THE USE OF PALM OIL SLUDGE AS BINDER IN THE PRODUCTION OF SAWDUST BRIQUETTES

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CERTIFICATION

This research project entitled the use of palm oil sludge as binder in the production of sawdust briquettes carried out by Oseromi Moses Kole meets the regulation governing the award of Engineering degree (M. Eng) in Agricultural Engineering and is approved for its contributions to knowledge and literary presentations.

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DEDICATION

This thesis is dedicated to my lovely wife Jane and my children Olamid and Tochi

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I am grateful to God Almighty for sparing my life till date and for giving me the opportunity to write this project.

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ABSTRACT

This study is on the use of palm oil sludge as binder in the production of sawdust briquettes. The specific objectives of the research are to establish the optimum proportion of palm oil sludge as binders, determine the quality parameters of the briquettes and evaluate the effects of varying proportions of palm oil sludge in briquetting. This research also exploited the dual potentiality of palm oil sludge as binder and combustible material.

Palm oil sludge was collected from palm oil processing industry in Okitipupa. The sawdust samples were collected from Ciab sawmill in Akure. Sawdust samples were obtained from two different wood species: Araba *(Ceiba Pentandra* and Apa *(Afzelia Africana)*. The Palm oil sludge was dried and milled. Sawdust mixtures were produced by mixing sawdust and dried palm oil sludge in percentage ratio. Three sawdust samples at 10.1, 14 and 17.8% moisture levels were each mixed with palm oil sludge to get mixtures containing 10, 20,30,40 and 50% sludge proportion by weight. Samples without palm oil sludge were also prepared. Briquettes were made at pressures of 13.5, 18.7 and 25.0MPa hold times 5,10 and 20 seconds and temperatures of 32.5 and 60^{0}C. For each briquette sample, the quality parameters were determined such as handling durability, densities (compressed and relaxed), ash content, comparative rate of weight loss during combustion and moisture content.

The relaxed density was found to be highest for sawdust mixture at 14% moisture content. The relationship between applied pressures and compressed density of briquette was established as being exponential. The ash content of briquettes increased as sludge proportion increasesd. The handling durability of the briquette increased with increasing sludge proportion between 20-50% by weight. Araba sawdust produced more durable briquettes than Apa.

From the research, the optimum proportion of palm oil sludge as binder was established to be 30% by weight, moisture of 14% hold time of 20s and pressure of 25.0Mpa.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

Figure **page**

CHAPTER ONE

1. INTRODUCTION

There are many countries that have substantial quantities of agricultural wastes which have not been utilized to the greatest economic advantage. Biomass is the generic name given to all dry plant materials and organic waste. Biomass has an advantage that it is readily available and the energy conversion techniques are not so expensive. Biomass can be derived from both plant and animals. Palm kernel shell, animal dung, rice husks, paper, sawdust is all examples of Biomass. Plant Biomass in the form of wood is the largest source of biomass compared to others. Most of these potentials lie in wood processing by products otherwise known as wood wastes such as sawdust (Probstein and Hicks, 1982). In the southern part of Nigeria where we have a lot of timber and sawmill, lots of sawdust are generated as wastes. These wastes can be converted to high grade solid fuel by improving the calorific value and ensuring a clean and blue flame suitable for cooking. This could be a way of turning wood waste to wealth (Adegoke and Kuti, 2004)). Investigation of composite sawdust briquettes and shared palm kernel shell as a source of fuel for domestic cooking compared with that of kerosene was carried out by Adegoke and Kuti, (2004). They observed that the briquettes cook faster than kerosene.

Sawdust, palm oil sludge and palm fruit fibres products from saw milling and palm oil processing respectively are examples of the numerous agricultural wastes that have not been put into full use on economic basis. The progress towards increasing the use of agricultural wastes and natural fibres in developing countries has been slow (Cote, 1982), even in countries with insufficient timber and non-renewable resources for domestic needs. Although, sawdust has a variety of possible industrial uses, it's present utilization in relation to the amount available is very low. Since sawdust is finely sub-divided wood fibre, it can be used for fuel like wood. However, the low bulk density of sawdust which makes its transportation very expensive and its high combustion rate have limited its usefulness as a source of fuel.

Briquetting is the process of densifying loose materials under pressure, with or without the use of a binder. Briquetting is one of the means by which the forms of agricultural wastes are changed. Sawdust and biomaterials briquetting may also improve their combustion efficiency, mechanical handling and reduce particulate emission and biodegradation.

One problem identified with the briquetting of fibrous agricultural residues like sawdust is the post compaction recovery of the materials in the die after the release of applied load and on exposure to environmental conditions (Faborode, 1988). By adding suitable binder such as resins, paraffin, or pitch to sawdust, the pressure required is reduced with corresponding reduction in pressing cost (Faborode, 1988). Binders also slow down the breakdown of briquette on exposure to environmental conditions.

Presently, most of the palm oil sludge produced from industrial palm oil processing plants is discharged as waste either into pits or rivers to pollute the rivers and the environment. Palm oil sludge has been found to contain phospholipids, crude fibres, crude protein and calcium compound (Glover and Mishra, 1996).

The presence of phospholipids and fibres in palm oil sludge may contribute to its binding properties. The use of palm oil sludge as binder in the briquetting of sawdust therefore, may help in reducing the ecological problems in palm oil producing areas and improving profit obtained from these agricultural wastes, that is, sawdust, palm oil sludge and palm fruit fibres.

1.1 Objectives of the research project

The specific objectives of the research are to:

a. establish the optimum proportion of palm oil sludge as binders and evaluate the effects of varying proportions of palm oil sludge on briquetting.

b. determine the quality parameters of the briquettes.

1.2 Expected output from the research

This research is expected to:

a. produce alternative source of energy

b. solve waste management problems in palm oil mills and sawmills thereby reducing the ecological problems associated with these mills.

c. produce sawdust briquettes with optimum proportion of palm oil sludge.

CHAPTER TWO

2. LITERATURE REVIEW

Wood is a variable and complex material. Wood which is the base material for sawdust is the principal product of the metabolism of a tree. Wood is comprised of cellulose, hemicelluloses, lignin and extractives. The extractives include different classes of organic compounds including resins essential oils, fats, sugar phenols and tannins. These compounds are of considerable interest because of the influence they have on some of the properties of the wood (Glover and Mishra, 1996).

2.1 Classification of Wood

Wood can be classified into the categories namely hardwood (deciduous wood). The proportions in which the three major structural components: cellulose, hemicelluloses and Lignin of wood substance are present vary only to a relatively small extent between species. There are however broad differences in composition (Table 2.1) of softwoods and hardwoods. Softwoods contain more Lignin and less hemicellulose than hardwoods

TABLE 2.1 Average % chemical composition of softwood and Hardwood

	Soft woods	**Hardwood**
Cellulose	42.± 2	45.± 2
Hemicelluloses	27 ± 2	30± 5
Lignin	28± 3	20± 4
Extractives	3±2	5±3

Source: Jane (1970)

The various physical properties of woods vary among species. Those most often noted are specific gravity and moisture content of standing tree. Wood is hygroscopic, and is a combustible material.

Wood fuel includes the following mill residue such as sawdust shavings, wood briquettes, wood charcoal and wood gas (Pant,1981). Aqa and Batthacharya (1992) noted that between 10-12% of the total content of the log is reduced to sawdust in milling operation and that the percentage of sawdust produced depends largely on the average width of the sawker and the thickness of timber sawn.

2.1.1 Properties of Sawdust as Fuel

Sawdust is a by product of wood processing, some of the properties that are important for thermal energy generation are heating value, moisture content, bulk density and proximate and ultimate composition (Aqa, 1990).

Sawdust from different parts of the same wood sometimes yields different values. Heartwood and sapwood sawdust may have different proportions. Sawdust with different proportion of these components might be compacted to have different over all energy contents. These variations of a few percentages in the measured energy content for a given type of sawdust are probably to be expected.

Aqa and Batthacharya (1992) pointed out that there are often discrepancies in the heating value for the same species of wood. They associated this mainly with regional, seasonal and individual tree differences.

Softwood and hardwood sawdust species containing significant portion of resin have remarkably higher heating values than resin free species. Reed et al. (1980) noted that on an oven dry basis the heating value of different sawdust (wood) species depend greatly on their chemical contents. Pant (1981) pointed out that in the case of energy generation the heating value and density of species are more important. He observed that the higher the value of these two parameters the better the species as a fuel. The heating value of a substance is a measure of the thermochemical property of the substance. It expresses the amount of heat released per unit weight of fuel. The heat content of various sawdust species varies considerably largely with chemical contents. Gum, waxes, lignin and such compounds with high carbon and hydrogen contents have higher heating values than carbohydrate because of the latter is high oxygen content.

The issue of moisture content is also significant and it also has effects on the heat recoverable from wood based materials. High moisture content is detrimental in three ways. It reduces the available heat of the fuel, lowers the furnace efficiency and raises the particulate emission rate. Aqa (1990) compared the combustion efficiency of dry and moist sawdust, and found dramatic decrease in efficiency with increasing, moisture content. The moisture content of sawdust is a function of extraneous water from storage or source, handling operations, and wood species.

2.2 Binder

Binder is a component of an adhesive composition that is primarily responsible for the adhesive forces that holds two bodies together. We have artificial and natural binder. Briquette specification put emphasis on the strength of the briquette which in turn depends on a number of variables such as briquetting pressure, binder content and moisture content but ultimately on the bonds between the particles (Joseph and Hislop, 1985).

The nature of bond between binder and materials is reflected in

(i) Binder embedding itself into each surface by being partly absorbed into the pores.

(ii) Binder behaving purely as adhesive, joining two inert surfaces.

(iii) Binder amalgamating with the material and effecting a softening and welding of the surface. (Mishra,1996).

2.2.1 Conditions of Using Binders

(i) The binder must wet the surfaces of particles hence it must be selected to be compatible with he material in surface properties

(ii) The binder has to be sufficiently fluid during the conditioning and pressing stage for it to flow between particles and to wet them.

(iii) The binder should be evenly dispersed by its proper preparation and mixing

To ensure that the binders sets to a solid and permanently adheres to particles after pressing, the drying out stage should be gradual so as to avoid differential shrinkage effects.

2.2.2 Classification of Binders

Binders are classified into three groups:

A. Classification by physical state.

(i) Liquid e.g. Tar, Oil

(ii) Semi-solid e.g. Tar, Pitch

(iii) Soil e.g. Pitch

B. Classification by chemical type include the followings:

(i) Organic e.g. Bitumen

(ii) Inorganic e.g. Clay

(iii) Compound e.g. Tar, lime.

The subdivisions of organic, inorganic and compound binders are listed below:

(i) Organic

This include

(a) Hydrophobic type e.g. tar, pitch, bitumen

(b) Hydrophilic type e.g. starch, sulphite liquor, molasses, vegetable pulp.

The organic binders are the most widely used. The hydrophobic binders give the strongest briquettes which are resistant to weather and water, but have the disadvantage of being smoky, when burned. The hydrophilic binders are usually applied in paste, gel or soluble form with water, but to a strong bond, they require drying after briquetting.

The advantage of these aqueous binders is that they are smokeless therefore, are widely used in the manufacture of smokeless fuels. These binders also have the disadvantage of weathering poorly and disintegrating when wet.

(ii) Inorganic

This includes:

a. Insoluble type e.g cement, clay, lime

b. Water soluble type e.g sodium silicate.

Inorganic binders are usually added as a wet paste and rely on chemical reaction with water or carbon dioxide to set. These binders are cheap and smokeless, but they have the disadvantage of contributing to the ash yield of fuel briquette and not being very resistant to weathering.

(ii) Compound

a. Extended pitch type e.g pitch/sulfite

b. Water proofed type e.g. starch/pitch, silicate/pitch.

Compound binders have been developed to overcome some of the disadvantages of the high cost and smokiness of organic binders or to improve the resistance of inorganic binders to water and weathering.

2.2.3. Selection of Binders

Binders should be selected for those factors considered to be the most important in each particular case (Joseph et al., 1985).

(i) Nature, cost and availability of feed material.

(ii) Requirements of briquetted product including.

a. Size, shape, strength and price

b. resistance to further treatment or weathering

c. Smokelessness

d. combustion behaviour.

2.3 Production and Chemical Composition of Palm Oil sludge.

Palm oil sludge is one of the by-products of palm oil processing. The extraction of palm oil from palm fruits, as described by Hartley (1977) and reported by Asiedu (1989) is carried out in a number of stages. (see Figs 2.1and 2.2) The oil extracted is crude oil which is accompanied by impurities in suspension. The impurity level will vary with handling storage and extraction method. The impurities affect the flavour and odour and are therefore removed during refining. The removal is done in a tank containing water heated to about 95°c. pure oil is then drawn off from the top of the tank while the impurities (the sludge water) is drained into a series of pits. The sludgy water is dried by evaporation and the solid product (palm oil sludge) is obtained.

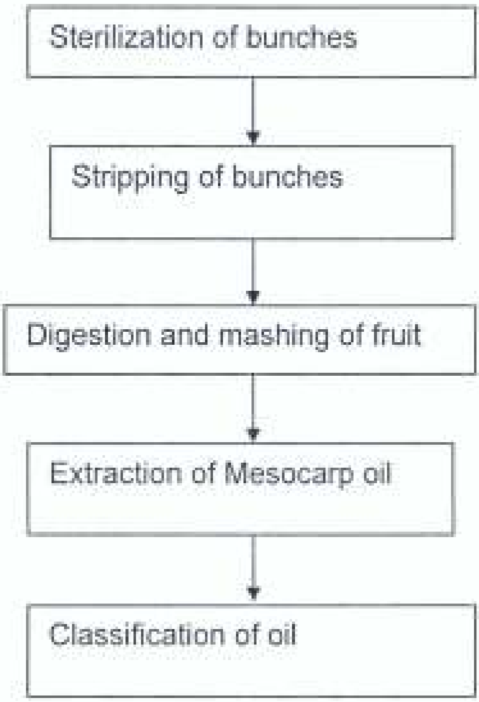


Fig. 2.1. Process line in palm oil processing (Asiedu, 1989)

Asiedu (1989) stated that the most important part of the oil palm from the oil processor's point of view is the bunch of palm fruits. He stated that the unit operations involved in the processing of palm fruit into Palm oil and kernels are as show in fig. 2.2.

Table 2.2 shows the chemical composition of palm oil sludge.

Chemical composition of Palm oil sludge

Dry Matter	Crude protein	Grude Fibre	Ether Extract	Ash	Nitrogen	
90%	10.6	18.3	17.0	12.1	42.0	0.75

Source: (Devendra 1979b)

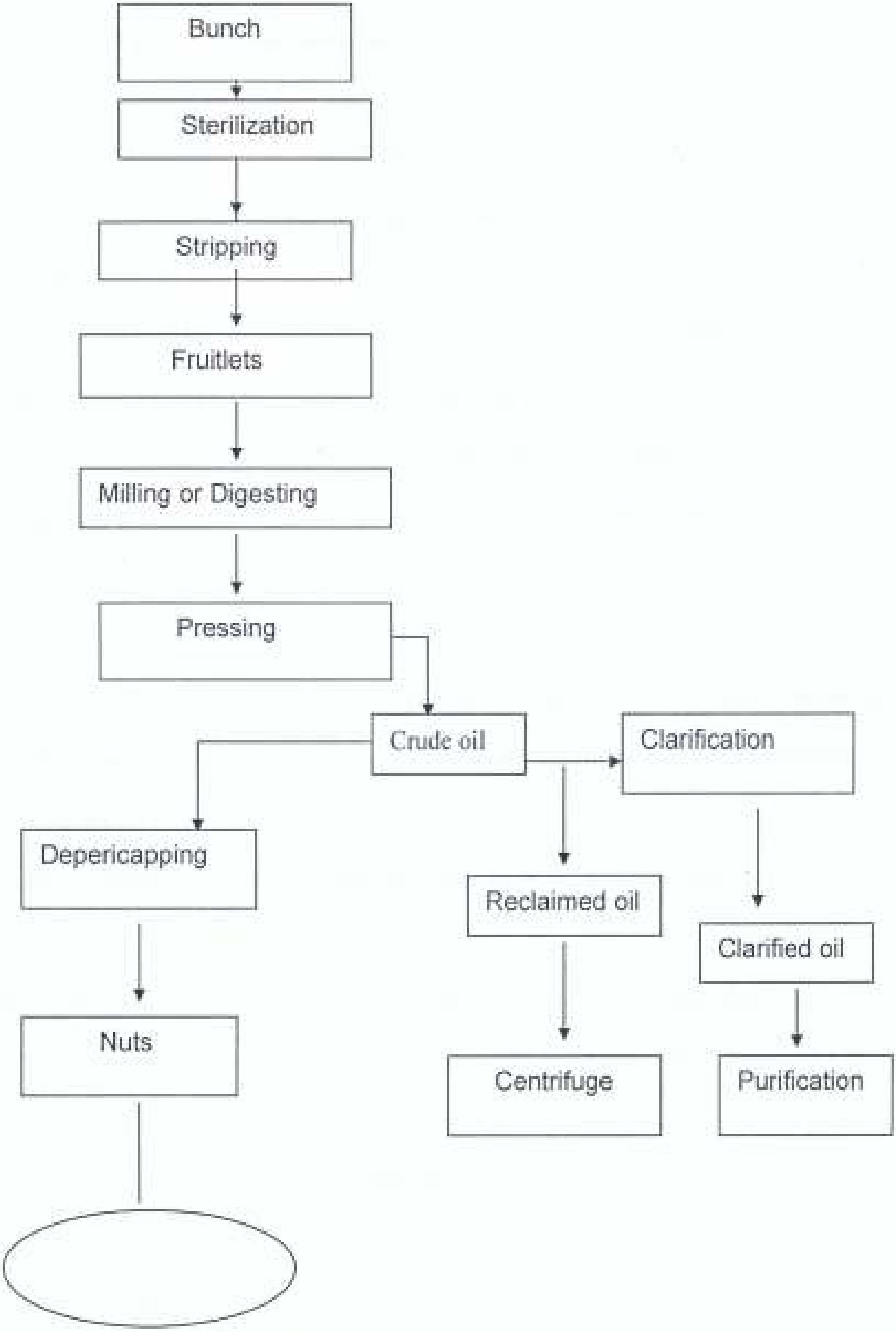


Fig. 2.2 Processing of Oil Palm Fruits.

Source: Asiedu, 1989.

When a binder is added to the material to be briquetted this supplements and substitutes for the forces of cohesion between particles. Thus, obviates the need for high pressures to quash particles together into bridges of contact. The application of external pressure creates within the briquette a complex system of relatively permanent internal forces which holds the particles tightly together.

The following types of cohesive forces are considered prominent (Scharabok, 1997)

a. Mechanical thrust and tension forces arising from particle interlocking.

b. Friction at points and surfaces of mutual contact between particles.

c. Long range forces of intermolecular attraction when particle surfaces are sufficiently close and

d. The relatively strong short range inters atomic forces of attraction.

Faborode and O' Callanghan (1986) analyzed compaction to be a mutual deformation problem which depends on the interplay of several properties of the material and conditions of the processing plant.

Such material properties include moisture content, particles size and shape, size distribution, biochemical characteristics of the material and its mechanical properties. Important processing variables are geometry of the die, hold time, temperature of the die and material, and magnitude and rate of application of forces to the material (Aqa and Bhattacharya, 1992).

Two major methods of briquetting are identified as:

a. Extrusion

b Closed end die

In the extrusion process the material is forced under high pressure through the forming die. This process according to Aqa and Bhattacharya (1992) depends on friction between the briquette and the die wall to develop the required pressure for the formation of briquette. The process although is a continuous flow process has the disadvantage of excessive power requirement, making the process very capital intensive to establish. There is also the difficulty of controlling friction between the die wall and briquette.

In the closed end, the material is forced into the die, held under pressure until the desired briquette is formed. The process is cyclic in nature, which lends itself to easier study in the laboratory. One of the disadvantages of the process according to Faborode and O' Callaghan (1986) is that very dense briquettes are not produced because of excessive post compaction recovery of the material. Briquette densities are generally below 700 kg/m^3 and usually about 400-500 kg/m^3 However, most of the studies on briquetting have been with closed end die process.

Until recently, the usual goal of briguetting was in the production of animal feed in a convenient form. Now there is considerable interest in forming sawdust and other residues into easily handled fuel.

2.5. Quality Parameters of Briquetting

Two quality parameters are used to characterize the briquette qualities in most research.

a Durability and

b Relaxed density

These two briquette parameters are of greatest practical interest in relation to handling, transporting and storage requirement (O' Doherty and Wheeler, 1984) higher relaxed densities are preferred for economical transportation and storage and for durability in handling while lower relaxed densities are preferred for briquettes meant for livestock feed (Nason, 1987).

A number of researchers (O' Doherty and Wheeler, 1984) have examined the change in density with time after removal form the die. It was found out that the major expansion occurred 30 minutes after release of the briquette form the die. Nason (1987) measured changes in water density of hay over a period of 12months and concluded that the final water density depends on when expansion finally ceases. Durability of packages has been attested to determine their ability to withstand mechanical handling. Such durability tests have used arbitrary drop or tumbling tests, but most recent work has used the test technique specified in ASAE standard. (1983).

Most of the previous works on material compaction were concerned with briquette parameters affecting handling, transporting and storage requirements like density and durability. The essential briquette parameters derived from domestic combustion requirements (such as heating value, ash content, smoke, resistance to weathering) for fuel applications were neither well defined nor standardized. A lot of work is still required in the characterization of the briquette quality for fuel application.

2.6 Use of Binders in Briquetting

Few works, (Smith, 1985; Faborode and O' Collagen, 1986) have been done on the use of binder to improve the quality of briquettes. This may probably be due to the fact that binders have objectionable implication on cost, die maintenance and combustion characteristics of the briquette produced.

The most extensive work on briquetting appears to be that of rice straw. The different binding materials used include:

i. All bond 200 – a pre-gelatinized starch from corn and soya flour containing both amylase and amylopectin starch

ii. Pms- a brown liquid feed supplement containing molases, liquid phosphoric acid and urea.

iii. Ground beet pulp.

iv. Organ GL 50-a brown liquid containing principally ammonium sulphated liquin, wood sugars, 3.7% nitrogen in the form of ammonia, and 50% water

v. Ground almond hulls

vi. Ground barley.

They found that organ provided the most consistent results in increasing wafer quality generally, dry adhesives were found to be more effective in increasing wafer density whereas liquid adhesive produced more durable wafers.

Mc Arthur (1981) used three binding agents, bentonite, ceredex and blackstrap, molasses, and found that neither bentonite nor ceredex was effective in increasing pellet density. However some increase in density was obtained by the addition of 5 and 10% blackstrap molasses but the process was accompanied with high frictional forces. This led them to conclude that the use of the binding agents does not appear to be practical.

Carre et al (1984) used 6% wax on wood base material (sawmill waste and shaving) and observed that the wax content decreased residual stress and the subsequent expansion acted as an adhesive resulting in higher durability of wafer.

The little progress made in binders' research can be attributed to initial lack of fundamental understanding of the mechanism of material binding during compaction (Faborode, 1988). Perhaps a good briquetting binder should not only process good binding properties but also conform to the basic requirements of briquetted products. It must be resistant to further treatment and weathering. Its combustion behaviour must be satisfactory in terms of smoke production It must be durable cheap and readily available.

Some of the binders used in briquetting by the previous researchers possess good binding properties, but do not meet the combustion requirements of the briquette products for fuel application. Hence, Palm oil sludge which possesses both the binding properties and combustion characteristics is considered in this work.

2.7 Effect of Pressure

Sawdust is quite compressible and its consolidation results in a product of higher density. When a bulk of sawdust is loaded in a container, material at any point in the bulk undergoes packing due to the weight of sawdust above it. (Self-packing) plus any mechanical pressure applied. Therefore, pressure and density vary within the material. In order to design appropriate compression equipment, information on the force and pressure needed to obtain a desired compressed density is required. A number of workers have been concerned with the form of the pressure-density curve when material is under pressure in the die (Smith, 1985; Vesiroghu, 1981).

Empirical equations have been derived in this regard and the analysis of Faborode and O' callaghan (1986) are of particular interest. It was assumed that the pressure rise on any section of the material during compression depends on the degrees of compression which he assumed to be a linear function of the compressive pressure and finally obtained an equation of the form

$$P = C\,(e^{a} - 1) \qquad 2.1$$

where p=compression pressure Mpa

a and c are empirical constants

$\square$ and $\square_0$ are current and initial densities respectively.

Preliminary analysis with experimental data showed that contrary to the assumption that the compressive pressure is a linear function of the degrees of compression, 0' Doherty and wheeler (1984) propose different equations for densities between 150-400 kg/m^3 and those above 400 kg/m^3 for barley straw compressed to a maximum pressure of 74 Mpa. In their analysis of result, they used simple power law relationship for densities up to 400 kg/m^3 but at higher densities it becomes a complex logarithmic power law.

0' Doherty and wheeler (1984) found that the final density of the compressed material varies linearly with the logarithm of the pressure applied and is represented by an equation of the form.

$$Pd = K_1 \ln\left[\frac{p}{K_2}\right] \qquad 2.2$$

Ed-final density of the compressed material

P = pressure applied

K_1 and K_2 are empirical constants

Equation 2.2 applies to pressures between 7-35 Mpa beyond this range density increase was not linear with increase in pressure.

The effect of pressure on wafer density up to 150 Mpa was investigated and it was discovered that there was an exponential increase in the pressure required with increasing relaxed density. The relationship was of the form

$$P = ae^{b}\,(S)W. \qquad 2.3$$

Where a & b are empirical contents

P= pressure applied MPa

(S)W = relaxed briquette density Kg/M^3

Reed et al. (1980) proposed the following pressure density relationship

$$P=C\ (\square - \square_0)\,m \qquad 2.4$$

C and M are empirical constants

The analyses of Reed were valid for low pressure (< 1.0 MPa). For pressure above 20 MPa, Faborode and 0' Callaghan (1986) noted the inadequacy of equation (2.4) and proposed a different expression as follows

$$P = Ae\ B\,(\square - \square_0) \qquad 2.5$$

where A and B are empirical constants

borode and 0' Callaghan (1986) observed that the empirical nature of the constants in these
pressions could not allows them to be associated with any material or process parameter for a
ear cut understanding of the process. They therefore proposed a single equation to express the
essure during the compression process in terms of compressed density.

$$= a\frac{\gamma_o}{b}\left(\frac{b(\gamma-1}{e \qquad -1}\right) \qquad 2.6$$

d it used the Cauchy number (ratio of inertia to elastic forces to demarcate the two district
ages of the compression process- the dispersed and densed stages.

here a & b = are empirical constants

ompression ratio $= \frac{\gamma_c}{\gamma_o}$

Further analysis by Faborode and O' Callaghan was aimed at providing a physical basis
the constants of equation 2.6 and they deduced that

$K_0 = a\ \Box_0$

and $b = \frac{\Box_0}{\Box_c}$

Where Ko is the initial bulk modulus of the material and $\Box_c$ is defined as the critical
nsity b is the porosity index. Equation 2.6 Thus becomes

$$P = K_o\left\{e^b(r-1)_{-1}\right\} \qquad 2.7$$

K_0 and b were found to express the compression behaviour of the material.

8 Effect of Material Temperature

Various researchers including Nason (1987) have examined the effect of temperature on
iquette quality and power requirement in a closed end die. The three possible methods of
pplying the necessary heat examined are:

a. Heating the die

b. Heating the material

c. Heating die and material

ey concluded that the addition of a modest amount of heat by any of the methods or mbination results in a definite improvement in relaxed density.

Cote (1982) carried out some experimental works which indicated that the heated die thod given the most consistent result. He studied the influence of die temperature up to 5^{o}c and found that increasing the die temperature enabled satisfactory briquettes to be made higher moisture contents, or at a lower pressure. Wheat straw was compressed in a closed d die which was heated to temperatures in a range 60^0 to 14^{0}c for 40 minutes. The work wed that maximum degrees of compaction was achieved for temperature of 90^{0}C and ve, giving a very high relaxed densities between 1200 and 1300kg/m^3 Cote (1982) mined the effect of pre heating wood and wood residues before briquetting. He ommends pre heating of feedstock between 50^0-100^{0}c, and explained that within the range, nin is fairly soft and aids the production of very dense and stable compressed products.

Mc Arthur (1981) identified the mechanism involved at different temperatures. Below ^{0}c the bonding mechanism was one of the plastic deformation for which a minimum perature of 60^{0}c was required. Above, 120^{0}c the dominant mechanism was though to be one s increased by over 30% through heating to 140^{0}c. However, more work is required in this a.

Effect of Material Moisture

Almost all of the researchers have shown that moisture content on material compaction have a profound effect on the process and the properties of the product. It has been found to e the greatest influence on the stability of briquettes. The salient finding from most of the dies was the wide range of moisture levels at which different materials could be compacted isfactorily.

Abd-Elrahim et al (1981) studied the effect of materials moisture content over a range between 10-25% for hay. O'Dogherty and Wheeler (1984), Abd-Elrahim et al (1981), Nason (1987) worked on different agricultural material at various moisture range. Within the ranges investigated, most of them found upper limits above which briquette formation is very difficult and would not be practical.

Also, there exists an optimum range of moisture within which the best durability could be obtained. The role of material moisture content was properly stated in the work of Abd Elrahim et al. (1981) who explained that adequate moisture is necessary to reduce inter particle friction so that the pore space may be occupied. Beyond the moisture requirement for reduction of inter particle friction the moisture begins to occupy volume that would otherwise be occupied by material particles, thus reducing the dry matter density. In more recent work, Faborode and O' Callaghan (1987) stated that some moisture is needed to aid binding by the materials natural binders whereas excess moisture becomes a disadvantage either by producing a "Watergum" or increasing the pore pressure which reduces the effective pressure on the material.

Abd Elrahim et al. (1981) concluded from their study on cotton stalk that the choice of the most suitable moisture content is the most critical requirement in a compaction process as it affects the density and energy consumed in the process. More stable wafers were obtained at lower moisture content at the expense of energy consumption.

Arends and Donker/rot-shoug, (1985) reported an increase of energy requirement with decreasing moisture content for hay. Studies by Arends and Donker/rot-shoug (1985), Glover and Mishra (1996) on hay wafering revealed that decrease in moisture content leads to increase in relaxed density. O' Doherty and Wheeler (1981) showed an exponential decrease in relaxed density with increasing moisture content. This effect therefore places a limit on the moisture at which satisfactory wafer could be formed.

O' Doherty and wheeler (1984) *also reported that the dry matter specific energy* required to compress staw was independent of moisture content over the range of 7-44% w.b. whereas durability generally showed a maximum at a moisture content in the range of 13-17% and decreases rapidly for moisture content greater than 20%. Nason (1987) also confirmed that dry matter specific energy of compression of partially dried Lucerne was constant over a moisture content range of 27-62% w.b.

O' Doherty and wheeler (1984) found out that the wood based wafers having a moisture content exceeding 25% exhibited a durability approaching "Zero" and that lower moisture content resulted in lower residual stress. The wide variation in material moisture levels from previous studies shows that further works need to be carried out on material compaction to reduce the variation as found out by early researchers.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Sample Collection and Preparation

Sawdust from two varieties of wood viz Araba *(Ceiba Pentandra)* and Apa *(Afzelia Africana)* were used in the study. The sawdust samples were collected from Ciab Sawmill in Akure, Ondo State. The palm oil sludge and palm fruit fibres were collected from a palm oil processing mill in Okitipupa, Ondo State.

The moisture contents of sawdust samples were determined immediately after collection. The samples were dried in an oven at a temperature of 103 ± 2^0C for 72hrs. The samples were weighed every 2 hrs until the weight for three consecutive weighings were constant. Sawdust samples of known moisture content were subsequently stored in airtight plastic bags to prevent re- absorption of moisture from the atmosphere.

3.1.1. Particle Size Distribution

Size characteristic was determined for the representative samples used in the experimental

The ASAE Standard (1983) was used. A sample of 100g was placed on the top sieve (number 8) of a set of sieves number 8,16, 30,50 and 100 (Appendix A.4) and was shaken mechanically until the weight retained on the smallest sieve was constant.

Material retained on the smallest sieve was monitored by weighing every 5min intervals after an initial sieving time of 10min. the sieving operation was stopped when the material in the smallest sieve remained constant after two consecutive weighings. The material on each of the sieve was then weighed and recorded mean particle size, fineness modulus and uniformity index were calculated using the standard relation from Henderson and Perry (1974).

3.1.2 Bulk Density

The bulk densities of the materials were determined using a box of known dimensions and weight. The box was then filled with the material without tempering. The box with the material was weighed and subjected to 50HZ vibration for 10min on a mechanical shaker. The apparent volume filled by the material after mechanical vibration was determined. The bulk density of the material was then obtained as the ratio of the bulk weight of the material and the apparent volume (Carre et al ; 1984).

3.1.3 Palm Oil Sludge Preparation

The Palm oil sludge which was wet on receipt from the mill was sun dried and subsequently milled using a Burr mill. The moisture content of the milled palm oil sludge was determined following the procedure recommended by the ASAE Standard: (ASAE, 1983b) for fats and oil materials. The sample was placed in the weighed container and then transferred to the oven. Drying was carried out for 6 hrs at 130^{0}C. After drying, the sample was weighed. The moisture content of sample was obtained from the equation 3:1

$$M_w \frac{Wd_1 - Wd_2}{Wd_1} x\,100 \tag{3.1}$$

Where Wd_1 = weight of sample before drying in the oven (g)

Wd_2 = weight of sample after drying in the oven (g)

Also, size characteristics were determined for the palm sludge samples used in the experiment which was used as dispersant as recommended in ASAE standard: (ASAE, 1983).

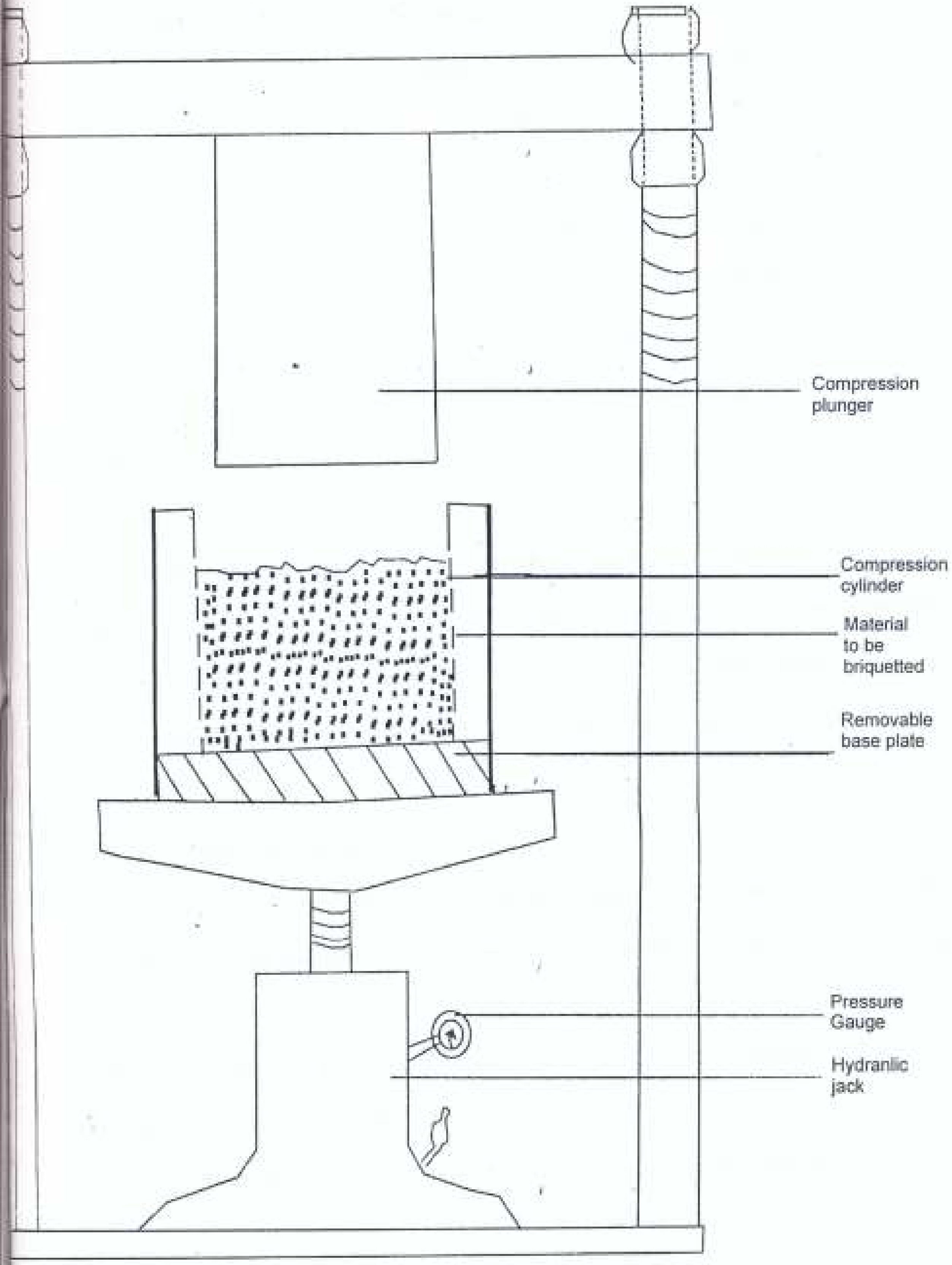


Fig. 3.1. A Schematic diagram of a Briquetting Apparatus

3.2 Experimental equipment for briquette making

Fig 3.1 shows the schematic diagram of the laboratory briquetting apparatus used. The compression plunger which was fixed to the top of the rig has diameter 50 mm and a length of 190 mm. The compression cylinder was made from a solid mild steel rod of 70 mm diameter. The solid rod was machined on a lathe machine to a length of 120 mm and an internal diameter of 50 mm so as to be able to withstand the pressure used in briquetting operation. At the button of the compression cylinder is a removable base plate to hold the material in the cylinder during briquetting. A pressure gauge on the apparatus was used to monitor the briquetting pressure at various stages of briquetting. The corresponding compressed heights of sample were measured with a steel rule.

In operation the hydraulic piston head moves the base plate upward and hence the material in the compression cylinder is pressed against the fixed compression plunger thus effecting briquetting. Afterwards, the briquette formed is ejected into a small container by pressing the cylinder against the compression plunger, after replacing the base plate with the container.

3.3. Procedure for Making a Briquette

To prepare the test sample, a fixed weight (20g) of each of the mixture of sawdust and palm fruit fibre samples were mixed with varying percentage of milled palm oil sludge determined as proportion of the total weight of mix (see Appendix A). The mixing was achieved by measuring the sawdust mixture into an aluminum bowl, adding the sludge, and mixing thoroughly with spatula.

The mixture was loosely fed into the compression cylinder with the base plate in place and the initial height of the material before compression was recorded. The loaded pressure cylinder was placed on the briquetting rig and the content compacted.

When the desired pressure was reached the briquette was kept under the maximum pressure for a specified hold time of 5, 10 and 20 seconds after which the briquette height in the cylinder was recorded as compressed height. The briquette was ejected and stored for 2 weeks to allow expansion to cease. Thereafter, tests were carried out on the representative samples of the briquettes.

Six levels of sludge proportion were considered in the experimental work. The range chosen (0-50%) by weight is justified since it is expected to be a minor constituents (binder) in the briquette produced. The processing and material parameters studied were applied pressure, moisture, content, sludge proportion, hold time and temperature.

3.3.1. Briquetting Pressure

To determine the compressed density and pressure relationship, applied pressure ranging from 0-25 Mpa which were the practical range of the equipment, were used. Three levels of pressure range (13.5, 18.7 and 25.0MPa) were used in the determination of effects of pressure on yield.

3.3.2 Material moisture content

Sawdust sample at moisture level of 10.1.14 and 17.8% (w.b.) were used in line with the suggestions of Dobie (1973) and Mohsenin and Zaske (1976).

. 3.3.3 Hold Time

Hold times of 5,10 and 20s were used.

3.3.4. Temperature

The temperatures used during briquetting were selected in line with Cote (1982). Therefore, briquetting was done at two temperature levels

(i) Briquetting at room temperature of 32.5^{0}C

(ii) Briquetting at 60^{0}C.

The oven was preset at the temperature of 110^0c, the sample in the cylinder was placed in the oven with a cover on it to reduce moisture loss from the sample. The sample was heated in the oven for 40 minutres to allow the heat penetrate to the centre of the sample and to prevent charring of sample. The centre temperature rise of the sample was quickly measured and transferred to the briquetting rig. The briquetting temperature of the sample was 60^0c.

3.4.1 Determination of the Briquette Characteristics.

To evaluate the effectiveness of palm oil sludge as binder for fuel application, some mechanical properties such as elongation (axial and redial), densities (compressed and relaxed), and handling durability were examined. Combustion characteristics and hydrogoscopic property were also determined. Combustion characteristics such as gross heating value, ash content and loss in weight during combustion were also investigated after two weeks exposure. However, the compressed density was determined with the briquette under pressure.

3.4.1 Density Determination

Density is an important criterion to assess the briquette quality. In some cases, it was noted that there was no clear distinction between the density under compression and the density after removal from the cylinder (relaxed density) In this study, three densities were determined viz the initial (or material packing) density $\square_0$, compressed density $\square_c$ and relaxed density $\square_r$.

The initial density of the material was regarded as the density of the material when packed in the compression cylinder before the application of the load or pressure.

Mathematically,

Initial density $\square_0 = \dfrac{M}{Ah_o}$ 3.2

Where

M = mass of the material in the cylinder (kg)

A =Gross sectional area of the cylinder (m^2)

h^1 = measured height of the briquette while under the desired pressure.

Relaxed density determinations were made from the geometry (height and diameter) and the mass of the briquette when the briquette has attained its final and stable dimensions. The final relaxed state was reached after 2 weeks exposure.

Mathematically expressed as

$$\gamma_r = \frac{M^1}{\frac{\pi d^2 h^2}{4}} \qquad 3.3$$

Where

M^1 = mass of the briquette after 2 weeks exposure (kg)

d = diameter of the briquette after two weeks

h_2 = measured height of the briquette after 2 weeks exposure.

The compression ratio is the ratio of the density at any given stage of compression to the initial density of sample being compressed (Faborode and O' callaghas, 1986).

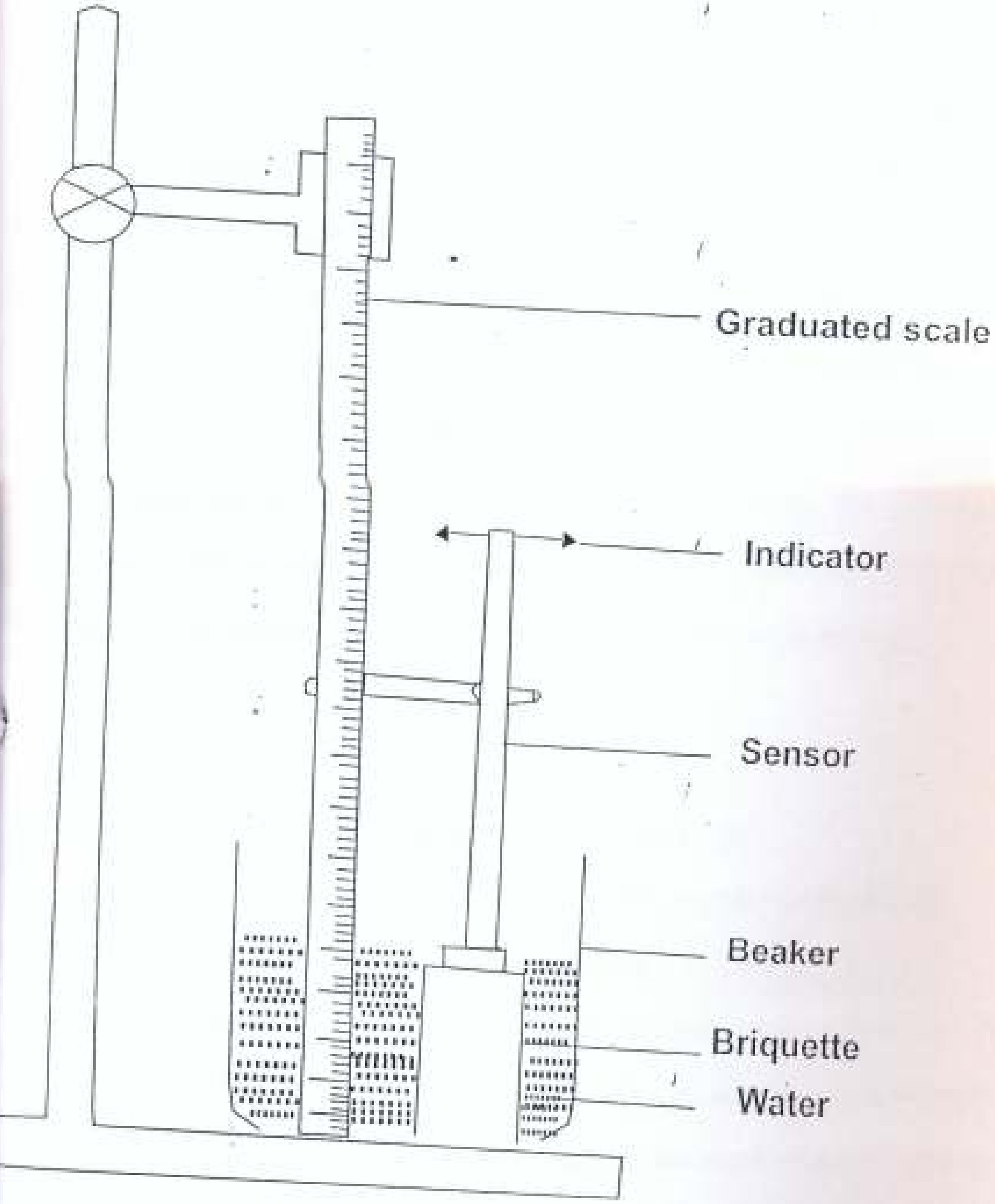
$$\text{Compression ratio } (r) = \frac{\square_e}{\square_0} \qquad 3.4$$

3.4.2. Determination of Swelling Properties of Briquette

To determine the hygroscopic property or the behaviour of the briquette sample in water or its resistance to moisture deterioration, immersion test was used. This is measured by the associated dimensional changes. With this a quick assessment of the samples resistance in water is made.

Fig: 3.2. Shows the apparatus used for the experiment.

The briquette sample was placed in a beaker and the initial height was measured. The beaker was then filled with water up to 3mm above the sample surface. The level of the water was kept constant throughout the test or experiment. The sample absorbed water and the corresponding height with time was monitored and recorded. The percentage relative change in height with time was then computed.



.3.2 schematic diagram of the Briquette Sample in Water.

3.4.3 Handling Durability Measurement

Durability measurement has been used to assess the ability of the briquette to withstand mechanical impact of limited nature such as those encountered during handling and transportation. Durability of the briquette was determined using arbitrary drop method by Abd-Elrahim et al., (1981).

The test briquettes were weighed and placed in a box. The box containing the briquettes was raised 2.0 m high and allowed to drop freely for a specific number of times onto a smooth concrete floor. After the drops, the briquettes and fractions from the drops were placed on top of a 35 mm square mesh screen and sieved. The weight of material retained on the screen after the specified number of drops was recorded. From the weights, the handling durability for a specified, number of drops was computed thus:

% Handling durability 3.5

$$= \frac{Wf}{W_1} x\,100$$

where w_1 = initial weight of briquettes before dropping (kg)

w_f = weight of the fraction retained on screen after a specified number of drops.

3.4.4. Dimensional Change Measurement

To effectively assess the stability of the compressed briquette, the expansion measurements are of utmost importance. The radial and axial changes of briquettes after 2 weeks exposure were calculated on the basis of the initial height and diameter of the briquette respectively, while confined under pressure (Mohsenin and Zaske, 1976).

Mathematically,

Axial Expansion % $= \frac{h_2 - h_1}{h_1}$ 3.6

$$= \frac{d_2 - d_1}{d_1}$$

Radial Expansion % 3.7

where h_1 = initial height of the briquette while under pressure.

h_2 = the height of the briquettes after 2 weeks exposure to environmental condition

d_1 = The initial diameter of the briquette while under pressure.

d_2 = The diameter of the briquette after 2 weeks exposure.

3.4.5 Crushing Strength

The crushing strength of a briquette sample is a measure of its cohesion. This is another means of assessing its durability.

An unconfined machine was used for the determination as described by Smith, (1985). In the test, the briquette sample was placed between two flat plates. Vertical load was applied to the briquette in its radial axis at a constant rate until the test sample failed. The axial load at failure of sample was expressed with respect to its radial curved surface area (radial axis)

Mathematically, it is expressed as

$$C = \frac{F}{S} \qquad 3.8$$

where F = applied load (N)

S = Area of curved surface along the radial axes.

3.4.6 Determination of combustion characteristics

(a) Ash Contact.

The ash content of the briquette sample was determined using muffle furnace. The sample was weighed into a crucible of known weight, put in the furnace and ashed at 850^0c until the weight of the sample left was constant. After ashing initially for 5hrs, the weight of sample was monitored every hour by weighing the crucible after removal from furnace and cooling in a desicator.

The ash content was then computed using the expression

$$\% \text{ ash content } = \frac{W_s}{W_c} x\, 100 \qquad 3.9$$

where Ws = Weight of sample after ashing and colling (kg)

Wc = weight of sample before ashing (kg)

b) Weight loss during combustion

In the weight loss determination, the apparatus in Figure 3.3 was used. The insulator, bunsen burner, tripod stand and wire gauze were arranged on the balance, and their weight was recorded. Briquette sample of known weight was placed on the wire gauze and the bunsen burner ignited. The relative weight loss of the test briquette with time was monitored with the balance and stop clock.

The relative weight loss at specified time was computed using the expression

$$\text{Relative weight loss} = \frac{\text{Relative change in weight of briquette}}{\text{original weight of briquette}} \qquad 3.10$$

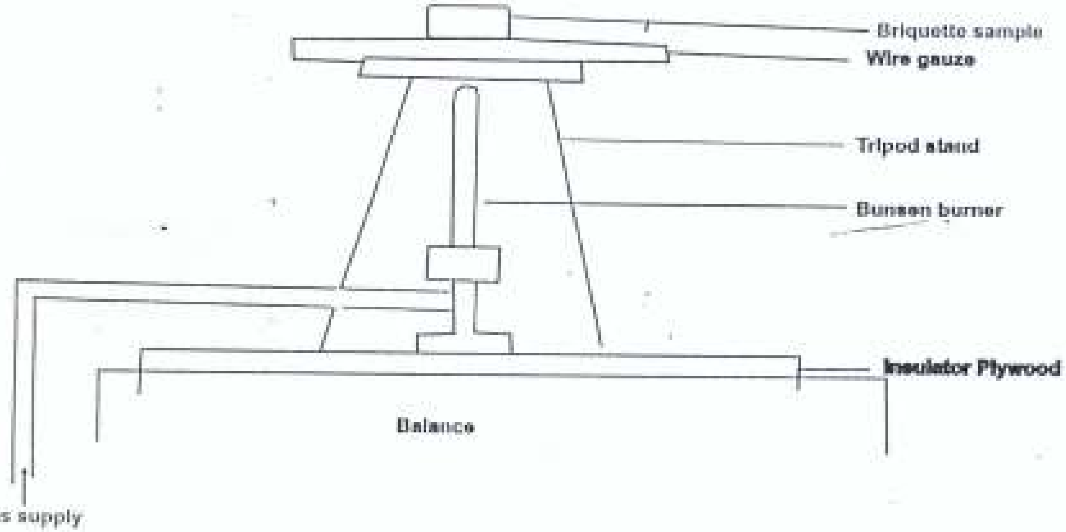


Fig. 3.3. Schematic diagram of the Apparatus used in determining weight loss of briquette during combustion.

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Pressure Density Relationship at Different sludge proportions

The variations of the compressed density with the applied pressure for both sawdust samples (Araba and Apa) at different sludge, proportions are shown in Figure 4.1 and 4.2 respectively.

Table 4.2 shows the regression analysis of the sample data which shows good relationship of exponential nature between the applied pressure and density at different sludge proportion for the two sawdust varieties. The general exponential relationship is of the form.

$$P = Ae^{B}\gamma_c / \gamma^{o} \qquad 4.1$$

Where γ_c and γ_o are compressive density and initial density respectively while A and B are regression coefficients.

The correlation coefficient achieved with the equation is within the range 0.97 and 0.99. The student t-test applied to the resulting coefficient using the equation in Appendix A.5 (Chat Fied, 1979) shows that the correlation between applied pressure and density was significant at the 5% level for all the results obtained. The effect of applied pressure on density can therefore be explained at different sludge proportions for the two varieties of sawdust used.

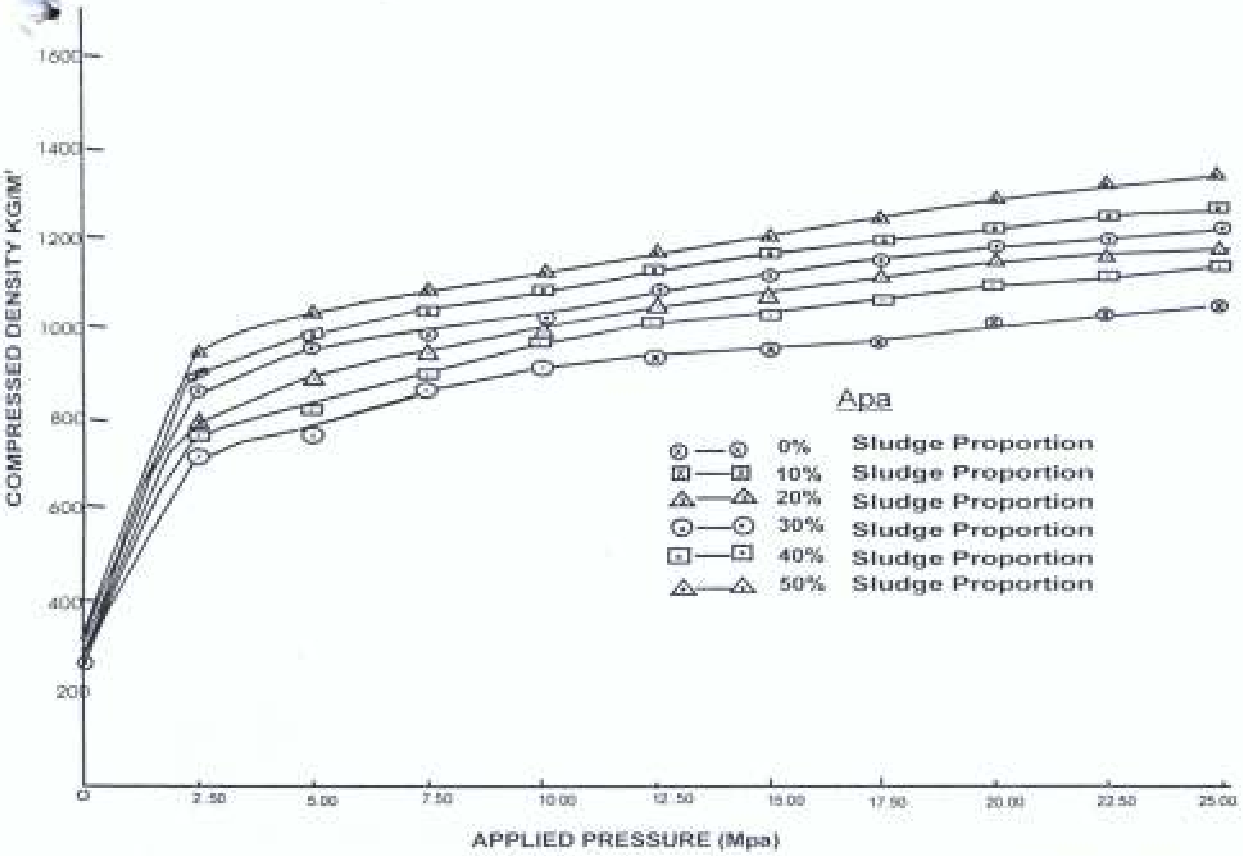


Fig 4.1 Effect of Applied pressure on compressed density of the briquette at different sludge proportion.

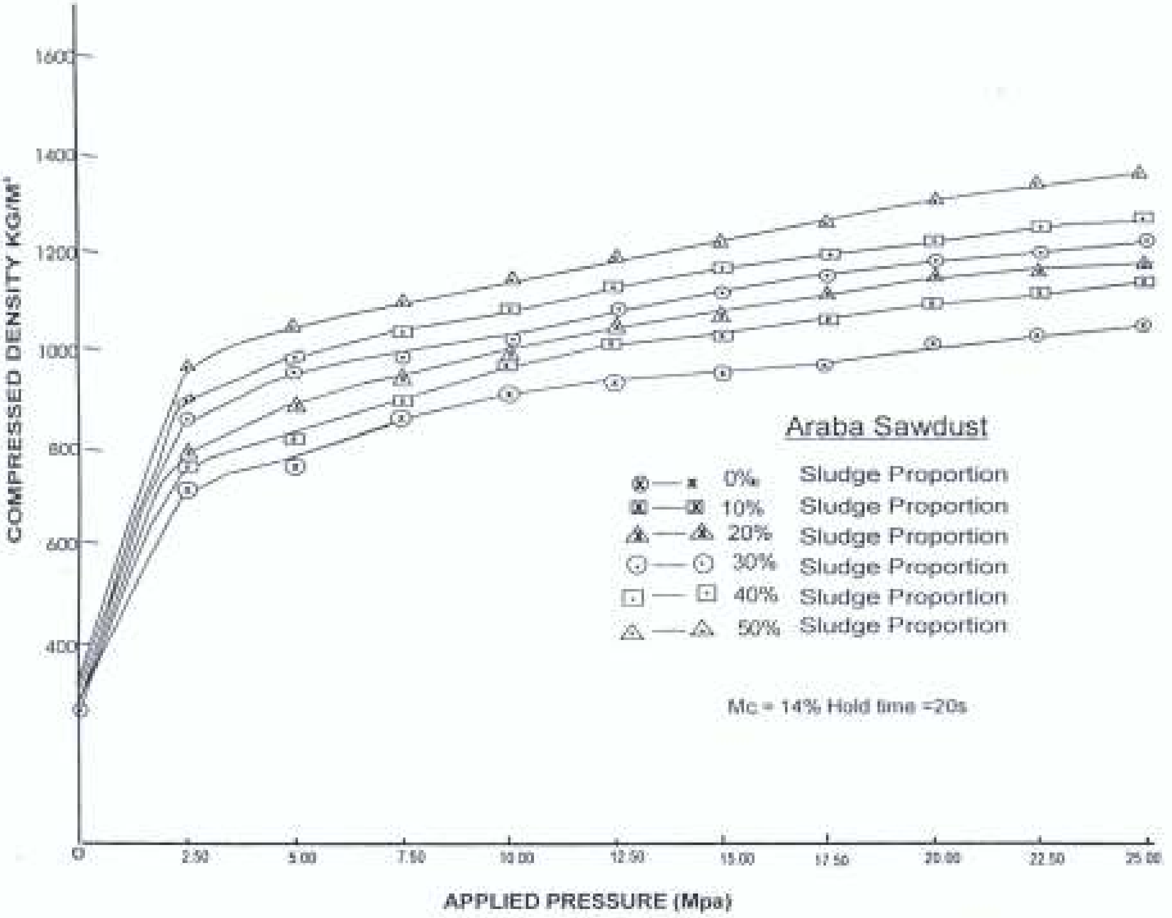


Fig 4.2 Effect of Applied pressure on compressed density of the briquette at different sludge proportion.

Table 4.1 Effect of applied pressure on compressed density of the material at different sludge proportion, M.c. = 10.4% w.b. Hold time = 20s.

Material	% sludge	Parameters	0	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00
Apa	0	Comp. Density kg/m^3	235.46	730.56	764.86	825	944.23	908.39	966.26	978.19	10.12.87	1054.94	1085.54
		Compression Ratio		3.10	3.25	3.58	3.67	3.89	4.10	4.1	4.30	4.48	4.61
Sawdust mixture	10	Compressed density kg/m^3		772.41	813.69	845.37	946.55	1002.63	1026.74	1077.31	1081.25	1099.42	1109.28
		Compression Ratio	240.36	3.21	3.38	3.52	3.94	4.17	4.27	4.48	4.50	4.57	4.61
	20	Compressed density kg/m^3	242.51	788.29	669.42	915.26	959.30	1021.43	1014.89	1062.51	1078.13	1104.21	1150.33
		Compression Ratio		3.25	3.58	3.77	3.99	4.21	4.31	4.38	4.45	4.55	4.78
	30	Compressed density kg/m^3	235.44	860.41	900.04	972.39	999.34	1032.46	1085.49	1112.32	1132.49	1168.73	1206.39
		Compression Ratio		3.65	3.82	4.13	4.24	4.38	4.61	4.72	4.81	4.96	5.12
	40	Compressed density kg/m^3	243.89	948.46	989.36	1059.79	1076.34	1155.89	1163.27	1174.92	1204.72	1240.36	1256.78
		Compression Ratio		3.69	4.06	4.34	4.41	4.74	4.77	4.83	4.94	5.09	5.15
	50	Compressed density kg/m^3	255.46	984.33	1041.42	1069.21	1136.46	1170.79	1198.83	[illegible]	1271.49	1282.41	1299.93
		Compression Ratio		3.85	4.07	4.26	4.44	4.58	4.69	4.90	4.98	5.02	5.09
Araba	0 -	Compressed density kg/m^3	- 94.56	746.13	782.49	855.41	894.21	961.29	968.80	1022.54	1053.99	1084.81	1096.34
		Compression Ratio		7.89	8.27	9.06	9.46	10.12	10.24	10.81	11.14	11.44	11.59
	10	Compressed density kg/m^3	105.13	798.96	839.41	898.26	950.66	1010.34	1036.96	1059.89	1078.44	1110.72	1152.88
		Compression Ratio		7.60	7.98	8.54	9.04	9.61	9.66	10.08	10.25	10.56	10.97
Sawdust mixture	20	Compressed density kg/m^3		802.94	858.61	919.73	958.81	1022.66	1045.16	1068.19	1132.52	1163.18	1192.73
		Compression Ratio	112.77	7.12	7.61	8.15	8.50	9.06	9.26	9.47	10.04	1031	10.58
	30	Compressed density kg/m^3	126.04	836.55	922.15	1008.47	1048.61	1062.41	1110.64	[illegible]	1198.10	1207.41	1232.16
		Compression Ratio		6.64	7.36	8.00	8.32	8.59	8.81	[illegible]	9.51	9.56	9.78
	40	Compressed density kg/m^3	137.15	909.44	978.56	[illegible]	1064.23	1143.84	1161.59	[illegible]	1233.46	1259.11	1281.27
		Compression Ratio		6.88	7.40	7.64	8.06	8.66	8.79	[illegible]	9.30	9.53	9.70
	50	Compressed density kg/m^3	141.62	1019.89	1095.46	[illegible]	1198.74	1240.66	1276.10	[illegible]	1298.31	1310.22	1331.48
		Compression Ratio		6.56	7.37	[illegible]	8.09	8.35	8.59	[illegible]	8.74	8.82	8.96

Table 4.2 Result of regression Analysis on the pressure density relationship at different sludge proportion for Araba and Apa briquette.

Sample	Palm oil sludge	Estimated coefficients regression		Correlation
	Proportion %	A	B	coefficients
	0	0.037	1.440	0.97
	10	0.020	1.566	0.97
	20	0.016	1.550	0.97
Apa	30	0.014	1,460	0.97
	40.	0.005	1.635	0.98
	50	0.004	1.654	0.98
	0	0.034	0.573	0.98
	10	0.020	0.640	0.98
	20	0.035	0.612	0.98
Araba	30	0.017	0.723	0.99
	40	0.013	0.780	0.98
	50	0.001	0.100	0.99

4.2. Effects of varying Palm-oil sludge (Binder) on the Briquette Quality

4.2.1 Densities

Fig: 4.3 Indicates that the compressed density of the briquettes increased with increasing binder proportions in the mix at constant pressure. This may be due to the effect of the sludge/sawdust ratio (sludge has a higher bulk density than sawdust), and the ease of compressibility of the mix. The latter results to variations in the thickness of the briquette in the die. The compressed density of Apa briquette was found to be lower than that of Araba at the same sludge proportion. This is as a result of the fact that Apa sawdust has a higher bulk density than Araba. Hence, Araba sawdust has a greater compressibility for the same mass of sawdust to attain the form of briquette.

Fig(4.4) shows that the relaxed density of the briquette was found to increase with increasing binder proportions for the two types of sawdust. Figs 4.3 and 4.4. show that the relaxed density for the briquette was lower than the compressed density for the same binder proportion. Similar observation was made by Aqa (1990) in briquetting of fibrous agricultural materials like straw and forage. The reduction in density is an indication of considerable elastic recovery and stress relaxation process that took place after the removal of the briquette from the die to attain its final and stable dimension. This was also noted in the works of Faborode and O' Callaghan, (1986). The values of relaxed density obtained for briquettes of Apa were consistently higher than those of Araba at each level of binder proportion used. The Apa sawdust mixture is less elastic in recovery than Araba

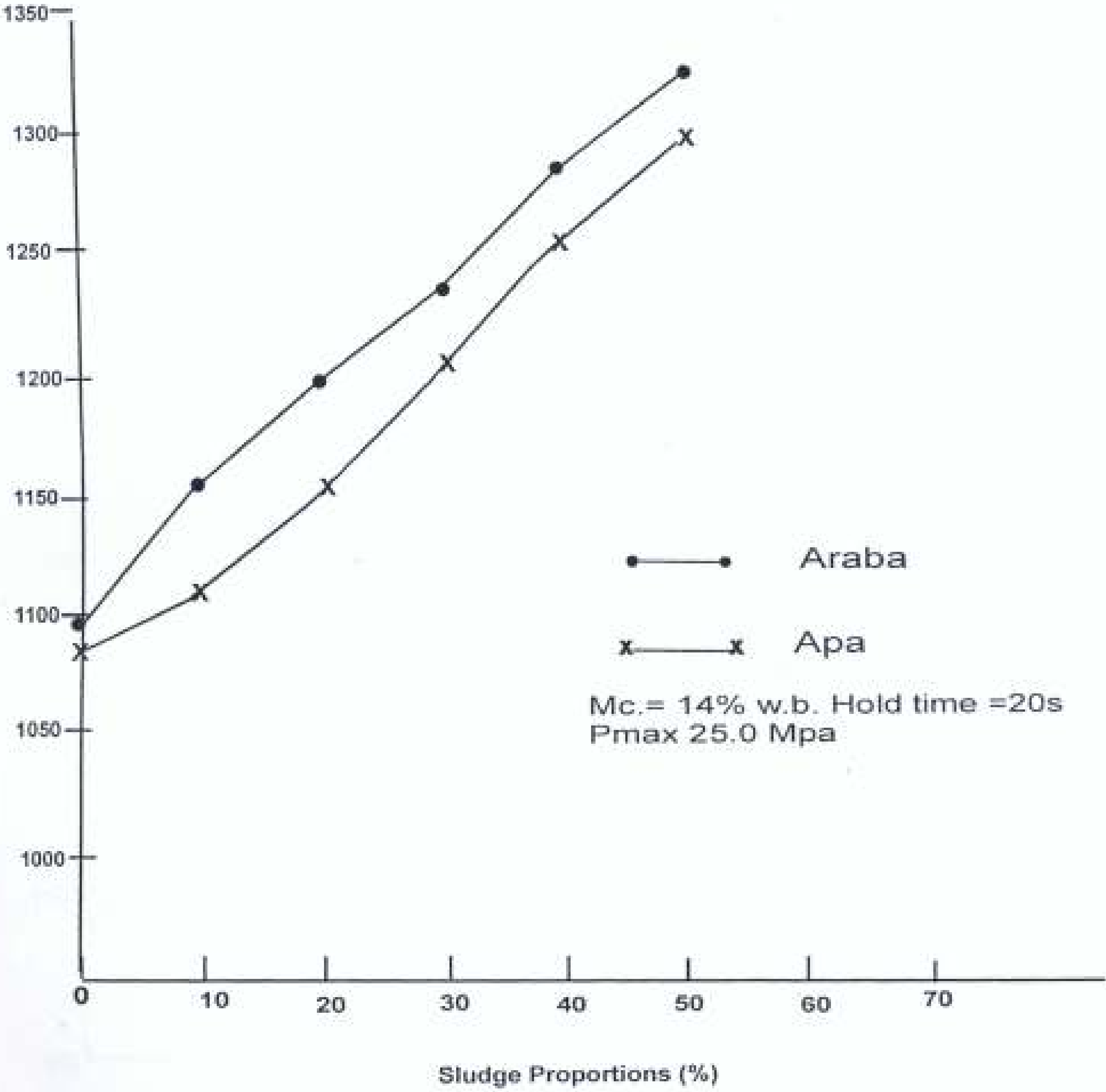


Fig. 4.3. Effect of sludge proportion on compressed density of briquette

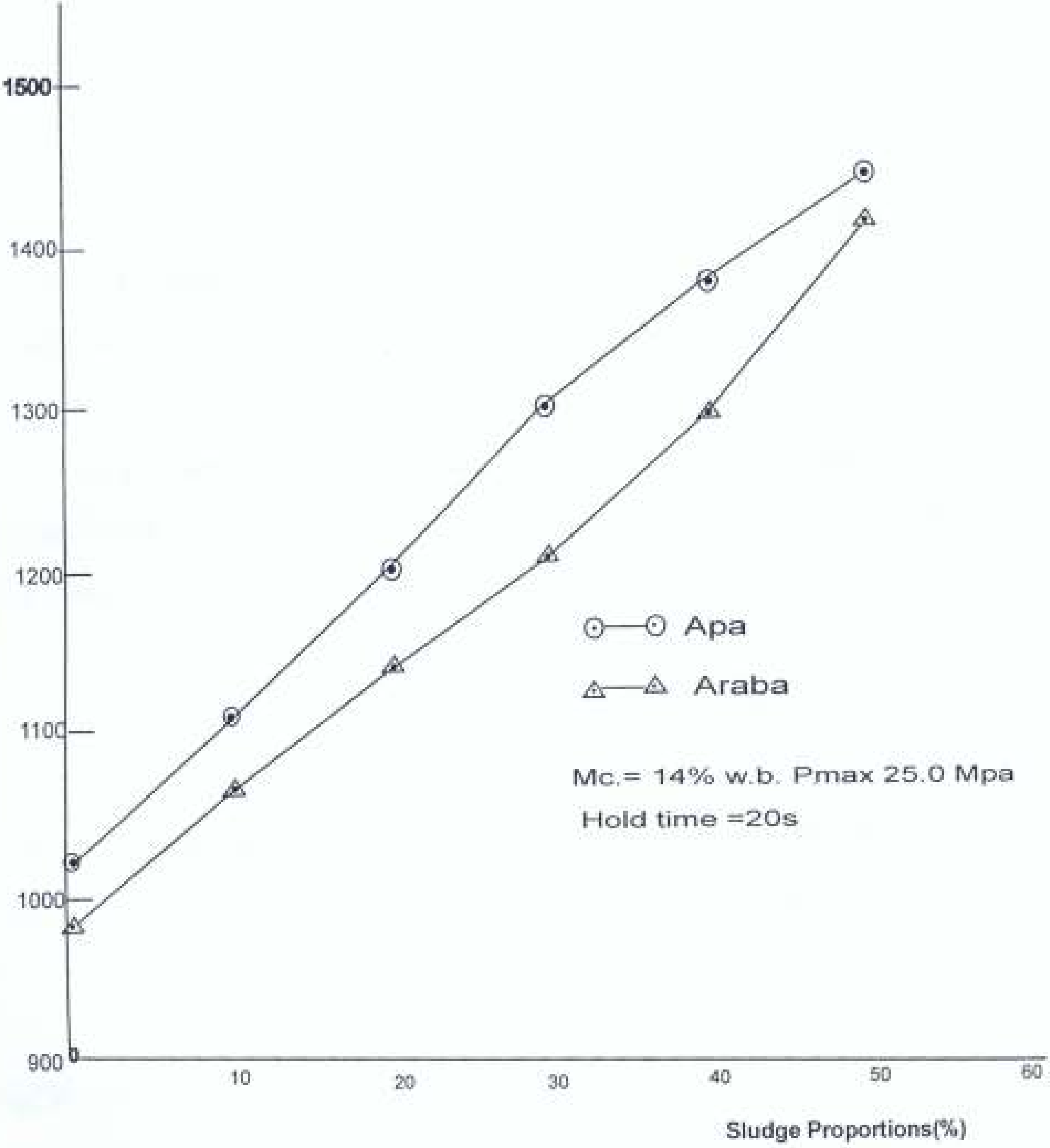


Fig: 4.4 Effect of sludge proportion on relaxed density of the briquette

4.2.2 Dimensional Changes

From the results of Table 4.5, it was observed that the length change of the briquette increased with increasing sludge proportion up to 10% and then decreased with further increase is sludge proportion for the two types of sawdust. This shows that as the binder proportions gets higher than 10% there were decrease in residual stress of the sludge and the subsequent change in length. Because Araba sawdust is more elastic in recovery than Apa the axial expansion of Araba briquette was more than that of Apa for the same binder level.

Table 4.3 shows that the radial change of the briquettes for both Araba and Apa briquettes was in the same range 1.6-3.0% for all levels of sludge proportion. Though the radial change increased with increasing sludge proportions, the range of radial change for Araba briquette (1.7-3.0%) and for Apa briquette (1.6-2.3%) which is 66-87 for Araba briquette and 47-65% for Apa briquette. The change in radial dimension was therefore negligible.

Table 4.3 Radial expansions (%) of Araba and Apa Briquettes at different sludge proportion after 2 weeks pressure 25.0 Mpa. Moisture content 14% w.b hold time= 20 sec.

	Sludge proportion (%)					
Type of briquette	0	10	20	30	40	50
Araba	1.7	1.8	2.0	2.3	2.5	3.0
Apa	1.6	1.8	1.9	2.1	2.1	2.3

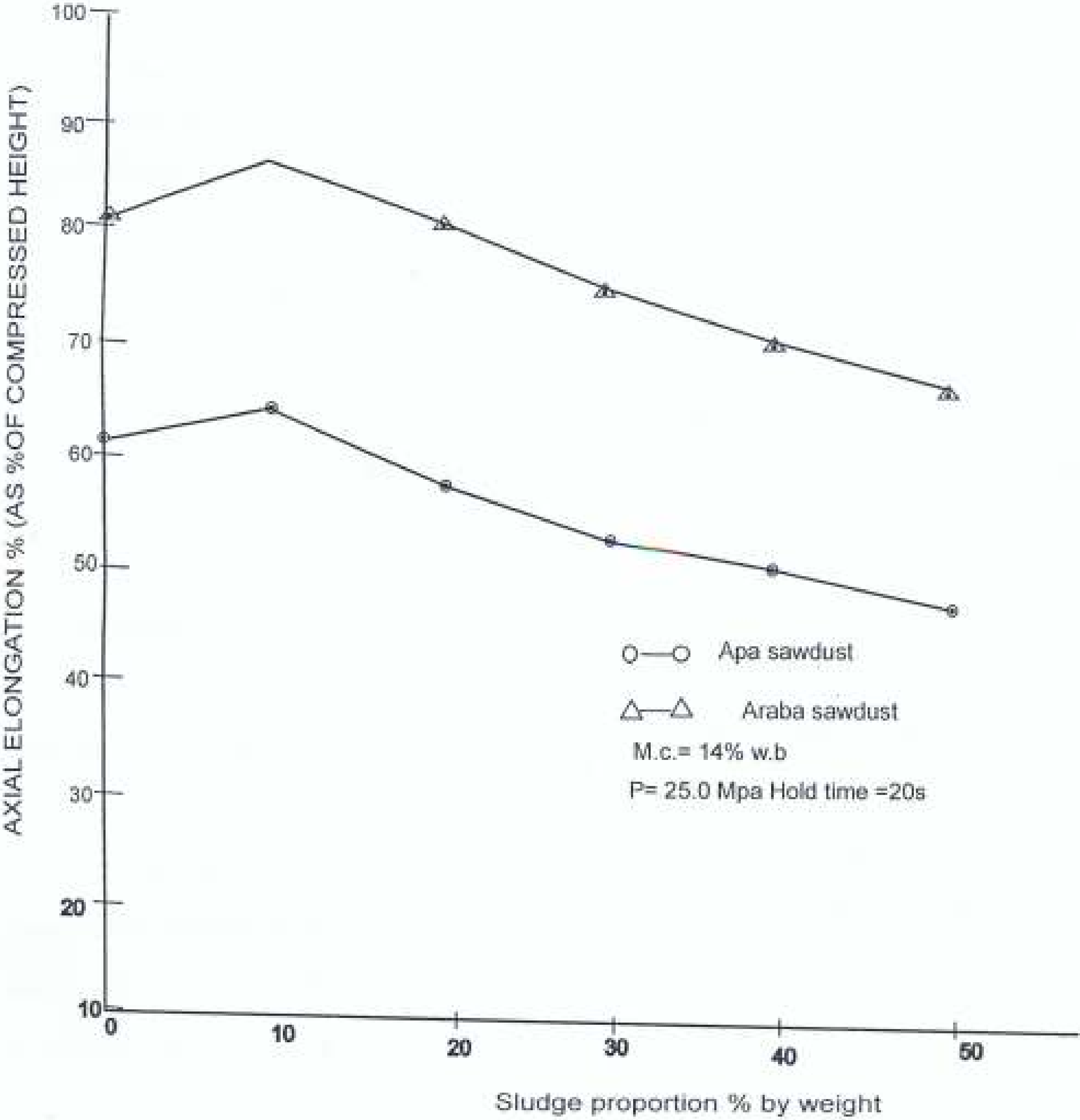


Fig 4.5. Axial elongation of the briquette at different sludge proportion

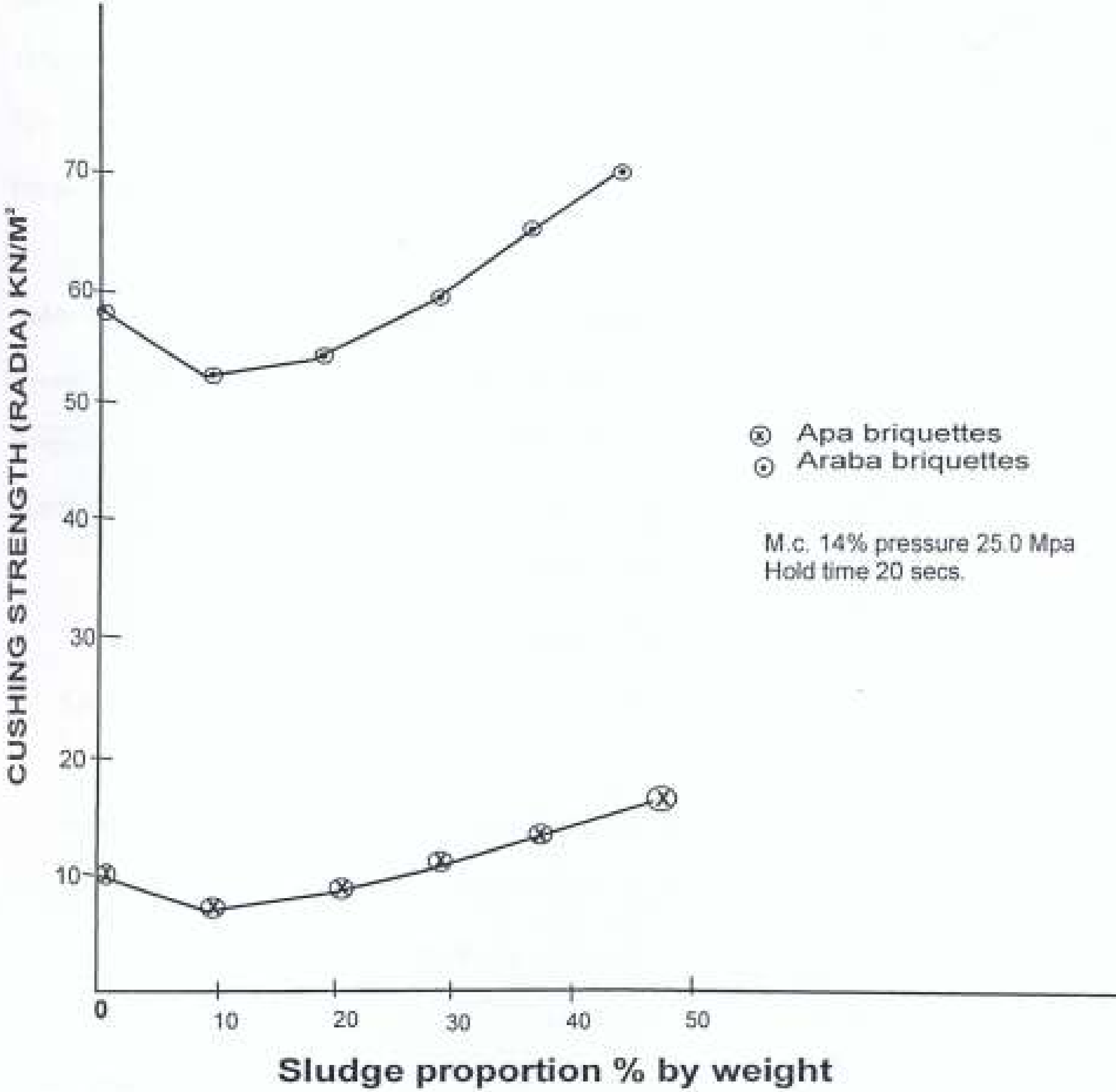
A similar result was obtained by Smith et al, (1977) in experiments with wheat straw.

Table 4.4 Result of relative change in length of briquettes at varying sludge proportion and time of immersion at pressure 25.0 Mpa, Hod time 20sec., MC = 14% w.b.

Briquette sample	Time of immersion in water (min).	Sludge proportion %					
		0	10	20	30	40	50
	5	2.54	2.14	1.73	1.61	1.42	1.39
Araba	10	2.60	2.20	1.82	1.70	1.53	1.46
	15	2.62	2.36	1.90	1.72	1.57	1.58
	5	0.92	0.88	0.76	0.60	056	0.49
Apa	10	0.89	0.86	0.78	0.72	0.59	0.46
	15	0.78	0.72	0.69	0.66	0.63	0.47

4.3.4 Hygroscopic Properties

When briquette samples were immersed in water, they absorbed water, swelled and elongated. As the sludge proportions increased, it was observed that the rate of change in length of briquettes over time in water was found to decrease.(Table 4.4). This may be as a result of the binding force between the sludge and sawdust mixture as the sludge proportion increased thus making it difficult to break the bond. Also, another possible explanation is that the oil contents of the sludge retards the absorption of water by the briquette (oil has low miscibility in water). For the same binder proportion it was observed that the Araba briquettes absorbed more water than those from Apa.



M.c. 14% pressure 25.0 Mpa
Hold time 20 secs.

Fig. 4.6 Effect of varying sludge proportion on the radial crushing strength of the briquet

4.2.4 Crushing Strength

Fig 4.6. Shows that the crushing strength measured along the radial axis initially decreased with increasing sludge proportions up to 10% by weight and later increased with further increase in sludge proportion. The increase in crushing strength at binder level above 10% may be due to the sludge behaving as an adhesive joining the sawdust particles together. The crushing strength of Araba briquettes was found to be higher than that of Apa for the same binder proportion this may likely be due to the difference in sawdust surface properties.

Table 4.5 Results of handling durability % of Briquettes at varying sludge proportion: Pressure 25.0mpa. M.c. 14% w.b. Ho,d time 20 secs.

Briquette Sample	No of Drop	Sludge Proportion %by weight 0	10	20	30	40	50
Apa	1	0	0	0	97.24	98.46	99.64
	2	0	0	0	60.00	98.46	99.64
	3	0	0	0	0	59.88	99.26
Araba	1	94.42	98.10	99.26	99.63	99.74	99.82
	2	98.21	99.04	99.23	99.46	99.68	99.92
	3	97.41	98.22	98.44	98.86	99.14	99.25

4.2.5 Handling Durability

From Table 4.5, it was observed that at the sludge proportion greater than 20% the handling durability increased slightly. This may be due to the sludge acting as adhesive. Araba briquette was found to have a higher handling durability than Apa briquette at the same sludge proportion.

Table 4.6 Relative weight loss of Briquette at different Sludge Proportion during Combustion (m.c 14% w.b. hold time 20s, pressure 25.0mpa)

Sludge prop. % by weight		0	10	20	30	40	50
Relative weight loss for apa at	T_1 = 5min	0.65	0.58	0.47	0.36	0.32	0.29
	T_2 = 10min	0.80	0.84	0.79	0.72	0.68	0.59
	T_3 = 15min	0.88	0.82	0.78	0.71	0.67	0.65
Relatives wt. loss for Araba	T_1 = 5min	0.60	0.55	0.49	0.41	0.36	0.28
	T_2 = 10min	0.79	0.72	0.66	0.59	0.52	0.48
	T_3 = 15min	0.86	0.81	0.74	0.69	0.61	0.58

4.2.6 Combustion Characteristics

Table 4.6 shows that the relative weight loss of briquette sample with time during burning decreased with increasing binder proportions. This may be due to increasing binding force between sawdust particles as the sludge proportion increases. This may not make the combustible material in the briquette sample readily available for combustion. The more the binder, the more the compaction, and the slower the burning.

The relative weight loss for Araba briquette during burning was also observed to be lower than that of Apa briquette for the same sludge proportion. This is due to the fact that the binding force in Araba briquette is greater than that of Apa for the same binder proportion.

Also, table 4.6 reveal that there was a rapid rate of weight loss at the first 10 minutes of burning, followed by a lower rate of weight loss.

Table 4.7 .Effect of Pressure on the Handling Durability of Briquetes at different Sludge Proportion (Araba) (m.c.)= 14%, hold time 20sec

Sludge proportion % by weight	Percentage of weight remaining on sieve after 7 drops from a 2m height		
	P_1 = 21.20MPa	P_2 = 16.90MPa	P_3 = 12.72 Mpa
0	84.67	64.29	48.66
10	81.42	60.18	44.46
20	85.53	61.26	41.65
30	87.64	68.44	49.84
40	89.15	70.67	51.77
50	90.92	75.83	60.82

4.2.7 Handling Durability and Pressure

Table 4.7 reveals that as the binder proportion increases the weight of briquettes remaining on the sieve increases. Also, as the pressure decreases the weight of briquette remaining on the sieve decreases. This implies that as pressure increases the handling durability also increases for the same binder proportion.

Table 4.8 Effect of Moisture Content on Briquette Quality at pressure 25.0Mpa Hold time 20s.

Sludge proportion % weight		0	10	20	30	40	50
Av. Relaxed density Kg/m^3	M_1	548.24	571.35	617.61	652.73	728.92	789.33
	M_2	550.98	619.37	652.44	691.57	758.34	822.76
	M_3	582.12	614.49	648.36	680.93	758.34	822.76
Av. Axial Elongation %	M_1	78.6B	83.47	75.66	72.19	65.78	63.29
	M_2	85.51	91.36	87.45	81.32	74.43	62.64
	M_3	98.27	99.26	94.19	86.72	79.57	71.22
% Handling durability after 7 drops from 2m height	M_1	84.49	81.37	83.42	86.11	88.36	90.04
	M_2	86.31	84.29	86.93	89.45	93.24	94.85
	M_3	85.69	83.12	85.76	86.97	89.57	92.13

M_1 = moisture content 10.1% w.b.

M_2 = Moisture content 14% w.b.

M_3 =Moisture content 17.8% w.b.

4.3 Moisture Content and Briquette Quality

From the table 4.8 it was observed that the relaxed density and handling durability were found to increase with increase moisture content from 10.1. 14.% and to decrease slightly with increasing moisture content from 14-17.8% at a given binder proportion. The decrease in relaxed density and handling durability beyond 14% moisture content may be due to excess moisture which now occupies volume that would otherwise be occupied by the materials thus resulting in higher residual stress. This was noted in the works of Faborode and O' Callaghan (1987).

With increasing moisture content from 10-17% w.b. it was noted that the relative rate of weight loss of briquette during combustion at a given binder proportion decreased slightly (Table 4.9).

Table 4.9 Effect of pressure on relative weight loss of Briquettes during combustion at different time MC = 10.% w.b. hold time 20s.

Sludge prop. % by weight	Time of rel. wt. loss of Briquette	P_1 25.0.Mpa	P_2=18.7 Mpa	P_3= 13.5Mpa
0	T_1	0.621	0.663	0.682
	T_2	0.840	0.871	0.893
	T_3	0.924	0.965	0.966
10	T_1	0.560	0.583	0.588
	T_2	0.788	0.829	0.850
	T_3	0.904	0.926	0.933
20	T_1	0.456	0.492	0.537
	T_2	0.687	0.741	0.811
	T_3	0.846	0.892	0.914
30	T_1	0.400	0.459	0.502
	T_2	0.621	0.667	0.698
	T_3	0.793	0.852	0.877
40	T_1	0.364	0.428	0.476
	T_2	0.604	0.635	0.672
	T_3	0.793	0.816	0.835
50	T_1	0.333	0.291	0.424
	T_2	0.569	0.622	0.648
	T_3	0.748	0.759	0.801

T_1 = 5mins T_2 10mins T_3 mins

Table 4.10 Effect of moisture content on relative weight loss of briquette during combustion pressure 25.0MPa hold time 20s.

Sludge prop. % by weight	Time of combustion (min)	Relative weight loss of Briquette		
		M_1 = 10.1%	M_2 = 14%	M_3 = 17.8%
0	5	0.621	0.576	0.532
	10	0.810	0.771	0.754
	15	0.885	0.855	0.845
10	5	0.590	0.565	0.547
	10	0.760	0.742	0.728
	15	0.880	0.867	0.851
20	5	0.514	0.456	0.443
	10	0.689	0.672	0.668
	15	0.810	0.790	0.765
30	5	0.424	0.325	0.314
	10	0.610	0.596	0.564
	15	0.799	0.738	0.719
40	5	0.384	0.305	0.295
	10	0.590	0.575	0.562
	15	0.785	0.753	0.749
50	5	0.340	0.262	0.258
	10	0.576	0.564	0.552
	15	0.792	0.175	0.704

5. CONCLUSION

From the results, the optimum proportion of palm oil sludge as binder in the production of sawdust briquettes was established. The study also showed that palm oil sludge is a good binder in the production of sawdust briquettes which could be used as solid fuel. Also, from the results of this study the following conclusions are made. A linear relationship was established between pressure and density at varying proportion of palm oil sludge in the mix for the two types of sawdust (Araba and Apa).

Increasing the binder proportion above 20% an increase in applied pressure increased the handling durability and decrease axial elongation of the briquettes. Increasing the applied pressure from 13.5 to 25.0 MPa increased the relaxed density and decreased the relative weight loss of briquette during combustion.

From the study. The processing and material parameters such as applied pressure, moisture content, hold time and temperature were established. Considering the limits of the conditions considered in this study, the establishment of the optimum proportion of palm oil sludge was established of the optimum proportion of palm oil sludge was established to be not less than 30% by weight, hold time of 20s, applied pressure of 25.0MPa and material moisture content of 14% w.b.

AREAS OF FURTHER RESEARCH

Although, the optimum proportion of palm oil sludge as binder in the production of sawdust briquettes has been established; further research work is still required on the effects of fibre orientation in the sludge on the binding process of palm oil sludge.

REFERENCES

Abd- Elrahim, Y.M. Huzayyinm A.S., and Taha, I.S. (1981) Dimensional analysis and wafering Cotton stalks, Transaction of the American society of Agricultural Engineers Michigan, 24, (4) 829-832.

Adegoke, C.O. and Kuti, O.A. (2004) Investigation of composite sawdust briquettes and charred Palm Kernel shall as a source of fuel for domestic cooking. International Journal of Engineering and engineering Technology, Federal University of Technology, Akure, Nigeria. 4 (2) 144-150.

Anon (1980) Energy in Developing Countries, the world Bank, 20p.

Anon (1987) Improved wood wastes and charcoal burning stoves. A practical manual. Intermediate technology publications, convent garden, London U.K.

Aqa, S. and Bhattacharya, S. C., 1992, Densification of Preheated Sawdust for Energy Conservation,

Aqa, S., 1990, A Study of Densification of Pre-heated Sawdust, Masters Thesis No. ET-90-4, Asian

Arends, G.J. and Donker/rot-shoug, S.S. (1985) An overview of possible uses of sawdust. Amsterd, Tool Foundation, 60p.

ASAE, (1983) Methods of determining and expressing the fineness of feed materials by sieving ASAE standard: ASAE S 319 Agricultural Engineers 'year Book.

ASAE, (1983b): Moisture measurement- Peanuts. ASAE, standard: ASAE 410 Agricultural Engineer's Handbook. Published by American Society of Agricultural Engineers, P. 325-327

Asiedu, J.J. (1989) : Processing Tropical Crops Macmillan Press London BEST, December. Biomass 3, pp. 1064-1068, Elsevier, London. Briquette Papyrus Through Partial Pyrolytic Conversion, Biomass Energy Services and Technology,

Carre, J. Herbert, J. and lacrosse (1984), Critical analysis of the dry process improvement of Ligneous material for energy producing purpose, report submitted to ministers

Belge de L' Agricultural centre de recherches Agronomiques de L'etat (CRA), station de Technologies foresteere, Gemblour, 677P.

Cote, W.I. (1982): Biomass utilization, ASI Plenum A67, NATO ASI series A: Life Science, Vol 67 P. 58-66.

Faborode, M.O, (1988), Rural domestic and agro industrial energy from biomaterials, Presented at CIGR inter-section symposium at Ilorin, Nigeria 5- 10 Dept, 13p.

Faborode, M.O. and O' Callaghan, J.R. (1986): Theoretical analysis of the compression of fibrous agricultural materials, Journal, of Agricultural Engineering Research, London 35, (3): 175-192.

Faborode, M.O. and O' Collagen, J.B. (1987): Optimizing the compression/Briquetting of fibrous Agricultural materials Journal of Agricultural Engineering research London, 38, (4) 242-260

Field Document no. 46, Food and Agricultural Organization of the United Nations, Bangkok, 1996.

Grover, P.D. and Mishra, S.K., 1996, Biomass Briquetting: Technology and Practices; RWEDP

Joseph, S., Hislop, D. and Errey, S., 1985, The Development of a Energy Production System, Forestry and Biomass Panel Forum, 33 – 40p.

Magowan, T.J. and O' Callaghan, J.R. (1987): The Effect of Density and Heat Treatment on the Combustion Characteristics of Pelleted Agricultural Residues. Intermediate Technology and Development Group (I.T.D.G.), Forestry and Biomass Panel Forum Meeting, 27-28 November, 20p.

Mc Arthur, D.S. (1981): Baggase Compaction, University of Queensland, Department of Mechanical Engineering Queenland 16pp.

Mishra, S. K., 1996, Hardfacing of Screw for Wear Resistance, Proceedings of the International

Nason, D. (1987): The compaction of partially dried Lucerne, Journal of Agricultural Engineering Research, London, 37, 70-79.

O' Doherty, M.J. and Wheeler, J.A. (1984): Compression of Straw to High Densities in Closed Cylindrical Dies, Journal of Agric. Engineering Research, London, 28, 61-72.

Pant, M.M. (1981): Wood to Alleviate Indian Energy Crisis, The Indian Forester. 107, (12) 790-805.

Probstein R.F. and Hicks R.E. (1982) Synthetic fuels Mc Graw-Hill Inc. USA.

Smith, M.J. (1985): Soil Mechanics, fourth Edition, London, Godwin, P. 80-90.

Veziroghu, N.T. (1981). Alternative Energy Sources 9 Volumes, Clean Energy Research Institute, Univeristy of Miamil Coral Cables, Florida U.S.A.Hemisphere publishing corporation pp. 9.

APPENDIX A.1

Determination of the sludge proportion by weight

$$\% \text{ of sludge proportion} = \frac{\text{weight of sludge}}{\text{Weight of sludge} + \text{Weight of sawdust mixture}} \text{ X } 100$$

$$\frac{P}{100} = P^1 = \frac{x}{x+20}$$

$$p^1 = \frac{X}{x+20}$$

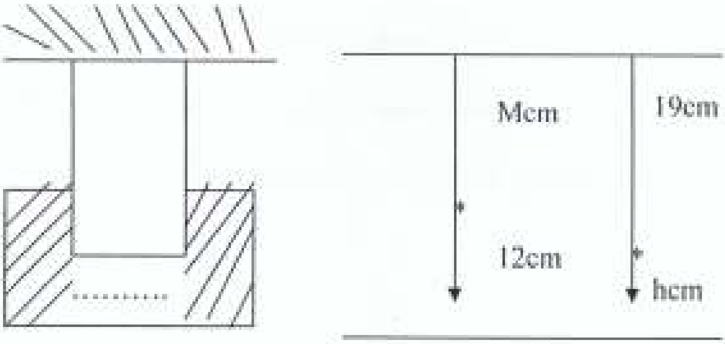
$$x = \frac{20P^1}{1-p^1}$$

Where x = weight of sludge (gm)

p^1 = % of sludge in the sample.

Appendix A.2

Determination of compressed density and compressed pressure.



i. Determination of Density (compressed)

compressed height of the briquette = h

$$=12-(19-m)=m-7\text{cm}$$

Diameter of the die d=5.00cm

Height of the cylinder = 12.00cm

area of the die = $\pi d^2 = 1.963 \times 10^{-3} m^2$

Volume of the compressed material = $1.963h \times 10^{-5}\ m^3$

Compressed density of the briquette

$$(kg/m^3) = \frac{m \times 10^2}{1.963h}$$

Where m =mass of the compressed material (gm)

h=compressed height of briquette (cm)

ii. Determination of pressure applied to the material in the cylinder

Force from the ram =PA_r

Where P= Gauge pressure reading on the instrument.

Ar = cross –sectional area of the ram,

Given as $1.872\ in^2$

F= F ram =P_A x A cylinder

PA= F/A = Px1.872x4.44822

Cylinder 1.96349×10^{-3}

$P = 4.241.P \times 10^{-3}\ N/m^2 = 4.241P\ kN/m^2$

Where P_A = pressure applied to the material in the cylinder

F= force transmitted from the ram to the material in the cylinder

APPENDIX A.3

Determination of particle size distribution Apa sawdust

Assigned N0	7	6	5	4	3	2	1	0
Sieve No	-	4	8	16	30	50	100	
Sieve opening (mm)	-	-	2.36	1.18	0.60	0.30	0.15	PAN
Average of sample Retained %	-	-	0.34	5.85	38.10	34.42	14.22	5.07
Sieve mesh No								
Grade	Coarse			medium		Fine		
Total % of sample Retained	0.34			43.95		55.71		
Dividing by 10	0.034			4.395		5.571		
Uniformity index	0.03			4.40		5.57		
% retained x Assigned number	-	-	1.70	23.40	114.30	72.84	14.22	

Fineness modulus = $\frac{226.46}{100}$ = 2.27

Uniformity index = 0.03 : 4.4. 5.57

Mean particle size = 0.44

APPENDIX 3 CONTD.

Determination of the particle size distribution

Araba sawdust

Assigned no	7	6	5	4	3	2	1	0
Sieve no.	-	4	8	16	30	50	100	
Sieve opening(mm)	-	-	2.36	1.18	0.60	0.30	0.15	PAN
Average of samples								
Retained %	-	-	0.92	12.34	39.74	25.89	14.56	6.55

SIEVE MESH NO

GRADE	**COARSE**	**MEDIUM**	**FINE**
Total % of sample			
Retained	0.92	52.08	47.00
Dividing by 10	0.092	5.208	4.700
Uniformity index	0.09	5.21	4.70

% retained x Assigned no	4.60	49.36	119.22	51.78	14.56	0

Fineness modulus = $\frac{239.52}{100}$ 2.4

Uniformity index = 0.09 5:21 :4:70

Mean particle size = 0.52

APPENDIX A.4

Formula for significant test of correlation

$$\frac{r\sqrt{(n-2)}}{\sqrt{(1-r^2)}}\Bigg| > t_{\frac{\gamma}{2}}, \quad n-2$$

Where r = correlation coefficient

n =degrees of freedom

$^{\gamma}$ =5%

APPENDIX A.5

Measurements of the height of briquette during compression at different binder proportion (m.c. 14% w.b)
Apa Sawdust

Pressure (MP$_a$)	(MP$_a$)	0	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00
Sludge prop	No of Runs											
0	1	8.50	1.50	1.45	1.38	1.33	1.29	1.20	1.17	1.10	1.05	1.00
	2	8.86	1.45	1.48	1.40	1.36	1.28	1.20	1.15	1.12	1.05	1.00
	3	8.69	1.50	1.46	1.40	1.33	1.30	1.20	1.17	1.12	1.05	1.00
	Average	8.88	1.48	1.46	1.39	1.34	1.29	1.20	1.16	1.11	1.05	1.00
10	1	930	1.55	1.50	1.46	1.39	1.33	1.25	1.20	1.16	1.13	1.10
	2	935	1.55	1.52	1.46	1.40	1.35	1.25	1.22	1.16	1.12	1.14
	3	9.20	1.40	1.38	1.35	1.35	1.30	1.20	1.15	1.13	1.10	1.08
	Average	9.28	1.50	1.47	1.42	1.38	1.33	1.23	1.19	1.15	3.35	1.11
20	1	9.70	1.61	1.55	1.49	1.45	1.40	1.37	1.32	1.26	1.20	1.16
	2	9.65	1.58	1.55	1.45	1.42	1.37	1.35	1.30	1.23	1.16	1.14
	3	9.70	1..61	1.55	1.50	1.40	1.40	1.37	1.33	1.25	1.18	1.16
	average	9.68	1.60	1.55	1.48	1.42	1.39	4.09	1.32	1.25	1.18	1.15
30	1	10.10	1.67	1.60	1.56	1.48	1.42	1.35	1.30	1.24	1.22	1.19
	2	10.10	1.66	1.61	1.55	1.50	1.41	1.35	1.29	1.24	1.23	1.20
	3	10.00	1.64	1.60	1.53	1.47	1.40	1.32	1.27	1.22	1.19	1.18
	Average	10.6	1.65	1.60	1.55	1.48	1.41	1.34	1.29	1.23	1.21	1.18
40	1	10.65	1.75	1.70	1.64	1.58	1.54	1.47	1.40	1.36	1.31	1.26
	2	10.50	1.171	1.65	1.60	1.52	1.48	1.45	1.40	1.34	1.30	1.24
	3	10.60	1.73	1.70	1.64	1.56	1.53	1.49	1.41	1.35	1.32	1.27
	Average	10.58	1.73	1.68	1.63	1.55	1.52	1.47	1.40	1.35	1.31	1.26
50	1	11.20	1.86	1.81	1.75	1.68	1.61	1.56	1.48	1.45	1.40	1.34
	2	11.15	1.84	1.79	1.72	1.66	1.60	1.56	1.49	1.45	1.39	1.34
	3	11.10	1.82	1.79	1.70	1.67	1.62	1.55	1.46	1.42	1.38	1.32
	Average	11.15	1.84	1.80	172	1.67	1.61	1.56	1.48	1.44	1.39	1.33

APPENDIX A.5 CONTD.

MEASUREMENT OF THE HEIGHT OF BRIQUETTE DURING COMPRESSION AT DIFFERENT BINDER PROPORTION (M.C. 14% w.b.)

Araba Sawdust

Pressure (MPa)	(MP_a)	0	2.50	5.00	7.50	10.00	12.50	15.00	17.50	20.00	22.50	25.00
Sludge prop	No of Runs											
0	1	8.50	1.50	1.45	1.38	1.33	1.29	1,20	1.17	1.10	1.05	1.00
	2	8.86	1.45	1.48	1.40	1.36	1.28	1.20	1.15	1.12	1.05	1.00
	3	8.69	1.50	1.46	1.40	1.33	1.30	1.20	1.17	1.12	1.05	1.00
	Average	8.88	1.48	1.46	1.39	1.34	1.29	1.20	1.16	1.11	1.05	1.00
10	1	930	1.55	1.50	1.46	1.39	1.33	1.25	1.20	1.16	1.13	1.10
	2	935	1.55	1.52	1.46	1.40	1.35	1.25	1.22	1.16	1.12	1.14
	3	9.20	1.40	1.38	1.35	1.35	1.30	1.20	1.15	1.13	1.10	1.08
	Average	9.28	1.50	1.47	1.42	1.38	1.33	1.23	1.19	1.15	3.35	1.11
20	1	9.70	1.61	1.55	1.49	1.45	1.40	1.37	1.32	1.26	1.20	1.16
	2	9.65	1.58	1.55	1.45	1.42	1.37	1.35	1.30	1.23	1.16	1.14
	3	9.70	1..61	1.55	1.50	1.40	1.40	1.37	1.33	1.25	1.18	1.16
	average	9.68	1.60	1.55	1.48	1.42	1.39	4.09	1.32	1.25	1.18	1.15
30	1	10.10	1.67	1.60	1.56	1.48	1.42	1.35	1.30	1.24	1.22	1.19
	2	10.10	1.66	1.61	1.55	1.50	1.41	1.35	1.29	1.24	1.23	1.20
	3	10.00	1.64	1.60	1.53	1.47	1.40	1.32	1.27	1.22	1.19	1.18
	Average	10.6	1.65	1.60	1.55	1.48	1.41	1.34	1.29	1.23	1.21	1.18
40	1	10.65	1.75	1.70	1.64	1.58	1.54	1.47	1.40	1.36	1.31	1.26
	2	10.50	1.171	1.65	1.60	1.52	1.48	1.45	1.40	1.34	1.30	1.24
	3	10.60	1.73	1.70	1.64	1.56	1.53	1.49	1.41	1.35	1.32	1.27
	Average	10.58	1.73	1.68	1.63	1.55	1.52	1.47	1.40	1.35	1.31	1.26
50	1	11.20	1.86	1.81	1.75	1.68	1.61	1.56	1.48	1.45	1.40	1.34
	2	11.15	1.84	1.79	1.72	1.66	1.60	1.56	1.49	1.45	1.39	1.34
	3	11.10	1.82	1.79	1.70	1.67	1.62	1.55	1.46	1.42	1.38	1.32
	Average	11.15	1.84	1.80	172	1.67	1.61	1.56	1.48	1.44	1.39	1.33

APPENDIX A.6

ELAXED HEIGHT OF BRIQUEETTES AFTER 2 WEEKS EXPOSUE M.C. 14% w.b.
ressure = 25.0 Mpa, Hold time =20s

dust ple	Sludge proportion % by weight	0	10	20	30	40	50
ba	No of replicates	1.34	1.45	1.56	1.65	1.77	1.94
	1	1.36	1.44	1.55	1.65	1.76	1.93
		1.36	1.46	1.53	1.64	1.74	1.92
	2	1.35	1.44	1.56	1.66	1.75	1.92
	3	1.35	1.45	1.55	1.55	1.75	1.93
	4						
	Av. Relaxed height (cm)						
	No of relicates	1.47	1.50	1.63	1.75	1.82	1.88
	1	1.47	1.52	1.60	1.74	1.80	1.87
		1.45	1.54	1.64	1.74	1.81	1.87
	2	1.40	1.50	1.60	1.72	1.85	1.89
	3	1.45	1.52	1.62	1.74	182	1.88
	4						
	Av. Relaxed height (cm)						

APPENDIX A.7

RADIAL EXPANSION MEASUREMENTS OF THE BRIQUETTES AFTER 2 WEEKS EXPOSURE

Sudge proportions % by weight	0	10	20	30	40	50
average diameter of Araba briquette x 10^{-2}	6.100	6.110	6.115	6.120	6.135	6.150
average diameter of Apa briquette $^{-2}$ CM	6.01	6.095	6.015	6.01	6.02	6.02

APPENDIX A.8

WATER ABSORPTION CAPACITY OF BRIQUETTES

Sludge proportion % by weight	0	10	20	30	40	50
Av. Original height of Araba briquette x 10^{-2}m	1.31	1.39	1.48	1.59	1.75	1..97
Average change in height of Araba briquette with time in water x $_{10}{}^{-2}$m						
T_1= 5min	3.01	2.85	2.52	2.28	2.33	2.46
T_2= 10min	3.05	2.88	2.57	2.36	2.38	2.68
T_3= 15min	3.10	2.90	2.59	2.45	2.48	2.92
Av. Original height of Apa briquette in water x 10^{-2}m	2.05	2.28	2.35	2.46	2.63	2.84
Average change in height of Apa briquette in water X $10.^{-2}$m						
T_1= 5min	1.02	1.07	1.08	1.06	1.03	0.99
T_2=10min.	1.00	1.07	1.06	1.09	1.11	1.04
T_3=15min.	* *	* *	**	1.06	1.08	1.02

T1, T2, T3 = periods of immersion in water

* * * = material disintegrated

APPENDIX A.9

Results of radial crushing strength of briquettes (Araba and Apa) at various sludge proportions, pressure 25.0 Mpa, M.c. 14% w.b hold time 20s

Sludge proportion % by weight	0	10	20	30	40	50
CURVED SURFACE AREA OF Araba briquettes x 10^{-4}m	21.96	24.10	25.24	26.75	27.96	29.65
Av. Axial load dial reading (Division) Araba	62.0	64.0	66.0	81.0	102.0	118.0
Curved surface area of Apa briquette x 10^{-4}m . Av. Axial load reading (div.) Apa	11.0	12.0	14.0	16.5	20.5	2.80

All readings are average of three runs.

APPENDIX A.10

Results of varying sludge proportion on the ash content of the briquette (Apa and Araba

P=25.0MPa m.c. 14% w.b. Hold time 20s

Sludge proportion % by weight			Weight of crucide (9)	Weight of crucible x content before ashing	Wt. of crucible x content after ashing
Araba					
	0	1	30	40.75	30.76
	0	2	32.84	43.54	33.49
	10	1	27.56	48.21	28.23
	10	2	25.38	46.49	25.99
	20	1	38.22	55.32	38.94
		2	45.64	56.57	46.51
	30	1	35.62	54.22	36.02
		2	44.45	69.84	47.21
	40	1	34.38	59.86	35.99
		2	47.25	72.75	48.45
	50	1	34.38	69.14	40.88
		2	46.22	76.57	48.45
Apa	0	1	39.56	43.61	39.72
		2	47.45	45.83	47.83
	10	1	48.44	63.64	48.61
		2	27.89	4301	28.15
	20	1	43.72	62.27	44.12
		2	25.86	44.10	26.27
	30	1	46.51	68.72	47.28
		2	44.23	45.66	44.96
	40	1	38.41	64.26	40.76
		2	27.92	53.48	29.84
	50	1	47.27	78.31	49.52
		2	43.52	73.56	45.83

APPENDIX A.11

Results of change in wt. of briquette at different sludge proportions during combustion

Sample	Sludge proportion % by weight	No of runs	Initial Wt of briquette (9)	Loss in weight of briquette at the combustion time . T (min) T_1=5 T^2=10 T_3=15		
	0	1	19.78	11.07	16.65	17.04
			19.56	10.82	16.02	16.71
	10	2	22.06	10.96	17.22	18.55
			22.02	10.80	17.10	18.04
	20	1	25.66	9.98	19.62	21.10
		2	25.50	9.32	1930	20.98
	30	1	29.20	9.45	20.02	24.26
		2	29.00	9.32	19.89	24.01
	40	1	34.75	9.36	20.96	25.23
		2	34.46	9.28	20.54	24.97
	50	1	39.56	9.86	21.42	26.65
		2	39.50	9.82	21.19	26.42
Araba	0	1	19.56	9.84	14.96	17.90
		2	19.45	9.61	14.72	17.68
	10	1	21.46	10.92	15.08	18.75
		2	21.54	10.98	15.16	18.96
	20	1	23.50	9.25	14.48	20.06
		2	23.45	9.00	14.12	22.23
	30	1	28.68	13.64	18.15	24.60
		2	28.56	13.21	18.46	24.24
	40	1	34.28	13.74	18.98	24.78
		2	34.38	13.50	18.75	24.96
	50	1	39.34	13.98	19.01	25.20
		2	39.36	13.65	19.25	25.45

APPENDIX 12

Results of varying pressure on the compressed and relaxed heights of Briquettes m.c. 10% w.b

hold time =20s

Sludge prop % by weight	0	10	20	30	40	50
Av. Compressed height of briquette at $P_1 \times 10^{-2}$ m,	0.83	0.87	0.96	1.04	1.13	1.25
Av. Relaxed height $P_1 \times 10^{-2}$ m	1.45	1.57	1.65	1.98	2.10	2.27
Av. Compressed height $p_2 \times 10^{-2}$ m	0.86	0.96	1.02	1.10	1.26	1.42
Av. Relaxed height at $P_2 \times 10^{-2}$ m	0.92	1.00	1.10	1.22	1.34	1.50
Av. Relaxed height at $P_3 \times 10^{-2}$ m	1.82	1.96	2.21	2.37	2.47	2.58

Note p_1= 25.0Mpa P_2=18.70Mpa P_3=13.5Mpa

Readings are average of three replicates

APPENDIX A.13

Results of varying pressure on the crushing strength of briquettes. M.c. 10% hold time = .20s

Pressure	Sludge proportion % by weight	Curved surface area of briquette X 10-4m^2	Force (N)
P$_1$	0	25.42 25.66	117.50 118.00
	10	28.05 27.80	125.00 130.50
	30	33.08 32.90	162.00 170.00
	40	36.36 36.25	210.00 205.50
P$_2$	50	39.68 39.86	225.00 236.00
	0	26.94 26.84	102.00 101.00
	10	27.96 27.84	108.00 104.00
	20	29.05 29.46	108.00 115.00
	30	31.50 31.65	130.00 134.00
	40	3.14 33.02	165.00 160.00
	50	36.68 36.95	160.00 190.00
P$_3$	0	27.56 27.48	80.00 79.50
	10	29.62 29.36	81.00 80.00
	20	31.07 31.24	86.00 85.00
	30	33.64 33.44	96.00 95.00
	40	36.6 36.24	122.00 120.00
	50	38.86 39.0A	164.00 165.00

P1=25.0Mpa P2=18.7Mpa P3= 13.5Mpa

APPENDIX A. 14

Effect of varying pressure on the handling durability of briquette at different sludge proportion

m.c. = 10% w.b. Hold time 20s

Sludge proportion % by weight	Av. Weight of 10 briquette (9)	Pressure (Mpa)	Wt. of briquette fractions remaining on 35mm level after 7drops from height of 2m (g)
0	162.80	$P_1 = 25.0$	125.76
	162.40	$P_2 = 18.7$	98.50
	160.84	$P_3 = 13.5$	73.25
10	188.70	$P_1 = 25.0$	136.80
	187.90	$P_2 = 18.7$	105.45
	188.50	$P_3 = 13.5$	20.68
20	209.20	$P_1 = 25.0$	154.75
	208.80	$P_2 = 18.7$	120.28
	208.00	$P_3 = 13.5$	30.22
30	235.55	$P_1 = 25.0$	189.34
	235.50	$P_2 = 18.7$	158.45
	236.00	$P_3 = 13.5$	110.55
40	272.65	$P_1 = 25.0$	224.20
	272.45	$P_2 = 18.7$	192.65
	272.56	$P_3 = 13.5$	140.58
50	354.25	$P_1 = 25.0$	272.80
	353.85	$P_2 = 18.7$	231.25
	352.45	$P_3 = 13.5$	196.45

Readings are average of 3 replicates.

APPENDIX A.15

Results of varying hold time on the briquettes height after 2 weeks exposure m.c. 10.1% w.b pressure 25.0mpa

Hold time	%					
5 secs	0	10	20	30	40	50
	1.57	1.69	1.80	1.91	1.99	2.17
	1.55	1.66	1.78	1.86	1.96	2.16
	1.58	1.68	1.77	1.87	1.1.96	2.14
	1.56	1.67	1.75	.188	1.98	2.13
Mean	1.56	1.67	1.77	1.87	1.97	2.15
10 secs	1.53	1.65	1.75	1.83	1.94	2.05
	1.54	1.63	1.72	1.81	1.91	2.09
	1.53	1.64	1.73	1.82	1.91	2.06
	1.53	1.64	1.73	1.82	1.92	2.06
Mean	1.53	1.163	1.73	1.82	1.92	2.06
20 secs	1.47	1.58	1.65	1.77	1.89	2.01
	1.46	1.55	1.66	1.75	1.90	2.03
	1.45	1.56	1.65	1.75	1.88	2.02
	1.47	1.56	1.64	1.76	1.87	2.03
Mean	1.46	1.57	1.65	1.76	1.88	2.02

APPENDIX A.16

Effect of different hold times on weight of briquette during combustion m.c. 10% w.b. Pressure 25.0mpa.

sludge proportion % by weight	Times of combustion (min)	Weight of briquettes (g)		
0	Hold Time	HOLD TIMES'		
		5s	10s	20s
	TO	19.99	19.98	19.99
	TI	11.45	11.60	11.65
	T2	7.75	8.05	8.15
	T3	5.25	5.85	6.27
10	TO	22.01	22.10	22.05
	TI	12.65	12.98	13.56
	T2	8.96	9.34	9.88
	T3	5.85	6.37	6.92
20	TO	24.05	24.03	24.06
	TI	13.74	14.28	14.96
	T2	9.86	11.04	11.87
	T3	7.04	7.56	7.98
30	TO	26.85	27.16	26.95
	TI	15.46	15.92	16.65
	T2	11.20	11.86	12.54
	T3	8.52	8.98	9.20
40	TO	30.48	31.14	30.96
	TI	20.56	20.88	21.58
	T2	14.40	14.96	15.27
	T3	14.40	10.84	11.35
50	TO	36.89	36.80	37.06
	TI	24.89	24.68	24.96
	T2	24.77	17.84	18.24
	T3	17.25	13.08	13.86

TO = 0min T1 = 5min T2 = 10min T3 = [illegible]

APPENDIX A.17

Comparison of handling durability of briquettes at different hold time of pressure application.

Sludge proportion %	Hold time of pressure application (sec)	Percent of weight remaining on 35mm sieve				
			Number of 2m drops			
		0	1	3	5	7
0	5	100	95.80	91.62	84.25	68.86
	10	100	97.04	95.21	91.46	74.57
	20	100	99.06	97.89	92.39	81.76
10	5	100	95.62	88.41	82.88	60.15
	10	100	97.28	89.96	85.42	71.96
	20	100	99.32	96.48	89.50	76.08
20	5	100	97.89	92.06	84.59	70.24
	10	100	98.42	94.76	88.86	73.54
	20	100	99.56	95.74	90.26	79.98
40	5	100	98.45	94.82	88.49	73.45
	10	100	97.32	95.65	91.46	81.73
	20	100	99.28	97.89	95.16	86.22
50	5	100	97.99	96.44	90.56	76.84
	10	100	98.48	96.89	92.48	86.29
	20	100	99.45	97.84	95.86	87.36

APPENDIX A.18

Effects of varying moisture contents on the compressed and relaxed height of briquettes after two weeks exposure. Pressure 25.2mpa hold time = 20s.

Sludge proportion by weight %		0	10	20	30	40	50
	M_1	0.765	0.810	0.915	0.980	1.150	1.300
Average compressed height	M_2	0.694	0.765	0.830	0.910	1.050	1.220
x10^{-7} m.	M_3	0.662	0.720	0.800	0.895	1.000	1.220
	M_1	1.380	1.485	1.555	1.670	1.785	1.985
Average relaxed height	M_2	1.275	1.390	1.500	1.598	1.690	1.790
x10^{-2} m.	M_3	1.290	1.395	1.505	1.630	1.766	1.940

M1 = 10.1% M_2 = 14% M_2 17.8% w.b.