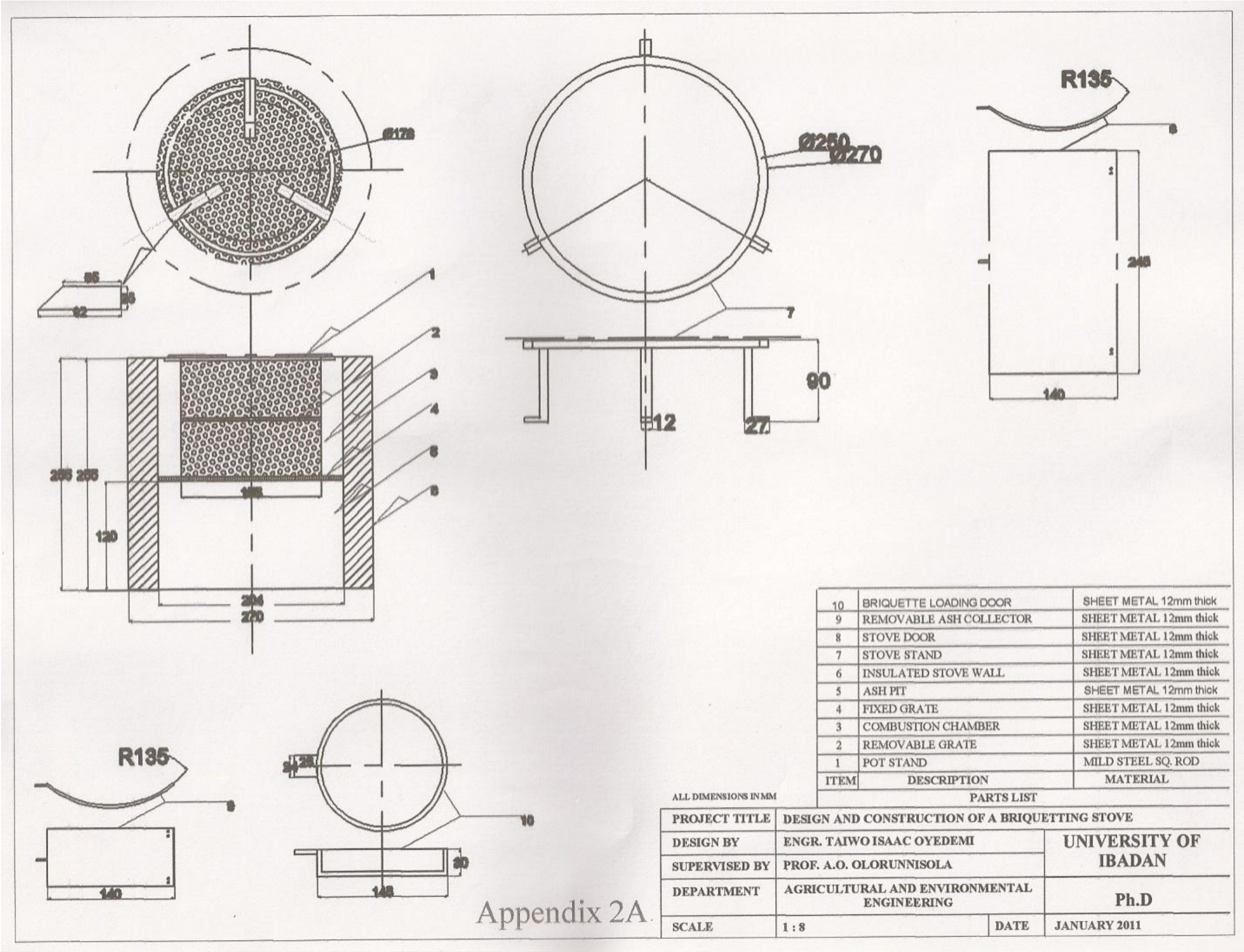
3. Briquette loading door: the briquette loading door is made of mild steel with dimension 140mm × 61mm. The thickness of the material is 1.2mm.

D (diameter of vents) = 2.5mm, h_{door} = 61mm

4. Stove door: t = 1mm, h_{door} = 245mm, arc length of door=240mm
5. Removable grate: d = 143mm, d_{vents} = 3.5mm, and t = 1mm.
6. Fixed grate: d=200mm. Clearance between fixed grate and stove wall = 4mm
7. Ash tray or removable ash collector: it is made of sheet metal. t=1mm, d_0=155mm, and d_i=151mm

D = 145mm, H = 30mm. The handle is made of mild steel. Handle length diameter = 66mm, and handle thickness = 3.2mm

8. Overall stove dimension: D = 270mm, and H = 255mm



Appendix 2A

10	BRIQUETTE LOADING DOOR	SHEET METAL 12mm thick
9	REMOVABLE ASH COLLECTOR	SHEET METAL 12mm thick
8	STOVE DOOR	SHEET METAL 12mm thick
7	STOVE STAND	SHEET METAL 12mm thick
6	INSULATED STOVE WALL	SHEET METAL 12mm thick
5	ASH PIT	SHEET METAL 12mm thick
4	FIXED GRATE	SHEET METAL 12mm thick
3	COMBUSTION CHAMBER	SHEET METAL 12mm thick
2	REMOVABLE GRATE	SHEET METAL 12mm thick
1	POT STAND	MILD STEEL SQ. ROD
ITEM	DESCRIPTION	MATERIAL

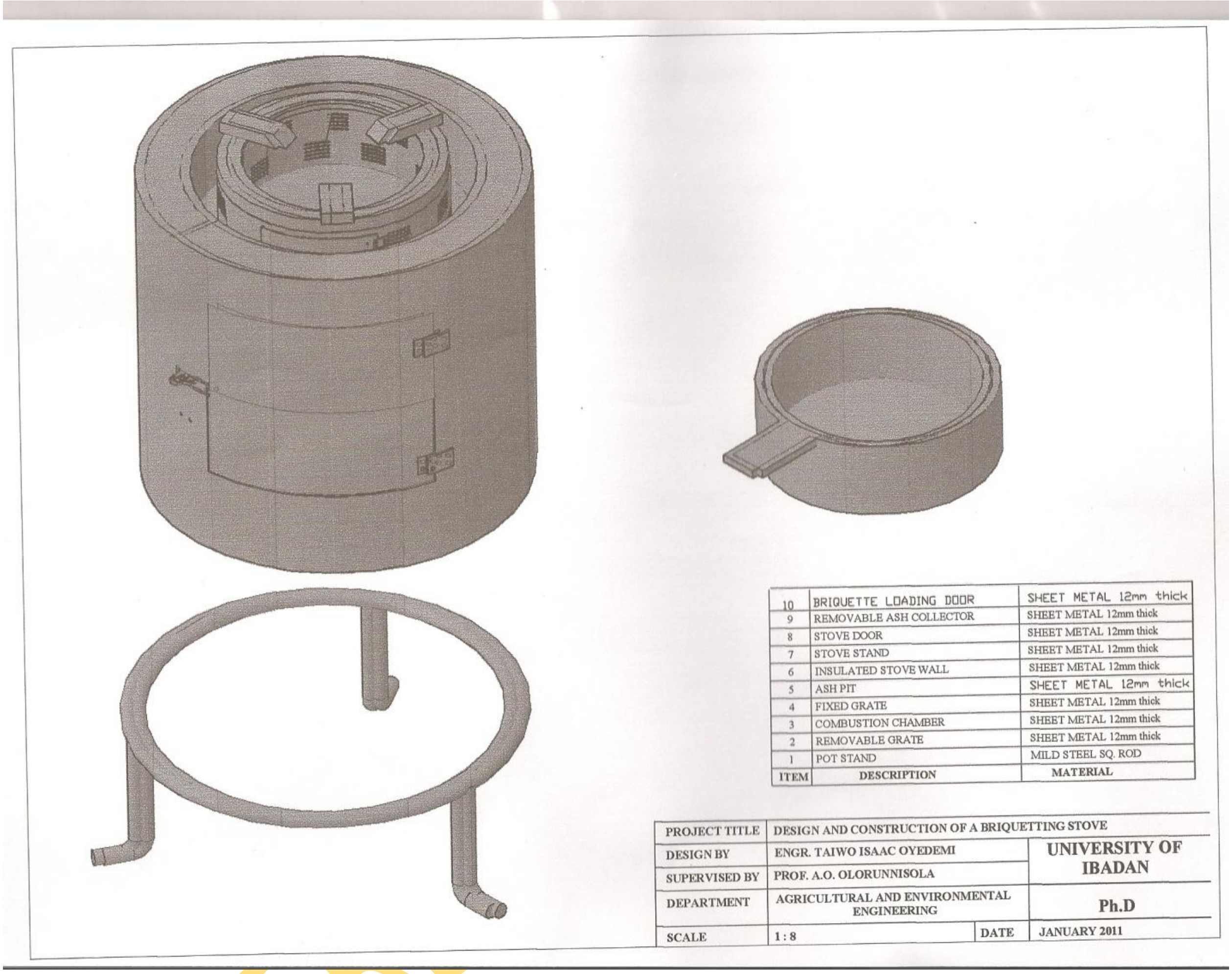
PARTS LIST

ALL DIMENSIONS IN MM

PROJECT TITLE	DESIGN AND CONSTRUCTION OF A BRIQUETTING STOVE		
DESIGN BY	ENGR. TAIWO ISAAC OYEDEMI		UNIVERSITY OF IBADAN
SUPERVISED BY	PROF. A.O. OLORUNNISOLA		
DEPARTMENT	AGRICULTURAL AND ENVIRONMENTAL ENGINEERING		Ph.D
SCALE	1 : 8	DATE	JANUARY 2011

APPENDIX 2B

AUTOCAD DRAWING OF THE BRIQUETTE BURNING STOVE



ITEM	DESCRIPTION	MATERIAL
10	BRIQUETTE LOADING DOOR	SHEET METAL 12mm thick
9	REMOVABLE ASH COLLECTOR	SHEET METAL 12mm thick
8	STOVE DOOR	SHEET METAL 12mm thick
7	STOVE STAND	SHEET METAL 12mm thick
6	INSULATED STOVE WALL	SHEET METAL 12mm thick
5	ASH PIT	SHEET METAL 12mm thick
4	FIXED GRATE	SHEET METAL 12mm thick
3	COMBUSTION CHAMBER	SHEET METAL 12mm thick
2	REMOVABLE GRATE	SHEET METAL 12mm thick
1	POT STAND	MILD STEEL SQ. ROD

PROJECT TITLE	DESIGN AND CONSTRUCTION OF A BRIQUETTING STOVE		
DESIGN BY	ENGR. TAIWO ISAAC OYEDEMI		UNIVERSITY OF IBADAN
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DEPARTMENT	AGRICULTURAL AND ENVIRONMENTAL ENGINEERING		Ph.D
SCALE	1 : 8	DATE	JANUARY 2011

APPENDIX 2C

BILL OF ENGINEERING MEASUREMENTS AND EVALUATION FOR THE BRIQUETTING STOVE

ITEM	DESCRIPTION	QUANTITY	UNIT RATE (₦)	AMOUNT (₦)
1	Fixed grate	1	350	350
2	Removable grate	1	350	350
3	Pot Stand	1	300	300
4	Combustion chamber	1	600	600
5	Removable ash collector	1	300	300
6	Stove door	1	300	300
7	Stove stand	1	350	350
8	Insulator stove wall	1	300	300
9			1000	1000
10			1000	1000
	TOTAL			**4,850**

APPENDIX 3A

RESULTS OF ANALYSIS OF VARIANCE TEST FOR WATER RESISTANCE OF BRIQUETTES

Variable Entered/Removed[a]

Model	Variables Entered	Variables removed	Method
1	WR_ GMB WR _MAB[6]		Enter

a. Dependent Variable: BINDER _PERC
b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000[a]	999	998	33800

a. Predictors: (Constant), WR_GMB, WR_MAB

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	249.772	2	124.886	1093.151	.001
	Residual	228	2	.114		
	Total	250.000	4			

Dependent Variable: BINDER_PERC
B. Predictors: (Constant), WR_GMB, WR_MAB

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	4.106	.435		8.458	.014
	WR_MAB	.431	.023	.898	18.480	.003
	WR_GMB	.053	.023	.111	2.293	.149

a. Dependent Variable: BINDER_PERC

APPENDIX 3B

RESULTS OF ANALYSIS OF VARIANCE TEST FOR DURABILITY OF BRIQUETTES

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	DU_GMB DU_MAB[b]		Enter

a. Dependent Variable: BINDER_PERC
b. All requested variables entered

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.967[a]	.935	.870	2.84772

a. Predictors: (Constant), DU_GMB, DU_MAB

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	233.781	2	116.890	14.414	.065
	Residual	16.219	2	8.110		
	Total	250.000	4			

a. Dependent Variable: BINDER_PERC
b. Predictors: (Constant), DU_GMB, DU_MAB

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	.109	8.354		.013	.991
	DU_MAB	.028	.190	.122	.145	.898
	DU_GMB	.282	.282	.847	1.002	.422

a. Dependent Variable: BINDER_PERC

APPENDIX 3C

RESULTS OF ANALYSIS OF VARIANCE TEST FOR COMPRESSIVE STRENGTH OF BRIQUETTES

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	CS_GMB CS_MAB[6]		Enter

a. Dependent Variable: BINDER_PERC
b. All requested variables entered

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	1.000	.999	.998	.34095

a. Predictors: (Constant) CS_GMB, CS_MAB

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	249.768	2	124.884	1074.271	.001
	Residual	.232	2	.116		
	Total	250.000	4			

a. Dependent Variable: BINDER_PERC
b. Predictors: (Constant), CS_GMB, CS_MAB

Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	4.243	.739		-5.743	.029
	CS_MAB	.979	.902	.098	1.085	.391
	CS_GMB	8.688	.867	.904	10.019	.010

a. Dependent Variable: BINDER_PERC

APPENDIX 3D

RESULTS OF ANALYSIS OF VARIANCE TEST FOR BURN RATE OF BRIQUETTES

Variables Entered/Removed

Model	Variables Entered	Variables Removed	Method
1	BR_GMB BR_MAB		Enter

a. Dependent Variable: BINDER_PERC

b. All requested variables entered

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.965	.930	.861	2.94915

a. Predictors: (Constant) BR_GMB, BR_MAB

ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	232.605	2	116.303	13.372	.070
	Residual	17.395	2	8.697		
	Total	250.000	4			

a. Dependent Variable: BINDER_PERC
b. Predictors: (Constant),BR_GMB, BR_MAB

Coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	1.378	9.853		.140	.902
	BR_MAB	-11.765	31.988	.402	.368	.748
	BR_GMB	36.303	29.218	1.358	1.242	.340

a. Dependent Variable: BINDER_PERC