

**DESIGN, CONSTRUCTION AND TESTING OF A CHARCOAL FIRED
CRUCIBLE FURNACE FOR MELTING OF 10KG OF ALUMINUM**

BY

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AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA.**

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MSc/ Eng/10752/2008-2009**

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DEDICATION

This work is dedicated to my mother and my father for their usual prayers and support given to me, may God reward them Amen.

DECLARATION

I declare that the work in the thesis entitled “Design, Construction and Testing of a Charcoal Fired Crucible Furnace for Melting of 10kg of Aluminum” has been performed by me in the Department of Mechanical Engineering under the supervision of Prof. S.Y. Aku and Prof. A.I. Obi. The information derived from the literature has been duly acknowledged in the list of references provided. No part of this thesis was previously presented for another degree or diploma at any university.

Garba Muh'd Sani

Signature

Date

CERTIFICATION

This thesis titled **”DESIGN,CONSTRUCTION AND TESTING OF CHARCOAL FIRED CRUCIBLE FURNACE FOR MELTING OF 10KG OF ALUMINIUM”** meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, and is approved for its contribution to knowledge.

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NOMENCLATURE

- t = Furnace wall thickness (mm)
- p = maximum working pressure of the furnace (N/m^2)
- P_d = Design pressure (N/m^2)
- D_1 = Internal diameter of the furnace (mm)
- C = Corrosion allowance
- σ = Allowable stress of the material of the furnace at operating temperature (N/m^2)
- R_f = Inner radius of the furnace
- J = Joint efficiency (%)
- α = Coefficient of thermal expansion of the materials (m^2/s)

- E = Modulus of elasticity of the materials (N/m^2)
- ν = Poisons ratio
- T_w = Temperature of the inside wall ($^{\circ}\text{C}$)
- T_b = Temperature of the desired stress location within the furnace radius ($^{\circ}\text{C}$)
- Δ_t = Change in temperature
- Δ_l = Change in length (mm)
- L_{fur} = Furnace length (mm)
- d_{cru} = Crucible diameter (mm)
- L_{cru} = Crucible length (mm)
- m_f = Mass of fuel (kg)
- Q_s = Heat supply (kJ)
- K = Thermal conductivity of the insulating material (W/Mk)
- h = Distance of fire gate between combustion chamber and crucible
- Q_C = Thermal load of the combustion chamber
- Q_g = Thermal load of the fire grate
- H_C = Height of the combustion chamber
- m_{ea} = Amount of air required for combustion
- m_g = Mass of the product of combustion
- T_{fg} = Flue gas temperature
- \emptyset = Fan discharge capacity
- P = Power supply
- N = Speed

L_{approx} = Belt pitch length

θ = Angle of contact

T_0 = Initial tension of the belt

T = Torque transmitted

R = Thermal resistance of the insulators

R_s = Thermal resistance of the outer surface

T_m = Melting temperature

T_P = Pouring temperature

L_f = Latent heat of fusion

C_p = Specific heat at constant pressure

β = Fan blade inlet angle

x_c = Crucible thickness

F = Surface coefficient

x_m = Thickness of the material

P_f = Fan discharge pressure

U_2 = Fan discharge velocity

D = Diameter of the pulley

d_0 = Internal diameter of the insulators

d_1 = Outside diameter of the insulators

Q_R = Heat required for melt

r_1 = Furnace radius

r_2 = Radius of clay insulators

r_3 = Radius of asbestos insulator

A = Area

r_c = Crucible radius

l_c = crucible length

ABSTRACT

This research work presents the design concept, construction and performance evaluation of a 10kg capacity portable crucible furnace which uses charcoal as fuel. The 10kg crucible furnace was designed, constructed using locally available engineering materials mild steel sheet of 3 mm, mild steel (angle iron) of 5 mm, scrap aluminum, asbestos, clay sand, stainless steel sheet of 2 mm, stainless steel pipe of 2 mm and wood charcoal. An electrical kitchen scale with model No ek5055 and thermocouple with model No Kane-may km 340 were used to measure the fuel consumption and heat generated respectively. The furnace produced the total heat $Q_T = 67,943.16$ kJ, and supplied the heat required to melt 10 kg of aluminum from room temperature to melting temperature $Q_T = 35,859.13$ kJ in a duration of 1hr 33min, the total heat absorbed by the furnace components was $Q_{FC} = 25,425.44$ kJ and the heat transferred to the crucible was $Q_C = 14,118.72$

kJ. The efficiency of the furnace was achieved at 76% dividing heat used by total heat supplied and multiplied by 100. The furnace is suitable for use both in the rural and urban areas for casting of different types of aluminum. The furnace is environmental friendly without health hazards to the workers and can be moved from one place to another unlike the local one. The results of the test of the furnace performance show that it consumes 3kg of charcoal in 1hr 33mins to melt 10kg of aluminum.

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND.

Foundry technology is practiced in both urban and rural areas of Nigeria; the local foundry man digs a hole on the ground to take the shape of an oven, using coal or charcoal as fuel and makes use of a clay or metal pot as the crucible. A blower is used to supply the air needed for the combustion process. Plate 1.1 shows the shape of the local furnace used in local foundries.



PLATE 1.1 A typical furnace.
Source: Muchia market 4/11/2011

The local foundry people use the crucible furnace for making of casting of different objects such as machines parts, domestic cooking pots of different sizes, serving spoons, fraying pans, etc.

The foundry people were having problems working with local type of crucible furnace such as excessive fuel consumption, excessive heat radiation to the operator, time consuming for operation and excessive heat lost in the system.

An attempt has been made to improve on the local method of melting being practiced by local foundry men in Nigeria, considering availability of materials, high demand of their products, reduction of cost of production and attraction of youth to foundry practice.

Kulla (2007) pointed out that due to inefficient burning and poor heat transfer; fuel wood that would have been sufficient for 10-33 years is consumed annually. Based on this and other reasons he conducted research on how to reduce the wood consumption in domestic cooking, this has indicated the need to improve the efficiency of the crucible furnace used in local foundries,

thus reducing the quantity of charcoal consumed. Another serious problem is the emission of combustion products which result in respiratory diseases (Kulla, 2004).

Komolafe, (1992) improved on the crude method of melting by foundry men by designing and constructing a gas fired crucible type furnace making use of locally sourced materials. It is noticed that gas as a source of energy can be very hazardous and is not as common as coal or charcoal in use. The gas furnace is found in big industries only and ordinary foundry men do not know much about gas, and gas is not readily available and cheap in every part of the country compared to charcoal.

The Industrial Development Centre Zaria foundry uses a gear driven blower to supply air needed for combustion to the coal or charcoal oven but since the oven or furnace is not covered, much heat is lost, as in the case of those used by local foundry men. Therefore there is need for improvement in the combustion efficiency and conservation of the heat generated.

Charcoal is available in all parts of the country and is cheap. An improved furnace can be designed and fabricated to improve on the locally used furnaces.

The charcoal fired crucible furnace will use a manually operated pulley driven blower.

The crucible furnace is the oldest form of foundry technology which has been used and has varied with time. The designs reflect the purposes for which they are used and there are regional variations. The earliest crucible form derives from the sixth/fifth millennium B.C. (Roberts et al; 2009). A typical local crucible furnace is shown in Plate 1.2



**PLATE 1.2 a typical old type crucible furnace used in the foundries.
Source: Muchia Market 4/11/2011**

1.2 STATEMENT OF THE PROBLEM

The major problems associated with the old type open crucible furnaces used in the local foundries are:-

- i. The foundry man is exposed to heat and combustion products which are harmful to his health.
- ii. More than half of the heat escapes due to the open nature of the local furnace.
- iii. These open crucible furnaces contribute to ecological problems, global warming and environmental degradation due to high demand of wood for charcoal production.
- iv. The process consumes large quantities of fuel (charcoal) due to its low combustion efficiency and high heat loss.

1.3 AIM AND OBJECTIVES OF THE WORK

The aim of the work is to improve on the technology of local foundry men in the melting of aluminum. The research is expected to come up with a portable, safe and economical crucible furnace, which is going to be used in small scale casting industries with maximum efficiency (i.e. efficient use of heat energy with minimum loss of heat energy).

Specific objectives of this research are as follows:

- i. To design a portable charcoal fired crucible type furnace that can melt 10Kg of aluminum.
- ii. To construct the furnace using local materials.
- iii. To test the furnace constructed.
- iv. To carry out performance evaluation of the furnace.

1.4 SIGNIFICANCE OF THE STUDY

The design and construction of a charcoal fired crucible furnace is significant in the following ways

- i. It will contribute significantly to the effort to convert scrap aluminum into useful products

- ii. It will also contribute significantly to the effort in the development of indigenous technology especially in the production industries,
- iii. It will contribute significantly in the training of students in casting practice.
- iv. It will improve working conditions of foundry men and encourage youths to venture into the foundry work.

1.5 JUSTIFICATION OF THE RESEARCH

This field of research is very important to small scale industries, considering the number of people in the industry. Each shop has the capacity of 10 to 15 people in the industry. It is important to work on this topic to improve the working environment and provide safety to the operator (foundry man) by designing and constructing a safer crucible furnace.

1.6 SCOPE OF THE WORK

The scope of the research work will be limited to:

- i. Designing of the essential components that make up the charcoal fuel crucible furnace for melting 10 kg of aluminum and these include;
 - a. Crucible
 - b. Furnace
 - c. Safety cover
 - d. Frame
 - e. Blower and rotating mechanisms
- ii. Construction of these components.
- iii. Assembly of the various components including accessories.
- iv. Testing of the device on a load of 10 kg of aluminum and observing working conditions and the duration of the work.

CHAPTER TWO

LITERATURE REVIEW

2.0 INTRODUCTION

It is clear that despite the advances in the mode of melting metal scrap (aluminum), the charcoal fired crucible furnace is commonly used in Nigeria due to the fact that it can easily be operated, is available all over the country and its construction materials are readily available. The charcoal fuel used is readily available in all parts of the country.

In any foundry, large or small, heat is required to melt different metals and alloys for casting. This has resulted in the utilization of many types of melting furnaces for ferrous and non-ferrous metals and alloys

A furnace is a device in which the chemical energy of a fuel or electrical energy is converted into heat which is then used to raise the temperatures of materials. Furnaces operating at low temperatures are often called ovens depending on their purposes and there are other furnace used at higher temperatures for various materials and purposes. (Folayan, 2001).

Furnaces are refractory lined vessels that contain the material to be melted and provide the energy to melt it. Modern furnace types include electric arc furnaces (EAF), induction furnaces, cupolas, reverbetory, and crucible furnaces. The furnace choice is dependent on the materials and quantities processed. For ferrous materials, EAFs, cupolas and induction furnaces are commonly used. Reverberatory and crucible furnaces are common for aluminum castings. (Beeley,2001).

A crucible furnace is among the oldest and simplest furnaces used in the foundry; it is primarily used to melt smaller amounts of nonferrous metals but can also be used for ferrous metals. It is mostly used in small foundries or for specialty alloy lines. The crucible or refractory container is heated in a furnace, typically fired with natural gas or liquid propane, although coke, charcoal, oil, or electricity can be used. (www.industrialmetalcasting.com)

A crucible furnace is a type of furnace which uses the crucible as a metal container for melting purposes. The crucible is made from the material of higher refractory properties with higher melting temperature than the materials being melted and it is normally made from clay.

Metals are cast into shapes by melting them, pouring the molten metal into a mold, and removing the molded material or casting after the metal has solidified and cooled. The most common metals processed are aluminum and cast iron. However, other metals, such as bronze, steel, magnesium, copper, tin, and zinc, are also used to produce castings in foundries. (Beeley 2001).

Folayan (2001), improved on the gas fired crucible type method of melting by designing a coal fired crucible furnace. He observed that charcoal remains the most available fuel as coal is not available in many parts of the country, whereas charcoal is always available everywhere and is cheaper than both gas and coal.

Charles, (2000) constructed an electric line crucible-type aluminum melting furnace featuring quiet "Buzzer" venturi burners. This furnace offers the cleanliness of gas heat, operates economically, does not require the maintenance of compressed air and will continue to operate during power failures. The furnace consists of sectioned cast iron furnace rings and a steel lined jacket.

Okada, Sasaki and Yoshikawa, (2004) conducted research on the development of an innovative continuous melting and holding crucible furnace. A high performance continuous aluminum smelting and holding crucible furnace was developed. It has a compact single-body combining the features of both a melting and holding crucible furnace. Continuous melting at minimum temperature in a crucible contributes to less generation of aluminum oxide and less metal loss. The ideal temperature for casting is achieved and higher metal quality with a lower number of hard spots is obtained. The utilization of exhaust heat improves energy saving. The furnace also provides a better work environment and other benefits for the realization of efficient in-house continuous melting and holding of aluminum ingots, and higher returns.

2.1 Crucible

A crucible is a refractory container used in a furnace for metal, glass and pigment production as well as a number of modern laboratory processes, which can withstand temperatures high enough to melt or otherwise alter its content. Historically crucibles were made of clay, but they can be made of any material with higher temperature resistance than the substance they are designed to hold, (www.britanica.com/Crucible furnace)

When metal is melted in a crucible furnace, because it is protected from the heat source by the crucible when molten, its metallurgical conditions are good and melt losses are kept to a minimum. Since the crucible is heated from the bottom, local overheating of the metal is avoided thus minimizing oxidation and/or volatilization of charge constituents.

2.2 Furnace

A furnace is a device in which the chemical energy of fuel or electrical energy is converted into heat which is then used to raise the temperature of the material, called the burden or stock, which is placed within it for that purpose. (Folayan, 2001).

The furnaces are stationary furnace and the crucibles are withdrawn from them for pouring with the aid of crucible tongs. Large crucibles are generally built into a tilting furnace chamber and the complete unit is tilted for pouring the charge. (Folayan, 2001).

2.2.1 Types of Furnaces

There are many types of furnaces in use, each having peculiar features which make it suitable for melting a particular type of metal. The most commonly used furnaces may be classified according to the source of heat, type of work and working environment. Furnaces can be broadly divided into two classes:

- i. Fuel fired furnaces, and
- ii. Electrically heated furnaces

Fuel-fired furnaces can be further classified depending on the type of fuel, i.e. solid fuel, liquid fuel and gaseous fuel.

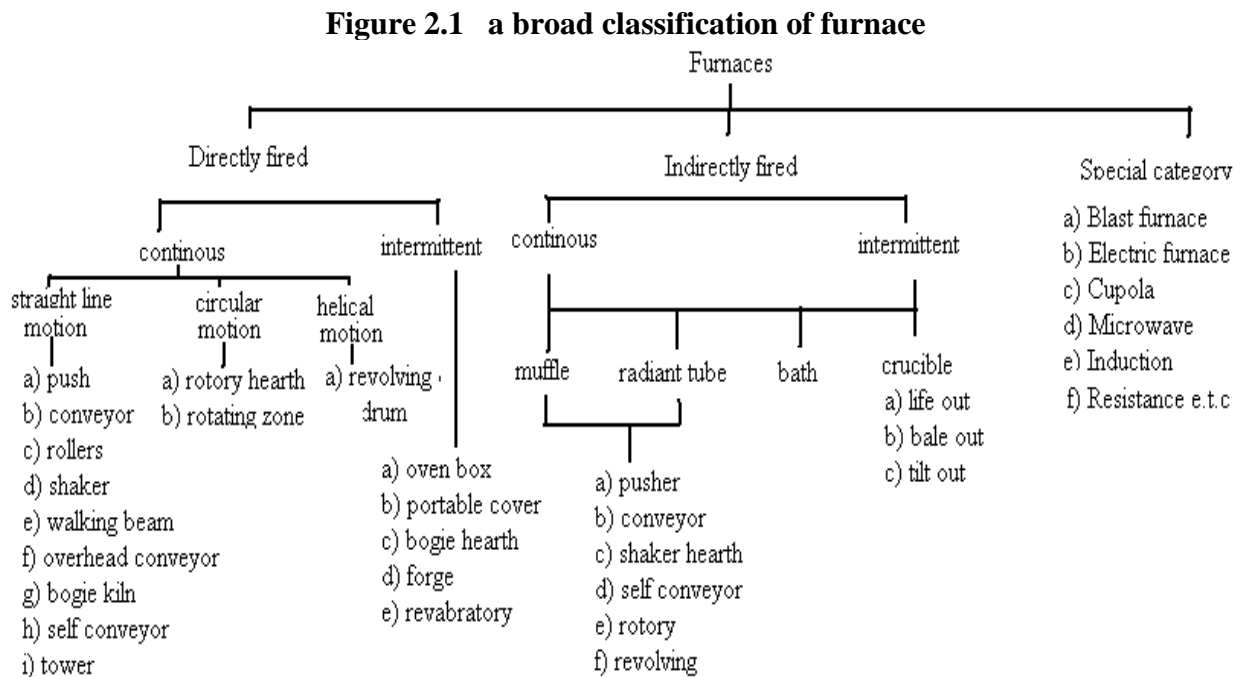
In electrical furnaces there is a conversion of electrical energy into heat energy. High temperatures can be achieved in electrical furnaces in several ways. Depending on the method of heating, electrical furnaces can be grouped into resistance, arc, induction, plasma and electron beam furnaces, (Sharma and Ashk, 1988).

2.2.2 Classification of Furnaces

Furnaces are classified from different points of view but each type of industrial furnace comprises three portions which are:

- The fire place where combustion of fuel takes place
- The working chamber or furnace proper where heat is transferred from the products of combustion to the materials being heated.
- The appliances for removal of the flue gases

The broad classification of furnaces is presented in Figure 2.1



Higgins R.A. (1984)

2.2.3 Crucible furnaces

Crucible furnaces vary considerably in design capacity and range; from laboratory furnaces which are used for melting a few kilogram of metal to industrial furnaces both small and large scale holding as much as thousands of kg. These include lift-out, tilting, bale-out, rotary and immersed crucible furnaces. (Folayan, 2001).

As their names imply, they are pre-fired crucibles to contain the molten metal.

- i. Lift-out: -in this type of crucible furnace the crucible is removed from the furnace for pouring.
- ii. Tilting type: - the furnace body containing the crucible is tilted to pour the molten metal.
- iii. Bale-out: - in this type of furnace the molten metal is ladled out.

There are other two types of furnaces utilizing crucibles, these are:

- iv. Rotary crucible furnace and
- v. Immersed crucible furnace

Although these types were very successful in filling a gap in the market at one time, they have been superseded by other types of furnaces.

2.3 Fuels

In engineering, those materials which on combustion are capable of generating heat energy which can be utilized for industrial purposes are called fuels. The greater the heat generated by the fuel, the better it is.

In order to evaluate a fuel, we must know the amount of heat which it generates on combustion. For this it is necessary to know the units in which heat is measured. A special unit has been accepted for measuring the amount of heat generated by any fuel during combustion. It is called the caloric (cal) which is that quantity of heat necessary to raise the temperature of 1g of water by one degree centigrade.

All fuels consist essentially of the same elements; the difference between the various types of fuels lies in the fact that they contain these elements in different proportions. The elements which go to make up fuels can be divided into two groups. The first group includes elements which either burn themselves or support combustion, hydrogen and oxygen are included. The second group which consists of elements which neither burn nor support in combustion, include nitrogen and water.

2.3.1 Types of fuels used

1. Solid fuels
2. Liquid fuels
3. Gaseous fuels
4. Mixed/multi fuels

2.4 Review of past work on charcoal

A number of researches have been carried out investigating the feasibility of the use of wood charcoal as a fuel for various applications both in industries and domestic purposes.

Kulla (2003) developed an improved wood charcoal stove. The results of which showed a faster controlled cooking time of 14 minutes for the improved charcoal stove compared to 20 minutes, 22 minutes, 26 minutes and 31 minutes for the open wood stove, kerosene stove, local charcoal stove and electric stove respectively.

Adeleke (2003) used four different methods of charcoal production, i.e. open air, earth kiln, casamance kiln and pit kiln to determine the calorific value of six species of wood in order to come up with the method that will produce the charcoal with the highest calorific value. The result of the investigation showed that the casamance kiln method of charcoal production yields the highest average calorific value of 35,201.72 kJ/kg followed by 34,378.92 kJ/kg, 33,440.72 kJ/kg and 29,833.03 kJ/kg for earth kiln, pit kiln and open air respectively.

Ndirika (2002) investigated the performance of different sizes of cooking stoves which utilize charcoal as sources of energy. A comparative evaluation of cooking efficiencies, fuel efficiencies, fuel consumption rate and cooking time between the three types of stoves and the traditional three stone open fire system, revealed that the cooking efficiencies and fuel efficiencies obtained were greater than the value obtained with the traditional three stone open fire system.

Ndirika (2004) designed and fabricated a baking oven which used charcoal as the source of energy for baking of cereal flour, the result of which proved to be very satisfactory.

Fuwape et al (1996) assessed the above ground biomass yield of seven year-old trees of gliricidia sepium, gmelina eaborea and leucaena leuccephala grown for fuel production in Nigeria. The average heat of combustion of charcoal (33.25Mj/kg) was higher than that of wood (21.6Mj/kg).

2.4.1 Charcoal fuel

Charcoal is the blackish residue consisting of impure carbon obtained by removing water and other volatile constituents from animal and vegetation substances. Charcoal is usually produced by heating wood, sugar, bone, or other substances in the absence of oxygen. The soft, brittle, light weight, black, porous material which resembles coal is 85% to 98% carbon with the remainder consisting of volatile chemicals and ash (en.wikipedia.org)

2.4.2 Types of charcoal

Commercial charcoal is found in lumps, briquettes or extended forms.

- i. Lump charcoal is made directly from hard wood material and usually produces less ash than briquettes.
- ii. Briquettes of charcoal are made by compressing charcoals typically made from saw dust and other wood by products with a binder and other additives
- iii. Extruded charcoal is made by extruding either raw ground wood or carbonized wood into logs without the use of binder. (Higgins 1984)

2.4.3 Uses of charcoal

Charcoal is a very good source of energy. It is used as:

- i. Cooking fuel:- in most non-industrialized countries, especially in Africa charcoal is used for daily cooking by a large portion of the population.
- ii. Industrial fuel: - historically charcoal was used in great quantities for smelting iron in bloomaries and later blast furnaces.
- iii. Automotive fuel: - in time of scarce petroleum, automobiles and even buses have been converted to burn wood gas released by burning charcoal or wood in a wood gas generator.

- iv. Purification/filtration: - the porosity of activated charcoal accounts for its ability to readily absorb gases and liquids. It is often used to filter water or absorb odors. Wood charcoal, also to some extent, removes coloring material from solutions.

(Agontu 2009)

The Food and Agriculture Organization (FAO) of the United Nations in its 1983 fuel wood survey reported that charcoal is the most important commercial fuel derived from wood. The report further outlined some advantages of wood charcoal over other wood fuels to include.

- It is smoke free, capable of being controlled in small and cheap stoves.
- It is capable of producing greater heat than wood
- It is suitable for a wide variety of industrial and domestic uses especially in urban environments.
- It can also be used as a reducing agent in metallurgy and as an absorbent in filters.
- Charcoal is easily stored, it takes up less space than wood for given quantity of heat and does not deteriorate.
- It is easier to handle in transport and distribution and is easily ignited, and it is safer for use than the wood.

2.5 Aluminum and its alloys

Aluminum is a very important metal because of its low density and excellent mechanical properties. Properties which stem largely from its face centered cubic crystal structure. It can be alloyed with elements like magnesium, silicon, copper, manganese, iron, e.t.c. to produce a variety of wrought products. The alloys of aluminum, copper, lead, magnesium, nickel and titanium can be turned to aircraft structural parts, it can also be cast into products like engine blocks and steering knuckles for automobiles, Aluminum and its alloys are used in a variety of cast and wrought forms. Forgings, sections, extrusions, sheet, plate, strips, foil and wire are some examples of wrought forms, while castings are available as sand, pressure and graving die castings.

It is when alloyed with small amounts of other metals that aluminum finds its widest uses. The addition of small quantities of other elements converts this soft, weak metal into a hard, strong metal with a wide range of applications, (Rajan and Sharma, 1988).

2.5.1 Aluminum

Aluminum is a white metal produced by electrical processes from the oxide (alumina), which is prepared from clayey mineral called bauxite. Bauxite is found in large quantities in various parts of the world and the successful extraction of the metal depends on the supply of large amounts of cheap electricity. The relative density of aluminum is 2.68 as compared with 7.8 of steel. In its pure stage the metal is too weak and soft for most purposes, but when mixed with small amounts of other alloys it becomes hard and rigid. Aluminum is very ductile and malleable, and it melts easily and may be formed into parts by casting (Chapman, 1972).

The melting temperature of aluminum foil is 660 °C or (1,220 °F) at standard pressure, so it won't melt with temperatures encountered in a standard household oven. The physical form of the aluminum, whether powder, blocks, foil or some other shape, does not affect the melting point as long as the metal is relatively pure; the melting point is an intrinsic property of the metal, but shape is not. ([www.engineersedge.com/properties of metal](http://www.engineersedge.com/properties_of_metal))

2.5.2 Cast Aluminum

Cast aluminum is often used to make automobile parts, like engine pistons, because it is heat resistant and lightweight. Many examples of cookware are made from cast aluminum because it is cheaper and lighter than iron. Die casting, mold casting, or sand castings are used to create cast aluminum items from liquid aluminum.

Cast aluminum is a specific metal that has gone through one of the several processes known as casting. Essentially, it is created when methods such as die casting, mold casting, or sand casting are used to temper the aluminum for use in creating components for many different types of products. This form of aluminum is used for a number of items around the house, as well as machinery and other products that are necessary to the manufacturing of a wide range of goods and services. (www.engineersedge.com/properties)

2.5.3 Aluminum casting alloys

The most important aluminum casting alloys, on a tonnage basis are those which depend on the eutectic reaction to improve castability to lower energy input and pouring temperature and to produce desired cast micro structures. These aluminum alloys contain primarily silicon,

magnesium and copper. Table 2.2 shows the properties and uses of some aluminum alloys.

Table 2.1: Uses and properties of aluminum alloys.

BSS 1470- 1477	APPROXIMATE COMPOSITION	CONDITION	TENSILE STRENGTH KN/MM ²	TYPES OF PRODUCT	USES
1 A1	99.99% A1 99.8% A1	0 0	0.045 0.060	Sheet & strip Sheet & strip	Linings for vessels in food and chemical plant
IC	99.0% A1	0 $\frac{1}{2}$ H H	0.900 0.120 0.150	Sheet, strip & wire Extrude sections	Lightly stressed and decorative paneling, wire and bus bars, foil for packing, kitchen and other hollow ware
N3	AL+1 $\frac{1}{4}$ % Mn	0 $\frac{1}{2}$ H H	0.110 0.160 0.210	Sheet, strip and extrude sections	Hollow ware roofing paneling, scaffolding tubes
N4	AL+2% Mg AL+3 $\frac{1}{2}$ % Mg AL+5% Mg	0 $\frac{1}{2}$ H 0 $\frac{1}{2}$ H 0 $\frac{1}{2}$ H	0.210 0.250 0.230 0.280 0.280 0.320	Sheet, plate, tubes and extrusions	Stronger deep drawn articles, ship and small boat construction, and other marine application
Lm6	AL+13% Si	m	0.200	Sand and die casting	Excellent casting alloy
H10	AL+0.75% Mg 1% Si	W Wp	0.270 0.325	Sheet forging extrusion	Structural components for road and rail transport vehicles
H14	Al+ 4 $\frac{1}{2}$ % Cu, 0.75% Mg Al+4 $\frac{1}{2}$ % Cu, 0.75% Mg, 0.75% Si, 0.75% Mn Al+1.75% Cu, 2% Mg, 7% Zn	T Wp Wp	0.440 0.500 0.620	Sheet forging extrusion Tube Sheet and extrusion	Highly stressed parts in aircraft construction and general engineering Aircraft construction

Sources: John, (1977)

2.6 Mode of Heat Transfer

Heat Transfer: - heat transfer may be defined as the transmission of energy from one region to another as a result of a temperature gradient and it takes place by conduction, convection and radiation. Heat transfer is usually expressed in terms of the temperature differences or temperature gradients between the two points in consideration.

The science of heat transfer is of great importance and has a very wide range of applications in the technological field; these include:-

- Design of heat exchanger systems
- Design of evaporators
- Design of steam generators
- Design of condensers
- Design of boilers
- Design of automobile engines, and so on.

When heat is added to a substance, the speed of the molecules determines whether the substance is a solid, liquid or gas. Temperature is an indication of speed of the molecules and when mechanical work is done, heat is produced. When heat is generated from any source it is transferred to where it is used. The heat generated in the furnace either by electricity, gas or other fuel can be transferred from one place to the other in the furnace by the following processes.

- i. Conduction
- ii. Convection
- iii. Radiation

2.6.1 Conduction

Conduction is the transfer of heat from one part of a substance to another part of the same substance, or from one substance to another in physical contact with it, without appreciable displacement of molecules forming the substance, when temperature difference is present in any matter, heat flows from the hot to cold regions until the temperature is equalized. This occurs even when movement of molecules in matter is prevented as in solids.

The high temperature value of conduction in metals is due to the well ordered crystalline structure while the less ordered crystalline nature of non-metals coupled with its porous nature reduces its conductivity. The pores contain air which is a poor conductor thus reducing

conductivity. The conductivity may also vary directly where material is laminated. Material with uniform conductivity in all directions is called isotropic and usually a mean value for conductivity is adopted in most practical applications.

Heat transmission by conduction Fourier's law of conduction

When it comes to analysis of heat transmission by the conduction mechanism, Fourier's law which is an empirical law based on observations states that the rate of flow of heat through a single homogenous solid material is directly proportional to the area of the section at right angles to the direction of heat flow, and to the change of temperature with respect to the length of the path of the heat flow. It may be represented by the equation Sinha and Goel, 1973.

$$Q \propto A \cdot \frac{dt}{dx}, \quad 2.1$$

or

$$Q = -K \cdot A \frac{dt}{dx}, \quad 2.2$$

where:

Q = heat flow through a body per unit time

A = surface area of heat flow

dt = temperature difference of the faces of the block through which heat flows

dx = thickness of the body in the direction of flow

K = thermal conductivity of the material

Consider a flow of heat through a composite material as shown in Figure 2.2

- i. Heat flow (Q) is proportional to the temperature difference ($T_1 - T_2$) across the specimen i.e $Q \propto (T_1 - T_2)$
- ii. Heat flow (Q) is proportional to increase in area of material i.e $Q \propto A$
- iii. Heat flow (Q) increases as the block thickness decreases i.e $Q \propto \frac{1}{l}$

Hence,

$$Q = \frac{-KA(T_2 - T_1)}{L}, \text{ For composite materials as shown in Figure 2.2}$$

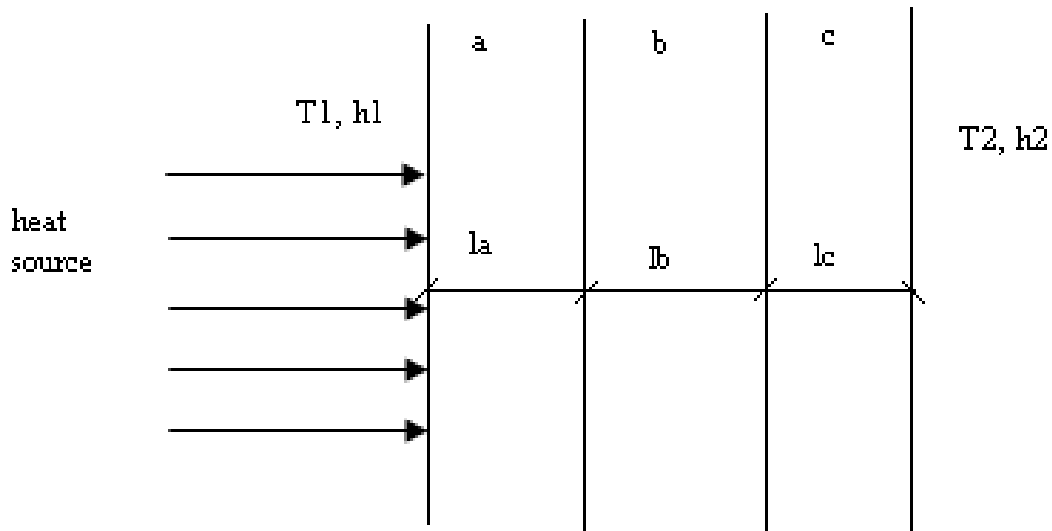


Figure 2.2 Conduction of heat through slabs of different materials

Hence the total heat flow is given by

$$Q = \frac{dT}{\sum R} = \frac{T_2 - T_1}{\sum R} \quad 2.3$$

where

$$\sum R = \frac{1}{h_1 A} + \frac{1}{h_0 A} + \frac{L_a}{K_a A} + \frac{L_b}{K_b A} + \frac{L_c}{K_1 A} \quad 2.4$$

Therefore,

$$Q = \frac{T_2 - T_1}{\frac{1}{h_1 A} + \frac{1}{h_0 A} + \frac{L_a}{K_a A} + \frac{L_b}{K_b A} + \frac{L_c}{K_1 A}}, \quad 2.5$$

where

$\sum R$ = total thermal resistance of the composite material

H = conductive heat transfer co-efficient

2.6.2 Convection

Convection is the transfer of heat within a fluid by mixing of one portion of the fluid with another. Free natural convection occurs when the fluid circulates by virtue of the natural differences in densities of hot and cold fluids. The denser portions of the fluid move downward

because of the greater force of gravity, as compared with the force on the less dense material. Through solid bodies heat transfer takes place by conduction alone, whereas the heat transfer from solid surfaces, liquids and gases takes place partly by conduction and partly by convection.

The transmission of heat per unit time from a surface by convection is given by:

$$Q = hA(t_1 - t_2), \quad 2.6$$

where Q = quantity of convective heat transferred

h = co-efficient of convective heat transfer

A = area of surface

$(t_1 - t_2)$ = temperature difference between the fluid and the surface.

2.6.3 Radiation

Radiation is the transfer of heat through space or matter by means other than conduction or convection. Radiation of heat is as electromagnetic waves or quanta (as convenient) an emanation of the same nature as light and radio waves. So a transfer of heat by radiation occurs because the hot body emits more heat than it receives and a cold body receives more heat than it emits.

When radiation passes or impinges on matter, it may be totally or partially reflected, transmitted through it or absorbed.

The Steffan - Boltzman law:- the law states that the emissive power of a block of body is directly proportional to fourth power of its absolute temperature.

i.e $Q \propto T^4$, 2.7

$$Q = \delta AT^4, \quad 2.8$$

where Q = rate of heat emission

A = radiation area of black body

δ = Stefan Boltzmann constant

T = absolute temperature

Hence when two bodies are placed side by side at different temperatures, the heat transfer from body one to the other or vice versa is given by

$$Q = \delta A_1 T_1^4 - \sigma A_2 T_2^4, \quad 2.9$$

$$Q = \delta A (T_1^4 - T_2^4), \quad 2.10$$

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials and Material Selection.

A large number of materials are available for engineering applications. The choice of a material for a given application can determine, to a large extent, the ultimate success or failure of the system as it is the final practical decision in the design process. Hence in selecting the materials suitable for use in this work, the physical properties of the materials were used as the basic parameters guiding the selection. The factors, properties used include cost effectiveness, availability, high or low tensile, strength as may be required, rigidity and/or flexibility, heat and corrosion resistance, etc.

The following materials were obtained for the construction of the crucible furnace:

mild steel sheet of 3mm thickness, mild steel sheet 1.5 mm thickness, iron, charcoal, scrap aluminum, rubber belt, ball bearings, spindle shafts (12 mm) diameter, mild steel angle iron of 5 mm thickness, asbestos, clay sand, stainless steel plate of 2 mm thickness, stainless steel pipe 45 mm diameter, screws, bolts and nuts, aluminum bicycle wheel of (550 mm) diameter. The materials were purchased at Zaria.

3.1.1 Material for the furnace unit

The material used for the furnace is a 3mm thick mild steel sheet selected based on the design calculations and specifications. It was selected to meet the following requirements:

- Ability to withstand internal pressure. Steel possesses high tensile strength ranging from 276Mpa – 2070Mpa (Singh, 2003) which is more than sufficient to withstand the internal pressure developed during operations.
- Ability to withstand the relatively high operational temperature both in the furnace unit and combustion chamber.
- Ease of machining and fabrication.

3.1.2 Materials for blower

The material used for the blower fan and its casing is aluminum. It was chosen based on its properties, its ability to be cast into different shapes, and the low cost of aluminum scrap.

3.1.3 Material for air pipe to combustion chamber

Stainless steel pipe was chosen for the air pipe to the combustion chamber, of 45 mm diameter, and 2 mm thickness. This material was selected based on its high resistance to corrosion and high resistance to heat.

3.1.4 The material used for furnace insulation.

A desirable property of a good insulator is resistance to heat flow per unit thickness. Asbestos and clay sand were selected as the furnace wall insulators because of their low thermal conductivities and heat resistance.

3.1.4.1 Asbestos

Asbestos is a mineral fiber that was commonly used in a variety of building construction materials for insulation and as a fire retardant. Asbestos is the name given to a group of naturally occurring minerals used in certain products, such as building materials and vehicle brakes, to resist heat and corrosion. Asbestos includes chrysotile, amosite, crocidolite, tremolite asbestos, anthophyllite asbestos, actinolite asbestos, and any of these materials that have been chemically treated and/or altered. (www.SafetyConsultants.Lni.wa.gov).

3.1.4.1(a) Types of asbestos

Asbestos minerals are divided into two major groups: serpentine asbestos and amphibole asbestos.

- I. Serpentine asbestos includes the mineral chrysotile, which has long, curly fibers that can be woven. Chrysotile asbestos is the form that has been used most widely in commercial applications.
- II. Amphibole asbestos includes the minerals actinolite, tremolite, anthophyllite, crocidolite, and amosite. Amphibole asbestos has straight, needle-like fibers that are

more brittle than those of serpentine asbestos and are more limited in their ability to be fabricated. (www.msha.gov)

3.1.4.1(b) Use of asbestos

Asbestos has been mined and used commercially in North America since the late 1800s. Its use increased greatly during World War II. Since then, asbestos has been used in many industries. For example, the building and construction industries have used it for strengthening cement and plastics as well as for insulation, roofing, fireproofing, and sound absorption. The shipbuilding industry has used asbestos to insulate boilers, steam pipes, and hot water pipes. The automotive industry uses asbestos in vehicle brake shoes and clutch pads. Asbestos has also been used in ceiling and floor tiles, paint coatings, adhesives, and plastics. In addition, asbestos has been found in vermiculite-containing garden products and some talc-containing crayons.

(www.osha.gov/html/map.html).

3.1.4.1 (c) Workers can protect themselves from asbestos exposure, (Hazard)

Workers should use all protective equipment provided by their employers and follow recommended workplace practices and safety procedures. For example, approved respirators that fit properly should be worn by workers when required.

Workers who are concerned about asbestos exposure in the workplace should discuss the situation with their employee, health / safety representative, and their employers if necessary,

(www.osha.gov/workers).

3.1.4.2 Clay sand

Clay is a fine-grained soil that combines one or more clay minerals with traces of metal oxides and organic matter. Geologic clay deposits are mostly composed of phyllosilicate minerals containing variable amounts of water trapped in the mineral structure. Clay is the smallest particle group, with an average particle diameter of less than 0.002 mm. Clay feels slippery when, wet and dry clay is very hard. When moistened and squeezed, it will stay together forming a tight ball. Its color is determined by the minerals it contains and a little humus. It has fine texture and small pore sizes. (Guggenheim, Stephen and Martin, 1995).

Clays are distinguished from other fine-grained soils by differences in size and mineralogy. Silts, which are fine-grained soils that do not include clay minerals, have larger particle sizes than clays, but there is some overlap in both particle size and other physical properties, and there are many naturally occurring deposits which include silts and clays (Ehlers and Harvey 1982).

3.1.4.2(a) Uses of clay soil

Clays exhibit plasticity when mixed with water in certain proportions. When dry, clay becomes firm and when fired in a kiln, permanent physical and chemical changes occur. These reactions, among other changes, cause the clay to be converted into a ceramic material. Because of these properties, clay is used for making pottery items, both utilitarian and decorative, and construction products, such as bricks, wall and floor tiles. Different types of clays, together with different minerals and firing conditions, are used to produce earthenware, stoneware, and porcelain. Prehistoric humans discovered the useful properties of clay. A traditional use of clay as medicine goes back to prehistoric times. An example is Armenian bole, which is used to soothe an upset stomach, similar to the way parrots (and later, humans) in South America originally used it. Kaolin clay and attapulgite have been used as anti-diarrheal medicines. (Hillier 2003)

3.1.5 Charcoal fuel

The charcoal fuel used in the work was obtained from within the research environment that is Zaria city, Sabon Gari market and Samaru market. About 30kg of charcoal was obtained and sorted out properly to remove all unwanted matter in the fuel.

3.1.5.1 Calorific value of the charcoal

Work has been done to determine the calorific values for various charcoal fuels produced from a variety of species of trees. Adeleke (2003) carried out extensive research and determined the calorific values of some species of trees found in and around the Ahmadu Bello University, Zaria whose average values of 33.210.86kj/kg agreed closely with the 33.250kj/kg obtained by Fawape and Akindele (1996). The heating value of 33.250kj/kg is used in this work.

3.2 Methodology

The following methods were adopted for this research work:

3.2.1 Engineering design

Furnace design is a complex process, and the design can be optimized based on multiple factors. Furnaces in foundries can be any size, ranging from one to hundreds of tonnes capacities (Beeley, 2001).

Design and construction of the crucible furnace was conceived and carried out using locally sourced materials, using the design criteria in section (3.3.0). One major advantage is the availability of the materials and expertise of technicians for mass production to meet rural and urban demands.

The furnace is 0.85 m high, and includes the blower and its mechanisms. Thus the furnace is portable and occupies little space which enables it to be moved from one place to another for easy operations.

The designed crucible furnace assembly has thirteen main components as listed below and shown in figure. 3.1

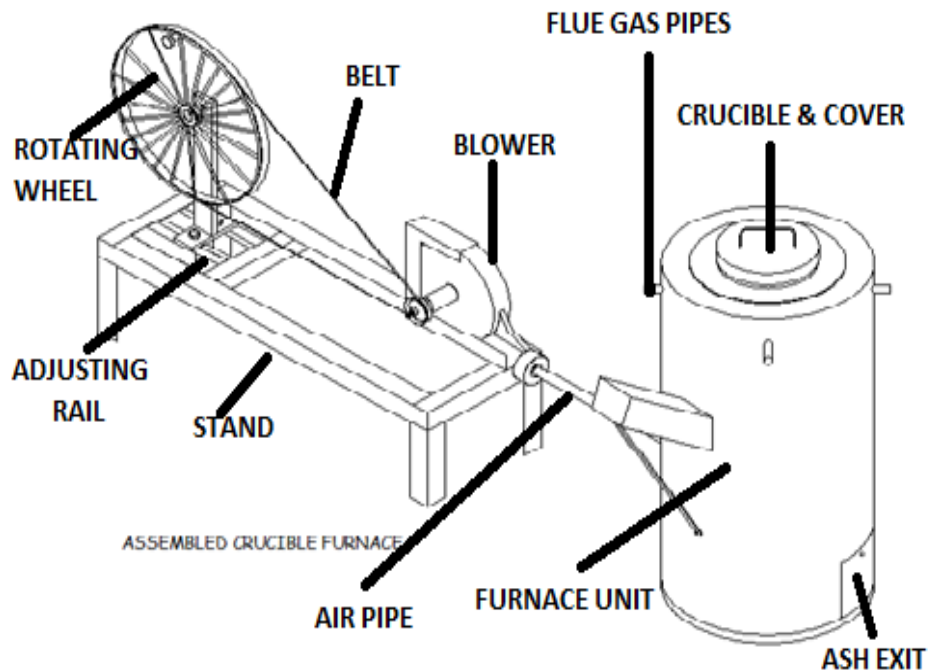


Figure 3.1 ASSEMBLED CRUCIBLE FURNACE

3.2.2 Design consideration:

The following factors were considered in carrying out the design; production cost, type of fuel used (charcoal) and its availability, materials selection and their availability, flexibility in fabrication, ease of maintenance, durability, cost of the selected materials, availability of the tools and equipment for fabrication, height and width of the furnace, blower and its capacity, and shape of the furnace.

3.2.3 General layout of the crucible furnace.

Figure 3.1 shows the general layout and profile of the crucible furnace. It consists of a rotating wheel mechanism, blower unit, stand, and crucible furnace unit, the furnace comprises a combustion chamber to which charcoal is fed and a crucible. Charcoal is fed to the combustion chamber through a feed port and air is supplied by the blower.

3.3.0 Design Criteria and Theories

The crucible furnace is a unit that operates under pressure at a very high temperature. The design of the furnace therefore, follows the criteria used for heat.

3.3.1 Determination of the minimum thickness of the furnace walls

The required thickness of the furnace wall to the design heat pressure is determined using the expression given by Singh K.P (2004) as

$$t = \frac{pD_1}{2\sigma J - p} + C, \quad (3.1)$$

3.3.2 Determination of the maximum allowable working pressure for the furnace

Assuming the furnace is in new condition. The maximum allowable working pressure for the furnace is obtained using the expression. (Megyesy, 1977)

$$p = \frac{\sigma jt}{R + 0.6t}, \quad (3.2)$$

where R is furnace radius

3.3.3 The stresses set up in the furnace

Assuming uniform internal pressure, the stresses set up in the cylindrical furnace longitudinally are equal to half of the stresses set up circumferentially. The longitudinal pressure induces stresses on the metal seam circumferentially and the radial pressure induces stresses on the metal longitudinally.

3.3.4 Determination of the thermal stresses set-up in the furnace walls

Thermal stresses are the stresses which result from restricting the natural expansion or contraction of the materials of the furnace wall due to temperature changes for the thin-walled furnace vessel, the longitudinal and circumferential thermal stress distribution over the thickness of the wall. Assuming a steady state condition is obtained from the expression suggested by Harvey (1980) as;

$$\sigma_{t_a} = \sigma_{l_a} = \sigma_{C_a} = \frac{-\alpha E(T_a - T_b)}{2(1 - \nu)} = \frac{-\alpha E \Delta T}{2(1 - \nu)} \text{ for the inside wall} \quad (3.3a)$$

and

$$\sigma_{t_b} = \sigma_{l_b} = \sigma_{C_b} = \frac{\alpha E(T_a - T_b)}{2(1 - \nu)} = \frac{\alpha E \Delta T}{2(1 - \nu)} \text{ for the outside wall} \quad (3.3b)$$

3.3.5 Investigation of the effect of internal pressure on the furnace dimensions

Hearn, (1982) provides expressions that can be used to investigate the extent of dimensional changes due to the effects of internal pressure on the walls of the furnace

3.3.6 The change in length of the furnace

This can be determined from the expression.

Change in length = longitudinal strain x original length

$$\text{Change in length } \Delta l = \frac{pd}{4tE} (1 - 2\nu)l, \quad (3.4)$$

3.3.7 Change in diameter of the furnace

The change in diameter due to the effect of the internal pressure in the furnace is obtained using this expression:

$$\text{Change in diameter } \Delta d = \frac{pd^2}{4tE} (2 - \gamma), \quad (3.5)$$

3.3.8 Change in the Volume of the Crucible

The expression for determination of the change of volume of the crucible is

$$\Delta v = \frac{pd(5 - 4\gamma)V}{4tE}, \quad (3.6)$$

but

$$V = \frac{\pi}{4} d^2 L, \quad (3.7)$$

3.4.0 COMBUSTION CHAMBER

This is the space below the crucible port in the furnace meant for burning charcoal in order to produce the required heat for melting of aluminum. It confines the products of combustion and is designed to withstand the high temperatures and pressures developed during the process of combustion. The combustion chamber consists of the charcoal grate upon which the charcoal is burnt. The perforation allows for easy discharge of ash during and after combustion.

To reduce loss of heat through the furnace walls the inner and outer walls are separated using soil clay and asbestos, soil clay which possess the good insulation properties of relatively low thermal conductivity and specific heat and are readily available. A blower is incorporated to provide sufficient air into the combustion chamber for complete combustion of the charcoal.

3.4.1 The amount of fuel burnt per hour:

According to Singh (2003), the heat supplied by the fuel is given by the equation

$$Q_S = M_F \times LCV, \quad (3.8)$$

The lower calorific value (LCV) of the wood charcoal is obtained using (Singh, 2003)

$$LCV = HCV - \frac{9}{100} \times H \times 2442 \text{ kJ/kg}, \quad (3.9)$$

3.4.2 Determination of the distance between the fire grate and the crucible port

The distance between the fire grate and the crucible port can be estimated using the expression, (Ndrika, 2001).

$$h = 0.4 \times D, \quad (3.10)$$

3.4.3 The thermal load of the combustion chamber

This is the number of kilojoules (Kj) generated by the fuel in one hour per volume of the combustion chamber it is given by the equation 3.11, (Yawas, 2003)

$$Q_c = \frac{MQ_s}{V}, \quad (3.11)$$

3.4.4 Thermal load of the fire grate

This is the number of kilojoules (kJ) generated by the fuel burnt on one square meter of fire grate in one hour, thus (Yawas, 2002)

$$Q_g = \frac{MQ_s}{A} \text{ (kJ/m}^3 \text{ hr)}, \quad (3.12)$$

For cylindrical fire grate A is given by equation (3.13)

$$A = \frac{\pi D^2}{4} \text{ (m}^2\text{)}, \quad (3.13)$$

3.4.5 Determination of the design height of the combustion chamber

This is given by the ratio of the volume of the combustion chamber (m^3) to the area of the fire grate (m^2): $h = \frac{V}{A}$

This can equally be obtained from the equation (3.11) and (3.12) above, from which

$$V = \frac{MQ_s}{q_c} \text{ (M}^3\text{)} \text{ and } A = \frac{MQ_s}{q_g} \text{ (m}^2\text{)}$$
$$\frac{V}{A} = \frac{MQ_s}{q_c} \times \frac{q_g}{MQ_s}$$

$$h = \frac{V}{A} = \frac{q_g}{q_c} = \frac{m^3}{m^2} = m, \quad (3.14)$$

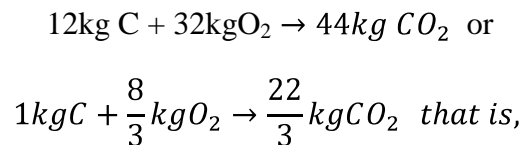
(Yawas, 2004)

3.5.0 CHEMICAL ANALYSIS OF THE FUEL

3.5.1 The amount of air required per kg of the fuel for complete combustion.

Adequate supply of air is essential for complete combustion and hence for obtaining the maximum amount of heat from a fuel. The amount of oxygen required for complete combustion of 1 kg of fuel may be calculated from the chemical analysis of the fuel. The composition of wood charcoal by mass produced from 91.8% of dry wood and a final pyrolysis temperature of 200 °C is 52.3% C, 6.3% H₂ and 41.4% O₂ (Prasad,2005). For the combustion process to be complete the weight of the external oxygen required per kg of charcoal is obtained by taking each constituent of the fuel separately and the amount of O₂ required for its complete combustion is derived by ultimate analysis, the composition of 1kg of charcoal becomes C = 0.523 kg, H = 0.063 kg and O₂ = 0.414 kg.

When carbon burns in a sufficient quantity of oxygen CO₂ is produced along with a release of large amounts of heat. The combustion reaction is



1kg of carbon requires $\frac{8}{3}$ kg of oxygen for its complete combustion.

Similarly, $1\text{kg H}_2 + 8\text{kgO}_2 \rightarrow 9\text{kg H}_2\text{O}$

That is, 1kg of hydrogen requires 8kg of oxygen for its complete combustion.

According to Khurmi and Gupta (1999)

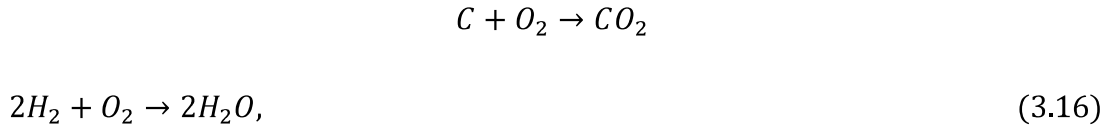
The theoretical amount of air required for complete combustion of 1kg of fuel is obtained using

$$m_{ea} = \frac{100}{23} \left[\left(\frac{2}{3}C + 8H_2 + S \right) - O_2 \right] \text{kg}, \quad (3.15)$$

C, H_2, S and O_2 are components of the fuel.

3.5.2 Determination of the mass of the products of combustion

The chemical equation of the reaction of carbon and hydrogen with oxygen are



3.5.3 Determination of the CO_2 content of the flue gas

Expressing the weight of the flue gas in terms of volume, Avogadro's law states that under the same condition of temperature and pressure (STP) 1 mol of any gas occupies a volume of $10.2m^3$. The volume per kg of any gas under these conditions can be found by dividing 10.2 by the molecular weight of the gas and correcting for the gas temperature by multiplying the volume by the ratio of the absolute flue-gas temperature and absolute atmospheric temperature hence.

The temperature correction factor, $T_f = \frac{\text{Absolute flue-gas temperature}}{\text{Absolute Atmospheric temperature}}, \quad (3.17)$

But, the weight of CO_2 produced is given by $\frac{22}{3} \times C$,

where: C = component of carbon in the fuel

3.6.0 Determination of the required fan capacity

The rate of fuel burning in the furnace depends on the availability of the fresh air that goes into the chamber. The fresh air enters the fuel bed if the gases of combustion are exhausted from the combustion chamber of the furnace. This is possible only if a difference of pressure is maintained above and below the fire grate. This is referred to as draught.

Draught is produced in the furnace chamber to:

- a. Produce adequate supply of air for the fuel combustion
- b. Exhaust the gases of combustion from the combustion chamber and
- c. Discharge the gases of combustion to the atmosphere

The device used to deliver air at the desired velocity with sufficient pressure to overcome resistance to the flow into the combustion chamber is the fan. Air is drawn into the impeller through the inlet which provides acceleration to the air. The impeller swings the air from a smaller to a larger radius and delivers it at a high pressure and velocity to the combustion chamber through a pipe 45 mm diameter.

3.6.1 Determination of the power required to drive the fan

According to Khurmi and Gupta (1999), the power required for driving the fan or the power of the motor driving the fan is given by

$$P = \frac{p_f Q}{60\eta_f} \text{ watts ,} \quad (3.18)$$

3.6.2 Determination of the peripheral discharge velocity

The peripheral discharge velocity of the air at the fan outlet expressed in terms of the impeller diameter and shaft speed is given by;

$$u_2 = \frac{\pi D_2 N}{60}, \quad (3.19)$$

3.6.3 Determination of the discharge velocity pressure

The fan total pressure p is derived using the expression suggested by Cherkassky (1977).

$$p_f = \eta_n \rho \mu_2 u_2^2, \quad (3.20)$$

3.6.4 Total dynamic head developed by the fan

Cherkassky (1977) suggested that the total dynamic head developed by the fan is obtained from:

$$h_d = \frac{p}{\rho_g} \text{ mm } H_2O, \quad (3.21)$$

3.7.0 FAN DESIGN

3.7.1 Determination of the fan major Diameter (d_2)

The fan major diameter can be derived from the equation 3.22 (Umar, 1988)

$$\phi = \frac{4Q}{\pi d_2^2 U_2}, \quad (3.22)$$

3.7.2 Determination of the fan minor Diameter (d_1)

According to Umar,(1988)

$$\frac{d_1}{d_2} = 0.4, \quad (3.23)$$

3.7.3 Determination of the fan blade width major (b_1)

This is given by equation 3.24 Umar, (1988)

$$b_1 = \frac{Q}{d_1 V}, \quad (3.24)$$

3.7.4 Determination of the fan blade width minor (b_2)

This can be determined using the relation below, Umar, (1988)

$$\frac{b_2}{d_2} = 0.16$$
$$\rightarrow b_2 = d_2 \times 0.16, \quad (3.25)$$

3.7.5 Determination of the fan blade inlet angle (β_1)

This is determined from the expression 3.26 (Umar, 1988)

$$\beta_1 = \tan^{-1} \left[\frac{V_{m1} \times d_2}{V_2 \times d_1} \right], \quad (3.26)$$

3.7.6 Determination of fan casing outlet velocity, (v_3)

This is given by; (Osborne, 1966)

$$V_3 = 0.25V_2, \quad (3.27a)$$

3.7.7 Determination of the casing outlet area (A_{out})

The casing out-let area can be obtained from the relation below; (Osborne, 1966)

$$A_{out} = \frac{Q_o}{V_3}, \quad (3.27b)$$

3.8.0 FAN CASING DESIGN CALCULATION

3.8.1 Fan casing in-let area (A_{in})

This is determined using the expression; (Church, 1984)

$$\frac{A_{out}}{A_{in}} = 0.68, \quad (3.27c)$$

3.8.2 Determination of the fan casing outlet diameter (d_o)

Out-let diameter can be obtained using relation; (Osborne, 1966)

$$d_{out} = \sqrt{A_{out} \times \frac{4}{\pi}}, \quad (3.28)$$

3.8.3 Determination of the fan casing in-let diameter (d_{in})

This can be determined using expression, (Church, 1984)

$$A_{in} = \frac{\pi d_{in}^2}{4}$$
$$d_{in} = \sqrt{\frac{A_{in} \times 4}{\pi}}, \quad (3.29)$$

3.8.4 Determination of the fan case width (b)

This is given by; (Church, 1984)

$$\frac{b}{b_2} = 3.19$$
$$b = b_2 \times 3.19, \quad (3.30)$$

3.9.0 BELT AND PULLEY SYSTEMS

3.9.1 Pulley

A pulley is a wheel on an axle that is designed to support movement and change of direction of a cable or belt along its circumference. Pulleys are used in a variety of ways to lift loads, apply forces, and to transmit power. In nautical contexts, the assembly of wheel, axle, and supporting shell is referred to as a block. Pulleys are also assembled as part of belt and chain drives in order to transmit power from one rotating shaft to another.

A pulley is also called a sheave or drum, and may have a groove between two flanges around its circumference. The drive element of a pulley system can be a rope, cable, belt, or chain that runs over the pulley inside the groove.

Pulley systems are used when there is a need to transmit rotary motion (Ryan, 2012). Figure 3.2 shows a simple system comprised two pulley wheels and a belt. It is a simple mechanical device.

When the motor is turned on it revolves the driver pulley wheel. The belt causes the driven pulley wheel to rotate as well, in this case the small pulley is known as the DRIVEN, because it is 'driven' round by the driver pulley wheel which provides all the power to drive the entire pulley system. The larger pulley is a DRIVER pulley and it rotates because of the power applied by the operator manually.

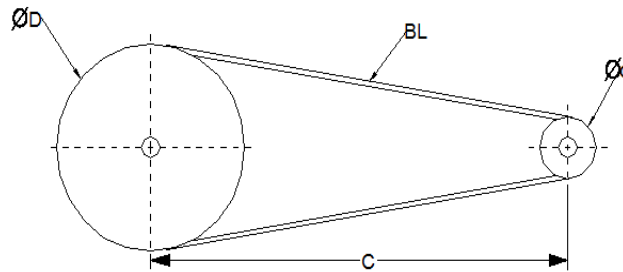


Figure 3.2 simple belt and pulley drive

3.9.2 Types of pulley systems:

- **Fixed:** A *fixed* pulley has an axle mounted in bearings attached to a supporting structure. A fixed pulley changes the direction of the force on a rope or belt that moves along its circumference. Mechanical advantage is gained by combining a fixed pulley with a movable pulley or another fixed pulley of a different diameter.
- **Movable:** A *movable* pulley has an axle in a movable block. A single movable pulley is supported by two parts of the same rope and has a mechanical advantage of two.
- **Compound:** A combination of fixed and movable pulleys forms a block and tackle. A *block and tackle* can have several pulleys mounted on the fixed and moving axles, further increasing the mechanical advantage.

3.9.3 Belt

A belt is a loop of flexible material used to mechanically link two or more rotating shafts, most often parallel. Belts may be used as a source of motion, to transmit power efficiently, or to track relative movement. Belts are looped over pulleys and may have a twist between the pulleys, and the shafts need not be parallel. In a two pulley system, the belt can either drive the pulleys normally in one direction (the same if on parallel shafts), or the belt may be crossed, so that the direction of the driven shaft is reversed (the opposite direction to the driver if on parallel shafts).

As a source of motion, a conveyor belt is one application where the belt is adapted to continuously carry a load between two points.

Belt drives are called flexible machine elements. Flexible machine elements are used for a large number of industrial applications.

3.9.4 Uses of belt drives

Belt drives are used as follows:

- i. In conveying systems, e.g. transportation of coal, mineral ores etc. over long distances.
- ii. For transmission of power used for running of various industrial appliances using prime movers like electric motors, driving compressors.
- iii. Replacement of rigid type power transmission systems for example, a gear drive may be replaced by a belt transmission system.

3.9.5 Types of Belts

All power transmission belts are either friction drives or positive drives; Drive belts rely on the friction between the belt and pulley to transmit power. They require tension to maintain the right amount of friction. Flat belts are the purest form of friction drive while V-belts have a friction multiplying effect because of the wedging action on the pulley.

Positive drive or synchronous belts rely on the engagement of teeth on the belt with grooves on the pulley. There is no slip with this belt except for ratcheting or tooth jumping. The various types of belts are; round belts, flat belts, V- belts, multi-groove belts, film belts, timing belts, and specialty belts. (www.pic-design.com)

3.9.6 Belt and pulley standard calculations

These are based on fig. 3.3

D = Pitch Diameter Large Pulley

d = Pitch Diameter Small Pulley

C = Center Distance

α = Angle between Belt and Centerline

$L =$ Belt Pitch Length

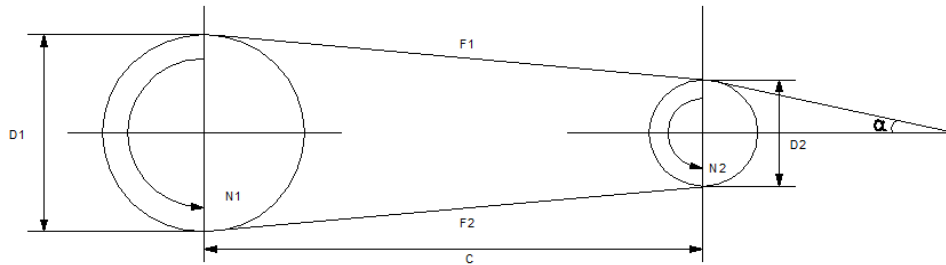


Figure3.3 simple belt and pulley

3.9.7 Determination of the length of an open belt (L)

This is determined using the expression below, (Khurmi and Gupta, 2012)

$$L_{approx} = 2c + 1.57(D + d) + \frac{(D - d)^2}{4c}, \quad (3.31)$$

3.9.8 Determination of the angle of contact or lap (θ)

This can be determined using expression; (Khurmi and Gupta, 2012)

$$\theta = (180^\circ - 2\alpha) \frac{\pi}{180} rad, \quad (3.32)$$

$$\text{where } \alpha = \frac{r_1 - r_2}{x}$$

3.9.9 Determination of the velocity ratio of a belt drive

This can be determined by the expression below (Khurmi and Gupta, 2012)

$$\frac{N_2}{N_1} = \frac{D_1}{d_2}, \quad (3.33)$$

3.9.10 Determination of the peripheral velocity of the belt on the driving pulley (V_1)

This can be determined by the expression (Khurmi and Gupta, 2012)

$$V_1 = \frac{\pi d_1 N_1 m}{60 s}, \quad (3.34)$$

And,

$$V_2 = \frac{\pi d_2 N_2 m}{60 s}, \quad (3.35)$$

3.9.11 Determination of the speed ratio (R)

The can be obtained by using either shaft speed or pulley diameter of the equations, (Khurmi and Gupta, 2012).

Shaft speeds:

$$R = \frac{RPM(PASTER\ SHAFT\ SPEED)}{RPM(SLOWER\ SHAFT\ SPEED)}, \quad (3.36)$$

$$\text{Pulley diameters } DP = \frac{D(LARGER\ PULLEY\ DIAMETER)}{d(SMALLER\ PULLRY\ DIAMETER)}, \quad (3.37)$$

$$\text{Number of pulley grooves } P_{GR} = \frac{N(LARGER\ PULLEY\ GROOVES\ NO)}{n(SMALLER\ PULLEY\ GROOVES\ NO)}, \quad (3.38)$$

3.9.12 Determination of the horse power (hp)

This can be determined by this expression;

$$P = \frac{T2\pi N}{60} \quad (\text{Khurmi and Gupta, 2012}) \quad (3.39)$$

3.9.13 Determination of the torque (T)

Torque transmitted can be determined by using the expression;

$$T = \frac{P \times 60}{2\pi N} \quad (\text{Khurmi and Gupta, 2012}) \quad (3.40)$$

3.9.14 Determination of the initial tension (T_o)

Initial tension can be determined by the equation below;

$$T_o = \frac{T_1 + T_2}{2} \quad (\text{Khurmi and Gupta, 2012}) \quad (3.41)$$

3.10.0 THERMAL INSULATION FOR THE FURNACE

The furnace shells are separated from direct contact with the surroundings by insulating materials. An insulating material is that which has high degree of heat resistance per unit thickness, the effectiveness of which is judged on the basis of its thermal conductivity and depends on the physical and chemical structure of the material. It slows down the rate of heat loss from a hot surface. It is necessary to insulate the furnace wall and the combustion chamber in order to:

- i. Reduce expansion and contraction of the furnace material.
- ii. Keep heat in the furnace for as long as possible and save energy.
- iii. To reduce temperature fluctuations within the furnace environment

A good insulation material should possess characteristics such as: resilience, low thermal conductivity, rigidity, and acoustical energy, fire resistance, ease of application and low cost (Folayan, 2006)

3.10.1 Determination of the effectiveness of insulators (q)

In order to perform effectively as an insulator, a material must restrict heat flow by conduction, convection or radiation.

The heat loss through insulation can be calculated from knowledge of the thickness and thermal conductivity of the insulation material.

For single layer insulation, the heat loss per m² of hot surface according to Snow, (1991) is

$$q = \frac{T_1 - T_2}{R} = \frac{T_1 - T_m}{R + R_s} \quad (3.42)$$

where R = thermal resistance of insulator per m² (m²k/w)

R_s = thermal resistance of outer surface of insulation system (m²k/w)

For cylindrical steel surfaces

$$R = 10^{-3} \frac{d_o}{2k} \ln \frac{d_1}{d_o} \quad (3.43)$$

and

$$R_s = \frac{d_o}{f d_1} \quad (3.44)$$

3.11.0 THEORETICAL DETERMINATION OF MELTING HEAT

3.11.1 Determination of the sensible heat of the metal (solid) Q_i :

This is the heat needed to raise the temperature of the metal from room temperature to the melting point of the metal. (Sinha and Goel, 1973)

Mathematically it is given as:

$$Q_i = M c p_1 (T_m - T_A), \quad (3.45)$$

where: M = mass of the metal (kg)

C_{p_i} = specific heat of the metal solid (J/KgK)

T_m = melting point temperature

T_A = ambient temperature

3.11.2 Determination of the enthalpy of fusion (Q_2):

The enthalpy of fusion is the heat required to convert the metal at its melting point into liquid at the same temperature. (Sinha and Goel, 1973)

It is given as:

$$Q_2 = ML. \quad (3.46)$$

where: M = mass of the metal

L = latent heat of fusion

3.11.3 Determination of the super heat value (Q_3):

Super heat is the heat required to raise the temperature of molten metal from its melting point to the required pouring temperature. (Sinha and Goel, 1973)

It is given as:

$$Q_3 = M C p_2 (T_p - T_m), \quad (3.47)$$

where:

C_{p_2} = specific heat of the melt (J/KgK)

T_p = pouring temperature of the molten metal (melt)

3.11.4 Heat transferred to the wall of the furnace(Q_w):

The heat transferred to the wall of the furnace from the equation according to Komolafe, (1992)

$$Q_w = \left[\frac{2\pi L_1 K_1}{\ln \frac{r_2}{r_1}} + \frac{2\pi L_2 K_2}{\ln \frac{r_3}{r_2}} \right] (T_{in} - T_{out}), \quad (3.48)$$

where L = length of each material

K = specific thermal conductivity of each material

r = inner and output radius of the material

3.11.5 Determination of the heat transferred to the crucible (Q_C)

The heat transferred to the crucible of thickness (X), length (L), radius (r) with temperature change ΔT will be:

$$Q_C = K_C \frac{A\Delta T}{x} \quad (3.49)$$

where : K_C = thermal conductivity of the crucible material.

3.11.6 Determination of the total heat absorbed by the furnace components (Q_{FC})

The total heat absorbed by the furnace components will be:

$$Q_{FC} = Q_w + Q_C \quad (3.50)$$

Substituting for Q_w and Q_C we get

$$\begin{aligned} Q_{FC} &= 2\pi(T_2 - T_1) \left[\frac{2\pi L_1 K_1}{\ln \frac{r_2}{r_1}} + \frac{2\pi L_2 K_2}{\ln \frac{r_3}{r_2}} \right] + K_C \frac{A(T_p - T_a)}{x} \\ &= U(T_2 - T_1) + K_C \frac{A(T_p - T_a)}{x}, \end{aligned}$$

$$\text{Where} \quad \frac{1}{U} = \frac{1}{2\pi L} \left[\frac{2\pi L_1 K_1}{\ln \frac{r_2}{r_1}} + \frac{2\pi L_2 K_2}{\ln \frac{r_3}{r_2}} \right] \quad (3.51)$$

3.11.7 Determination of the total heat required for a melt (Q_n)

The total heat needed to raise the temperature of the metal of mass (m), change the metal from its solid state to molten state and to raise the temperature of the molten metal to its pouring temperature will be:

$$Q_n = Q_1 + Q_2 + Q_3 \quad (3.52)$$

$$Q_n = MCp_1(T_m - T_a) + ML + MCp_2(T_p - T_m) \quad (3.53)$$

3.11.8 Determination of the total heat required to be supplied by the furnace (Q_T)

The total heat required to be supplied by the furnace to perform the melting of metal and heating it to its pouring temperature will be:

$$Q_T = Q_{FC} + Q_n \quad (3.54)$$

i.e.

$$U(T_2 - T_1) + K_c \frac{A(T_p - T_a)}{x} + MCp_1(T_m - T_a) + ML + MCp_2(T_p - T_m), \quad (3.55)$$

3.11.9 Determination of the total useful heat (Q_u)

The total useful heat supplied to the furnace will be

$$Q_u = Q_c + Q_n, \quad (3.56)$$

3.11.10 Efficiency of the furnace ($\% \eta_f$)

The efficiency of the furnace for complete combustion will be

$$\eta_f = \frac{\text{total useful heat}}{\text{total heat supplied}} \times 100\%, \quad (3.57)$$

3.12.0 DETERMINATION OF THE HEAT LOSSES IN THE FURNACE

3.12.1 Loss from the heat carried by dry flue-gas

For any furnace, the dry flue-gas loss is given by

$$Q_2 = M_g C_p (T_g - T_a), \quad (3.58)$$

3.12.2 Loss due to evaporation of hydrogen

Hydrogen in the fuel is burned and forms H_2O . This water is evaporated by heat in fuel thus less heat is produce.

The loss due to hydrogen formed H_2O is given by

$$Q_3 = M_{st}(h_f - h_a) \text{ (Singh, 2003)}, \quad (3.59)$$

where:

m_{st} = mass of steam formed per kg of fuel due to the combustion of H₂ in fuel

h_f = enthalpy of steam at the gas temperature

h_a = enthalpy of water at ambient temperature

3.12.3 Loss from evaporation of fuel moisture

This is determined using the relation

$$Q_4 = m_m(1089 - T_t + T_g), \quad (3.60)$$

where m_m = Mass of moisture per kg of fuel

T_t = fuel temperature

T_g = flue gas temperature

3.12.4 Loss from moisture in the air

This can be obtained using the expression

$$Q_5 = M_a(T_g - T_a), \quad (3.61)$$

where M_a = kg of aluminium per kg of dry air

3.12.5 Loss due to unconsumed fuel

This is given by

$$Q_{luf} = M_c \times LCV, \quad (3.62)$$

where M_c = weight of charcoal not assumed

3.12.6 Radiation loss in the furnace

The American Furnace and Affiliated Industries Association (AFAI) recommend that radiation

Loss is 1.09% of the higher calorific value of the fuel burnt in the furnace (Tyler and Hicks, 1986).

3.13.0 PERFORMANCE OF THE FURNACE

3.13.1 Theoretical thermal efficiency of the furnace

This is given by,

$$\eta = \frac{\text{Heat output of the furnace}}{\text{Heat supplied by the fuel}} \times 100\% \quad (3.63)$$

3.14.0 ENERGY BALANCE

The amount of heat energy generated in the furnace used in melting the aluminum can be analyzed by carrying out the energy balance of the system. It is a statement based on the principle of conservation of energy which states that if no energy is stored within a system, the heat energy supplied to the system should be equal to the heat energy leaving the system. That is,

$$\sum Q_{supplied} = \sum Q_{utilised} + \sum Q_{loss}$$

The energy balance is a calculation procedure that basically checks if directly or indirectly measured energy flows are in agreement with conservation principles. This balance is of utmost importance and is an indispensable tool for a clear understanding of the energy situation in practice.

3.14.1 Heat balance in the furnace

In carrying out heat balance, the furnace and its auxiliaries is considered a system for the energy analysis. The total energy supplied to the furnace is balanced against that leaving the system in different forms. This is illustrated in Figure 3.4

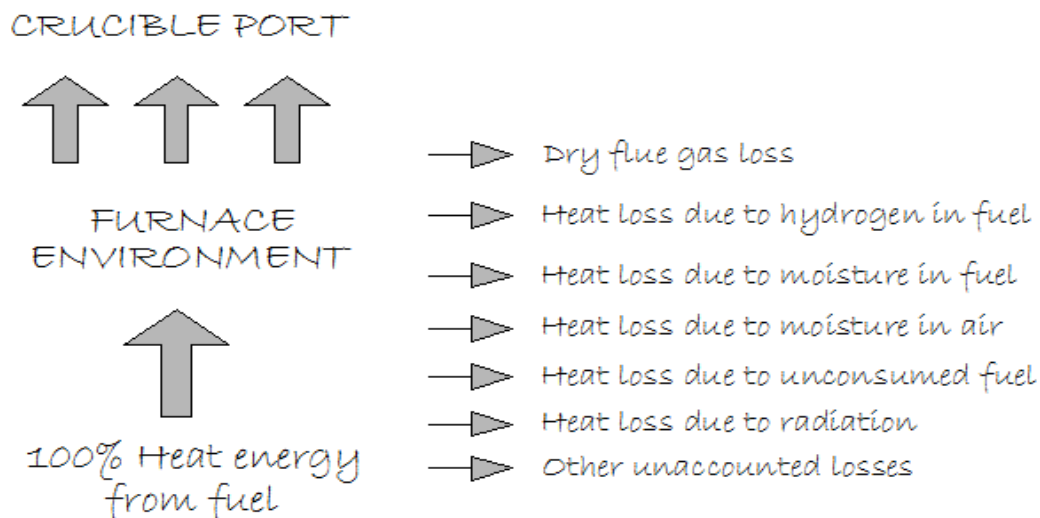
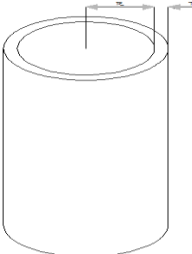


Figure 3.4 Heat balance diagram of the furnace

3.15.0 DESIGN CALCULATIONS

3.15.1 Design Calculations of the minimum thickness of the furnace (t)		
Initial Data	Calculations	Results
<p>$J = 0.70$ $\sigma = 88 \times 10^6 \text{ N/m}^2$ $D_1 = 0.26\text{m}$ $c = 1.5 \times 10^{-3}\text{m}$ Assuming the working pressure is $p = 7.5 \times 10^5 \text{ N/m}^2$ $T = ?$</p> <p>where P is the design pressure from table, C is the corrosion allowance for the material, σ is the yield stress for the material, and J is the weld joint efficiency of the material.</p>	<p>From equation (3.1)</p> $t = \frac{pd_1}{2\sigma_j - p} + c$ $t = \frac{7.5 \times 10^5 \times 0.26}{2 \times 88 \times 10^6 \times 0.70 - 7.5 \times 10^5}$ $= \frac{195,000}{123,200,000 - 750,000}$ $= \frac{195,000}{122,450,000}$ $= 1.592 \times 10^{-3} + 1.5 \times 10^{-3}$ $= 0.00309\text{m}$ $t = 3\text{mm}$ <p>Therefore the 3mm thickness material was selected for the furnace.</p>  <p>Figure 3.5 the furnace body shell</p>	<p>The thickness of the furnace material is: t = 3mm</p>
3.15.2 Calculation for the maximum working pressure for the furnace (p)		
<p>$J = 0.70$ $\sigma = 88 \times 10^6 \text{ N/m}^2$ $R = 0.13\text{m}$ $p = ?$ $T = 3.0\text{mm}$</p>	<p>Assuming the furnace in new condition</p> $p = \frac{\sigma jt}{R + 0.6t} \text{ --- (3.2)}$ $= \frac{88 \times 10^6 \times 0.70 \times 0.003}{0.13 + 0.6 \times 0.003}$ $= \frac{184,800}{0.1318}$ $p = 1,402,124 \text{ N/m}^2$ $p = 14.02 \times 10^5 \text{ N/m}^2$	<p>$p = 14.02 \times 10^5 \text{ N/m}^2$</p>

3.15.3 Calculation of the thermal Stresses Set-up in the Furnace Walls (σt_a)		RESULTS
$\alpha = 17 \times 10^{-6} m^2/s$ $E = 206 \times 10^9 N/m^2$ $\nu = 0.3$ $t_a = 301k$ $t_b = 943k$ $\Delta t = 943 - 301$ $\Delta t = 642k$	<p>From equation (3.3a)</p> $\sigma t_a = \sigma l_a = \sigma C_a = \frac{-\alpha E (T_a - T_b)}{2(1 - \nu)} = \frac{-\alpha E \Delta T}{2(1 - \nu)}$ <p>The thermal stresses set up inside the furnace wall whose temperature is raised to 1045°C</p> $\sigma t_a = \frac{-\alpha E \Delta T}{2(1 - \nu)}$ $\sigma t_a = \frac{-17.7 \times 10^{-6} \times 206 \times 10^9 \times 642}{2(1 - 0.3)}$ $\sigma t_a = \frac{-2.340 \times 10^9}{1.4}$ $\sigma t_a = -1.672 \times 10^9 N/m^2$	$\sigma t_a = -1.672 \times 10^9 N/m^2$ <p>Compressive</p>
	<p>From equation (3.3b)</p> $\sigma t_b = \sigma l_b = \sigma C_b = \frac{\alpha E (T_a - T_b)}{2(1 - \nu)} = \frac{\alpha E \Delta T}{2(1 - \nu)}$ <p>The maximum thermal stress at the outside of the furnace wall is;</p> $\sigma t_b = \frac{2.340 \times 10^9}{1.4}$ $\sigma t_b = 1.672 \times 10^9 N/m^2$	$\sigma t_b = 1.672 \times 10^9 N/m^2$ <p>(Tensile)</p> <p>The results obtained from the calculation show that the selected material is good for the furnace.</p>
<p>The buildup of pressure within the furnace causes slight expansion of the furnace thus resulting in changes in the dimensions which are investigated below.</p>		
<p>3.15.4 Calculation of the changes in the furnace dimensions due to internal pressure</p>		
$E = 206 \times 10^9 N/m^2$ $d = 0.26m$ $\nu = 0.30$ $p = 7.5 \times 10^5 N/m^2$ $t = 0.003m$ $l_{fur} = 0.85m$	<p>Change in length of the furnace (Δl)</p> <p>From equation (3.4)</p> $\text{Change in length } \Delta l = \frac{pd}{4tE} (1 - 2\nu)l$ <p>Change in length of the furnace wall (body)</p> $\Delta l = \frac{7.5 \times 10^5 \times 0.26}{4 \times 0.003 \times 206 \times 10^9} (0.6) \times 0.85$ $\Delta l = \frac{195000 \times 0.4 \times 0.85}{4 \times 0.003 \times 206 \times 10^9}$ $\Delta l = 2.682 \times 10^5 m$ <p style="text-align: center;">or 0.03mm</p>	$\Delta l = 2.682 \times 10^5 m$

$E = 206 \times 10^9 \text{ N/m}^2$ $d = 0.26\text{m}$ $v = 0.30$ $p = 7.5 \times 10^5 \text{ N/m}^2$ $t = 0.003\text{m}$	<p>Change in diameter of the furnace (Δd) From equation (3.5)</p> $\Delta d = \frac{pd^2}{4tE}(2 - \nu)$ <p>The change in diameter due to the effect of the internal pressure in the furnace is</p> $\Delta d = \frac{pd^2}{4tE}(2 - \nu)$ $\frac{7.5 \times 10^5(0.26)^2(2 - 0.3)}{4 \times 0.003 \times 206 \times 10^9}$ $\Delta d = 3.486 \times 10^{-5}\text{m}$ <p style="text-align: center;"><i>or</i></p> $\Delta d = 0.035 \text{ mm}$	$\Delta d = 3.486 \times 10^{-5}\text{m}$
$E = 206 \times 10^9 \text{ N/m}^2$ $d_{cruc} = 0.201\text{m}$ $v = 0.30$ $p = 7.5 \times 10^5 \text{ N/m}^2$ $t = 0.0018\text{m}$ $l_{cruc} = 0.37\text{m}$	<p>Change in Volume of the Crucible (Δv) From equation (3.6) and (3.7)</p> <p>The change in Volume of Crucible is</p> $\Delta v = \frac{pd(5 - 4\nu)v}{4tE}$ <p style="text-align: center;"><i>but</i></p> $V = \frac{\pi}{4}d^2L$ $V = \frac{\pi}{4}(0.201)^2 \times 0.37$ $V = 1.17 \times 10^{-2}\text{m}^3$ <p>Therefore,</p> $\Delta v = \frac{7.5 \times 10^5 \times 0.201(3.8) \times 1.17 \times 10^{-2}}{4 \times 0.0018 \times 206 \times 10^9}$ $\Delta v = 4.51 \times 10^{-6}\text{m}^3$ <p>It can be observed that the changes induced in the furnace and crucible dimensions due to the effect of internal pressure and the thermal stresses are negligible, hence will not cause significant distortion of the walls that could result to its failure</p>	$V = 1.17 \times 10^{-2}\text{m}^3$ $\Delta v = 4.51 \times 10^{-6}\text{m}^3$

3.15.5	Calculation of the Combustion Chamber	
<p> $H = 6.3\%$ $Q_s = 33,440.72 \text{ kJ/kg}$ Adeleke A.F.(2003) The practical value of m_f is 3 Kg therefore $m_f = 3 \text{ Kg}$ $Q_s = HCV$ </p>	<p>The amount of Fuel required per hour</p> <p>From equation (3.8) and (3.9)</p> $Q_s = M_F \times LCV \text{ from which}$ $m_f = \frac{Q_s}{LCV}$ <p>Therefore,</p> $LCV = \frac{Q_s}{m_f}$ $LCV = \frac{3 \times 33,440.72}{3}$ $LCV = 33,440.72 \text{ kJ/kg}$ $LCV = HCV - \frac{9}{100} \times H \times 2442 \text{ kJ/kg}$ <p>The ultimate analysis of the fuel shows it has 0.063kg of hydrogen or 6.3% H. the average higher calorific value of wood charcoal as determined by Adeleke (2003) of a variety of woods which represents the heat supplied to the Crucible furnace is:</p> $Q_s = HCV = 33,440.72 \text{ kJ/kg}$ $LCV = 33,440.72 - \frac{9}{100} \times 6.3 \times 2442 \text{ kJ/kg}$ $LCV = 33,440.72 - 1,384.614 \text{ kJ/kg}$ $LCV = 33,440.72 \text{ kJ/kg}$ <p>Therefore,</p> $m_f = \frac{100,322.16}{33440.72}$ $m_f = 3 \text{ kg/hr theoretical}$ $m_f = 3 \text{ kg/hr practical}$	<p>From practical value $LCV = 33,440.72 \text{ kJ/kg}$</p> <p>$m_f = 3 \text{ kg/hr}$</p>

3.15.6 Calculation of the distance between the fire grate and the crucible		
$D = 0.201m$	<p>From equation (3.10)</p> $h = 0.4 \times D$ <p>the distance between the charcoal grate and the crucible port is</p> $h = 0.4 \times 0.201$ $h = 0.08m$	$h = 0.08m$
3.15.7 Calculation of the thermal load of the combustion chamber (Q_c)		
$l = 0.25m$ $b = 0.19$ $m = 3 \text{ kj/hr}$ $Q_s = 33440.72 \text{ kj/kg}$	<p>From equation (3.11)</p> $Q_c = \frac{MQ_s}{V}$ <p>For rectangular shape $V = A$</p> <p>where: $A = L \times B$</p> $A = 0.25 \times 0.19$ $= 0.0475m^2$ $Q_c = \frac{3 \times 33,440.72}{0.0475}$ $Q_c = 2,112,045.47 \text{ kJ/m}^2\text{hr}$	$Q_c = 2,112,045.5 \text{ kJ/m}^2\text{hr}$
3.15.8 Calculation of the thermal load of the fire Grate (Q_g)		
$d_{g\text{fur}} = 0.26m$ $m = 3 \text{ kj/hr}$ $Q_s = 33440.72 \text{ kj/kg}$	<p>From equation (3.12)</p> $Q_g = \frac{MQ_s}{A}$ <p>For cylindrical shape,</p> $A = \frac{\pi d_g^2}{4}$ $= \frac{\pi \times (0.26)^2}{4}$ $A = 0.20m^2$ $Q_{g\text{fur}} = \frac{3 \times 33440.72}{0.20}$ $Q_g = 477,724.57 \text{ kJ/m}^2\text{hr}$	$A = 0.20m^2$ $Q_g = 477,724.57 \text{ kJ/m}^2\text{hr}$

3.15.9 Calculation of the height of the Combustion Chamber (h_c)		
$Q_c =$ $2,112,045.47 \text{ kJ/m}^2 \text{ hr}$ $Q_g =$ $477,724.57 \text{ kJ/m}^2 \text{ hr}$ $h_c = ?$	From equation (3.14) $h = \frac{V}{A} = \frac{q_g}{q_c} = \frac{m^3}{m^2}$ <i>the design height of chamber is</i> $h = \frac{477,724.57}{2,112,045.47}$ $= 0.232m$	$h = 0.226m$
3.15.10 Chemical analysis of the fuel		
Calculation of the amount of air required for complete combustion		
$C = 0.523 \text{ kg}$ $H_2 = 0.063 \text{ kg}$ $O_2 = 0.414 \text{ kg}$ $S = 0 \text{ kg}$	From equation (3.15) $m_{ea} = \frac{100}{23} \left[\left(\frac{2}{3}C + 8H_2 + S \right) - O_2 \right] \text{ kg}$ <p>The theoretical external air supply required per kg of charcoal is,</p> $m_{ea} = \frac{100}{23} \left[\left(\frac{2}{3} \times 0.523 + 8 \times 0.063 + 0 \right) - 0.414 \right] \text{ kg}$ $= \frac{100}{23} (1.899 - 0.414) \text{ kg}$ $m_{ea} = 6.46 \text{ kg}$ <i>there for 3 kg is</i> 6.46×3 $m_{ea} = 19.38 \text{ kg}$	$m_{ea} = 19.38 \text{ kg}$
3.15.11 Calculation of the mass of the products of combustion		
$C = 0.523 \text{ kg}$ $H_2 = 0.063 \text{ kg}$	From the combustion reaction. 1kg of carbon produces $\frac{22}{3} \text{ kg}$ of carbon dioxide and 1 kg of hydrogen produces 9 kg of water. Therefore the total mass of the products of combustion (flue gas) is obtained as, $= \frac{22}{3} \times C + 9H_2 \text{ kg}$ $= \frac{22}{3} \times 0.523 + 9 \times 0.063$ $m_g = 2.485 \text{ kg}$ That is, 2.485kg of flue gas per kg of wood charcoal is produced during the combustion process.	Mass of products of combustion (flue gas) $m_g = 2.485 \text{ kg}$

<p>Flue gas temp is</p> $t_{fg} = 260^{\circ}\text{C}$ $t_a = 28^{\circ}\text{C}$	<p>From equation (3.17) The temperature correction factor</p> $T_f = \frac{\text{Absolute flue gas temperature}}{\text{Absolute atmospheric temperature}}$ <p>Therefore, Correction factor T_f</p> $T_f = \frac{260^{\circ}\text{C} + 273}{28 + 273}$ $= \frac{533}{301}$ $= 1.77$	$T_f = 1.77$
3.15.12 Determination of the total air flow required in the furnace		
<p>The theoretical amount of air required for a complete combustion of 1kg of wood charcoal is</p> $m_{ea} = 19.38 \text{ kg/s}$	<p>The total air flow required in the furnace is given by the sum of the theoretical air require excess air and leakages from the furnace. The combustion calculation earlier showed that the amount of air that is theoretically required for the complete combustion of 1kg of the wood charcoal is</p> <p>6.46kg/s</p> <p>If 10% excess air is allowed into the furnace, the required excess air becomes</p> $19.38 \times \frac{10}{100} = 1.938 \text{ kg/s}$ <p>Tyler and Hicks (1986) recommend that furnace air leakage ranges between 5 – 10% of the theoretically required air flow. Taking 5% allowance, the leakage in the furnace therefore becomes</p> $19.38 \times \frac{5}{100} = 0.969 \text{ kg/s}$ <p>Hence, the total air flow required for the complete combustion process in the furnace is.</p> $19.38 + 1.938 + 0.969 = 22.28 \text{ kg/s}$ <p>The fan must supply at least 22.28 kg/s of air into the furnace.</p>	1.938 kg/s 0.969 kg/s. 22.28 kg/s

3.15.13 calculation of fan air discharge capacity		
<p><i>factor of safety</i> = 10%</p> <p>The density of air at 302k from table is, $\rho = 1.166 \text{ kg/m}^3$</p>	<p>To ensure adequate air supply throughout the operating period, a factor of safety 10% of the total air flow is applied. Then fan air discharge becomes Agontu, (2009)</p> $22.28 + 22.28 \times \frac{10}{100} = 24.50 \text{ kg/s.}$ <p>During times of high ambient temperatures, the density of air is usually lower. Thus making the fan to discharge less air to the furnace. The practice is to apply a factor of safety between 10-20% to the known ambient temperature. Agontu, (2009)</p> <p>Taking an ambient temperature of 28 °C Taking the factor of safety =15% Hence the ambient temperature for the fan selection</p> $\begin{aligned} &= 28 + (28 \times 0.15) \\ &= 32 \text{ }^\circ\text{C} + 273 \\ &= 305 \text{ k} \end{aligned}$ <p>From the table of thermodynamic and transport properties of fluids, at the ambient temperature of 302k and at atmosphere pressure, the density of air is</p>	<p>24.508 kg/s</p> <p>305.2k</p>
	<p>$\rho = 1.166 \text{ kg/m}^3$.</p> <p>Hence the fan air discharge capacity is</p> $\phi = 24.508 \frac{\text{kg}}{\text{s}} \times \frac{1 \text{ m}^3}{1.66 \text{ kg}} = \frac{14.76 \text{ m}^3}{\text{s}} \quad \text{or}$ $= 14.76 / \frac{1}{60} \text{ m}^3 \text{ min}$ <p>Fan discharged air capacity $\phi = 885.83 \text{ m}^3 / \text{min}$ But for manual operated fan, the discharged is $\phi = 0.10$</p>	<p>$\phi = 885.83 \text{ m}^3 / \text{min}$</p> <p>$\phi = 0.10$</p>
3.15.14 Calculation of the power Required Driving the Fan		
<p>$P = 1.5 \text{ kw}$</p>	<p>From equation (3.18) The power required to drive the fan is:</p> $P = \frac{Qp_f}{60\eta_f} \text{ watts}$ <p>Since the fan is manually operated, An average man can supply the power of 1.5kw (Umar, 1988).</p> <p>Therefore,</p> $P = 1.5 \text{ kw}$	<p>$P = 1.5 \text{ kw}$</p>

3.15.15 Calculation of the fan peripheral discharge velocity (u_2)		
for manually operated fan the values are: $\phi = 0.10$ $N = 400 \text{ rpm}$ $Q = 0.03$ $P = 1.5 \text{ kw}$ Take $D = 0.24 \text{ m}$ $N = 400 \text{ rpm}$	Using equation (3.19) $u_2 = \frac{\pi D_2 N}{60}$ Then the peripheral discharge velocity at the outlet is $u_2 = \frac{\pi \times 0.24 \times 400}{60}$ $u_2 = 5.03 \text{ m/s}$	$u_2 = 5.03 \text{ m/s}$
3.15.16 Calculation for the fan discharge velocity pressure		
$\rho = 1.166 \text{ kg/m}^3$ $u_2 = 5.03 \text{ m/s}$ $\mu_2 = 0.50$ $\eta_f = 0.70$ $p = 6.3 \text{ N/m}^2$	using equations (3.20) $p_f = \eta_n \rho \mu_2 u_2^2, \quad (3.20)$ From which the fan total pressure $p_f = \eta_n \rho \mu_2 u_2^2,$ $p_f = 0.70 \times 1.166 \times 0.50 \times (5.03)^2$ $p_f = 10.33 \text{ N/m}^2$	$p_f = 10.33 \text{ N/m}^2$
3.15.17 The total dynamic head developed by the fan		
$\rho = 1.166 \text{ kg/m}^3$ $p_t = 10.33 \text{ N/m}^2$ $g = 9.81400 \text{ m/s}^2$	From equation (3.21). $h = \frac{P}{\rho g} \text{ mm H}_2\text{O}$ the total dynamic head developed by the fan is $h = \frac{10.33}{1.166 \times 9.81}$ $= 0.90 \text{ mm H}_2\text{O}$	$h = 0.90 \text{ mm H}_2\text{O}$
3.16.0 FAN DESIGN CALCULATIONS		
3.16.1 Calculation for the fan major Diameter (d_2)		
$\phi = 0.10$ $Q = 0.03$ $u_2 = 5.03 \text{ m/s}$	From equation (3.22) $\phi = \frac{4Q}{\pi d_2^2 U_2} \quad (3.22)$ Making d the subject of the formula $d_2^3 = \frac{4Q}{\pi \phi U_2}$ Therefore, $d_2^3 = \frac{4 \times Q}{\phi \times \pi^2 \times 5.03}$ $d_2 = 3 \sqrt{\frac{4 \times 0.03}{0.10 \times \pi^2 \times 5.03}}$ $d_2 = 0.2394 \text{ m}$	$d_2 = 0.2394 \text{ m}$ $d_2 = 239.4 \text{ mm}$

3.17.0 FAN CASING DESIGN CALCULATION		
3.17.1 Calculation for fan casing outlet velocity, (v_3)		
$V_2 = 5.01 \text{ms}^{-1}$	Using equation (3.27a) $V_3 = 0.25V_2 \quad (3.27a)$ $V_3 = 0.25 \times 5.01$ $V_3 = 1.25 \text{ms}^{-1}$	$V_3 = 1.25 \text{ms}^{-1}$
3.17.2 Calculation of the casing outlet area (A_{out})		
$V_3 = 1.25 \text{ms}^{-1}$ $A_{out} = ?$ $Q_o = 0.0027 \text{m}^3/\text{s}$	From equation (3.27b) $A_{out} = \frac{Q_o}{V_3} \quad (3.27b)$ $= \frac{0.0027}{1.25} = 0.00216 \text{m}^2$ $A_{out} = 0.00216 \text{m}^2$	$A_{out} = 0.00216 \text{m}^2$
3.17.3 Fan casing in-let area (A_{in})		
$A_{out} = 0.00216 \text{m}^2$ $A_{in} = ?$	Using equation (3.27c) $\frac{A_{out}}{A_{in}} = 0.68 \quad (3.27c)$ $A_{in} = \frac{A_{out}}{0.68}$ $A_{in} = \frac{0.0027}{0.68}$ $A_{in} = 0.00397 \text{m}^2$	$A_{in} = 0.00397 \text{m}^2$
3.17.4 Calculation of the fan casing outlet diameter (d_o)		
$A_{out} = 0.00216 \text{m}^2$ $d_{out} = ?$	From equation (3.28) $d_{out} = \sqrt{A_{out} \times \frac{4}{\pi}} \quad (3.28)$ $d_{out} = \sqrt{\frac{0.00216 \times 4}{\pi}}$ $d_{out} = 0.0524 \text{m}$	$d_{out} = 0.0524 \text{m}$ $= 52.4 \text{mm}$ $d_{out} = 53 \text{mm}$
3.17.5 Calculation of the fan casing in-let diameter (d_{in})		
$A_{in} = 0.00397 \text{m}^2$ $d_{in} = ?$	Using equation (3.29) $A_{in} = \frac{\pi d_{in}^2}{4} \rightarrow d_{in} = \sqrt{\frac{A_{in} \times 4}{\pi}} \quad (3.29)$ $d_{in} = \sqrt{\frac{0.00397 \times 4}{\pi}}$ $d_{in} = 0.0711 \text{m}$	$d_{in} = 0.0711 \text{m}$ $d_{in} = 71 \text{mm}$

3.17.6 Calculation of the fan case width (b)		
$b_2 = 0.0383 \text{ m}$ $b = ?$	From equation (3.30) $\frac{b}{b_2} = 3.19 \rightarrow b = b_2 \times 3.19 \quad (3.30)$ $b = 0.0383 \times 3.19$ $b = 0.122 \text{ m}$	$b = 0.122 \text{ m}$ $b = 122 \text{ mm}$
3.18.0 CALCULATION FOR BELT AND PULLEY		
3.18.1 Calculation for the Belt pitch length		
$D = 530 \text{ mm}$ $d = 60 \text{ mm}$ $C = 630 \text{ mm}$ $L_{approx} = ?$	From equation (3.31) $L_{approx} = 2c + 1.57(D + d) + \frac{(D - d)^2}{4c} \quad (3.32)$ $L_{approx} = 2 \times 630 + 1.57(530 + 60) + \frac{(530 - 60)^2}{4 \times 630}$ $L_{approx} = 1,260 + 926.3 + 87.66$ $L_{approx} = 2,273.96 \text{ mm}$	$L_{approx} = 2,274 \text{ mm}$
3.18.2 Calculation for the Angle of Contact or lap (θ)		
$D = 530 \text{ mm}$ $r = 265 \text{ mm}$ $d = 60 \text{ mm}$ $r = 30 \text{ mm}$ $x = 630 \text{ mm}$	From equation (3.32) $\theta = (180^\circ - 2\alpha) \frac{\pi}{180} \text{ rad} \quad (3.31)$ Where, $\alpha = \frac{r_1 - r_2}{x}$ $\alpha = \frac{265 - 30}{630}$ $\alpha = 0.37 \text{ rad}$ $\theta = (180 - 2 \times 0.37) \times \frac{\pi}{180}$ $\theta = 3.128 \text{ rad}$	$\theta = 3.128 \text{ rad}$
3.18.3 Calculation for the velocity ratio of a belt drive		
$D_1 = 530 \text{ mm}$ $d_2 = 60 \text{ mm}$ $N_1 = 400 \text{ rpm}$ $N_2 = ?$	Using equation (3.33) $\frac{N_2}{N_1} = \frac{D_1}{d_2}$ $N_2 = \frac{N_1 D_1}{d_2}$ $N_2 = \frac{400 \times 530}{60}$ $N_2 = 3,533 \text{ rpm}$	$N_2 = 3,533 \text{ rpm}$

3.18.4 Calculation for the speed ratio (R)		
$D_1 = 530 \text{ mm}$ $d_2 = 60 \text{ mm}$	From equation (3.37) $R = \frac{D(\text{larger pulley diameter})}{d(\text{smaller pulley diameter})}$ $R = \frac{530}{60}$ $R = 9:1$	$R = 9:1$
3.18.5 Calculation for the initial tension in the belt (T_o)		
$T_1 = 1 \text{ kN}$ $T_o = ?$	From equation (3.38) $T_o = \frac{T_1 + T_2}{2}$ $T_o = \frac{1000}{2}$ $T_o = 500 \text{ N}$	$T_o = 500 \text{ N}$
3.18.6 Calculation for Torque Transmitted (T)		
$P = 1.5 \text{ kN}$	From equation (3.39) $T = \frac{P \times 60}{2\pi N}$ $T = \frac{1.5 \times 10^3 \times 60}{2 \times \pi \times 400}$ $T = 35.81 \text{ N}$	$T = 35.81 \text{ N}$

<p>When $m = 9kg$ $T_A = 600 + 273 = 873K$ $T_m = 660 + 273 = 933K$</p>	<p>when $m = 9kg$ $Q_1 = 9 \times 910 \times 60$ $Q_1 = 491,400j$ $Q_1 = 491.4 kJ$</p>	<p>$Q_1 = 491.4 kJ$</p>
<p>When $m = 10kg$ $T_A = 605 + 273 = 878K$ $T_m = 660 + 273 = 933K$</p>	<p>when $m = 10kg$ $Q_1 = 10 \times 910 \times 55$ $Q_1 = 500,500j$ $Q_1 = 500.5 kJ$</p>	<p>$Q_1 = 500.5 kJ$</p>
	<p>$Q_2 = ml \quad (3.35)$</p>	
<p>$Q_2 = ?$ $L_f = 398 \times 10^3 jkg^{-1}$</p>	<p>when $m = 1kg$ $Q_2 = ml$ $Q_2 = 1 \times 393 \times 10^3$ $Q_2 = 398,000j$ $Q_2 = 398 kJ$</p>	<p>$Q_2 = 398 kJ$</p>
<p>$m = 1 kg$</p>		
<p>$m = 2 kg$</p>	<p>when $m = 2kg$ $Q_2 = 2 \times 398 \times 10^3$ $Q_2 = 796,000j$ $Q_2 = 796 kJ$</p>	<p>$Q_2 = 796 kJ$</p>
<p>$m = 2 kg$</p>		
<p>$m = 3 kg$</p>	<p>when $m = 3kg$ $Q_2 = 3 \times 398 \times 10^3$ $Q_2 = 1,194,000j$ $Q_2 = 1,194 kJ$</p>	<p>$Q_2 = 1,194 kJ$</p>
<p>$m = 3 kg$</p>		
<p>$m = 4 kg$</p>	<p>when $m = 4kg$ $Q_2 = 4 \times 398 \times 10^3$ $Q_2 = 1,592,000j$ $Q_2 = 1,592 kJ$</p>	<p>$Q_2 = 1,592 kJ$</p>
<p>$m = 4 kg$</p>		
<p>$m = 5 kg$</p>	<p>when $m = 5kg$ $Q_2 = 5 \times 398 \times 10^3$ $Q_2 = 1,990,000j$ $Q_2 = 1,990 kJ$</p>	<p>$Q_2 = 1,990 kJ$</p>
<p>$m = 5 kg$</p>		
<p>$m = 6 kg$</p>	<p>when $m = 6kg$ $Q_2 = 6 \times 398 \times 10^3$ $Q_2 = 2,388,000j$ $Q_2 = 2,388 kJ$</p>	<p>$Q_2 = 2,388 kJ$</p>
<p>$m = 6 kg$</p>		

	when $m = 7kg$	$Q_2 = 2,388 kJ$
$m = 7 kg$	$Q_2 = 7 \times 398 \times 10^3$ $Q_2 = 2,786,000j$ $Q_2 = 2,786 kJ$	$Q_2 = 2,786 kJ$
	when $m = 8kg$	
$m = 8 kg$	$Q_2 = 8 \times 398 \times 10^3$ $Q_2 = 3,184,000j$ $Q_2 = 3,184 kJ$	$Q_2 = 3,184 kJ$
	when $m = 9kg$	
$m = 9 kg$	$Q_2 = 9 \times 398 \times 10^3$ $Q_2 = 3,582,000j$ $Q_2 = 3,582 kJ$	$Q_2 = 3,582 kJ$
	when $m = 10kg$	
$m = 10 kg$	$Q_2 = 10 \times 398 \times 10^3$ $Q_2 = 3,980,000j$ $Q_2 = 3,980 kJ$	$Q_2 = 3,980 kJ$
	$Q_3 = MCP_2 (T_P - T_M) \quad (3.36)$	
$Q_3 = ?$ $M = \text{mass in kg}$ $CP_2 = 0.96 \times 10^3 jkg^{-1}k^{-1}$ $T_P = 700^\circ C + 273k = 973K$	when $m = 1kg$	
when $m = 1kg$	$Q_3 = MCP_2 (T_P - T_M)$ $Q_3 = 1 \times 0.96 \times 10^3 (973 - 933)$ $Q_3 = 1 \times 960 \times 40$ $Q_3 = 38,400j$ $Q_3 = 38.4 kJ$	$Q_3 = 38.4 kJ$
$T_M = 660 + 273 = 933K$	when $m = 2kg$	
when $m = 2kg$	$Q_3 = 2 \times 960 \times 40$ $Q_3 = 76,800j$ $Q_3 = 76.8 kJ$	$Q_3 = 76.8 kJ$
$T_m = 660 + 273 = 933K$	when $m = 3kg$	
when $m = 3kg$	$Q_3 = 3 \times 960 \times 40$ $Q_3 = 115,200j$ $Q_3 = 115.2 kJ$	$Q_3 = 115.2 kJ$
$T_m = 660 + 273 = 933K$	when $m = 4kg$	

<p>when $m = 4\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>$Q_3 = 4 \times 960 \times 40$ $Q_3 = 153,600\text{j}$ $Q_3 = 153.6 \text{ kJ}$</p>	<p>$Q_3 = 153.6 \text{ kJ}$</p>
<p>when $m = 5\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>when $m = 5\text{kg}$ $Q_3 = 5 \times 960 \times 40$ $Q_3 = 192,000\text{j}$ $Q_3 = 192 \text{ kJ}$</p>	<p>$Q_3 = 192 \text{ kJ}$</p>
<p>when $m = 6\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>when $m = 6\text{kg}$ $Q_3 = 6 \times 960 \times 40$ $Q_3 = 230,400\text{j}$ $Q_3 = 230.4 \text{ kJ}$</p>	<p>$Q_3 = 230.4 \text{ kJ}$</p>
<p>when $m = 7\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>when $m = 7\text{kg}$ $Q_3 = 7 \times 960 \times 40$ $Q_3 = 268,800\text{j}$ $Q_3 = 268.8 \text{ kJ}$</p>	<p>$Q_3 = 268.8 \text{ kJ}$</p>
<p>when $m = 8\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>when $m = 8\text{kg}$ $Q_3 = 8 \times 960 \times 40$ $Q_3 = 307,200\text{j}$ $Q_3 = 307.2 \text{ kJ}$</p>	<p>$Q_3 = 307.2 \text{ kJ}$</p>
<p>when $m = 9\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>when $m = 9\text{kg}$ $Q_3 = 9 \times 960 \times 40$ $Q_3 = 345,600\text{j}$ $Q_3 = 345.6 \text{ kJ}$</p>	<p>$Q_3 = 345.6 \text{ kJ}$</p>
<p>when $m = 10\text{kg}$ $T_m = 660 + 273 = 933\text{K}$</p>	<p>when $m = 10\text{kg}$ $Q_3 = 10 \times 960 \times 40$ $Q_3 = 384,000\text{j}$ $Q_3 = 384 \text{ kJ}$</p>	<p>$Q_3 = 384 \text{ kJ}$</p>
	<p>3.20.2 The total heat for melt of each kilogram of aluminum (Q_{R1})</p>	
<p>when $m = 1 \text{ kg}$</p>	<p>when $m = 1\text{kg}$ $Q_{R1} = Q_1 + Q_2 + Q_3$ $Q_{R1} = 575.12 + 398 + 38.4$ $Q_{R1} = 1,011.52 \text{ kJ}$</p>	<p>$Q_{R1} = 1,011.52 \text{ kJ}$</p>
	<p>when $m = 2\text{kg}$</p>	

when $m = 2 \text{ kg}$	$Q_{R2} = 203.84 + 796 + 76.8$ $Q_{R2} = \mathbf{1,076.64 \text{ kJ}}$	$Q_{R2} = \mathbf{1,076.64 \text{ kJ}}$
when $m = 3 \text{ kg}$	<p>when $m = 3 \text{ kg}$</p> $Q_{R3} = 286.65 + 1,194 + 115.2$ $Q_{R3} = \mathbf{1,595.85 \text{ kJ}}$	$Q_{R3} = \mathbf{1,595.85 \text{ kJ}}$
when $m = 4 \text{ kg}$	<p>when $m = 4 \text{ kg}$</p> $Q_{R4} = 364 + 1,592 + 153.6$ $Q_{R4} = \mathbf{2,109.6 \text{ kJ}}$	$Q_{R4} = \mathbf{2,109.6 \text{ kJ}}$
when $m = 5 \text{ kg}$	<p>when $m = 5 \text{ kg}$</p> $Q_{R5} = 423.15 + 1,990 + 192$ $Q_{R5} = \mathbf{2,605.15 \text{ kJ}}$	$Q_{R5} = \mathbf{2,605.15 \text{ kJ}}$
when $m = 6 \text{ kg}$	<p>when $m = 6 \text{ kg}$</p> $Q_{R6} = 480.48 + 2,388 + 230.4$ $Q_{R6} = \mathbf{3,098.88 \text{ kJ}}$	$Q_{R6} = \mathbf{3,098.88 \text{ kJ}}$
when $m = 7 \text{ kg}$	<p>when $m = 7 \text{ kg}$</p> $Q_{R7} = 509.6 + 2,786 + 268.8$ $Q_{R7} = \mathbf{3,564.4 \text{ kJ}}$	$Q_{R7} = \mathbf{3,564.4 \text{ kJ}}$
when $m = 8 \text{ kg}$	<p>when $m = 8 \text{ kg}$</p> $Q_{R8} = 524.16 + 3,184 + 307.2$ $Q_{R8} = \mathbf{4,015.36 \text{ kJ}}$	$Q_{R8} = \mathbf{4,015.36 \text{ kJ}}$
when $m = 9 \text{ kg}$	<p>when $m = 9 \text{ kg}$</p> $Q_{R9} = 491.4 + 3,582 + 345.6$ $Q_{R9} = \mathbf{4,419 \text{ kJ}}$	$Q_{R9} = \mathbf{4,419 \text{ kJ}}$
when $m = 10 \text{ kg}$	<p>when $m = 10 \text{ kg}$</p> $Q_{R10} = 500.5 + 3,980 + 84$ $Q_{R10} = \mathbf{4,864 \text{ kJ}}$	$Q_{R10} = \mathbf{4,864.5 \text{ kJ}}$

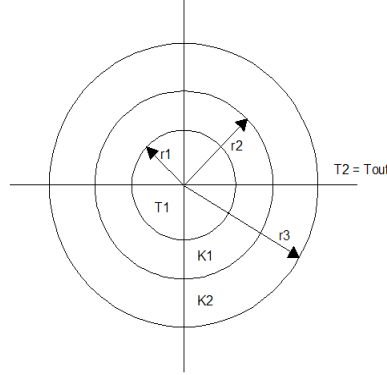
3.21.0 HEAT TRANSFER TO THE WALL OF FURNANCE PER SECOND (Q_w)

Furnace environment temp. is
 $T_{in} = 750 + 273 = 1023K$
 Outside furnace temp is
 $T_{out} = 105 + 273 = 378K$

Soil $k_1 = 1.1 W/mK$

Asbestor k_2
 $= 0.744 W/mK$

$r_1 = 0.13 m$
 $r_2 = 0.17 m$
 $r_3 = 0.21 m$
 $l_{fn} = 0.85 m$



From equation 3.37
 $Q_w = U(T_{in} - T_{out})$ — (3.37)

Where U is given $\frac{1}{U} = \frac{1}{2\pi l} \left[\ln \frac{(r_2)}{r_1} + \ln \frac{(r_3)}{r_2} \right]$

Therefore to find U we use

$$\frac{1}{U} = \frac{1}{2\pi l} \left[\ln \frac{(r_2)}{r_1} + \ln \frac{(r_3)}{r_2} \right]$$

$$\frac{1}{U} = \frac{1}{2\pi \times 0.85} \left[\ln \frac{(0.17)}{0.13} + \ln \frac{(0.21)}{0.17} \right]$$

$$\frac{1}{U} = \frac{1}{5.3407} \left[\ln \frac{1.3077}{1.1} + \ln \frac{1.2353}{0.744} \right]$$

$$\frac{1}{U} = \frac{1}{5.3407} [0.1730 + 0.5070]$$

$$\frac{1}{U} = \frac{1}{5.3407} [0.67995]$$

$$\frac{1}{U} = 0.1273$$

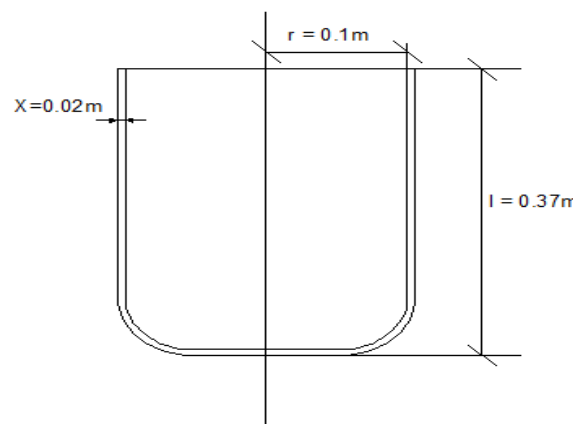
$$U = \frac{1}{0.1273}$$

$$U = 7.8544$$

Therefore

$$Q_w = U(T_{in} - T_{out})$$

$$U = 7.8544$$

<p> $Q_c = ?$ $k_c = 0.84 \text{ W/mK}$ $A = \pi r l$ $\Delta t = t_{in} - t_{out}$ $r_c = 0.1 \text{ m std}$ $x = 0.002 \text{ m}$ $l = 0.37 \text{ m std}$ Furnace environment temp is $t_{in} = 750 + 273 = 1023 \text{ K}$ Melting temp is $t_{out} = 660 + 273 = 933 \text{ K}$ </p> <p> $Q_{fc} = ?$ $Q_w = 6.526 \text{ kj}$ $Q_c = 14,118.72 \text{ kj}$ </p>	<p> $Q_w = 7.8544(1023 - 378)$ $Q_w = 7.8544 \times 645$ $Q_w = 5,066.11 \text{ j}$ $Q_w = 5.066 \text{ kj}$ </p> <p> 3.21.1 Heat transfer to the crucible per second (Q_c) From equation (3.38) $Q_c = kA \frac{\Delta T}{X} \text{ --- (3.38)}$  $A = \pi r l = 3.142 \times 0.1 \times 0.37$ $A = 0.1162 \text{ m}^2$ $\Delta T = T_{in} - T_{out}$ $\Delta T = 1023 - 973$ $\Delta T = 90 \text{ K}$ <p>Therefore,</p> $Q_c = K_c A \frac{\Delta T}{X}$ $Q_c = \frac{0.84 \times 0.1162 \times 90}{0.002}$ $Q_c = 4,392.36 \text{ kj/s}$ <p> 3.21.2 Total heat absorbed by furnace component (Q_{fc}) $Q_{fc} = (Q_w + Q_c) 30 \times 60 \text{ (3.39)}$ $Q_{fc} = (5.0668 + 4,392.36) 30 \times 60$ $Q_{fc} = 4,397.43 \times 1800$ $Q_{fc} = 7,915,368.24 \text{ kj}$ $Q_{fc} = 25,425.44 \text{ kj}$ <p> 3.21.3 Heat for melt of n kg of aluminum (Q_n) $Q_n = Q_{R,1} + Q_{R,2} + Q_{R,3} + Q_{R,4} + Q_{R,5} + Q_{R,6} + Q_{R,7} + Q_{R,8} + Q_{R,9} + Q_{R,10} \text{ --- (3.40)}$ </p> </p></p>	<p> $Q_w = 5.066 \text{ kj}$ </p> <p> $A = 0.1162 \text{ m}^2$ </p> <p> $\Delta T = 90 \text{ K}$ </p> <p> $Q_c = 4,392.36 \text{ kj/s}$ </p> <p> $Q_{fc} = 25,425.44 \text{ kj}$ </p>
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$Q_T = ?$ $Q_{FC} = 25,425.44 \text{ kJ}$ $Q_n = 35,859.13 \text{ kJ}$ $Q_u = ?$ $Q_c = 14,118.72 \text{ kJ}$ $Q_n = 35,859.13 \text{ kJ}$ $N_n = ?$ $Q_T = 61,284.573 \text{ kJ}$ $1_{cal} = 4.187 \text{ j}$ $N_g = ?$ $N_n = 14.6 \times 10^6 \text{ Cal.}$	<p>Therefore</p> $Q_n = 1,011.52 + 1,076.64 + 1,595.85$ $+ 2,109.62 + 2,605.15$ $+ 3,098.88 + 3,564.4 + 4,015.36$ $+ 4,419 + 4,864.5$ $Q_n = 35,859.13 \text{ kJ}$ <p>3.21.4 Total heat supplied by the furnace (Q_T)</p> $Q_T = Q_{fc} + Q_n \quad (3.41)$ $Q_T = 25,425.44 + 35,859.13$ $Q_T = 67,943.54 \text{ kJ}$ <p>3.21.5 Total used heat (Q_u)</p> $Q_u = Q_c + Q_n \quad (3.45)$ $Q_u = 14,118.72 + 35,859.13$ $Q_u = 49,977.85 \text{ kJ}$ <p>3.21.6 Number of calories needed for the melt (N_n)</p> $N_n = \frac{Q_T}{4.187} \quad (3.53)$ $N_n = \frac{61,284.573 \times 10^3}{4.187}$ $N_n = 14,636,869.2 \text{ Cal}$ $N_n = 14.6 \times 10^6$ <p>3.21.7 Number of gramme (n_g) needed to give number of calories (n_n) of energy</p> $N_g = \frac{N_n}{8000} + 2 \quad (3.54)$ $N_g = \frac{14.6 \times 10^6}{8000} + 2$ $N_g = 1,825 + 2$ $N_g = 1,827 \text{ g}$	$Q_n = 35,859.13 \text{ kJ}$ $Q_T = 67,943.54 \text{ kJ}$ $Q_u = 49,977.85 \text{ kJ}$ $N_n = 14.6 \times 10^6$ $N_g = 1,827 \text{ g}$
3.22.0 THEORETICAL CALCULATION OF THE FURNACE		
3.22.1 Heat supplied to the furnace		
	<p>In the furnace heat balance, the input is usually stated in kJ/kg of the fuel as fired. Therefore, the heat input equals the higher calorific value of the fuel. That is;</p> $Q_s = HCV = 33,210.86 \text{ KJ/kg}$ <p>therefore, Q_s for 3kg of charcoal fuel is</p> $33,440.72 \times 3 = 100,322.16 \text{ kJ}$	

3.22.2 Heat output of the furnace		
	The heat output of any furnace is given by the sum of the heat used to melt the metal and all furnace heat losses. $Q_{output} = Q_{used} + Q_{losses}$	
3.23.0 DETERMINATION OF HEAT LOSSES IN THE FURNACE		
3.23.1 Calculation of loss from heat carried by dry flue gas (Q_{lfg})		
$m_g = 2.485\text{kg/kg}$ of Charcoal (as determined in 3.13.11) $C_p = 1.005\text{ kJ}$ $T_{fg} = 260^\circ\text{C}$ $T_a = 28^\circ\text{C}$	From equation (3.47) $Q_{lfg} = m_g c_p (T_g - T_a)$ the dry flue gas loss for 3kg becomes $2.485 \times 3\text{kg} = 7.455\text{kg}$ Therefore, $Q_{lfg} = 7.455 \times 1.005 (260 - 28)$ $Q_{lfg} = 1,738.21\text{ kJ}$	$Q_{lfg} = 1,738.21\text{ kJ}$
3.23.2 Calculation of loss from evaporation of fuel moisture (Q_{lfm})		
$m_m = ?$ $T_{flg} = 260^\circ\text{C}$ $T_{fuel} = 750^\circ\text{C}$ $Q_{lfm} = ?$ 1089 = constant	From the equation(3.48) $Q_{lfm} = m_m (1089 - T_{fuel} + T_{flg})$ For a fuel that is 91.8% dry the fuel contains 8.2% moisture in Items of dry charcoal, thus $m_m = \frac{8.2}{100 - 8.2} = 0.089 \text{ or } 8.9\%$ Then $Q_{lfm} = 0.089(1089 - 750 + 260)$ $Q_{lfm} = 7.031\text{ kJ/kg of fuel}$ Therefore, for 3kg of fuel is $7.031 \times 3 = 21.093\text{kJ}$ $Q_{lfm} = 21.093\text{ kJ}$	$Q_{lfm} = 21.093\text{ kJ}$
3.23.3 Calculation of loss of heat from moisture In the air (Q_{lma})		
From the psychometric chart, the moisture content/kg of dry air at 28.1°C day bulb and 26.7°C wet bulb temperature is $M_a = 0.008\text{kg/kg}$ of dry air (previously determined) $Q_{lma} = ?$ $T_a = 28^\circ\text{C}$ $T_g = 260^\circ\text{C}$ $m_a = 0.008\text{ Kg/kg}$ $fuel = 3\text{ Kg}$	From equation(3.49) $Q_{lma} = m_a (T_g - T_a)$ $m_a = 0.008\text{kg/kg of dry air}$ Therefore, $m_a = 0.008 \times 3\text{kg}$ $m_a = 0.024\text{kg of dry air}$ Therefore, $Q_{lma} = 0.024 (260 - 28)$ $Q_{lma} = 5.568\text{ kJ}$	$Q_{lma} = 5.568\text{ kJ}$

3.23.4 Calculation of the loss due to unconsumed fuel (Q_{luf})		
<p>$LCV = 11,146.91 \text{ kJ/kg}$</p> <p>For 3kg of charcoal $3 \times 11,146.91 = 33,440.73 \text{ kJ}$</p>	<p>From equation(3.51)</p> $Q_{luf} = m_c \times LVC$ <p>Assuming 2% of the charcoal did not burn. Then the mass of the un-burnt fuel is</p> $m_c = \frac{2}{100} \times 3\text{kg} = 0.06 \text{ Kg}$ <p>The heat loss due to un-consumed fuel is therefore</p> $Q_{luf} = 0.06 \times 33,440.73 \text{ kJ}$ $Q_{luf} = 2,006.4 \text{ kJ}$	$Q_{luf} = 2,006.4 \text{ kJ}$
3.23.5 Radiation loss in the furnace (Q_{rlf})		
	<p>The American Furnace Affiliated Industries Association (FAAI) recommends that radiation loss is 1.09% of the higher calorific value of the fuel burnt in the furnace (Tyler and Hicks, 1986) Recall that total heat input is 33,440.72kJ/kg.</p> <p>Therefore, for 3kg of fuel is</p> $33,440.72 \times 3 = 100,322.16 \text{ kJ}$ <p>Hence radiation loss</p> $Q_{rlf} = \frac{1.09}{100} \times 100,322.16\text{kJ}$ $Q_{rlf} = 1,093.512 \text{ kJ}$	$Q_{rlf} = 1,093.51 \text{ kJ}$
3.23.6 Calculation of unaccounted heat loss (Q_{UHL})		
<p>$Q_{ifg} = 1,738.21 \text{ kJ}$ $Q_{ifm} = 91.352 \text{ kJ}$ $Q_{lma} = 35.97 \text{ kJ}$ $Q_{luf} = 3,344.07 \text{ kJ}$ $Q_{lrf} = 1,093.51 \text{ kJ}$</p>	<p>From equation (3.41)</p> $Q_{UHL} = EQ_{supplied} - EQ_{losses}$ <p>the unaccounted heat loss is</p> $Q_{UHL} = Q_s - (Q_u + Q_{ifg} + Q_{ifm} + Q_{lma} + Q_{luf} + Q_{lrf})$ $= 61,284.57 - (49,977.85 + 1,738.21 + 21.093 + 5.568 + 2,006.44 + 1,093.51)$ $Q_{UHL} = 61,284.573 - 54,84200.671$ $= 6,441.902 \text{ kJ/kg}$	$Q_{UHL} = 6,441.902 \text{ kJ}$

3.23.7 Efficiency of the furnace in melting 10kg of aluminum (η_f)		
$\eta_f = ?$ $Q_u = 49,977.85 \text{ kJ}$ $Q_T = 61,284.573 \text{ kJ}$	From equation (3.46) $\eta_f = \frac{Q_u}{Q_T} \quad (3.46)$ $= \frac{49,977.85}{67,943.54} \times 100$ $= 0.735579 \times 100$ $= 73.55$ $\eta_f = 73.55\%$	$\eta_f = 73.55\%$

3.24 These calculations are presented in table 3.1

Table 3.1: Furnace Heat Balance

Heat Balance			
s/n	Items	kJ for 3kg of fuel	percent
1.	Heat input	100,322.16	100
2.	Heat output	67,943.54	67.725
Losses			
1.	Heat carried by flue gas	1,738.2	1.73
2.	Evaporation of fuel moisture	21,093	21.03
3.	Moisture in the air	5.568	0.0055
4.	Unconsumed fuel	2,006.44	2
5.	Radiation	1,093.51	1.09
6.	Uncounted	6,441.902	6.42
Total (Heat output + Losses)		100,322.16	100

From the calculations above, the energy situation achieved in the furnace can then be shown on a heat balance diagram illustrated in the figure 3.6

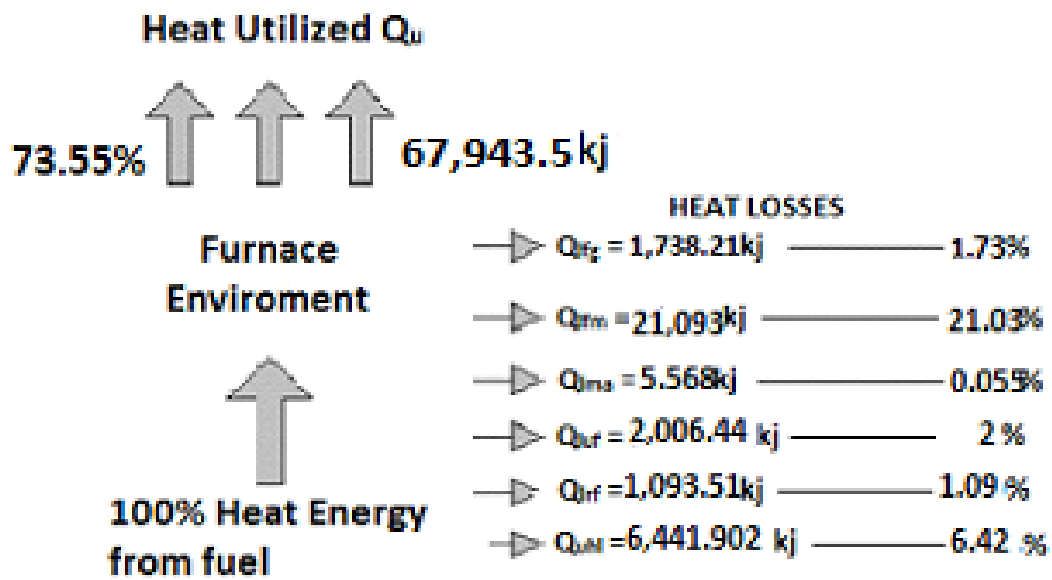


Figure 3.6 Heat Balance diagram of the furnace

3.25 CONSTRUCTION

The designed furnace was constructed in the Mechanical engineering Department workshop of Ahmadu Bello University Zaria. The manufacturing process involved in the construction is fabrication work, cutting and welding. Different components were separately fabricated and later assembled. After assembling the sharp edges were chamfered and the structure was painted. The furnace consists of several components as presented in the working drawing, Appendix II.

Therefore, the methods and steps adopted for this work are design theory, calculation and construction work, which involve numerous operations starting from material selection, measurement, cutting, folding, joining, e.t.c up to the end of the work and testing of the furnace, the details for the fabrication process were given below.

3.25.1 FABRICATION PROCESS

Having selected the materials that meet the required specifications for the construction of crucible furnace, the fabrication processes and the equipment used are as tabulated below.

S/ no	Components	Materials	Fabrication process	Equipments/tools used
1	Crucible cover	Mild steel sheet 3 mm thick	<ul style="list-style-type: none"> - On a suitable location on a mild steel sheet mark and draw a circle of \varnothing 220 mm. - Cut the circle drawn out - On a suitable location mark and cut out 1 piece 20 mm x 350 mm - Attach (weld) it to the circle plate <p>(see drawing no 1 for details)</p>	Scriber, punch, steel rule, cutting disc and arc welding machine.
2	Furnace cover	Mild steel sheet 3 mm thick.	<ul style="list-style-type: none"> - On a suitable location on a mild steel sheet mark \varnothing422 mm draw a circle and cut it out - From the centre of the circular plate, draw a circle to circumscribe \varnothing 220 mm hole - On a suitable location mark and cut out 1 piece 20 mm x 350 mm and 1 piece 20 mm x 450 mm - Attach (weld) the 2 metals at the ends of the circles respectively, to form a complete cover <p>(see drawing no 2 for details)</p>	Scriber, punch, steel rule, cutting disc and arc welding machine.

3.	Flue gas exit pipes	Mild steel pipes \varnothing 20 mm.	<ul style="list-style-type: none"> - On a suitable location on a mild steel pipe of \varnothing 20 mm mark a measurement of 200 mm length - Cut 4 pieces of the same measurement 	Scriber, measuring tape and hacksaw.
4.	Crucible port	Mild steel 1.7 mm thick	<ul style="list-style-type: none"> - This is a standard port of \varnothing 201 mm and length of 370 mm. - On a suitable location on a mild steel sheet mark a circle of \varnothing 310 mm and cut it out - From the centre of the circle, circumscribe \varnothing201 mm hole - Attach it to the crucible port at a distance of 40mm from the top (detail as shown in drawing no 4) 	Scriber, cutting disc, steel rule and welding machine.
5.	Fuel entrance port	Mild steel 2 mm thick	<ul style="list-style-type: none"> - On a suitable location on a mild steel sheet, measure 400 mm x 250 mm and cut it out. - Then divide 250 mm in to three points according to the following dimensions 80 mm, 90 mm, and 80 mm, and fold them up right to form the rectangle shape funnel. - At the distance of 280 mm on the upper sides of the rectangle, measure as angle of 34° downward and draw a line 	Scriber, measuring tape, hacksaw, bending machine and welding machine.

			<p>to meet with the other end at a distance of 40 mm. from down and cut it out.</p> <ul style="list-style-type: none"> - On a suitable location on the mild steel sheet measure a rectangle plate of dimension 80 mm x 90 mm and cut it out - Weld the plate at the end of the funnel to give the exact shape of fuel entrance as shown in (drawing no 5) 	
6.	Fuel entrance support	Mild steel 2 mm thick	<ul style="list-style-type: none"> - On a suitable location on a mild steel flat bar mark a 420 mm length and cut it out. - Mark 10 mm distance at both ends of the bar and bend it to an angle of 4° - Drill through Ø 5 mm hole at each end (see detail on drawing no 6) 	Scriber, measuring tape, hacksaw, drilling machine, centre punch, and Ø 5 mm drill bit.
7.	Furnace layers	Mild steel sheet 3 mm thick	<ul style="list-style-type: none"> - 3 furnace layers were produced, main layer as furnace body second and third layers serve as insulator separators that separated asbestos and clay sand. - On a suitable location on a mild steel sheet measure and mark <ul style="list-style-type: none"> 1. 1300 mm x 850 mm for first layer 2. 1050 mm x 380 mm for second layer 3. 830 mm x 380 mm for third layer 	Measuring tape, marking tool, cutting machine and disc, rolling machine, welding machine, and pressing machine.

			<p>cut them out separately</p> <ul style="list-style-type: none"> - Roll each sheet and weld free end together to form a circumference of \varnothing 420 mm, \varnothing 340 mm, and \varnothing 260 mm respectively (see drawing no 7) 	
8.	Combustion chamber seat	Mild steel 3 mm thick	<ul style="list-style-type: none"> - On a suitable location on a mild steel sheet mark and draw a circle of \varnothing 420 mm. - Cut the circle drawn out. - Mark centre point on a circle plate and measure a square of 190 mm x 190 mm on the plate and cut it out. - Drill 4 \varnothing 3 mm holes through at the middle of each side of the square (see detail on drawing no 8) 	Scriber, punch, steel rule, cutting disc, and cutting machine.
9.	Combustion chamber protector	Mild steel 2 mm thick	<ul style="list-style-type: none"> - On a suitable location on a mild steel sheet measure and mark 960 mm x 270 mm, and cut it out - Measure 240 mm at 4 points on the 960 mm and bend the 4 points measured to form rectangular shape - Measure 20 mm out of 270 mm at each Conner and bend each side - Drill through \varnothing 5 mm hole at the middle of each side (see detail on drawing no 9) 	Measuring tape, marking tool, cutting machine and disc, drilling machine, drilling bit, welding machine.

10.	Combustion chamber	stain steel 2 mm thick	<ul style="list-style-type: none"> - Combustion chamber is at rectangular shape with three different dimensions. - On a suitable location on a mild steel sheet measure 760 mm x 270 mm and cut it out. - Divide 760 mm in to 4 points at dimension of 190 mm each point and bend the 4 points to form rectangular shape. - Measure 20 mm at each side of 270 mm - Bend 20 mm measured of each side left. - On a suitable location on a mild steel sheet measure and mark 190 mm x 190 mm and cut it out - Weld it at the lower end of the rectangular shape - Drill through \varnothing 5 mm hole at sides of the rectangular shape including the lower part of it - At the angle of 90° of one side draw a circle to circumscribe \varnothing 45 mm hole (see detail on drawing no 10) 	Measuring tape, marking tool, cutting machine and disc, drilling machine, drilling bits, welding machine.
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11.	Ash exit cover	Mild steel 2 mm thick	<ul style="list-style-type: none"> - On a suitable location on a mild steel sheet measure and mark 200 mm x 200 mm, and cut it out - Drill through \varnothing 5 mm holes at the upper and lower sides on the centre of the plate (see drawing no 11) 	Measuring tape, marking tool, cutting machine and disc, drilling machine, drilling bit.
12.	Air pipe	Stainless steel \varnothing 45 mm	<ul style="list-style-type: none"> - On a suitable location on a stainless steel pipe measure and mark 400 mm and cut it out (see drawing 12) 	Measuring tape, marking tool, hacksaw.
13.	Blower	Aluminum scrap	<ul style="list-style-type: none"> - After blower design calculations (3.16 – 3.17.4) and set up a pattern, melt scrap aluminum in the furnace to its pouring point and cast the blower blades, blower casing (see details on drawing no 13) 	Furnace, foundry equipments.
14.	Base stand	5 mm thick angle iron	<ul style="list-style-type: none"> - Mark different measurements on a mild steel (angle iron) to cut out the pieces, each to its specific dimensions - Weld pieces to their suitable locations - Drill through 2 \varnothing 10 mm holes for attaching the wheel stand (see details on a drawing no 14) 	Measuring tape, marking tool, cutting machine and disc, drilling machine, drilling bit.
15.	Wheel	Aluminum	<ul style="list-style-type: none"> - Standard with \varnothing 530 mm (see detail drawing no 15) 	—

16.	Handle	Mild steel bolt, nut and mild steel pipe	<ul style="list-style-type: none"> - Standard mild steel bolt and nut of size 130 mm length and Ø 10 mm - On a suitable location on a mild steel pipe of Ø 15 mm measure length of 120 mm and cut it out. - The bolt passes through the pipe and is tied onto wheel to provide means of rotating the wheel (details on drawing no 16) 	Scriber, measuring tape, hacksaw, and spanners
17.	Pulleys, ball bearings and shafts	Mild steel hard carbon steel	- Standard pulley , shaft and bearing according to specifications (see drawing no 17 for details)	_____
18.	Belt	Rubber	- Standard rubber was used as belt (see drawing no 18)	_____
19	Insulators	Asbestos and clay sand	<ul style="list-style-type: none"> - Grind asbestos to a fine ash mix with water and put in between first and second layers - Grind clay sand, Mix with water and put in between second and third layers 	Hammer, grinding machine, and water.

3.26 COMPONENTS ASSEMBLING PROCESS

Having fabricated all components of the design crucible furnace as described in a tabular form above, the assembly of the crucible furnace components was carried out as tabulated below:

s/n	Components	Assembling process	Equipments used
1.	First layer (main furnace body) height 850 mm, Ø 420 mm.	<ul style="list-style-type: none"> - Keep it standing and weld in four combustion chamber seat hangers inside at the distance of 380 mm from the top. - Attach combustion chamber seat with combustion chamber protector and tie them together by means of (4) 5 mm bolts and nuts - Put the combustion chamber seat into the furnace and place it on its seat. 	Welding machine and spanners.
2.	Second layer of the furnace	- Put the second layer into the furnace on top of the combustion chamber seat, the distance between first layer and second layer is 40 mm, that is the thickness of the furnace lagging with asbestos material and the diameter of the second layer is Ø 340 mm.	
3.	Third layer of the furnace	- Put the third layer into the furnace on top of the combustion chamber seat, the distance between second layer and third layer is 35 mm, that is the thickness of the furnace lagging with sand and the diameter of the third layer is Ø 260 mm.	



4.	Flue gas pipes	- Put in (4) flue gas pipes to pass through the layers as shown in the (drawing no 18)	
5.	Insulators	- Fill in the 40 mm distance between first and second layers with asbestos ash. - Fill in the 35 mm distance between second and third layers with clay sand.	
6.	Furnace cover	- Put the furnace cover on top of the furnace to cover the two layers and insulators.	
7.	Combustion chamber	- Insert the combustion chamber into the furnace and hang on the combustion chamber seat.	
8.	Fuel entrance port	- A hole of equal dimensions to the fuel entrance funnel was made on the furnace layers from the main furnace body to the inner layers. - Put in the fuel entrance funnel through its hole in to the furnace main body to pass through the layers to reach the head of combustion chamber. - Put the support to hang the fuel entrance and hold them with 5mm screws, upper end to fuel entrance port lower end to the furnace body (see drawing no 18 for details).	Spanners, screw driver.
9.	Ash exit cover	- Then put the exit cover to cover exit port and screws up and dawn.	- Screw driver

10.	Crucible port	<ul style="list-style-type: none"> - Put crucible into the furnace - Put the crucible cover to cover it. 	
11.	Air pipe	<ul style="list-style-type: none"> - Put in the air pipe through the furnace to the combustion chamber - and connect it to blower 	
12.	Wheel and blower frame	<ul style="list-style-type: none"> - Several parts of the frame were joined together by welding at appropriate positions to form a frame (320 mm x 920 mm x 250 mm) 	Welding machine
13.	Blower	<ul style="list-style-type: none"> - The blower was positioned on the frame and hooked in its position. 	
14.	Wheel and its stand	<ul style="list-style-type: none"> - The wheel was attached to its stand by means of ball bearings and spindle together with 14 mm nuts. - Rotating handle is joined to the wheel by 13 mm bolt and nut. - Wheel and its stand are attached to the base stand (frame) with 17 mm bolts and nuts. 	<ul style="list-style-type: none"> - welding machine, - spanners,
15.	Wheel adjuster	<ul style="list-style-type: none"> - The adjuster is positioned on the frame attached to the wheel stand for adjusting the wheel to and fro for belt tensioning 	
16.	Belt	<ul style="list-style-type: none"> - The belt is to connect the big and small pulleys to transmit drive from big pulley to small pulley to drive the blower. 	
17.	<ul style="list-style-type: none"> - Complete Crucible Furnace Assembled (see plate 5.1) 		

3.27 COMPARISON OF THE DESIGNED CRUCIBLE FURNACE AND CONVENTIONAL TYPE FURNACE.

When comparing the two types of furnaces the following performance results are presented in table 3.2 below.

Table 3.2 designed furnace and the conventional type

Comparison of the two furnaces	
Designed furnace	Conventional type crucible furnace
 <ol style="list-style-type: none"> 1. Maximum utilization of heat 2. Less fuel consumption, 3kg of charcoal for 10kg of aluminum 3. Less operating time, 1:33min for melting 10kg of scrap aluminum 4. Easy to operate 5. Environmental friendly 6. Less emission of combustion product and heat to operator. 7. Safer from health hazard 8. The furnace unit is movable 9. It can be detach in to different components 10. It has mission control 	 <ol style="list-style-type: none"> 1. Heat loss due to open space 2. More fuel consumption, 7kg of charcoal for 10kg of aluminum 3. Longer operating period (heating time is long), 4. Difficult to operate and requires more energy. 5. Not environmental friendly 6. High emission of combustion products. 7. Very hazardous to human health. 8. The furnace is not movable 9. It cannot be separated from the furnace 10. No emission control

3.28 TESTING OF THE FURNACE AND OPERATING PROCESS

3.28.1 Measurement of kilogram's and temperature.

The following instruments where used to measure weight and temperature in the experiment, Electrical kitchen scale ek5055 and Thermocouple respectively. **Plate3.1** and **Plate 3.2**



Plate 3.1 Electrical kitchen scale ek5055



Plate 3.2: Thermocouple.

3.28.2 The charcoal fuel

The charcoal fuel used in the work was obtained from Muchia market of Sabon Gari, Zaria About 40kg of the charcoal was obtained and sorted out properly to remove all unwanted matter in the fuel.

3.28.3 Scrap aluminum

The scrap aluminum used for the experiment was sourced from Muchia Market from the scrap sellers. About 30 kg of cast aluminum was obtained and sorted out to remove all unwanted material from the aluminum, then 10 kg was measured and separated aside.

3.28.4 Temperature Measurement

The following temperatures are important in this research, and were measured in the experiment;

- i. The Ambient temperature T_a
- ii. The initial temperature of the charcoal fuel T_f ($^{\circ}\text{C}$)
- iii. The temperature of the products of combustion (flue gas) T_g ($^{\circ}\text{C}$)
- iv. Melting temperature of the aluminum T_m

A digital thermocouple was used to measured temperature in the experiment before and during the experiment. The thermocouple wires were led into the crucible directly to determine the temperature at which the aluminum melt, and thermocouple wire was also re-inserted into the furnace environment through one of the flue gas exits pipe to determine furnace temperature. Melting temperature readings were taken at regular time intervals of time to determine when each kilogram of aluminum was completely melted. Plate 3.3 below shows the location where thermocouple wire was inserted in to crucible.

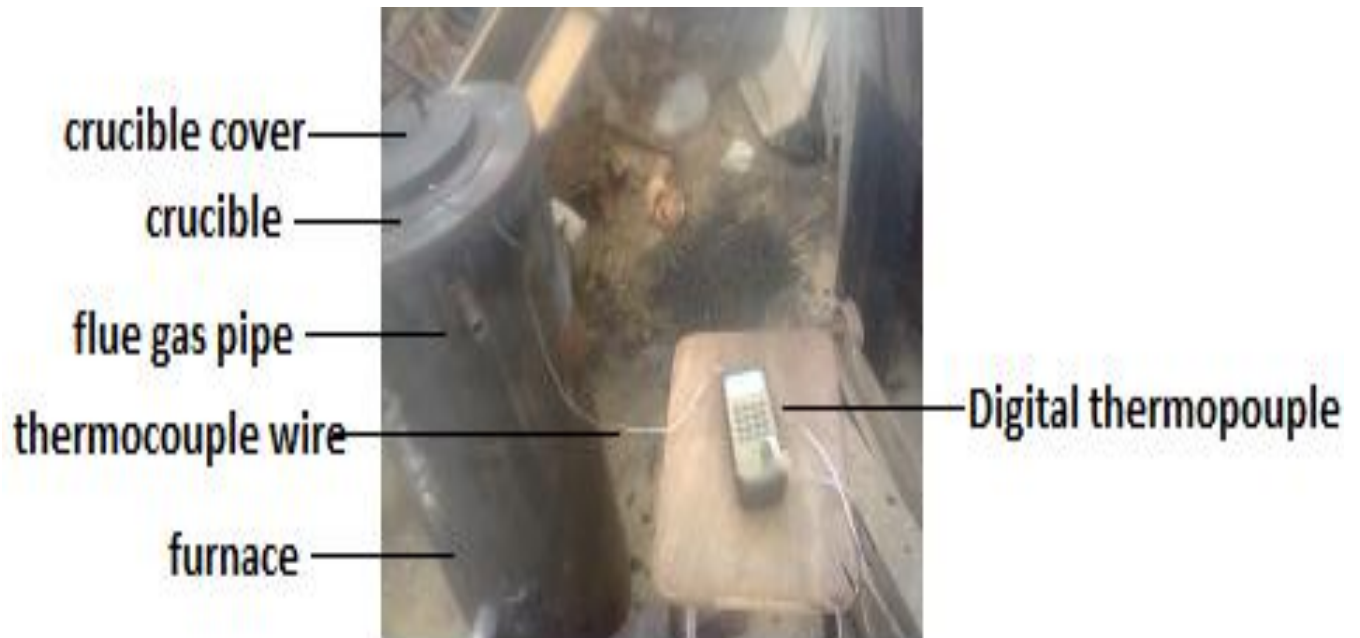


Plate 3.3 Temperature measurement

3.29.0 EXPERIMENTAL PROCEDURES

The designed and fabricated crucible furnace along with accessories were assembled and stationed in the Department of Mechanical Engineering workshop welding section, Ahmadu Bello University, Zaria.

3.29.1 The Environment

The experiment was carried out in the welding workshop in order to reduce the effect of the wind on the testing operation.

3.29.2 Starting the furnace

Red hot charcoal was placed in the combustion chamber and covered with charcoal. The rotating wheel of the furnace was propelled continuously at a medium speed to rotate the blower which supplied the air needed to the combustion chamber and caused the unburned charcoal in contact with the live coals to catch fire this started the furnace.

3.29.3 Sequence of the testing procedures

The following steps were followed in testing the furnace;

- i. Scrap aluminum was measured to get the exact 10 kg,
- ii. All the 10kg of aluminum was further broken to small pieces and it was kept aside.
- iii. Measure the quantity of charcoal based on calculated value and feed into the combustion chamber.
- iv. Light the charcoal fuel in the furnace combustion chamber.
- v. Place the crucible inside the furnace.
- vi. The aluminum was feed in to the crucible kilogram by kilogram after given time intervals;
- vii. Propel the wheel to blow air into the combustion chamber to generate the required heat for melting of the aluminum.
- viii. Add flux when necessary.
- ix. When heat is generated and 1 kg is completely melted then add another kilogram of aluminum after a given time interval and that is how it is done up to 10 kg of aluminum
- x. remove the slag from the melted aluminum (liquid)
- xi. When the aluminum is completely melted, and reached its pouring point use approved tongs to fetch the molten metal from the crucible for casting.
- xii. Pour the molten metal into the sand or iron mould for the desired casting and allow it to solidify.
- xiii. And end the operation cycle.

3.29.4 Furnace on testing

After all furnace components were due appropriate assembled and the lead down testing procedure and steps were duly followed, **Plate 3.4** shows the furnace on testing.

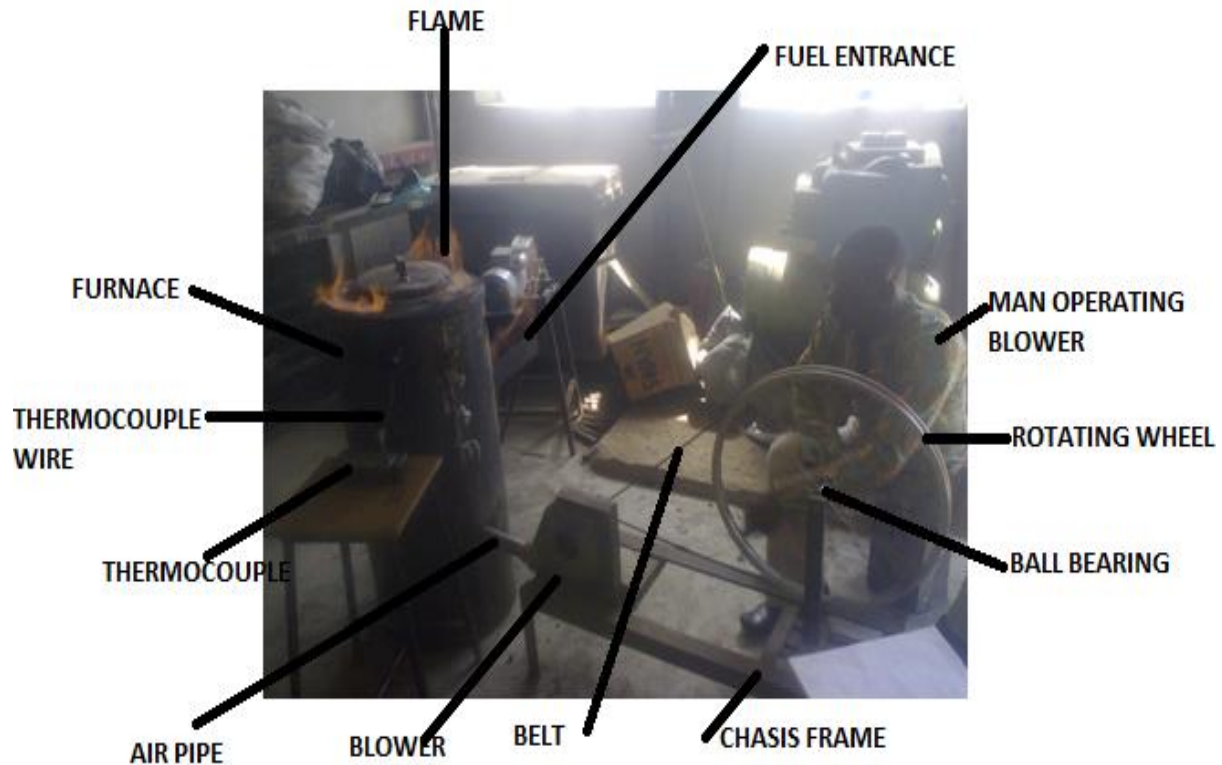


Plate 3.4 shows complete crucible furnace under testing operation

3.30 The Amount of heat generation

The total amount of heat generated was determined by calculation from the amount of fuel and air supplied, the amount of air supplied was determine by knowing the capacity of the blower itself and the amount of air discharged by the fan for 1 revolution of driver pulley when 1.5 Kw was applied for manual operation, determined in the calculations.

3.31 The Amount of fuel used

This was determined from the difference between the initial weight of the charcoal and the final weight after the experiment, this was achieved by measuring the required charcoal to be used and recorded the weight then after the experiment the furnace was quenched off and allowed it to

cooled the remaining residue of the charcoal was sieved and weigh the remaining unburned charcoal and record the result, therefore the difference between the initial and final weight give the amount of fuel used.

3.32 Duration for complete melting of aluminum

The temperature readings were taken at regular intervals using a stop watch to monitor the time taken for each kilogram of aluminum to melt completely. The readings of the test as presented in tables 4.5, 4.6, 4.7, and 4.8 in Appendix II.

3.32 COST ANALYSIS

Costing is an important aspect of engineering design and construction. The evaluation of the cost of the designed and constructed crucible furnace has three components viz: materials, labour and overhead costs.

Material costs involve the detailed breakdown of materials and it sum up costs of all materials used. The labour cost is what was spent on labour during the manufacturing process, and overhead costs involve transportation and other miscellaneous expenses. Table 3. is a breakdown of the crucible furnace cost.

Table 3.3 break down of the production cost, materials and their dimensions.

s/No	Component	Materials	Dimensions	Qty	Unit price cost ₦	Total cost ₦
1.	Furnace	Mild steel	1000 x 800 x 3 mm	1 ¹ / ₂ sheet	14,500:00	21,750.00
2.	Combustion chamber	Stainless steel	400 x 400 x 2 mm	¹ / ₂	1,300:00	1,300.00
3.	Crucible port	Mild Steel	∅ = 200 mm L = 370 mm std	1	2,500:00	2,500.00
4.	Air supply pipe	Stainless steel	∅ = 40 mm L = 500 mm	1	1000:00	1000.00
5.	Insulators	Clay sand and asbestos	-	bulk	400:00 600:00	400.00 600.00
6.	Screws	-	3 mm	15	10:00	150.00
7.	Blower casing	aluminum	Scrap	bulk	1000:00	1000.00
	Ball bearings	-	∅ = 30 mm	2	50:00	100.00
9.	Bolts and nuts	std	10 mm	5	30:00	150.00
10.	Rubber belt	Rubber	-	-	100:00	100.00
11.	Rotating wheel	steel	∅= 500 mm	1	550:00	550.00
12.	Frame	Mild steel	1 length	1	2,000:00	2,000.00
13.	Bolts and nuts	Mild steel	17 mm	4	50:00	200.00
14.	Nuts	Mild steel	14 mm	4	25:00	100.00
15.	Welding electrode		Gauge 10	2 pkts	750:00	1,500.00
16.	Welding and fabrication work					13,000.00
17.	Spraying					5,000.00
18.	Transport and miscellaneous expenses					5,000.00
19.	Total					56,400.00

The overall cost of producing the crucible furnace unit is fifty six thousand four hundred naira only.

(₦56,400:00).

CHAPTER FOUR

RESULTS

4.1 Experimental results

Having fabricated the furnace it was tested in a three different ways to determine the time it takes to raise the temperature up to 660 °C and above for melting of aluminum in each of the tests conducted. The three tests that were conducted are:

1. No load test of the furnace
2. Furnace with Load of 10kg at once test
3. Continuous load test.

The results obtained are as follows.

1. No load test

In the no load test carried out, the sequence of testing procedures were followed and the furnace was tested empty without loading aluminum, the following results were obtained from the test.

- a. Time taken to raise the temperature of the crucible to 660 °C and above was 30mins
- b. The quantity of charcoal consumed for this test was 1 kg

2. With load test (batch method)

The load test was carried out with the load of 10 kg of aluminum at once, the following result were obtained from this test.

- a. Time taken to raise the temperature to 660 °C was 55 min and the holding time for the aluminum to melt completely melted was 10 min, therefore, the total time taken for melting of 10 kg of aluminum at once was 1:05 min.
- b. The quantity of charcoal consumed for this test was 2.5 kg

3. With load test continuous method

This test was carried out by adding the load of aluminum, kilogram by kilogram in continuous form, to determine the time taken to melt each kilogram of aluminum in the furnace; the results obtained are given in Table 4.1 in appendix II.

The under listed parameters were measured before and during the experiments.

- a. Weight of charcoal fuel used $m_f = 3 \text{ kg}$
- b. Ambient temperature = $28 \text{ }^\circ\text{C}$
- c. Temperature of the products of combustion (flue gas) $T_g = 260 \text{ }^\circ\text{C}$
- d. Initial temperature of the charcoal fuel $T_f = 28 \text{ }^\circ\text{C}$
- e. Melting temperature = $660 \text{ }^\circ\text{C}$
- f. Furnace external temperature $105 \text{ }^\circ\text{C}$
- g. Furnace environment temperature $750 \text{ }^\circ\text{C}$

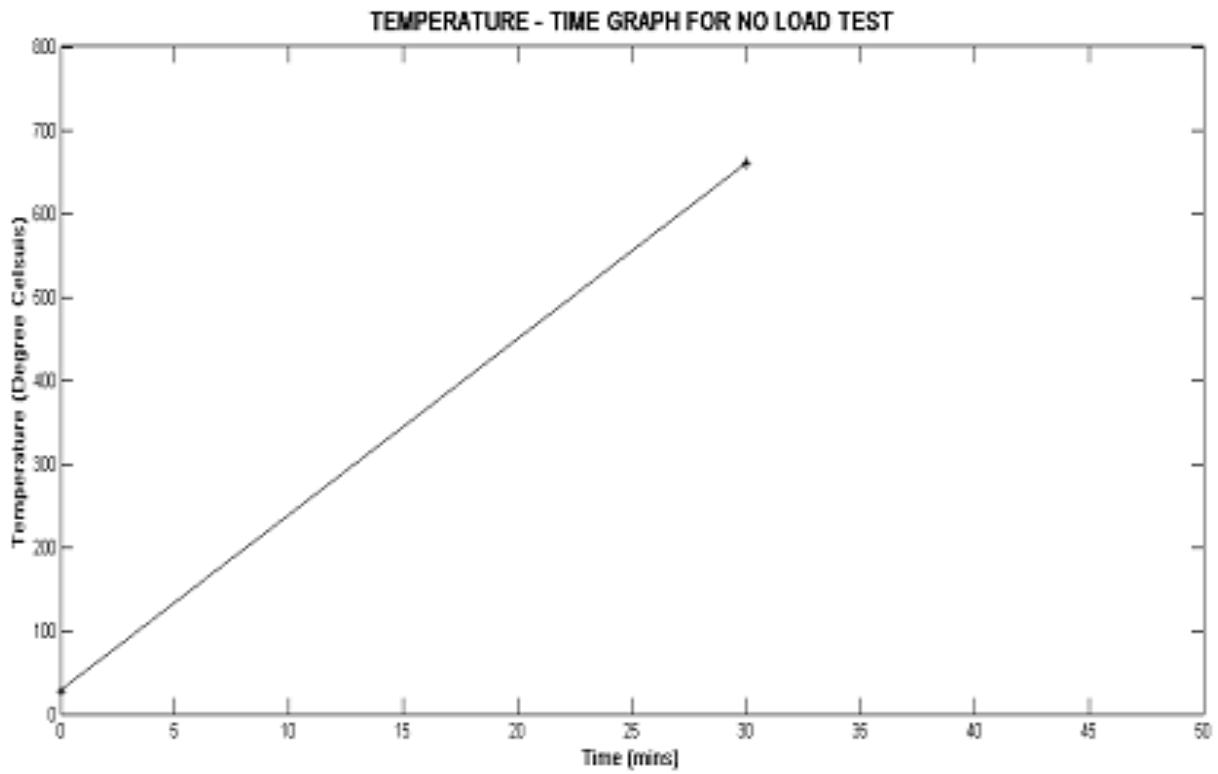


Figure 4.1 Vanatun of temperature versus time for no load test of a furnace.

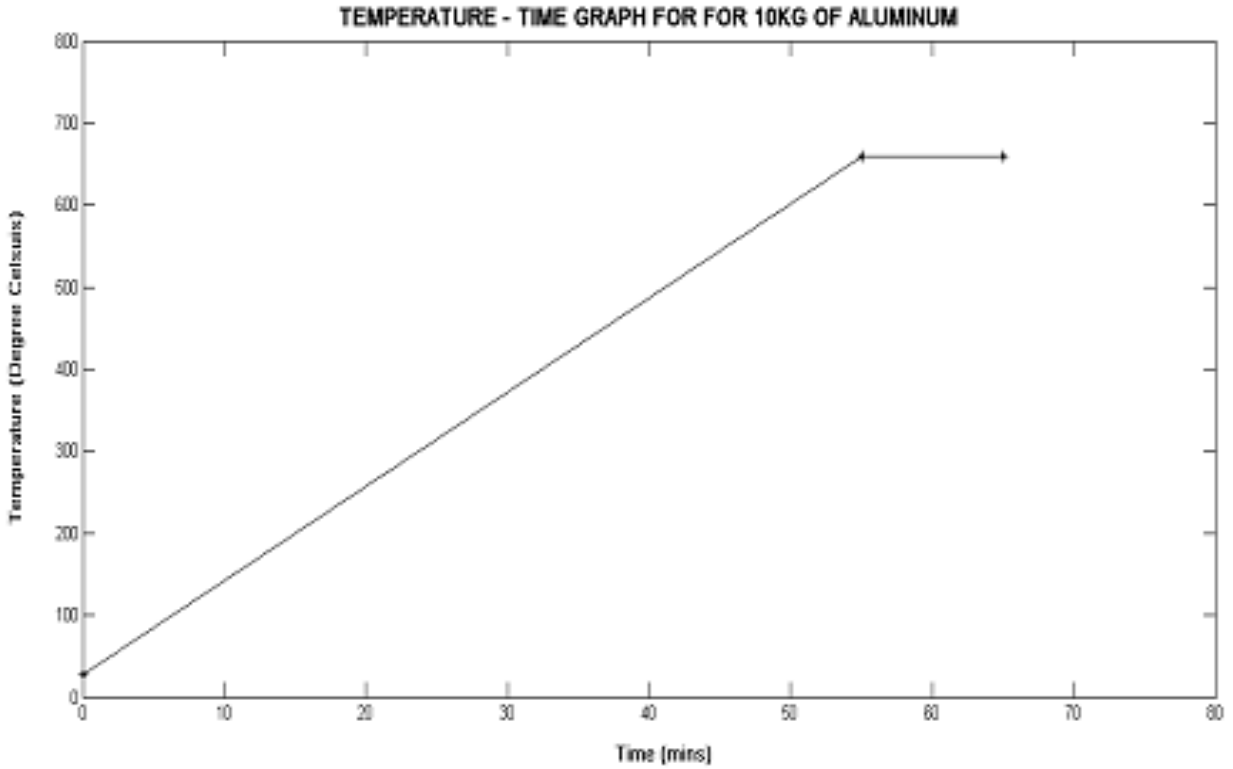


Figure 4.2 Vanatun of temperature versus time for 10kg of aluminum.

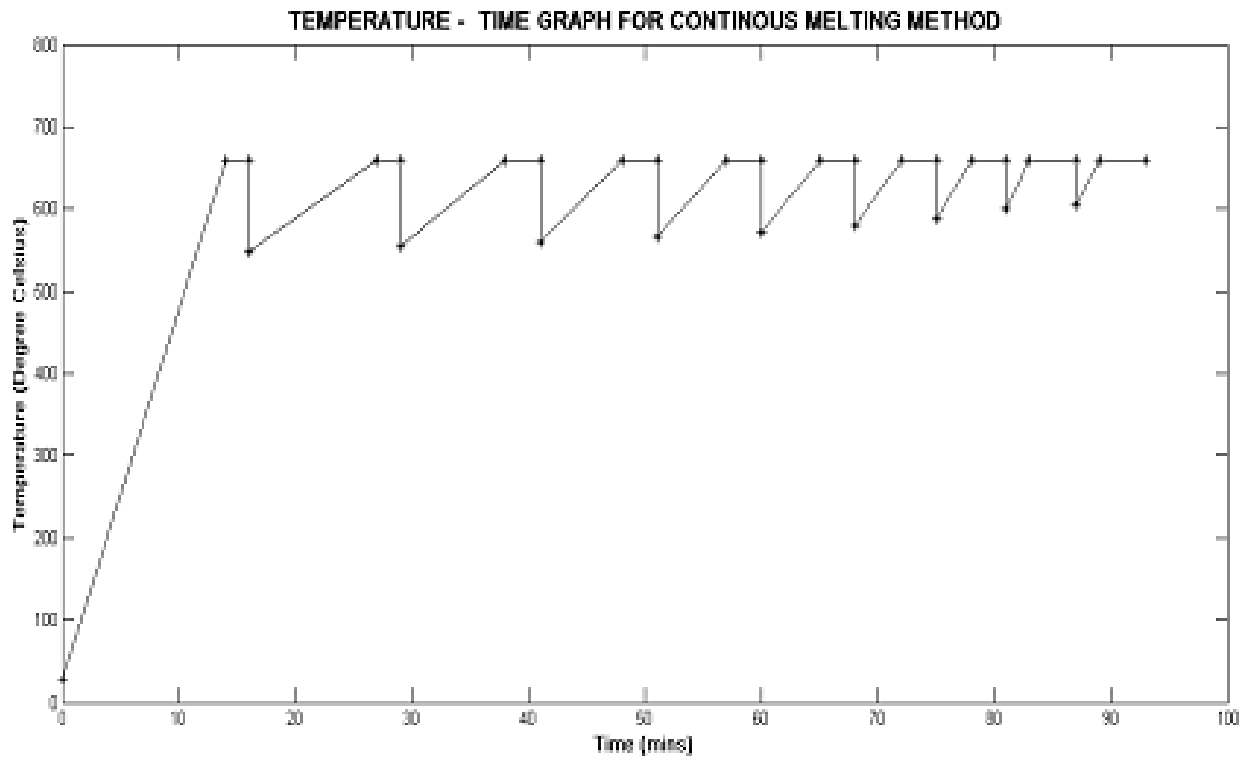


Figure 4.3 Vanatun of temperature versus time for melting 10kg of aluminum continues method.

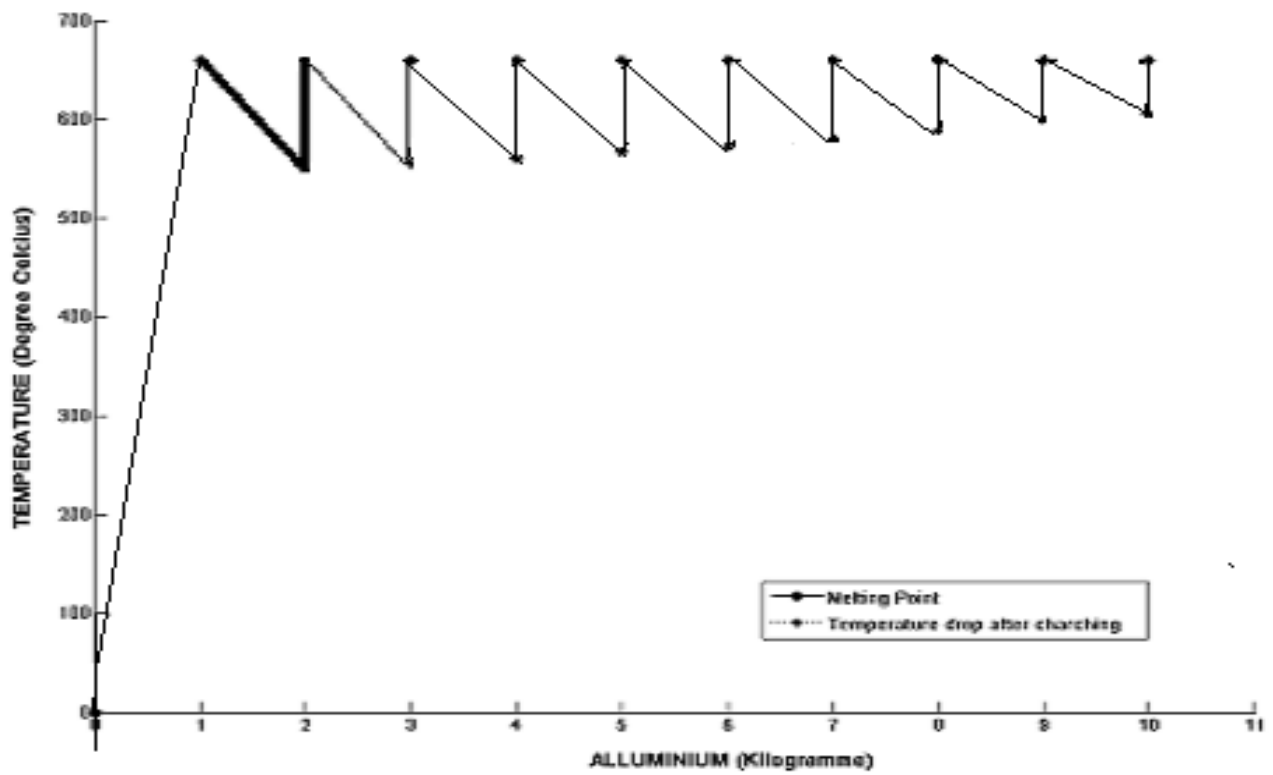


Figure 4.4 Vanatun of temperature versus increase in kilograms of aluminum and temperature dropped.

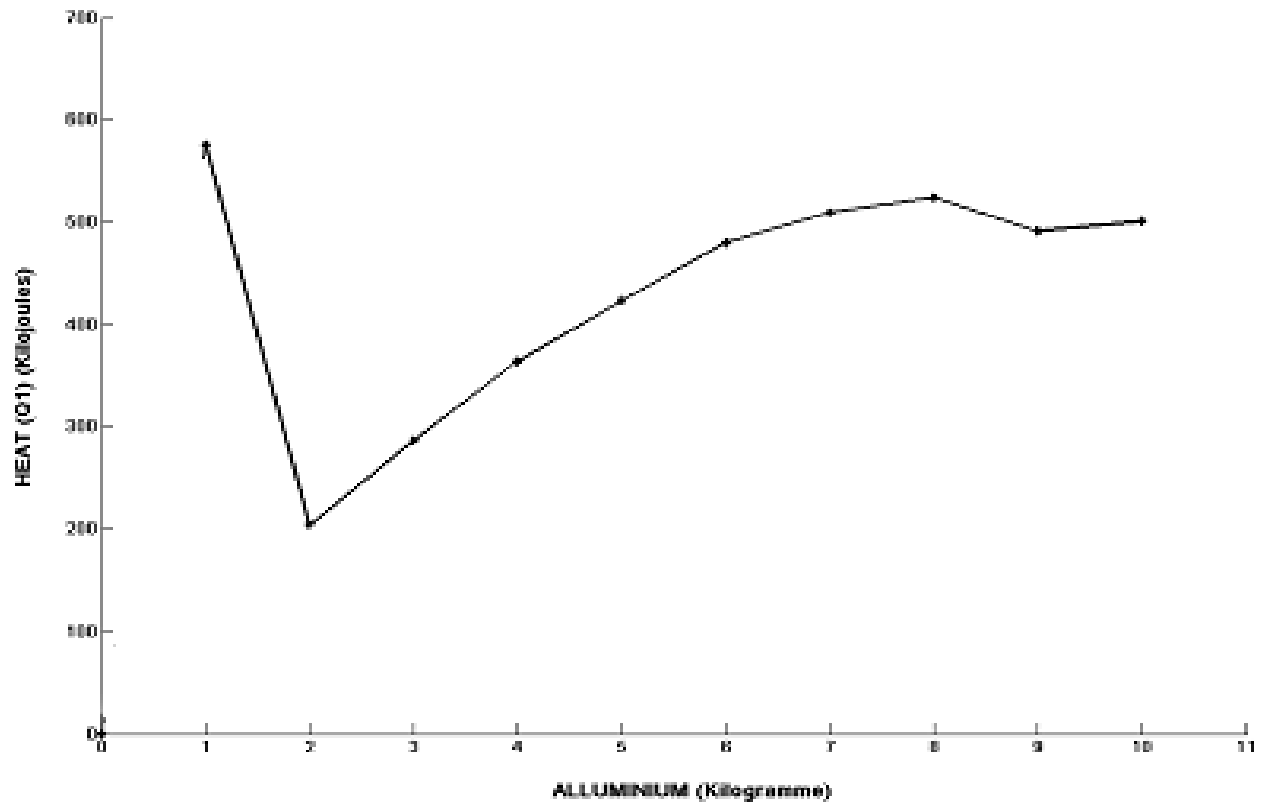


Figure 4.5: Curve of Sensible heat (Q_1) versus increase in kilograms of aluminum.

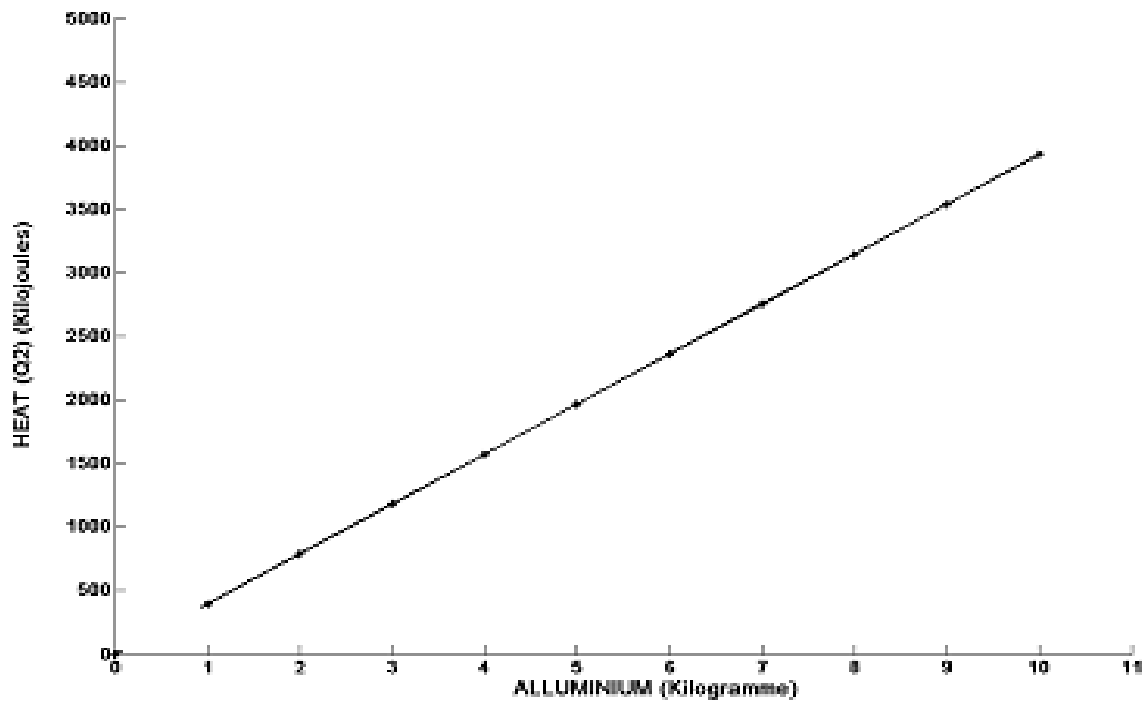


Figure 4.6: Curve of Enthalpy of fusion Heat (Q_2) versus increase in kilograms of aluminum.

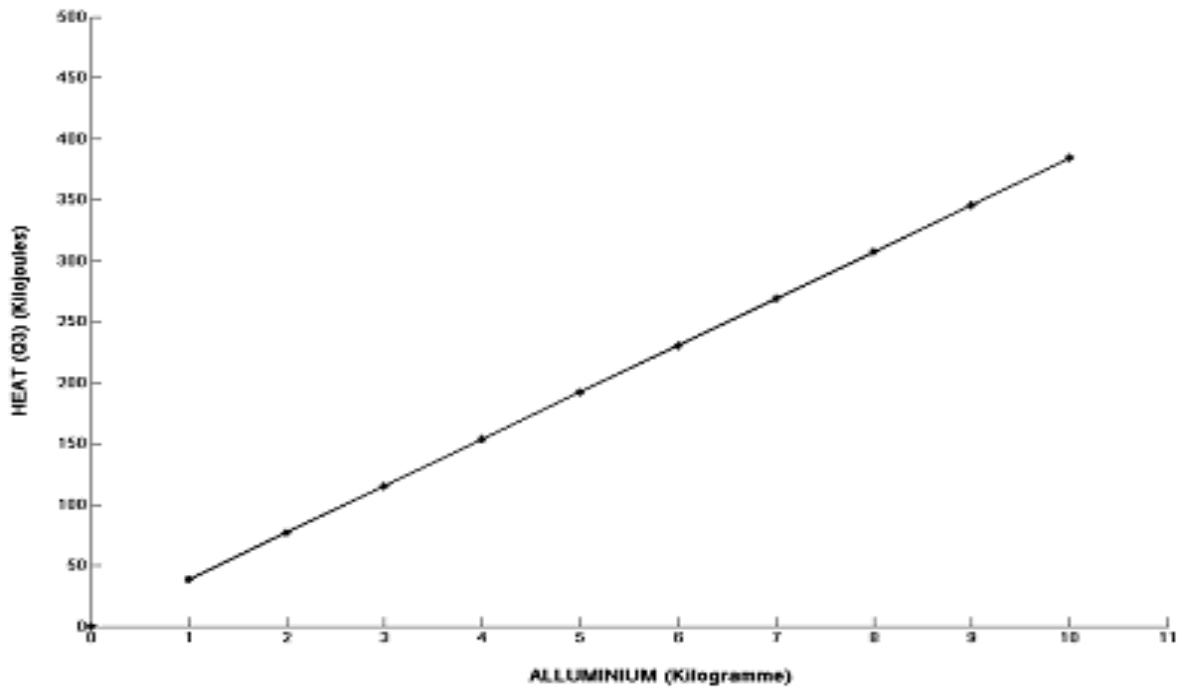


Figure 4.7: Curve of Super heat (Q_3) versus increase in kilograms of aluminum

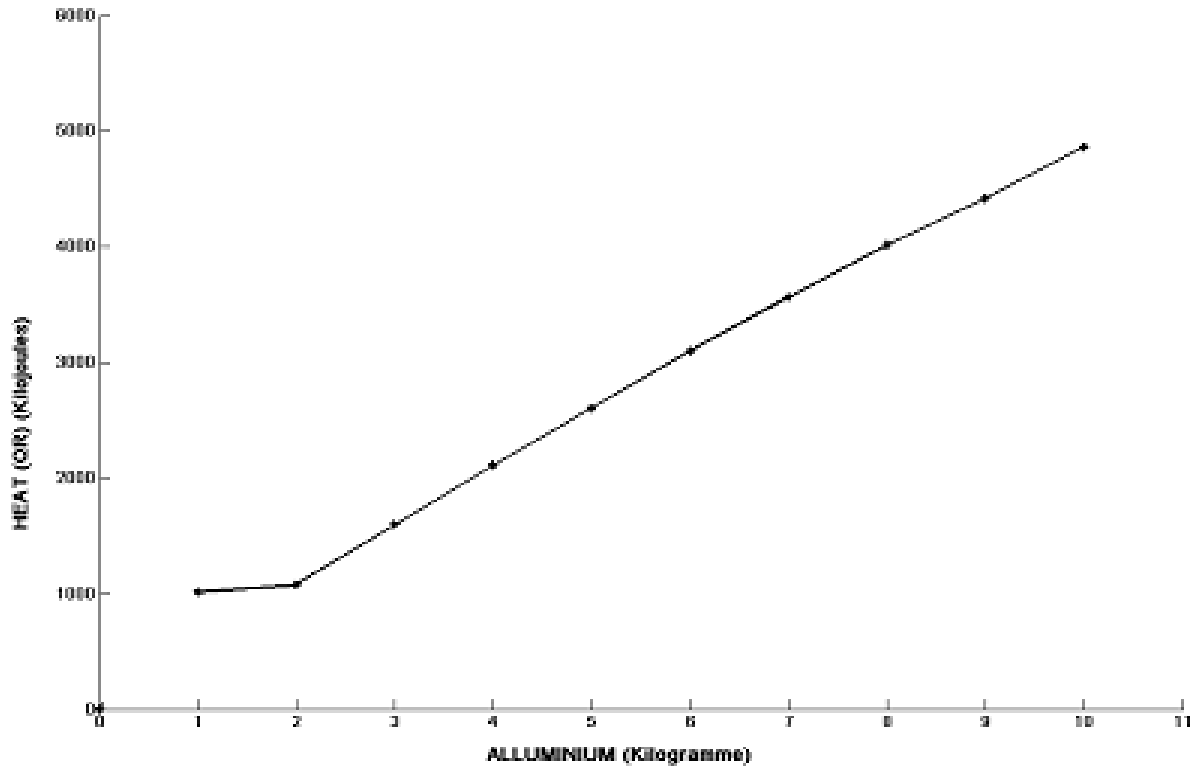


Figure 4.8: the curve of the total Heat required (Q_R) versus kilograms of Alluminiums.

CHAPTER FIVE

5.0 DISCUSSION OF RESULTS

From the results obtained from the various (three) test carried out, showed that;

5.1 No-load test

During this experiment the furnace was tested with the crucible empty without load of aluminum, Figure 4.1 shows that temperature of the crucible rose from room temperature of 28 °C to the aluminum melting point of 660 °C in 30 min, and it consumed only 1 kg of charcoal.

5.2 With load test

Figure 4.2 shows the trend of temperature –time for this experiment, the furnace was tested under the load of 10 kg at once, the load of 10 kg of aluminum was put in to the crucible furnace at once and tested the furnace performance, it was observed that the crucible temperature rose to the melting point of 660 °C in 55 min and it was maintained and held for 10 min while steering the aluminum to ensure the complete melting of aluminum, this test consumed 2.5 kg of charcoal.

5.3 Continuous test method

The continuous method of melting process was adopted in order to determine the time taken to melt each kilogram of aluminum and holding time for steering the molten aluminum to ensure complete melting of aluminum Table 4.1 in appendix II

Figure 4.3 shows the trend of the temperature rise and drop in the crucible while adding kilogram by kilogram of aluminum in to the mol aluminum in the crucible the temperature dropped to certain level before it rose back to 660 °C, the graph further show the holding time for every kilogram of aluminum to melt. After adding a kilogram of aluminum and continue firing the furnace when it reach the melting point the temperature drop after the addition of each kilogram decreased as the amount of aluminum increased and the holding time decreased as the drop in temperature became lower.

At the beginning of the experiment when the process started from room temperature the system takes longer time to melt 1kg of aluminum as the furnace was at its coldest state. It was observed that from the beginning of the experiment it takes 14 min to melt 1 kg at the temperature of 660 °C from room temperature 28 °C and 2 min as holding time. When another kilogram of aluminum was added into the molten aluminum in the crucible it quickly absorbed the heat and the temperature dropped from 660 °C to 548 °C, it took 11 minutes for it to rise from 548 °C to 660 °C with holding time of 2 min. when another kilogram was added to the melted aluminum in the crucible the temperature dropped to 555 °C and rose from 555 °C to 660 °C in 9 min and melted the 3 kilograms of aluminum in a holding time of 3 min. Another 1 kg was added to the molten aluminum in the crucible and the temperature dropped to 560 °C then rose in 7 min to melt 4 kg of aluminum at the temperature of 660 °C with a holding time of 3 min. the fifth kilogram was added to the molten aluminum in the crucible and it absorbed the heat from the molten metal and the temperature dropped to 567 °C. It took 6 min to rise the temperature from 567 °C to 660 °C and melt the 5 kg with 3 min holding time. when the sixth kilogram of aluminum was added to the molten aluminum in the crucible, it absorbed the temperature it dropped to 572 °C, and then rose to 660 °C in 5 min and holding time for steering was 3 min. The seventh kilogram of aluminum was added and the temperature dropped to 580 °C and after 4 minutes it rose to 660 °C and melted 7 kilograms of aluminum at 3min holding time. Another kilogram of aluminum was added in to the crucible which made the temperature drop to 588 °C and it took 3 minutes to rise the temperature to 660 °C to melt 8 kilograms of aluminum at a holding time of 3min. Another 1 kg of aluminum was added to the molten aluminum in the crucible which caused the temperature to drop to 600 °C and after 2 minute the temperature rose to 660 °C and 9 kg of aluminum was completely melted while steering it for 4min, with the gain at 660 °C. The last tenth kilogram of aluminum was added to the crucible and the temperature drop to 605 °C and rose after 2 minutes to 660 °C and the 10 kg of aluminum was melted completely at a holding time of 4 min.

The experimental results obtained agree with the theory of heat transfer, that when cooled body is in contact to hot body or cooled body dropped into the hot liquid is absorbed heat from it and causes its temperature to drop. As the amount of molten metal increases, the temperature dropped decreases and the time taken for it to be melted decreases.

Figure 4.4 shows the variation of temperature trend during the melting process, it shows how the temperature started to rise from room temperature to melting temperature of 660°C for 1kg of aluminum, from that stage the temperature dropped to certain point when the cold kilogram of aluminum was added into the crucible and continued to rise back to melting point after whiling the wheel for some time Table 4.2 in appendix II It can be seen from the graph trend that there is a steady temperature increase from room temperature to the melting point of aluminum, first kilogram melted completely for the period of 16 min including steering time, after adding another kilogram of aluminum the temperature suddenly dropped down from 660°C to 548°C Table 4.1 in appendix II give the detail for the time taken to raise the temperature back to melting point after charging each kilogram, the graph shows that the temperature raised and dropped was steady with reduction in time taken from 1 kg to 2 kg, 3 kg, 4 kg, 5 kg, 6 kg, 7 kg, 8 kg, 9 kg, 10 kg, the temperature drop reduced respectively, therefore from the graph we can see that furnace performance was good and the efficiency is also good. Temperature difference between each melting is reduced as shown in the graph, the experiment shows it takes longer time to melt 1kg of aluminum at the beginning of the experiment when the system (furnace) started working from room temperature, and it takes less time to melt 1kilogram when the furnace is completely hot as shown in table 4.1in appendix II.

From figure 4.5 the graph shows the trend of the sensible heat Q_1 of the heat at each point of melting a kilogram of aluminum after charging. Sensible heat is heat exchanged by a body or thermodynamic system that changes the temperature, and some macroscopic variables of the body, but leaves unchanged certain other macroscopic variables, such as volume or pressure. It is the heat needed to raise the temperature of the metal from room temperature to the melting point of the metal, it can be calculated by using this formula, $Q_1 = MCP (T_M - T_A)$, to determine the behavior of sensible heat at each point of melting a kilogram of aluminum from 1 – 10 kg of aluminum Table 4.3 in appendix II it can be seen from the figure that the sensible heat was raised from zero up to 575.12 kJ while melting 1 kilogram of aluminum, after adding another 1 kg of aluminum the heat surged and dropped to 203.84 kJ as the result of the heat absorbed by the cold aluminum of equal kilogram with the molten one, from that point of adding third kilogram of aluminum the sensible heat continued to increase with the increase in quantity of molten aluminum, this shows that the more the quantity of molten aluminum is increasing the more it conserved heat, the less a kilogram of cold aluminum it absorbed heat, that is after

adding another kilogram because the quantity of the molten aluminum in the crucible is increasing and conserved more heat, at the point of adding ninth kilogram the sensible heat dropped from 524.16 kJ from eight kilogram to 491.4 kJ and increased to 500.5 kJ at 10 Kg, this was due to the thickness of the aluminum added in to the crucible.

Figure 4.6 from Table 4.4 and appendix II, show the trend of enthalpy of fusion Q_2 for the aluminum, enthalpy of fusion also known as (latent) heat of fusion is the change in enthalpy resulting from heating a given quantity of a substance to change its state from a solid to a liquid. The temperature at which this occurs is the melting point, it was calculated by this formula $Q_2 = ML$, M is mass of aluminum which varies from 1 to 10 kg while L is the latent heat of fusion of aluminum which is given as 398 kJ/kg constant, therefore, from the formula we can see only the mass of aluminum is changing while the value for latent heat remain the same for 1 – 10 kg it give little variation, it can be seen from the graph the trend gives almost a straight line due to the small variations when adding 1 kg, the value of enthalpy of fusion at 1 kg is 398 kJ while at 10 kg the value is 3,980 kJ, the result shows that there was no decrease in enthalpy of fusion completely, this shows that enthalpy of fusion value at each point of melting a kilogram of aluminum is sufficient, and that the furnace efficiency is good.

Figure 4.7 shows the curve of super heat (Q_3) against mass of aluminum from Table 4.5 and appendix II, Superheat refers to the number of degrees a vapor is above its saturation temperature (boiling point) at a particular pressure. It is also known as the heat required to raise the temperature of the molten metal from its melting point to the required pouring temperature, super heated value at the point of melting a kilogram of aluminum was obtained using the following formula $Q_3 = MCP_2 (T_P - T_M)$, after calculating for super heat value for 1kg to 10 kg, the figure shows that there is raised in temperature of the molten metal from its melting point to the required pouring temperature, the graph shows that super heat at each point of melting a kilogram was sufficient to raise the temperature of the 10 kg of aluminum to the required super heat value.

Figure 4.8 from Table 4.6 in Appendix II shows the trend of the summation of heat in melting the metal Q_R is the summation of sensible heat, enthalpy of fusion and super heat at a point of melting every kilogram of aluminum, from the figure 4.8 it seen that the trend of the graph shows that at point of 1kg to 2 kg the total heat of sensible, enthalpy and super heat was low at

about 1,011.52 kJ to 1,076.64 kJ, when the quantity of kilograms continue to increase and molten metal conserved higher heat than at 1 kg, the heat also increase proportionally to the increase in kilograms. The highest heat required to raise the temperature of the metal from room temperature to the melting point, from the melting point to the liquid point from liquid point to the pouring point Q_R , was achieved, this curve shows that the heat at 1 kg to 2 kg was almost the same. the trend shows that the more molten kilograms of aluminums in the crucible the more it conserved heat and the less heat was absorbed when 1 kg of solid (cold) aluminum was added, this shows that the heat required to melt each kilogram was increased steady in the furnace, it indicate that the furnace performance achieved was in accordance with the theoretical efficiency of 76% from calculation.

The furnace produced the total heat $Q_T = 67,943.16$ kJ, and supplied the heat required to melt 10 kg of aluminum $Q_T = 35,859.13$ kJ, and the total heat absorbed by the furnace components was $Q_{FC} = 25,425.44$ kJ and the heat transferred to the crucible was $Q_C = 14,118.72$ kJ. The efficiency of the furnace was achieved at 76% dividing heat used by total heat supplied and multiplied by 100.

CHAPTER SIX

6.0 CONCLUSION AND RECOMENDATIONS

6.1 CONCLUSION

In developing countries like Nigeria, where job opportunities are very scarce, it is not wise to allow the few operating ones to close down. Therefore, Based on the results obtained from the performance test carried out on the fabricated crucible furnace the set objectives of the research was achieved, such as fuel economy, health hazard reduction and time required for the operation, the following conclusions can also be made:

1. The crucible furnace proved to be effective for melting of aluminum.
2. Melting aluminum in the crucible furnace proved to be more economical and time saving during operation.
3. It can be concluded that the device is suitable for use in small scale foundries and tertiary institutions.
4. The fabricated crucible furnace reached a temperature of 700 °C and produced 67,943.16kJ of heat in 1:33min.
5. The practical performance of the fabricated crucible furnace was in accordance with the efficiency value gotten from the calculation.

This research work has shown that with this simple device, the problem of casting in the small scale foundries in Nigeria will be solved.

6.2 RECOMMENDATIONS

1. Further research is recommended to ease the operation of the system.
2. The capacity of the combustion chamber should be increased to accommodate more fuel for longer operation period.
3. A seat should be designed for the operator for convenience of operations.
4. An awareness campaign should be undertaken to encourage the use of crucible furnace.

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APPENDICES
APPENDIX 1



Rotating wheel



Blower



Crucible



Furnace



Complete furnace unit

APPENDICES

APPENDIX II

a. Experimental results:

Table 4.1 test results of fabricated furnace

material mass (kg)	Aluminum				
	T_1 °C Temp. drop after charge	T_2 °C Melting temp.	Temp. difference ($T_2 - T_1$) °C	Time taken to raised the temp to melting point after charge (min)	Holding time for complete melting of aluminum (min)
1	Room temp.28	660	632	14	2
2	548	“	112	11	2
3	555	“	105	9	3
4	560	“	100	7	3
5	567	“	95	6	3
6	572	“	88	5	3
7	580	“	80	4	3
8	588	“	72	3	3
9	600	“	60	2	4
10	605	“	55	2	4
				Total time = 63min	30min
				Total time for the experiment is 1:33min	

Table 4.2: the temperatures at which kilograms of Aluminum melt

Aluminum (kg)	1	2	3	4	5	6	7	8	9	10
Melting point of each kilogram. (T_2) °C	660	660	660	660	660	660	660	660	660	660
Temperature drop (T_1) °C	28	548	555	560	567	572	580	588	600	605

b. Theoretical results

The following results were obtained by calculations using the experimental data, to determine the sensible heat, enthalpy of fusion and super heat values at each point of melting a kilogram of aluminum, the results obtained are given in Tables 4.3 – 4.6 in appendix II, and the graphs are shown in Figure 4.4 to 4.8.

The Theoretical results for heat needed for melting of metals are:

- a. Sensible heat (Q_1)
- b. Enthalpy of fusion (Q_2)
- c. Super heat (Q_3)
- d. Total heat at each melting point (Q_R)

Table 4.3: calculated values of the Sensible Heat (Q_1) at each point of melting 1 – 10 kgs of Aluminum in the furnace.

Aluminum (kg)	1kg	2kg	3kg	4kg	5kg	6kg	7kg	8kg	9kg	10kg
Heat $Q_1(KJ)$	575.12	203.84	286.65	364	423.15	480.48	509.6	524.16	491.4	500.5

Table 4.4: calculated values of the Enthalpy of fusion (Q_2) Heat for melting 1 – 10 kgs of Aluminum in the furnace

Aluminum (kg)	1kg	2kg	3kg	4kg	5kg	6kg	7kg	8kg	9kg	10kg
Heat Q_2KJ	398	796	1,194	1,592	1,990	2,388	2,786	3,184	3,582	3,980

Table 4.5: calculated values of the Super heat (Q_3) Heat raised the temperature of the 1 – 10 kgs of Aluminum from its melting point to the pouring temperature in the furnace.

Aluminum (kg)	1kg	2kg	3kg	4kg	5kg	6kg	7kg	8kg	9kg	10kg
Heat Q_3KJ	38.4	76.8	115.2	153.6	192	230.4	268.8	307.2	345.6	384

Table 4.6: Total Heat raised the temperature of 1 – 10 kgs of Aluminum from its solid state to molten state, and its pouring temperature (Q_R).

Weight (kg)	1kg	2kg	3kg	4kg	5kg	6kg	7kg	8kg	9kg	10kg
Heat Q_RKJ	1,011.52	1,076.64	1,595.85	2,109.6	2,605.15	3,098.88	3,564.4	4,015.36	4,419	4,864.5

APPENDIX III

WORKING DRAWINGS OF THE CRUCIBLE
FURNACE UNIT