DESIGN AND DEVELOPMENT OF SAWDUST HEAT GENERATOR

BY

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CERTIFICATION

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DEDICATION

This project is dedicated to my late brother, Mr. Martins Eric Igun, who stood by me when all hope of getting admission was almost lost, but died on 27th December 2001. May his soul rest in peace.

ACKNOWLEDGEMENT

Firstly, my study would not have been successful without God Almighty, to whom I am most grateful for his strength, love, and guidance through my study period.

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ABSTRACT

The sawdust heat generator was made to generate heat that could be tapped for many purpose such as drying e.t.c. It uses sawdust as fuel, in which the sawdust is burnt in a chamber (combustion chamber). The equipment is designed for a fuel (sawdust) capacity of 10.5kg/hr. This burns for about 2.5hrs and gives a thermal load of 783596.15kJ/m^3 -hr. the furnace was fabricated with 3 mm mild steel (120 x 240cm) for the inside wall while 2mm mild steel was used for the outside wall. Fiber wool glass was used as the lagging material. The volume of the furnace is 0.234m^3. The sawdust is fed inside the furnace through the hopper via the auger. The ash is collected below the grate. The exit pipe at the side provides outlet for the flue gas. The efficiency of the heat generator is 40.7% and its cost of fabrication is ₦10.792.

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CHAPTER ONE

INTRODUCTION

The use of heat in drying agricultural produce has long been used by farmers. In order to dry their farm produce, so as to preserve some crops, both for the next planting season and marketing, farmers have always resorted to either drying in the sun or drying over fire. In both drying methods mentioned above, heat energy is due to temperature difference between the source from which the heat energy is coming and where it is going. Though there are other types of energy in transition such as work, our interest in this work is on heat energy, which is very important in almost every aspect of man's life on earth. Heat energy being very important to man has made many researchers to investigate into a cheap and possible means of acquiring it for maximum use.

Developed countries, with their high technology have focused attention on alternative sources such as solar energy, oil from tar sands and geothermal energy for maintaining established life styles. But these sources of energy mentioned above can only be beneficial to those who can afford them.

The sources of energy stated above cannot be fully utilised by the developing countries due to their limitation (such as not been readily available, cost etc) which in many cases could prevent their effective use. Therefore, efforts have to be made to find ways of making use of other energy sources which can be used to conserve the present reserve of petroleum .

In this manner, the problems related to ecological degradation, which results from the extraction of these other sources of energy such as oil from tar sand, will be reduced. Attention has thus been given to identifying fuel sources, which can be used with relatively little technological input. Unfortunately, in such cases where potentially useful fuels exist, their use is managed without careful planning or without proper scientific basis, which leads to waste and inefficiency. This is the case of burning sawdust in open air as it gives room to loss of energy. This obviously shows that there is need to design heat generators to run on solid fuels. Furthermore, in view of the drastic increase in the prices and scarcity of natural gas and other petroleum products which have affected all facets of primary agriculture and realising that well over 70% of grain crops is currently dried, the importance of alternative source of energy for drying becomes clearer.

1.1 Objectives

This study is intended to solve the problems associated with sun drying and drying over the fire place. It is also aimed at generating heat with the use of solid fuel (sawdust).

The specific objectives are:

a) To design and develop a furnace fired by sawdust.

b) To eliminate the problems faced during sun drying and drying over fireplace.

1.2 Justification

The problems faced by the use of different sources of heat for drying farm produce and materials used as fuel in some existing dryers would be put to rest if the objectives of the study were achieved. The problems of scarcity of petroleum products, which are the commonest fuel material used for energy generation today, will be solved.

It would then be feasible and possible to determine the potential contribution of sawdust to energy requirement of Nigeria for grain drying and other thermal applications.

Though sawdust is useful in the plywood industry, in many parts of the world, (Nigeria nclusive), sawdust is regarded as a waste. This study also aims at managing the waste from the wood industry.

CHAPTER TWO

LITERATURE REVIEW

The generation of heat has been in existence since the origin of man. It has been in use mostly for cooking of food and keeping the body warm. In this study, heat is to be generated through a furnace for the drying of farm produce. In heat generating process, any chemical substance, which releases an appreciable amount of heat on chemical combination with oxygen, is a fuel. This study shall deal with some of the sources of heat, but the major classes of combustible fuel materials that will be considered are solid, liquid and gas. Meanwhile, more attention will be given to solid fuels especially sawdust which is regarded in many countries of the world as a waste.

2.1 Sources of Heat

Heat is a form of energy. Heat energy continually arrives on the earth in the form of solar radiation and leaves the earth as low temperature radiation. Fuel provides energy from combustion as they combine chemically with oxygen. Electrical energy will produce heat in a number of ways with resistance heating, induction heating and heat pump operation as examples.

For nearly two centuries the primary source of heat energy for industries, companies and the home has been a class of substances called fossil fuel. Principally, coal, petroleum and natural gas are a part of the earth's storehouse of energy laid down over millions of years in the past. They are non-renewable and the supply is dwindling rapidly. Consequently, a high priority is now given to both fossil fuel conservation and to the development of renewable energy sources. In the latter category, solar energy, hydrologic energy, wind energy, ocean thermal energy, biomass conservation (energy from forest plants of which sawdust is regarded as a waste product in many countries) and the nuclear fission are all examples of energy sources presently under intensive development.

At one time in developed and developing countries, or indeed all over the world, wood was extensively used for domestic heating and cooking purposes, as locomotive fuel and for generating steam in industrial establishments. Though sawdust is got from wood, it has advantage over wood. These are obvious because wood must be seasoned, thus requiring a large storage space. Also due to the bulkiness and relatively low margin of profit, wood can be transported only over a short distance.

2.1.1 Types of fuel

Fuel is any material that burns and produces heat or power. Solid, liquid and gas are the major classifications of the fuel under this study. The chemical elements of importance in combustible fuel are carbon, hydrogen and sulphur. Other constituents like oxygen, nitrogen, moisture, e.t.c only contribute to their dead weight (Chinwe, 1984).

2.1.2 Solid fuel

Among the relevant naturally occurring solid fuels are wood, coal, rice husk and sawdust. Sawdust is what remains after trees and logs are cut into boards for building houses and other structures. In many parts of the world, sawdust is considered a "waste". It is thrown away or left for the rain to wash away. Sawdust exists in large quantities in areas where sawmills are located, such as Sapele, Delta State. In Sierra Leone, for example, large quantities of sawdust are available but are discarded as waste (Emmanuel, 1983). Both in Nigeria and abroad where there are lumbering activities, sufficient large quantities of sawdust are produced.

Sawdust has a gross calorific value of 17,463 kJ/kg and moisture content of 11.45% 50% wb (Chukwu, 1987). This value is more than half that of Nigeria's sub-bituminous coal with a gross calorific value (G.C.V) of 28,466 kJ/kg, and it is more than that of the rice husk and wood shavings (Softwood) that have gross calorific values of 13,643 kJ/kg and 16,769kJ/kg respectively. In order to exploit the potential benefit of this material to produce energy, a heat generator furnace that is to be used as a dryer has been designed in this study.

Rice husk is another solid fuel, which is a by-product of the rice mill industry. Paddy husk alone constitutes about 22% of paddy on a dry weight basis (Chukwu, 1987). On this basis, the estimated quantity of husk produced in Nigeria annually is 880,000 metric tonnes and though this ha s a variety of possible industrial uses, its present utilisation in relation to the amount available is very small The gross calorific value of rice husk is 13,643 kJ/kg (chukwu, 1987).

Although wood has a wide domestic use as fuel all over the world, it cannot be compared to other types of fuel, such as coal and gaseous fuel because it consists mainly of cellulose, which in its chemical composition includes over 43% of oxygen. It has low calorific value (C.V). The calorific value of absolutely dry wood is of the order of 1.82 2.26 MJ/kg (Chukwu, 1987). The value of wood as a fuel lies in its low ash content – 0.3 to 0.6 per cent and in the clean long flame that can be obtained from it. The high volatile matter content makes it necessary to provide about 90% of the air for combustion as secondary air. However, wood as fuel can perform better when it is made into wood briquette. In U.S.A, however, briquetting attained a degree of success only after the equipment was perfected for compressing dry sawdust and wood shaving without artificial binders (VOA, 2001). A number of systems have been devised for briquetting wood materials. Wood briquettes are formed under pressure adequate to destroy the natural elasticity of wood particles. Required pressure for briquette ranges from 1000 - 1700 bars (Archie, 1985).

Wood briquettes are used for domestic heating in furnaces and fireplace and in heating and cooking stove. Some of the advantages of wood briquettes are cleanliness, ease of handling and small volume of smoke.

Coal is a fossil fuel of great importance and varying properties. Coals are classified according to their rank (carbon content). The major ranks of coal are lignite, sub-bituminous and bituminous coals and anthracite, in their order of increasing rank and decreasing calorific value. The calorific value of coal varies from 15 – 34 MJ/kg on dry, mineral - matter -free basis as Chukwu (1987). Coal was at a time before the advent of crude oil, one of the sources of Nigerian revenue. Till date, it is available in Enugu but with little or no interest given to its mining by the Federal Government.

The gross calorific values of some Nigerian solid fuels are presented in table 2.1.

Table2. 1: Gross Calorific Values of Some Nigerian Solid Fuels

Solid fuel material	Moisture content %wb	Calorific value
Sawdust	9.50	17,463
Wood shavings (hardwood)	9.45	17,831
Wood shavings (soft wood)	7.50	16,769
Coal	Bone dry	28,466
Rice husk + corn cob (1:1)	Bone dry	13,042
Corn cob + wood shaving (softwood)	Bone dry	16,600
Corn cob	9.23	17,163
Rice husk	8.50	13,643
Palm kernel husk	8.80	19,642
Corn grain	12.00	22,165
Corn Stover	13.20	16,043

Source:{ Chukwu, 1987}

Calorific value is the amount of heat generated by a complete combustion of unit weight of the fuel. This has been found to be inversely dependent on moisture content of the biomass solid materials, which is significant in determining energy availability from the biomass. This brings to mind that the properties of solid fuels have to be known for its efficient utilisation. Therefore for any given purpose, an exact statement of the properties of solid fuel materials concerning the moisture content should be made at the time of usage. The proximate analysis, ultimate analysis and calorific values, should all be known

Normally the carbon (C), hydrogen (H) and the volatile combustible sulphur (S) that make up the composition of a solid fuel determine its quality. The higher the percentage of these elements in the biomass the larger is the amount of heat generated when complete combustion is attained.

Several workers have derived empirical relationship for the calculation of the calorific value of solid fuels whose ultimate analysis is known. Such relationship are based on the assumption that each element in solid fuel material makes the same contribution to the calorific value as it would make if it were present in a mixture and not in chemical combination with other elements. For this purpose, the percentages of each component in the fuel are multiplied by the known calorific value of the component and the results summed together. For example, the well known Dulong equation assume that the oxygen present combines with hydrogen as water and hence reduces the amount of combustible hydrogen. Thus for low oxygen content materials;

L.C.V = 338.2 C + 144 OH + 93 S KJ/kg --------------- (2.1)

Where L.C.V = lower calorific value (KJ/kg) and C, H, O, S are the respective percentages of the elements on a dry basis.

When the oxygen content is high (>10%), a more precise expression is used (Chukwu, 1987).

$$L.C.V = 338.2C + 1442.8\,(H - {}^{O}/_{8}) + 94.2S\ (KJ/kg) \ldots\ldots\ldots\ldots (2.2)$$

2.1.3 Liquid fuel

Crude *petroleum is the main naturally-occurring liquid* fuel. Petroleum or crude oil is normally found in large cleomes porous rock. Crude oil is a yellowish-brown to black, relatively free-flowing liquid of relative density from about 0.78 to 1.00 consisting essentially of saturated hydrocarbon compounds (Chukwu, 1987). Crude oils are normally ranked into three categories, depending on the type of residue left after been refined, the petroleum is classified as paraffin – based crude oil, as asphalt-based crude oil, or as mixed-based crude oil. Crude petroleum is not used directly as fuel, but is separated into its various components or fractions by physical processes, the most important of these being distillation.

The primary step in fractionation of a petroleum feedstock is distillation. This entails thermal separation into streams of products ranging from gasoline through kerosene, gas oil and diesel fuel. Since this step is basically a physical separation only, the resulting "strength run" yield represents the proportion of these fractions initially present in the parent crude oil.

The gasoline is a colourless blend of volatile hydrocarbons with compounds ranging from C_5 to C_{12}. These fuel blend boil within the temperature range of about 30 to 200 °C, and have relative density of about 0.72 (aviation gasoline, or Avgas) (Chukwu:1987) and 0.74 (motor gasoline or Mogas) (Chukwu:1987).

The kerosene is a colourless blend of relatively non-volatile petroleum fraction which boils between 150°C and 300°C, and have a relative density in the region of 0.8 on overall average properties. Kerosene equates approximately to $C_{13}H_{25.5}$ (Chukwu, 1987).

The gas oils are brownish coloured petroleum fraction comprising distillates, boiling between 180 - 360°C (which overlaps to some extent with kerosene) and with a relative density of about 0.84. They equal roughly to $C_{15}H_{28}$ (Chukwu, 1987).

The diesel fuel is darkish-brown petroleum fractions comprising distillates and/or residual components, with a relative density of about 0.87 They are used in the heavier larger diesel engine used in marine and stationary electricity generating installations.

The laboratory examination of fuel oils to ascertain how far they satisfy the criteria for satisfactory performance involves wide range of analytical tests than is necessary in the case of sawdust and or any other solid fuels such as coal. This is a disadvantage, the criteria used to assess the suitability of fuel oils for their uses, or condition of use are. Specific gravity – the ratio of density of the fuel to that of water at 15.5°C; Viscosity, a measure of fluid's resistance to flow; Pour point – the lowest temperature at which the fuel ceases to flow; Flash point – the temperature at which a liquid fuel gives a enough vapour for an instantaneous inflammable mixture with air, other properties of liquid fuels are sulphur content, ash content, carbon residue and moisture content.

2.1.4 Gaseous fuels

All gaseous fuels are either fossil fuels or by-products of fossil fuels. These fuels can be divided into three general groups including natural gas, manufactured gas and by-product gas.

Liquefied petroleum gas, sometimes called refinery gas or simply L.P.G, is composed of light distillates of petroleum – primarily propane and butane. Because of this gas it has a higher volumetric heating value than natural gas. Blast-furnace gas is a low-quality fuel gas that is a by-product of steel industry. It is produced by burning coal with insufficient air. Although the gas has a heating value which is only one-tenth that of natural gas, there is so much of this generated in the operation of a blast furnace that it is economically feasible to recover and burn it.

2.2 Mass energy dependence and the development in utilisation of solid fuel

Throughout the history of human race, major advance in civilisation has been accompanied by an increased consumption of energy. Today, energy consumption appears to be directly related to the level of industrialisation of the country. Those countries that have had abundant supplies of energy available to them have realised substantially high production. In many instances, the availability of low cost energy has led to the infinite utilisation of the energy and in some instances with disastrous ecological effects. However, it is obvious that in order to raise the level of living of the majority, consumption must be greatly expanded.

Recently, some of the countries that have large supplies of low cost energy are using these supplies as potential and economic weapons to achieve political diplomatic means. Because of this "energy blackmail", the people of the energy-dependent countries of the world are becoming increasingly aware of the importance of the conversion and development of new energy sources. In a country like Nigeria today, much interest has been given to the petroleum industry for the source of energy and revenue, putting aside the mining of other fossils such as coal and developing the utilisation of the sources of fuel from biomaterials.

Even though we do not certainly know how much petroleum and other fossils that remain in the earth, we do at least know with some certainty that as they are being used up, they are not being replaced, as in the case of biomass fuel material that can be in abundance when conserved. The seriousness of the problem increases year by year due to the fact that the population of the world is increasing rapidly and because of the increasing industrialisation of these countries that are not well developed.

A country's development is highly and positively correlated with its degree of degree of industrialisation, a process that cannot start without the use, of energy and power. Similarly, the rate of industrialisation, agricultural growth and material welfare are therefore directly proportional to the rate of energy and power consumption.

The development of a new technology for the use of biomass has posed challenges to scientists and engineers alike and they have come up with ideas and equipment, which need to be improved upon. It is with their ideas in mind that research into the use of solid fuel as sawdust has been carried out in this study.

To achieve a reliable and efficient heat-generating furnace that uses solid fuel, many things come to mind in the selection and design of the heat generator furnace. Firstly, the purpose for which it is required and the probable fuel consumption are points of primary importance. Its capacity should be closely related to the probable output since one of the main causes of heat loss lies on incompletely filled furnace. An apparently high capital cost spread over the life of the generator may in the long run produce a considerable economy.

Ease of maintenance, insulation and provision for adequate draught air are areas that needs to be given special attention too. Ease of maintenance means accessibility, the use of readily replaceable parts and means for inspection and cleaning. Insulation must be regarded as an essential feature of almost any type of furnace. A chimney is needed to avoid build up energy and allows the evacuation of the smoke. Though this will have negative effect on the draught but it is necessary for high efficiency of the furnace.

2.3 Review of some equipment that use solid fuel

As it has been said earlier in this study, many people have worked on the use of sold fuel and tried developing equipment that can best be used. Equipments discussed here are mainly mechanically fired systems, but a mention is made about other solid fuels which are hand-fired.

2.3.1 Tin can stove (Jon,1985)

The single chimney tin can stove is the simplest home made stove to use sawdust for cooking. A hole is cut in the bottom of one side of a five-gallon can. A short length of broomstick is placed horizontally in the hole so that it reaches just to the centre of the can. Another stick is held upright in the centre of the stove, with the ends of the two stick touching. The can is filled with sawdust, stamped down with a wooden block during filling and sprinkled with water to keep the dust level down. The sticks are removed, some diesel oil or kerosene is dripped through the hole where the centre stick was. The oiled area is ignited with a burning rag through the air hole at the bottom. The mass will burn for about six to seven hours. Obstructing the airflow through the bottom passage can control the burning rate. A "trivet" (three legged stand for cooking pots) can be placed on top of the can and a cooking pot can be heated on it. Food cooked on this stove will tend to smell and taste wood smoke.

2.3.2 Double drum stove

The double drum stove is larger and more complicated than the tin can stove, but still inexpensive to construct. It consists of a 30-gallon steel drum, supported on a false floor inside a 55-gallon steel drum. A drawer, opening below the false floor, provides draft and catches dropping ashes, which are then easily removed. A hole in the centre of the false floor and the inner barrel bottom lets air passes up to the fuel, and ashes fall into the drawer. A lightly filling lid covers the outer barrel and two stovepipes exhaust smoke. It should stand at least two feet away from any combustible material and be set on a fireproof floor pad. With dry sawdust and good draft, one charge of this stove can heat a room 7 metres square, six to eight hours with no tending. (VOA, 2000)

2.3.3 Bassey's investigation (Hole-Through Sawdust Type Burner)

Bassey as reported by Chukwu(1987), carried out a study to investigate the characteristics of a burner, which uses sawdust as fuel. The method of burning consists of packing the fuel, making hole vertically through it and lighting the sawdust in the hole. Through a series of experiments, he was able to establish the behaviour of the quantities, which characterise the operation of the burner. The method of burning sawdust as investigated by Bassey is illustrated schematically in Figure 2.1. This burner is manually fed. The apparatus used to study the characteristics of the burner is shown in Figure 2.2

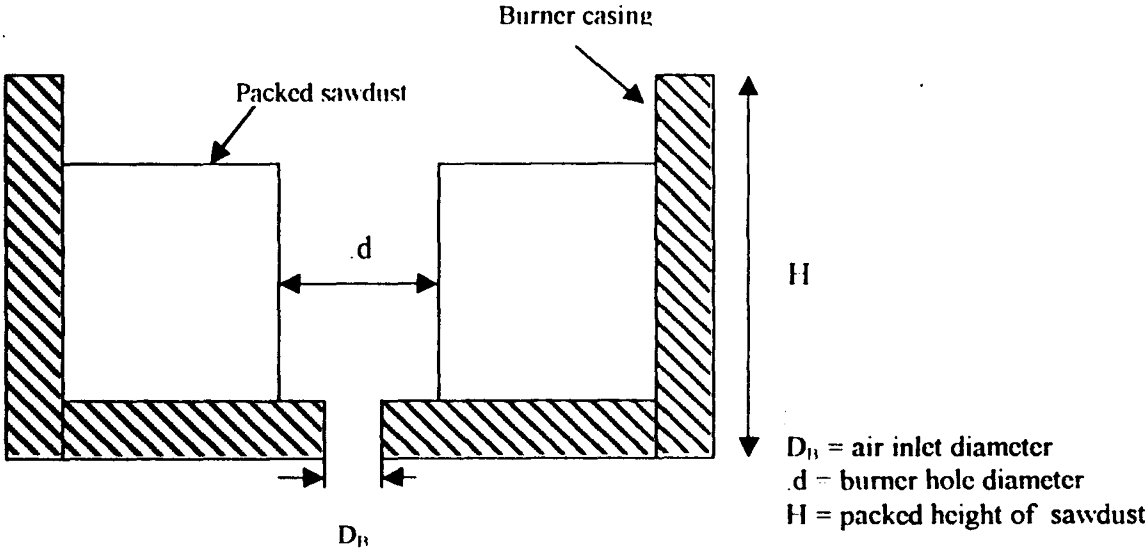


Fig. 2.1: Schematic diagram showing the method used to burn sawdust

Source: (Chukwu, 1987)

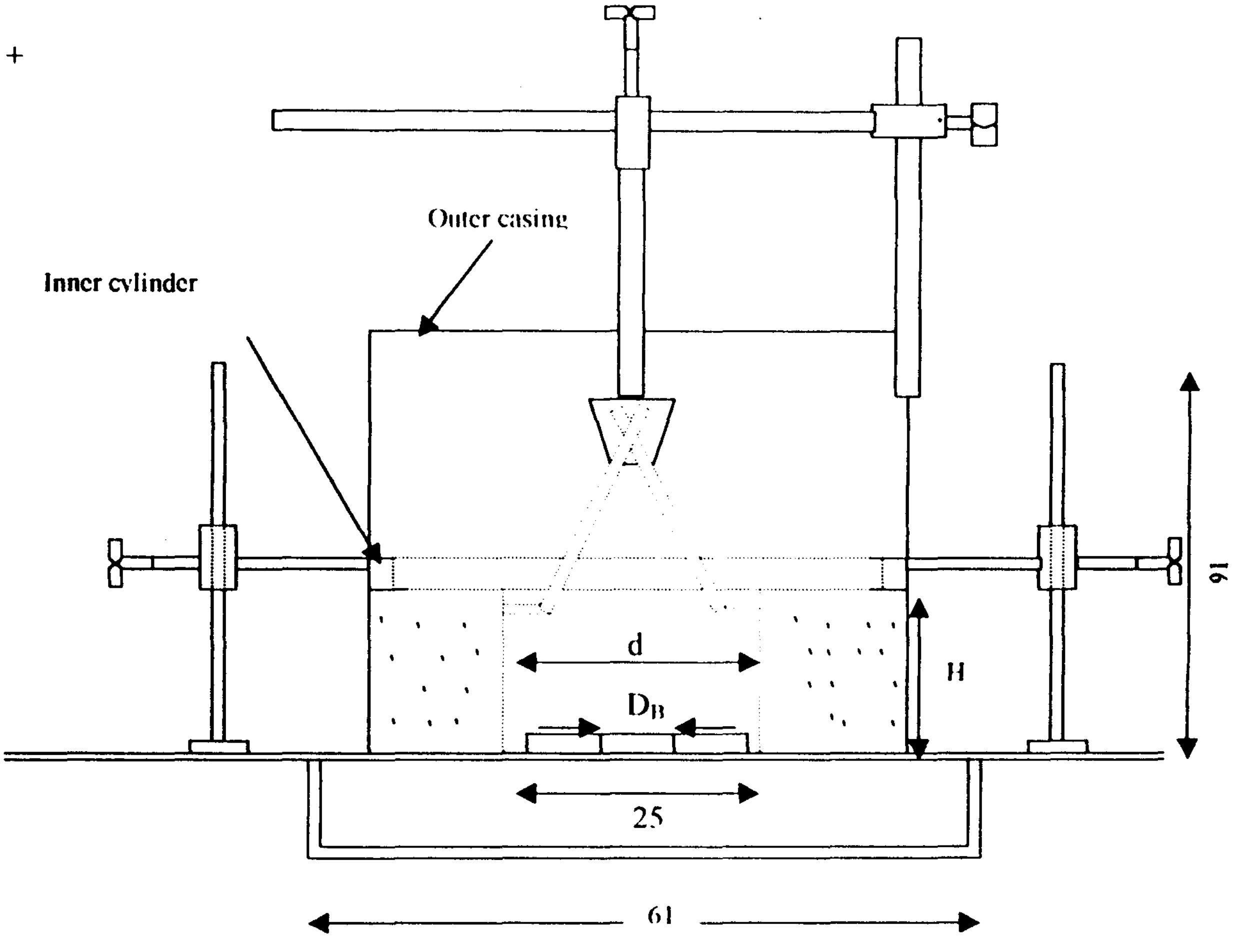


Fig. 2.2: Schematic diagram of the apparatus used to study the characteristics of burner (all dimensions in mm)
Source: (Chukwu, 1987)

2.3.4 Coking stoker

The coking stoker employs a flat reciprocating ram to introduce coal into the furnace. The fuel is first deposited into the coking plate where the volatile matter is partially distilled and gassified to be burned subsequently as it passes over the fire bed.

CHAPTER THREE

METHODOLOGY AND DESIGN CALCULATIONS

3.1 Combustion mechanism

The basic mode of combustion of sawdust involves the introduction of sawdust and air at the burner with no premixing of the reactants. This results in a very short heating time and in a rapid heating of the fuel and air. Because of this rapid heating, the hydrocarbon compounds are "cracked" into lighter compounds and eventually into the basic elements, carbon and hydrogen. As a result of this thermal decomposition, most of the combustion occurs between elemental hydrogen and oxygen, which burns with almost invisible flame. Elemental carbon burns with a characteristic yellow flame. Consequently, this mode of combustion produces a luminous flame or "yellow flame". This type of combustion also predominates in the combustion of solid and most liquid hydrocarbon fuels. Actually, contrary to popular opinion, "yellow flame" is usually desired in a large power boiler because it increases the radiative heat transfer from the flame to the tubes and reduces combustion temperature.

3.1.1 Fuel and air quantification

The quantity of fuel F, needed to produce any given amount of heat is given by:

$$F = \frac{\text{amount of heat energy (Q)}}{\text{Calorific value of fuel (C.V)}} \text{ kg} \qquad \text{.....(3.1)}$$

Where F = quantity of fuel to be combusted (kg)

Q = amount of heat energy needed, MJ

C.V. = calorific value of fuel, MJ/kg

The quantity of air and the flue products involved in combustion can be computed from the reaction equation of the individual combustible elements of the fuel with oxygen. The oxygen is derived from the air, which contains mainly oxygen and nitrogen in the ratio 1:3.31 and 1:3.76 by weight and volume, respectively. The combustion equations (Chukwu, 1987)are:

$$C + O_2 \longrightarrow CO_2 + 372.7\ MJ \quad \ldots\ldots\ldots\ldots (3.2)$$

$$2H_2 + O_2 \longrightarrow 2H_2O + 525.4\ MJ \quad \ldots\ldots\ldots\ldots (3.3)$$

$$S + O_2 \longrightarrow SO_2 + 26.9\ MJ \quad \ldots\ldots\ldots\ldots (3.4)$$

The quantities of materials involved in these reaction are given in Table3.1. With Table 3.1, one can calculate for a given fuel consumption, the theoretical air requirement and quantity of flue product involved.

Table 3.1. Quantities of Materials Involved in the Perfect Combustion of 1kg of Combustible Elements.

Material quantities involved in 1 kg (or m^3 at stp)

	Reactants			Products			
	O_2	N_2	Air	CO_2	N_2	H_2O	SO_2
SP. Vol. (m^3/kg)	0.48	0.792	0.72	0.509	0.792	1.24	0.343
Carbon (C)	2.66 (1.74)	8.82 (6.53)	11.48 (8.27)	3.66 (1.86)	8.82 (6.53)	- -	- -
Hydrogen (H)	8 (3.78)	26.4 (20.99)	34.4 (24.77)	- -	26.4 (20.99)	9 (11.16)	- -
Sulphur (S)	1 (0.48)	3.3 (2.62)	4.3 (3.10)	- -	3.3 (2.62)	- -	2 (0.686)

Source : (Chukwu, 1987)

3.2 Analysis of combustion

To determine the overall performance of a section of a furnace, what needs to be carried out is the calculation, which is essentially concerned with materials and energy balance across the unit.

Combustion calculations are carried out to determine/estimate the quantities of different chemical elements in a given fuel. This is based on the quantitative determination of the amounts of these elements present in the solid fuel - ultimate analysis

3.2.1 Theoretical volume of air required to burn 1 kg of sawdust

The composition of sawdust as determined by Miles (1996) is given in Table 3.2

Table 3.2: Composition of Sawdust (Red Oak Wood)

Component	Weight (Kg)	Molecular weight	Mole
Carbon (C)	44 24	12	3 687
Hydrogen (H)	5. 24	2	2.62
Oxygen (O)	38.76	32	1.211
Nitrogen (N)	0.03	28	0.001
Sulphur (S)	0.01	32	0.0003
Moisture (m)	11.45	18	0.636
Ash	0.28	-	-

Source(Miles, 1996)

a) Stoichiometric method

The reactions involved are:

(i) $C + O_2 \longrightarrow CO_2$
12 32 44

(ii) $H_2 + {}^1/_2\, O_2 \longrightarrow H_2O$ (Assuming that water condenses out)
2 16 18

(iii) $S + O_2 \longrightarrow SO_2$
32 32 64

Taking 1 kg of sawdust as a basis of burning carbon in 1 kg fuel

Weight of oxygen required is = $\frac{0.4424 \times 32}{12}$

= 1.1797kg

Weight of oxygen required for H_2 = $\frac{0.0524 \times 16}{2}$

= 0.4192kg

Weight of oxygen required for S $\frac{0.0001 \times 32}{32}$

= 0.0001 kg

Total oxygen required is 1.599 kg

However, 0.4424kg of oxygen is available in the sawdust.

Oxygen to be supplied is (1.599 – 0.4424) = 1.1566 kg sawdust

Thus the ratio to be supplied = $\frac{1.1566 \times 100}{23}$

= 5.0286 kg/kg sawdust

(Air = 23 % w/w oxygen)

Taking the molecular weight of air as 28.9 (N_2 5= 28, O_2 = 32), density of air at s.t.p will be 28.9/22.4 = 1.290 kg/m^3 (22.4 m^3 is the gas molecular volume)

Volume of air required for combustion is = $\frac{.0286}{1.290}$

= 3.898 m^3/kg sawdust

To burn 10.5 kg/hr of sawdust, the air required is 40.929 m^3/hr or 52.80 kg/hr

(b) 'Mol' method (Miles, 1996)

The reactions involved are:

1kmol C + 1kmol O_2 ⟶ 1kmol CO_2..............................(3.5)

1kmol H_2 + ½ kmol O_2 ⟶ 1kmol H_2O..................(3.6)

1kmol S + 1kmol O_2 ⟶ 1kmol SO_2..............................(3.7)

This can better be shown in Table 3.3

<u>Table 3.3: Kmol Oxygen Required to Burn Combustible Elements in Sawdust (Dry)</u>

Components	% Weight	Molecular weight	Kmol	Kmol O_2 required
C	44.24	12	3.687	3.687
H	5.24	2	2.62	1.31
N	0.03	28	0.001	0.001
S	0.01	32	0.0003	0.0003
O	38.76	32	1.211	-1.211
ASH	0.28	-	-	-
Moistened	11.45	18	0.636	-
			TOTAL	**3.7873**

Basis = 100 kg sawdust

Air to be supplied is $\frac{3.7873}{21} \times 100$

= 18.0348Kmol/100kg Sawdust

(Kmol are required to volume (22.4 m^3) and air is 21% v/v O_2)

Weight of air to be supplied = 18.03484 x 28.9

= 521. 21kg/100kg sawdust

= 5.212kg/kg sawdust

Volume of air to be supplied = 18.0348 x 22.4

= 403.98m^3 / 100kg sawdust

At the sawdust feed rate of 10.5kg/hr, the volume of air to be supplied is 38.474m3/hr or 52.80kg/hr

3.2.2 Composition of dry flue gas

The sawdust with analysis given in Table 3.2 is burnt with 20% excess air, then the volumetric composition of the dry flue gas can be calculated from 3.2.1 (b), the theoretical (or stoichiometic) air required is 18.0348 Kmol/100kg sawdust

the actual air is 18.0348 x 1.2

= 21.642 kmol/100kg sawdust

This air contains 0.792 x 21.642 = 17.140Kmol N_2 and (21.64-17.140) = 4.50 Kmol O_2

Recall that amount of oxygen required for combustion is 3.7873 Kmol (table 3.3)

Excess O_2 which appears in the flue gas is 4.50 - 3.7873 = 0.713 Kmol in addition, the flue gas contains

3.687 Kmol Co_2 (from the combustion of 3.271 Kmol C), 0.0003 Kmol So_2 (from the combustion of 0.0003 Kmol S), 0.001 Kmol N_2 (from the sawdust (sand 17.140 Kmol N_2 (from the air)= 17.141 Kmol N_2. this gives a total of 20.83 Kmol/ 100kg sawdust. The analysis by volume is therefore

$$Co_2 + So_2 = \frac{3.687 + 0.0003}{20.830} \times 100 = 17.7\%$$

$$O_2 = \frac{0.713}{20.830} \times 100 = 3.42\%$$

$$N_2 = \frac{17.141}{20.830} \times 100 = 82.28\%$$

3.2.3 Weight of flue gas and excess air used.

From the value obtained in 3.2.2 above, using the values CO_2 17.7%, O_2 3.42%, N_2 82.28%, the weight of the gas produced pe kg sawdust burnt and the percentage of excess air used in the combustion can be computed

(a) Weight of the gas

By carrying out carbon balance across the furnaces the weight of the flue gas can be obtained

100kmol of sawdust contain 3.687kmol C (including S)

100kmol dry flue gas contain 17.7Kmol C (1koml Cos contain 1 Kmol C). Hence, amount

of dry flue gas produced $= \frac{3.687}{17.7} \times 100 = 20.83$kmol/100kg sawdust

(b) Actual Air Used

This is obtained by carrying out nitrogen balance across the furnace. If 2 Kmol of air used 100kg sawdust

N_2 from air + N_2 from sawdust = N_2 in flue gas or 0.792 + 0.001 = 0.8228 x 20.83

Or = 21.69 Kmol/100kg sawdust

This weight of air used $= \frac{21.69}{100} \times 28.9 = 6.268$kg/kg sawdust

$$\% \text{ Excess air} = \frac{(\text{actual air} - \text{theoretical air})}{\text{Theoretical air}} \times 100\%$$

$$= \frac{(6.269 - 5.948)}{5.948} \times 100$$

$$= 5.396\%$$

3.3 Combustion of fuel (Sawdust)

Two things to be borne in mind when carrying out the combustion of any material are firstly, sufficiently high temperature and secondly, a proper supply of oxygen. Since air contains only about 21% oxygen and about 79% N_2, a large amount of air is needed for combustion.

So called complete combustion, results in the maximum conversion of the fuel into heat. Complete combustion requires careful control of the rate at which fuel and air supplied as a safety factor to guide against incomplete combustion with which produces carbon monoxide. Excess air however, reduces the efficiency of the energy conversion process since the volume of flue gas is increased and more heat is carried up the flue.

3.3.1 Formation of carbon monoxide

The composition of sawdust of interest in this case is 49.96% ash and 0.31% C. The calorific value of sawdust is 17,463 kJ/kg. Flue gas composition is CO_2 17.19%, O_2 3.34%, N_2 79.47%, CO 0.01%. The weight of carbon converted to carbon monoxide per kg sawdust can be calculated as follows

$$C + O_2 \longrightarrow CO_2;\quad H = 33{,}914.7 \text{ kJ/kgC} \qquad (3.8)$$

$$C + 1/2\, O_2 \longrightarrow CO;\ H = 10{,}300 \text{ kJ/kgC} \qquad (3.9)$$

The ratio of carbon forming CO to the total carbon burnt $= \dfrac{\%\,C}{\%\,CO + \%CO_2}$ .... (3.10)

Substituting values of CO and CO_2 into equation (3.10) and subsequent computation gives 0.00061kg/kgC.

In burning 1 kg sawdust, i.e. 0.4996 kg C, weight of carbon forming CO = 0.0061 x 0.4996

= 0.00030 kJ/kg sawdust

For every kg carbon which is converted to CO

(33,914.7 - 10,300) = 23, 614.7 kJ are lost

Heat lost = 0.00030 x 23, 614.7   7.19 kJ/kg sawdust

$$= \frac{0.00030}{7.19} \times 100 = 0.004\% \text{ of sawdust}$$

3.3.2 Description of the heat generator

The idea of using sawdust as fuel material has long been in existence, but there is high loss of heat to the surrounding due to improper trapping of the heat generated. The method of using this heat generator is simple: the fuel material (sawdust) is fed into the combustion chamber with the aid of the auger. After feeding the auger, it is removed and the feeding hole is blocked. The initial ignition is done through the door, which is also blocked after 10 -15 minutes, and combustion fully takes place with draft from the bellow.

3.4 Design considerations and calculations

3.4.1 Choice of fuel

Sawdust is to be used as fuel material in this heat generator. This fuel is chosen because of its availability and ease of handling. It is readily obtainable from the sawmill industries and at times free of charge. Also because of its higher calorific value among other solid fuel materials such as corncob, rice husk: which has calorific value of 17,163 kJ/kg while sawdust with calorific value of 17,463 kJ/kg will generate more heat per time.

In the design of heat generator furnace, the thermal load of the furnace grate and furnace space are two important parameters.

These can be obtained by applying the equation below:

$Q_r = mQ/v$ ....(3.11)

$Qg = mQ/R$ ....(3.12) where,

Q_f = thermal load of the furnace space (kJ/m^3-hr)

Qg = thermal load of the fire grate (kJ/m^2-hr)

Q = calorific value of fuel being considered (kJ/kg)

.v = volume of the fuel space (m^3)

.m = amount of fuel burnt in one hour (kg)

R = area of the fire grate (m^2)

The thermal load of furnace space is the number of kilojoules (kJ) generated by fuel in one hour per cubic meter volume of furnace space, while the load of fire grate is the number of kilo joules (kJ) generated by the fuel burnt on 1 m^2 of fire grate in one hour.

Since the hourly expenditure of the fuel (sawdust) and it's calorific value is known, the appropriate or design volume of the space can be calculated. The thermal load of furnace space for sawdust is 784,448 kJ/m^3-hr while the thermal load of fire grate is From 2,664,886-3,324,682kJ/m^2 –hr (Jon, 1985).The upper limit of the permitted thermal load is used for safety reason, this values are 784,448 kJ/m^3 –hr and 3,324,683kJ/m^2 for furnace space and fire grate respectively. In this design the hourly expenditure of sawdust is 10.5kg and calorific value of sawdust is 17,463KkJ/kg. Then recasting equation (3.11) as

$$V = \frac{MQ}{Qf} \quad \ldots\ldots\ldots\ldots\ldots 3.13$$

The volume of the furnace space is calculated as.

$$Vs = \frac{10.5 \times 17{,}463}{784{,}448} = 0.234m^3$$

Also when equation (3.12) is recasted as

$$R = \frac{MQ}{Qg} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3.14)$$

Similarly from equation (3.14) the area of fire grate R is calculated as:

R = (10.5 x 17,463)/3,324,682

= 0.055m^2

The ratio V/R (m^3/m^2) is used to calculated the design height for the furnace for the assumed conditions. This gives height of 4.25m. This is a rather high value if the financial cost of this project is put into consideration, to cut down of the height of the furnace, 15% of this calculated value is chosen. This gives a height of 0.6m. and the length and breadth of furnace as 0.5m 0.4m respectively.

3.4.2 Determination of amount of heat to be generated

The heat to be generated is the product of the calorific value and the weight of the sawdust to be burnt.

Q = C.V x F ....(3.15)

where, Q = amount of heat energy to be generated

C.V = calorific value of sawdust (kJ/kg)

F = quantity of the fuel to be combusted

∴Q = 17, 463 x 10.5 = 183361.5 kJ

3.4.3 Thermal load of furnace

Knowing the hourly expenditure of sawdust and the volume of the furnace space, the thermal load of the furnace can be calculated.

From equation (3.11), the thermal load of the furnace is calculated as:

$$Q_f = \frac{10.5 \times 17463}{0.234}$$

=783596.15 kJ/m^3 -hr

Taking $1m^3$ of the value obtained we have 783596kJ/hr

3.4.4 inside wall temperature of the furnace.

Heat input , Q=MCθ

Where, Q =783596.15 KJ/hr

M = hourly expenditure of sawdust = 10.5 kg/hr

C = Specific heat capacity of sawdust =26.23kJ/kg °c (Emmanuel, 1993)

θ =inside wall temperature t, minus ambient temperature (t-ta)

Ambient temperature, ta =31°c

Substituting these values gives:

136119.89 =10.5 X 26.23(t –ta)

$$t - 31 = \frac{783596.15}{10.5 \times 26.23}$$

t =2876.15°c

3.4.5 Furnace casing/insulator material

Heat insulators are material whose principal purpose is to retard the flow of heat. Thermal or heat insulator material may be divided into two classes: bulk insulation and reflective insulation .The classes and material within aclasses to be used for a given application depend upon such factors as temperature , abient condition, and material strength requirement. Examples of bulk insultion are: Mineral wool, fibre wool glass, organic paper e.t.c, and theyretard the flow of heat.

Reflective insulation are usually aluminium foil or sheet, although, occasionally a coated steel or silver are used .Their effectiveness is due to their 'lumisivity (high reflectivity) of heat. (Donald, 1992)

For a given thickness of material exposed to temperature difference, the rate of heat flow per unit area is directly proportional to the thermal conductivity of the material.

Putting into consideration material handling and economic effectiveness, fibre wool glass was used as the insulator for this design and the casing used is mild steel plates for the inside and outside walls respectively for the combustion chamber

33.4.6 Design for insulation thickness

$$Q = \frac{KA\theta}{S} \qquad \text{3.16 (Akinbode F.O ,1998)}$$

Where Q = Heat loss(783,596.15kJ/hr

K = Thermal conductivity (81wm $^{-1}$ $^{o}c^{-1}$)

A = Area of the material (o.2m^2)

S = Thickness of the material

θ = Temperature difference (2845.15^{o}c)

Therefore, substiting our values we have

S = 81(0.2 X 2845.15)/783.596.15

S = 0.60m

S = 60mm

3.4.7 Design of the feeding mechanism

The fuel (sawdust) is to be fed through a hopper and moved with the aid of an auger. The pitch distance of the auger is given as:

$$H = 0.5.p \text{ (Vogler, 2000)}$$

Where, H = height of auger (mm)

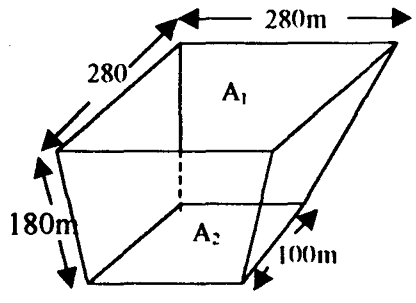
P = pitch distance (mm)

The length for the auger is 20 mm

$\therefore P = 40mm = 4.0 \times 10^{-2}m$

The auger is suspended by a bearing, which aids the rotation of an auger, the bearing was selected using the diameter of the auger shaft.

3.4.8 Hopper Design



] Fig. (3.1): a frustum of a pyramid

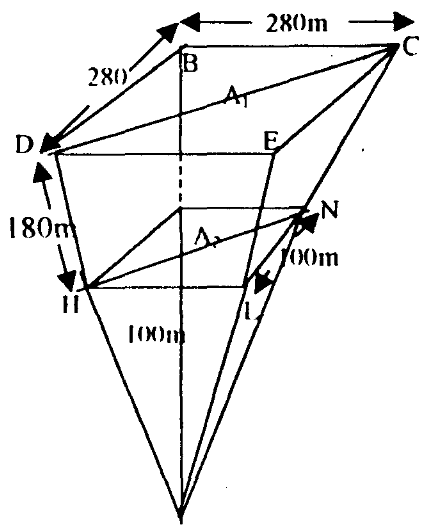


Fig. 3.2 a complete pyramid

The dimensions of the hopper are as shown in Fig. 3.1

The volume of the hopper is given as

V= 1/3 (Area x Height)......................... (3.17)

Where, V = Volume of the hopper

A_1 = area of the top

A_2 = area of the base

$A_1 = 1 \times b$

$= 280 \text{ X } 280 = 78400\text{mm}^2 = 78.4\text{m}^2$

$A_2 = 100 \times 100$

$= 10{,}000\text{mm}^2 = 10\text{m}^2$

To obtain the volume of the figure above

V = (Volume of A_1 – Volume of A_2) ______________ (3.18)

The diagonal length of A_1 (DC) = $\sqrt{DB^2 + BC^2}$

$= \sqrt{280^2 + 280^2}$

$= 395.98\text{mm}$

To obtain the point of DC = $\frac{395.98}{2}$ = 197.99mm

The diagonal length of A_2 (HN) = $\sqrt{100^2 + 100^2}$

$= 141.42\text{mm}$

To obtain the mid point of HN = $\frac{141.42}{2}$ = 70.71mm

To obtain the height we use equation for solving similar triangles

Therefore, $\frac{h}{70.71mm} = \frac{h + 180}{197.99mm}$

$h = 100mm$

To obtain the height of bigger figure $H = h + 180mm$

$H = 280mm$

Substituting into the equation (3.18)

$V = [1/3\ (78400 \times 280) - 1/3\ (10000 \times 100)]$

$V = [7317333.333 - 3333333.\ 333]$

$V = 6984000mm^3$

$V = 6.984 \times 10^{-3}\ m^3$

3.4.9 Description of air and sawdust distribution pipes

The secondary air needed for fast combustion is supplied from the bellow through a 0.051m pipe with a conical top that distributes the fed-in sawdust uniformly. The pipe is connected with smaller pipes, which further aid in the distribution of the air.

The distribution pipes are smaller so as have high-pressure head. The air pipe with the sawdust distributor cone is shown in fig 3.3

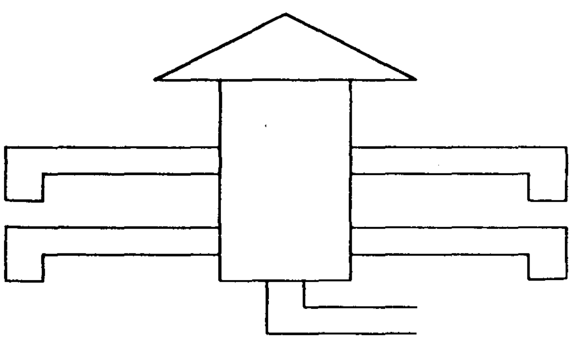


Fig 3.3 The air and sawdust distributor pipes

3.4.1.0 Oven design

In order to carry out test on how this heat generator could be used, an oven was designed. The oven is to be placed on top of the heat generator. The dimensions are: 40 cm, 50 cm and 60 cm respectively for the breadth, length and height. Depending on what is to be dried on the oven, the tray can be changed. The sides and top of the oven are insulated with fibre wool grass of 2 mm thickness.

3.5 Experimental Methods

The sawdust is to fed into the combustion chamber through the metering device (auger), after which the fuel is ignited. The initial ignition is to be introduced through the small opening at the front of the heat generator. About 10 – 15 minutes should be allowed for the heat generator to attain a self-supporting ignition of the sawdust.

The openings are to be blocked and the bellow is to be used in supplying air for combustion. The air ventilation door at the base of the heat generator is to be kept opened after about 15 – 25 minutes of ignition of the heat generator.

A thermocouple is to be used in recording the temperature at different points and times. The inside wall and outside surface temperature of the heat generator are to be recorded.

The temperature measurements are to be recorded at intervals of one hour, the experiment is to repeated at least 3 times. An apparatus is to be placed on top of the heat generator to help determine the amount of heat that can be utilised (in this case an oven) for drying agricultural products (e.g. tomatoes). The surface area of the food crop should be increased by any means of size reduction e.g cutting, slicing, e.t.c. The values obtained are recorded in a table format as shown in table 3.4.

Table 3.4: The experimental record format of the heat generator

	Quantity of fuel fed in (Kg)	Inside wall temperature oven dryer (0^0C)	Time interval
1			
2			
3			
4			

3.6 Material Selection

In every design, the economic effectiveness in engineering has to be given due consideration. In fact, the first basic consideration is the cost and availability of materials to be employed for a particular design. Other parameters that were considered include: Performance, Workability and Weld ability, so that specific purposes can be achieved using the selected materials. In the design of this heat generator, the cost and availability of required materials were first considered after which strength and its ability to resist heat were considered, which are needed parameters in any heating chamber.

All these considerations and materials specifications led to the selection of mild steel, which is the most available and easy to work. Paint was used to reduce the action of rusting with time, as well as beautify the work.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Furnace efficiency

The efficiency of any furnace may be defined as the ratio of the actual heat utilised for an operation in the furnace to the total heat liberated in the furnace. For the sawdust fired furnace designed, the actual heat utilised is the average heat recorded in the oven. The total heat liberated inside a furnace is the calorific value of sawdust.

After carrying out heat test on the furnace using the following fuel feed ratio of 10,15,20,25 and 30 kg/hr the following value were obtained for the amount of heat inside the oven dryer as shown in Table 4.1

Table 4.1: record of the value of heat inside the oven (dryer)

Quantities of fuel feed in (kg)	Inside wall temperature of oven dryer (^0C)	Time interval (hr)
10	23.0	10pm – 11pm
15	24.6	11noon – 12noon
20	26.0	12noon – 1pm
25	27.4	1pm – 2pm
30	28.0	2pm – 3pm
	Total = 129^0C	

$$\text{Furnace efficiency} = \frac{\text{heat generated per kg of sawdust fired}}{\text{Calorific value per kg of sawdust fired}} \times 100$$

$$\text{Or } \eta_f = \frac{Hc}{C.V} \times 100$$

Where, H = heat generated per kg of sawdust fired.

η_f = furnace efficiency

C.V = calorific value of sawdust

From table 4.1 above the average heat inside the oven dryer is given as

$129/5 = 25.8^0C$

and C.V. is 17463

Therefore

$$\eta f = \frac{10.5x\ 26.23x\ 25.8x100}{17463}$$

$= 40.7\%$

4.2 Sources of heat loss

There are various ways in which the heat is lost. These include:

1. Heat loss due to unburnt combustibles in the residue.
2. Heat loss due to moisture formed by burning hydrogen in the fuel.

Heat loss due to conduction through furnace walls.

4.3 Cost analysis

In the design of this heat generator, cost effectiveness was one of the major considerations having the rural dwellers at the back of my mind. In this section, the cost of the equipment shall be analysed under the following headings:

a) Material cost

b) Labour cost

c) Overhead cost

Material cost

In the course of fabrication, all the materials used were bought locally. Table 4.2 shows the cost of each material, the quantity bought and the unit price of each of the materials used in the construction. The cost of all materials is added to give the total cost of the material used for the construction.

Table 4.2 Material specification

Material	Dimension	Quantity	Unit price N K	Cost N K
Mild steel sheet (2mm)	120 x 240 cm	1 ½	1200	1800
Mild steel sheet (3mm)	120 x 240 cm	1	2000	2000
Square pipe (2.54 x 2.54)cm	480 cm	1	400	400
Lagging material (fibre wool grass)	5 x 45 x 100	2	500	1000
Galvanised pipe (scrap)	30 x 5 cm (dia)	1		100
Galvanised pipe (scrap)	80 x 10 cm (dia)	1		120
Bearing		1	150	150
Galvanised pipe (scrap)	80 x 120cm (dia)	1	200	200
Pai	1ltr	2	250	500
Electrodes	Gauge 12	1 packet	700	700
			Total	**₦6970**

Labour cost

In the construction of the equipment, direct labour was used, hence direct labour cost was incurred. It took the period of 10 days to complete the construction of the equipment.

Judging from the minimum wage earned by the civil servants in Nigeria, which is ₦7,500, at 8 official working hours, daily wage is ₦312.5 excluding the weekends This implies that for 10 days the cost of labour = 10 x 312.5 = ₦3125

Overhead cost

This is the cost incurred during the production, which is not directly related to the product. They include transportation and other petty expenses. The overhead cost is taken to be 10% of material cost.

Overhead cost = 10/100 x 6970 = ₦697

Therefore, production cost is the sum of all the cost incurred.

Total cost = material cost + labour cost + overhead cost

= 697 + 6970 +3125

= ₦10, 792.

CHAPTER FIVE

CONCLUSIONS AND RECONMENDATIONS

5.1 Conclusions

The need for the development of a cheap means of generating heat that can serve the populace especially the rural dwellers is a matter of great importance when the cost of generating heat from other means is considered. This necessitated the design of this sawdust heat generator furnace.

The design involved as has been seen in this report,:

1) The design of the volume of the furnace
2) The determination of the thermal load
3) The design of the feed mechanism (auger)
4) The determination of various ways heat can be lost to the surrounding and ways of reducing it by insulation.

The efficiency of the furnace is 40.7 %. The amount of sawdust that the equipment can consume in one hour is 10.5 kg. The volume of the furnace space is $0.234m^3$. The sawdust is to be fed in through the hopper via the auger.

The insulator thickness is 60mm and the gross heat output is 183361.5KJ. The heat generator can be adopted for use in drying or parboiling of rice, depending on the needs.

The application of solid fuel material in the generation of heat is been given attention as this will help in conserving other fuel materials such as petroleum products.

5.2 Recommendations

The heat generator can be adapted to burn other solid fuels of close substitute such as palm kernel shell, rice husk, corn grain e.t.c.

Future designs of the furnace should include a blower that will enhance faster combustion thus leading to reduction of carbon monoxide from the flue gas. Other lagging materials can be used e.g. clay: which has the ability to reduce heat loss by conduction through the furnace wall.

Lastly, the fire grate should be designed in a better way such that the ash can drop easily.

REFERENCES

Akinbode F.O (1998): Thermodynamics I lecture material. Federal University of Technology, Minna.

Archie, W. C. (1985): Principles of energy conservation. International student edition. McGraw Hill Book, Tokyo, Pp 6-115.

Chinwe, C. E. (1984): Designed of solid fuel fired dryer. M. Eng. Thesis, Agricultural Engineering Department, University of Nigeria, Nsukka, Enugu State.

Chukwu, O. (1987), (Unpublished): Design of a rice husk heat generation furnace. B. Eng. Project Agricultural Engineering Department, University of Nigeria, Nsukka. Enugu State.

Donald Fred, W. B. (1992): Drying and storage of grain and oil seeds. Van no strand. Reinhold library of Congress Catalogue. Pp 24-160.

Emmanuel, B. A (1993): Development of waste in the wood industries. Mechanical Engineering Department, University of Benin, Edo State.

Gary, G. (2000): Double drum sawdust stove. VOA special English development report. http://www.teleport com/ tmiles alkali fuelse 2 h.

Jon, V. (1985): Understanding wood waste as fuel. Volunteers in technical assistance. 1600 Wilson Boulevard, Suite 710, Arlinton, Virginia 22209 U.S.A. E-mail: vita@ vita. Org.

Measurement converter, (www convertit.com Go ConvertIt Measurement/Converte).

Miles, T.R.(1996): Consulting Design Engineering, Portland Oregon. U.S.A.

Perry, R. H. and Green, D. W: Perry's Chemical Engineering Handbook. Seventh edition.

Vogler, A (2000) NAHB Research Centre Inc. 4000 Prince George's Blvd. Upper Marlboro, MD 20774. Tool Base Hotline 8000-898-284. www nah brc.org.