EVALUATION OF COMPOSITE SAWDUST BRIQUETTE AS A HIGH GRADE FUEL FOR DOMESTIC COOKING.

BY

KUTI, OLAWOLE ABIOLA {*B.Eng. (Hons.),FUTA*}

MEE/92/3640

A THESIS SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE.

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ENGINEERING (M.Eng) DEGREE IN MECHANICAL ENGINEERING (BUILDING SERVICES ENGINEERING OPTION) OF THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, ONDO STATE, NIGERIA.

AUGUST 2003

DEDICATION

This research work is dedicated to **God Almighty** in whom is hidden all the treasures of wisdom and knowledge; **Jesus Christ** my Saviour, the centre of my joy; **Holy Spirit** my inspiration and comforter.

"You are the love of my life

You are the hope I cling to

You mean more than this world to me

I won't trade you for silver or gold

I won't trade for riches untold

You are; You are my everything".

CERTIFICATION

This is to certify that this research work was carried out by **Kuti, Olawole Abiola** of the **Department of Mechanical Engineering** and is accepted as meeting part of the requirement for the award of Master of Engineering (M.Eng.) degree in Mechanical Engineering (Building Services Engineering option).

.....
Prof. C.O. Adegoke
(Project Supervisor)

.....
Prof A.A. Aderoba
(Chief Examiner)

ACKNOWLEDGEMENT

To God be the glory, great things He has done. I ascribe all honour, glory, power and adoration. Without Him, I cannot exist talk less of succeeding in life. Lord, you have been the Alpha and Omega throughout the entire M.Eng. Degree programme. I stand and bow in awe of You. You are everything to me. Great! is thy faithfulness.

My profound gratitude goes to my mentor in the field of Applied Energy and Building Services Engineering; my dynamic major supervisor, Engr. Prof. C.O. Adegoke. I sincerely appreciate his concerted efforts lauded towards the successful completion of this research. His discussions and constructive criticisms during the time of consultations really made the work interesting. May God bless him abundantly. Also to my co-supervisor, Engr. Dr. O.P. Fapetu, I'm not taking him for granted. I really appreciate your immense contributions given during the course of the research. Thanks very much.

I'm greatly indebted to my honourable Head of Department, Engr Prof. A.A. Aderoba. His excellent advices and encouragement contributed immensely to the successful completion of the programme. I'm ever grateful. I also acknowledge all my lecturers and entire staff in the Department of Mechanical Engineering who at various capacities contributed towards the success of my studies. I appreciate you all.

I appreciate all my course mates. Special regards to Pastor Peter Ayodeji and Tunde Ogedengbe. Thanks for your cooperation and advice. It has been a time of fun. You are not only a friend in time of need but also indeed. May God continue to lift you higher.

I also want to acknowledge those whom God used one way or the other. Special regards to Dr. (Mrs) M.O. Ajayi of the Registrar's office FUTA , Dr. A.M Oguntuase, H.O.D Civil Engineering FUTA, Engr. K. Afolabi (Afolabi Construction Company,

Akure), Messrs Tunji Ogunniyi, A. Johnson (Fisheries Dept. FUTA) and my colleagues in other departments.

I thank my parents in the Lord; Bishop and Dr.(Mrs) Felix Adejumo of the Agape Christian Ministries Inc. Thank you so much for your prayers and words of advice and encouragement.

To my loving and caring parents, Mr. and Mrs. J.O Kuti, I remain ever grateful for their unflinching supports. You are a rare gem, precious and so dear to me. When I look back, God has used you tremendously to be my source of lifting and achievement in life. I thank God for making you to see the rewards of your labour. I pray that God will continue to preserve your soul, so that you will continue to be witnesses of more good things to come. I love and really appreciate you. To my brothers; Kunle, Gbenga, Yinka and Jide ; my sister, Omolara, thanks a lot for your total support and affection . God bless you all.

Finally, I wish everyone whatever will bring joy, good health, prosperity and all other goodies in life. Amen

Kuti, O.A.(2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PAGE

LIST OF PLATES

ABSTRACT

Evaluation of Composite Sawdust Briquette as a high-grade fuel for domestic cooking is discussed in this write-up.

Composite sawdust briquettes were produced by mixing sawdust and palm kernel shell of sizes 1.18mm, 2.00mm and 2.36mm in percentage ratios of 90:10, 80:20, 70:30, 60:40 and 50:50 respectively. Starch was used as a binding agent. The whole mixtures were compressed at 6.89Mpa (1000 Psi.) using a manually operated hydraulic briquetting machine.

Experimental tests like Calorific Value Test, Water Boiling Test and Controlled Cooking Test were carried out on the samples having sun dried them properly for some days. The 70:30 composite briquettes with palm kernel shell size of 1.18mm were considered best under the Calorific Value and Water Boiling Tests. These were used to cook food items like yam, rice and beans under the Controlled Cooking Test. Its performance was compared to that of kerosene fuel under the same test.

The data obtained at the end of the experiments were analysed statistically. A cost analysis was carried out to compare the cost effectiveness of using the briquettes with kerosene fuel.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The world population is growing rapidly and rising sharply. It is now about 6 billion and is projected to be twice this every 35 years (Veziroglu, 1981). Based on this fact, the energy demand of the entire world is getting more and more since this is needed to raise and satisfy the standard of living. Nations consuming more energy per capita always have better standard of living. In search of improving the standard of living, the world energy consumption is seriously increasing at a critical rate when compared to the world population.

It is obvious that most of the world's energy demand is met by fossil fuels mainly coal, petroleum and natural gas. Fossil fuels provide about 80% of man's energy usage now and this makes them enjoy widespread use. These fuels, which we have depended on so much, are non-renewable and it is obvious that their supply is not keeping up with peoples' demand. The world production of fossil fuels will start to depreciate in the next 20 to 30 years and this has been the major concern of the entire world. (Veziroglu, 1981; Adegoke and Mohammed, 2002)

Nigeria has been facing energy crisis over the past ten to fifteen years despite the fact that she is an oil producing and exporting nation. This has led to acute shortage of petroleum and allied products thus affecting our economy and standard of living.

Hike in petroleum price is another phenomenon associated with shortage of fuels. People especially those in the rural areas can not afford the high price of this

conventional fuel such as kerosene, to meet their daily domestic need most especially for cooking.

Although efforts have been made by the past and present governments to alleviate all these problems, it has proved abortive especially in the area of hike in price. It is in view of this that much attention has to be given to the search for alternative energy sources that will be renewable i.e. replenished more rapidly. This renewable energy includes solar energy in its direct form, wind, geothermal, water and biomass.

Out of all these types of renewable energy, Biomass which is the generic name given to all dry plant materials and organic waste has found more recognition. This is because its development always results in a cleaner environment and at the same time can provide the means to recycle waste thus turning what is called rubbish to something valuable. Another advantage of biomass over other sources of renewable energy is its ready availability and energy conversion that is not so expensive.

Biomass can be derived from plant and animal materials through a variety of conversion and end use. Examples of biomass include; sawdust, rice husk, palm kernel shell, paper, animal dung, etc. Plant biomass in the form of wood was the first and for a long time universal and only fuel providing external energy for cooking, space heating and later manufacturing (White and Plaskett, 1981).

Since 1973, when oil prices began to rise, considerable interest has been shown in the possibility of using various present day biomass sources especially those from wood or wood wastes otherwise known as sawdust to produce fuel substitutes and chemical feedstock. Many sources especially wood possess an average energy content of 4 kcal/g (approximately 1.5×10^7 kJ/metric tonne). This is about half of the energy of bituminous

coal. The energy content of some plant is even higher than coal and oil. These plants can be cultivated by means of different processes and converted into solid fuel otherwise known as briquettes, liquid and gaseous fuel. (Diana *et.al*, 1985)

Most of the developed countries that hitherto depended much on improved oil as their major source of energy are now cutting back on imports of oil and moving towards the development of alternative sources open to them. An example of such country is the United States of America, which had reviewed the technology for obtaining energy and synthetic fuels from biomass energy, which already are commercial energy resources (Probstein and Hicks,1982) .

It is envisaged that if much priority is given to alternative sources of energy especially biomass, the problem associated with fuel supplies will be drastically minimized.

1.2 Statement of the Problem

The most critical energy problems today are those that confront certain countries of the world especially the third world countries, which cover the world's poorest nation and these include countries of Latin America, Africa and Asia. The third world countries are also referred to as developing countries and Nigerian falls under this category.

The problems usually associated with energy production particularly in the third world countries may be attributed to the following: -

Firstly, the sharp rising cost of oil imports has imposed severe strains in developing countries economic and thus constrained their continued development. In view of this, the very poor people have already been deprived of energy needed for essentials of life

like cooking, drying etc. This is because they cannot avail themselves in buying conventional fuels like kerosene or gas due to the high price. In addition, the non-renewable sources such as kerosene and gas are even outside the reach of the common person.

Secondly, conventional fuel needed for cooking such as kerosene is becoming an ever-scarcer commodity since it is non-renewable. The developing countries will find it increasingly difficult and expensive to get the basic fuel supplies they need.

Thirdly, the conventional fuels when used for cooking are quite effective but their products of combustion always have an adverse effect of pollution on the atmosphere, hence they are not environmental friendly.

Lastly, sawdust which is commonly found at sawmills site in all parts of Nigeria is always burnt off as a waste and this would have been a better means of converting what could be termed as rubbish to something valuable which can be used as an alternative fuel for cooking.

It is against all these facts that this research is being proposed. The following are the research questions under consideration:

(i) Why the need to search for an alternative source of energy such as composite sawdust briquette?

(ii) How can this be achieved?

1.3 General Objective of the Study

The broad objective of the research is to carry out a further investigation on sawdust briquettes as an alternative fuel for domestic cooking.

1.4 Specific Objectives of the Study

The specific objectives are to:

(i) Evaluate sawdust briquette as an alternative energy source, which is renewable and could be used to meet domestic needs thus alleviating the problems associated with fuel price increase, shortage and scarcity particularly in the rural areas of developing countries.

(ii) Utilize wood wastes by turning it into wealth through the conversion of sawdust to briquettes thus producing small-scale industrial materials for fund generation.

(iii) Determine the Combustion characteristics of Composite Sawdust briquette.

1.5 Scope of the Study

Sawdust and charred palm kernel shell were collected, screened and converted into briquettes using a manually- operated hydraulic briquette making machine. The following mixing ratios of sawdust to palm kernel shell were used: 50:50, 60:40, 70:30, 80:20 and 90:10 respectively. Palm kernel shell of sieve sizes 1.18mm; 2.00mm and 2.36mm respectively were utilized. A control was set which is 100% pure sawdust and starch gel was used as a binder for all the mixtures.

Calorific Value Test was carried out on the various samples using the Gallenkamp Ballistic Bomb Calorimeter. The Water Boiling Test (W.B.T.) was conducted on the samples. The composite with highest energy content was used to conduct the Controlled Cooking Test (C.C.T). Food items such as yam, rice and beans were used during the test. The cooking performances of the composite briquette were compared with that of

kerosene. The resultant data were analysed statistically. A cost analysis was carried out to compare the effectiveness of using the briquettes with kerosene fuel.

1.6 Expected Contribution to Knowledge

The contribution to knowledge of this research work can be looked at from the relevance of the research to:

(i) The field

(ii) The National development

1.6.1 Relevance to the field

The successful execution of this research will go along way to contribute immensely to the knowledge of engineers and scientists in the field of energy especially in developing countries.

It is ascertained that the result generated will be used to analyze, develop and re-evaluate the importance of sawdust briquette as an alternative fuel for domestic applications.

1.6.2 Relevance to National Development

It is envisaged that the result from this research will go a long way to alleviate the problems associated with energy production in Nigeria. This will make our nation to depend solely on her indigenous technology.

Furthermore, the standard of living will improve making life easier for the entire populace. Finally, the judicious use of sawdust waste generated in large quantities in

sawmills can provide a source of national income. This will surely boost our economy apart from depending totally on conventional fuels.

CHAPTER TWO

2.0 LITERATURE REVIEW

The role and impact of natural resources in the functioning of an economic system can never be over-emphasized. In view of these, energy which is usually obtained when all these natural resources are harnessed plays a vital role in the overall development planning of any nation (Akinbami, 1997).

Energy, which is simply defined as the ability to do work, has been the central cross-sectoral issue, which affects all human activities either directly or indirectly. It is a vital input to economic growth and development of any economy developed or developing.

According to Bansal et-al (1990), energy have been seen to be a crucial input in the process of economic, social and industrial development. Apart from the other three classical factors i.e. land, capital and labour, the role of energy cannot be underestimated when it comes to development. It has been seen to be the linchpin of all development efforts highly important for the sustenance of life; hence it is an indispensable commodity.

2.1 SOURCES OF ENERGY

Energy resources are generally classified under two broad generic names- conventional and non- conventional.

2.1.1 CONVENTIONAL ENERGY

The conventional energy sources, which are also termed non-renewable, are energy sources that are gradually diminishing or not capable of being replenished. They include fossilized and exhaustible energy sources such as coal, petroleum, natural gas and nuclear fuel such as uranium. Out of the fossil fuels, coal was in local use in the middle ages but did not begin to be exploited in quantity until the nineteenth century. The use of oil is predominantly a phenomenon of the twentieth century and is likely to die out in this century. For example, experts have forecasted that petroleum resources will be exhausted by the year 2025. (White and Plaskett, 1981; Momoh, 1997).

The fuels upon which our civilization largely depends have a limit to their availability. It is for this reason that much concern is now being given to the search for alternative and supplementary fuel, which will surely have the advantage of being replenished.

2.1.2 NON-CONVENTIONAL ENERGY.

The non-conventional energy resources also known as renewable energy are those that can be replenished quickly and not exhaustible. These include solar, wind, water and geothermal. They also include other forms of organic material known as biomass.

Renewable energy sources are more environmentally friendly and are thus better candidates for use in achieving some measure of technological development under a sustainable environment both in the developed and the developing nations (Adegoke , 2002).

By comparing with the conventional energy forms, it has been revealed that the non-conventional energy resources have been denied the privilege of widespread use. This is because of their expensive relative prices rather than their availability. However, time will soon prove this argument wrong because in the shortest time, the conventional energy forms will be used up if restrictions are not applied to their consumption rates. Then humankind will have to depend on renewable energy resources at any cost.

The renewable energy source has a potential of decentralizing the energy needs of the rural population and its environmentally benign nature makes it an attractive option for meeting the future needs of people particularly in the poorest countries of the world. Unlike non-renewable forms of energy, an increase in their consumption will not only have adverse effect on the environment causing global warming but further drains the limited reserves of currencies (Karekezi and Ranja,1997).

Renewable energy resources are found to be well distributed around. Presently, they provide a little over 20% of world's energy needs out of which biomass constitutes 14%. Twenty five percent of renewable energies are obtained from timber, paper and pulp industries; these are capable of providing the global energy picture. (Jackson, 1991; Sorenson, 1991).

2.2 HOUSEHOLD ENERGY CONSUMPTION.

One of the vital areas in which energy is consumed is in the household. Domestic cooking constitutes a major way by which energy is consumed in households either in a rural or in an urban setting.

According to Kyiogwom et-al. (1997), from a survey carried out on households in Northern Nigeria, it was observed that a substantial part of income is usually spent to meet domestic cooking needs in both rural and urban areas as shown in Table 2.1.

Table 2.1:Proportion of monthly income spent on domestic cooking by household in Northern Nigeria for 1997.

Location	Average monthly Income (₦)	Proportion spent on energy source (%)		
		Fuel wood	*Others	Total
Rural	725.00	20.60	4.12	24.81
Urban	2,418.58	4.16	19.32	23.44

*Others-(gas, kerosene, electricity) Source:- Kyiogwom *et.al* (1997)

From Table 2.1, fuel wood is the major source of energy for domestic cooking in the rural area although urban household spent the least proportion of their income on fuel wood.

In addition, Fig. 2.1 reveals the annual consumption of fuel wood by both rural and urban household.

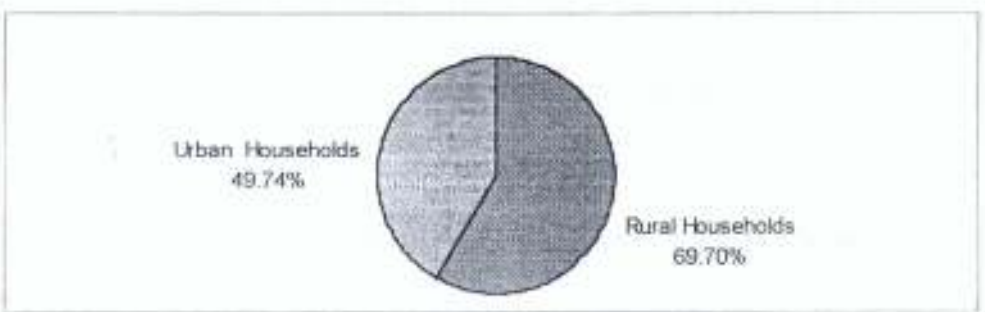


Fig. 2.1: Annual Consumption of Fuel wood by both Rural and Urban household

Source: Kyiogwom *et. al* (1997)

From Table 2.1 and Fig. 2.1, the actual amount spent and the quantity of fuel wood consumed were substantial. Fuelwood as an energy source played a significant role in both rural and urban households. In most communities in the developing countries, fuel wood is regarded as a free commodity that can be collected at will from communal lands or obtained as a by product of bush fallow systems. The effect of this is that the use pattern can be very wasteful thus endangering the environment. (Palmer, 1988)

The undesirable impact on the sustainability of fuel wood as a source of energy could always have adverse effect on the environment if its use is not controlled. This can put an unbearable pressure on the fragile ecosystem.
Therefore, it is expedient to source for other forms of energy that will be capable of meeting up with household demands particularly in the rural areas. This form of energy should be the kind that can act as close substitute to fuel wood

2.3 BIOMASS

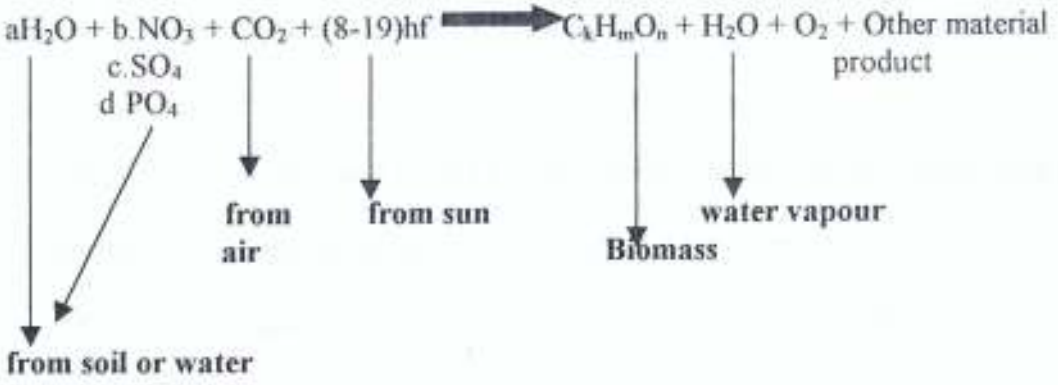
Biomass is the generic term given to dry plant materials and organic wastes. It is also used to describe vegetation and wastes that are subsequently used for conversion into fuel (Diana *et.al*, 1985). Biomass is one of the most versatile renewable energy source which include all the living or dead organic materials in form of wastes or residues. Plants, animals and their wastes are not only regarded as biomass. Materials, which originate through a conversion process like paper, cellulose, organic residues from Food Industry and organic

waste materials from industries and houses i.e. Municipal Solid Wastes (M.S.W.) constitutes a larger part of biomass (White and Plaskett, 1981).

Biomass is the organic material produced by photosynthesis, a process that converts solar energy into stored chemical energy in plants. In essence, the photosynthesis process in plants produces carbohydrates (sugar) that form the building blocks of biomass. It is obvious that plant is the highest source of biomass that makes biomass to be a material that is directly or indirectly derived from plant life (Madu and Sodeinde, 2001).

Bansal *et.al.* (1990) gave a vivid explanation that in nature biomass is usually formed by the process of photosynthesis of inorganic materials like water and Carbon dioxide. With the aid of solar radiation in the visible range of 0.4 to 0.8 μm, the coloured material molecules which is mainly chlorophyll acts as a photo sensitizer by splitting water in organic cells under a process known as Photolysis. In this process hydrogen molecules is released and this combines with carbon dioxide in the air to form carbohydrate (i.e. biomass). During this process, molecular oxygen is released into the air. It is evident that the origination of biomass, therefore is the basis for the existence of human on earth and it forms the most important component of the carbon dioxide loop.

The formation of biomass can be represented by the following equation.



where:

a, b, c, d are in various small quantities

h is the Planck's constant = 6.625×10^{34} Js

f is frequency in hertz or cycles/s

(Source: - Bansal *et.al*, 1990).

The left hand side of the equation shows that along with the carbon dioxide from the air, a large number of trace elements like Nitrogen, Phosphorus, and Sulphur etc. are taken from the soil. These trace elements however, are not really important in the formation of biomass but are essential constituents of fertilizer.

It is obvious that the fossil fuel that man has exploited and depended on originated from biomass. One cannot help but be impressed by the major physical and chemical differences between these fuels and the original biomass from which they were derived. Present day reserves of coal, oil and natural gas have been subjected to extremely effective cost free processing operations through the combined action of climate and geological forces over enormous spans of time (White and Plaskett, 1981).

The stored energy in biomass can only be harnessed when it is converted to other bio-energy forms either through a combustion process or transformation into solid, liquid or gaseous fuel by some other methods of conversion (Karekezi and Ranja, 1997). Biomass energy can be modernized through the application of advanced technology to convert raw biomass into modern, easy to use carriers like electricity, liquid or gaseous fuels, or processed solid fuels. When a biomass is burnt efficiently (extracting the energy stored in the chemical bonds) oxygen from the atmosphere combines with the carbon in plants to produce carbon dioxide and water. The whole process is cyclic because the carbon dioxide is then available to produce new biomass.

Biomass is considered one of the key renewable resources of the future at both small and large-scale levels. It should be noted that three quarters of the world population living in developing countries use biomass as their most important source of energy especially in cooking. Also 14-percent of the energy consumed in the world and 35-percent of consumption in developing countries is obtained from Biomass (Madu and Sodeinde, 2001.; Hall, 1993a).

With increase in population per capital demand and depletion of fossil fuel resources, the demand for biomass is expected to increase rapidly in developing countries including Nigeria.

Madu and Sodeinde, (2001) highlighted the benefits of biomass as source of energy. These are:

- Rural economic development.
- Increase in farm income and market diversification.

- Reduction of negative environmental impacts.
- New income for farmers and rural population.

In addition, it improves the material welfare of rural communities and this might result in a further activation of local economy. In the end, this will cause a reduction in the emigration rate to urban areas and more jobs will be created in the rural communities.

The environmental benefits derived from the utilization of biomass as energy include reduction in acid rain due to low sulphur compounds, (S0x) and nitrogen compounds, (N0x) emission. This can help in rehabilitating degraded lands. It has been found that biomass play a crucial role in limiting carbon emissions and global warming which means it would not contribute to the green house effect. Also soil erosion is considerably controlled, there is reduction in water pollution and pressure on land fills; this will enhance provision of wide life and help in maintaining forest health through better management. Lastly, the ash content of biomass is much lower than that of non-renewable such as coal. The ash is generally free of toxic metals and other contaminants and can be used as soil fertilizer.

2.3.1 CONSTITUENT OF BIOMASS

Biomass manifests itself in various forms, which are generally present in the organism. The constituent of biomass invariably deals with its chemical composition. Basically the constituents of biomass are:

i. **Cellulose:** This is the most common substance in all forms of biomass. It is a fibrous polysaccharide (a chain of glucose molecules;

$C_6H_{12}O_6$) which forms the main constituent of the cells walls of land plants, this make it to be the most abundant naturally occurring organic substance in plants. Cellulose is a major constituent in cotton fibre, wood and straw e.t.c. The important chemical properties of cellulose that affects its conversion in biomass process are its extreme insolubility in water and chemical inertness. It can be soluble in alkaline and acidic solution when it swells up and this converts it into glucose.

ii. **Hemicelluloses:** This is contained in 20 to 40% of the lumber plants (Bansal *et.-al* 1990). It has energy content of 18.8MJ/kg. It is a polysaccharide that occurs in association with cellulose. Hemi cellulose is more soluble than cellulose when dissolved in dilute alkaline solutions. The combination of cellulose and hemicelluloses is referred to as Holocellulose.

iii. **Lignin:** This is another important constituent of the walls of woody cells and acts as natural glue providing the plant with added mechanical strength. It is about 30% of the lumber type of plants. It is formed in plants through the storage lignified plant cell in the cell membrane. It is an important constituent of wood because it offers a considerable resistance to the mechanical and enzymatic digestion of cellulose through microbial degradation. The energy content in liquid is about 25.5MJ/kg.

iv. **Starch:** This is also a polysaccharide but with very weak hydrogen bonding in comparison with cellulose and hemi-cellulose. Because of this weak hydrogen bonding in the molecules, starch and sugar are especially suitable for chemical and enzymatic digestion.

2.3.2 SOURCES OF BIOMASS

There are three sources of raw materials from which biomass can be obtained. These are:

(i) Natural Vegetation

Biomass from natural vegetation has been used mainly in the form of wood from trees. Wood is about 50 percent cellulose, 25 percent hemi-cellulose, 25 percent lignin with extraneous materials such as resins, gums, tannins and waxes (Diana *et.al*, 1985; Probstein and Hicks, 1982).

When forests are cut down for papermaking or timber, over 50 percent of tree is usually wasted. This waste contains cellulose for possible conversion into alternative fuels such as methane or charcoal, or for direct combustion after drying.

When wood is burnt directly, the fuel obtained from this kind of energy conversion process is referred to as Primary Forest Fuel. If it is converted to more valuable fuels such as charcoal, methane by carbonization, distillation or gasification process, it is called Secondary Forest Fuel .

Each of the fuel derived from wood through the different energy conversion process has a unique application. For example, in conditions of forest,

abundance wood is often the most practical solid fuel for heating and cooking purposes; charcoal would be the most suitable choice for meeting a requirement for smokeless fuel, whilst types of engine requiring a very high octane fuel, methanol may be ideal. Producer gas may be the most practical fuel for many industrial uses (Earl, 1975).

About 90 percent of the world's energy stored in biomass is in the form of trees. This is mainly used in Third World countries. It accounts for as much as 95 percent of total energy consumption (Diana *et.al*, 1985).

The advantage of natural vegetation as a fuel is that it is frequently free and locally accessible especially for those in the remote or rural areas. This attribute makes wood from commercial forest land to be largest potential source of biomass even in developed countries like U.S.A (Probstein and Hicks, 1982).

However, natural vegetation contains a variety of species to stabilize the ecosystem and this makes large-scale mechanical harvesting difficult.

An urgent and pressing problem which needs serious attention is the cutting and burning of wood. This is more predominant in the Third World countries. The result is serious ecological and environmental deprivation through soil erosion, flooding and desertification. Many measures have to be taken so that this will not become a "Second energy crisis".

(ii) Energy Plantation and Energy Crops

Many countries especially the developed have investigated the possibility and feasibility of planting crops for use as biomass source. Several authorities

have estimated the land area needed for energy – crop cultivation in order to produce for a country's energy requirement.

In U.K., it was estimated that at a 1 percent conversion photosynthesis efficiency, one tenth of total energy requirements could be met by about 9 percent of the land area .In Australia it was calculated that from energy inputs in harvesting and processing, 3 million hectares of land would produce one – third of energy requirements. In the U.S.A. it was calculated that a national total of some 430 million dry tonnes of biomass was available each year from agricultural residues and this could supply 31 percent of the nation's electricity, 20 percent of the natural gas or 8 percent of its oil requirements. In practice about one fifth of this might be collectable. From further research it has been estimated that biomass fuels could supply some 9-20 percent of the total 1980 U.S. fuel consumption by the year 2000, with wood, forage crops and municipal waste making the main contribution. (Diana *et.al*, 1985).

Energy crops and biofuel can best be cultivated at competitive costs by choosing the appropriate plant species, planting density and harvest schedule for each plantation site for its specific market requirements. The fuels produced can be used on site to power industrial machines, converted to electricity or other forms such as domestic fuel.

An important factor that arises in considering the use of crop land for energy is the competition with the food market. It has been concluded that there is no assurance that cropland will in the future be available for energy uses and

the cultivation of specific energy crops may have to be limited to avoid inflation of food prices.

Examples of energy crops include: Grain crops, Eucalyptus and pine, Sugar cane, Soya beans, sunflower, Aquatic plants, etc.

(iii) ORGANIC WASTE

This is a vital source of biomass suitable for conversion into biofuels. This includes agricultural, forest, industrial, domestic and animal wastes.

Agricultural wastes are the material remaining after processing crops to a marketable material. Common wastes are sugar cane bagasse, cotton gin trash, palm kernel shells, etc.

Materials unsuitable as feed are usually burned directly on site to generate energy. They can also be converted to other source of fuel such as ethanol. Table 2.2, gives a brief account of the residues or wastes generated by the agricultural sector in Malaysia.

Table 2.2: Residues generated by the Agricultural sector in 1988

Source	Million m^3
Rubber wood residues	11.32
Oil palm residues	8.69
Rice husk residues	3.41

Source: Razak *et. al* (1997)

Much forest waste from the timber and paper can also be a good source of biofuel rather than disposing them because of the high cost of collection, transportation and handling. Wood chippings from sawmills are frequently used by the paper industries to power their plants.

Industrial and domestic wastes such as paper and pulp, urban garbage by-products of food production etc are referred to as municipal solid wastes. They have the advantage that they are more easily collected but they usually create an increasing disposal problem. Industrial and domestic wastes are sources of energy probably with as much potential as wood. Inorganic constituents such as metals and glasses must be removed so that the remaining material could be utilized as biofuels having being converted through different processes such as biochemical, thermal and direct combustion.

Lastly, animal wastes or manure as a source of biomass has the advantage that it is not competitive with other uses. It includes the waste obtained from dairy farms; cattle feed lots, poultry and other livestock operation. Anaerobic digestion, a biochemical process is most applicable for converting animal wastes into methane a major biofuel from animal waste.

It is worth mentioning that two or more biomass sources can be combined and mixed together depending on proportion to form a composite solid fuel known as briquette. These briquettes definitely will be a good source of domestic cooking fuel when burnt directly.

2.4 WOOD

Wood from commercial forestland is the largest potential source of biomass when compared to others. Most of this potential lies in wood processing by- products otherwise known as wood wastes such as sawdust, spent paper – pulping liquor, forest management by- products such as thinning and logging residues (Probstein and Hicks, 1982)

Wood has been one of the oldest renewable sources of energy and even today half the wood harvested in the world is burnt as fuel. It has for long served as one of the sources of energy known and utilized by mankind and it may continue to remain so for a long time despite the availability of other sources of energy such as coal, kerosene, electricity, wind, solar etc.

The utilization of wood and wood wastes as sources of energy is by no means a newly discovered technology. It is evident that over 65% of the world population depends on wood to meet their domestic energy and to some extent industrial energy requirements (Samir and Oskar, 1981; Harker *et. al*, 1982).

Also over 80% of wood consumed annually in developing countries is used for fuel whether in the rural or urban areas. For example in Nigeria, fuel wood is still the most utilized energy for cooking when the entire populace is to be considered (Danshehu *et. al*, 1992).

Quality wood on the other hand is a valuable commodity for both commercial and industrial applications e.g. for construction, fabrication, making of paper and various particle boards. The wood waste generated from these wide range operations constitutes a high considerable potential biomass energy source.

With no proven reserves and increasing high costs of conventional fossil fuel, much attention should be given to preservation of existing forest coupled with good afforestation programmes to enhance ecosystem balance and to reduce pressure on already depleted forests, acute shortage of wood as well as to meet the domestic energy demands.

In view of this, the judicious use of wood wastes and even other wastes such agricultural wastes can be made as alternative source of energy. Luis *et al*, (1976) affirmed that if all organic residues were converted into energy, the resulting output would fulfil about 5 – 10 % of the nation's total energy requirement. While these percentages may seem small, it should be remembered that any contribution however, has significance. With all these prospects and the increase in price of conventional fuel, it is expected that the demand for wood waste as alternative sources of energy will continue to increase.

2.4.1 SOURCES OF WOOD WASTES

The steps involved from the harvesting and utilization of forest resources are multiple and complex and in each step, a certain amount of wood wastes are generated. (Samir and Oskar, 1981). Wood wastes can be defined as "those forms of wood that cannot be marketed at a profit from a given logging or manufacturing operation under the current economic situation and state of technological development". (Razak, *et al.*, 1997).

When forests are cut down for paper making or timber, over 50% of the tree is usually wasted. The wastes can be disposed off or can become a source of feedstock e.g. for the manufacturing of particle boards. Wood waste usually arises from two main sources; these are forestry and manufacturing wastes.

2.4.1.1 FORESTRY WASTES

These wastes are usually generated in the field. They represent up to 40% of the total above grand biomass of a clear felled forest (White and Plaskett, 1981). These include annual litter falls, dead trees, forest fire remains and wastes generated in the course of logging and culling. The logging residues are usually generated during the various phases of the logging operation. These residues come in the form of barks, stumps, branches etc. Those from culling include dead and over- age trees.

2.4.1.2 MANUFACTURING WASTES

Manufacturing wastes also known as processed plant waste are the waste generated because of an industrial activity. Two major industries serve as source of manufacturing wastes namely wood products and pulp and paper (Samir and Oskar, 1981)

According to Razak *et. al*, (1997), the following wastes are always associated with the two industries mentioned earlier.

(i) Primary Manufacturing Wastes: These are wastes generated in the primary wood-based industries. These include slabs, edgings, trimmings, sawdust etc.

(ii) Plywood Wastes: These are wastes generated by the plywood mills. These are in form of veneer cores, defective ends and irregular pieces of veneer sheets.

(iii) Secondary Wastes: These are wastes generated by the planning mills, moulding plants, flooring mills, furniture factories and others. These

residues are in the form of sawdust, planer shaving, small pieces of lumber trimmings, edgings, barks, fragments etc.

(iv) Pulp and Paper Manufacture Wastes: Two residues usually produced in pulp and paper manufacture, which are major sources of energy, are bark and spent cooking liquor. Bark is the outer layer of the pulpwood and is removed at the pulp mill. On the other hand the spent cooking liquor is a liquid waste generated in the pulping process and characterized by a heavy concentration of dissolved organic chemicals.

Table 2.3 gives a brief account of the wastes generated by the forestry industry in Malaysia.

Table 2. 3: Wastes generated by the forestry industry in Malaysia.

Source	Million m^3
Logging Residues	5.10
Primary Manufacturing Residues	2.92
Plywood Residues	0.91
Secondary Residues	0.90
Total	9.83

Sources: Razak *et.al* (1997).

From the Table, it is obvious that the logging residues contribute the largest volume of wood waste and it has been found to be most significant in terms of energy source.

2.5 SAWDUST

Out of all the various kinds of wood wastes, sawdust is of high importance. Sawdust, a wood waste is always obtained from forest waste or manufacturing waste. The largest quantity is often obtained through manufacturing process.

Table 2.4 shows the proportions of component of a bark free log, obtained at a mill through manufacturing process.

Table 2.4: Breakdown of the proportions of component of a bark free log.

Bark Free Component	Proportion
Lumber recovery from debarked log	45%
Chips	20%
Sawdust	20-25%

Source: (Abeels, 1987)

Sawdust constitutes a major source of residues of small particles of wood waste available in sawmill industries, wood processing and pulp plants. It has been observed that the forestry and wood-based industries is usually characterized by the production of large volumes of residues without any economic utilization. In the past, these residues were left in the field to be wastefully burnt away. However, in recent years, burning of wood residues in the open has been discouraged because of environmental problems associated with this practice. It has been found that there is a potential for utilizing forestry and wood residues especially sawdust for energy. (Razak *et- al*, 1997).

It has also been affirmed that the volume of sawdust generated in Nigeria, particularly in the southern part is quite high. This is due mainly to the increasing number of operating sawmills. The presence of these wastes in large quantity poses disposal problems for the industry. These wastes can be converted to a useful form and utilized as a high-grade solid fuel by improving the calorific value and ensuring a clean and bluish smoke free flame suitable for cooking. This could be a way of turning wood waste to wealth (Adegoke, 2002).

The availability of biomass wastes is dependent on the time in the year. There are always growing and harvesting periods. An all year round utilization of raw biomass implies storage. It introduces risks of degradations due to the biological nature of the products. The more of biomass available to feed living organisms the more bio-degradation can occur (Abeels, 1987).

In view of this, it has been observed that sawdust wastes out of all the different sources of wood waste are always found available through out the year. This is obvious in majority of sawmills around. With these entire facts one must look for a better way of converting sawdust wastes to a good form of high-grade solid fuel suitable for cooking. This will surely alleviate both storage and disposal problems, thus making the environment more conducive.

2.6 BIO-CONVERSION PROCESS OF BIOMASS INTO ENERGY

The term bio-conversion in the real sense of energy means the conversion of biomass into useful form of heat or into solid, liquid or gaseous energy carriers. (Bansal et- al, 1990.)

Karekezi and Ranja, (1997) defined the bio- conversion process as those technologies that enhance the most efficient utilization of biomass whether in large or small scale. Large-scale commercial applications require substantial investment and a wide distribution network, producing large amount of energy and create employment for many people both directly and indirectly. Small scale commercial refers to subsistence applications that can only create a limited number of jobs per unit, but generate a large number at an aggregate level.

Table 2.5 gives the various elements of a bioconversion system.

Table 2.5: Elements of bioconversion system

Primary Material	Conversion Technology	End Product	Technological Applications
1. Terrestrial Biomass 2. Biomass in Sea 3. Plant and Animal Residue 4. Wastes	Physical Method Thermo-chemical Method Biological Method	Solid fuels Liquid fuels Gaseous fuels Electricity, Heat	Agriculture Chemical process Industry Transport Domestic

Source: (Bansal *et al.*, 1990)

From Table 2.5, it can be inferred that four forms of biomass can be converted into suitable energy by employing the three basic technologies of biomass conversion, namely Physical, Thermo chemical and Biological Processes.

The physical method has been found to be the simplest method of conversion. It always involves the mechanical process such as pelletization or briquetting of wood waste, straw e.t.c. The physical method can also include the extraction of plant oils and hydrocarbon and their direct use as energy carriers.

On the other hand, the thermochemical process converts biomass into usable energy forms by the supply of heat or through appropriate chemical reactions. The biomass here, is either converted into heat through the process of oxidation or it is converted into a secondary form like producer gas e.g. methane, Carbon (iv) oxide etc by some chemical process.

Furthermore, the biological process depends on microbiological activity such as fermentation or anaerobic digestive process to produce both liquid and gaseous fuel like ethanol, methane gas, methanol etc.

From all indications, it is evident that all forms of biomass can be converted into solid, liquid or gaseous fuel by the various methods under discussion. The biofuels obtained can be further converted into useful heat, which can be used to generate either mechanical or electrical energy using an appropriate thermodynamic cycle. Table 2.6 shows a wider breakdown of the bioconversion process.

Table 2.6:Assortment of bioconversion process

Process	Basic material	End product	Total average efficiency	Status
Mechanical conversion	Waste wood	Pellets	90	Commercial
		Briquettes	90	Commercial
Extraction	Straw	Resin oil	20	Commercial
Combustion	Wood	Steam Heat	70	Commercial
Combustion	Wood	Steam force	70	Commercial
Combustion	Wood	Steam Power	20	Commercial
Gasification	Wood	Hot, dirty LBG	80	Commercial
Gasification	Wood	Cold, clean LBG	70	Demonstration
Liquefaction	Wood	MBG	80	Demonstration
-through chemical reduction	Wood	Dirty oil	60	Prototype
-through pyrolysis	Wood	Oil and wood coal	30	Commercial
-through synthesis	Wood	Methanol	60	Demonstration
-through synthesis	Wood	Petrol, LPG	45	Demonstration
Fermentation (alcohol production)	Corn	Ethanol	60	Commercial
Fermentation (alcohol production	Sugar plants	Ethanol	30	Commercial
Fermentation (alcohol production)	Water plants	Ethanol	40	Commercial
Fermentation	Alga			
(Biogas generation)	Agricultural	SNG	50	Commercial
	Waste	MBG	50	Commercial
Decaying (land fill)	City and agriculture waste	Heat	50	Commercial

(Source: Bansal *et al*, 1990).

LNG = Low Joule Value Biogas.
MBG = Medium Joule Value Biogas.
SNG = Synthetic Natural Gas.
LPG = Liquid Petroleum Gas.

From the table, it is evident that the efficiencies of the various conversion processes fall in a very broad spectrum (20 – 90%) with mechanical conversion, a physical method of bioconversion, having the highest efficiency. Some of the processes

are already being used in the commercial sector, while some of these methods are at the stage of research, development and demonstration.

Biomass conversion today offers the necessary required secondary energy. For this reason it can be supplied in domestic, agricultural, industrial sectors etc.

2.6.1 BRIQUETTING

Briquetting can be defined as the densification of loose granular material into compact and easily transportable fuel (Karekezi and Ranja, 1997). Razak and Hoi (1997) also defined briquetting as the process of converting loose wastes into a dense compact and consolidated unit through the application of high temperature and pressure with or without a binding agent.

The briquetting process always involves the pressing together of small particles of solid materials to form coherent shapes of larger size. According to Bansal *et al* (1990), it is the first and simplest method of physical conversion of biomass, categorized under the mechanical conversion process, which always involves the compression of combustible materials.

The methods, which are in practice today predominantly, employ the use of straw, peat and especially wood wastes. The basic material has only a very small bulk density as shown in Table 2.7.

Table 2.7: Bulk density of a few combustible materials.

Combustible material	Bulk density (kg/m^3)
Straw	60 to 160
Wood dust	80 to 120
Shavings, saw clipping	90
Shavings, production	120
Brush wood, softwood	120
Brush wood, hardwood	160
Peat dust	180 – 200
Wood flour	190
Domestic waste	180 – 250
Machine peat, air dried	325 – 425
Softwood in parts	420
Hard wood in parts	560
Briquettes and pellets	600 to 800

Source: (Bansal *et al*, 1990).

The mechanical compression of combustible materials simultaneously leads to the drying of the product. The moisture content in the biomass i.e. the ratio of the mass of water in the biomass to the mass of the dried substance shows values even up to 90%. The compression of biomass leads to a moisture content of 15 – 18%. Depending on the form and density the end product of the compression mechanism are known as cobs, pellets, or briquettes.

Briquetting technology has been in use since the nineteenth century to make solid fuel out of peat, animal feed and fertilizer.(Karekezi and Ranja, 1997). The history of briquetting process can be traced back to the year 1848 when a patent was granted to an English man named William Easby. This process was employed for converting fire coal into solid lumps. In his application, Easby made one claim, "The formation of small particle of any variety of coal into solid lumps by pressure". It was discovered that this process i.e. briquetting enhances the conversion of article of small value and almost worthless into valuable articles of fuels for cooking, steaming, forges and other purposes, thus saving what should have been lost.

Almost 50 years later economic pressure joined forces with technological process to give substance to Easby's vision. The coal briquetting first began in the United States. It involved the drying of coal first, then crushing and screening it; mixing the dry coal with about 6% molten asphalt binder, briquetting this mixture in roll type briquette machines and finally cooling the briquettes on a conveyor before loading them into cars or diverting them to stock pile. Over 6 million tones of coal briquettes were produced annually in the United States before the process was doomed by cheap oil and gas just after the Second World War.

The briquettes made by this process were used primarily for domestic heating and many attempts were made to eliminate the asphalt binder, as the smoke from the binder was the major objection to the product.

Nowadays, many other biomass materials can be briquetted into solid fuel apart from coal. These include rubbish or garbage, charcoal residues etc.

2.7 TYPES OF BRIQUETTES

Briquettes can generally be of two forms namely, carbonized and uncarbonized.

2.7.1 CARBONIZED BRIQUETTE

Carbonized briquettes are those formed when biomass is charred to from charcoal - like fuel.

They are quite affordable and are used as a substitute for wood charcoal owing to their similar burning characteristics. It is also possible to make producer gas if carbonization is carried out at the briquetting plant. The gas can either be used to generate electricity for drying or can be heated to dry the briquettes.

2.7.2 UNCARBONIZED BRIQUETTE

Uncarbonized briquettes do not usually require charring process like carbonized types. They are usually obtained by compressing combustible biomass materials without being charred to form charcoal like fuel and usually require a special stove.

2.8 BRIQUETTING TECHNOLOGIES

Technology has advanced in the area of briquetting wastes to generate energy sources. In practice, various technologies have evolved and these are especially being applied on a large-scale basis. According to Karekezi and Ranja, (1997), there are two major technologies used in briquetting. These are Extrusion Technology and Pelletization Technology.

2.8.1 EXTRUSION TECHNOLOGY

In the extrusion technology, a piston, conical screw or cylindrical press is usually employed for briquetting operation.

Briquettes are usually produced at high temperature (say about 250°C) and high pressure (approximately 1000 bars) under extrusion technology without the use of a binder. (Karekezi and Ranja,1997). A binder is a substance used to hold the loose material together.

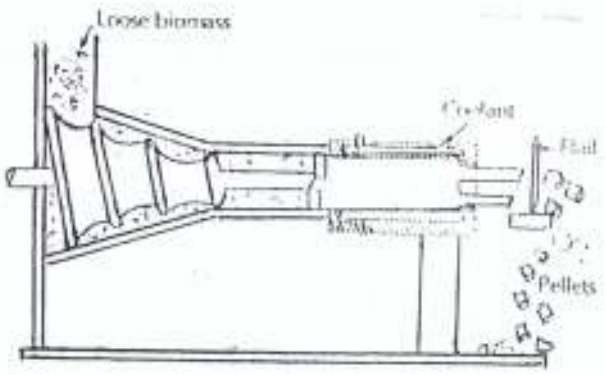


Fig.2.2: Principles of briquetting under extrusion technology.

Extrusion technology can also be referred to as hot briquetting because it always involves a high temperature process. It is understood to mean the briquetting of materials that have been heated to temperatures above ambient where plasticity has developed or become imminent.

Since briquettes are made without binders under this condition, the success of the process will depend upon crushing or plastically deforming the particles to bring them closely together. Also, the forces that bind these particles together when pressure is applied alone are neither strong nor specific, so it is necessary only to squeeze the individual particles into close contact. Fig. 2.2 shows the principle of briquetting by extrusion technology.

2.8.2 PELLETIZATION TECHNOLOGY

Pelletization technology usually involves the agglomeration and densification of wastes in low pressure eccentric pelletizers (Walubengo, 1990; Bachou, 1990). The process involves enlargement by gluing powder particles together in a rotating piece of equipment. The rotation causes smooth rolling of the balls, which grow larger in diameter until they are finally pushed out of the pelletizer.

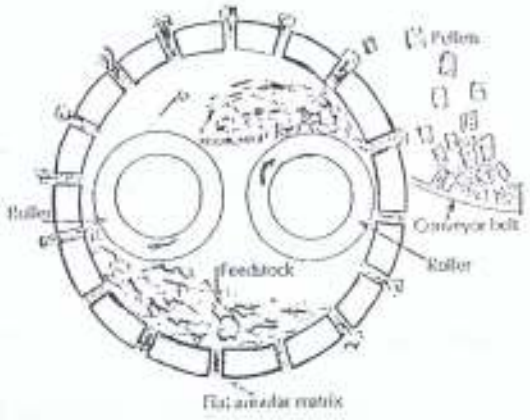


Fig.2.3: Principles of briquetting under pelletization process

Pelletization technology can also be referred to as cold briquetting. This is because it always involves low temperature of up to 100°C and the addition of binder is inevitable. Since this will improve the briquette forming characteristics binders are primarily used for the briquetting of substances that have an inadequate adhesive power and unable to produce a firm briquette.

For fuel pellets i.e. briquettes a number of binding agents have been tried . Examples include bitumen, tar, resins such as cassava glue, starch and gums (White and Plaskett 1981 ; Adegoke and Mohammed, 2002).

Terry (1978) reported that the use of thermoplastic resin as a binding agent for briquetting wood wastes makes the briquettes much stronger, easier to be handled, transported and fed into boilers. It was observed that the addition of this material increases the energy content of the fuel considerably, thus burning at higher temperature from untreated wood.

Apart from these two main types of technology briquettes may be made very simply by manual means using the hand, but their heat valve increase if they are pressed using simple devices such as presses made from rope, wood or metal (Karekezi and Ranja, 1997)

2.9 SAWDUST BRIQUETTING

Sawdust briquetting has been found to be a better way of releasing and controlling the amount of heat during the combustion process when used for cooking applications. (Adegoke, 2002). When sawdust is briquetted, chemical pollutants are eliminated and with enough supply of oxygen complete combustion of the fuel is guaranteed.

The lack of control of heat was the shortcoming of the locally produced stove called "Abacha" stove in 1997 during the kerosene scarcity in Nigeria. In the construction, sawdust is rammed into the stove and aided with a small amount of firewood at the base, and then the sawdust is burnt as cooking fuel. (Adegoke, 2001).

On the other hand, agricultural residues such as palm kernel shell, straw, etc in their raw form are generally not good quality fuels. They burn too quickly to be used for cooking purposes. They also produce too much smoke and not much heat (Walubengo, 1989). Briquetting these residues or adding them as additives with sawdust briquettes turns them into good quality fuel.

2.10 REASONS FOR BRIQUETTING

According to Karekezi and Ranja (1997), briquetting of biomass wastes has been proposed as one of the ways in which fuel shortages in developing countries might be alleviated. Several wastes that can be briquetted include sawdust groundnut shell, rice husks, straw of various cereals, papyrus, baggase etc.

Briquetting residues expand their use in energy production by improving their calorific value and reducing the cost of transportation to urban areas. It may also improve the availability of fuel in rural areas thus reducing the storage costs of fuels (Kristofferson and Bokalders, 1987).

Furthermore, fuel briquettes have uniform properties and are an effective means of using loose agricultural residues, unsuitable for fodder or fertilizer and too difficult to transport, which otherwise would be discarded (Dutt and Ravindranath, 1993).

An economical way for energy – processing industries to deal with wastes as well as producing fuel to meet their energy requirement is briquetting. Briquette production has been found to be economical if it is part of a disposal strategy in agro industry (Gamser, 1987).

Briquettes could be an important alternative energy for cooking in households especially during periods of charcoal and fuel wood shortages. In addition to all these, the following are the merits of briquetting biomass wastes.

(i) Production of good quality fuel that is often cheaper than ordinary charcoal.

(ii) Simplicity of the technology involved in making the briquettes and the stove to burn them.

(ii) It is a means of turning waste to wealth through the conversion of sawdust to briquettes that can be sold.

(iii) The briquettes produced always burn longer owing to high pressure applied during briquetting process.

(iv) Reduction of moisture content

(v) Increase in bulk density of loose waste material

(vi) It enhances the addition of other additives thus increasing the heating value.

(vii) Indirectly, it minimizes waste disposal in rivers, lakes and useful land thus preventing environmental pollution.

(viii) It enhances improvement in handling and transportation characteristics.

In spite of all these numerous advantages, briquettes has some short comings; one of this is that agricultural waste, which can be used as feedstock and fertilizer, could be eliminated as important source of nutrients to soil when briquetted. This could lead to lower farm yields or more application of synthetic fertilizers.

Also, the price of briquettes is often higher than that of wood and charicoal on a short term and this can limit their demand. They are unlikely to become cheaper than conventional fuels on a short term and may find a niche only when the price of the latter has risen sharply (Mc Chesney, 1989). On the long run, it is evident that the use of briquette can be advantageous over the conventional fuel.

Young (1987) clearly stated that the burning of briquettes produces a lot of smoke especially during the initial stage of combustion and may cause technical problem requiring specialized equipment in certain application.

2.11 RESEARCH AND DEVELOPMENT IN BRIQUETTING

Briquetting of biomass wastes has been practised for a long time. Much impact is being seen in the developing countries of Africa.

Adegoke and Mohammed, (2002) in their research demostrated and showed that sawdust mixed with an agricultural biomass has improved calorific value. This mixture of the sawdust and the agricultural biomass materials were compressed using a specially developed hydraulic briquetting machine that works on the principle of pelletization. The briquettes produced were then sun dried.

The agricultural biomass material used as an additive was palm kernel shell of grain sizes 3mm, 5mm and 9mm respectively. The palm kernel was mixed with the sawdust in ratios 1:9, 2:8, 3: 7, 4:6, and 5: 5 in that order. Starch and cassava glue were used as binding agents. The calorific value of individual mix was determined using a ballistic Bomb Calorimeter. At the end of the experiment it was observed that the 3:7 ratio mix having palm kernel shell of 3mm grain size yielded the maximum calorific value of 23.03MJ/kg.

The starch bound briquettes displayed the highest calorific value when compared to those with cassava glue. When the briquettes were burnt in an internally lined stove, heat losses to the environment was much reduced and a lot of cooking energy was obtained from a relatively small quantity of sawdust briquettes.

Walubengo (1989) affirmed in his work that a paper manufacturing company in Nairobi, Kenya makes briquettes out of sawdust and wood shavings using two types of presses, a "Thai" screw press and a Piston press. The briquettes were then burned in a

factory boiler. It is claimed that the company saves Ksh 60, 000 (1 U. S $ = Ksh 54) per month using this briquetted fuel which is an alternatie to oil.

Briquettes are more likely to succeed if introduced as a fuel for industrial or institutional use. The reasons for this are that (i) briquettes burn better in large furnaces and (ii) it may be necessary to introduce a new stove to burn briquettes in households for cooking. (Walubengo, 1989).

In Uganda, attempts at small-scale biomass briquette production have been made. A briquetting plant was installed by a company named "Black Power" in 1986. The raw material base was coffee husks and sawdust. Initially 5 tonnes/month of charcoal briquettes were produced. However, machinery started breaking down and production went down drastically.

Turyahikayo et.- al (1995) reported the efforts of some women groups called

Y. W. C. A. in Uganda. The Y. W. C. A. produced a manually operated plant which uses some portable parts. The Uganda Small-Scale Industries association (USSIA) is also supporting at least four briquetting groups. The rural women make use of old tins or pots instead of kilns for carbonizing, a process that takes more than 24 hours. The moulding of the briquettes is then done by hand. The more elementary method of briquetting which is popular among rural women is binding waste biomass with banana peels or soil, moulding with hands, and then sun drying. The raw materials are not carbonized.

In Zimbabwe, a project to evaluate the technical and material potential of briquetting technology was carried out at a farm, owned by the Agricultural Rural Development Authority (BUN, 1995a). Its objective was to use crop wastes to produce

fuel briquettes that can partly substitute the present consumption of fossil fuels. Crops wastes used during the project were maize stalks and cobs, coffee husks, cottons stalks, soya beans, sun flower stalks, farm grass, pine sawdust, teak sawdust, groundnut shells and leucaena seed pods. Briquettes of good quality were produced and tested during the pilot phase and distributed among rural and urban household.They were later found to be acceptable based on their performances. Engineering companies that are in position to provide back-up services to briquetting technology were later identified. Also a small briquette market for household use was identified. The Biomass User Network (B. U. N) a research group provided funds for project management, manpower, communication, documentation, project, vehicle maintenance and infrastructure development.

In Sudan, briquetting was developed within a decentralized carbonization and centralized briquetting strategy (Ali and Hood, 1992). This programme makes use of cotton stalks, traditionally burnt every year as a phyto- sanitary measure. Molasses from the sugar industry is used as a binding agent for the carbonized stalk briquettes. The programme has generated significant employment and provided rural household with an additional income.

Marketing of briquettes in Kenya especially in the household sector has been hampered by competition from charcoal and fuel wood which cost less. The management of briquetting plants has also been a major draw back as far as production and marketing is concerned. According to a survey conducted in Kenya, briquettes were considered to be more marketable as a fuel for industrial and institutional purposes than as a household fuel (Makau and Obura, 1991; Walubengo, 1990).

Razak and Hoi, (1997), carried out a survey on wood briquettes otherwise known as sawdust briquettes produced in Malaysia In their research, they compared the performance of the sawdust briquettes produced by five wood briquetting manufacturing companies to that of ordinary wood . It was discovered that sawdust briquettes has a high calorific value of 21MJ/kg as against 18MJ/kg of energy in wood. The moisture content was considerably reduced to 6% in the briquettes while that of ordinary wood was 25%. It burns with less smoke while wood burns with a high smoke causing pollution. Sawdust briquettes combusts or ignites easily when compared with ordinary wood. From survey, the cost of producing sawdust briquettes in Malaysia is MR$160/tonne (1U.S $= MR$4). All the sawdust briquettes manufactured are exported to Taiwan, South Korea and Japan.

More research and development works are still going in the area of briquetting. It is believed that in a question of time, biomass products will become inevitable for use especially during the shortage of conventional fuels.

2.12 PROPERTIES OF BIOMASS SOLID FUEL

In order to use biomass solid fuel such as composite sawdust briquette effectively, it is worthwhile to have a clear understanding of its physical and chemical properties. These will determine the combustion, heat released characteristics and material handling.

2.12.1 PHYSICAL PROPERTIES

There are many types of biomass fuels including sawdust, grasses, shells, husks etc. and these have variations in their physical properties. Each type of biomass behaves differently when they combust and it is essential to know their physical properties in

order to maximize their effectiveness and efficiency as fuels. Anon. (1987), gave the four main physical properties that can affect combustion of solid fuel as:size/shapes; density; moisture content and calorific value.

(i) SIZE/SHAPE

The greater the overall surface area of fuel exposed to the required quantities of oxygen and heat, the faster the combustion process will occur and hence the greater the power output.

Biomass fuels such as sawdust, husks are more useful in briquetted form. In this regard, there is an increase in the size of the fuel, reduction in overall surface area. Also the burning process is slowed down and the handling of the fuel is easily enhanced.

The size and shape of a fuel will always affect the configuration of the stove combustion chamber.

(ii) DENSITY/STRUCTURE

The density and structure are related in so much, as the proportion and size of pores in a biomass fuel affect its density. As the proportion of pores to solid matter increases, so the density decreases. These pores holding air or moisture have the effect of facilitating the escape of volatile gases and the breakdown of the structure as the material is burnt.

In a fuel such as wood in its natural state, the plant fibres lie virtually parallel; this promotes better burning and escape of volatiles. In many briquette fuels, this structure is partially disrupted, often making such fuels more difficult to burn. However, if low-density residue is not compacted into pellets or briquettes, much larger combustion

chambers are needed for a given heat output. The density of briquetted fuels can be varied to a certain extent.

(iii) MOISTURE CONTENT

Most biomass fuels are hygroscopic (i.e. they attract water and are therefore rarely dry). Charcoal is the least hygroscopic but its porous structure can hold large quantities of water if it gets wet. Most recently cut biomass fuels were found to contain a great deal of water (80-90% on a dry –weight basic). Over a period of several months, most of this moisture will evaporate, but a point will be reached when no further moisture loss occurs; the biomass is then considered 'air dried', having reached its equilibrium moisture content. The moisture content of air-dried biomass depends on the relative humidity and can vary from 10% – 26%.

The moisture content of the fuel has a very significant effect upon combustion. After the water content of the fuel has been heated to about 100°C, it evaporates; leaving the stove and the heat energy involved in the process is effectively lost and not recovered. For example, the moisture content of recently cut biomass (80-90% moisture content on dry weight basic) would reduce the net available energy by 50-60% as against the same biomass when it had been dried, and in practice the evaporation of this moisture can cool the fire so much that it cannot burn. Seasoning and drying the fuel correctly can correct this problem. Fuels with a high moisture content burns better in the traditional open fireplace, than in many improved stores that tend to restrict the air flow.

In the combustion process of biomass, the products of combustion are carbon dioxide, water vapour, ash and sulphur which if present, burns to SO_2. (Bansal *et-al*, 1990). The solid combustion products (ash) form just 1% of the total weight.

Fig.2.4 reveals the relationship between the combustion temperature and relative consumption of wood with the moisture content.

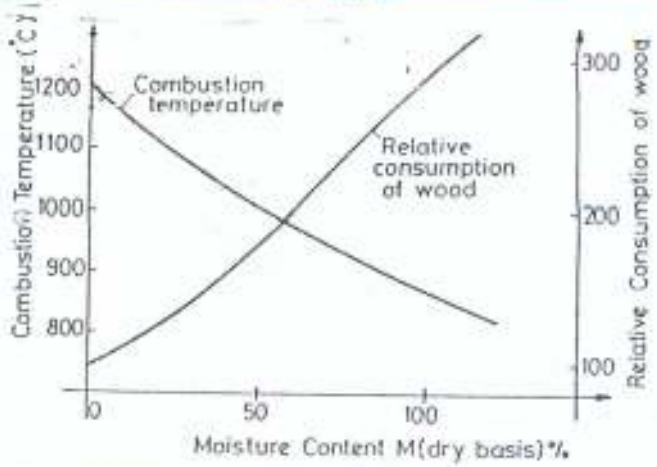


Fig.2.4: Combustion Temperature and Relative consumption of wood (Source: Bansal *et al*, 1990)

From Fig. 2.4 for dry wood, the consumption temperature reaches a value of about 1200°C. With increased moisture in the wood, the wood consumption increases as well while the combustion temperature declines.

(iv) CALORIFIC VALUE

The most important fuel property is its calorific or heating value. (Akachuku, 1997). It is a property of a biomass fuel that depends on its chemical composition and moisture content. Any fuel containing water or hydrogen has two calorific values namely: the higher or gross calorific value and the lower or net calorific value.

When fuels are compared the figure usually quoted for the calorific value is the gross calorific value (Earl, 1975). The gross calorific value always includes the heat derived from the condensation of any water vapour produced by combustion to liquid water.

The lower or net calorific value of a biomass fuel is the heat generated when the fuel is completely combusted to carbon dioxide and gaseous water, that is, the exhaust gases remaining above 100°C. It is usually expressed as the higher heat value less the latent heat of evaporation of the water formed as a by-product of the combustion process per kilogramme. Consequently, the difference in the higher and lower calorific values can be said to be the heat required to evaporate the water contained in the fuel and that produced by the consumption of hydrogen. It should be noted that apart from moisture content the calorific value of oven dry, ash free wood is related to the elemental composition of wood and to the structural components made up from these elements. In reality, the fuel is seldom oven dried and the effect of water supported within the fuel has an even greater effect upon the heat released.

The calorific value of wood varies from one tree to another. (Bansal *et. al,* 1990). Table 2.8 shows that for completely dried trees the calorific value lies between 18000 and 20000 kJ/kg.

Table 2.8: Calorific value of completely dried wood of various trees:

Type of Wood	Calorific Value (kJ/kg.)
Ash tree	18631
Beech (nut) tree	18841
Oak tree	18254
Pine tree	20180
Cilliandra calothyrus	19300
Emblica officinalis	21700
Anogeissus latifolia	20500
Acacia latifolia	19500

Source:(Bansal *et al*, 1990.)

Roughly speaking, the calorific value of average dried wood of nearly all kinds is almost half the value of the calorific value of oil.

Cheremisinoff (1980) stated that the gross calorific values of different woody species do not vary greatly, the average value being about 19259.28 kJ/Kg.

Neeman and Steinbeck (1979) worked on nine hardwood species and reported that the average calorific value of the wood and bark were 20,000 and 19,389kJ/kg respectively.

Wang *et. al* (1981) reported that the Calorific values of wood, bark, terminal branches and foliage were 18422; 25791;19301 and 20138 kJ/kg respectively all in a free species called "Mela Leuca" species.

2.12.2 CHEMICAL PROPERTIES

Most biomass such as sawdust briquette consist of three complex chemical compounds namely hemi cellulose, cellulose and lignin. It also contains water, smaller quantities of resins and mineral salts; the later remaining as ash after combustion which usually produced has no heating value.

Two analyses are usually carried out to describe the chemical properties of fuel namely; The Ultimate Analysis and Proximate Analysis.

The ultimate analysis always gives the approximate chemical composition of elements like carbon, oxygen, hydrogen, sulphur, nitrogen etc present in a fuel. The slight differences in chemical composition do not significantly affect the combustion performances of the different biomass fuels. However, the way biomass structure is broken down into its component during the initial heating up period prior to combustion often determines the heat release characteristics.

Table 2.9 gives an example of the ultimate analysis of certain biomass fuels.

Table 2.9: Ultimate analysis of some biomass fuel by percentage.

Fuel	Carbon (%)	Hydrogen (%)	Nitrogen & Sulphur(%)	Oxygen(by difference) (%)
Straw	49.4	6.0	0.4	44.2
Bagasse	48.0	6.0	-	46.0
Coconut shell	53.0	5.8	0.2	41.0
Wood (oak)	49.4	6.3	-	44.5
Wood (pine)	49.9	6.3	-	43.8
Peat	60.0	6.0	2.0	32.0

It can be seen that most fuels have an approximate composition of 50% carbon, 43% oxygen, and 6% Hydrogen.

On the other hand, the Proximate Analysis always gives the composition of biomass in terms of the amount of fixed carbon, volatile matter and of ash produced when it is heated in the absence of air. Table 2.10 shows the proximate analysis of some biomass fuels in percentage.

Table 2. 10: Proximate Analysis of some biomass fuels by percentage.

Fuel	Volatile matter	Fixed carbon	Ash
Straw	78.4	16.3	5.3
Rice husks	60.9	17.4	21.7
Bagasse	83-87	10-15	2-2.5
Coconut shell	78.0	21.6	0.4
Groundnut shell	67.0	32.4	0.6
Softwood	82.7	14.9	2.4
Hardwood	78.4	19.8	1.8
Peat	62.5	33.7	3.8

(Source: Anon., 1987)

2.14 COMBUSTION

Combustion is the process of burning a fuel in the presence of oxygen. The combustion of biomass solid fuel such as sawdust briquettes can be considered as taking place in stages (Anon., 1987). However, all the stages can be taking place at the same time. For example, a log of wood does not burn in one go. Similarly, a stove that is re-

charged during cooking will be experiencing different phases of combustion simultaneously.

The various stages involved during the combustion of a biomass solid fuel are:

(i) In lighting the fire, supplying the initial heat sources the water content of the fuel is evaporated off at 100°C.

(ii) When the fuel temperature reaches about 200°C and 350°C the volatile gases (carbon dioxide, hydrogen, and oxygen) are released.

(iii) The volatile gases evolved mix with more oxygen and ignite at temperatures in excess of about 450°C and burn with a yellowish flame radiating heat. Some of this heat is re-absorbed by the fuel to release more volatiles. This process is expected to become self-sustaining until all the volatiles have been released. The volatiles need sufficient heat, oxygen, space and time to ignite. If any of these are lacking the volatiles may leave the combustion chamber without igniting thus making the combustion to become incomplete and inefficient. The fire will be smoky and may die altogether. If the airflow through the combustion chamber is slightly turbulent, the volatiles and oxygen will mix more thoroughly. When all the volatiles have been released, charcoal, which is mostly fixed carbon, remains.

(iv) The charcoal burns and oxidizes provided there is sufficient oxygen at the fire bed at a temperature around 800°C. The carbon monoxide produced reacts with oxygen, provided it is available, just above the fire bed to give

carbon dioxide. The charcoal will usually continue to burn long after the volatiles have been used up.

A charcoal fire requires oxygen both at the fire bed (primary air) and just above the coals (secondary air). If there is insufficient secondary air, the fire will give off carbon monoxide, which can be dangerous especially in an enclosed space.

Figure 2.5 illustrates what happens when a fuel is combusted

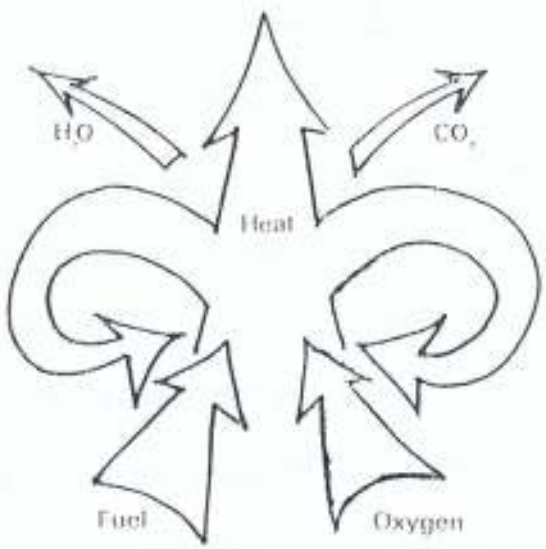


Fig. 2.5 : What happens in a fire : (Source: Anon., 1987)

CHAPTER THREE

3.0 EXPERIMENTAL PROCEDURE

3.1 MATERIALS.

In order to execute this research work, the materials that were used are; sawdust, charred palm kernel shell, starch, water, food items like rice, beans, and yam and kerosene fuel.

The sawdust was collected from one of the sawmills in Akure. In addition, the charred palm kernel shell was bought from a local market and the starch was obtained from a cassava-processing factory. The starch was later made into non-viscous gel to facilitate binding.

The following materials were also utilized during the course of research; briquetting machine, briquette stove, kerosene stove, weighing balance, cooking utensils, food stuff, bomb calorimeter and oven.

3.1.1 BRIQUETTING MACHINE

The briquetting machine was used for the production of the sawdust briquette. It is a manually operated hydraulic briquette making machine that can produce up to 16 briquettes at the same time depending on the type of mould used. It operates under the principle of pelletization. The briquetting machine developed by Adegoke *et.al* (1999), is constructed using mild steel plates, cylindrical hollow pipes, pistons, struts, springs, angle iron together with bolts and nuts as frame. Furthermore, a hydraulic system is incorporated to enhance the loading and unloading of the product. On the hydraulic system, there is a pressure

gauge, which indicates the pressure at which the compression of the briquetting is taken place. Plate 3.1, shows the machine under description.

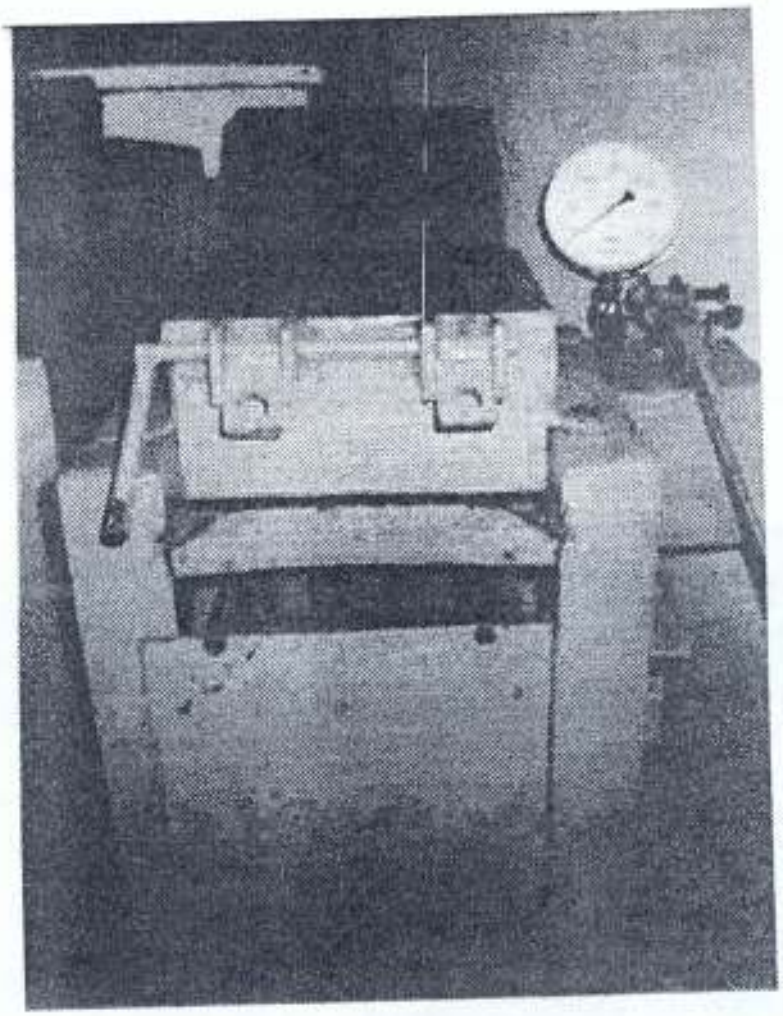


Plate 3.1: Briquetting Machine.

3.1.2 BRIQUETTE STOVE

The briquette stove is a special stove used for burning solid fuel like sawdust briquette. The frame of the stove is made of mild steel. The internal part of the stove is lined with local clay of low thermal conductivity. The major reason of lining the cook stove is to drastically reduce the heat loss through conduction from the sides of the metal plates and bottom thus ensuring that more heat is

available for cooking. The bottom of the lining material and that of the metal body are perforated and the two are rightly aligned. The holes perforated constitute grates. At the extreme towards the stand of the stove, there are air openings. In addition, there is an ash collecting point at the bottom of the stove. The grates together with the openings permit air needed for combustion of the fuel to be circulated properly in the combustion chamber. This promotes the complete combustion of the fuel. The grates permits ash obtained during combustion, which has a negligible energy value to be collected at the ash collecting point. Plate 3.2 shows the briquette stove.

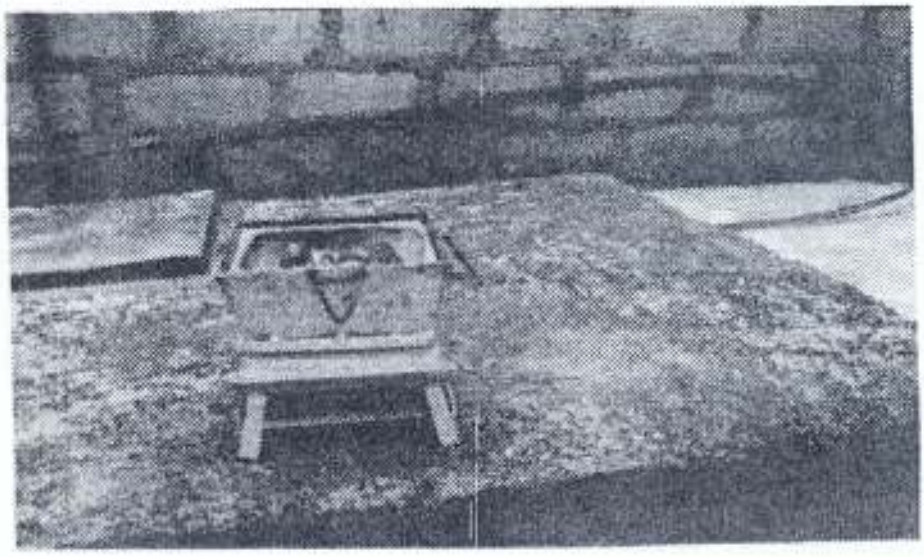


Plate 3.2: Briquette stove.

3.1.3 KEROSENE STOVE

This type of stove uses wick in the combustion chamber. The body frame is made of mild steel. The wick draws fuel from the fuel tank located at the base by capillary action. It has a regulator through which the flame can be controlled. The combustion zone has grates, which surround the wick and allow air to circulate properly thereby improving its combustion efficiency.

3.1.4 WEIGHING BALANCE

This is vital equipment employed in the course of the research. A balance is needed to weigh accurately and conveniently the various materials and even some equipment during the experiments. Two digital weighing balances and a mechanical balance were used during the experiments. One of the digital balances can weigh up to an accuracy of 5g. It was used at the experimental field. The second digital balance can weigh up to an accuracy of 0.5g. It was used for laboratory experimental work. The last weighing balance weighs up to an accuracy of 50g and was used at the experimental field.

3.1.5 TIMING DEVICES

Time devices like stop watch, wristwatch were needed to keep good time to determine the duration of the experiments. The stopwatch was used for the experiment. It always displays seconds as well as minutes.

3.1.6 THERMOMETER

Two types of thermometers were employed. These are Mercury- in- glass thermometer and digital thermometer. The Mercury-in-glass thermometer was used to measure the initial boiling and cooking temperatures. The digital thermometer is quite effective in measuring the ambient temperature and the stack temperatures.

3.1.7 COOKING MATERIALS

Cooking materials used during the course of the experiment include cooking utensils and standard meal. The cooking utensils used are cooking vessels such as cooking pots, lids pans, etc. In addition, the standard meals are those commonly consumed in the locality. The standard meals used during the experiments are yam, rice and beans.

3.1.8 BOMB CALORIMETER.

The Bomb Calorimeter is essential equipment used to determine the energy content of the briquette. It operates by igniting samples electrically and burning in an excess of oxygen in the bomb. The maximum temperature rise of the bomb is measured with the thermocouple and galvanometer system. By comparing this rise with that obtained when a sample of known calorific value is burnt, the calorific value of the sample material can be determined.

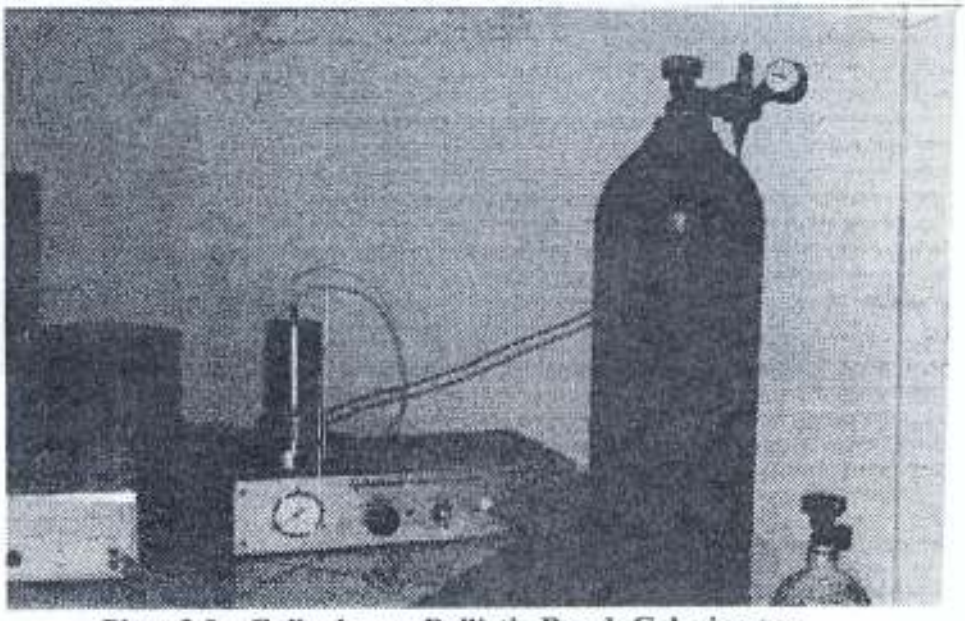


Plate 3.3 : Gallenhamp Ballistic Bomb Calorimeter

The Gallenhamp Ballistic Bomb Calorimeter as shown on Plate 3.3 was the type used for the experiment.

3.1.9 OVEN

The oven is a heating equipment usually meant for drying samples in the laboratory. Before the calorific values of the samples were determined, the samples were first oven dried in order to reduce their moisture content to the barest minimum.

Other equipment found useful includes tongs, gloves. A test record sheet is also essential to allow simple and logical recordings of all the data needed to carry out the final calculations. Plate 3.4 shows some of the equipment used at the experimental site.

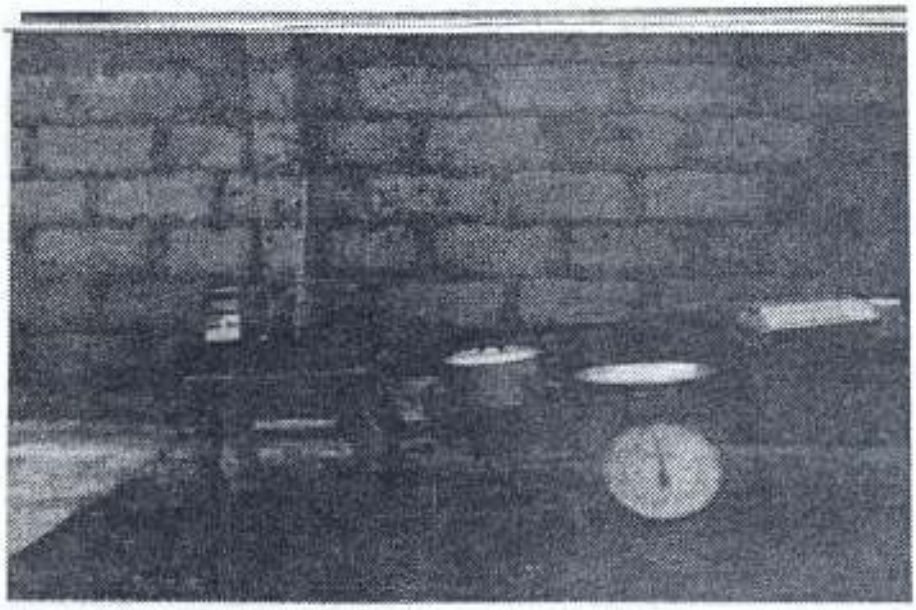


Plate 3.4: Equipment at the experimental site.

3.2 MATERIAL PREPARATION

The major materials used in the production of briquettes are sawdust, charred palm kernel shell and starch gel.

The process of preparing and getting these materials ready for the production of sawdust briquettes entails the following steps:

- Collection of sawdust sample from the sawmill
- Air-drying of sawdust in the sun or in the oven if possible for 3 weeks to reduce the moisture content.

- Screening of sawdust to remove unwanted materials like chaff etc.
- Crushing of charred palm-kernel shell to smaller grain size with the aid of a laboratory crusher.
- Sieving of the crushed palm kernel shell to the required grain size of 1.18mm, 2.00mm and 2.36mm respectively.
- Preparation of the starch material into a gel (very thick and non-viscous not watery). .

The briquettes were later produced using these materials by mixing sawdust and palm kernel shells forming a composite product in percentage ratios of 90: 10, 80:20, 70:30, 60:40 and 50:50 respectively. Starch gel was added to facilitate binding. The materials were thoroughly hand mixed to ensure homogeneity.

The batch production of the composite briquette using the manually operated briquetting machine was made feasible having measured each material according to their ratios. The briquettes produced were unloaded and later sun dried for few days. Plate 3.5 shows the composite briquettes under drying process in the sun.

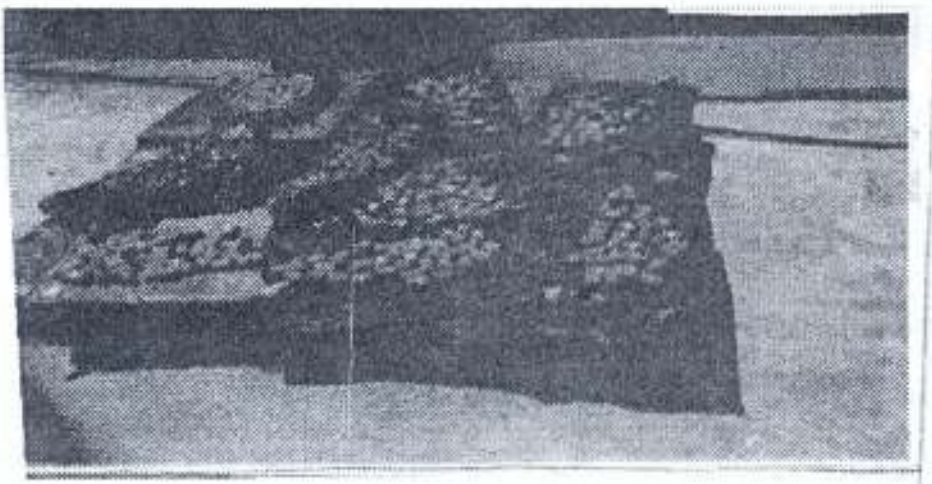


Plate 3.5: Composite Briquettes under sun drying process.

3.4 METHODS

The following are the methods used to carry out the various experiments.

3.4.1 CALORIFIC VALUE TEST

The calorific value test is one of the major tests to determine the energy content of a fuel. In determining the calorific value of the briquette, the apparatus was first calibrated using a standard sample of Benzoic acid whose known calorific value is 6.32 kcal/g. A known mass of sample of small quantity, 0.5g of the different compositions was placed in the crucibles. Small quantities of the sample material i.e. sawdust, palm kernel shell and starch binder were weighed individually in the stated ratios before being placed in crucible since they do not form a complete homogenous mixture.

One end of a cotton thread strand of length 50mm was inserted between the coil of ignition wire and the other end dipped into the centre of the sample in the crucible. The thread enhances the combustion of the sample inside the crucible. The bomb body was placed and tightly screwed in position.

The thermocouple wire was plugged into the hole on top of the bomb body. The pressure release valve was closed and oxygen was admitted into the bomb until the pressure rose to 25 bars.

The light spot index was set to zero using the galvanometer zero knob ensuring a stable temperature before the firing knob was depressed and released to fire the bomb. Heat is released and the maximum deflection of the galvanometer scale was recorded after which the burnt gases were released from the apparatus with the aid of the pressure release valve.

The maximum deflection obtained in the galvanometer was converted to energy value of the sample material by comparing the rise in galvanometer deflection with that obtained when a sample of known calorific value of benzoic acid is combusted.

The whole experiment was repeated and for each sample of different grade of palm kernel shell, 3- different readings were obtained. The following steps were taken in obtaining the calibration constant for the bomb calorimeter used.

Mass of Benzoic, $m_b = 0.384$

Calorific value of Benzoic = 6.32kcal/g

Galvanometer reflection without sample, $\theta_1 = 1$ division

Galvanometer deflection Benzoic acid $\theta_2 = 6.3$ divisions

Calibration constant, $\gamma = \frac{6.32 m_b}{\theta_2 - \theta_1}$ .....(3.1)

$\gamma = 0.46$

Having known the calibration constant, the calorific values of the various samples can now be obtained as follows

Let mass of sample = Z g

Galvanometer deflection with sample, $= \theta_3$ divisions

Heat releases from sample, $Q = (\theta_3 - \theta_1)\gamma$ kcal.

Therefore calorific value of sample = $(\theta_3 - \theta_1)\frac{\gamma}{Z}$ kcal /g can now be multiplied by a factor of 4.2 to obtain the final calorific value result in MJ/kg.

3.4.2 PERFORMANCE TEST OF SAMPLES

Before promoting the use of any new type of fuel, it is expedient to have good understanding of its performance. The performance of any solid biomass fuel such as sawdust briquette can be evaluated effectively when it is combusted in a specially made stove that has been designed and developed for this purpose.

Cook stoves which are internally lined with local clay of low thermal conductivity have been found to be more effective and efficient to burn sawdust briquettes in order to evaluate their performances (Adegoke,1999; Adegoke,2001; Adegoke and Mohammed, 2002).

The reasons for carrying out performance tests are:

(i) To determine the comparative performance of fuel to the stove.

(ii) To determine the potential and expected fuel savings offered by a stove.

(iii) To obtain the data necessary for optimization of stove design.

Anon. (1987), highlighted the three main types of tests that can be carried out on solid fuel in order to realize the above reasons these are:

(i) Field Test: This is carried out in a kitchen to determine actual fuel use.

(ii) Water boiling test

(iii) Controlled cooking test

These tests revealed quantitative and qualitative information about the fuel performance, by embracing the following characteristics:

(i) The amount of fuel required to cook a given quantity of food.

(ii) The thermal efficiency (i.e. Percentage Heat utilized, PHU) for different rates of boiling water i.e. high or low power.

(iii) The range of Power output from the fuel (i.e. also expressed as 'turn down ratio')

(iv) The ease of operation

(v) Level of pollution

(vi) Maintenance requirement.

(vii) Life time

Each of these tests highlighted earlier shall be explained one after the other

3.4.2.1 WATER BOILING TEST

This is a well-developed test that measures the time taken by a given quantity of fuel to heat and boil a given weight or volume of water.

It is a short, simple simulation of standard cooking procedures that measures the fuel consumed and time required for simulated cooking.

Scientist or field workers, at the initial assessment and development stage, usually carry out W. B. T in a laboratory or a field station. It can be used for assessment of stove design and optimizations of stoves when a solid fuel is made to combust. In some cases where cooking tests or kitchen field tests cannot be undertaken, water boiling test can be used to give a rough approximation of relative fuel savings. Its advantage is that it requires minimal equipment such as a stopwatch, a bottle to measure equal volume of water, thermometer and measuring scale.

In conducting the water boiling tests, the following procedures were taken. Dry weights of experiment materials like pot and stove were taken and recorded. The pot was filled with an initial known weight of water and the same weight was maintained throughout the course of the experiment. The standard quantity of water inside the pot is

preferably two-thirds of the full pot capacity. The initial water temperature was taken about 1cm above the bottom of the pot.

The initial weight of the sawdust briquette was taken before it was stacked in a round form inside the internally lined stove. A minimum of twelve pieces of briquettes was utilized during the course of an experiment. The fuel was ignited by adding a very small amount of kerosene to speed up the rate of initial combustion. One gramme of kerosene is assumed to be about 2g of briquettes. The kerosene used can be considered as fuel consumed, however the energy involved is so small that it may be safely ignored in the calculation. Although kindling the fuel would have been preferable since it would not permit the use of another fuel apart from briquettes, the rate of initial combustion will not be faster.

The lighting time was recorded. The fuel burns with fire during combustion. Immediately the fire went off, it started glowing with a red-hot flame having been fanned. The pot containing the known weight of water was placed on the stove with burning fuel. The temperature of the water was taken at 5 minutes interval until boiling took place. The boiling time was recorded. The weight of fuel remaining inside the stove at this point was recorded. Likewise, the weight of water remaining in the pot was recorded. The pot of water was placed back on the stove burning with fuel and the whole process continued for the next 15 minutes with rapid boiling. At the end of 15 minutes, the weights of fuel and water remaining were taken.

Furthermore, the process continues for the next 30 minutes and it was observed that boiling was reduced to the lowest level needed to keep the water simmering. At the end of the test, the water and fuel weight remaining were recorded. The stack temperature of

fuel was taken. The weight of charcoal remaining was taken into consideration. The values obtained during the experiment were used for analysis. The whole process of experiment continued with other briquettes composition.

The experiment was carried out in an open space where the wind is under a calm condition. At the initial stage, air was blown across the burning fuel by fanning at regular interval to enhance combustion performance.

The following parameters can be obtained during the water-boiling test:

(i) PERCENTAGE HEAT UTILIZED (P.H.U)

This is otherwise known as thermal efficiency or energy. The standard quantity of water that can be used to obtain this parameter is estimated as two-thirds the full pot capacity.

The P. H. U when used in the laboratory or fieldwork can be expressed as:

$$\text{P.H.U} = \frac{\text{Net heat supplied to the water}}{\text{Net total Heat utilized by fuel}} \times 100 \quad \ldots\ldots(3.2)$$

It can also be expressed as the ratio of the energy transferred to the water, divided by the energy liberated by the burning fuel.

$$\text{i.e. P.H.U} = \frac{\text{Energy transferred to the water}}{\text{Energy liberated by the burning fuel}} \times 100 \quad \ldots\ldots(3.3)$$

Using symbols or notations,

$$\text{P.H.U} = \frac{m_n C_p (T_b - T_0) + m_e L}{m_f E_f} \times 100\% \quad \ldots\ldots(3.4)$$

where:

PHU = Percentage Heat Utilized (Thermal Efficiency)

m_w = Mass of water in the pot (kg)

C_p= Specific heat of water (kJ/kgK)

T_o = Starting Temperature of the water (K)

T_b= Boiling Temperature of the water (K)

m_e = mass of water evaporated (kg)

L = Latent heat of evaporation (kg)

m_f = mass of fuel burnt (kg)

E_f = Calorific value of the fuel (kJ/kg)

According to Anon. (1987), if charcoal is left at the end of test i.e. the fuel does not completely burn to ashes, then a correction should be made to allow for the energy retained in the charcoal. The equivalent mass of fuel burnt, m_{eq}, in this regard is then given by:

m_{eq}= 1.5 (m_f– mass of fuel left – mass of charcoal) .....(3.5)

Fig. 3.5 gives a typical power/time curve that can be used to analyse the Percentage Heat Utilized.

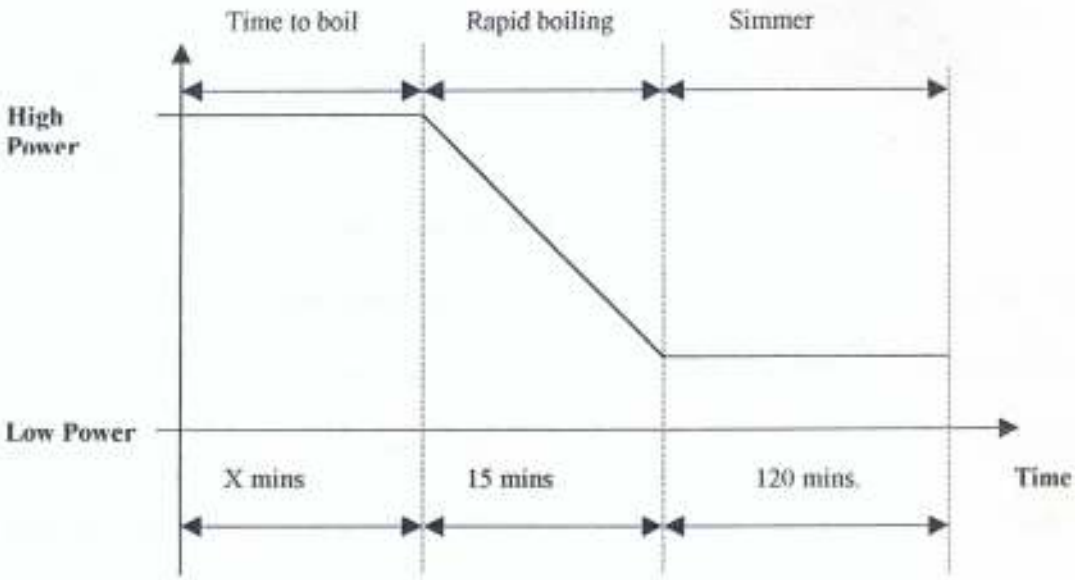


Fig. 3.5: Power/Time curve for analyzing P.H.U. (Source: Anon., 1987)

At the end of the experiment, in conjunction with the calorific test, the best fuel with good performance was selected. This was used to carry out the controlled-cooking test.

(ii) POWER OUTPUT

The power output is another parameter that can be used to determine the available amount of energy released from the fuel in a given time. For example a power output of 3kW equals 3 kilojoules per second, which is equivalent of about 0.6kg dry wood per hour.

The power output of fuel burnt in a stove is given by

$$P = \frac{m_f \times E_f}{t} \quad \text{.....(3.6)}$$

where: m_f = Mass of fuel burnt (kg)

E_f = Calorific Value of the fuel (kJ/kg)

t = Time taken for combustion (seconds)

In defining the performance of a fuel when burnt in a stove quoting the thermal efficiency (i.e. P.H.U) does not help since cooking usually involves a high power phase

as well as intermediate (boiling) and lower (simmering) power phases. Thermal efficiency (i.e. P.H.U) should always be quoted in relation to specific power output of fuel since they are dependent on each other.

Fig.3.6, shows the dependency of the P.H.U. on the Power Output. On the graph the maximum efficiency is gained at an output of 3kW but the stove can be used at lower or higher outputs with a consequent loss in thermal efficiency. The curve will vary with the type of wood or sawdust waste, moisture content etc. the curve may also shift if the operating conditions changes.

Once the P.H.U.- Power Ratio is known for a certain set of conditions then the aggregate efficiency for any cooking operation can be calculated.

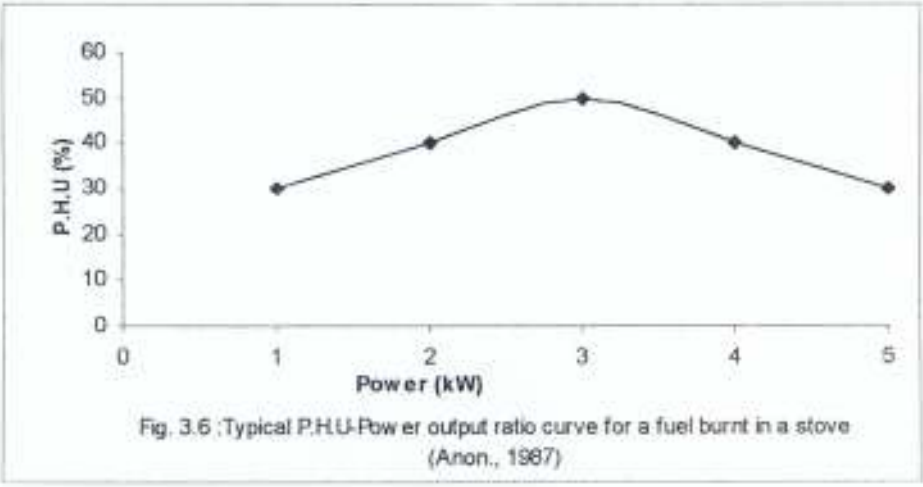


Fig. 3.6 :Typical P.H.U-Power output ratio curve for a fuel burnt in a stove (Anon., 1987)

(iii) SPECIFIC FUEL CONSUMPTION (S.F.C)

The use of Specific Fuel Consumption (S.F.C.) as a means for expressing the performance of a solid fuel when burnt in a stove is extremely useful and is becoming increasingly more popular.

In water boiling test the S.F.C. is defined as the amount of solid fuel equivalent used in achieving a defined task divided by the weight of the task. It can be expressed as:

$$S.F.C = \frac{m_f}{m_w} \quad \text{.....(3.7)}$$

where:

m_f is the mass of solid fuel required to achieve task (kg)

m_w is the mass of water (kg)

(iv) BURNING RATE (B.R.)

Other property that can be used under the Water Boiling Test to evaluate the performance of a fuel is the Burning Rate. This determines the rate at which a certain mass of fuel is combusted in air. It can be evaluated as:

$$B.R = \frac{m_f}{t} \quad \text{.....(3.8)}$$

where:

m_f is the mass of solid fuel required to achieve task (kg)

t is the time taken for combustion of fuel. (Seconds)

Appendix 2 could be consulted for more information and analyses on the Water Boiling Test.

3.4.2 CONTROLLED COOKING TEST

The Controlled Cooking Test (C.C.T) is another major test carried out to evaluate the performance of biomass fuel. It is intended to be an intermediate step between the water boiling tests and the kitchen performance test. This test involves the cooking of a standard meal and the results are most simply reported or recorded as the amount of fuel needed to cook the meal.

Danshehu *et.al* (1992), applied the controlled cooking test on a variety of local food items such as rice, beans, tuwon dawa and stew. Dry wood and dry sawdust were used for the test. The test enabled the determination of the Specific Fuel Consumption (S.F.C) and time spent. The Specific Fuel Consumption expresses the amount of dry wood and dry sawdust required to obtain 1kg of cooked food. According to Danshehu *et.al* (1992), S.F.C under the Controlled Cooking Test is given as:

$$S.F.C_{C.C.T} = \frac{m_f(1-Y) - 1.5m_{char}}{m_c - m_p} \quad \text{---------- (3.9)}$$

where :

$S.F.C_{C.C.T}$= Specific Fuel Consumption under Controlled Cooking Test

m_f = Mass of fuel burnt (kg).

Y = Moisture content of fuel (taken as 100% dry).

$m_{char.}$ = Mass of charcoal remaining after test (kg).

m_p = Mass of the pot(kg).

m_c = Mass of pot with cooked food (kg).

It should be noted if the fuel would not produce charcoal when burnt, the factor $1.5m_{char}$ in the equation is negligible.

On the other hand, the time spent when cooking a known weight of a food item, can be obtained from this relation according to Danshehu *et.al* (1992) as:

$$T_{C.C.T} = \frac{T_t}{m_{cp}} \quad \text{.....(3.10)}$$

where:

$T_{C.C.T}$ =Time spent (under Controlled Cooking Test)

T_t= Total time spent in cooking

m_{cp} = Total mass of cooked food.

In the course of the experiment, Controlled Cooking Test was carried out on three different foodstuffs namely, yam, rice and beans.

The following procedures were taken. Just like the water boiling test, the dry weights of pots, initial weight of the fuel of best composition were measured. The fuel was stacked inside the internally lined stove and ignited the same way it was done. During the test the quantity of food in the pot was equal and same weight of water was added into all the pots. The first experiment was carried out with yam. The pot containing water and yam was placed on the glowing fuel and left to cook. When the cooking was properly done, the weight of the cooked yam and time to achieve cooking were taken and recorded. In addition, the fuel remaining after cooking was also taken and recorded. The same process was carried on other foodstuffs. The experiment was repeated again for all the foodstuffs. Plate 3.6 shows the Controlled Cooking Test on the various food items.

Along side using the briquettes for cooking, a controlled cooking test was also carried out using kerosene stove. The essence of doing this is to compare the performance of the sawdust briquette produced with kerosene fuel under same cooking condition. This will enable one to compare the performance of a non- conventional energy source to that of conventional type, which is known to be of widespread use.

The same procedures were followed for other foodstuffs and the data collected were computed and analyzed. Controlled Cooking Test has an advantage over Water Boiling Test in that it gives a better production of actual fuel saving and consumption. APPENDIX 3 contains further information on the Controlled Cooking Tests.

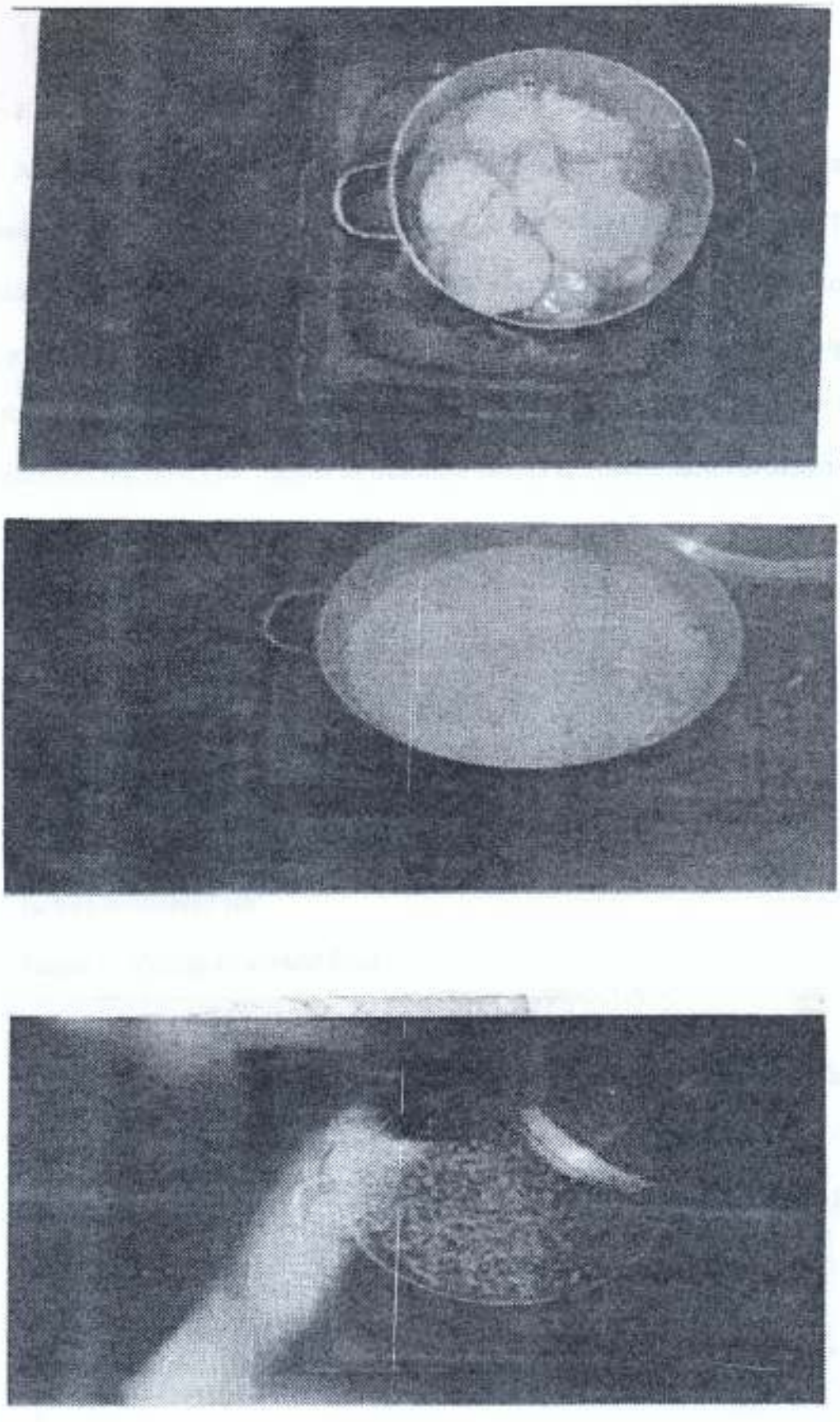


Plate 3.6: Controlled Cooking Test on yam, rice and beans.

3.4.4 FACTORIAL EXPERIMENTAL DESIGN

A factorial experiment was arranged as 2-factor factorial in a Complete Randomised Design (C.R.D) for calorific value test and controlled cooking test. Three replicates were obtained for the calorific test while two were obtained for the controlled cooking test. For the Calorific Value Test, a 3x5 factorial experiment can be designed, while for the Controlled Cooking Test a 2x2 factorial experiment can be obtained. Each of the numbers represents the number of treatment factors in 2-factor factorial design.

The following treatment factors were considered for each parameter.

(i) Calorific Value

Factor A: Size of Palm kernel shell

Factor B: Percentage composition of Palm kernel shell in samples.

(ii) Controlled Cooking Test.

The Specific Fuel Consumption and time spent in cooking were dealt with. The factors considered are:

Factor C: Variety of cooked food.

Factor D: Fuel Types.

Interactions AB and CD can be obtained between the treatment factors. Their effect could also be studied.

The mathematical model for the 2-factor factorial design is given by an expression:

$$y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk} \qquad (3.11)$$

Where,

μ = General mean for individual observation

A_i = Effect of factor A (same holds for C)

B_j = Effect of factor B (same holds for D)

$(AB)_{ij}$ = Effect of interaction AB (same holds for CD)

ε_{ijk} = Experimental error.

3.4.5 STATISTICAL ANALYSIS

3.4.5.1 Analysis of Variance (ANOVA)

Analysis of variance is a tool used to analyze data obtained from the 2-factor factorial experiment. It was conducted to estimate the relative importance of various sources of variations or treatment factors on Calorific value, specific fuel consumption and time spent in cooking under the controlled cooking test. In addition, the interaction effects between the factors under the factorial experiment were considered.

The following hypotheses were set up under ANOVA to justify the factorial experiment:

(i) Calorific Value Test.

factor A

Null hypotheses, H_0: The effect of factor A on the Calorific value is not significant

Alternative hypotheses, Ha: The effect of factor A on the Calorific value is significant

factor B.

Null hypotheses, H_0: The effect of factor B on the Calorific value is not significant.

Alternative hypotheses, Ha: The effect of factor B on the Calorific value is significant.

Interaction AB

H_0 :- The effect of interaction AB is not significant

Ha:- The effect of interaction AB is significant.

(ii) Controlled Cooking Test

factor C

Null hypothesis, H_0 :- The effect of factor C on S.F.C and Time Spent in cooking is not significant

Alternative Hypothesis, Ha: The effect of factor C on S.F.C and Time Spent in cooking is significant.

factor D

Null hypothesis, H_0 : There is no significant variability in the type of fuel used on S.F.C and Time Spent in cooking.

Alternative Hypothesis, Ha:- There is a significant variability in the type of fuel used on S.F.C and Time Spent in cooking.

Interaction CD.

Null hypothesis, H_0 :- The added variance component due to interaction CD is not significant.

Alternative hypothesis, Ha: There is a significance in the added variance component due to interaction CD.

The hypotheses set up were tested at 0.01 and 0.05 levels of significance using F-test. (APPENDIX 4).

The following inferences are to be deduced from the ANOVA TABLE

When F-calculated is greater than F-tabulated: reject H_0 and accept H_a

When F- calculated is less than F-tabulated: Accept H_0 and reject H_a from tables (APPENDIX 4) each tabulated value was obtained using the degrees of freedom of the numerator with respect to mat of the denominator in relation with the F-calculated

3.4.4.2 Graphical Representation

Graphs were plotted to show the patterns of variations in the parameters with amount of Palm kernel shell in the samples and also on the comparison of the type of fuel used during the controlled cooking test.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

The experimental results obtained during the course of this research are discussed as follows:

4.1 CALORIFIC VALUE

The results as shown on Table 4.1 indicates that the addition of palm kernel shell in various proportions increases the average calorific values, q_{av}, remarkably particularly when compared to the briquette produced from 100% pure sawdust material .The finer the grain size of palm kernel shell in the briquette, the higher is the calorific value up to a percentage by weight of 30%.

Fig.4.1 shows the graphical relationship between the average calorific value and the percentage by weight of palm kernel shell in briquette for the different sizes of shell using starch as the binding agent. Furthermore, the results obtained from the factorial experiments (Table 4.2) reveals that with respect to factor A i.e., the effect of variation of the different sizes of palm kernel shell on the calorific value is highly significant at both 0.05 and 0.01 level of significance. Hence, the null hypothesis at his point is to be rejected.

Also with respect to factor B (percentage composition), there is a significant added variance component on the calorific value at 0.05 level of significance. There is no significant interaction between the two factors A and B at any level of significance. Conclusively, the results in the calorific value show that the addition of palm kernel shell

into the briquette caused an improvement in the calorific values and that the various sizes of palm kernel shell and the briquette composition have a significant effect on the calorific values.

TABLE 4. 1: CALORIFIC VALUE OF SAMPLES

Size of P.K.S	% composition	q_1, MJ/kg	q_2, MJ/kg	q_3,MJ/kg	q_{av}, MJ/kg
1.18mm	50/50	21.83	22.8	20.87	21.85
	60/40	20.87	20.48	21.45	20.93
	70/30	21.64	20.02	23.57	22.41
	80/20	21.02	20.48	23.18	21.89
	90/10	20.87	21.24	22.78	21.63
2.00mm	50/50	19.32	22.02	18.55	19.96
	60/40	19.32	21.04	19.32	20.09
	70/30	21.64	20.09	22.02	21.25
	80/20	20.77	19.32	22.02	20.74
	90/10	18.16	17.77	18.93	18.29
2.36mm	50/50	18.93	18.16	19.71	18.93
	60/40	19.32	19.32	19.32	19.32
	70/30	19.71	20.09	19.32	19.71
	80/20	18.35	17.77	18.93	18.35
	90/10	17.77	17.00	18.55	17.77
CONTROL	100	18.35	17.58	17.00	17.64

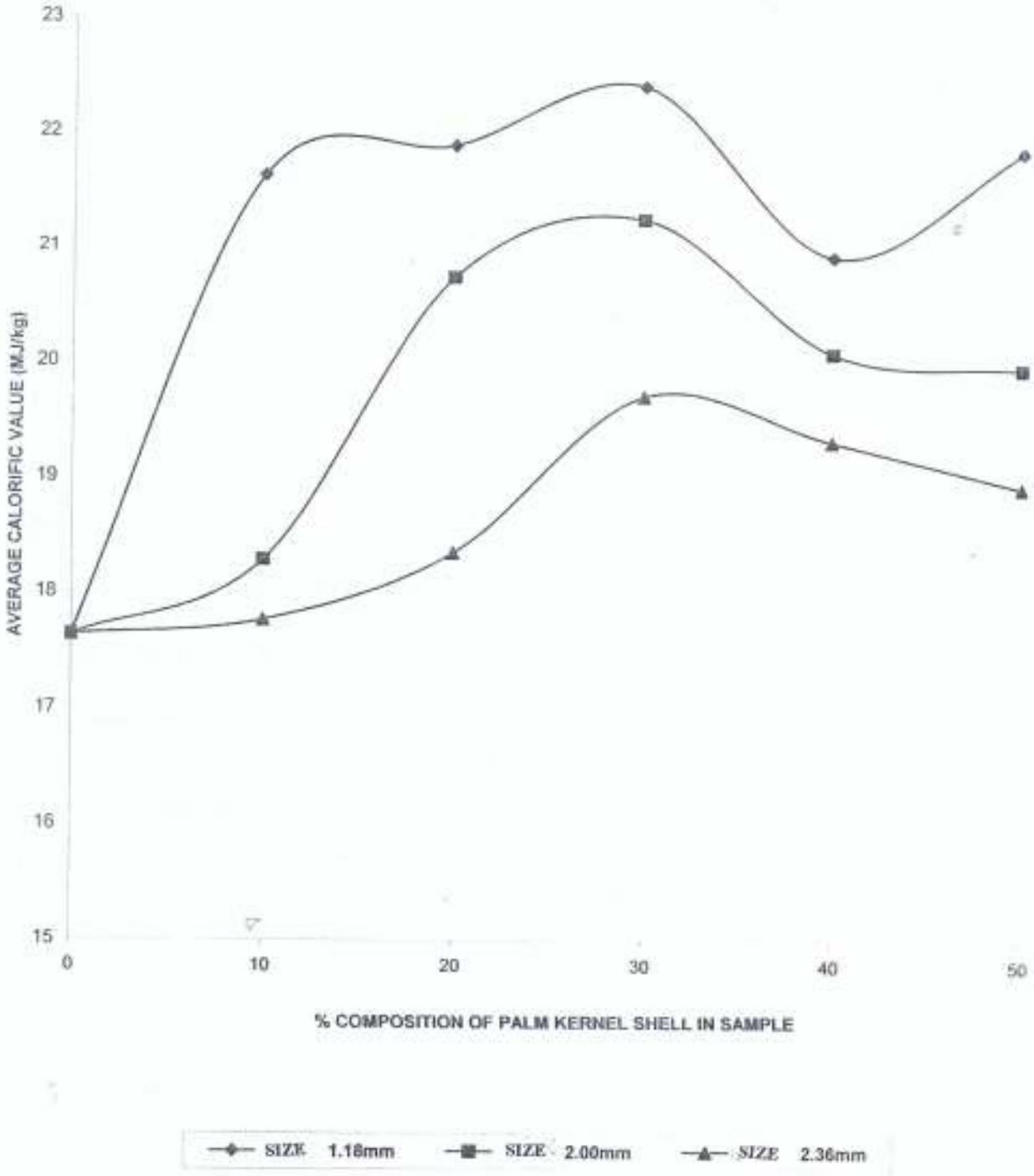


FIG. 4.1: CALORIFIC TEST

TABLE 4.2: ANOVA TABLE FOR CALORIFIC TEST.

S.V	d.f	S.S	M.S	F- Calculated	F- Tabulated		Comments
					0.05	0.01	
A	2	67.37	33.69	36.42	3.32	5.39	**
B	4	16.34	4.085	3.07	2.69	4.02	* / n.s
AB	8	10.62	1.33	1.44	2.27	3.17	*
Error	30	27.74	0.925				

S.V – Source of Variance

d.f - degree of freedom

S.S – Sum of Squares

M.S- Mean of Squares

**- highly significant ($p < 0.01$)

* _ Significant ($p<0.05$)

n.s. – value not significant ($0.01<p>0.05$)

4.2 WATER BOILING TEST

4.2.1 Percentage Heat Utilized. (P.H.U)

From the experiment, the Percentage Heat Utilized increases considerably from one power phase to another as shown on Table 4.3. It increased from the intermediate phase (i.e. initial boiling) through the high power phase (15 minutes after initial boiling) to the low power phase (30mins after high power phase) except in 70%/30%, 80%/20%, 90%/10% and 100% samples. Looking critically at Fig. 4.2, by following the trend, the average Percentage Heat Utilized increases gradually as the percentage of palm kernel shell in the samples increases.

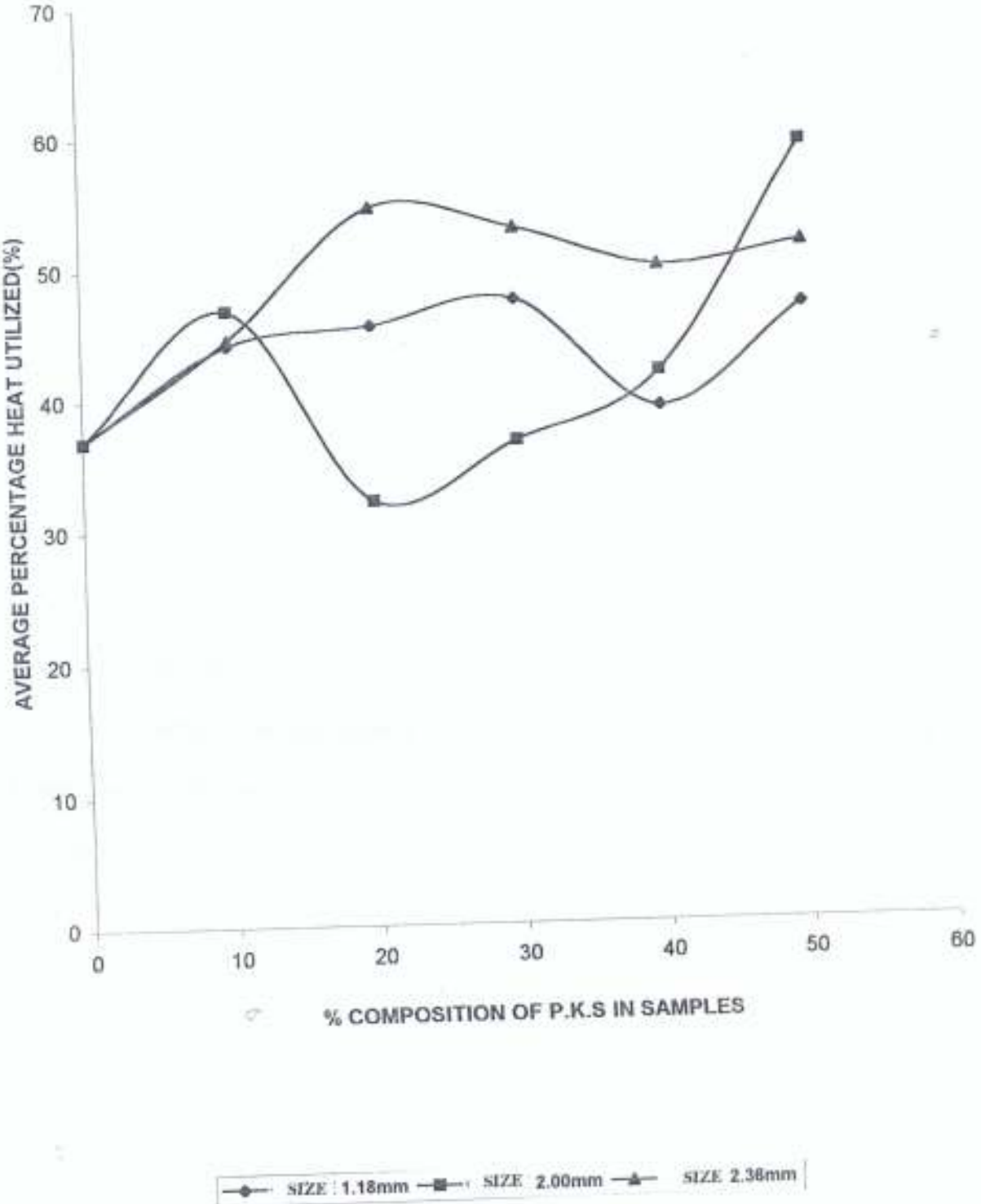


Fig. 4.2 :VARIATION OF AVERAGE PERCENTAGE HEAT UTILIZED WITH PERCENTAGE COMPOSITION OF P.K.S IN SAMPLES

TABLE 4.3: P.H.U- Percentage Heat Utilized

Size Of P.K.S	% Composition Sawdust/ P.K.S.	Intermediate Phase	High Power Phase	Low Power Phases	$P.H.U._{av}$
1.18mm	50/50	7.17	12.63	37.62	46.79
	60/40	4.22	15.63	29.81	39.03
	70/30	5.20	11.74	40.24	47.41
	80/20	5.24	7.4	40.45	45.52
	90/10	5.19	14.78	39.68	44.14
2.00mm	50/50	7.51	10.71	51.5	59.09
	60/40	7.37	6.54	36.4	41.73
	70/30	5.93	2.20	34	36.62
	80/20	5.16	22.54	19.71	32.15
	90/10	5.89	17.3	37.15	46.82
2.36mm	50/50	8.99	22.3	37.78	51.47
	60/40	7.8	17.79	38.51	49.83
	70/30	6.09	17.70	41.99	52.84
	80/20	5.90	37.55	34.64	54.5
	90/10	6.63	58.03	14.43	44.53
CONTROL	100	13.32	7.02	30.3	36.91

4.2.2 Specific Fuel Consumption (S.F.C)

The specific fuel consumption for each sample decreases from the intermediate power phase to the low power phase in most of the fuel compositions irrespective of the sizes as shown on Table 4.4. This shows that much fuel was required to bring water into boiling i.e. the intermediate phase and this decrease up to the point of simmering i.e. low power phase. Looking critically at Fig.4.3, the Specific Fuel Composition increases as percentage of palm kernel in sample composition irrespective of sizes, decreases. Fuel composition irrespective of sizes with high specific fuel consumption will be best suitable for high power cooking (i.e. rapid frying and boiling). Fuel with percentage compositions 80/20, 90/10 and 100 are most suitable for these tasks. On the other hand, fuel with low specific fuel consumption can be best used for both low and high power cooking. The low power cooking always takes longer time to be done e.g. beans.

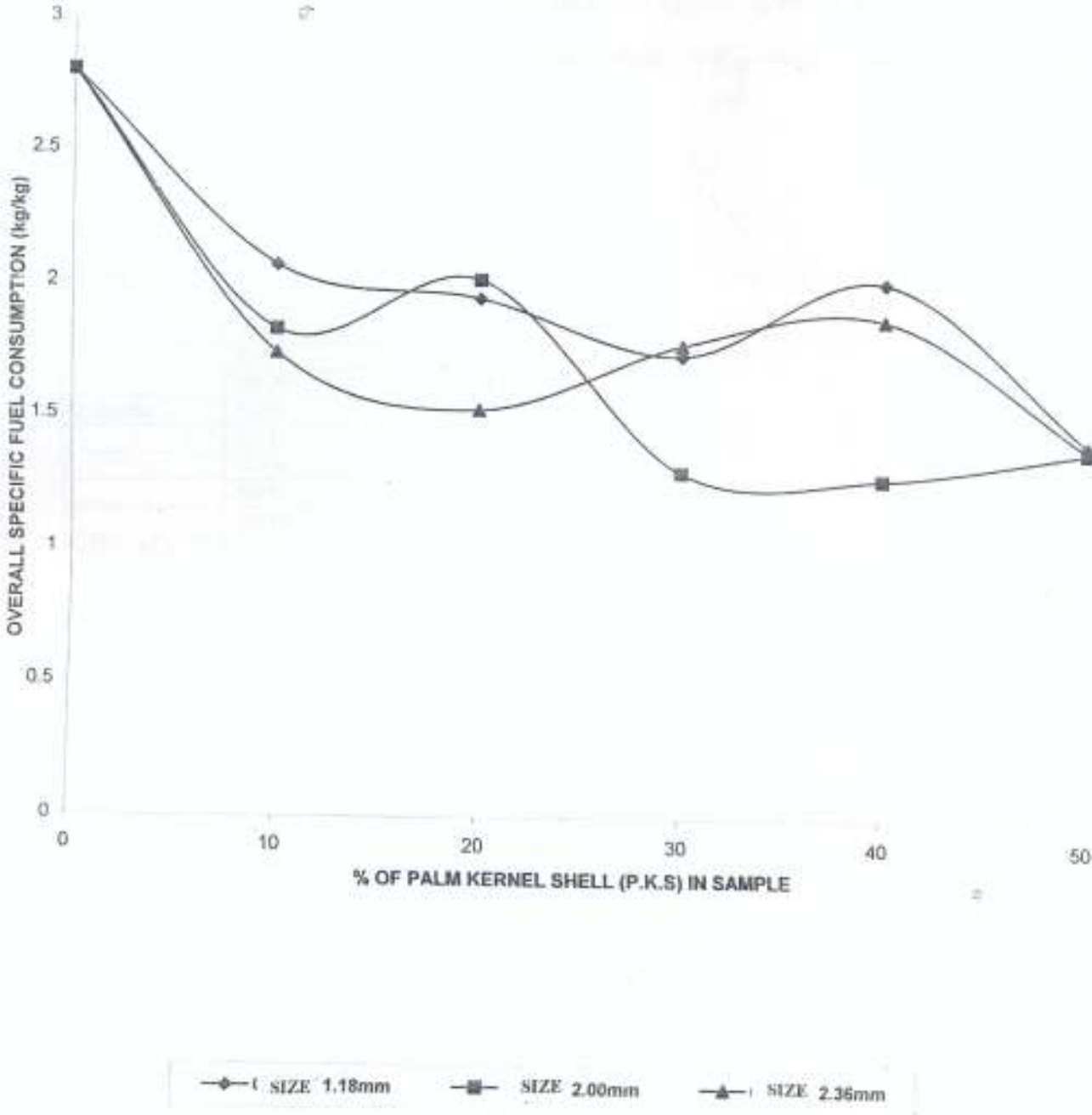


FIG. 4.3: VARIATION OF OVERALL SPECIFIC FUEL CONSUMPTION WITH PERCENTAGE COMPOSITION OF P.K.S IN SAMPLES

TABLE 4.4: Specific Fuel Consumption (S.F.C),(kg/kg) under W.B.T

Sizes of P.K.S.	% Composition Sawdust/ P.K.S.	Intermediate Phase	High Power Phase	Low Power Phase	Overall.
1.18mm	50/50	4.49	1.45	0.419	1.42
	60/40	6.5	3	0.59	2.02
	70/30	6.76	2.23	0.402	1.74
	80/20	7.23	3.07	0.421	1.95
	90/10	8.49	1.334	0.576	2.07
2.00mm	50/50	6.13	0.922	0.307	1.39
	60/40	8.27	1.1	0.569	1.28
	70/30	4.14	0.83	0.461	1.30
	80/20	6.93	0.943	0.843	2.02
	90/10	12.26	1.3	0.613	1.83
2.36mm	50/50	3.58	1.08	0.55	1.40
	60/40	4.44	1.58	0.36	1.88
	70/30	5.42	1.473	0.884	1.78
	80/20	11.46	0.664	0.656	1.53
	90/10	10.12	0.431	1.663	1.74
CONTROL	100	2.67	6	1	2.8

4.2.3 Burning Rate.

Table 4.5, shows the burning rate of the sawdust briquette fuel at each phase. From the table it is observed that the burning rate is highest at the end of Intermediate Phase when changing to High power phase. This makes the boiling of water to be rapid and faster at the beginning of the High Power Phase. The burning rate was lowest at the low power phase. At this point the water is said to be simmering.

Fig. 4.4 indicates that the overall burning rate of the fuel increases as size increases. This is true up to 35% of palm kernel shell in sample composition when comparing the sizes. The implication of this is that as the grain size increases the number of pores inside the fuel increases thus making the fuel to be less dense. This in turn causes the fuel to burn faster.

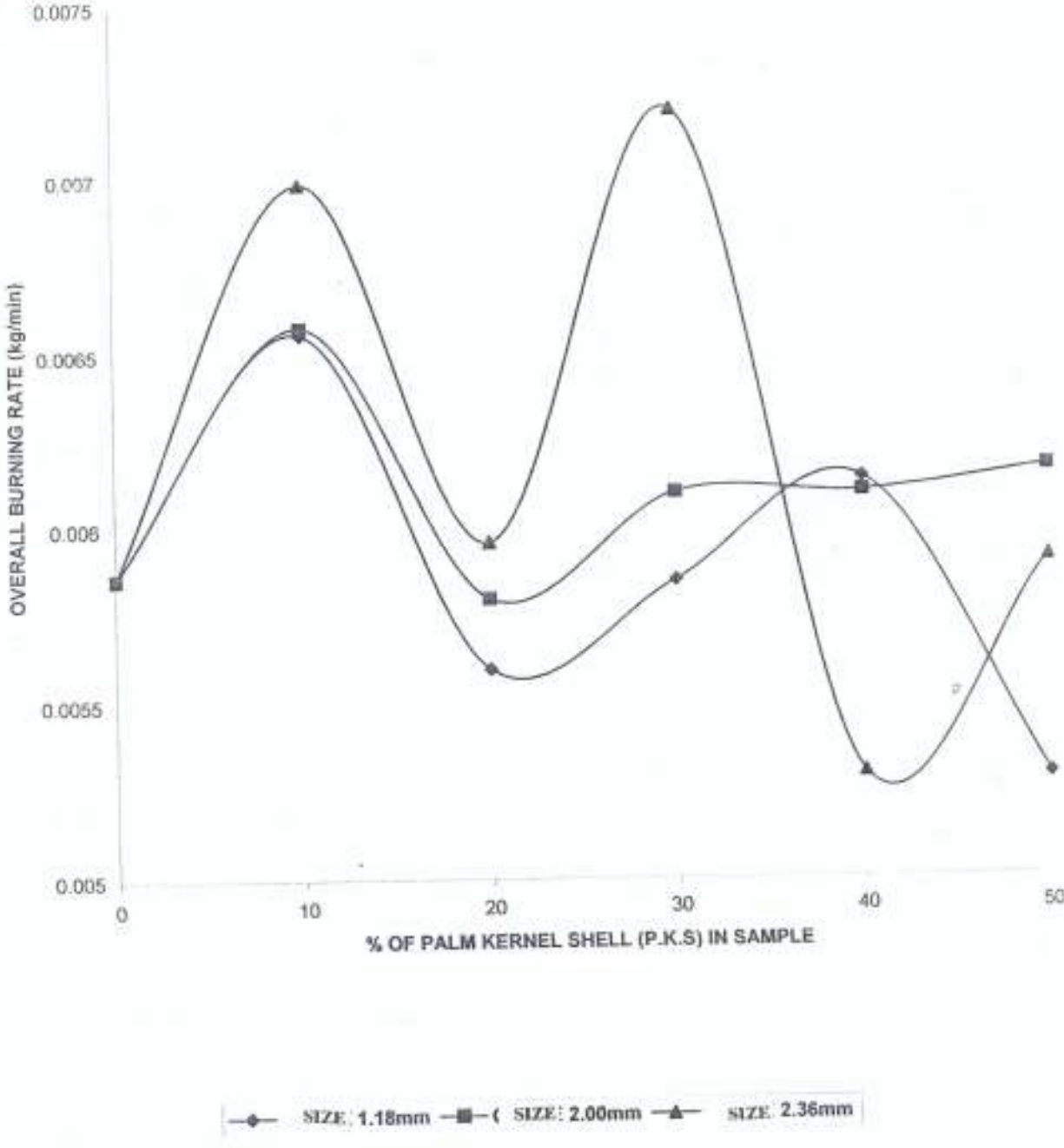


FIG.4.4 :VARIATION OF OVERALL BURNING RATE WITH PERCENTAGE COMPOSITION OF P.K.S IN SAMPLES

TABLE 4.5: BURNING RATE, (kg/min).

Size Of P.K.S	% Composition Sawdust/ P.K.S.	Intermediate Phase	High Power Phase	Low Power Phases	Overall
1.18mm	50/50	0.00741	0.00979	0.00156	0.00529
	60/40	0.01375	0.0049	0.00245	0.00614
	70/30	0.01366	0.0067	0.00167	0.00585
	80/20	0.00126	0.0067	0.00083	0.00056
	90/10	0.01386	0.00431	0.0057	0.00656
2.00mm	50/50	0.01421	0.0067	0.00167	0.00617
	60/40	0.0094	0.01	0.075	0.00610
	70/30	0.0146	0.005	0.00217	0.0061
	80/20	0.01524	0.000497	0.00167	0.00658
	90/10	0.0144	0.00962	0.00167	0.00658
2.36mm	50/50	0.0125	0.007	0.00183	0.00591
	60/40	0.0122	0.00634	0.00084	0.0053
	70/30	0.0194	0.00650	0.00074	0.0072
	80/20	0.01514	0.0046	0.00238	0.00596
	90/10	0.0138	0.00332	0.00564	0.00699
Control	100	0.0083	0.0120	0.00167	.00586

4.2.4. Power Output.

Table 4.6, shows the power output of the composite briquette at each phase during the W.B.T. It is observed that in most of the samples it is highest at the intermediate phase while lowest at the low power phase. This is so because more power is needed to bring water to boiling at the intermediate phase whereas at the low power phase the power output would have been reduced drastically having passed through the high power phase. The average power output for most of the samples especially those of 1.18mm size of palm kernel shell falls within the range of 3 kW as shown in Fig. 4.5. There is more stability in the power output of sample having 1.18mm palm kernel shell size when compare to others as shown in Fig. 4.5.

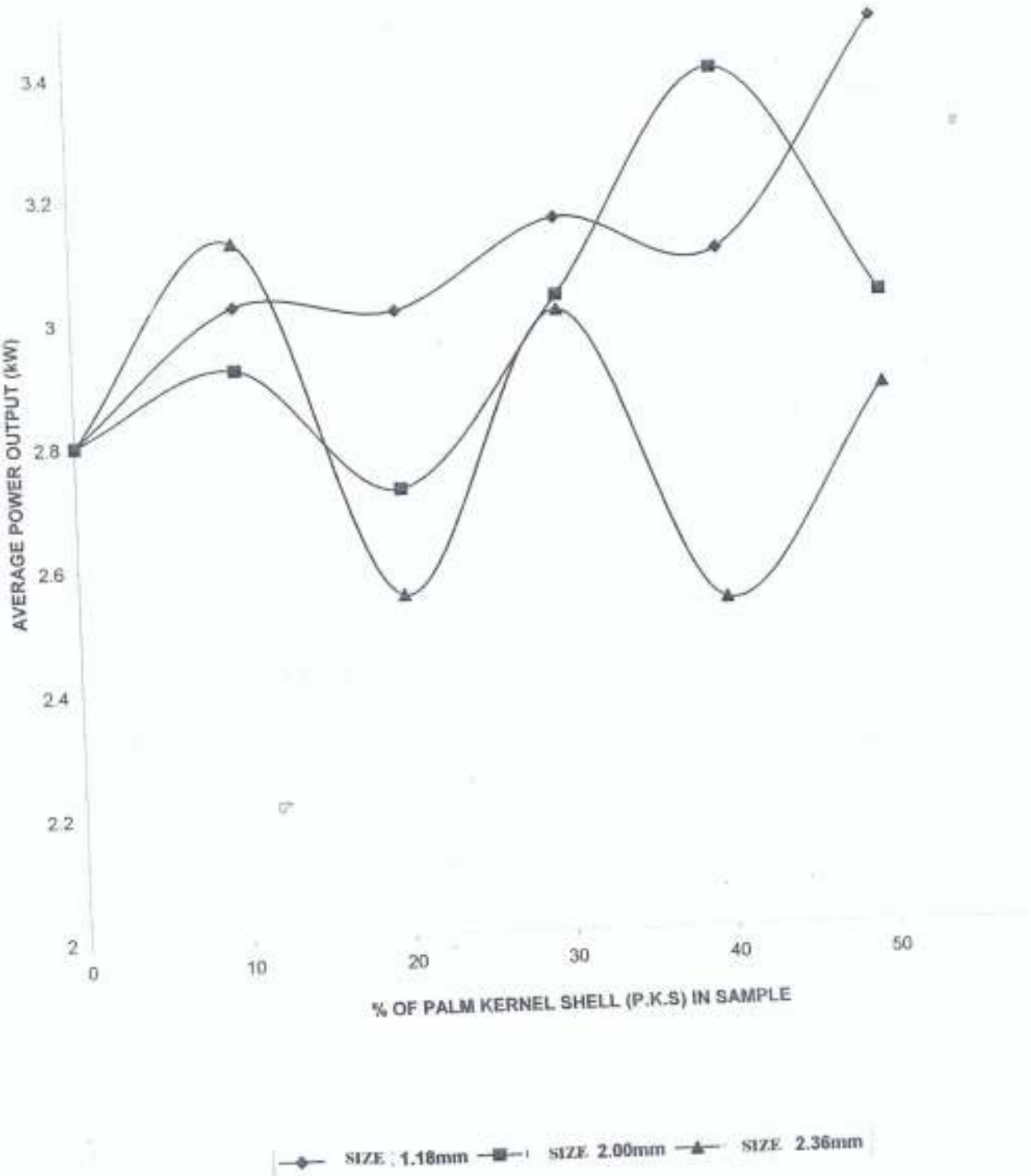


FIG.4.5 :VARIATION OF AVERAGE POWER OUTPUT WITH PERCENTAGE COMPOSITION OF P.K.S IN SAMPLES

TABLE 4.6 : POWER OUTPUT DURING COMBUSTION ,(kW)

Size Of P.K.S	% Composition Sawdust/ P.K.S.	Intermediate Phase	High Power Phase	Low Power Phases	Average Power Output
1.18mm	50/50	2.75	3.64	0.607	3.467
	60/40	4.83	1.744	0.872	3.096
	70/30	5.14	2.49	0.6225	3.1525
	80/20	4.61	2.43	0.608	3.01
	90/10	4.996	3.004	0.3605	3.023
2.00mm	50/50	4.81	2.22	0.554	3.02
	60/40	3.188	3.32	0.837	3.39
	70/30	5.186	1.771	0.7674	3.028
	80/20	5.281	1.728	0.5761	2.720
	90/10	4.41	2.941	0.508	2.92
2.36mm	50/50	4.054	2.0314	0.631	2.87
	60/40	4.008	2.147	0.322	2.53
	70/30	6.43	2.19	0.2694	3.004
	80/20	4.664	1.427	0.7432	2.55
	90/10	4.09	0.9872	1.67	3.126
Control	100	2.434	2.271	0.49	2.802

4.3 CONTROLLED COOKING TEST

The 70/30 percent composite briquette having palm kernel shell of size 1.18mm was selected to be the best having considered the calorific values, which is one of the most important properties for selecting a good fuel. This sample was used to carry out the control-cooking test. Its performance was compared to that of kerosene fuel; a conventional source of energy commonly used for cooking.

Figs.4.6 and 4.7 respectively shows the graphical relationship between the S.F.C, time spent in cooking per kg and cooked food types using both 70/30-percentage composition briquette and kerosene fuel.

The graphical results reveal that yam has the lowest specific fuel consumption ratio of 0.12 when sawdust briquette is used and 0.0435, when kerosene was used; followed by rice, and beans had the highest value. These indicate that the higher the

specific fuel consumption, the higher the quantity and weight of fuel that will be burnt to achieve cooking tasks. On the other hand, yam has the lowest time spent in cooking per kg of 40.34min/kg for briquette fuel and 30.36min/kg for kerosene fuel. This value increased for those of rice and beans. Furthermore, on the graph, kerosene fuel possessed a low S.F.C. The cooking times when compared to briquette fuel both have a close value when used for cooking beans.

Considering the results obtained from the factorial experiments, using Table 4.7, it can be inferred that with respect to factor C (i.e. the effect of the type of cooked food on the specific fuel consumption is highly significant at both 0.05 and 0.01 levels of significance, the same effect holds for the time spent in cooking per kg. Hence, the null hypotheses at these points are rejected. Considering factor D, the effect of the type of fuel used for cooking on the S.F.C. is not significant since F-calculated is less than the F-tabulated, hence the null hypotheses hold. Same effect holds also for the time spent in cooking per kg. (Table 4.8). There is no significant interaction between the two factors under consideration at any level of significance.

It can be concluded that only the type of cooked food have significant effects on the Specific Fuel Consumption ratio and the Cooking Time irrespective of the type of fuel used.

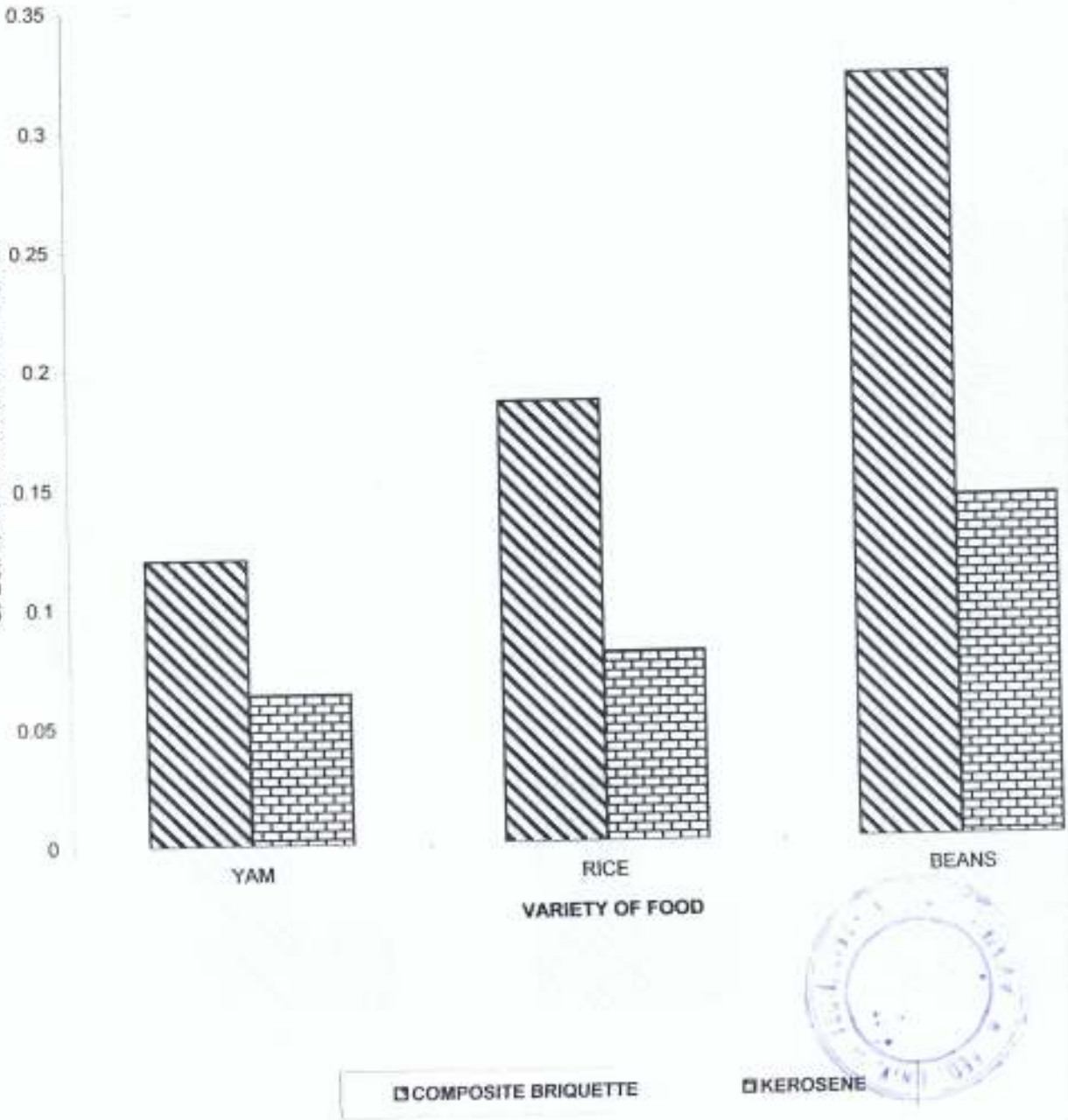


FIG.4.6 :COMPARISON OF SPECIFIC FUEL CONSUMPTION UNDER CONTROLLED COOKING TEST

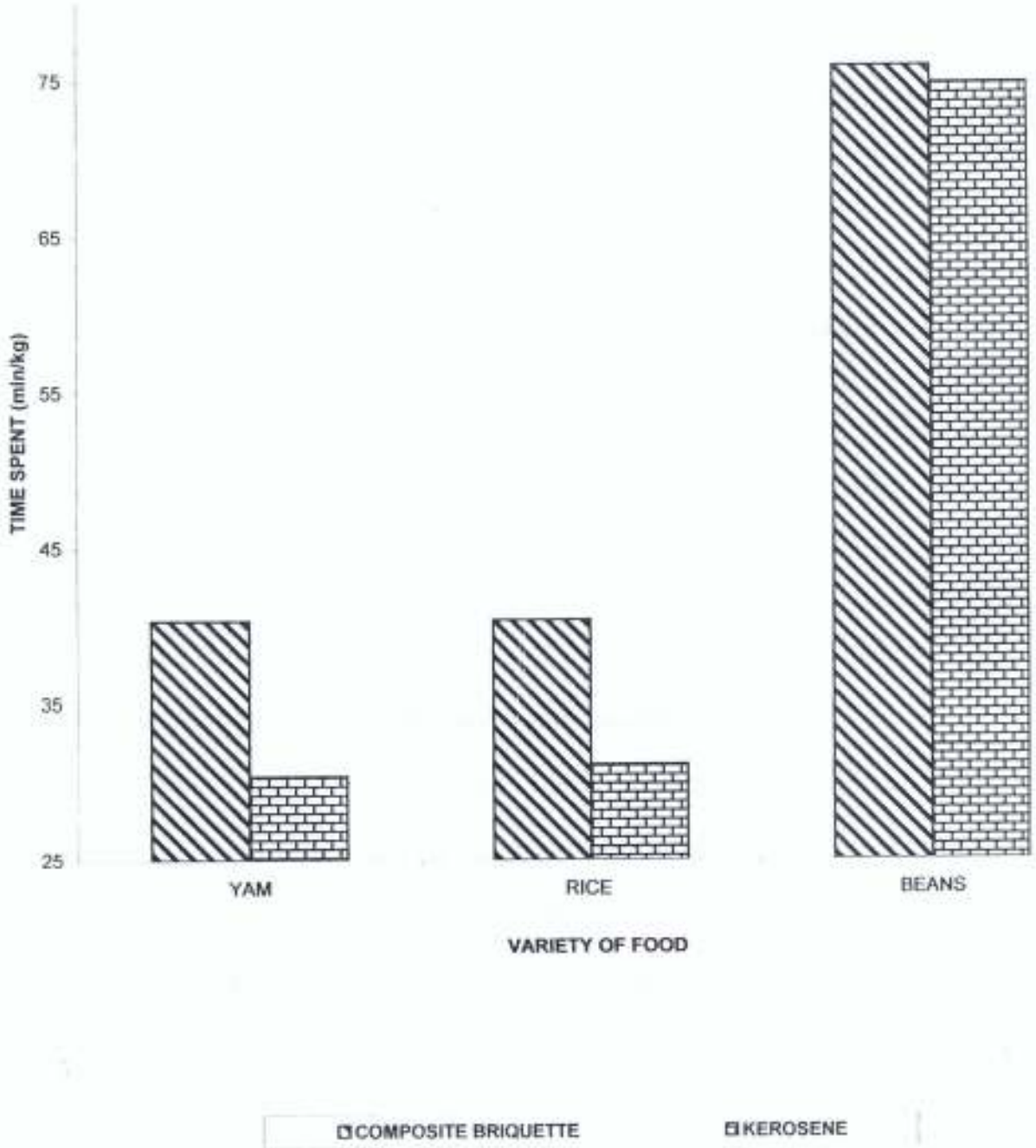


FIG.4.7 :COMPARISON OF TIME SPENT TO COOK 1kg OF FOOD

temperatures in excess of about 450^{0}C and burned with a yellow –bluish flame radiating heat.

Towards the end of the high power phase, the level of smokiness was not significant and this led to the commencement of the low power phase. This lasted for 30 minutes after the high power phase has taken place. At the low power phase, the process becomes self-sustaining until all the volatiles have been released. At this point charcoal was formed and it burns provided there is sufficient oxygen at the fire-bed. The charcoal will continue to burn long after the volatiles have been used up.

At the end of combustion the amount of ash and charcoal formed were weighed and recorded in Table 4.4I (APPENDIX 3). It was keenly observed in Fig.4.8 that the mass of ash formed increases as the percentage of palm-kernel shell increases on the sample. It is highest for the 2.36mm grade size. The same observation also holds for the amount of charcoal formed as shown in Fig. 4.9. The mass of charcoal remaining at the end of combustion increases as the percentage of palm-kernel shell increases in the sample as shown in Fig. 4.9. It is highest for the 2.36mm grade size.

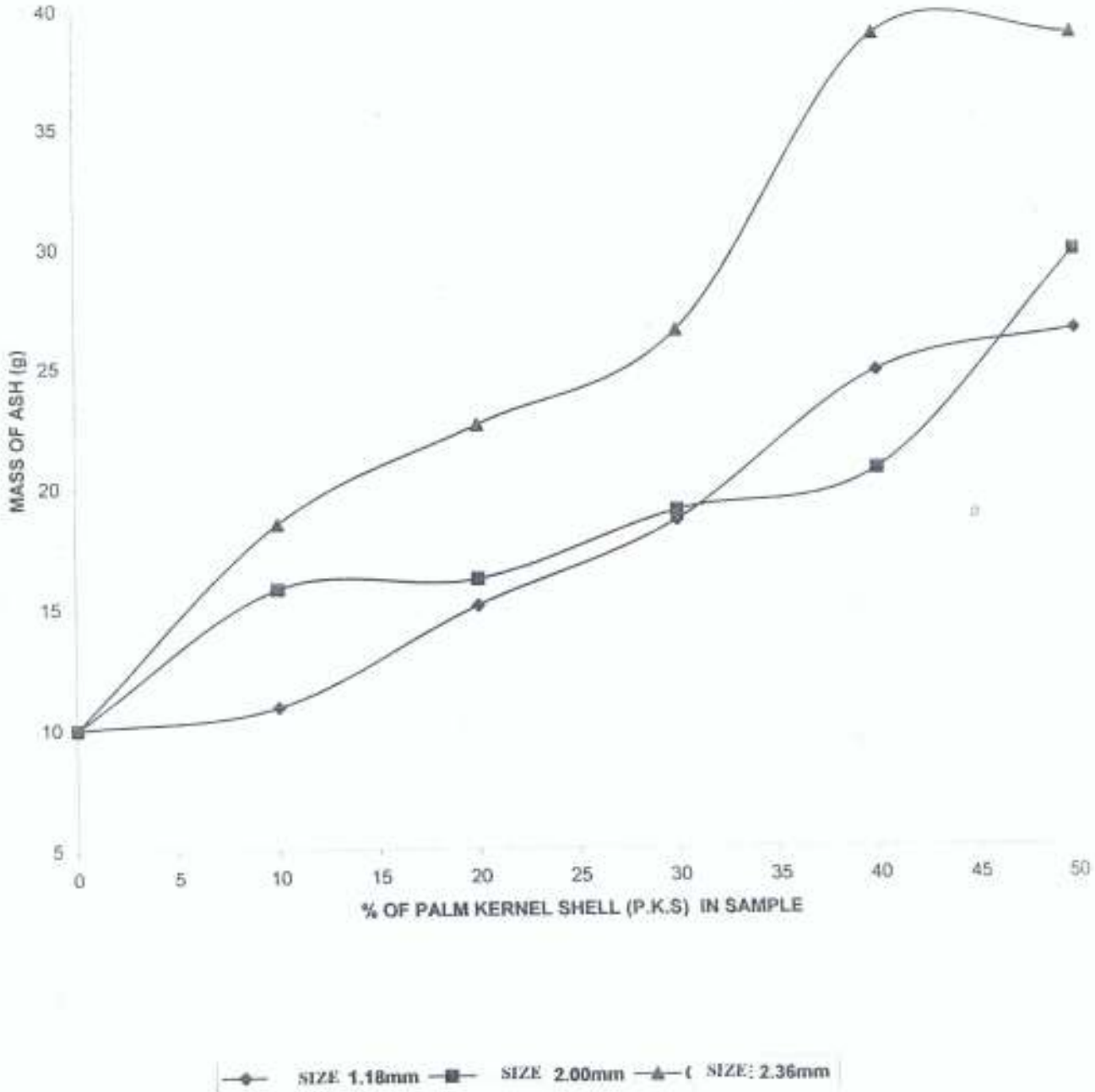


FIG.4.8 : VARIATION OF MASS OF ASH LEFT AFTER COMBUSTION WITH PERCENTAGE OF P.K.S IN SAMPLE

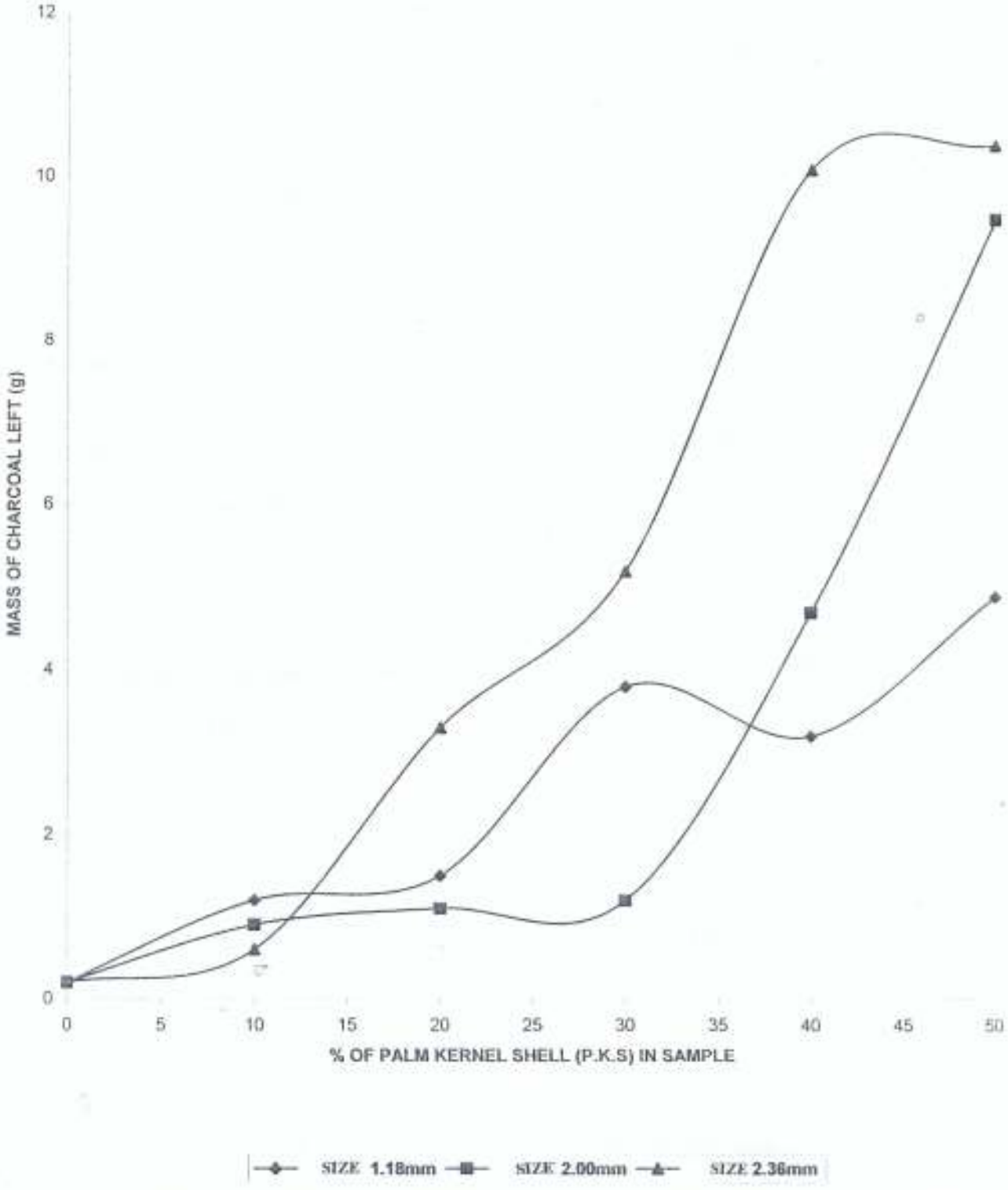


FIG. 4.9 : VARIATION OF MASS OF CHARCOAL LEFT AFTER COMBUSTION WITH PERCENTAGE OF P.K.S IN SAMPLES

4.5 Observation during the Compression of Briquettes

The force exerted during the compaction of briquettes using the manual operated briquette machine is a Compressive force. It can be determined by using the relation:

$$F = P\,A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Where

F = the force exerted during compression (N)

P = the Pressure mounted by the piston over the briquettes inside the moulds measured by the pressure gauge. (N/m^2)

A = the cross sectional area of the hydraulic piston. (m^2)

The pressure for compression was maintained at 1000 Psi = 6.89 x 1000 = 6.89 MPa. Since 1 Psi = 6.89kPa

Also the Cross Sectional Area, $A = \frac{\pi d_p^{\,2}}{4}$ .....(4.2)

where d_p is the diameter of the hydraulic piston = 103mm = 0.103m

$$A = \frac{\pi(0.103)^2}{4} = 8.33 \times 10^{-3} m^2$$

The overall force exerted during compaction of briquette is therefore calculated thus:

$$F = 6.89 \times 8.33 \times 10^{-3}$$

$$F = 57.4 \times 10^{-3} \text{kN}$$

Since a maximum of 16 briquettes can be produced at the same time, the force exerted on each briquette during compaction is calculated as

$$F = \frac{57.4 \times 10^{-3}}{16} = 3.59 \times 10^{-3} \text{ kN} = 3.59\text{N}$$

It was observed that this load is sufficient to compress this number of briquettes at the same time without shearing the product.

By reducing the number of briquettes produced say to around 8 or 4 still using the same pressure, the load on each briquette will be increased tremendously to twice or four times that of the maximum possible number of briquette to be produced. It was observed that this could shear the briquette produced thus causing a reduction in size. The surface finish will also be affected in this regard. Hence, the pressure has to be reduced considerably to achieve this task.

4.6 Comparative Cost Analysis Between Sawdust Briquette And Kerosene Fuel

A comparative cost analysis has to be carried out for composite sawdust briquette and kerosene a conventional fuel commonly used for domestic cooking. This will be done to know the fuel with the best economy.

Generally, cost analysis and comparisons often consider only the internal cost elements involved in the production and distribution of various energy forms. The internal cost is also referred to as the variable or material cost. In standard cost analysis and comparisons, all cost elements of production and consumption processes, which are handed down to the third parties i.e. the consumers, do not show up in the market prices. These cost elements are called social costs and are termed external effects since they are external to the market process and the economic agents producing them. Examples of Social cost include fixed costs (i.e. wages, administration cost etc.), operating cost, total production costs etc.

Hohmeyer (1992) gave a list of possible costs that are often excluded from the normal pricing of energy that can be used for comparison of different energy technologies. These include:

(i) Impacts on human health: short term impacts like injuries, long term diseases like cancer, intergenerational impacts due to genetic damage.

(ii) Environmental damages to global climate materials.

(iii) Long term costs of resources depletion.

(iv) Structural macroeconomic impacts such as employment effects.

(v) Subsidies such as Research and Development (R&D) subsidies, investment subsidies, operation subsidies etc.

(vi) Psycho-social costs of serious illness and death, relocation of population due to construction or accidents

For simplicity and benefit of the research work, the cost borne by each fuel shall be used for the comparative cost analysis.

The breakdown of the cost incurred in the production of sawdust briquette is as shown on Table 4.9:

TABLE 4.9: COST INCURRED ON COMPOSITE SAWDUST BRIQUETTE.

Item No.	**Cost**
Sawdust	Nil
Palm kernel shell	₦12.14/kg
Starch	₦ 50.00/kg
Total material cost	₦ 62.14
Labour	₦ 20.00/kg {estimated wage expected to be collected by worker per day assuming 4000 pieces of briquettes (25g each) are produced}

On the other hand, the material cost of kerosene incurred when compared to this is about ₦ 45/litre by volume or ₦ 59.10/kg by mass. Considering all these factors that can be borne by these forms of energy based on overall cost, it is expected that the cost of production, distribution and utilization of renewable energy sources such as composite sawdust briquette will be much lesser than that of kerosene. This is expected to be realized on a long-term basis.

CHAPTER FIVE

5.0 CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

5.1 Conclusion

Sawdust briquettes were produced and evaluated as alternative fuel for domestic cooking in the course of the research. Experimental analyses carried out have revealed that sawdust wastes usually generated in large uncontrolled quantities together with some other biomass additives can be converted to a high-grade solid fuel that will be suitable for domestic cooking.

In addition, the cost effectiveness of using this type of fuel when overall cost is to be considered will surely make sawdust briquettes more economical compared to conventional domestic fuels like kerosene. This will be a better way of fashioning an energy system that will not only be sustainable by the society but relatively equitable on a long term.

5.2 Suggestions for Further Work

Having realized the stated goals and objectives of this research, the following suggestions are made:

(i) The comparative cost analysis between the composite sawdust briquettes and kerosene fuel could not be carried out adequately. This is because the idea of briquetting is a new development; still in the feasibility and experimental stage. Therefore, an intensive cost analysis i.e. an overall cost should be carried out to really determine the economy of using composite briquette as a cooking fuel over conventional fuel like kerosene. This can be possible when the full production of composite sawdust briquettes begins.

(ii) The various elemental compositions in the composite briquettes were not determined. It is suggested that the Proximate and Ultimate analyses should be carried out for further work.

(iii) Other biomass additives like paper wastes, coconut husks etc. should be tried apart from palm kernel shell.

(iv) Binding agents like cassava glue, thermoplastic resins etc. should be tried to compare their performances with starch.

Further research work could be done in the following areas of renewable energy:

a. Conversion of sawdust wastes into energy sources through other methods like pyrolysis and gasification.

b. Investigation on other renewable energy source like biogas, wind energy, geothermal energy and solar energy.

c. Investigation on sawdust species best suitable for the production of briquette.

REFERENCES

Abeels P.F.J. (1987). Biomass Harvesting Technology and Energy balance. A paper in Biomass Energy: From Harvesting to Storage. Elsevier Applied Science Publishers Ltd. Pp 119-121.

Adegoke, C.O. (1999). A Prelimnary Investigation of Sawdust as High Grade Solid Fuel, Nigerian Journal Renewable Energy, 7(1and 2):102-107.

Adegoke, C.O. (2001). Waste to Wealth: Sawdust Briquettes as a Case Study, Paper presented at the Mechanical Division of NSE Conference Lafia Hotel, Ibadan 20-21 April

Adegoke, C.O. (2002). Energy As Veritable Tool For Sustainable Environment, Inaugural Lecture Series 31 of The Federal University of Technology Akure, delivered in April 2002.

Adegoke, C. O. and Mohammed T. I (2002). Investigation of Sawdust Briquette as High Grade Fuel. West Indian Journal of Engineering. 25(1):1-8.

Adegoke, C.O; Alatise, M.O and Mohammed, T.I. (1999). Development of a manually operated Hydraulic Briquetting Machine. Personal Communication.

Akachuku, A.E. (1997). Calorific Value of Gmelina Arborea Wood and its Relationship with Plantation Age. The Nigerian Journal of Forestry.: Pp 47-49.

Akinbami, J.F.K (1997). Comparative Environmental Effects and Cost Analysis between Conventional and Non-conventional Energy Source- A Case for Objective Analysis and Decision making in Nigeria's Energy Policy, Nig. Journal of Renewable Energy.5(1 and 2): 131-139.

Akindele,S.O.(1996). Basic Experimental Designs in Agriculture Research. Montem Paperbacks, Akure, Nigeria.

Ali, G.E.F and Hood,A.H (1992). Household Energy in Sudan. KENGO wood Energy programme for Africa, Nairobi,Kenya. Pp 7-10.

Anon., (1987). Improved Wood, Waste and Charcoal Burning Stoves. A Practical Manual. Intermediate Technology Publications, Covent Garden, London, U.K.

Bachou, S.A (1990). Key factors for the dissemination of Renewable Energy Technologies: Cookstoves and Briquettes in Uganda. Paper prepared for the fourth AFREPREN workshop, 10-16 August. Pp 26-29.

Bansal, N.K.; Manfred, K. and Michael, M. (1990)- Renewable Energy Sources and Conversion Technology. Tata McGraw- Hill; New Delhi.

British Standards Institution (1961). Defintions of the calorific values of fuels. BS 526, London, U.K.

BUN {Biomass Users Network}(1995a). "Crop Waste Briquetting a Success", Biomass News.Causaway, Zimbabwe. 1(1): 7.

Cheremisi noff, N.P. (1980). Wood for Energy Production Ann. Arbor Publishers Inc.

Danshehu B.G., Sambo A.S. and Musa M. (1992). Comparative Performance of Saw-dust and Wood-Burning stoves. Nigerian Journal of Renewable 3(1&2): 50-55.

Diana ,S.; Israel, B ;Ross, H and Judith, S(1985): Energy: Crisis or Opportunity? An introduction to Energy Studies. Macmillan Publishers Ltd.

Dutt,G.S. and Ravindranath N.H.(1993). Bioenergy: Direct applications in Cooking.Island Press Washington D.C.

Earl D.E. (1975). Forest Energy and Economic Development. Clarendic Press Oxford.

Gamser, M.S.(1987). Briquetting and the Poor, Intermediate Technology Development Group (U.K.).

Hall, D.O. (1993a). "Biomass Energy". Renewable Energy Prospects for Implementation edited by Jackson, T. Stockholm Environment Institute, Sweden.

Harker, A.P, Sandels, A. and Burley, J. (1982). Calorific Values for wood and bark and bibliography for fuel-wood. Published by Tropical Product Institute Germany. Pp.162.

Hohmeyer, O. (1992). Renewable and the Full Costs of Energy. Energy Policy, April. Pp 365-375.

Jackson T. (1991). Renewable Energy- great hope or false promise? Energy Policy Journal.1 (1): 2-7.

Karekezi, S. and Ranja, T. (1997). Renewable Energy Technologies in Africa. Zed Books Ltd., London.

Kristoferson,L.A. and Bokalders, V.,(1987). Renewable Energy Technologies: Their Applications in Developing Countries, Pergamon Press, Oxford.

Kyiogwom,U.B.; Rades,M.J. and Garba,B. (1997). Economics of Household Energy Consumption and Its Environmental Implications in Semi-Arid area of Northern Nigeria. Nigerian Journal of Renewable Energy. 5(1and2):61-63.

Luis, F.D; Savage, G.M.; Gobel, R.P; Golueke, C.G; and Trezek, G.J. (1976). Market Potential of Materials and Energy recovered from Bay Area Solid Wastes. A report submitted by the College of Engineering, University of California, Berkeley to the State of California Solid Waste Management Board. Pp.352.

Madu, C. and Sodeinde O.A. (2001): Relevance of Biomass in the Sustainable Energy Development in Nigeria . A paper in Proceedings of the National Engineering conference and A.G.M of NSE. Port-Harcourt, Nigeria. Nov. 5-9.

Makau,D. and Obura, B., (1991). Briquetting of Biomass wastes. Proceedings of the International Biomass Centre, Nairobi, Kenya.

Mc.Chesney, I (1989). "Briquettes". Potential Impact on Urban Poor. Boiling Point Special Edition.

Momoh, M. (1997). Wood Conversion to Energy. The Potentials and Constraints of Wood Energy Utilisation in Africa. Nigerian Journal of Renewable Energy. 5(1and2):140-142.

Neeman,M. and Steinbeck,K. (1979). Short Rotation Forestry for Production of Fuelwood. A monograph of Agric. Inst. Oak Park, Carlow, Ireland.

Palmer, P.D. (1988). Issues and Options in Fuel Wood Conservation, EDI Working Papers, 2-5.

Probstein R.F and Hicks R.E.(1982). Synthetic Fuels. McGraw –Hill Inc.

Razak M.A. and Hoi W.K. (1997). Biomass Energy Utilization Opportunities in Asia with special reference to Malaysia. Proceedings of the International Conference on Biomass for Energy, Industry and Environment. Elsevier Science Publishers Ltd., England.

Razak M.A. ,Hoi W.K., Bridgwater, A.V. and Smith E.I. (1997). Biomass Utilization Systems in Malaysia. A paper in Proceedings of the International Conference on Biomass for Energy, Industry and Environment. Elsevier Science Publishers Ltd., England.

Samir S.S. and Oskar R.Z. (1981). Biomass Conversion Processes for Energy and Fuels. Plenum Press New York.

Sorenson, B. (1991). Renewables provide 25 percent of Global Energy. Update United Nations Centre for Science and Technology for Development 46(2).

Terry, M.C (1978). Franjon Fuel Pellets in "Energy from Biomass and Wastes". Institute of Gas Technology, Chicago.

Turyahikayo,G.R., Hatanga, E.S., Otiti,T. and Kebirungi, P. (1995). Renewable Energy Technologies Dissemination.Case study of Uganda, AFREPREN Uganda .pp 8-43.

Veziroglu, N.T. (1981). Alternative Energy Sources, 9 volumes. Clean Energy Research Institute, University of Miami. Coral Cables, Florida U.S.A. Hemisphere Publishing Corporation. Pp ix.

Walubengo, D. (1989). Institutional Stoves in Kenya: The Present and Future. Boiling Point, No 10, August,17. Pp 4-13.

Walubengo, D. (1990). Briquetting of Biomass Waste. Report of the Proceedings of the International Biomass Course Nairobi Kenya pp 26-28.

Wang,S., Huffman, J.B. and Litell, R.C.(1981). Characterisation of Melaleuca Biomass, as a Fuel for Direct Combustion. Wood Science 13(4): 216-217.

White L.P. and Plaskett L.G. (1981). Biomass as Fuel. Academic Press Inc. Pp 111-118.

Young, P. (1987). Sawdust Briquettes and Stoves. International Technology and Development Group. Pp 5-9.

APPENDICES

APPENDICES

APPENDIX 1

(1) CALORIFIC TEST READINGS

GALVANOMETER DEFLECTION,θ, AFTER TEST

(a) BRIQUETTE WITH PALM-KERNEL SHELL OF GRADE 1.18mm

% COMPOSITION	θ_a	θ_b	θ_c
50/50	6.65	6.37	6.4
60/40	6.4	6.3	6.55
70/30	6.6	6.7	7.1
80/20	6.7	6.3	7.0
90/10	6.4	6.5	6.9

(b) BRIQUETTE WITH PALM KERNEL SHELL OF GRADE 2.00 mm

% COMPOSITION	θ_a	θ_b	θ_c
50/50	6.0	6.7	5.8
60/40	6.0	6.6	6.0
70/30	6.6	6.2	6.7
80/20	6.4	6.0	6.7
90/10	5.7	5.6	5.9

(c) BRIQUETTE WITH P.K.S OF GRADE 2.36mm

% COMPOSITION	θ_a	θ_b	θ_c
50/50	5.9	5.7	6.1
60/40	6.0	6.0	6.0
70/30	6.1	6.2	6
80/20	5.75	5.6	5.9
90/10	5.6	5.4	5.8

FOR BRIQUETTE, 100% PURE SAWDUST

θ_a	θ_b	θ_c
5.75	5.55	5.4

APPENDIX 2

(1) WATER BOILING TEST DATA

TEST NO: 1 (100% Sawdust).

DATE: 17-07-2002

TEST CONDITION: The weather is cool, drill and the environment is damp. The stove was used in an open environment.

AMBIENT. TEMP. : 24^0c.

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (I.E. BOILING STAGE).

WATER TEMPERATURE / ^{0}C	TIME / mins.
26	0
59	5
85	10
91	12
100	14

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	730	700	650
(e)	Weight of Stove with Fuel/k_g	6.5459	6.43	6.25	6.20
(f)	Water Temp./^{0}c	0	100	100	84
(g)	Time	0	14	29	59

1-Initial Measurement 2-End of Intermediate Phase 3- End of High Phase 4- End of Low Phase

(i). Briquette with Palm kernel shell of grade 1.18mm

TEST NO: 2 (50%/50%)

DATE: 18-07-2002

TEST CONDITION: The weather is cool, drill and the environment is damp.

AMBIENT TEMP: 22.6^0c

TABLE 1:PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
24.5	0
44	5
64	10
70	13
84.5	15
100	21

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	738.8	637.8	526
(e)	Weight of Stove with Fuel/k_g	6.5587	6.4	6.25	6.20
(f)	Water Temp./^{0}c	24.5	100	100	84
(g)	Time	0	21	36	66

TEST NO: 3 (60%/40%)

DATE: 18-07-2002

TEST CONDITION: The weather is cool, the day is bright and the environment is damp.

AMBIENT. TEMP.: 23.9^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	**TIME / mins.**
25	0
43	5
59	10
83	15
100	17

S/N		**1**	**2**	**3**	**4**
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	740	715.5	548.9
(e)	Weight of Stove with Fuel/k_g	6.5353	6.3	6.225	6.15
(f)	Water Temp./^{o}c	25	100	100	84
(g)	Time	0	17	32	62

Mass of charcoal + Pan = 138.8g

Mass of ash + Pan = 160.4g

TEST NO: 4 (70%/30%)

DATE: 18-07-2002

TEST CONDITION: The weather is cool, the day is bright not too sunny and the environment is damp.

AMBIENT TEMP.: 27.3 ^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25	0
46	5
75	10
100	15

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	741.1	697.1	577.3
(e)	Weight of Stove with Fuel/k_g	6.5068	6.3	6.2	6.15
(f)	Water Temp./^{o}c	25	100	100	84
(g)	Time	0	15	30	60

Mass of charcoal + Pan = 139.4g Mass of ash + pan = 154.2g

TEST NO: 5 (80%/20%)

DATE: 19-07-2002

TEST CONDITION: The weather is moderately cool, bright and a little bit sunny

AMBIENT TEMP.: 23.8^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25	0
44	5
71	10
90	15
100	15.5

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	746.4	714.0	596.9
(e)	Weight of Stove with Fuel/k_g	6.4959	6.3	6.2	6.15
(f)	Water Temp./^{o}c	25	100	100	84
(g)	Time	0	15.5	30.5	60.5

Mass of Charcoal + Pan = 137.1g Mass of ash + Pan = 150.7.g

TEST NO: 6 (90%/10%)

DATE: 19-07-2002

TEST CONDITION: Weather is getting warmer, the day is bright and a little bit sunny

AMBIENT TEMP.: 26.7^{0} C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25	0
55	5
85	10
100	14

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	750.6	657.3	606
(e)	Weight of Stove with Fuel/k_g	6.4690	6.275	6.15	6.12
(f)	Water Temp./^{o}c	25	100	100	84
(g)	Time	0	14	29	53

Mass of charcoal + Pan = 136.8g

Mass of ash + Pan = 146.5g

(ii) Briquette with Palm kernel shell of grade 2.00mm

TEST NO: 7 (50%/50%)

TEST CONDITION:- Weather is warm, the day is bright and sunny

AMBIENT TEMP.: 27.2^{0}C

DATE: 19-07-2002.

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25	0
45	5
74	10
90	15
100	17

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	750.3	646.9	499.4
(e)	Weight of Stove with Fuel/k_g	6.5462	6.3	6.2	6.15
(f)	Water Temp./^{o}c	25	100	100	84
(g)	Time	0	17	32	62

Mass of charcoal + Pan = 145.1g

Mass of ash + Pan = 165.4g.

TEST NO : 8 (60%/40%)

DATE: 22-07-2002.

TEST CONDITION : Weather is cool, bright and the environment is not too damp.

AMBIENT TEMP.: 28.2 ^{0}C.

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
27	0
45	5
65	10
89	15
100	16.5

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	742.6	608.3	480.5
(e)	Weight of Stove with Fuel/kg	6.5571	6.4	6.25	6.175
(f)	Water Temp./^{o}c	25	100	100	84
(g)	Time	0	16.5	31.5	61.5

Mass of charcoal + Pan = 140.3g.

Mass of ash + Pan = 156.3

TEST NO : 9 (70%/30%)

DATE: 22-07-2002

TEST CONDITION: Weather is cool and calm, it was getting dark.

AMBIENT TEMP.: 25.8 ^{0}C.

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25.4	0
47	5
72	10
93	15
100	16

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	716.9	626.9	486.9
(e)	Weight of Stove with Fuel/kg	6.5343	6.3	6.225	6.16
(f)	Water Temp./'c	25.4	100	100	84
(g)	Time	0	16	31	61

Mass of charcoal + Pan= 136.8g

Mass of ash + Pans = 146.6.

TEST NO: 10(80/20 (2mm)

DATE: 23-07-2002

TEST CONDITION: Weather was cool, dull and the environment is not damp,

AMBIENT TEMP.: 25.2 ^{0}C.

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
24.8	0
46	5
73	10
100	14.5

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	741.5	662.5	603.1
(e)	Weight of Stove with Fuel/kg	6.4965	6.275	6.2	6.15
(f)	Water Temp./°c	24.8	100	100	84
(g)	Time	0	14.5	29.5	59.5

Mass of charcoal + Pan = 136.7g.

Mass of ash + Pan = 151.8g.

TEST NO: 11 (90%/10%)

DATE: 25-07-2002

TEST CONDITION: Weather was dull, cool, the environment is quite damp,

AMBIENT TEMP.: 22.5 ^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
24	0
48	5
77	10
100	13

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	758.1	646.7	565.7
(e)	Weight of Stove with Fuel/kg	6.5327	6.3447	6.2	6.15
(f)	Water Temp./°c	24	100	100	84
(g)	Time	0	13	28	58

Charcoal + Pan =136.5g

Ash + Pan = 151.4g

TEST NO: 11 (90%/10%)

DATE: 25-07-2002

TEST CONDITION: Weather was dull, cool, the environment is quite damp,

AMBIENT TEMP.: 22.5 ^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
24	0
48	5
77	10
100	13

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	758.1	646.7	565.7
(e)	Weight of Stove with Fuel/kg	6.5327	6.3447	6.2	6.15
(f)	Water Temp./^{0}c	24	100	100	84
(g)	Time	0	13	28	58

Charcoal + Pan =136.5g

Ash + Pan = 151.4g

(iii) Briquette with Palm kernel shell of grade 2.36mm

TEST NO: 12{(50%/50%)

DATE: 25-07-2002

TEST CONDITION: Weather was bright and cool and not sunny, and calm.

AMBIENT TEMP.: 23^0C.

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25	0
45	5
66	10
90	15
100	16

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	776.5	717.4	617.3	517.0
(e)	Weight of Stove with Fuel/k_g	6.5556	6.35	6.24	6.18
(f)	Water Temp./^{0}C	25	100	100	84
(g)	Time	0	16	31	61

Mass of Charcoal + Pan = 146.0g

Mass of ash + Pan = 174.5g

TEST NO: 13 (60%/40%)

DATE : 25-07-2002

TEST CONDITION: Weather was bright, cool and getting sunny.

AMBIENT TEMPERATURE: 27.8^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
25.8	0
44	5
60	10
80	15
100	17

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	726.9	666.9	596.9
(e)	Weight of Stove with Fuel/kg	6.5116	6.3	6.2	6.17
(f)	Water Temp./^{0}C	25	100	100	90
(g)	Time	0	17	32	62

Mass of Charcoal + Pan = 145.7g

Mass of ash + Pan = 174.5g

TEST NO: 14{(70/30)

DATE: 25-07-2002

TEST CONDITION: Weather was bright and sunny

AMBIENT TEMP.: 30^0C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
29	0
59	5
91	10
100	13

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	726.9	660.7	635.7
(e)	Weight of Stove with Fuel/kg	6.5291	6.2746	6.1746	6.15
(f)	Water Temp./^{o}c	29	100	100	86
(g)	Time	0	13	28	53

Charcoal + Pan = 140.8g

Ash + Pan = 162.1g

TEST NO: 15 (80/20)

DATE : 25-07-2002

TEST CONDITION: Weather was bright, sunny and warm.

AMBIENT TEMPERATURE : 30^0C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
27	0
55	5
80	10
100	14

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot/g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	754.9	651.8	543.1
(e)	Weight of Stove with Fuel/kg	6.5064	6.2929	6.2229	6.15
(f)	Water Temp./^{o}c	27	100	100	84
(g)	Time	0	14	29	59

Charcoal + Pan = 138.9g

Ash + Pan = 158.2g

TEST NO: 16 (90%/10%)

DATE: 27-07-2002

TEST CONDITION: Weather condition was cool, fairly warm.

AMBIENT TEMP.: 28.5 ^{0}C

TABLE 1: PRELIMINARY W.B.T. FOR THE INTERMEDIATE POWER PHASE (BOILING STAGE)

WATER TEMPERATURE / ^{0}C	TIME / mins.
29	0
59	5
91	10
100	14

S/N		1	2	3	4
(a)	Fuel Moisture				
(b)	Dry weight of Pot /g	273.4			
(c)	Dry weight of stove/kg	6.20			
(d)	Weight of Pot with H_2O/g	773.4	754.3	638.7	537.0
(e)	Weight of Stove with Fuel/kg	6.5628	6.3693	6.3193	6.15
(f)	Water Temp./^{o}C	29	100	100	80
(g)	Time	0	14	29	59

Charcoal + Pan = 136.2g

Ash + Pan = 154.1g

(2) CALCULATIONS FOR WATER BOILING TEST

The following equations were used to analyze and generate data used for the Water Boiling Test.

(1) Specific Fuel Consumption at end of each phase

S.F.C = Change in mass of fuel at the end of each phase
Change in mass of fuel at the end of each phase

$$\frac{(m_i - m_{i+1})(1-x) - 1.5(\frac{m_c}{3})}{m_j - m_{j+1}} \quad \text{.....(i)}$$

Where m_i = mass of fuel at the beginning of each phase

m_{i+1} = mass of fuel at the end of each phase.

m_c = mass of charcoal

m_j = mass of water at the beginning of a phase

m_{j+1} = mass of water at the end of each phase

x = moisture content of briquette fuel.

The factor 1.5 is used to compensate for the mass of charcoal remaining at the end of experiment. Also the factor 3 is used since there are 3 phases in all. It is assumed that the moisture content of briquette fuel is taken as 100% dry.

Hence x = 0

(2) Overall Specific Fuel Consumption

$$S.F.C_{overall} = \frac{(m_{f0} - m_{f1})(1-x) - 1.5m_c}{m_{w0} - m_{w1}} \quad \text{.....(ii)}$$

Where, m_{f0} = Original mass of fuel
m_{f1} = Final mass
m_{w0} = Original mass of water
m_{w1} = Final mass of water

(3) Burning Rate of fuel at each phase (B.R)

B.R = Change in mass of fuel at the end of each phase
Change in time at the end of each phase

$$\frac{(m_i - m_{i+1})(1-x) - 1.5(\frac{m_c}{3})}{T_k - T_{k+1}} \quad \text{.....(iii)}$$

Where T_k = Time recorded at the beginning of a phase

T_{k+1} = Time recorded at the end of a phase

(4) Overall Burning Rate

$$B.R_{overall} = \frac{(m_{f_0} - m_{f_1})(1-x) - 1.5m_c}{\Sigma T} \quad \text{.....(iv)}$$

Where ΣT = Overall Time taken to complete the Water Boiling Test.

(5) Percentage Heat Utilized (P.H.U)

The Percentage Heat Utilized at each phase of boiling is evaluated as

$$P.H.U = \frac{M_n C_p (T_b - T_0) + M_c L}{M_f E_f} \times 100\% \quad \text{.....(v)}$$

Where:

M_n= Mass of water in the pot (kg)

C_p= Specific Heat of Water (kJ/kg°C)

T_0= Starting Temperature of the water (°C)

T_b= Boiling Temperature of the water (°C)

M_c= Mass of water evaporated (kg)

L= Latent heat of evaporation (kJ/kg.)

M_f= Weight of fuel burnt (kg.)

E_f= Calorific Value of the fuel (kJ/kg)

(6) Average Percentage Heat Utilized ($P.H.U_{AV.}$).

$$P.H.U_{AV.} = PHU1(\frac{T_1}{\Sigma T}) + PHU2(\frac{T_2}{\Sigma T}) + PHU3(\frac{T_3}{\Sigma T}) \quad \text{.....(vi)}$$

Where PHU 1= Percentage Heat Utilized at the Intermediate phase

PHU 2 = Percentage Heat Utilized at the High Power phase

PHU 3 = Percentage Heat Utilized at the Low Power phase

T_1 = Time taken to reach and complete Intermediate

T_2 = Time taken to reach and complete High Power phase

T_3 = Time taken to reach and complete Low Power phase

(6) Power Output

The Power Output at phase of boiling is evaluated as

$$P = \frac{M_f \times E_f}{t} \quad \text{..... (vii)}$$

Where:

M_f= Weight of fuel burnt (kg.)

E_f= Calorific Value of the fuel (kJ/kg)

t =Time taken for combustion

(7) Average Power Output ($P_{AV.}$).

$$P = P_1 (T_1/\Sigma T) + P_2 (T_2/\Sigma T) + P_3 (T_3/\Sigma T) \quad \text{.....(viii)}$$

Where P_1 Percentage Heat Utilized at the Intermediate phase

P_2= Percentage Heat Utilized at the High Power phase

P_3= Percentage Heat Utilized at the Low Power phase

T_1 = Time taken to reach and complete Intermediate

T_2 = Time taken to reach and complete High Power phase

T_3 = Time taken to reach and complete Low Power phase

TABLE I: ASH AND CHARCOAL CONTENT LEFT AT END OF EXPERIMENT.

GRADE OF P.K.S	% COMPOSITION SAWDUST/ P.K.S.	Mass of Ash/g	Mass of Charcoal/g
1.18mm	50/50	26.5	4.9
	60/40	24.8	3.2
	70/30	18.6	3.8
	80/20	15.1	1.5
	90/10	10.9	1.2
	50/50	29.8	9.5
	60/40	20.7	4.7
	70/30	19	1.2
	80/20	16.2	1.1
	90/10	15.8	0.9
	50/50	38.9	10.4
	60/40	38.9	10.1
	70/30	26.5	5.2
	80/20	22.6	3.3
	90/10	18.5	0.6
	100	10	0.2

APPENDIX 3

CONTROLLED COOKING TEST

(i) CONTROLLED COOKING TEST DATA USING COMPOSITE BRIQUETTE

TEST NO: 1

DATE: 28-08-2002

AMBIENT TEMPERATURE: 24.3 ^{0}C

TYPE OF COOKED FOOD: YAM

BASIC DATA	**1**	**2**
A. Weight of fuel/g	314.4	219
B. Weight of pot/g	275.2**(empty)**	835.2**(with cooked food)**
C. Time of cooking/mins	0	20

1- INITIAL MEASUREMENT **2**-FINAL MEASUREMENT

TEST NO: 2

DATE: 28-08-2002

AMBIENT TEMPERATURE: 24.3 ^{0}C

TYPE OF COOKED FOOD: YAM

BASIC DATA	**1**	**2**
A. Weight of fuel/g	232.2	185.1
B. Weight of pot/g	278.1**(empty)**	834.2**(with cooked food)**
C. Time of cooking/mins	0	25

TEST NO: 3

DATE: 29-08-2002

AMBIENT TEMPERATURE: 22.8 ^{0}C

TYPE OF COOKED FOOD: RICE

BASIC DATA	**1**	**2**
A. Weight of fuel/g	347.7	188.2
B. Weight of pot/g	275.2**(empty)**	1240**(with cooked food)**
C. Time of cooking/mins	0	37

TEST NO: 4

DATE: 29-08-2002

AMBIENT TEMPERATURE: 22.8 ^{0}C

TYPE OF COOKED FOOD: RICE.

BASIC DATA	**1**	**2**
A. Weight of fuel/g	369.8	180.7
B. Weight of pot/g	278.3**(empty)**	1221.7**(with cooked food)**
C. Time of cooking/mins	0	40

TEST NO:5

DATE: 30-08-2002

AMBIENT TEMPERATURE: 25.2 ^{0}C

TYPE OF COOKED FOOD: *BEANS*

BASIC DATA	**1**	**2**
A. Weight of fuel/g	429	193.2
B. Weight of pot/g	278.3**(empty)**	1015**(with cooked food)**
C. Time of cooking/mins	0	55

TEST NO: 6

DATE: 30-08-2002

AMBIENT TEMPERATURE: 25.2 ^{0}C

TYPE OF COOKED FOOD: BEANS

BASIC DATA	**1**	**2**
A. Weight of fuel/g	417.2	176.6
B. Weight of pot/g	279.6(empty)	1033.6(with cooked food)
C. Time of cooking/mins	0	58

(ii) CONTROLLED COOKING TEST DATA USING KEROSENE

TEST NO: 7

DATE: 02-09-2002

AMBIENT TEMPERATURE: 24.5 ^{0}C

TYPE OF COOKED FOOD: YAM

BASIC DATA	**1**	**2**
A. Weight of fuel/g	1563.5	1527.6
B. Weight of pot/g	352.8 **(empty)**	1027.5 **(with cooked food)**
C. *Time of cooking/mins*	*0*	16

TEST NO: 8

DATE: 02-09-2002

AMBIENT TEMPERATURE: 24.5 ^{0}C

TYPE OF COOKED FOOD: YAM

BASIC DATA	**1**	**2**
A. Weight of fuel/g	1497.5	1457.3
B. Weight of pot/g	352.1**(empty)**	893.6**(with cooked food)**
C. Time of cooking/mins	0	20

TEST NO: 9

DATE: 03-09-2002

AMBIENT TEMPERATURE: 23.2 ^{0}C

TYPE OF COOKED FOOD: RICE

BASIC DATA	**1**	**2**
A. Weight of fuel/g	1578.5	1524.2
B. Weight of pot/g	358**(empty)**	1064.7**(with cooked food)**
C. Time of cooking/mins	0	19

TEST NO: 10

DATE: 03-9-2002

AMBIENT TEMPERATURE: 23.2 ^{0}C

TYPE OF COOKED FOOD: RICE.

BASIC DATA	**1**	**2**
A. Weight of fuel/g	1525.3	1463.0
B. Weight of pot/g	356.8**(empty)**	1150**(with cooked food)**
C. Time of cooking/mins	0	28

TEST NO: 11

DATE: 04-09-2002

AMBIENT TEMPERATURE: 24^{0}C

TYPE OF COOKED FOOD: BEANS

BASIC DATA	**1**	**2**
A. Weight of fuel/g	1729.3	1634.2
B. Weight of pot/g	350.8**(empty)**	972.7**(with cooked food)**
C. Time of cooking/mins	0	48

TEST NO: 12

DATE: 04-09-2002

AMBIENT TEMPERATURE: 24 ^{0}C

TYPE OF COOKED FOOD: BEANS

BASIC DATA	**1**	**2**
A. Weight of fuel/g	1458.2	1359.4
B. Weight of pot/g	350.8**(empty)**	1085**(with cooked food)**
C. Time of cooking/mins	0	53

(2) DATA CALCULATION

The following relationship can be deduced using the data.

(i) The Specific Fuel Consumption, SFC for a Controlled Cooking Test

$$S.F.C = \frac{\text{Mass of consumed Fuel}}{\text{Total mass of cooked food}}$$

$$S.F.C = \frac{(m_{f_0} - m_{f_1})(1-x) - 1.5m_c}{m_{pc} - m_p} \quad \text{.....(ix)}$$

(ii) The time spent in cooking per Kg, T for a Controlled Cooking Test.

$$T = \frac{\text{Total time spent in cooking}}{\text{Total mass of cooked food}}$$

$$T = \frac{T_0 - T_1}{m_{pc} - m_p} \quad \text{.....(x)}$$

Where

T_0 = Initial Time (before cooking)

T_1 = Final Time (after cooking)

m_{pc} = mass of empty pot with cooked food

m_c = mass of empty pot

The mass of charcoal m_c left after the briquettes were combusted was found negligible, hence $m_c = 0$. The same hold for the kerosene fuel since charcoal was not produced.

TABLE 4.7: SPECIFIC FUEL CONSUMPTION/kg/kg UNDER C.C.T.

TYPE OF FOOD	BRIQUETTE FUEL	KEROSENE FUEL
Yam	0.17	0.053
	0.17	0.074
Average	0.12	0.0635
RICE	0.17	0.08
	0.2	0.079
Average	0.185	0.0795
Beans	0.32	0.15
	0.32	0.135
Average	0.32	0.1425

TABLE 4.8:TIME SPENT IN COOKING (min./kg)

TYPE OF COOKED FOOD	BRIQUETTE FUEL	KEROSENE FUEL
YAM	35.71	23.71
	44.96	37
Average	40.34	30.36
RICE	38.35	26.89
	42.4	35.3
Average	40.38	31.10
BEANS	74.66	77.2
	77.00	72.2
Average	75.83	74.7

APPENDIX 4

(i) FACTORIAL EXPERIMENT TO INVESTIGATE THE EFFECT OF VARIATION OF PALM KERNEL SHELL GRADES ON BRIQUETTE COMPOSITION IN RELATION TO CALORIFIC VALUES.

Having obtained the various calorific values, a factorial experiment can be designed to investigate the effect of two different factors on each other.

The two factors under consideration are different grades of palm kernel shell, denoted as factor A, and percentage composition of briquettes denoted as factor B.

With this, a 3 x 5 factorial experiment can be designed. The value 3, represents the number of treatments of factor A, i.e. grades of palm kernel shell depicted by a_0, a_1 and a_2 .On the other hand, the value 5, represents the number of treatments of factor B depicted by b_o, b_1, b_2, b_3 and b_4 respectively. The type of experiment under consideration is referred to as Complete Randomized design (C.R.D)

The data obtained from the calorific test can be grouped from the calorific test shown in table 13:

TABLE I: FACTORIAL EXPERIMENT TABLE FOR CALORIFIC VALUE TESTS

FACTOR B (PERCENTAGE COMPOSITION)	FACTOR A (GRADE OF P.K.S.)		
	a_0 (1.18mm)	a_1 (2.00mm)	a_2 (2.36mm)
50/50 (b_0)	21.83	19.32	18.93
	22.80	22.02	18.16
	21.87	18.55	19.71
60/40 (b_1)	20.87	21.64	19.32
	20.48	21.64	19.32
	21.45	19.32	19.32
70/30 (b_2)	21.64	21.64	19.71
	22.02	20.09	20.09
	23.57	22.02	19.32
80/20 (b_3)	22.02	20.87	18.35
	20.48	19.32	17.77
	23.18	22.02	18.93
90/10 (b_4)	20.87	18.16	17.77
	21.25	17.77	17.00
	22.78	18.93	18.55

(ii) ANALYSIS OF 3 X 5 FACTORIAL EXPERIMENT GROUPED – DATA.

The ANOVA. (Analysis of variance) will be used as a statistical tool to analyze the factorial experiment of the grouped data.

COMPUTATIONS

The treatment combinations from the table are a_0b_0, a_0b_1, a_0b_2, a_0b_3, a_0b_4, a_1b_0, a_1b_1, a_1b_2, a_1b_3, a_1b_4, a_2b_0,a_2b_1, a_2b_2, a_2b_3, and a_2b_4. We have fifteen treatments combination in all.

TABLE FOR THE TREATMENT COMBINATION

The treatments combination a_0b_0, a_0b_1, ... a_2b_4 are the individual summation of the calorific values replicates. Therefore the table for the treatment combination is as shown below

TABLE II: TREATMENT COMBINATIONS FOR THE CALORIFIC VALUES

	a_0	a_1	a_2	B_{totals}
b_0	66.5	59.88	56.79	183.17
b_1	62.79	60.27	57.96	181.02
b_2	67.23	63.75	59.13	190.01
b_3	65.67	62.21	55.05	182.93
b_4	64.89	54.87	53.4	173.16
A_{Totals}	327.08	300.98	282.33	910.39

From the table, the following can be obtained

(i) Correction factor, $C.F = \frac{910.39}{nab}$

Where n, is the number of replicates i.e. the number of times of repeating the experiment.

n= 3, a is the number of treatments factor A, b is the number of treatment of factor B.

$$C.F = \frac{\left(910.39\right)}{3x3x5}$$

C.F = 18418

(ii) Total sum of squares, S.S

$$S.S_{total} = \Sigma Y^2_{ij} - C.F$$

Where Y^2_{ij} is the sum of all squares of individual calorific values on Table

$$\therefore S.S_{Total} = \{(21.83)^2 + (22.8)^2 + \ldots\ldots(22.78)^2\} - C.F$$

$$= 18539.01 - 18418$$

$$= 121.07$$

(ii) Sum of square among treatments

$$SS_{treatment} = \sum_{j=1}^{t} \frac{T_j^2}{r_j} - C.F$$

Where Tj is the value of the treatment combination for each cell

$$\therefore SS_{Treatment} = \frac{66.5^2 + 59.88^2 + \ldots.53.4^2}{3} - 18418$$

$$= 93.33$$

(iii) Sum of square due to error:

$$SS_{error} = SS_{Total} - SS_{treatment}$$

=121.07 – 94.33

=27.74

The $SS_{treatment}$ is now partitioned as follows:

(iv) Sum of squares among factor A

$$SS_A = \frac{\Sigma A^2_{Total}}{nb} - CF$$

$$= \frac{(327.08)^2 + (300.98)^2 + (282.33)^2}{3x5} - 18418$$

$$SS_A = 67.37$$

(v) Sum of square among factor B:

$$SS_B = \frac{\Sigma B^2_{Total}}{na} - CF$$

$$\frac{(183.17)^2 + (181.02)^2 + (190.11)^2 + (173.16)^2}{3x3} - 18418$$

$$SS_B = -16.34$$

(vi) Sum of squares among interaction AB

SS_{AB} = Ss treatment – SS_A – SS_B

=94.33 – 67.37 – (-16.34)

SS_{AB} = 10.62

The following has to be deduced:

The mean of square, Ms = $\frac{Sum - of - Squares}{Degrees - of - Freedom} = \frac{S.S}{d.f.}$

For A, df_A = a-1 = 2

For B, df_B = b-1 = 4

For AB, df_{AB} = (a-1) (b-1) = 2x4 =8

For total, df_{total} = nab –1 = 3x3x5 –1 = 44

For error, $df_{error} = df_{total} - df_A - df_B - df_{AB}$

$= 44 - (2+4+8) = 30$

Since the experiment is considered to be model III, the variance ratio, F in factorial experiments is calculated as :

Source of variance, S.V.	$F_{CALCULATED}$
A	$\frac{M.S_{.A}}{M.S_E}$
B	$\frac{M.S_{.B}}{M.S_{.AB}}$
AB	$\frac{M.S_{AB}}{M.S_E}$

With all these parameters we can draw the ANOVA TABLE as shown below

TABLE III : ANOVA PRESENTATION FOR CALORIFIC TEST.

Source of Variance	**Degree of freedom**	**Sum of Squares**	**Mean of Squares**	**F - Calculated**	**F- Tabulated**	
					0.05	**0.01**
A	2	67.37	33.69	36.42	3.32	5.39
B	4	16.34	4.085	3.07	2.69	4.02
AB	8	10.62	1.33	1.44	2.27	3.17
Error	30	27.74	0.925			

2x3 FACTORIAL EXPERIMENT TO INVESTIGATE THE EFFECT OF THE TYPE OF FUEL AND VARIETIES OF COOKED FOOD ON THE SPECIFIC FUEL CONSUMPTION AND TIME SPENT IN COOKING.

TABLE IV: FACTORIAL EXPERIMENT FOR SPECIFIC FUEL CONSUMPTION.

	FACTOR C (VARIETY OF COOKED FOOD)		
FACTOR D (FUEL TYPES)	c_0 (Yam)	C_1 (Rice)	c_2 (Beans)
BRIQUETTE (d_0)	0.17	0.17	0.32
	0.07	0.2	0.32
KEROSENE (d_1)	0.053	0.08	0.15
	0.074	0.079	0.135

ANALYSIS OF 2X3 FACTORIAL EXPERIMENT GROUPED DATA.

The ANOVA will be used to analyze tbe factorial experiment of the data above

COMPUTATIONS

The treatment combinations from the table are c_0d_0 , c_0d_1, c_1d_0, c_1d_1, c_2d_0 and c_2d_1

. The table for the treatment combination is drawn below.

TABLE V : TREATMENT COMBINATION TABLE FOR SPECIFIC FUEL CONSUMPTION UNDER C.C.T

	c_0	c_1	c_2	D_{total}
d_0	0.240	0.390	0.640	1.27
d_1	0.127	0.159	0.500	0.786
C_{totals}	0.367	0.549	1.14	2.056

From the table, (i) the correction factor, C. F. is calculated as,

$$C.F = \frac{(GrandTotal)^2}{nab}$$

Where the Grand total is the overall total of factor A or B

$$\therefore C.F = \frac{(2.056)^2}{2x3x2}$$

$$C.F = 0.17133$$

(iii) Total sum of square, SS total

$$SS\ total = \Sigma Y_y^2 - C.F$$

$$SS\ total = (0.17)^2 + (0.07)^2 + ...(0.35)^2 - C.F$$

$$= 0.473426 - 0.17133$$

$$= 0.3021.$$

(iii) Sum of square among treatments

$$SS\ treatment = \sum_{j=1}^{t} \frac{T^2 j}{rj} - C.F$$

$$SS\ treatment = \frac{\left[(0.24)^2 + (0.127)^2 + - - -(0.50)^2\right]}{2} - 0.17133$$

$$= 0.284025$$

(iii) Sum of square due to error, SS_E

$SS_{error} = SS_{total} - SS_{treatment}$

$=0.3021 - 0.284025$

$=0.0181$

The SS treatment is now partitioned as follows:

(iv) Sum of squares among factor C., SS_C

$$SS_C = \frac{\sum C^2 Total}{nd} - C.F$$

$$SS_C = \frac{(0.367)^2 + (0.549)^2 + (1.14)^2}{2x2} - 0.17133$$

$SS_C = 0.4339225 - 0.17133.$

$SS_C = 0.2626.$

(v) Sum of squares among factor D, SS_D

$$S.S_D = \frac{\sum D^2 total}{nc} - C.F$$

$$SS_D = \frac{(1.27)^2 + (0.786)^2}{2x3} - 0.17133$$

$SS_D = 0.371783 - 0.17133.$

$= 0.20045$

(vi) Sum of squares among interactions CD, SS_{CD},

$SS_{CD} = SS_{Treatment} - SS_C - SS_D$

$=0.284025 - 0.2626 - 0.20045$

$=- 0.17903.$

The following are deduced for the generation of the ANOVA Table.

The mean of square, $M.S = \frac{Sumofsquare}{Degreeoffreedom}$

$$= \frac{S.S}{d.f}$$

For factor A, d.f = C-1 = 3-1= 2

For factor B, d..f = D-1 = 2-1=1

For factor AB d.f = (C-1)(d-1) = 2x1 =2

For total, d.f total = n.a.d –1 = (2x3x2) –1 =11

For error,d.f error = d.f total – d.fC = d.fd- d.f

=11-(2+1+2)

=6

For a model III type factorial experiment, the variance ratio (f) is calculated as

Source of Variance, S.V	F calculated
C	$M.S._C / M.S._E$
D	$M.S._D / M.S_{CD}$
CD	$M.S._{CD} / M.S_E$

With all these parameters we can draw the ANOVA Table.

TABLE VI : ANOVA TABLE PRESENTATION FOR SPECIFIC FUEL CONSUMPTION.

Source of Variance	Degree of freedom	Sum of Squares	Mean of Squares	F - Calculated	F- Tabulated	
					0.05	0.01
C	2	0.2626	0.1313	43.62	5.14	10.92
D	1	0.20045	0.20045	-2.24	19.00	99.00
CD	2	-0.17903	-0.0895	-29.73	5.14	10.92
Error	6	0.01801	0.00301			

TABLE VII: FACTORIAL EXPERIMENT FOR TIME SPENT IN COOKING.

FACTOR D (FUEL TYPES)	FACTOR C (VARIETY OF COOKED FOOD)		
	c_0 (Yam)	c_1 (Rice)	c_2 (Beans)
BRIQUETTES (do)	35.71 44.96	38.35 42.4	74.66 77.00
KEROSENE (d_1)	23.71 37	26.89 35.3	77.2 72.2

Still using the ANOVA method, the following computations can be made

COMPUTATIONS

The treatment combinations from the table are c_0d_0 , c_0d_1, c_1d_0, c_1d_1, c_2d_0 and c_2d_1 .

The table for the treatment combination is drawn below.

TABLE VII : TREATMENT COMBINATION TABLE FOR TIME SPENT IN COOKING

	c_o	c_1	c_2	D-totals
d_0	80.67	80.75	151.66	313.08
d_1	60.71	61.89	149.94	272.54
C. Totals	141.38	142.64	301.60	585.62

From the table

(i) Correction factor, $C.F = \frac{(585.62)^2}{2x3x2}$

$= 28579.23$

(ii) Total sum of square, SSTotal

$SS_{Total} = \sum Y_{ij}^2 - C.F$

$SS_{Total} = \left[(35.71)^2 + (44.96)^2 + ----(72.2)^2\right] - 28579.23$

$= SS\ Total = 33141.21 - 28579.23$

$SS\ Total = 4561.98$

(iii) Sum of squares among treatments, SS Treatment

$$SS_{Treatment} = \sum_{j=1}^{i} \frac{Tj}{rj} - C.F$$

$$\frac{(80.67)^2 + (60.71)^2 + ...(272.54)^2}{2} - 28579.23$$

$SS_{Treatment} = 33013.12 - 28579.23$

$SS_{Treatment} = 4434.3$

(iV) Sum of square due to error, SS error

SS_{error} = SS Total – SS Treatment

= 4561.98 – 4434.3

= 127.68

The $SS_{Treatment}$ is partitioned as follows:

(v) Sum of squares among factor C, SSc

$$SS_C = \frac{\left[(1411.38)^2 + (142.64)^2 + (301.60)^2\right]}{2x2} - C.F.$$

SS_C = 328.24.26 – 28579.23

SS_C = 4245.03

(VI) Sum of squares among factor D, SS_D

$$SS_D = \frac{(313.08)^2 + (272.54)^2}{2x3} - C.F$$

SS_D = 136.96

(VI) Sum of squares among interaction C and D, SS_{CD}

$SS_{CD} = SS_{Treatment} - (SS_C + SS_D)$

= 4434 – (4245.03 + 136.96)

SS_{CD} = 52.31

TABLE VIII : ANOVA TABLE PRESENTATION FOR TIME SPENT IN COOKING

Source of Variance.	Degree of freedom	Sum of Squares	Mean of Squares	F-Calculated	F-Tabulated 0.05	0.01
C	2	4245.03	2122.52	100.54	5.14	10.92
D	1	136.96	136.96	5.235	19.00	99.00
CD	2	52.31	26.16	1.239	5.14	10.90
Error	6	127.68	21.28			

Table 6(a) Values of $F_{0.05}$*

= Degrees f freedom for nominator	ν_1 = Degrees of freedom for numerator																		
	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	161	200	216	225	230	234	237	239	241	242	244	246	248	249	250	251	252	253	254
2	18.50	19.00	19.20	19.20	19.30	19.30	19.40	19.40	19.40	19.40	19.40	19.40	19.40	19.50	19.50	19.50	19.50	19.50	19.50
3	10.10	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.59	8.57	8.55	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.72	5.69	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.46	4.43	4.40	4.37
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.77	3.74	3.70	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.34	3.30	3.27	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	3.04	3.01	2.97	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.83	2.79	2.75	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.66	2.62	2.58	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.53	2.49	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.38	2.38	2.30	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.34	2.30	2.25	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.27	2.22	2.18	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.20	2.16	2.11	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.15	2.11	2.06	2.01
17	3.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	2.10	2.06	2.01	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	2.06	2.02	1.97	1.93
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	2.03	1.98	1.93	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.99	1.95	1.90	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.96	1.92	1.87	1.81
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.94	1.89	1.84	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.91	1.86	1.81	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.89	1.84	1.79	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.87	1.82	1.77	1.71
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.79	1.74	1.68	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08	2.00	1.92	1.84	1.79	1.74	1.69	1.64	1.58	1.51
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99	1.92	1.84	1.75	1.70	1.65	1.59	1.53	1.47	1.39
120	3.92	3.07	2.68	2.45	2.29	2.18	2.09	2.02	1.96	1.91	1.83	1.75	1.66	1.61	1.55	1.50	1.43	1.35	1.25
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.39	1.32	1.22	1.00

* This table is reproduced from M. Merrington and C. M. Thompson, "Tables of percentage points of the inverted beta (F) distribution", *Biometrika*, Vol. 33 (1943), by mission of the *Biometrika* trustees.

TABLE 5(c) Values of $F_{0.01}$

ν_2 = Degrees of freedom for denominator	ν_1 = Degrees of freedom for numerator																	
	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	40	60	120	∞
1	4,052	5,000	5,403	5,625	5,764	5,859	5,928	5,982	6,023	6,056	6,106	6,157	6,209	6,235	6,261	6,287	6,313	6,339	6,366
2	98.50	99.00	99.20	99.20	99.30	99.30	99.40	99.40	99.40	99.40	99.40	99.40	99.40	99.50	99.50	99.50	99.50	99.50	99.50
3	34.10	30.80	29.50	28.70	28.20	27.90	27.70	27.50	27.30	27.20	27.10	26.90	26.70	26.60	26.50	26.40	26.30	26.20	26.10
4	21.20	18.00	16.70	16.00	15.50	15.20	15.00	14.80	14.70	14.50	14.40	14.20	14.00	13.90	13.80	13.70	13.70	13.60	13.50
5	16.30	13.30	12.10	11.40	11.00	10.70	10.50	10.30	10.20	10.10	9.89	9.72	9.55	9.47	9.38	9.29	9.20	9.11	9.02
6	13.70	10.90	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87	7.72	7.56	7.40	7.31	7.23	7.14	7.06	6.97	6.88
7	12.20	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62	6.47	6.31	6.16	6.07	5.99	5.91	5.82	5.74	5.65
8	11.30	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81	5.67	5.52	5.36	5.28	5.20	5.12	5.03	4.95	4.83
9	10.60	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26	5.11	4.96	4.81	4.73	4.65	4.57	4.48	4.40	4.31
10	10.00	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85	4.71	4.56	4.41	4.33	4.25	4.17	4.08	4.00	3.91
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54	4.40	4.25	4.10	4.02	3.94	3.86	3.78	3.69	3.60
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30	4.16	4.01	3.86	3.78	3.70	3.62	3.54	3.45	3.36
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10	3.96	3.82	3.66	3.59	3.51	3.43	3.34	3.25	3.17
14	8.86	6.51	5.56	5.04	4.70	4.46	4.28	4.14	4.03	3.94	3.80	3.66	3.51	3.43	3.35	3.27	3.18	3.09	3.00
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80	3.67	3.52	3.37	3.29	3.21	3.13	3.05	2.96	2.87
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69	3.55	3.41	3.26	3.18	3.10	3.02	2.93	2.84	2.75
17	8.40	6.11	5.19	4.67	4.34	4.10	3.93	3.79	3.68	3.59	3.46	3.31	3.16	3.08	3.00	2.92	2.83	2.75	2.65
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51	3.37	3.23	3.08	3.00	2.92	2.84	2.75	2.66	2.57
19	8.19	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43	3.30	3.15	3.00	2.92	2.84	2.76	2.67	2.58	2.49
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37	3.23	3.09	2.94	2.86	2.78	2.69	2.61	2.52	2.42
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31	3.17	3.03	2.88	2.80	2.72	2.64	2.55	2.46	2.36
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26	3.12	2.98	2.83	2.75	2.67	2.58	2.50	2.40	2.31
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21	3.07	2.93	2.78	2.70	2.62	2.54	2.45	2.35	2.26
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17	3.03	2.89	2.74	2.66	2.58	2.49	2.40	2.31	2.21
25	7.77	5.57	4.68	4.18	3.86	3.63	3.46	3.32	3.22	3.13	2.99	2.85	2.70	2.62	2.53	2.45	2.36	2.27	2.17
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98	2.84	2.70	2.55	2.47	2.39	2.30	2.21	2.11	2.01
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80	2.66	2.52	2.37	2.29	2.20	2.11	2.02	1.92	1.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63	2.50	2.35	2.20	2.12	2.03	1.94	1.84	1.73	1.60
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47	2.34	2.19	2.03	1.95	1.86	1.76	1.66	1.53	1.38
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32	2.18	2.04	1.88	1.79	1.70	1.59	1.47	1.32	1.00

* This table is reproduced from M. Merrington and C. M. Thompson, "Tables of percentage points of the inverted beta (F) distribution," *Biometrika*, Vol. 33 (1943), with permission of the *Biometrika* trustees.