INVESTIGATION OF BRIQUETTE OF DIFFERENT SPECIES OF WOOD SAWDUST AS SOLID FUEL

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DEDICATION

This project is dedicated to God Almighty who *guided* me through the course of my programme at the Federal University of Technology, Akure

CERTIFICATION

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

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ABSTRACT

Investigation of briquettes of different species of wood sawdust as solid fuel was carried out.

Briquettes of sawdust species of Teak, Masonia, Iroko, Afara and Common Sawdust (mixture of difference species of wood) were produced by mixing them with binders. Two different binders, the starch paste and sodium silicate were used to agglomerate different sets of the sawdust mixture together. For each of the species, briquettes of 100% sawdust were produced. Also briquettes of sawdust mixed with palm kernel shell of 0.85mm and 1.18mm in grain sizes in ratio of 70:30, (sawdust to palm kernel shell) were produced. The mixtures were compressed at 6.89MPa (1000psi) using a manually operated hydraulic briquetting machine.

Experimental tests, which involved the determination of Calorific Value and Flame Temperature, were carried out. Proximate Analysis was also carried out to determine the constituent of the briquettes, which includes, Percentage Volatile Matters, Percentage Ash Content, Percentage Moisture and Percentage Fixed Carbon. Water Boiling Test which involve Percentage Heat Utilized, Specific Fuel Consumption and Time Spend in Boiling 1kg of water were carried out on each of the sample briquettes having been sun-dried properly. The masonia briquette with grain size of 1.18mm palm kernel shell was found to be the best solid fuel under the different tests.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Energy

Energy, which is simply the ability to do work, is the central cross-sectoral issues that affect all human activities either directly or indirectly (Akinbami, 1997). It plays a central role in the overall framework of development planning of any national and a vital input to economic growth and development of any economy. Our modern economics and way of life would be impossible without massive reliable and affordable supplies of energy. Industrialization has thus made energy indispensable to manufacturing, commerce, agriculture, transport, lighting, comfort and most of our leisure activities.

The importance of energy differs for different socio-economic setting. For developed nations, energy availability may mean the difference between economic growth and recession and possibly, a shift in lifestyles from energy extravagance to moderation. High-energy consumption has been associated with higher quality of life, which in turn is related to Gross National Product (GNP). The concern for economic development amongst nations has drawn considerable interest to global energy resource inventories as well as regional or country wise energy source endowments.

Energy sources can be classified into either non-renewable or renewable. Non-renewable energy is one that is finite, exhaustible and cannot be replenished. These types are obtained from static stores of energy that remain bound unless released by human interaction. Examples are fossil fuel such as coal, petroleum, natural gas and nuclear fuels such as uranium (Adegoke, 1999). On the other hand, renewable energy is non-depletable energy obtained from the continuing or repetitive current of energy occurring

in the natural environment (Tidwell and Weir, 1987). This energy includes wind, wave, tidal, geothermal, hydro, solar and biomass.

1.2 Statement of the Problem

1.2.1 Problem Posed by Energy Crisis

The energy crisis started in 1973 when members of the Organization of Petroleum Exporting Countries (OPEC) took advantage of market conditions to quadruple oil prices, sending shockwaves through the world economy. In most advanced countries, the stock markets suffered their biggest ever fall and inflation rose to an all time high of 25 per cent per year. This first "Oil Crisis" showed how vulnerable the oil importing industrial countries had become to Middle Eastern and South American oil producers who could raise prices further, or limit supplies, on a political whim. In 1979 Iran did just that, stopping exports and forcing up prices to well over ten times their 1972 level (Bartholomew et al, 2000). The industrialized countries reacted with international efforts to find new oil resources, to increase the efficiency with which energy is used and to develop alternative sources of energy. Since the oil crises, considerable progress has been made towards finding new sources of fuel under secure Western control, increasing diversity of supply, and improving energy efficiency. The search for oil reveal large and widely spread reserves of natural gas, which rapidly displaced oil in much non-transport, uses (Bartholemew et al, 2000).

Nevertheless, security of supply remains a very real concern. Nearly all the western world's energy still comes from fossil fuels that will become increasingly hard to secure. Affordable oil and gas are unlikely to last more than another century. The International Energy Agency forecast in 1999 that conventional oil production would

peak before 2020 (Bartholomew et al, 2000). As supplies decline, prices will rise and use will increasingly be restricted to premium applications like in transport and plastics manufacture. Shortage will create a renewed risk of instability in international markets. Nigeria as a member of OPEC, which she joined in 1971, has been firstly a beneficiary and secondly, a victim of the price increases. (Ayodele and Nweke, 1987).

The increasing price of oil over the last decades has created very obvious difficulties for all countries reliant on oil for a major proportion of their commercial energy requirements. These problems seem certain to increase in the future as diminishing reserves and growing political pressure combine to force up the price and reduce the availability of oil (Hall, 1993). The pressure placed by oil price rises in Nigeria has been particularly severe in recent time, although the consumption is only modest compared to the industrialized nations.

The only effective counters to the declining supply are further improvements in energy efficiency; more dematerialization and a broader-based energy mix including nuclear power and renewable sources. If nuclear power remains severely restricted by public opinion, then renewable energy resources will have to become one of the world's main energy sources of our modern time.

1.3 Solution to the Energy Crisis

1.3.1 Need to Develop Alternative Energy Sources

Since the energy crisis of 1973, there had been global awareness for alternative to fossil fuels necessitating the need for diversified sources of energy. There is thus an urgent need for this transition to alternative sources of energy in Nigeria that is presently one of the countries mostly affected by this energy crisis from the revenue and

productivity angle. Nigeria in indeed got the oil boom and enjoyed it until the1980's when she was greatly hit by the oil glut (Ayodele and Nweke, 1987). A good example of its problem was the oil crisis, which engulfed the whole country as a result of the oil workers strike in 1994. This paralyzed all economic activities as a result of over dependent on petroleum energy and allied products sources. Acute shortage of fuel was manifested and hence a tremendous high increase in fuel price became so rampant that all the entire sectors of the economy were greatly affected. This scenario keeps re-occurring every year and fuel scarcity saga has re-emerged in Nigeria.

Most of the advance countries who hitherto depended much on imported oil as their major source of energy are now cutting back on imports of oil and moving towards the development of alternative sources of energy. An example of such country is United States of America, which had reviewed the technology for obtaining energy and synthetic fuels from biomass energy, which already is a commercial energy resource (Klass, 1983). The United Kingdom is also working towards the aim of sourcing ten percent of its electricity using renewable energy, by 2010, together with a substantial amount of this energy used as heat (Bartholomew et al, 2000). One could therefore imagine the implication of this on Nigeria being a country that depends so much on the revenue from oil given its wealth in crude oil resources.

As a result of these problems and because of increased energy consumption that is unavoidable pre-requisite for future economic development, the need to develop alternative energy sources cannot be over emphasized. Renewable energy offers a way to resolve some of the tension between the claims of development and environment. The climate in many developing countries like Nigeria favours renewable energy, if only

there is a concerted effort on the part of government and stakeholders in energy matters in Nigeria to initiate major policies that would be supported by a variety of other measure including targets, strategies and energy studies. One of such alternatives energy sources is biomass energy, which is highly favoured because of its results in cleaner environment. Briquetting this biomass for energy utilization could also be the answer to the ever – increasing energy crisis in the country.

1.4 Utilization of Sawdust- A Biomass as Solid Fuel

The term biomass is used for the natural products of plants that have the ability to generate carbon by photosynthesis (Mukunda, 1989). Its energy can be derived from plant and animal materials through a variety of conversion and end-use processes (Hall, 1993). Notable examples of biomass includes sawdust, wood, charcoal, leaves, bark, tiny branches, agricultural residues like rice, straw, wheat husk, wheat straw, groundnut shells, baggasse, coconut shell, palm kernel shell, coconut fibre and a most of other materials grown on the soil and animal wastes (manure) from diary farms, cattle feed lots and poultry (Mukunda, 1989).

The use of biomass for combustion dates back to several million years. The composition of all biomass form is about the same on an ash-free basis. The ash content of most biomass is about 0.5 - 3%. (Mukunda, 1989) stated that sawdust is utilized as a solid fuel by burning it directly to generate heat in three distinct categories as follows:

(a) Household fuel energy:- sawdust is used in stove for cooking and other heating applications in the home.

(b) Agriculture: - In the agricultural sector it can be used for

- Food drying and curing

that accommodates a lot of logging activities with the resultant milling operations. A lot of residues are generated from these logging and milling operations, these resides are lying as waste in different locations scattered across all states of Nigeria. They constitute disposal problems while sometimes attempts are made to burn then off, which also contribute immensely to environmental pollution (Ayodele and Nweke, 1987).

At present, wood energy is only being used for cooking, heating etc by vast majority of rural and even urban populace. It has been observed that household, whether in rural or urban areas usually spend a substantial part of their income on energy to meet domestic cooking or heating needs (kyiogwom et al, 1997). Since Nigeria manages large areas of forestlands from which timber is harvested, residues (wood waste i.e. sawdust) from the timber harvesting and milling activities could be an important source of renewable energy. Consequent to the recent emphasis on renewable energy resources, a positive re-visitation to wood-based energy is desirable. With the rising demand for fuels and reduced supplies due to a number of limiting factors, there has to be a wide spread substitution of alternative fuels and selection of appropriate wood waste species that have optimal thermal properties suitable for various uses that could be briquetted as solid fuel.

1.7 The Objectives of the Study

The general objective of the research is to carry out investigation of briquettes of different species of tropical wood sawdust as solid fuel.

The specific objectives of the study are to:

(i) make briquette from different species of wood sawdust.

(ii) evaluate the thermal properties of sawdust briquettes of different species of wood; the Teak, Masonia; Iroko, Afara and Common Sawdust as an alternative

energy source which could be used to meet ever- increasing domestic energy need in Nigeria.

(iii) evaluate the effect of the addition of palm kernel shell, which is another biomass material on the thermal properties of the different species of sawdust briquettes at certain proportion and grain sizes to confirm whether it could improve the calorific values.

1.8 Expected Contribution to Knowledge

The expected contribution to knowledge of this research work could be viewed from two perspectives:

(i) The National Development

(ii) The Field of Engineering.

1.8.1 Relevance to National Development

The result of the research work is expected to contribute to the development of alternative sources of energy in Nigeria which would eventually reduce the total dependence on petroleum products for our domestic usage. This in turn is envisaged to alleviate the problems associated with energy crisis in Nigeria thereby making life easier through affordable and easily accessible source of energy while the hitherto waste is converted to wealth.

1.8.2 Relevance to the Field of Engineering

The successful execution of the research work will go long way to contribute immensely to the field of engineering especially engineers and scientists who are into research and development in the energy sector or field of their respective economy particularly in the developing countries like Nigeria. This research may

therefore act as additional information and source of knowledge to work being carried out on utilization and briquetting of sawdust.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Energy Survey

The ultimate source of almost all energy consumed on earth especially the energy used by living things is the sunlight (Barden et al, 1987). The sun is the huge thermonuclear furnace that supplies the earth with the heat and light that is essential to life. The solar energy that reaches the earth's surface, is used by green plants, to convert carbon dioxide and water into various energy storing compounds through photosynthesis (Evans, 1989). When such plants are eaten, the energy stored in their tissues is transferred to and used by animal bodies spreading throughout the food chain. In addition, the remains of plants and animals buried in the sands, and mud of swamp and seas millions of years ago were transformed into fossil fuels such as coal, liquid petroleum and natural gas.

2.2 Structure of Energy Consumption

At the moment the world consumes energy at the rate of 12.8 TW per year. By 2050, that energy consumption rate will more than double, to 28TW (Archer, 2000). It needs to do so because energy is vital to world economy and social well being and without reliable energy supplies economic growth will be stultified.

Innovative low-carbon energy technology will be essential in powering tomorrow's world in a sustainable way. Even if global warming and sustainability were not of concern, fossil fuels are finite resources.This point is underlined by the Global

Energy Resources (Table.2.1), in which every row represents an amount of energy greater by a factor of between ten and twenty than the row below.

In the first row is shown the convectional energy resources with correspondent estimated values in the third row. The second row shows the renewable energy resources per year with their correspondent estimated values in the third row. Archer, 2002 reported that the world primary energy supply per annum in the years between 1970 and 2000 is put at 10^{20}Joules. It is therefore clear that the world annual energy consumption is edging uncomfortably close to the total amount of energy in the world proven reserve. The oil and gas prospectors say that they will find more resources when the price is right and so they will, but even then the years of plenty for oil will pass within a few decades.

For these reasons, and others connected with energy security and diversity, renewable energy is currently attracting a lot of interest. In the pre-industrial world, renewable energy was of course all there, but people reasonably ask whether renewable resources could possibly deliver the amounts of energy we need in the modern world with its hugely increased population. The answer is yes. In table2.1 the world's energy income in joules per year from the renewable is as shown in the third row.

Table 2.1: Global Energy Resources

S/N	CONVENTIONAL ENERGY RESOURCES	RENEWABLE ENERGY RESOURCES PER YEAR	ESTIMATED VALUES (JOULES)
1	-	Solar	10^{24}
2	Coal	-	10^{23}
3	Gas	Wind	10^{21}
4	Oil	Biomass	10^{21}
5	Uranium	-	10^{21}
6	-	Hydropower	10^{20}
7	-	Geothermal	10^{18}
8	-	Tidal	10^{18}

(Source: Archer, 2002).

Table 2.1 shows the amount of solar energy falling on the earth in one year, which is by far our most abundant renewable energy resource: every 44 minutes, enough solar energy strike the earth to power it for one year (Archer, 2002). The energy available from some of the other renewable, particularly biomass and wind, is also substantial compared with global energy demand.

2.2.1 Energy Consumption Per Capita

The energy consumption per capita is a function of the Gross National Product (GNP). Variations in energy intensity in different countries are due to variations in the structure of energy consumption. As development proceeds, energy demand shifts from

house holds to industry and transport. For instance, less than 20 per cent of the energy consumed in high-income countries is used in domestic applications, against over 50 per cent in low-income countries like Nigeria (Desai, 1990). The following observations could be made about the evolution of energy consumption in the developing countries during the last decade:

- A sharp decrease in the energy intensity of the household (domestic sector)
- No large changes in industry and transportation sector.

Energy planning for the developing countries like Nigeria has largely overlooked the structure of energy demand and how it is likely to change as development proceeds. This shortcoming has made it difficult to assess realistically the potential for conservation and inter fuel substitution in the major end use sectors.

There were two reasons, for this past neglect. The first was that, until the sharp rises in oil prices in the 70's, developing countries were little concerned with conservation or substitution. Since petroleum was available, its supplies were cheap and readily available, and the exceptional flexibility of petroleum-based fuels meant that they could be used in a variety of ways for raising steam, process heat, cooking, lighting and motive power. The second reason was the lack of basic data on consumption of energy by main users. Typically, energy consumption data for Nigeria were limited to total consumption of different types of fuel (coal, oil, gas, primary electricity).

2.2.2 Overall Energy Intensities

Data on total energy consumption per head, gross national product (GNP) per head and total energy consumed in millions of dollars of GNP for 1980 are given in Table 2.2 for some countries including Nigeria for which energy balances are available (Desai,

1990). These countries are selected as representative of the developing world, including low and medium income countries with different economic structure and location. Selected industrial countries are included for reference. Energy consumption data include both traditional and commercial fuels. These data support two conclusions. First, per capita energy consumption and GNP per capita are closely correlated. Secondly, despite this strong correlation, level of income does not account for all the variation in Per Capita Energy consumption.

TABLE 2.2:Energy Consumption and Gross National Product of selected Countries, 1980

Country	Total Energy Consumed Per US $ Million GNP	Energy Consumption Per Person	GNP Per Person (US $)
Developing Countries			
Argentina	625	1.617	2587
Brazil	585	1.260	2156
Chile	454	1.039	2288
Colombia	995	1.252	1259
Coted' Ivoire	452	0.503	1114
Egypt	884	488	552
Gabon	484	1.791	3700
India	1154	0.262	227
Indonesia	1097	0.498	454
Jamaica	1283	1.396	1088
Kenya	1734	0.669	386
Mexico	716	1.420	1983
Nigeria	**541**	**0.469**	**868**
Pakistan	849	1.266	313
Philippines	737	0.525	713
Thailand	727	0.513	706
Venezuela	684	2.678	3914
Zimbabwe	1181	0.918	777
Industrialized countries			
France	329	3.688	11200
Germany	362	4.463	12321
Japan	346	3.127	9025
UK	426	3.633	8524
USA	685	7.936	11592

Source: (Desai, 1990)

been burnt as early as 6000BC in the Middle East where huge surface deposit exists. The abundance of fossil fuels probably contributed to the development of burnt brick, pottery, and other furnace products in this period.

Asphalt played a notable role in the technological advances made under the Babylonian Empire-Mesopotamia (538-250 BC), but its use diminished after 538 BC (Russell, 1979) Petroleum from which fuel oil and gasoline are refined is pumped from natural reservoirs within the earth. Coal is mined from areas within the earth where it was formed and is ready to be used as fuel as soon as it is mined and broken into burnable pieces (Priest, 1979).

2.4.1.1 Coal

Coal was mined in Europe from the 12th century AD beginning in England. The use of coal continued, and with the development of steam engine during the Industrial Revolution, its production increased rapidly.

By 1850, the world output of coal was 130 million tonnes per annum and by the early 20th century, this amount had increased by a factor of 10. In the mid 1970's, coal was mined at the rate of about 3 billion tonnes per annum. (Evans, 1989)

Con-currently, a shortage of trees for making charcoal to use in smelting iron led to the use of coal. This became the principal source of energy for the metallurgical and ceramic industries. The market for coal led to a need for pumps to remove water from coal mines and that in turn led to the development of New Comer Steam Engine almost 300years ago. (Fraas, 1982). Later, coke, which is produced from coal, was introduced from 1800 as a fuel for production of steel (Kennedy, 1989).

2.4.1.2 Petroleum and Natural Gas

Petroleum, known to the Babylonians though not extensively used, first came into prominence in the 17th century; when oil drilled in Modena, Italy, in 1640 provide fuel for street lighting (Russell, 1979). The Chinese also drilled for natural gas, which was then transported through a considerable distance from the wells in bamboo pipelines so that the palaces of emperors would have illumination and heat (Evans, 1989). Petroleum became important during the 18th century with the increased use of petroleum products such as kerosene for lighting. The industry expanded rapidly, and with the introduction of the automobile and internal combustion engine, petrol or gasoline that is another petroleum product, became of primary importance, followed by manufactured gases, which came into use for lighting streets, homes and factories and later for heating. Manufactured gases have since been mostly replaced by natural gas (Kennedy, 1989).

2.4.2 Nuclear Energy

This is the energy that binds together the components of an atomic nucleus. The nucleus, a very small core at the centre of the atom constitutes almost all of the mass of the atom but takes up only minute portion of its volume (Binney, 1989). When the nucleus of a heavy element splits into two smaller nuclei, the process is called "nuclear fission". On the other hand when two or more nuclei of light elements combine to form a large nucleus, the process is called "nuclear fussion". In both fission and fussion, the total mass of the original nucleus or nuclei is greater than the total mass of the end products (Binney, 1989).

In 1945, the explosion of the first atomic bomb proved that man could tap the energy locked in atomic nuclei. Since then, nuclear energy has come to offer seemingly

limitless energy resources for mankind (Evans, 1989). In 1951, nuclear energy was first used for experimental production of power in the United States of America (Kennedy, 1989). The nuclear-powered industry was born in 1956, when the 4.2 megawatts Calder-Hall reactor in England began generating electricity. Apart from this, nuclear energy has also been widely developed as a therapeutic tool in medical practice; example is in the treatment of cancer (Binney, 1989). Since then nuclear energy has played an increasingly important role in the world's power generation (Kennedy, 1989).

2.4.3 Forms Of Fuel

Fuel is a combustible substance containing carbon as main constituent, which on proper burning gives large amount of heat, that can be used for, domestic and industrial purposes (Jain and Jain, 1991). This can be classified into gaseous, liquid and solid forms. We burn fuels for two major purposes:

(i) For generating power like in internal combustion reciprocating or rotating machinery and rocket.

(ii) For generating heat for cooking, melting metals, heat treatment etc.

2.4.4 Qualities of a Good Fuel

A good fuel should posses the following characteristics:

(i) **High Calorific Value**: This is very important since the amount of heat liberated and temperature attained depends largely on the calorific value.

(ii) **Non-Toxicity:** Product of combustion should not be harmful, and should not give out objectionable and harmful gases, which may act as poison for human lives.

(iii) Low Cost of Bulk Storage: Storage cost of any good fuel should not be expensive.

(iv) Easy To Transport:- Fuel must be easy to handle, store and transport at a low cost.

2.4.5 Limitations of Non-Renewable Fuels

(i) **High Cost**: The cost of obtaining either petroleum products or nuclear energy fuels, are so expensive.

(ii) **High Technology**: High degree of technology is required from exploration to exploitation and refining of the petroleum product and maintenance of nuclear energy as fuel.

(iii) **Land Depletion**: Serious mining of petroleum and coal causes land depletion due to exploration activities on such land.

(iv) **Environmental Pollution**: Serious environment pollution results as a result of gas flaring and emission of product of combustion from petroleum products.

2.5 Renewable Energy Sources

Global concern over climate change means that renewable energy is becoming an increasingly important element of the world's energy supply.

The greatest long-term scope for renewable energy sources does lie in the countryside where space is available for wind farms and energy forest that can be utilized for biofuels. Hydropower, wind, wave, geothermal and solar energy systems, can provide heat and electricity without emitting any carbon dioxide, while biomass- including wastes of biological origin, is carbon-neutral.

Since the oil crises of the 70's, considerable progress has been made toward finding new sources of fuel under western control, increasing diversity of supply, and improving energy efficiency. Affordable oil and gas are unlikely to last more than another century and if nuclear power remains severely restricted by public opinion, renewable sources - which are non-depletable - will have to become one of the world's

main energy sources in the post-oil era. The following highlight some of the renewable energy sources.

2.5.1. Wind Energy

The fastest growing energy sector throughout Europe, which is now a main stream technology, generating electricity at prices that are competitive with, and in some cases cheaper than conventional fossil fuel generation is wind energy (Hill, 2002). Already most commentators accept that wind is likely to represent at least half of the world 10 per cent energy need by 2010 target (Bartholomew et al, 2000). Generating electricity from the power of the wind is very simple itself; as air passes over the blades of a turbine it creates a turning force on the hub, connected to a generator that transforms kinetic energy into electricity.

The extraction of power from the wind with modern turbines and energy conversion system is an established industry. Machines are manufactured with a capacity from a few kilowatt to several megawatt in Europe, United States and increasingly, in other parts of the world including the developing countries. The maximum rated power capacity of a Wind Energy Conversion System (WECS) is given for specified wind speed. Commonly, this rated wind speed is about 12m/s, in which case power production of about 300 W/m^2 would be expected.

Wind power for mechanical purposes, milling and water pumping has been established for many hundreds of years. Modern designs for electricity production date from about 1930 to about 1955 (Twidell and Weir, 1987). At this time, development subsided owing to the availability of cheap oil, but interest reawakened and increased rapidly from about 1973. The ultimate world use of wind power cannot be estimated in

any meaningful way, since it is so dependent on the success and acceptance of machines and suitable energy end-use systems. The use of wind power has increased greatly and wind-generated electricity is currently the world's fastest growing renewable resource. Recent, technical innovation in wind, turbines include the introduction of compact permanent magnetic generators (which avoid the 1 - 2 % power loss suffered by synchronous wind generators) and advance power electronics and software, to ensure grid-complaint power quality (Archer, 2000). In Nigeria, the Sokoto Energy Research Centre had embarked upon research and development of wind energy. This led to the development of three types of system using wind energy.

2.5.2 Wave Energy

Very large energy fluxes can occur in deep water sea waves. The power, in the wave, is proportional to the square of the amplitude and to the period of the motion. The possibility of generating electricity power from these deep-water waves has been realized for many years, and there are countless ideas for machines to extract the power. In recent years, interest has revived, particularly in Japan, Britain and Scandinavia, so research on small-scale development has progressed to the stage of commercial construction for meaningful power extraction. The present trend support moderate power generation levels at about 1MW from modular device about 50m wide across the wave front. Such device is economical to replace diesel-generated electricity, especially on Islands. A number of machines have been devised to convert wave energy into mechanical energy form that can drive an electric generator. These include mechanical cams, gears and levers, hydraulic pumps and pneumatic turbines, but particularly important are oscillating water column.

2.5.3. Geothermal Energy

The inner core of the earth reaches a maximum temperature of about 4000°C (Twidell and Weir, 1987). Heat passes out through the solid submarine and land surface mostly by conduction - geothermal heat - and occasionally by active convective currents of molten magma or heated water. The average geothermal heat flow at the earth's surface is only 0.06W/m, with a temperature gradient of <30°C/km (Twidell and Weir, 1987). This continuous heat current is trivial compared with other renewable supplies in the above surface environment that will in total average about 500W/m^2. However, at certain specific locations, increased temperature gradients occur, indicating significant geothermal resources. These may be harnessed over areas of the order of square kilometers and depths of about 5km at fluxes of 10 to 20W/m^2 to produce about 100MW (thermal) in commercial supplies for at least 20 years of operation. Geothermal heat is generally of low quality, and is best used directly for building or process heat at about 50 to 70°C or for preheating of conventional high temperature energy supplies. Such supplies are established in several parts of the world and many more projects are planned especially in Italy, New Zealand and USA (Twidell and Weir, 1982).

2.5.4 Hydropower

The term hydropower is usually restricted to the generation of shaft power from falling water (Twidell and Weir, 1987). The power is then used for direct mechanical purposes or, more frequently, for generating electricity. The first major installation being at Niagara falls North America in 1895. (Mc Mullan et al, 1977). Another good example of hydropower is at Kainji Dam, in Niger State, Nigeria. Hydropower is by far the most established renewable source of energy for electricity generation and commercial

investment. The early generation of electricity from about 1880 often derived from hydro-turbines, and the capacity of total worldwide installations have grown at about 5% per year ever since, i.e. doubling about every 15 years. Hydro installations and plants are long lasting e.g. turbines for about 50 years. This is due to continuous steady operation without high temperature or other stress. Consequently established plants often produce electricity at low cost with consequent economic benefit.

The power in flowing rivers has been used to drive water turbines from medieval which produce predictable power.

2.5.5 Solar Energy

Solar radiation arrives on the earth at a maximum flux density of about $1kW/m^2$ in a wavelength band between 0.3 and 2.5μm. This is called short wave radiation and includes the visible and near to far infrared spectra for habited areas, which received fluxes ranging widely from about 3 to 30 $MJ/m^2/day$, depending on place, time and weather (Twidell and Weir, 1987). The quality of radiation is characterized by the photon energy of around 2eV as determined by the 6000K surface temperature of the sun. This is an energy flux of very high thermodynamic quality. From an accessible source, at a temperature very much greater than those of convectional engineering sources, the flux can be used thermally with devices relating to conventional engineering (e.g steam turbines), and more importantly with methods developed from photochemical and photo-physical interactions. Radiation energy fluxes relating to the earth's atmospheric and surface temperature are also of the order of $1kW/m^2$, but occur in a wavelength band between 5 and 25μm, (Twidell and Weir, 1987). An obvious use of solar energy is for

heating air and water. Dwellings in cold climates use heated air for comfort, and hot water for washing and other domestic purposes.

The Sun's energy can of course be used simply as heat. Operational solar thermal power stations such as the Solar Energy Generation Station (SEGS) in the Mohave Desert have provided proof of concept of concentrating direct sunlight to generate high-temperature heat while flat-plate solar collectors for water heating are a common sight in sunny parts of the world (Hodgson, 2002). The possible use of solar thermal energy instead of conventionally generated heat to drive energy intensive chemical processes is under investigation in the International Energy Agency's Solar programme in the United Kingdom (Hodgson, 2002). Solar furnaces or power towers are used to generate high-temperature process heat to drive such reactors as the reforming of natural gas and the production of zinc, aluminum and hydrogen. In this way, solar energy could be used as substitute for fossil fuels. In Nigeria, there are various uses of solar energy and the consequent development of various renewable solar energy systems.

2.5.6.1 Solar Photovoltaic

Photovoltaic (PV) systems convert solar radiation directly into electricity (Fordham et al, 1999). They are not to be confused with solar panels, which use the sun's energy to heat water (or air) for water and space heating. The principal reason for this is that photovoltaic (PV) systems are becoming more widely spread as their advantages become apparent and as costs fall. PVs are an advanced materials technology that will help us design buildings, which are environmentally responsible, responsive and exciting.

The most common PV devices at present are based on silicon. When devices are exposed to the sun, direct current (DC) flows, the PV respond to both direct and diffuse

radiation and their output increases with increasing sunshine or, more technically, irradiance. PVs are ubiquitous; they power calculators and navigation buoys, form the wings of satellites and solar planes, use are beginning to appear on cars. A number of building in the advance countries use PVs e.g. the solar office in Doxford, UK (Fordham et al, 1999). Common PVs available are now crystalline silicon, polycrystalline silicon and thin film silicon (using amorphous silicon). A typical crystalline cell might be 100 x 100 mm, which are combined to form modules (Fordham et al, 1999). Table 2.3 shows typical efficiencies of PVs system.

Table 2.3: Pv Efficiencies

S/N	Type	Approximate Cell Efficiency (%)	Approximate Module Efficiency (%)
1.	Mono crystalline Silicon	13 – 17	12 – 15
2.	Poly crystalline Silicon	12 – 15	11 – 14
3.	Thin-Film Silicon using (Amorphous Silicon)	5	4.5 – 4.9

Source: (Fordham et al, 1999)

In solar car races, PVs with efficiency of about 25% are being used. New materials such as copper indium diselenide (CIS) and cadmium telluride (CdTe) are being investigated (CdTe modules are in pilot production). Novel approaches such as producing multi-junction cells, which use a wider part of the solar spectrum, are another aspect of a drive to increase efficiency. Crystalline silicon cells consist of p-type and n-type silicon. The cells, which are of low voltage, are joined in series to form a module of a higher, more useful voltage. The modules are constructed like a sandwich (and sometimes

referred to as laminates) and have a backing sheet and a cover of low-iron glass, which protects the front surface of the material while maintaining a high transitivity. A structural frame is used in a number of designs to protect the glass (Fordham et al, 1999). At the Doxford Solar Office in UK, the PV Cells are encapsulated between two layers of glass with transparent spacing between cells; thus light passes through the transparent areas. This produces an effect inside the building, which in the architect's words is like "Sunlight filtered through trees" (Fordham et al, 1999). This Film Silicon (TFS) PVs, using amorphous silicon is manufactured by a vapour deposition process. Between the p and n layers in the i (for intrinsic) layer. Overall thickness are much less than with crystalline technologies hence the name. Typically, the cells are laminated into glass but modules can also be made flexible by using plastics or metal.

Modules electrically connected together in series are often referred to as a string and a group of connected strings as an array. An array is also a generic term for any group of modules connected in series and/or parallel. Power from the array goes to a power-conditioning unit (PCU). The PCU is a general term for the device or (devices) which converts the electrical output from the PV array into a suitable form for a building. Most commonly, the PCU has a principal component, an inverter (which converts DC to alternating current, AC) and associated control and protection equipment. PCU and inverter are sometimes loosely used interchangeably. The AC output from the PCU goes to a distribution board in the building or to the grid if supply exceeds demand (Fordham et al, 1999)

Generally, grid-connected PV systems are most efficient when the array experiences uniform conditions. This tends to favour the same orientation and tilt for all

modules, similar module and cell types and sizes, uniform temperature conditions and so forth. Crystalline silicon modules come in variety of sizes and shapes, although rectangular patterns of $0.3m^2$ to say $1.5m^2$ have been most common to date. The weight of a 0.5 by 1.2m framed module is about 7.5kg. The laminate (without the frame) is about 4.5kg. Large modules of 1.5m by 2.0m have been used in installations and at least one manufacturer has modules up to 2.1m by 3.5m available to meet the needs of the building market. Monocrystalline silicon modules normally appear as a solid colour, ranging from blue to black. A wider variety of colours is available but at a cost of lower efficiency since their colour comes from reflection of some of the incident light, which would otherwise be absorbed. Polycrystalline modules are normally blue (but again other colours are available) and have a multi-faceted appearance. Looking at polycrystalline array is a bit like looking at a very starry night sky except that the background is blue rather than black. Environmentally, PVs have the significant advantages of producing no pollutant emissions by replacing grid-generated electricity with solar energy generated ones, reduces CO_2, NOx (nitrogen oxides) and SO_x (SO_2 and SO_3) emissions.

Apart from the rather rudimentary attempt to construct solar cell in Nigeria and the series of characterization of solar modules, the bulk of the research and development on solar photovoltaic relates to the use as the modules to provide alternative power to a number of systems (Atiku, 1998).

2.5.7 Biomass

The material of plants and animal is called biomass. It is organic carbon based material that reacts with oxygen in combustion and natural metabolic processes to release heat (Twidell and Weir, 1987). The initial material may be transformed by chemical and biological process to produce intermediate bio-fuels such as methane gas, ethanol liquid or charcoal solid. The initial energy of the biomass-oxygen system is captured from solar radiation in photosynthesis, when released in combustion the bio-fuel energy is dissipated, but the elements of the material are available for recycling on natural ecological or agricultural processes.

In the photosynthesis process, energy from the sun is used to break down the table molecules: carbon dioxide and water to remove some of their oxygen and build up complex organic molecules. The result is various forms of biomass (such as wood or wood sawdust), all of which are largely made up from cellulose and similar molecules. The overall chemical reaction for the formulation of cellulose can be given as:

$$6CO_2 + 5H_2O \longrightarrow C_6H_{10}O_5 + 6O_2 \quad \text{(2.1)}$$

The biomass produced can then be stored until the energy is required. In order to release energy from the biomass, the chemical reaction must be reversed by providing oxygen in an environment such as a fire, which will allow the reaction to proceed at a suitable rate, (Garba and Atiku, 1997). Hence:

$$C_6H_{10}O_5 + 6O_2 \longrightarrow 6CO_2 + 5H_2O + \text{Energy} \quad \text{(2.2)}$$

For each kilogram of cellulose oxidized, certain amount of energy (calorific value) is released. In practical terms, the energy can be released when the cellulose is eaten, burnt or converted to a secondary fuel in the form of solid (e.g. wood or wood

sawdust), liquid (by fermentation to alcohol or extraction by mechanical pressing) or gas (e.g. digestion to form CH_4), Figure 2.1. All the conversion routes attempt to retain the basic constituents of carbon and hydrogen in the original biomass.

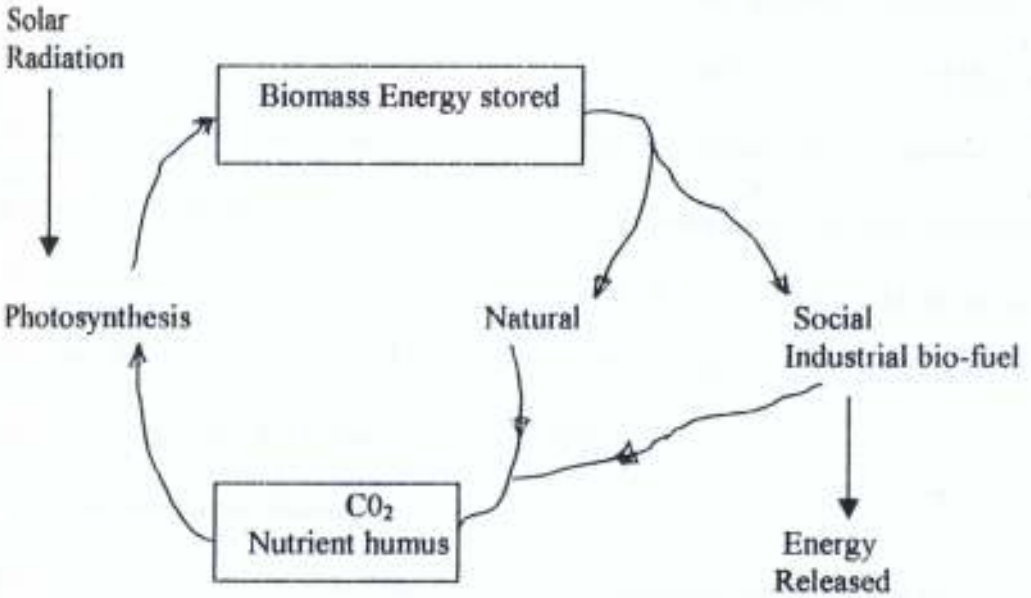

Fig. 2.1: Natural and Managed Biomass System

Thus the use of industrial bio-fuels, when linked carefully to natural ecological cycle, may be non-polluting and sustainable. Such systems are called agro-industries, of which the most established are the sugarcane and forest products industries. Bio-energy has the longest history as a fuel source for mankind. It is sustainable, renewable, efficient and harmless to the environment when used properly. Crucially, it is said to be the only renewable carbon fuel with potential to address the full range of energy markets including heat, electricity and transport in the future. It addresses the four core themes of sustainable development: protection of environment, economic growth, social equity and prudent use of natural resources (Rajgor, 2000).

The dry matter mass of biological material cycling in the biosphere is about $250x10^9$ t/y incorporating about $100x10^9$ t/y of carbon. According to Twidell and Weir (1987), the associated energy bound in photosynthesis is $2x10^{21}$ t/y ($0.7x10^{14}$ W). Of this, about 0.5% by weight is biomass used for human food. Biomass production varies with local conditions and is about twice as great per unit surface area on land than at sea. The industrial use of biomass energy may be large e.g. about 40% of national commercial supplies in some sugarcane producing countries, where crop residues (bagasse) are burnt for process heat. The domestic use of biofuel in wood, dung and plant residues for cooking is of prime importance for about 50% of the world's population, the supply totaling about 300GW (Twidell and Weir, 1987).

7.1 Constituents of Biomass

The constituents of a biomass can basically be classified into four namely:

(i) Cellulose: This is the most common substance in all forms of biomass. It is a fibrous polysaccharide (a chain of glucose molecules -C_6 H_{12} O_6), which forms the main constituents of the cell walls of land plants; this makes it to be the most abundant naturally occurring organic substance in plants. Cellulose that affects its conversion in biomass process is its extreme insolubility in water and chemical inertness. It can be soluble in alkaline and acidic solution when it swells up and converts into glucose.

(ii) Hemicelluloses: This is contained in 20-40% of the lumber plants (Bansal et al, 1990). It has energy of 18.8 MJ/kg and is a polysaccharide that occurs in association with cellulose. Hemicelluloses is more soluble than cellulose when dissolve 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 like natural glue providing the plant with added mechanical strength. It is about 30% of the lumber type of plant. 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 week hydrogen bonding in comparison with cellulose and hemicellulose. Because of this weak hydrogen bonding in the molecules, starch and sugar are especially suitable for chemical and enzymatic digestion.

Sources of Biomass

i) **Organic waste:** Organic wastes can be grouped into two categories;

rimary and secondary wastes. The primary wastes are the residues of traditional activities irectly associated with forestry and agriculture. These include forest residues (logging lash, non-merchantable trees, land clearing and sort-yard debris), mill residues (sawdust, havings, solid trim and clarifier sludge and spent pulping liquors and crop residues primary straw and corn hub). Crop and forest residues are often left on the ground to rot nd return nutrients to the soil. Mill residues tend to be a waste disposal problem and are sually burnt to provide some form of process energy. In some countries of the world, the end is now to transport wood waste at no charge to small thermal generating stations. Here, he wood is burnt in high efficiency, low polluting furnaces and the heat used to generate lectricity, which is fed into provincial electricity grid (Mittelstaedt, 1991). Secondly, gnocellulosic wastes are derived from domestic, commercial and industrial activities.

These include municipal solid waste (paper, cloth, garden debris) and commercial and industrial wastes (paper, packing materials, textiles, demolition wood). The lignacellulosic wastes that are destined for disposal in landfills may be available to an emergent wood - to- ethanol industry at very low cost (Foody and Foody, 1991).

(ii) **Natural Vegetation:** Biomass from natural vegetation has been used mainly in the form of wood from trees. Wood is about 50% cellulose, 25% hemicellulose, 25% lignin and waxes (Diana et al, 1985). When forests are cut down for timber, over 50% 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 energy obtained from this conversion process is called primary forest energy. When it is converted to more valuable fuels such as charcoal, methane by carbonization, distillation or gasification process it is called secondary forest energy. Each of the fuel derived from wood through the different energy conversion processes has a unique application. For example, in condition of forest, abundant wood is often the most practical solid fuel for heating and cooking purposes, while charcoal would be the most suitable choice for meeting fuel requirement.

ii) **Energy Plantation:** Many countries especially the developed ones have now resulted into energy plantation. Biomass crops may take the form of tree farms or the cultivation of herbaceous shrubs and grasses. Switch grass, sweet sorghum, reed canary grass, and alfalfa have been identified as herbaceous crops that have economic potential for use as biomass sources (Cherney et al, 1989). These crops grow well on marginal lands and help prevent erosion. Switch grass and reed canary

grass have the advantage of a high fibre content with a lower than usual lignin concentration. In addition, switch grass exhibits high productivity with low requirement for fertilizer. Short rotation intensive culture (SRIC) or tree farming as it is more commonly known offers an almost unlimited opportunity for biomass production (Foody and Foody, 1991).

In the British Columbia and Pacific Northwest States in the United State of America, the black cottonwood is the fastest growing hardwood. This tree has many characteristics, which makes it well suitable to genetic improvement, including large species diversity, high inter-specific cross- ability, in which plants can be regenerated from tissues and cells and ease of vegetative propagation. To date, about 2,000 black cottonwood cloned have been produced and tested in the field trials. Some hybrids are better than parent stock by 1.5-2 folds, attaining heights of 15m and base diameters of 25cm in 6 years and annual productivities of 27.5 tonnes per hectare per year (Abelson, 1991).

2.5.9 Wood-Based Energy

The earliest fuels used by Stone Age man were wood, shrubs, dried bones and dung. Also oils from birds and fish were burnt with wicks in stone lamps to give light (Kennedy, 1989). Archaeologists have found that in the Middle East, at about the time when agriculture was first being developed. Wood fires were used in the manufacture of bricks, which is a great improvement over the sun drying of bricks. By 3000BC vast quantities of wood were burnt in the process of turning limestone into mortar and of producing glazed and enamel pottery (Evans, 1989). As technology progresses, mining of metal was accompanied with heat from wood, to form them into tools and weapons.

Later, wood was baked to form charcoal, which was the fuel for the ancient industrial processes. Greek and Roman civilizations used lignite and peat as fuel (Kennedy, 1989). Wood charcoal was employed to separate iron and other metals from their ores (Evans, 1989).

2.5.9.1 Energy-Bearing Wood

Wood-based gasification, or 'dentro-thermal' energy could provide one such alternative pathway and is one that seems to hold the promise promoting both sustainability and energy security in an economical way. Wood-based systems involve the cultivation of energy plantations, which feed wood-based power generating units (Bartholomew et al, 2000). These units could be connected to 33KVA grid lines, feeding the main grid-based system, or connected to mini-grids for those regions that are currently off-grid. By no means is this new technology; indeed, there is considerable experience in energy plantation development, and wood based gasification in both developing and developed countries. The Philippines, Brazil and India have been experimenting with gasification systems for several decades. In the USA, wood based electricity generating capacity is in the range of about 6000 – 7000MW. Wood has also for long served as one of energy sources known and used by mankind, for cooking in both urban and rural areas of especially the developing countries.

In Nigeria, fuel wood is still the most utilized energy for cooking Concerted efforts are essential in order to change this for the sake of protecting our environment with specific reference to desert encroachment and soil erosion. While the long-term aspiration in respect of cooking energy is the complete substitution of fuel wood by other sources like the solar and other renewable energy sources, it is certainly obvious that this change

will take a few decades to materialize in term of household utilization. Consequently, utilization and briquette of large volumes of residues from forestry and wood-based industry, which are not being put into economic use, will certainly be steps in the right direction. Presently, these wood residues are left in the sawmills to be wastefully burnt away. The presence of these residues in large quantity poses disposal problem, for the sawmill industry and burning them in the open also contribute to environmental pollution (Hoi and Razak, 1997).

2.5.9.2 Wood Residues

Wood residues are 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 (Hoi and Razak, 1997).

In Nigeria, wood residues can be classified as follows:

(i) Logging Residues: These are residues generated during the various phases of the logging operation. These residues come in the form of bark, stumps, tops, branches, broken legs, defective logs, injured standing trees and others.

(ii) Primary Manufacturing Residues: These are residues generated in the primary wood-based industries. These are residues that include slaps, edgings, trimmings, sawdust and others.

(iii) Plywood Residues: These are residues generated by plywood mills in the countries. These are in the form of veneer cores, defective ends and irregular pieces of veneer sheets.

(iv) Secondary Manufacturing Residues: These are residues generated by the planing mills, moulding plants, flooring mills, furniture factories and others. These residues are in the form of sawdust, planner shavings, and small pieces of lumber trimmings, edgings, barks, fragments and others.

It is rather difficult to quantify the residues generated by the forestry industry in Nigeria but what is certain is that most of the residues are disposed off by burning. Instead of burning these residues, they could be briquetted for use as a high-grade solid fuel.

2.5.10 Bio-Conversion Process of Biomass into Energy

The term bioconversion simply means the conversion of biomass into useful form of heat or into solid, liquid or gaseous fuels (Bansal et al, 1990). Karekezi and Ranja, (1997) also 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 application refers to subsistence applications that can only create a limited number of jobs per unit, but generate a large number at an aggregate level.

2.5.10.1 Physical Methods of Bioconversion of Biomass into Energy

Compression of Combustion Materials:

The first and the simplest method of physical conversion of biomass is through the compression of combustible materials. The methods, which are in practice today,

predominantly use straw, peat and wood waste. The basic materials has only a very small bulk density as can be seen from Table 2.4

Table 2.4: Bulk Density of a few Solid Combustible Materials

Combustible materials	Bulk density (kg/m^3)
Straw	60 to 160
Wood dust	80 to 120
Shavings, saw clipping	90
Shavings, production	120
Brush wood, soft wood	120
Brush wood, hard wood	160
Peat dust	180 to 200
Wood flour	190
Domestic waste	180 to 200
Machine peat, air dried	325 to 425
Soft wood 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 ratio of the mass of water in the biomass to the mass of the dried substance, shows values even up to 90% (Bansal et al, 1990). Freshly cut wood has moisture content of about 10-20%. The calorific value of biomass relates to the dry weight of the biomass, i.e the weight of the substance corresponding to the absolutely water free materials. The compression of biomass leads to moisture content of 15-18%. Depending on the form and density, the end products of the compression mechanism are known as pellets, cobs or briquettes. However, a uniform standardization of the end products does not exist.

2.5.10.2 Thermo-Chemical Method

The oldest thermo-chemical method of bioconversion is combustion. The main biomass, which have been used over the years for combustion is wood. Nearly 50% of the present world's wood felling is used for burning purposes (Bansal et al, 1990). This is especially the case in developing countries, where along with wood, other forms of biomass such as dung and agricultural wastes e.g. straw are burnt.

In the combustion process of biomass ($C_kH_mO_n$), in the case especially of wood, the products of combustion are usually carbon dioxide, water vapour and ash. If sulphur is present, it is burnt to SO_2. The solid combustion products (ash) form just 1% of the total weight. For absolutely dry wood, the combustion temperature reaches a value of about 1200°C.

In thermo-chemical processes generally, the biomass is either converted into heat through the process of oxidation or it is converted into a secondary form like producer gas by some chemical processing. One can roughly distinguish three different classes of thermo-chemical reactions:

(i) combustion

(ii) gasification

(iii) liquefaction

In the technical realization, these processes run either parallel or one after each other. Consequently, a district classification for each of these processes is not possible.

2.5.10.3 Biological Method

The biological process depends on microbiological activity such as fermentation or anaerobic digestion process to produce both liquid and gaseous fuel like ethanol, methane gas, methanol etc. Decaying biomass and animal wastes are broken down to elementary nutrients and soil humus by decomposer organism fungi and bacteria (Twidell and Weir, 1987). The processes are favoured by wet, warm and dark conditions. The final stages are accomplished by many different species of bacteria classified as either aerobic or anaerobic. Aerobic bacteria are favoured in the presence of oxygen with the biomass carbon being fully oxidized to $C0_2$.

In closed conditions with no oxygen available from the environment, anaerobic bacteria are able to exist by breaking down general carbohydrate materials. The carbon may be ultimately divided between fully oxidized CO_2 and fully reduced CH_4. Nutrients such as soluble nitrogen compounds remain available in solution, so providing excellent fertilizer and humus. Being accomplished by microorganisms, the reactions are all classed as fermentations, but in anaerobic condition leading to methane the term "digestion" is often preferred.

2.5.11 Sawdust Briquettes

Briquetting is the physico-mechanical conversion with or without an additive of a dry loose wood waste of fine particles size into a solid state characterized by a regular shape and high density (Bamiyo, 1999). It could also be defined as the process of converting loose wood wastes or sawdust into a dense, compact and consolidated unit through the application of high temperature and pressure (Hoi and Razak, 1997). Basically low-pressure binding requires binder unless heat is applied from an external

source at an elevated temperature of between 163°C and 195°C while high-pressure binding requires no binder.

Apart from the problems of transportation, storage, and handling, the direct burning of loose sawdust in conventional grates or stove is associated with very low thermal efficiency and widespread air pollution. In addition, a large percentage of un-burnt carbonaceous ash has to be disposed. Briquetting of this sawdust could militate against these pollution problems while at the same time making use of this important industrial/domestic energy source.

Historically, biomass including sawdust briquette technology has been developed in two distinct directions. Europe and the United States have pursued and perfected the reciprocating ram/piston press while Japan has independently invented and developed the screw press technology. World wide, both technologies are being used for briquetting of sawdust, but briquette technology is yet to get a strong foothold in many developing countries including Nigeria because of the technical constraints involved and the lack of knowledge to adapt the technology to suit local condition.

Overcoming the many operational problems associated with this technology and ensuring the quality of the raw material used are crucial factors in determining its commercial success. At present, two main high-pressure technologies: ram or piston press and screw extrusion machines, are used for briquettes. While the briquettes produced by piston press are completely solid, screw press briquettes on the other hand have a concentric hole, which give better combustion characteristic due to large specific area. Having a high combustion rate, can substitute for coal in most applications and in boilers. The manually operated hydraulic briquette machine fabricated at the Federal

University of Technology, Akure is a piston press based but incorporates the concentric hole arrangement. Screw extrusion briquettes technology was invented and developed in Japan in 1945. As of April 1969, there were 638 plants in Japan engaged in manufacturing sawdust briquettes, known as **'ogalite'** amounting to a production 0.81MT/Y **(http://www.rwedp.org/fd46chl.html)**. The facts that the production of briquettes quadrupled from 1964 to 1969 in Japan speak for the success of this technology. This technology has also been successful in most advance countries of the world while some developing countries are making efforts to develop it into commercial venture.

In Thailand, both small and high production capacities can be found and the general plant performance in terms of profitability and management is encouraging. In India, briquettes sector is growing gradually in spite of some failures. As a result of a few successes and promotional efforts, a number of entrepreneurs are confidently investing in biomass briquettes. These entrepreneurs are also making strenuous effort to improve both the production process and the technology. The recent successes in briquettes technology and growing number of entrepreneurs in briquettes sector are evidence that biomass briquettes will emerge as a promising option for the new entrepreneurs and other users of biomass (http://www.rwedp.org/fd46chl.html).

The briquettes produced are normally of two forms: carbonized and uncarbonised. Carbonized or charred briquettes are formed when biomass is subjected to a destructive distillation in a closed reactor devoid of oxygen and quenched after attaining a predetermined temperature. O n the other hand, uncarbonised briquettes are plain briquettes produced without undergoing carbonization process.

In Nigerian, a lot of research work had been done on the utilization of sawdust for domestic cooking using improved burning stove (Danshehu et al, 1992) while attempt had been made to densify the sawdust with appropriate equipment fabricated by the Raw Materials Research and Development Council in collaboration with Abubakar Tafawa Balewa University, Bauchi (Aliyu, 1996) There have been various research work at the Federal University of Technology, Akure on the suitability of utilizing sawdust as high grade solid fuel under the supervision of Professor C. O. Adegoke. Ogundeji, (1995), reported that the addition of some biomass material such as palm kernel shell, charcoal, coconut shell and fibre to sawdust in various proportions and determined their calorific values. A summary of the finding indicated that the calorific value of mixture of sawdust and palm kernel shell mixed in the ratios of 9:1, 8:2, 7:3 increased in calorific value whilst the mixture of sawdust with coconut shell and fibre in the same ratios have decreased calorific values. It was then conclude that the mixture with ratio of 7:3 sawdust/palm kernel-shell gave the highest calorific value. The report then recommended the densification of briquette of the sample with highest calorific value to further improve the calorific value. Other research work carried out was the evaluation of composite sawdust briquettes as a high- grade fuel for domestic cooking (Kuti, 2003). This involved the use of common sawdust (mixture of different species of wood) with palm kernel shell as additive to improve the calorific value. In carrying out the research work, sawdust and charred palm kernel shell were mixed at ratios of 50:50, 60:40, 70:30, 80:20, and 90:10 with the gain sizes of 1.18mmpks, 2.00mmpks and 2.36mmpks respectively to produce different composite briquettes. Calorific value, water boiling and control cooking tests

were then conducted on the briquettes so produced. It was discovered that the briquettes with 70:30 and grain size of 1.18mmpks was the best solid fuel.

2.5.11.1. Qualities of Sawdust Briquettes

Good quality sawdust briquettes should have the following characteristics:

(i) **Smokeless**: This briquettes burn with minimal smoke or fume during initial ignition and during the burning duration.

(ii) **Higher Fixed Carbon and Calorific Value**: Fixed Carbon over 82%, the good grade reaches 90% with high caloric value averaging 31.38MJ/kg or better.

(iii) **Odourless**: Minimum evaporative substances thus eliminating the possibility of odour.

(iv) **Longer burning hours**: 2 times longer burning hours compared to hardwood charcoal, the normal sawdust briquette last about 3 – 4 hours the best grade lasts about 6 -8 hours

(v) **Chemical Free:** The briquette is produced with untreated timber waste.

(vi) **Sparkless**: This briquette will not produce sparks as compared to Hardwood charcoal.

2.5.11.2 Reasons for Briquetting

According to Karkezi and Ranja (1997), briquetting of biomass 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 cost 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).

Briquettes could be an important alternative energy for cooking in house holds 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;

(iii) It is a means of turning waste to wealth through the conversion of sawdust to briquettes that could be sold;

(iv) Reduction in oil or other costly fossil fuel needs.

2.5.11 Properties of Solid Biofuel

There are various properties of solid bio-fuel, which, needs to be understood before being put into use.

2.5.12.1 Physical Properties

(i) Calorific Value

The most important property of fuel is its calorific or heating/combustion 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 as two calorific values namely: the higher or gross calorific value, and the lower or net calorific value. The higher or gross calorific value is defined as the heat generated when the material is completely combusted to carbon dioxide and liquid water at 25^0C (British Standards Institution, 1961). It is the maximum amount of energy that can be liberated when the fuel reacts with air. It is measured in Mega Joules per kilogramme (MJ/kg) of oven-dried fuel by the specific methods as laid down by international standard.

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 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 100^0 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 higher and lower calorific values can be said to be the heat required to evaporate the water contained in the fuel and produced by the consumption of hydrogen.

The calorific values of wood vary from one tree to another (Garba and Atiku, 1997). Table2.5 shows the thermal properties of eight selected tropical woods. The

calorific value lie between 17.40 and 22.80 MJ/kg while the flame temperature is between 340 and 510°C respectively.

Table 2.5:Thermal Properties of Some Tropical Wood

S/N	Materials	Oxygen Index (%)	Calorific Value (MJ/kg)	Flame Temperature (^{O}C)
1.	Aduwa	24	17.4	470
2.	Bagaruwa	30	12.4	340
3.	Kirya	28	14.9	380
4.	Isirir	22	21.0	480
5.	Marka	26	15.5	430
6.	Chediya	25	16.0	435
7.	Kalgo	32	11.8	300
8.	Kuka	21	22.8	510

Source: (Garba and Atiku, 1997)

Cheremisinoff, (1980) also reported that the gross calorific values of different wood species do not vary greatly, the average value being about 19259.28kJ/kg. Neeman and Steinbeck, (1979) also 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.

(i) Density and Structure

The density and structure are related in so much, as the proportion and size of pores in 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 break down of the structure as the materials are burnt.

(ii) Moisture Content

Most biomass fuels are hygroscopic (i.e. they absorb 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 fuel, were found to contain a great deal of water (80-90% on a dry-weight basis). 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; for instance, a recently cut biomass with a moisture content of 80-90% dry weight basis could reduce the net available energy by 50 – 60% against the same biomass when it is dried.

(iii) Shape and Size

The greater the overall surface area of fuel exposed to the required quantity of oxygen and heat, the faster the combustion process and hence the greater the power output. Solid biofuels such as sawdust, husks etc are more useful in briquettes form.

2.5.12.2 Chemical Properties

Biomass such as sawdust 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 have no heating value.

Two analyses are usually carried out to describe the chemical properties of fuel namely; the ultimate and proximate analyses. The ultimate analysis always gives the approximate chemical composition of elements like carbon, oxygen, hydrogen, sulphur, nitrogen etc present in a fuel whilst the proximate analysis always gives the composition of biomass in terms of the amount of fixed carbon, volatile matter and ash produced when it is combusted. While combustion itself is the process of burning a fuel in the presence of oxygen, the combustion of solid bio-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. The following chronicles the various stages involved during the combustion of solid bio-fuel.

During the establishment of flame, the initial heat would be supplied to evaporate the water content of the fuel at about 100°C. Then the temperature of the fuel will rise, after reaching about 200 to 350°C, the volatile gases (carbon dioxide, hydrogen etc) would be released. The volatile gases evolved mix with more oxygen and ignite at a temperature in excess of about 450°C and burn with 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.

During combustion, charcoal burns and oxides 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.

CHAPTER THREE

3.0 MATERIALS AND METHODS.

3.1 Choice of Sample

Information gathered at the Forestry Department, Ondo State Agricultural Development Project showed that any hand wood would have high calorific value than soft woods. The following categories of hard woods were said to have advantages over others; they are the Teak, Masonia, Iroko and Afara.

Five samples of sawdust comprising four special species as highlighted above and common sawdust (different species of wood) were used for the research work. Apart from sawdust, a biomass material was added. This biomass material is palm kernel shell, which was added in different proportions and in different grain size with a view to improving the calorific value.

3.1.1 Sample Collections

The sawdust samples were collected from sawmills around Akure while the palm kernel shells were purchased at the open market at Oja-oba in Akure. Special attention was paid to the collection of the different samples in order not to mix them up at the sawmills. The materials used and their botanical names are as follows:

ble 3 .1: Materials used and their Botanical Names

S/N	Common Name	Botanical Names
1.	Teak	Tectonia grandis
2.	Masonia	Masonia altisima
3.	Iroko	Melicia execial
4.	Afara	Tamilaina superba
5.	*Common sawdust	-
6.	Palm kernel shell	-

lixture of different species of wood

Selections and Preparation

The five collected samples of sawdust were screened of impurities like sand, tallic objects and chips of wood. They were then sun-dried to reduce the moisture ntent in the materials. It was then ensured that uniform size of the materials samples re prepared to ensure easy compression. Preparatory to briquetting, the five samples re labeled and six samples each from the five original samples were made.

The palm kernel shell was milled at the Mineral Processing Laboratory of the ning Engineering Department, Federal University of Technology, Akure, where two ipments, a Jaw Crusher and Ball Mill were used to mill the palm kernel shell (pks) to ticle sizes of 0.85mm and 1.18mm. The Jaw Crusher did the pre-crushing while the l Mill was involved in further size reduction. Two different sizes of mesh 0.85mm and 8mm were available at the laboratory, which were used to sieve to the required mesh es.

Three sets of sample were then made from the five original samples either mixed at certain proportion with palm kernel shell (pks), which is the additive or without additives (Table 3.2). These samples were weighed with Mettler Toledo PB 300 digital weighing machine within the range of 5 to and 3100g. Adegoke and Mohammed (2002) in their research findings stated that irrespective of the grain size, calorific value increased with increase in the weight of palm kernel shell in the sawdust briquette up to about 30% by weight and grain size not above 5mm. Hence the mixture of sawdust and palm kernel shell, were based on this ratio. The samples were mixed at 70/30% sawdust/palm kernel shell (pks) at different grain sizes of palm kernel shell (pks) and 100% pure sawdust without the addition of palm kernel shell.

Other materials used in the research work are starch paste, sodium silicate; water, weighing balance, sawdust briquette stove and briquette machine, cooking pot, bomb calorimeter, crucible and a muffle furnace. The starch was purchase at Ojota Chemical Market in Lagos. The sawdust briquette stove used was fabricated by ACOM Associates Limited, Akure. The starch paste was made into non-viscous gel preparatory to briquette while the sodium silicate was used as purchased.

Table 3.2: Composition of Materials used with Palm Kernel Shell

Sample	Composition of Sawdust/Pks (%)	Grain Size of Pks (mm)
Teak	100:0	Nil
	70:30	0.85
	70:30	1.18
Masonia	100:0	Nil
	70:30	0.85
	70:30	1.18
Iroko	100:0	Nil
	70:30	0.85
	70:30	1.18
Afara	100:0	Nil
	70:30	0.85
	70:30	1.18
Common Sawdust	100:0	Nil
	70:30	0.85
	70:30	1.18

Three sets of samples were made from the five original samples. Some samples were mixed at certain proportion with palm kernel shell (pks) while some are without palm kernel shell. Starch, which is a binder, was also added at a weight ratio of 70:30 (Sawdust/pks: starch paste). The same procedure was repeated while using sodium silicate as a binder, the weight ratio being 70:30 (sawdust/pks: sodium silicate).

3.3 Compression of Briquettes

A manually operated Hydraulic Briquetting Machine Fabricated by ACOM Associates Limited, Akure was used for compression of the sawdust samples into cylindrical shaped briquettes. The machine is equipped with pressure guage, a hand lever with a mould that could produce 16 briquettes at the same time. Briquettes of the various mixtures were made under maximum pressures of 1000Psi (6.89MPa). The pressure was then released gradually to eject the compressed briquettes. A maximum of 16

briquettes were obtained at each operation of the machine under a total load of 57.4N. This procedure was repeated 30 times in six days to produce 30 sets of different samples making a total number of 480 cylindrical briquettes.

The total compression force, $F = P \times A$ ..... (3.1)

Where F = Load exerted during compression, otherwise know as Compression force, (N)

P = Pressure exerted by the Piston over briquettes in the mould measured by a pressure gauge, (N/m^2)

A = Cross-section area of the hydraulic piston, (m^2)

$A = \pi(d_p)^2/4$

Where:

d_p = diameter of hydraulic piston, (m)

$P = 6.89 \times 10^6$ (where 1Psi =6.89kPa) and

(1000psi = 6.89kPa x 1000 =6.89MPa)

$A = \pi (0.103)/4$

$n = 16$

$d_p = 103mm = 0.103m$

$F = [6.89 \times 10^3 \times \pi (0.103)^2]/4$

$F = 57.41N$

Load on each of the piston

$F_p = F/n$ ---------- (3.2)

Where:

n = number of briquettes in the mould

F_p = 57.41/16

3.59N

3.3.1 Observation during Briquetting

It was observed that the hydraulic arm was very short which necessitated a lot of force being applied to bring the pressure to 1000psi. There is a lot of hydraulic oil leakage during compression this affected the maximum pressure at each operation of the machine. The leakage was as a result of damaged seal, which was promptly rectified. The machine used in briquetting is shown in Plate 3.1

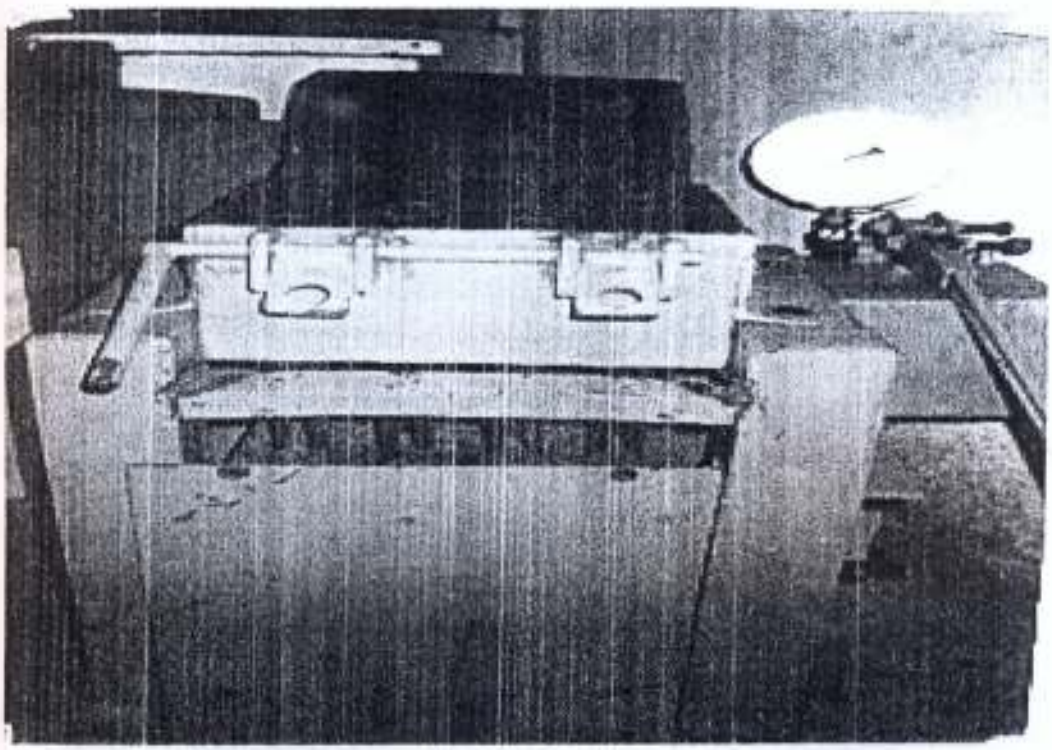

Plate 3.1: Briquetting Machine

3.3.2 Sun-Drying of Briquettes

After each successive operation whereby cylindrical briquettes were obtained, the products were then transferred to the open space for sun drying to enhance solidification of the briquettes thereby removing the inherent moisture content to a tolerable level. This could also be oven dried but there was no oven for use during the course of the research work.

3.4 Sawdust Briquette Stove:

The sawdust briquetting stove used in this research work was fabricated also by ACOM Associates Limited, Akure. The body is made of mild steel sheet. The bottom of the heating chamber is perforated, this constitute a grate. There is also ash-collecting port at the bottom of the stove. The grate at the bottom of the combustion chamber allows the ash to go through to the ashtray (Plate 3.2).

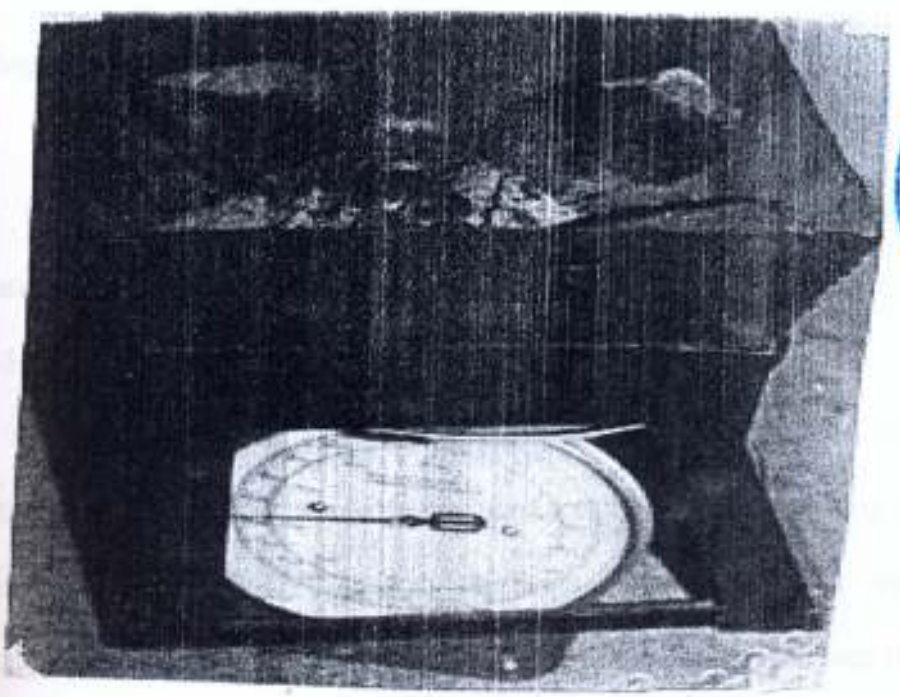

Plate 3.2: Briquette Stove on a weighing Balance

3.5 Timing Device

A stopwatch was used during the experiment to record the timing of the different stages of the test. It has ability to display seconds and minutes.

3.6 Weighing Balance

Two weighing balances were employed during the test. One was a digital type while the second was an analogue, the digital weighing balance weighs up to an accuracy of 5g and the other one weighs up to an accuracy of 50g, these were used at both the experimental field and laboratory experiments.

3.7 Mercury-In-Glass Thermometer

A mercury-in-glass thermometer was used to take the different range of temperatures during the water-boiling test.

3.8 Cooking Pot

A cooking pot made of stainless steel with a lid was used during the water-boiling test.

3.9 Analytical Techniques

The following steps were taken when performing the experiment for the determination of calorific value.

3.9.1 Calorific Value

A mass of water of 2500g was poured into calorimeter vessel. The Bomb Calorimeter cap was opened and the prepared weighed of sample was inserted into the crucible. The crucible with the sample was inserted on a ring stand. A coiled resistance wire was immersed in the sample. The wire ends were inserted into electrode notches and a little quantity of nitric acid is added to the sample to aid ignition. The bomb

calorimeter cap was then screwed in. The pressure regulator with pressure gauge up to $3MN/m^2$ was screwed to the oxygen cylinder. The connecting capillary tube was then attached to the pressure regulator outlet.

The bomb calorimeter was transferred carefully in vertical position on the stand fixed to the table near the stand of the oxygen cylinder. A screw nut from the bomb inlet valve was removed and the free end of the connecting capillary tube was screwed by hand into the free inlet valve of the bomb.

The bomb outlet valve, was opened by screwing in knurled knob clockwise by a turn. The pressure-reducing valve on the oxygen cylinder was adjusted to the initial pressure of $3MN/m^2$ after opening the oxygen cylinder valve.The pressure regulator outlet valve was opened while the bomb outlet valve closed, by unscrewing fully the knurled knob anticlockwise. The time between opening the pressure regulator outlet valve and closing the bomb outlet valve is necessary for displacing the air contained in the calorimetric bomb by oxygen.

After obtaining the pressure required in the calorimeter bomb, the oxygen flow to the bomb was closed by closing the pressure regulator outlet valve, and the cylinder valve.Connecting capillary tube from the calorimeter bomb is disconnected by screwing the capillary tube clamp out of the bomb inlet valve, and screwing in, in its place a special screw of the valve. $0.002m^3$ of distilled water by means of a pipette was sprayed into the bomb body

The bomb was carefully transferred in vertical position to the Calorimeter and was placed into the calorimeter vessel with the prepared water, the bomb was held during this operation by the protruding valve. The contact pins with the electrical lead was

connected while the mechanical stirrer was put on and this stirring continued throughout the experiment. After 5minutes the thermometer was read to an accuracy of $0.001^{0}C$. The thermometer was read at intervals of 1minutes for 5minutes, which is referred to as the initial period.

At the end of the initial period, the bomb was fired and ignition started immediately while increase in temperature was observed. The thermometer was then read at intervals of 1minutes, which is referred to as the chief period. After the maximum temperature was reached, the temperature started to fall, which is referred to as the end period and the temperature were read at intervals of 1minute for 5minutes. The Gallenkamp Ballistic Bomb Calorimeter used during the experiment is as shown in plate 3.3.

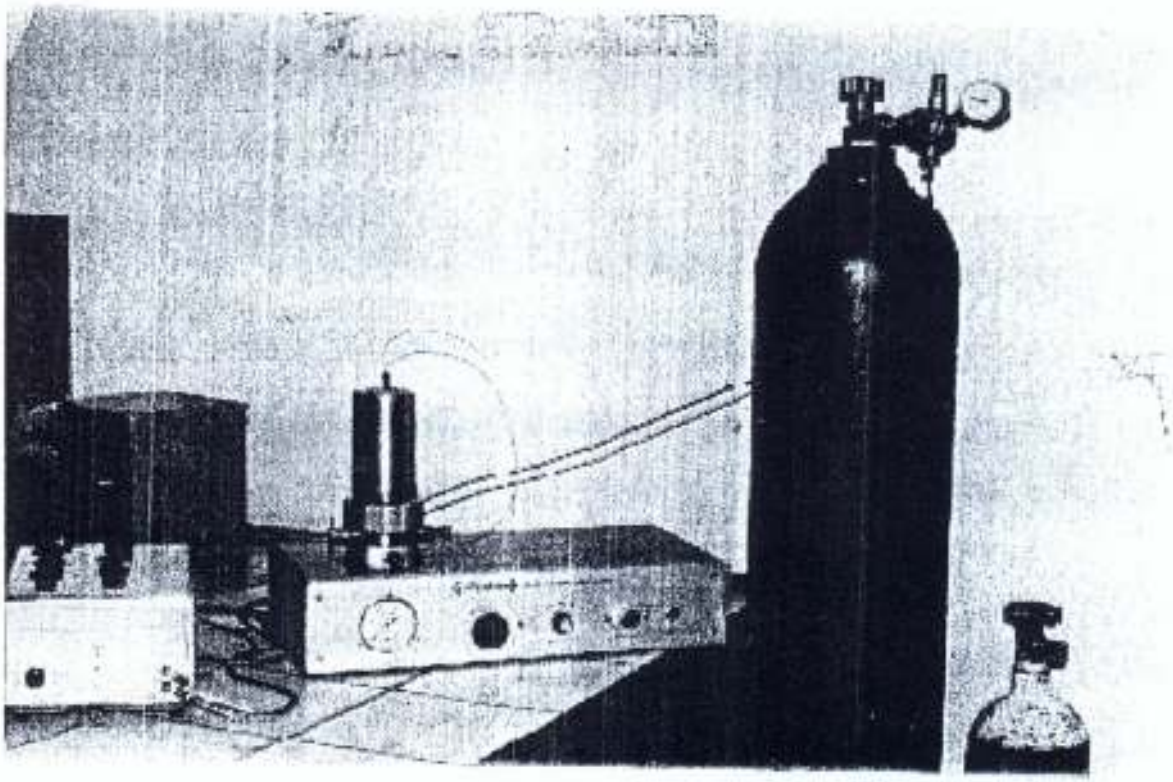

Plate 3.3: Gallenkamp Ballistic Bomb Calorimeter

3.9.2 Precaution

(i) All values were tightened so as to prevent gas leakage

(ii) Care was taken such that the Bomb was not rested upon when being filled with oxygen.

(iii) It was ensured that pressure regulator fitted on the cylinder was not directed towards the place occupied most frequently by people.

(iv) The wire ends were inserted into electrode notches, for proper ignition.

3.9.3 Determination of the Calorific Values of Samples

To obtain the value of a fuel, which is the amount of energy liberated by burning a unit mass. The following must be accomplished.

The heat must be balanced i.e.

$$E = [(m + m_a)/m_f] \times C \times \Delta T \quad \text{..... (3.3)}$$

Where:

E = energy released by fuel, (J/kg)

m = mass of water used, (kg) = (2.50kg)

m_a = equivalent mass of apparatus (given by the manufacturer as 0.10kg), (kg)

m_f = mass of fuel, (kg)

ΔT = temperature rise, (K)

C = specific heat capacity of water = 4.1868 kJ/kg^{0}C

The cooling correction obtained from the Regnault – Pfaundler cooling correction equation (Joel, 1987) should be added to the measured temperature rise. This is obtained from the equation (3.4)

$$F_C = n'v' + \left[v''-v'/\ t''-t'\right] \times \left[\sum_{t}^{n-1}(t) + \tfrac{1}{2}(t_n - t_o) - n'\,t'\right] \quad \text{---------- (3.4)}$$

$$= n'\,v' + k\,s$$

Where:

n' = number of minutes within **CHIEF PERIOD**, which is the beginning of firing the bomb, commencement of ignition and rapid temperature increase. The thermometer is read at an interval of 1minute until it reaches the maximum temperature.

v' = rate of fall of temperature per minute within **INITIAL PERIOD** which is the period of determination of the heat exchange between the calorimeter and the environment. The thermometer is also read at 1minute interval for 5minutes.

v" = rate of fall of temperature per minute in the **END PERIOD** which is the period of heat exchange between the calorimeter and environment, when the temperature starts to fall and the thermometer was read at interval of 1minute for 5minutes.

$$S = \sum_{t}^{n-1}(t) + \tfrac{1}{2}(t_n - t_o) - n'\,t' \quad \text{---------- (3.5)}$$

$S = \sum_{t}^{n-1}(t)$ = sum of the temperature readings during the chief period.

$k = v''-v'/\ t''-t'$ = cooling constant of the calorimeter

$\tfrac{1}{2}(t_n - t_o)$ = mean of the firing temperature (t_o) and the maximum temperature (t_n) attained after which the temperature drops.

t" - t' = average temperature during the initial and end period respectively.

3.9.4 Flame Temperature

The flame temperature of all the sample briquettes were measured when flaming has been fully established by using a German made HBS-Geroz Watt Metre, model 4014.

3.9.5 Volatile Matter

1g of moisture free sample was weighed into a tarred crucible, covered with the lid and the crucible and its content placed in the muffle furnace. It was removed after exactly 10minutes residence in the hot zone of the furnace just before attaining the ignition temperature and was then cooled in a desiccator. The crucible with its content was weighed and expressed as the weight loss% volatile matter.

3.9.6 Ash Content

1g of the sample was weighed into a clean crucible. The uncovered crucible was places in cold muffle furnace and heated gradually so that the temperature increased to increased to 500°C in one hour and 750°C in 2 hours. The crucible was therefore cooled and covered in a desiccator and weighed. The percentage ash content was then calculated.

3.9.7 Moisture Content

1g of the sample was weighed into crucible. The crucible was placed in cold muffle furnace and heated to 100°C to evaporate the moisture. The crucible was then cooled in a desiccator and weighed. The percentage moisture was then calculated as weight loss % moisture content.

3.9.8 Fixed Carbon

After the ash has been separated, what was left was carbon; percentage fixed carbon was then calculated by subtracting the sum of volatile matter, moisture content and ash from 100.

3.10 Performance Test of Samples

Before promoting the domestic and commercial use of any type of solid fuel, it is expedient to have good understanding of its performance. The performance of any biomass fuel such as sawdust briquette of different species of wood can be evaluated effectively when its combustion characteristics are obtained using sawdust briquette stove, hence this type of stoves has been found to be more effective and efficient to burn sawdust briquettes in order to evaluate their performance (Adegoke and Mohammed, 2002).

This performance can be evaluated using tests that would reveal quantitative and qualitative information about the fuel by embracing the following:

(i) The amount of fuel require to boil a given quality of water

(ii) The thermal efficiency (i.e. Percentage Heat Utilized, PHU) for different species of sawdust briquettes.

(iii) The overall specific fuel consumed of each specie of sawdust briquettes

(iv) Time spent in boiling a give mass of water by different species of sawdust briquettes.

Some of the materials and equipment used at the experiment site are shown in plate 3.4.

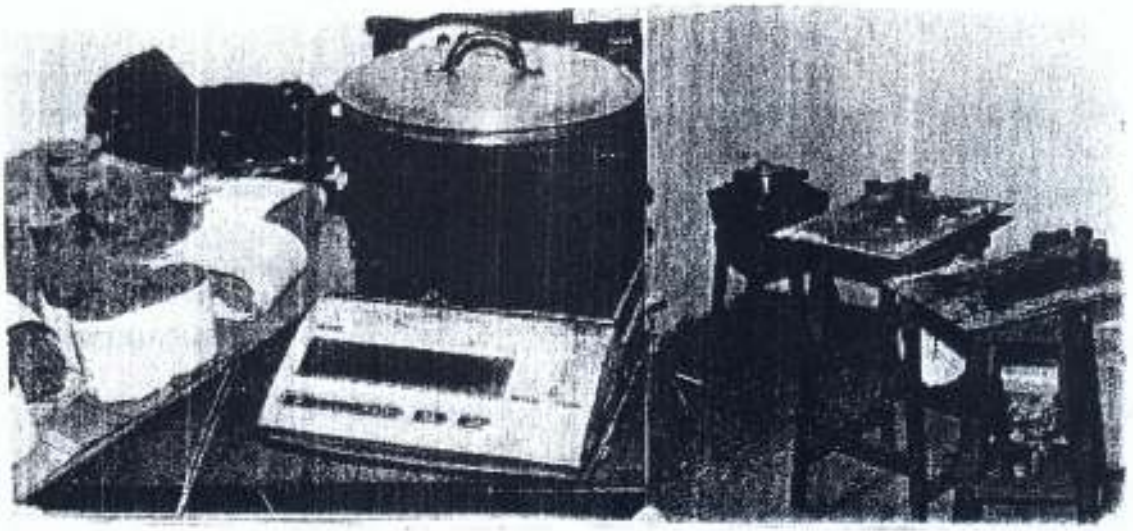

Plate 3.4: Materials and Equipment at the Experiment Site.

3.10.1 Water Boiling Test

3.10.1.1 Percentage Heat Utilized (PHU)

Water boiling tests (WBT) are short, simple simulations of standard cooking procedures. They measure the fuel consumed and time required for simulated boiling. It could also be used for assessment of stove design and optimization of stoves when solid fuel is made to combust. In some cases, where cooking test or kitchen field test 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 test, the following procedures were taken. Dry weight of experiment materials like pot and stove were taken and recorded. The pot was filled with 1kg of water. The same mass (1kg of water), was maintained at each successive test and throughout the course of carrying out a water-boiling test. The initial temperature of water was taken. The initial mass of sawdust briquette was taken before it

was stacked in a round form inside the sawdust briquette stove. A minimum of twelve pieces of briquette was used during each experiment. The fuel was ignited by adding a little amount of kerosene about (39.6g) to speed up the rate of initial combustion. One gramme of kerosene is assumed to be about 2g of briquettes hence the kerosene was used to start the ignition of the briquette.

After the briquettes have been lit, the pot containing 1kg of water was placed on the stove and both the stove and pot containing the water were placed on the analogue weighing balance. The temperature of the water was taken at 5minutes interval until boiling took place. The time at the point of boiling was recorded and tagged "boiling phase". The mass of fuel remaining inside the stove at this point was also recorded on the analogue weighing balance. Likewise, the mass of water remaining inside the pot was recorded on the digital weighing balance

The pot of water was quickly transferred back to the stove and the process continued for the next 15minutes after which the above procedure was repeated, this point being tagged "high boiling phase". The process also continued for another 30minutes so as to reduce the combustion power to the lowest level to keep the water simmering. This is tagged as "low boiling phase". At the end of the low boiling phase, the mass of water and fuel remaining were recorded. The mass of charcoal and ash remaining were recorded. The values obtained during the experiment were used for analysis. The whole process was repeated for all the 15 samples of sawdust briquettes of different species of wood earlier produced. Heat utilized (P.H.U) at each phase of boiling, was then evaluated as follows:

P.H.U = Net heat supplied / Net total heat utilized x 100%

$$P.H.U = [m_w C_p (T_b - T_i) + m_e L] / [m_f \times E_f] \times 100\% \quad \text{---------- (3.6)}$$

Where:

m_w = mass of water in the pot, (kg)

C_p = specific heat of water, (kJ/kg K)

T_i = initial temperature of water, (K)

T_b = boiling temperature of water, (K)

m_e = mass of water evaporated, (kg)

L = latent heat of evaporation, (kJ/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 did 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} is therefore given as:

$$m_{eq} = 1.5 (m_f - m_l - m_c) \quad \text{..... (3.7)}$$

Where:

m_l = mass of fuel left, (kg)

m_c = mass of charcoal, (kg)

3.10.1.2 Specific Fuel Consumption (S.F.C)

Part of the objective, of water boiling test (WBT) is to compare the fuel consumed and the time spent in boiling a particular quantity of water. The tests were also carried out on all the 15 samples involved in the research work. The tests therefore enable

the determination of the specific consumption figure, which expresses the amount of sawdust briquettes of different grades required to obtain 1kg of boiled water. To obtain the specific fuel consumption (S.F.C.), which is the amount of sawdust, briquette required to boil 1kg of water, this must be evaluated thus:

S.F.C. = mass of sawdust briquette burnt /mass of water boiled

$$S.F.C = m_i - m_b / m_w - m_p \quad \text{..... (3.8)}$$

Where:

m_i = initial mass of sawdust before burning, (kg)

m_b = final mass of sawdust burnt , (kg)

m_w = mass of pot and water, (kg)

m_p = mass of pot, (kg)

3.10.1.3 Time Spent in Boiling

The time spent in boiling 1kg of water for each of the 15samples were obtained by measuring the temperature at the boiling phase, the high boiling phase and the low boiling phase respectively.

3.11 Factorial Experiment Design

A factorial experiment was arranged as 3-factor factorial in a complete Randomized Design (C.R.D) for calorific value test and water boiling test (P.H.U, S.F.C). Three replicates were obtained for calorific value, percentage heat utilized and specific fuel consumption. For the parameters evaluated, a 5x3x3 factorial experiment can be designed. The following treatment factors were considered.

Calorific Value

Factor A: Species of wood sawdust Briquettes.

Factor B: Percentage composition of Pks in sample

Factor C: Grain size of Pks in samples.

The parameters evaluated are the Calorific Value, Percentage Utilized and Specific Fuel Consumption.

Interaction AB, AC, BC and ABC can be obtained between the treatment factors.

Their effect could also be studied. The mathematical model for the 3–factor factorial design is given by an expression

$$Y_{ijkl} = \mu + A_i + B_j + C_k (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + (ABC)_{ijk} + \varepsilon_{ijkl} \quad \text{---------- (3.9)}$$

Where:

μ= general mean for individual observation

A_i= effect of factor A

B_j= effect of factor B

C_k=effect of factor C

$(AB)_{ij}$= effect of interaction AB

$(AC)_{ik}$= effect of Interaction AC

$(BC)_{jk}$= effect of interaction BC

$(ABC)_{ijk}$=interaction ABC

ε_{ijkl}= experimental error

3.11.1 Statistical Analysis

Analysis of Variance (ANOVA)

Analysis of variance is a tool to analyze data obtained from the 3–factor factorial experiment. It was conducted to estimate the relative importance of various sources of

variations or treatment factors on Calorific Values, Percentage Heat Utilized and Specific Fuel Consumption.

In addition, the interaction effect between the factors under the factorial experiment were considered by ANOVA to justify the factorial experiment

(i) Calorific Value Test

Factor A:

Null hypothesis, Ho: The effect of factor A on the Calorific Value is not significant.

Alternative hypothesis, Ha: The effect of factor A on the Calorific Value is significant.

Factor B:

Null hypothesis, Ho: The effect of factor B on the Calorific Value is not significant.

Alternative hypothesis, Ha: The effect of factor B on the Calorific Value is significant.

Factor C:

Null hypothesis, Ho: The effect of factor C on the Calorific Value is not significant.

Alternative hypothesis, Ha: The effect of factor C on the Calorific Value is significant.

Interaction AB, AC, BC and ABC:

Null hypothesis, Ho: The effect of interaction AB, AC, BC and ABC is not significant.

Alternative hypothesis, Ha: The effect of interaction AB, AC, BC and ABC is significant

(ii) **Water Boiling Test**

Null hypothesis, Ho: The effect of factor A on the P.H.U and S.F.C is not significant.

Alternative hypothesis, Ha: The effect of factor A on the P.H.C and S.F.C is significant.

Factor B:

Null hypothesis, Ho: The effect of factor B on the P.H.U and S.F.C is not significant

Alternative hypothesis, Ho: The effect of factor B on the P.H.U and S.F.C is significant.

Factor C:

Null hypothesis, Ho: The effect of factor C on P.H.U and S.F.C is not significant.

Alternative, Ha: The effect of factor C on the P.H.U and S.F.C is significant.

Interaction AB, AC, BC and ABC

Null hypothesis Ho: The effect of interaction AB, AC, BC and ABC on the P.H.U and S.F.C is not significant.

Alternative hypothesis, Ha: The effect of interaction AB, AC, BC and ABC on the P.H.U and S.F.C is significant.

The hypotheses set up were tested at 0.01 level of significance using "Statistical Package for Social Science" (SPSS), a computer software package.

The following inferences are to be deduced from the ANOVA Table4.1 when level of significance is zero reject Ho and accept Ha. When level of significance is greater than zero accept Ho and reject Ha. The hypotheses set up were tested at .01 level of significance using F- test (Appendix 3-5). Each tabulated values was obtained from "SPSS".

3.11.2 Graphical Representation

Graphs were plotted to show the pattern of variations in the parameters as regards the Calorific Values, Percentage Heat Utilized and Specific Fuel Consumption.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

The results of tests and experiments carried out during the course of carrying out the research work as well as the statistical analysis are hereby presented.

4.1 Variation in Calorific Values of Sawdust Briquettes of different Species of Wood

Figure 4.1 shows the calorific values of sample sawdust briquettes at 70:30 percentages by weight (sawdust to palm kernel shell) and grain sizes of 1.18mm and 0.85mm grain sizes of palm kernel shell using starch as a binder. Looking closely at the calorific values, it is found that the Common sawdust briquette was about 18.8MJ/kg, which serves as the standard for the comparison of other calorific values of selected species of sawdust briquette.

As can be seen, the calorific values of species of sawdust briquettes were found to have higher calorific values than the common sawdust briquette, the 100% Masonia sawdust briquette has the highest calorific value of 20MJ/kg among this group of briquette while the Teak, Afara and Iroko have 19.80, 19.70, and 19.20 MJ/kg respectively. Figure 4.2 is also similar to Figure 4.1 and the calorific values are closely related while sodium silicate was used as a binder. The need for figure 4.2 was a search

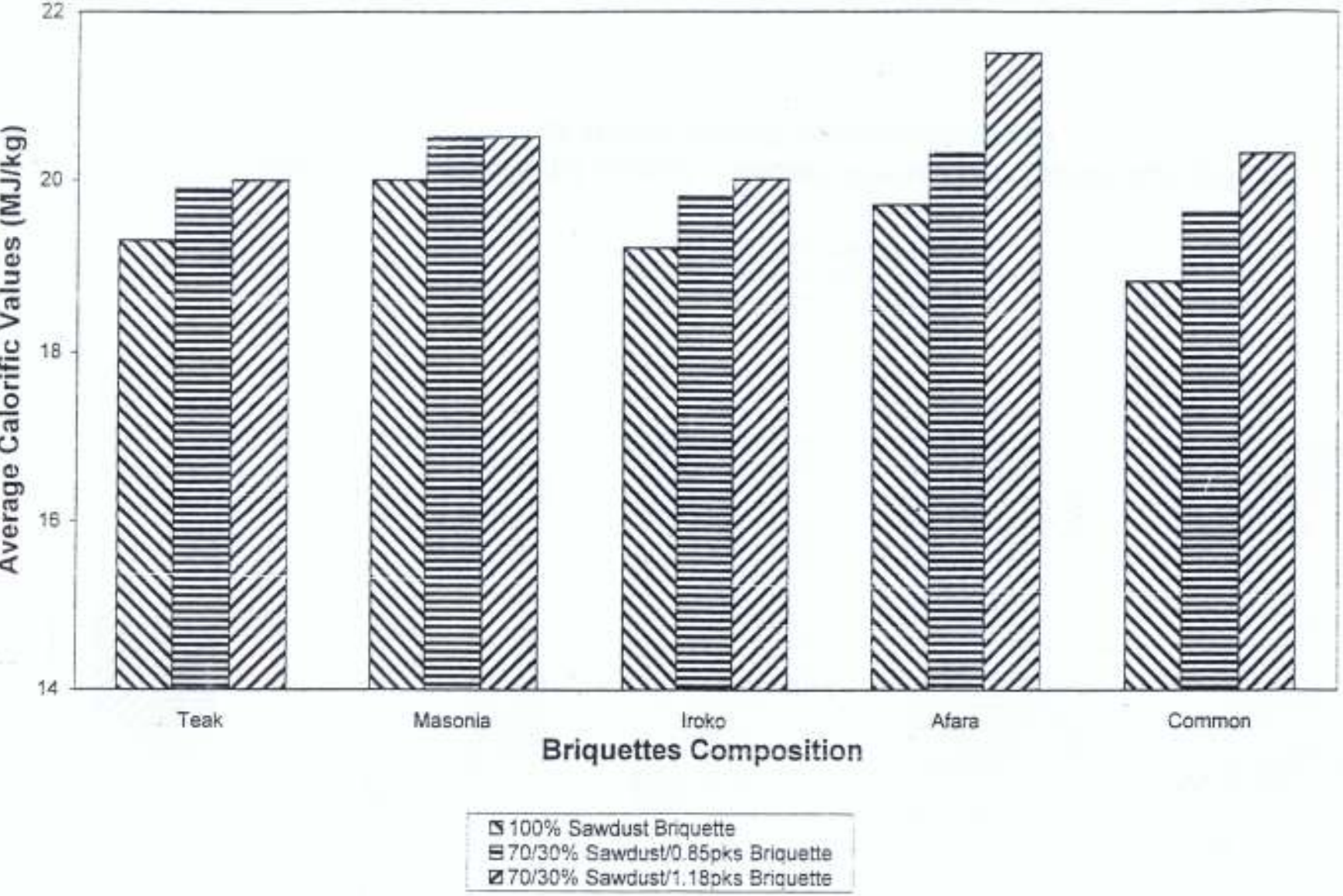

Fig. 4.1: Variation in Calorific Value of Sample Sawdust/Pks Briquette Composition Using Starch as Binder

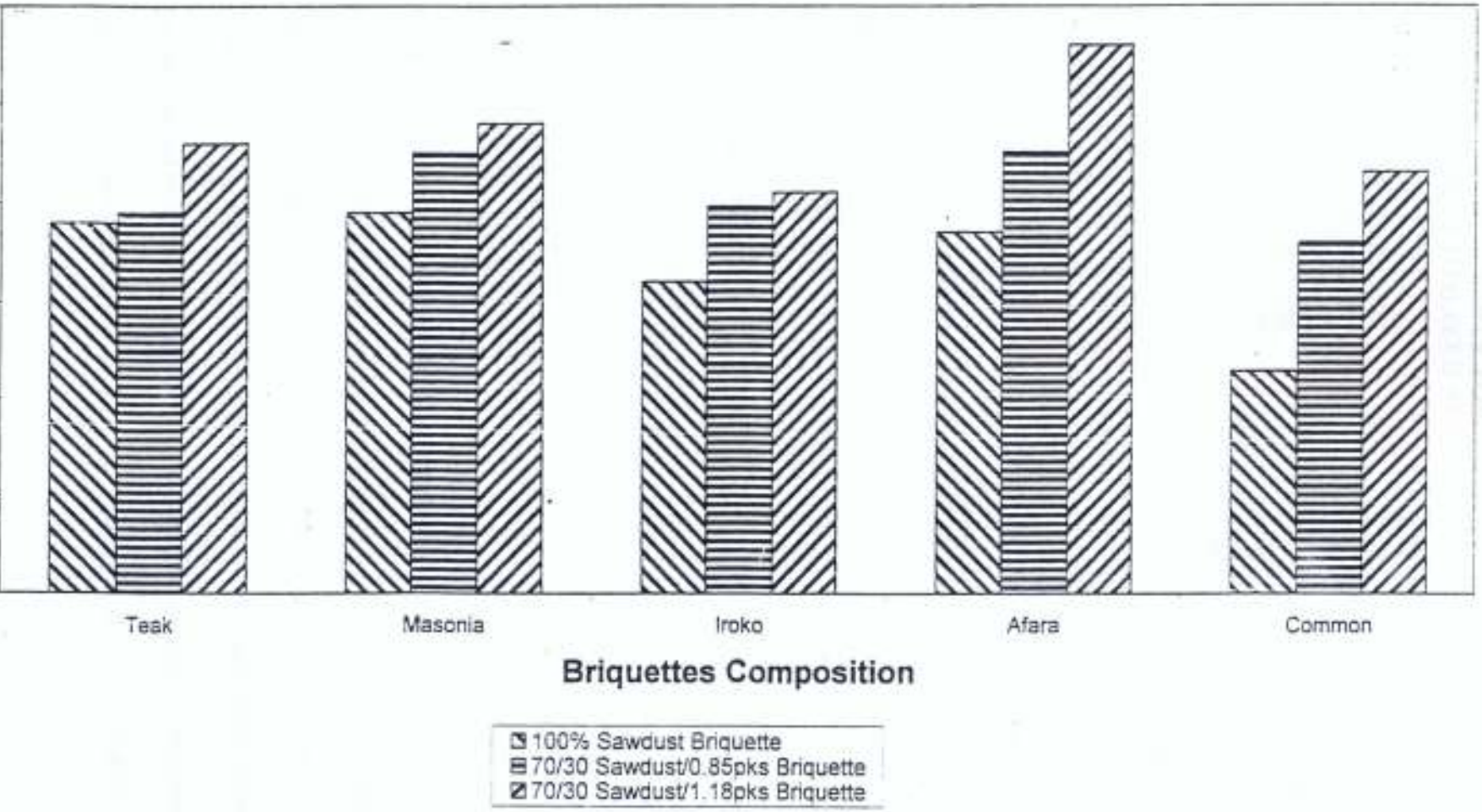

Fig. 4.2: Variation in Calorific Values of Sample Sawdust/Pks Briequette Composition using Sodium Silicate as Binder

TABLE 4.1: ANOVA TABLE FOR CALORIFIC VALUES, PERCENTAGE HEAT UTILIZED AND SPECIFIC FUEL CONSUMPTION

	d.f	F – Values CV	F – Values PPHU	F – Values SFC
	4	91.722**	1177.811**	52.553**
	2	0.193ns	15.216**	.001ns
	2	264.584**	1177.527**	1.376**
	8	0.138ns	15.216**	.001ns
	8	12.586**	112.219**	17.651**
	4	0.137ns	2.648ns	.001ns
	16	0.141ns	2.648ns	00.1ns

A: species

B: mixing Ratio

C: grain size

AB: interaction AB

BC: interaction AC

ABC: interaction BC

S.V – Source of variance

d.f – degree of freedom

** – significant @ 0.01

ns – not significant @ 0.01

for a more durable binder whose briquette will not develop hair line crack and which could withstand more stress without breaking, with the combustion characteristics of the sample unimpeded. Sodium silicate satisfies all these conditions and from the physical examination of the briquettes it is a better binder than starch paste. There is also a slight increase in calorific values for the 100% sawdust briquettes as compared to the calorific values when starch was used as a binder (Figure 4.1). The calorific values of Afara

Masonia Teak and Iroko increased by about 0.1MJ/kg. Although not all that significant it shows that the sodium silicate does not impede the calorific values of samples.

Furthermore, the result obtained from the factorial experiment (Table 4.1) reveals that with respect to factor A i.e. effect of different species of wood sawdust on the calorific value is significant at 0.01 level of significance. Hence the null hypothesis at this point is to be rejected. Also with respect to factor B (percentage composition), there is no significant added variance component on the calorific value at 0.01 level of significance. Interaction between AB is not significant at 0.01 level of significance.

4.2 Effect of adding Palm Kernel Shell (Pks) with different Species of Sawdust Briquette

Figure 4.1 shows that on adding 1.18mm grain size palm kernel shell to the samples, the calorific values increased considerably with Afara having the highest calorific value of 21.50MJ/kg followed by Masonia, Common Sawdust, Teak and Iroko briquettes with 20.50, 20.30, 20 and 20 MJ/kg. It could be further seen that when 0.85mm grain size palm kernel shell was added, there was a drop in the calorific value of the entire sample from 20.50MJ/kg obtained from Masonia to 20.30, 19.90, 19.80 and 19.50 for Afara, Teak, Iroko and Common sawdust briquettes in that order.

Figure 4.2 also shows the same trend but with slightly higher calorific values, for all the samples when sodium silicate was used as a binder. Figures 4.1 and 4.2 show that a mixture of sawdust briquette has lower calorific values than other species of sawdust briquette except for Iroko where the calorific value is less than the Common sawdust. The calorific values of different species of briquette vary between 19.20 and 19.90MJ/kg. This goes to show that the gross calorific value of different briquette species does not

vary greatly, the average value being 19.26MJ/kg. (Cheremisinoff,1980). Neeman and Steinback (1979), also supported this assertion by their research work on nine hard wood species and reported that the average calorific value of the wood and wood bark were 20.00 and 19.39MJ/kg respectively. Since there was increase in calorific values when 1.18pks was added in both Figures 4.1 and 4.2, this also supported the assertion that the finer the grain size of palm kernel shell between 5mm and 1.18mm particle sizes in the briquette the higher is the calorific values up to a percentage by weight of 30%. For grain sizes above 5mm there is no marked improvement in calorific values but the calorific value increase from 5mm to 1.18mm particle size. Hence, the grain sizes of palm kernel shell must be below 5mm for improved calorific values (Adegoke and Mohammed, 2002). It has also been confirmed that briquettes with palm kernel shell of particle size of 1.18mm is the best (Kuti, 2003). Below 1.18mm and down to 0.85mm there is decrease in the calorific value as can be seen in Figure 4.2 from the highest calorific value of 21.60MJ/kg to 20.50MJ/kg. It could also be seen that adding palm kernel shell at various proportions increase the calorific values of all the samples.

In addition, the result of the factorial experiment (Table 4.1) shows that the effect of factor C (Grain size) on the calorific values is significant at 0.01 level of significance. The null hypothesis at this point is also rejected. The interaction between AC is significant while the interactions between BC and ABC is not significant at 0.01 level of significance. The results in the calorific value show that the addition of palm kernel shell into briquette at some grain size caused an improvement in the calorific values

4.3 Variation in Flame Temperature of Various Sample Briquettes

In Figure 4.2, the 100% Masonia sawdust briquette has the highest calorific value of 19.90MJ/kg among the species with a corresponding flame temperature of 440°C as can seen in Figure 4.3. On addition of 1.18mm Pks grain size, there was increase in the flame temperature with Masoina sawdust briquette having the highest flame temperature of 490°C with a calorific value of 20.80 MJ/kg while the Afara with the highest calorific value has a flame temperature of 450°C. It then follow that the sample with higher calorific value suppose to be supported with corresponding higher flame temperature or the sample with higher flame temperature should also be supported by a corresponding higher calorific value (Garba and Atiku, 1997). However, some extraneous factors, like the plantation age and plot within plantations of wood as well as the moisture content of each wood plant could affect the calorific value of a particular specie of wood particularly when the wood were not oven-dried before processing from where sawdust is obtained as a residue (Akachuku, 1979). This could also be supported by the values of percentage of volatile matter in each sample where Afara with the highest calorific value of 21.60MJ/kg has 73% and flame temperature of 450°C while Masonia with 20.80 MJ.kg and 490°C has percentage volatile matter of 62.9% and moisture content of 7.10% in Table 4.2. This is also in agreement with the assertion that with increased moisture in a wood, its consumption increases while the combustion and flame temperature on the other hand fall (Bansal et al, 1999). The grain size of 0.85mm also diminishes the flame temperature in all the samples. It then follows that the fuel with high calorific value and

corresponding high flame temperature is better as fuel, hence Masonia briquette with

1.18mm Pks composition has proved to be the best fuel.

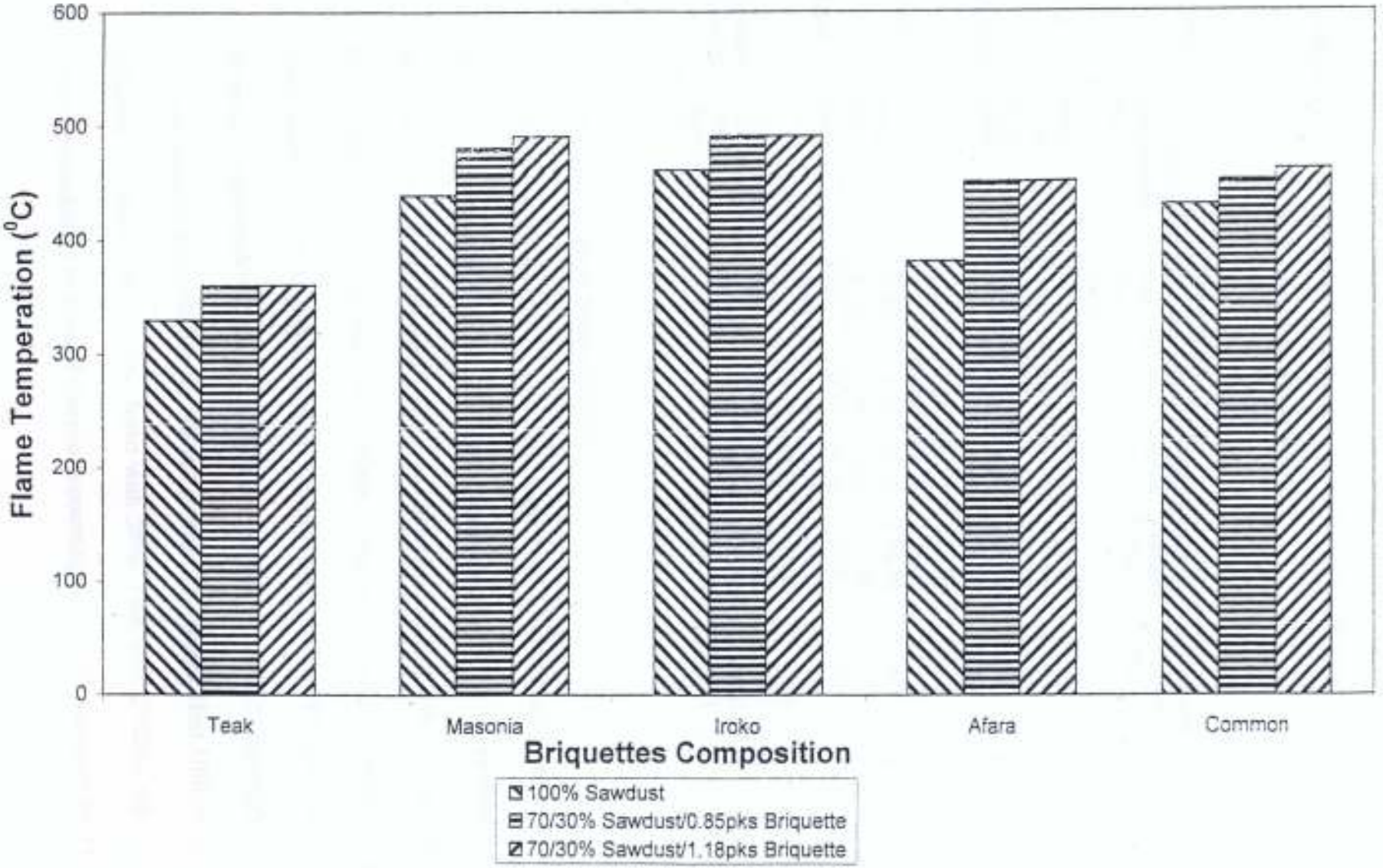

Fig. 4.3: Variation in Flame Temperature of Various Sample Briquettes

Table 4.2: Results of Proximate Analysis of Sawdust Briquettes using Sodium Silicate as Binder

ple		Parameters				
	Composition of sawdust/Pks (%)	Grain Size of Pks (mm)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Moisture content (%)
	100/0	Nil	0.57	69.19	21.03	9.21
	70/30	0.85	1.28	67.22	22.02	9.48
	70/30	1.18	1.62	66.52	22.38	9.48
nia	100/0	Nil	0.52	64.1	27.48	7.90
	70/30	0.85	1.15	63.15	28.30	7.40
	70/30	1.18	1.88	62.90	28.12	7.10
	100/0	Nil	0.68	62.97	26.02	10.33
	70/30	0.85	1.30	62.15	26.30	10.25
	70/30	1.18	1.54	62.00	26.46	10.00
	100/0	Nil	0.18	65.55	23.82	10.45
	70/30	0.85	1.50	63.75	24.50	10.25
	70/30	1.18	2.10	63.00	24.90	10.00
mon	100/0	Nil	0.68	71.52	17.00	10.81
ust	70/30	0.85	1.22	70.28	18.00	10.50
	70/30	1.18	1.44	69.79	18.56	10.21

4.4 Percentage Heat Utilized (PHU)

From Figure 4.4 the average Percentage Heat Utilized during water boiling test increased considerably from the 100% sawdust briquettes to 70/30 sawdust/ 1.18pks in all the sample of Teak, Masonia and Afara. In Iroko briquettes, the average Percentage Heat Utilized increased only in 0.85pks composition, which drops in 1.18pks composition. As for Common sawdust, the increment from 100% sawdust maintained the same level in both 0.85pks and 1.18pks compositions. The 30% by weight of 1.18pks Masonia sawdust briquette has the highest average Percentage Heat Utilized of 40.37% followed by Afara with 32.13%, Iroko with 28%, Teak with 27.23% and 26.78% for Common sawdust. The mass of charcoal amounting to 285.33g recovered for Masonia is

the highest followed by Afara, Iroko, Common sawdust and Teak with 280, 260.56, 214.60 and 240.93g respectively. It then followed that the fuel with high percentage heat utilized and high carbon content is better as fuel, hence Masonia briquette with 1.18mm Pks has also proved to be the best, followed by Afara, Iroko, Teak and Common Sawdust respectively.

As for the factorial experiments, Table 4.1 reveals that with respect to factor A, B and C on the Percentage Heat Utilized are significant at 0.01 level of significance. The null hypothesis is therefore rejected at this point. The interaction between AB and AC is also significant while interactions BC and ABC is not significant.

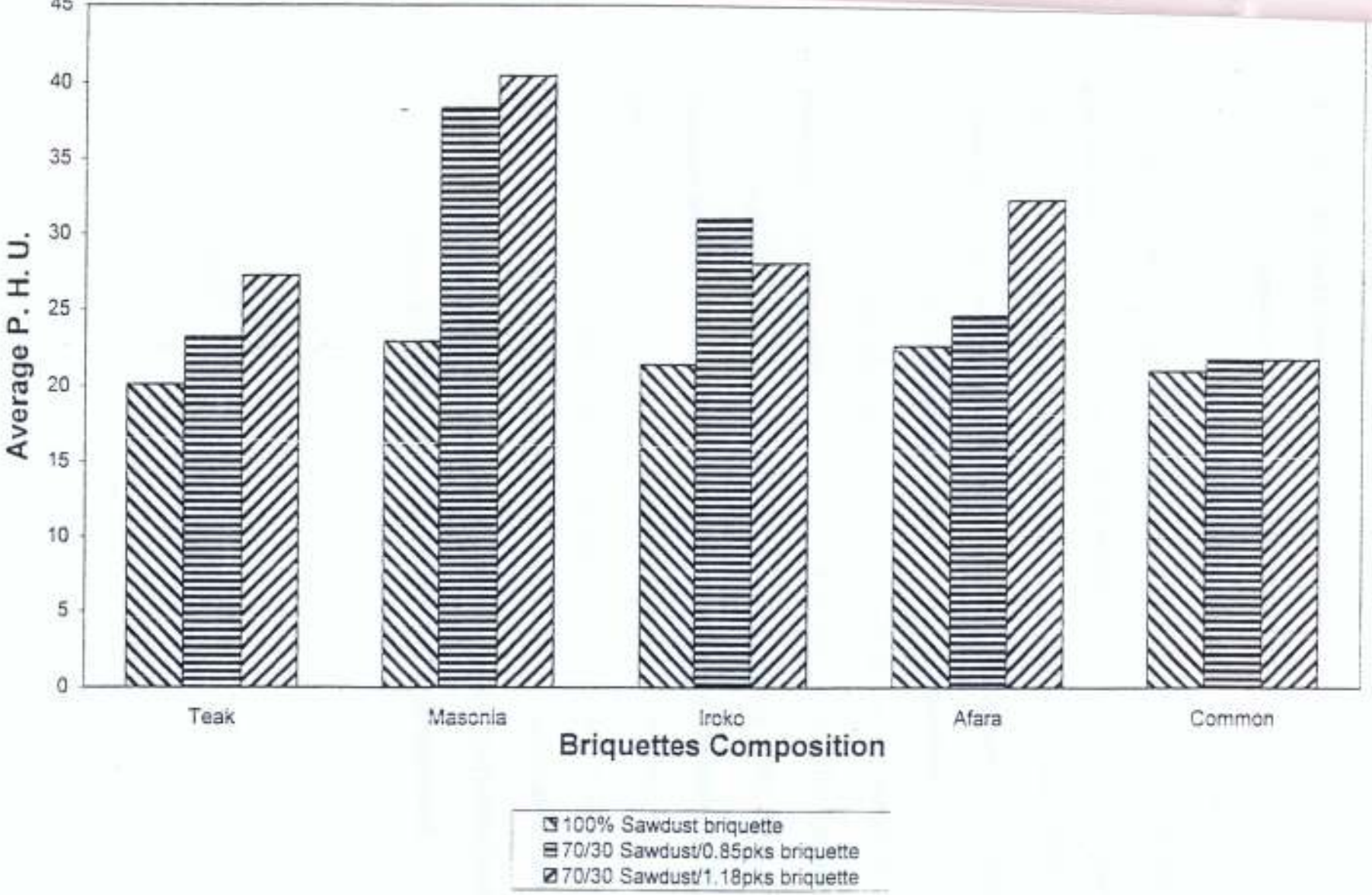

Fig. 4.4: Variation of Percentage Heat Utilized by Various Sample Briquettes

4.5 Specific Fuel Consumption (S.F.C)

Figure 4.5 shows that the specific fuel consumption for the Teak decreased from 100% sawdust through 70/30sawdust/0.85pks to 70/30sawdust/1.18pks briquettes. In Masonia, it decreases from 100% sawdust to the same level in both the 0.85pks and 1.18pks briquettes. As for Iroko, the briquettes with 0.85pks and 1.18pks have higher specific fuel consumption than 100% sawdust briquettes. In Afara and Common Sawdust, the specific fuel consumption increased from 100% sawdust through 70/30sawdust/0.85pks to 70/30sawdust/1.18pks briquettes. On the other hand, the Afara sawdust briquettes have the lowest overall specific fuel consumption in all its samples. Generally, the fuel with high specific fuel consumption such as Teak and Masonia could be used for rapid cooking while Afara, Iroko and Common sawdust briquettes could be utilized for both low and high boiling cooking particularly in bakery where there is need for heat retention in the oven.

Also, Table 4.1 shows the factorial experiment with respect to factors A and C on the Specific Fuel Consumption are significant at 0.01level of significance. The effect of factor B on the Specific Fuel Consumption is not significant at 0.01level of significance. Interaction between AC is significant while BC and ABC is not significant.

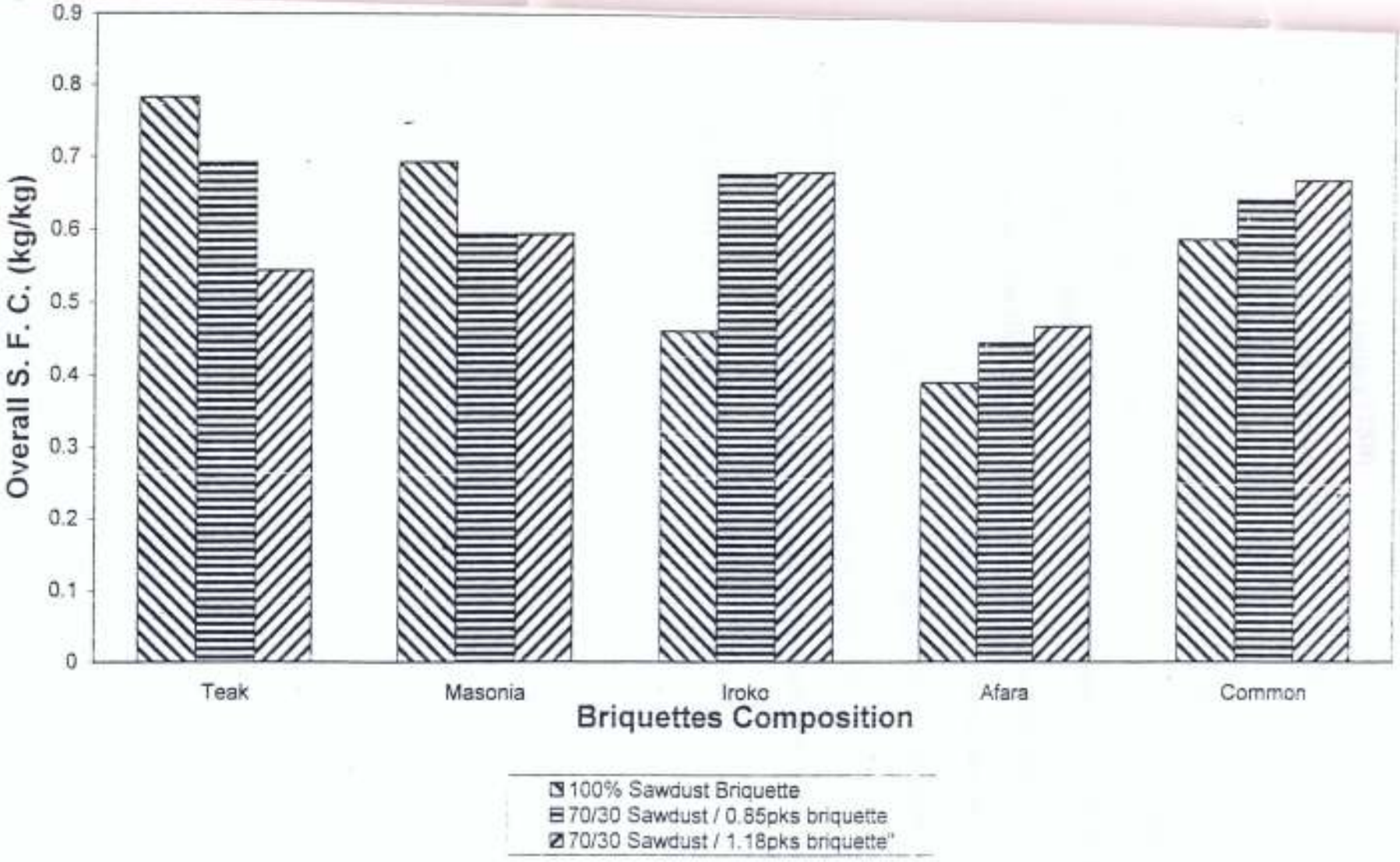

Fig. 4.5: Variation of Overall Specific Fuel Consumption of Various Sample Briquettes

.6 Time Spent in Boiling (TSB)

Table 4.3 shows the time spent in boiling 1kg of water (i.e the ime it takes a given quantity of fuel to boil 1kg of water). The 70/30 Masonia awdust/1.18 pks and 100% Teak sawdust have the lowest time of 9minutes each to bring kg of water to boiling. This may be as a result of the grain size of 1.18pks, which might ave increased the number of pores inside the Masonia sawdust. These pores holding air r moisture have the effect of facilitating the escape of volatile gases and the break down f the structure as the briquette is burnt. That of 100% Teak may be as a result of low ensity of the sawdust that makes it to burn faster. The 70/30 Iroko sawdust/1.18pks riquette has the highest time of 15minutes to bring water to boiling among this grade, vhich may also be due to the high density of the sawdust, which makes the pores to be ess spacious for air to penetrate for easy combustion.

Table 4. 3 Time Spent in Boiling (TSB)

mple	Composition of Sawdust/Pks (%)	Grain Size of Pks (mm)	Time Spent in Boiling (min.)
ak	100/0	Nil	9
	70/30	0.85	14
	70/30	1.18	13
asonia	100/0	Nil	13
	70/30	0.85	12
	70/30	1.18	9
oko	100/0	Nil	18
	70/30	0.85	16
	70/30	1.18	15
Afara	100/0	Nil	14
	70/30	0.85	13
	70/30	1.18	12
Common sawdust	100/0	Nil	15
	70/30	0.85	14
	70/30	1.18	13

CHAPTER FIVE

5.0 CONCLUSION AND SUGGESTIONS FOR FURTHER WORK

5.1. Conclusion

Until recently, sawdust, a by- product of saw-milling operation, abounds in large heaps in all parts of the Country and is normally burnt off, resulting in atmospheric pollution. These "wastes" could be utilized as high-grade solid fuel by finding ways of improving the calorific value and also maximizing the sawdust usage by the appropriate selection of good combustible species of wood sawdust.

In this study, four species of wood and a common sawdust (mixture of different species of wood) were briquetted as solid fuel. For each of the species, briquettes of 100% sawdust were produced. Also briquettes of sawdust mixed with palm kernel shell of 0.85mm and 1.18mm grain sizes in ratio of 70:30,(sawdust to palm kernel shell) were produced. Two different binding materials, starch paste and sodium [illegible] were used to agglomerate the sawdust mixture together.

From the result of calorific values and flame temperature obtained and the subsequent experimental tests carried out which involved Percentage Heat Utilized, Specific Fuel Consumption and Time Taken in Boiling as well as the statistical analysis Carried out, the best specie of wood sawdust suitable in all ramifications as solid fuel was identified to be the Masonia briquettes.

Although it was revealed that the calorific values of the briquettes of different hard wood species involved in the study did not vary greatly, there were marginal

increment among them, which ranged between 19.20 and 20MJ/kg while the flame temperature varied greatly between 330 and 460°C.

It was also revealed that the addition of palm kernel shell to all the species increased the calorific values but with a grain size limit of palm kernel shell. When 1.18 mm of palm kernel shell was added there was a significant increase in calorific value, which ranged between 20.10 and 21.60 MJ/kg with flame temperature of between 360 and 490°C respectively. When the grain size dropped to 0.85mm there was a reduction in the calorific value, which also ranges between 19.60 and 20.60MJ/kg. Generally, the sawdust briquettes of different species of wood all have calorific values higher than the common sawdust; hence, they could all be utilized as high-grade solid fuel.

When starch paste was used as binder it was discovered that there were hairlines and cracks on the briquettes as against when sodium silicate was use. This shows that sodium silicate is a better binder for sawdust. Having identified the sawdust of the best tree species that could be used for briquettes as solid fuel, it is envisaged that its utilization would save the quantity of fuel wood wasted daily during cooking activities. It will also reduce cooking time, reduce wood consumption and effectively act as alternative source of energy in domestic applications especially now that gas and kerosene fuels are becoming out of reach of an average Nigeria family.

5.2 Suggestions for Further Work

Having realized the stated objectives of this research, the following suggestions are hereby made for further work:

Further research work should be carry out on:

- Production of carbonated or charred briquettes, which is now in vogue in the international market.

- Briquettes produced under high pressure that will not require binder, which is also in high demand in the international market.
- Establishment of pilot plant for the production of sawdust briquettes, which should act as demonstration center for would be investors in the briquettes industry.

It is also recommended that:

(i) Government should establish Nigerian Renewable Energy Agency **"NIRENA"** to coordinate the renewable energy research activities in tertiary institutions as well as research institutes so as to commercialize the various research results already on the shelf.

(ii) There should be legislation to compel the citizens or corporate organizations to make use of between 20 – 30% of their energy need from renewable energy sources so as to reduce the pressure on conventional energy source.

(iii) The burning of sawdust in sawmills around the country should be discouraged to avoid environment pollution.

(iv) The sawdust should be economically utilized by making it into briquettes, which could be used in domestic energy application.

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APPENDIX 1

Table A1: Calorific Values of Various Fuels

Fuel	Gross calorific value[a] MJ/Kg	MJ/Kg [b]	Remarks
Crops			
Wood			
Green	~8	~6	Varies more with moisture
Seasonal	~13	~10	content than species of wood
Oven dry	~16	~12	
Vegetation dry	~15		Examples: grasses, hay
Crop residues			
Rices husk}			For dry materials
Bagasse}			
(Sugarcane solids) }	12-15		In practice residues may
Cow dung}			be very wet
Peat			
Secondary biofuels			
Ethanol	30	25	C_2H_5OH: 789kgm^{-3}
Methanol	23	18	CH_3OH
Biogas	28	$20x10^{-3}$	50%methane + 50% CO_2
Producer gas	5-10	$(4-8)\ x10^{-3}$	Depends on composition
Charcoal			
- Solid pieces	32	11	
- Powder	32	20	
Coconut oil	39	36	
'Coconut'	39	33	Ethyl esters of coconut oil
Fossil fuels			
Methane	55	38×10^{-3}	Natural gas
Petrol	47	34	Motor spirit, gasoline
Kerosene	46	37	
Diesoline	46	38	Automotive distillate, derv
Crude oil	44	35	
Coal	27		Black, coking grade

a – Gross Calorific value
b – Net Calorific value

(Source: Twidell and Wier, (1987)

APPENDIX 2

WATER BOILING TEST DATA

Test No 1:	100% Teak sawdust Briquette Composition
Date:	20/8/2003
Test Condition:	Cool weather.
Store used:	Sawdust briquette stove
Environment:	FUTA R & A workshop
Ambient temp:	32° C
Weight of water:	1000g
Thermometer:	Mercury in glass and
Weighing balance:	Digital and Analogue
Weight of pot :	278.1g
Weight of sawdust briquette:	306.2g.

Table 1: WBT

Water Temp (°C)	Time (min)
25	0
73	5
100	9
98	24
89	54

Mass of Ash: 81g

Mass of charcoal: 18g

Yellowish flame at the commencement of burning. Bluish flame after 7minutes.

Not smoky at the commencement of burning. Flame is very pronounced.

Test 2: 70/30 Teak sawdust/0.85pks briquette composition

Date: 20/8/2003

Test condition: Cool weather

Store used: Sawdust briquette stove

Environment: FUTA R& A Laboratory

Ambient Temp: 32°C

Weight of water: 1000g

Thermometer: Mercury in glass

Weight balance: Digital and analogue

Weight of pot: 278.19

Weight of Sawdust Briquette: 375.6g

Table 2: WBT

Water Temp (°C)	Time (min)
25	0
88	10
100	14
100	29
96	59

Mass of Ash: 22.2g

Mass of charcoal: 200.26g

Yellowish flame at the commencement of burning. .Bluish flame after 7 minutes

A bit smoky at the commencement of burning. Flame is pronounced.

Test 3:	7-/30 Teak sawdust/1.18pks briquette composition
Date:	20/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and analogue
Weight of pot:	278.1g
Weight of Sawdust Briquette:	375.6g

Table 3: WBT

Water Temp (°C)	Time (min)
25	0
68	5
91	10
100	13
100	28
98	58

Mass of Ash:	=	29.5g
Mass of charcoal:	=	240.93g

Yellowish flame at the commencement of burning. Bluish flame after 7 minutes.

A bit smoky at the commencement of burning. Flame is pronounced.

Test 4:	100% Masonia Sawdust briquette composition
Date:	20/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust: Briquette	276g

Table 4: WBT

Water Temp (°C)	Time (min)
25	0
68	5
86	10
100	13
100	28
98	58
Mass of Ash:	24g
Mass of charcoal:	83g

Yellowish flame at the commencement of burning. Bluish flame after 6minutes

Less smoky. Burnt to ashes with a small mass of charcoal.

Test 5: 70/30 Masonia Sawdust/0.85mm pks briquette composition

Date:	20/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass thermometer
Weight balance:	Digital and Analogue
Weight of pot:	27.81g
Weight of Sawdust: Briquette	387.6

Table 5: WBT

Water Temp (°C)	Time (min)
25	0
68	5
88	10
100	12
100	27
98	57

Mass of Ash: 30g

Mass of charcoal: 234.4g

Yellowish flame at the commencement of burning. Bluish flame after 6minutes

Less smoky. Flame is pronounced.

Test 6:	70/30 Masonia Sawdust/1.18mm pks briquette composition
Date:	20/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.19
Weight of Sawdust: Briquette	433.2g

Table 6: WBT

Water Temp (°C)	Time (min)
25	0
70	5
100	9
100	24
98	54
Mass of Ash:	32g
Mass of charcoal:	285.33g

Yellowish flame at the commencement of burning. Bluish flame after 6 minutes

Less smoky. Flame is pronounced.

Test 7: 100% Iroko Sawdust briquette composition

Date:	21/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust Briquette:	292.3g

Table 7: WBT

Water Temp (°C)	Time (min)
25	0
79	5
81	10
95	15
100	18
97	33
88	63

Mass of Ash: 16.8g

Mass of charcoal: 152.3g

Flame not pronounced

Very smoky at the commencement of burning up to 10minutes after which bluish flame emerged.

Test 8:	70/30 Iroko Sawdust/0.85mm pks briquette composition
Date:	21/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust: Briquette	407.9g

Table 8: WBT

Water Temp (°C)	Time (min)
25	0
66	5
90	10
100	16
100	31
89	61
Mass of Ash:	50g
Mass of charcoal:	261.23g

Flame not pronounced up till 13minutes of burning. Smoky at the commencement of burning up till 13 minutes after which bluish flame emerged.

Test 9: 70/30 Iroko Sawdust/1.18mm pks briquette composition

Date:	21/8/2003
Test condition:	Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust: Briquette	407.9g

Table 9: WBT

Water Temp (°C)	Time (min)
25	0
68	5
93	10
100	15
100	30
92	60
Mass of Ash:	48g
Mass of charcoal:	260.56g

Flame not pronounced up till 13minutes of burning. Smoky at the commencement of burning up till 13 minutes after which bluish flame emerged.

Test 10:	100% Afara Sawdust briquette composition
Date:	21/8/2003

Test condition:	Relatively Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust Briquette:	312g

Table 10: WBT

Water Temp (°C)	Time (min)
25	0
65	5
90	10
100	14
100	29
78	59
Mass of Ash:	25.1g
Mass of charcoal:	178g

Flame not pronounced up till 6minutes of burning. Smoky at the commencement of burning up till 13 minutes after which bluish flame emerged.

Test 11:	70/30 Afara Sawdust/0.85mm pks briquette composition
Date:	22/8/2003
Test condition:	Relatively Cool weather

Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust: Briquette	409g

Table 11: WBT

Water Temp (°C)	Time (min)
25	0
66	5
92	10
100	13
100	28
85	58
Mass of Ash:	45g
Mass of charcoal:	273g

Flame less pronounced at the commencement of burning up to 6minutes after which bluish flame emerged.

Test 12:	70/30 Afara Sawdust/1.18mm pks briquette composition
Date:	22/8/2003
Test condition:	Relatively Cool weather
Store used:	Sawdust briquette stove

Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust Briquette:	407.9g

Table 12: WBT

Water Temp (°C)	Time (min)
25	0
66	5
94	10
100	12
100	27
88	57

Mass of Ash:	47g
Mass of charcoal:	280.9g

Flame less pronounced at the commencement of burning up to 6minutes after which bluish flame emerged.

Test 13	100% General Sawdust briquette composition
Date:	22/8/2003
Test condition:	Relatively Cool weather
Store used:	Sawdust briquette stove

Environment:	FUTA R& A Laboratory
Ambient Temp:	32°C
Weight of water:	1000g
Thermometer:	Mercury in glass
Weight balance:	Digital and Analogue
Weight of pot:	278.1g
Weight of Sawdust Briquette:	309.6g

Table 13: WBT

Water Temp (°C)	Time (min)
25	0
65	5
90	10
100	15
100	30
74	60
Mass of Ash:	23g
Mass of charcoal:	150.27g

Yellowish flame at the commencement of burning. Bluish flame after 8minutes

Smoky at the commencement of burning. Flame is pronounced.

Test 14	70/30 General Sawdust/0.85mm pks briquette composition
Date:	22/8/2003
Test condition:	Relatively Cool weather
Store used:	Sawdust briquette stove
Environment:	FUTA R& A Laboratory

Ambient Temp: 32°C

Weight of water: 1000g

Thermometer: Mercury in glass

Weight balance: Digital and Analogue

Weight of pot: 278.1g

Weight of Sawdust: 373.6g
Briquette

Table 14: WBT

Water Temp (°C)	Time (min)
25	0
67	5
92	10
100	14
100	29
76	59

Mass of Ash: 40g

Mass of charcoal: 205.6g

Yellowish flame at the start of burning. Bluish flame after 8minutes

Smoky at the Commencement of burning. Flame is pronounced.

Test 15 70/30 General Sawdust/1.18mm pks briquette composition

Date: 22/8/2003

Test condition: Relatively Cool weather

Store used: Sawdust briquette stove

Environment: FUTA R& A Laboratory

Ambient Temp: 32°C

Weight of water: 1000g

Thermometer: Mercury in glass

Weight balance: Digital and Analogue

Weight of pot: 278.1g

Weight of Sawdust: 374.6g

Briquette

Table 15: WBT

Water Temp (°C)	Time (min)
25	0
67	5
89	10
100	13
100	28
95	58

Mass of Ash: 42g

Mass of charcoal: 214.6g

Yellowish flame at the commencement of burning.

Smoky at the Commencement of burning. Yellow flame up till about 8minutes after which bluish flame emerged.

APPENDIX 3

Tests of Between-Subjects Effects

Dependent Variable: CAL.VAL

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Model	54563.667[b]	45	1212.526	20894.679	.000	940260.54	1.000
SPECIES	21.291	4	5.323	91.722	.000	366.888	1.000
MIX.RAT	2.237E-02	2	1.118E-02	.193	.825	.385	.019
GRAIN.SZ	30.708	2	15.354	264.584	.000	529.167	1.000
SPECIES * MIX.RAT	6.429E-02	8	8.036E-03	.138	.997	1.108	.022
SPECIES * GRAIN.SZ	5.843	8	.730	12.586	.000	100.686	1.000
MIX.RAT * GRAIN.SZ	3.183E-02	4	7.956E-03	.137	.968	.548	.019
SPECIES * MIX.RAT * GRAIN.SZ	.130	16	8.099E-03	.140	1.000	2.233	.026
Error	5.223	90	5.803E-02				
Total	54568.890	135					

a. Computed using alpha = .01

b. R Squared = 1.000 (Adjusted R Squared = 1.000)

APPENDIX 4

Tests of Between-Subjects Effects

Dependent Variable: PHU

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Model	101953.7[b]	45	2265.637	3652.472	.000	164361.26	1.000
SPECIES	2922.394	4	730.599	1177.811	.000	4711.243	1.000
MIX.RAT	18.877	2	9.438	15.216	.000	30.432	.993
GRAIN.SZ	1460.845	2	730.422	1177.527	.000	2355.053	1.000
SPECIES * MIX.RAT	75.507	8	9.438	15.216	.000	121.726	1.000
SPECIES * GRAIN.SZ	556.876	8	69.610	112.219	.000	897.750	1.000
MIX.RAT * GRAIN.SZ	6.571	4	1.643	2.648	.038	10.593	.477
SPECIES * MIX.RAT * GRAIN.SZ	26.283	16	1.643	2.648	.002	42.371	.947
Error	55.827	90	.620				
Total	102009.5	135					

a. Computed using alpha = .01

b. R Squared = .999 (Adjusted R Squared = .999)

APPENDIX 5

Tests of Between-Subjects Effects

Dependent Variable: SFC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Model	49.019[b]	45	1.089	261.589	.000	11771.503	1.000
SPECIES	.875	4	.219	52.553	.000	210.211	1.000
MIX.RAT	.000	2	.000	.000	1.000	.000	.010
GRAIN.SZ	1.146E-02	2	5.732E-03	1.376	.258	2.753	.117
SPECIES * MIX.RAT	.000	8	.000	.000	1.000	.000	.010
SPECIES * GRAIN.SZ	.588	8	7.350E-02	17.651	.000	141.206	1.000
MIX.RAT * GRAIN.SZ	.000	4	.000	.000	1.000	.000	.010
SPECIES * MIX.RAT * GRAIN.SZ	.000	16	.000	.000	1.000	.000	.010
Error	.375	90	4.164E-03				
Total	49.393	135					

a. Computed using alpha = .01

b. R Squared = .992 (Adjusted R Squared = .989)