DESIGN AND FABRICATION OF A GAS FIRED CRUCIBLE FURNACE

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UNDER THE SUPERVISION

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EDO STATE, NIGERIA.

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BENIN CITY, EDO STATE, NIGERIA

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CERTIFICATION

This is to certify that this project entitled “DESIGN AND FABRICATION OF GAS FIRED CRUCIBLE FURNACE” submitted by ETAGHENE BRIAN EJOVI meets the regulation governing the award of Bachelors of Engineering (B.ENG) in Production Engineering, University of Benin.

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DEDICATION

This project is dedicated to my late father Dcn. Benjamin E. Etaghene who started my academic journey with me but unfortunately is not here to see me cross the finish line. Also, I want to thank GOD for His wisdom, grace and immeasurable infinite mercy for seeing me through my study in the University of Benin.

ACKNOWLEDGEMENT

I wish to express my profound gratitude to God Almighty who is the source of all knowledge, for His inspiration, tender mercy, wisdom and love throughout my stay in the University of Benin, Edo State.

1 wish to acknowledge my supervisor Prof J.O Osarenwinda for his wonderful contribution in my academic pursuit and for making my project a success. I acknowledge my course adviser Engr. Mrs T.I Akilaki who played the role of a mother to me as a Production Engineering student and have inculcated academic knowledge into me during this period of my academic pursuit.

My love goes to my parents Mrs. Florence Awaritoma and my foster father Hon. (Barr.) Ejaife Omizu Odebala for their confidence, moral and financial support throughout my stay in the University of Benin, may God bless you all abundantly.

ABSTRACT

A crucible furnace is an equipment used in the foundry workshop or industry for melting metals for casting operations. They are the oldest type of melting furnaces used for melting and holding small batches of non-ferrous alloys for which a refractory crucible filled with metal is heated through the crucible wall. This paper focuses on the development of a 38-kilogram capacity LPG butane gas-fired crucible furnace used to melt aluminium metal. Drawings were produced to aid the fabrication of the furnace using a mild steel sheet while the other components needed for the fabrication were selected based on functionality, durability, availability of local materials and cost. The test was carried out on the furnace to evaluate the performance and the results obtained showed that it took the furnace 24minutes to completely melt 38kg of aluminum scrap between 630^0C to 700^0C. The heating rate is 56.11^0C/min, melting rate of 1.58kg/min and a 39.6% maximum efficiency, which is quite impressive when compared with the conventional crucible furnace.

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NOMENCLATURE

t = Furnace wall thickness (mm)

p = maximum working pressure of the furnace (N/m^2)

Δd = Change in diameter(mm)

D = Internal diameter of the furnace (mm)

Rf = Inner radius of the furnace

E = Modulus of elasticity of the materials (N/m^2)

C = Poisons ratio

$\Delta\theta$ = Change in temperature(°C)

Δl = Change in length (mm)

∅ = Crucible diameter (mm)

Δv = Crucible length (m^3)

Q = Heat supply (kJ)

K = Thermal conductivity of the insulating material (W/Mk)

Tm = Melting temperature

T_p = Pouring temperature

L = Latent heat of fusion

Cp = Specific heat at constant pressure

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to The Study

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. Aluminum recycling is one of the most lucrative business practices in Nigeria and the world at large. The recycling of aluminum involves melting of aluminum scraps and further casting it into ingots, billets or finished/semi-finished products. Most of the crucible furnaces are imported which costs Nigeria a lot of foreign exchange thus producing the crucible furnace with locally made materials saves a lot of foreign exchange.

Furnace choice may be dependent on the alloy system and quantities produced. Most aluminum foundries use either an electric resistance or gas heated crucible or reverberatory furnaces. 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.

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 University of Benin foundry uses a diesel fired furnace and a pipe to supply diesel needed for combustion 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. An improved furnace can be designed and fabricated to improve on the locally used furnaces. The crucible furnace is the oldest form of foundry technology which has been used and has varied with time. The design reflects the purposes for which they are used.

1.2 Statement of Problem

The major problems associated with the crucible furnaces used in the local foundries like the Production Engineering Laboratory are: -

I. Most of the crucible furnaces are imported which costs Nigeria a lot of foreign exchange thus producing the crucible furnace with locally made materials saves a lot of foreign exchange.

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.

IV. Gas as a source of energy can be very hazardous.

V. The foundry man is exposed to heat and combustion products which are harmful to his health.

1.3 Aim of Study

The aim of study is to design and construct a gas fired crucible furnace using locally sourced materials.

1.4 Objectives

Specific objectives of this research are as follows:

I. To design a gas fired crucible type furnace that can melt aluminum.

II. To construct the furnace using local materials.

III. To carry out performance evaluation of the crucible furnace.

1.5 Significance of The Study

The design and construction of a gas 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.

1.6 Scope/Limitation of Study

The scope of the work will be limited to the designing and constructing of a gas fired crucible furnace from locally sourced materials for melting aluminum and these materials include; Mild steel, firebricks, durax and sodium silicate. The design philosophy is to eliminate the use of heating elements requiring electric power which is very expensive cost. This project is done in other to meet the ever-increasing demand for molten metal in carrying out foundry operations.

1.7 Definition of Terms

1.7.1 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.

1.7.2 Fuel

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.

1.7.3 Aluminium

Aluminium 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.

1.7.4 Furnace

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 furnaces used at higher temperatures for various materials and purposes.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Historical Background

It is clear that despite the advances in the mode of melting metal scrap (aluminum), the gas fired crucible furnace is not commonly used in local foundries in Nigeria due to the fact that gas cannot easily be accessed locally except in big industries. Also, the gaseous fuel used (butane) is not readily available and cheap 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 furnaces 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, reverberatory, 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 butane, although coke, charcoal, oil or electricity can be used.

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 mould and removing the moulded 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 lined 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, et al (2004), conducted a 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.

2.2 Types of Furnaces

There are many types of furnaces in use, each having peculiar features which makes 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

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).

2.2.1 Classification of Furnace

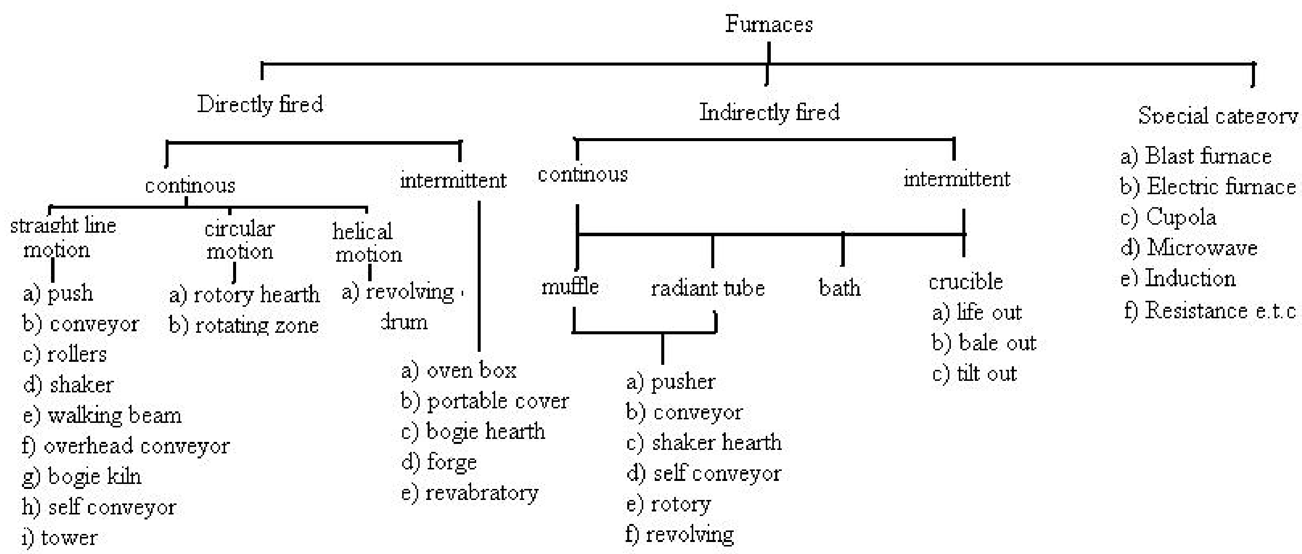
Furnaces are classified from different points of view but each type of industrial furnace comprises three portions which are:

- 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

Figure 2.1 a broad classification of furnace



Higgins R.A. (1984)

2.2.2 Crucible Furnaces

Crucible furnaces vary considerably in design capacity and range; from laboratory furnaces which are used for melting a few kilograms of metal to industrial furnaces both small and large scale holding as much as thousands of kg. These include lift-out, tilting, bail-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. Bail-out: In this type of furnace, the molten metal is ladled out.

There are other types of furnaces utilizing crucibles. These are:

IV. Rotary Crucible Furnace

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.

2.2.3 Blast Furnace

A blast furnace is a type of metallurgical furnace used for smelting to produce industrial metals, generally pig iron, but also others such as lead or copper. Blast refers to the combustion air being "forced" or supplied above atmospheric pressure. In a blast furnace, fuel (coke), ores, and flux (limestone) are continuously supplied through the top of the furnace, while a hot blast of air (sometimes with oxygen enrichment) is blown into the lower section of the furnace through a series of pipes called tuyeres, so that the chemical reactions take place throughout the furnace as the material falls downward.

2.2.4 Reverberatory Furnace

A reverberatory furnace is a metallurgical or process furnace that isolates the material being processed from contact with the fuel but not from contact with combustion gases. The term reverberation is used here in a generic sense of rebounding or reflecting, not in the acoustic sense of echoing.

2.2.5 Puddling Furnace

The puddling furnace is a metal making technology used to create wrought iron or steel from the pig iron produced in a blast furnace. The furnace is constructed to pull the hot air over the iron without the fuel coming into direct contact with the iron, a system generally known as a reverberatory furnace or open-hearth furnace. The major advantage of this system is keeping the impurities of the fuel separated from the charge.

2.2.6 Open Hearth Furnace

Open-hearth furnaces are one of several kinds of furnace in which excess carbon and other impurities are burnt out of pig iron to produce steel. Since steel is difficult to manufacture owing to its high melting point, normal fuels and furnaces were insufficient and the open-hearth furnace was developed to overcome this difficulty. Compared to Bessemer steel, which it displaced, its main advantages were that it did not expose the steel to excessive nitrogen (which would cause the steel to become brittle), was easier to control, and permitted the melting and refining of large amounts of scrap iron and steel.

2.2.7 Cupola Furnace

A cupola furnace is a melting device used in foundries that can be used to melt cast iron, Ni-resist iron and some bronzes. The cupola can be made almost any practical size. The size of a cupola is expressed in diameters and can range from 1.5 to 13 feet (0.5 to 4.0 m).[1] The overall shape is cylindrical and the equipment is arranged vertically, usually supported by four legs. The overall look is similar to a large smokestack. The bottom of the cylinder is fitted with doors which swing down and out to 'drop bottom'. The top where gases escape can be open or fitted with a cap to prevent rain from entering the cupola. To control emissions a cupola may be fitted with a cap that is designed to pull the gases into a device to cool the gases and remove particulate matter.

2.2.8 Electric Furnace

Electric furnaces have heating chambers with electricity as the heat source for achieving very high temperatures to melt and alloy metals and refractories. The electricity has no electrochemical effect on the metal but simply heats it. Modern electric furnaces generally are either arc furnaces or induction furnaces. A third type, the resistance furnace, is still used in the production of silicon carbide and electrolytic aluminum.

2.2.8.1 Electric Arc Furnace

An electric arc furnace (EAF) is a furnace that heats charged material by means of an electric arc. Industrial arc furnaces range in size from small units of approximately one ton capacity (used in foundries for producing cast iron products) up to about 400 tonne units used for secondary steelmaking. Arc furnaces used in research laboratories and by dentists may have a capacity of only a few dozen grams. Industrial electric arc furnace temperatures can reach 1,800 °C (3,272 °F), while laboratory units can exceed 3,000 °C (5,432 °F).

2.2.8.2 Induction Furnace

An induction furnace is an electrical furnace in which the heat is applied by induction heating of metal. Induction furnace capacities range from less than one kilogram to one hundred tonnes and are used to melt iron and steel, copper, aluminum, and precious metals. The advantage of the induction furnace is a clean, energy-efficient and well-controllable melting process compared to most other means of metal melting. Most modern foundries use this type of furnace, and now also more iron foundries are replacing cupolas with induction furnaces to melt cast iron, as the former emit much dust and other pollutants. Since no arc or combustion is used, the temperature of the material is no higher than required to melt it; this can prevent loss of valuable alloying elements. The one major drawback to induction furnace usage in a foundry is the lack of refining capacity; charge materials must be clean of oxidation products and of a known composition and some alloying elements may be lost due to oxidation (and must be re-added to the melt).

2.2.8.3 Resistance Furnace

Resistance furnaces are heating installations that use the heat generated by Joule effect in appropriate heating elements (resistors) located on the walls of the furnace chamber, and transmitted to the workpiece to be heated mainly by radiation and convection. The resistance furnace is still used in the production of silicon carbide and electrolytic aluminum; in this type, the furnace charge (i.e., the material to be heated) serves as the resistance element. In one type of resistance furnace, the heat-producing current is introduced by electrodes buried in the metal. Heat also may be produced by resistance elements lining the interior of the furnace.

2.3 Furnace 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 consists of elements which neither burn nor support combustion includes nitrogen and water.

2.3.1 Types of Fuel Used

1. Solid Fuels

2. Liquid Fuels

3. Gaseous Fuels

4. Mixed/Multi Fuels

2.4 Butane Gas

Butane gas is any one of a number of fuels that under ordinary conditions is gaseous. Many fuel gases (like butane, methane or propane), are composed of hydrocarbons, hydrogen, carbon monoxide, or mixtures thereof. Such gases are sources of potential heat energy or light energy that can be readily transmitted and distributed through pipes from the point of origin directly to the place of consumption.

Fuel gas is contrasted with liquid fuels and from solid fuels, though some fuel gases are liquefied for storage or transport. While their gaseous nature has advantages, avoiding the difficulty of transporting solid fuel and the dangers of spillage inherent in liquid fuels, it also has limitation. It is possible for a fuel gas to be undetected and collect in certain areas, leading to the risk of a gas explosion. For this reason, odorizers are added to most fuel gases so that they may be detected by a distinct smell. The most common type of fuel gas in current use is natural gas.

2.4.1 Types of Fuel Gas

There are two broad classes of fuel gases, based not on their chemical composition, but their source and the way they are produced: those found naturally and those manufactured from other materials.

I. Manufactured Fuel Gas - Manufactured fuel gases are those produced through an artificial process usually gasification at a location known as a gasworks. Manufactured fuel gases include: Coal gas, water gas, producer gas, syngas, wood gas, uncompressed hydrogen or compressed hydrogen may be used as a fuel gas, biogas, blast furnace gas, acetylene.

II. Natural Gas - composed primarily of methane became the dominant source of fuel gas as instead of having to be manufactured in various processes, it could be extracted from deposits in the earth. Natural gas may be combined with hydrogen to form a mixture known as HCNG. Additional fuel gases can result as a process of refining natural gas or petroleum: Propane, butane and regasification of liquefied petroleum gas.

2.4.2 Uses of Fuel Gas

Fuel gases have been used in numerous applications. One of the earliest was gas lighting, which enabled the widespread adoption of streetlamps and the illumination of buildings in towns with a municipal gas supply. Fuel gas is also used in gas burners, in particular the Bunsen burner used in laboratory settings. It may also be used gas heaters, camping stoves, and even to power vehicles, they have high calorific value.

2.5 Aluminium and Its Alloys

Aluminium 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 aluminium, 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, Aluminium 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 aluminium 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 Aluminium

Aluminium 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 aluminium 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. Aluminium is very ductile and malleable, and it melts easily and may be formed into parts by casting (Chapman, 1972).

The melting temperature of aluminium 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 aluminium, 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.

2.5.2 Cast Aluminium

Cast aluminium 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 aluminium because it is cheaper and lighter than iron. Die casting, mold casting, or sand castings are used to create cast aluminium items from liquid aluminium.

Cast aluminium 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 aluminium for use in creating components for many different types of products. This form of aluminium 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.

2.5.3 Aluminium Casting Alloys

The most important aluminium 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 aluminium alloys contain primarily silicon, magnesium and copper.

2.6 Refractory Materials

A refractory material or refractory is a material that is resistant to decomposition by heat, pressure, or chemical attack, and retains strength and form at high temperatures. Refractories are inorganic, nonmetallic, porous, and heterogeneous. They are typically composed of oxides or non-oxides like carbides, nitrides etc. of the following materials: silicon, aluminum, magnesium, calcium, and zirconium. Some metals with melting points >1850 °C like niobium, chromium, zirconium, tungsten, rhenium, tantalum etc. are also considered as refractories. Refractory materials are used in furnaces, kilns, incinerators, and reactors. Refractories are also used to make crucibles and moulds for casting glass and metals and for surfacing flame deflector systems for rocket launch structures. Today, the iron and steel industry and metal casting sectors use approximately 70% of all refractories produced.

2.6.1 Classification of Refractory

Refractories are classified in multiple ways based on:

- Chemical composition
- Method of manufacture
- Fusion temperature
- Refractoriness
- Thermal conductivity

2.6.2 Uses of Refractory Materials

Refractory materials are useful for the following functions:

I. Serving as a thermal barrier between a hot medium and the wall of a containing vessel
II. Withstanding physical stresses and preventing erosion of vessel walls due to the hot medium
III. Protecting against corrosion
IV. Providing thermal insulation

2.6.3 Application of Refractory Materials

Refractories have multiple useful applications. In the metallurgy industry, refractories are used for lining furnaces, kilns, reactors, and other vessels which hold and transport hot medium such as metal and slag. Refractories have other high temperature applications such as fired heaters, hydrogen reformers, ammonia primary and secondary reformers, cracking furnaces, utility boilers, catalytic cracking units, air heaters, and sulfur furnaces.

2.7 Mode of 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

2.7.1 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.

2.7.1.1 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.

$$Q \propto A.\frac{dt}{dx}, \qquad 2.1$$

or

$$Q =- K.A\frac{dt}{dx}, \qquad 2.2$$

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,

$$Q = \frac{-KA(T_2 - T_1)}{L}$$

For composite materials as shown in Figure 2.2

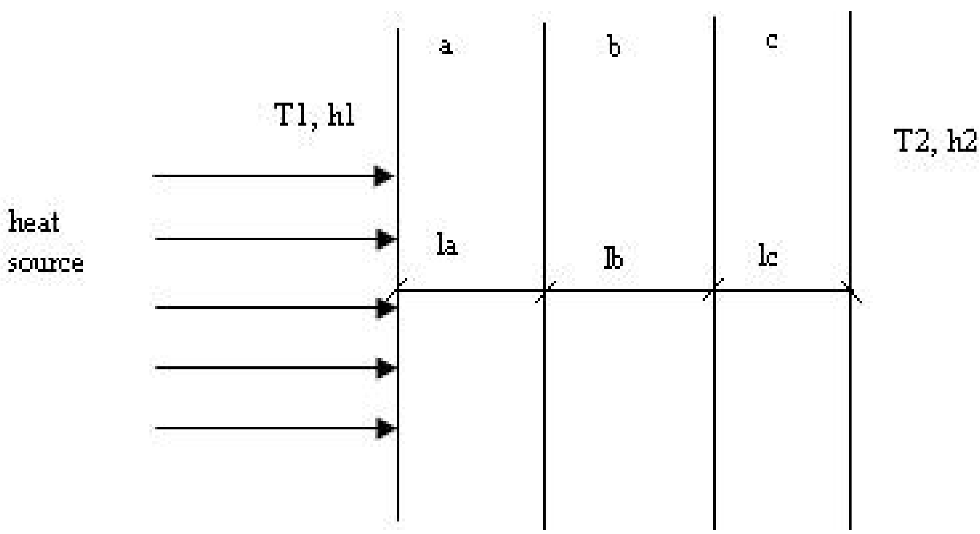


Figure 2.2 Conduction of heat through slabs of different materials

$$Q = \frac{dT}{\Sigma R} = \frac{T^2 - T^1}{\Sigma R} \qquad 2.3$$

Where;

$$\Sigma R = \frac{1}{H^1 A} + \frac{1}{H^0 A} + \frac{L_a}{K_a A} + \frac{L_b}{K_b A} + \frac{Lc}{K^1 A} \qquad 2.4$$

Therefore,

$$Q = \frac{T^2 - T^1}{\frac{1}{h^1 A} + \frac{1}{h^0 A} + \frac{L_a}{K_a A} + \frac{Lь}{KьA} + \frac{Lc}{K^1 A}} \qquad 2.5$$

Where;

ΣR = Total Thermal Resistance of The Composite Material

H = Conductive Heat Transfer Co-Efficient

2.7.2 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:

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

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.

2.7.3 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. $$Q \propto T^4 \qquad 2.7$$

$$Q = \partial A T^4, \qquad 2.8$$

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:

$$Q = \partial A_1 T_1{}^4 - \sigma A_2 T_2{}^4 \qquad 2.9$$

$$Q = \partial A(T_1{}^4 - T_2{}^4) \qquad 2.10$$

2.8 Review of Past Work

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

Osarenmwinda J.O. (2015) carried out a project on fabrication and performance of an oiled fired crucible furnace using locally sourced materials. The crucible furnace was found to have an efficiency of 10.34% which was relatively low as a result of comparable energy loss due to the opening of the top which has been a characteristic for most oil and gas fired furnaces. The furnace was observed to have a good melting rate and a fast-heating rate of 43.9degrees per minute and attains a temperature as high as 1386 degrees. The furnace can therefore be used to melt and treat most metals including cast iron.

Jim Roberts (2015) used a case study of Eck Industries in Manitowoc, Wis., which showed the fuel savings realized by the addition of a self-recuperative gas burner to crucible melting furnaces. It was realized that over 60% of the fuel required for melting and holding high-grade aluminum was saved, costs was cut and efficiency was increased.

Roffel, B (1974) developed a non-linear model for a gas fired furnace. The model is applicable from minimum to maximum heat load of the furnace. The dynamics of the model have been compared to experimental results, which were obtained for a pilot-scale furnace.

OA Ighodalo (2013) developed a cylindrical gas-fired crucible furnace for recycling aluminum in small-scale foundries in Nigeria. The furnace chamber was 410mm high and 510mm diameter and had a design capacity of 15kg/hr. A heat balance program was used to estimate the fuel consumption and the burner power was determined as 56.6KW. The furnace was assembled and tested by melting 2.5kg of aluminum scrap. It was able to melt the aluminum at an efficiency of 25.6%. It was observed that there were large energy losses which could be reduced by proper furnace sealing and the use of a recuperator to recycle heat from exhaust gases to preheat the air for combustion.

Newbold J; (1997) on the combustion measurements in an industrial gas fired flat glass furnace discovered that a region of intense reaction is observed near the glass with large concentration gradients and incomplete combustion even in the tail of the flame. Significant variations were observed in the exhaust profiles of most measured variables. A normal preheat air temperature 1420K and a variation of exhaust temperatures between 1630K and 1835K were noted.

Weatherspoon (1996) conducted a study on the Holden gas-fired furnace which is used in the enriched uranium recovery process to dry and combust small batches of combustibles. Regulators and orifice valves were used to provide a minimum gas pressure at a rate of approximately 1,450scf/h to the burners. The gas flow rate was calculated by determining the gas flow appropriate for the instrumentation of the gas line. A review of the furnace safety showed that safety is ensured by design, interlocks, procedure and a safety system.

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.

CHAPTER THREE

3.0 MATERIALS AND METHODOLOGY

3.1 Design Flow Chart

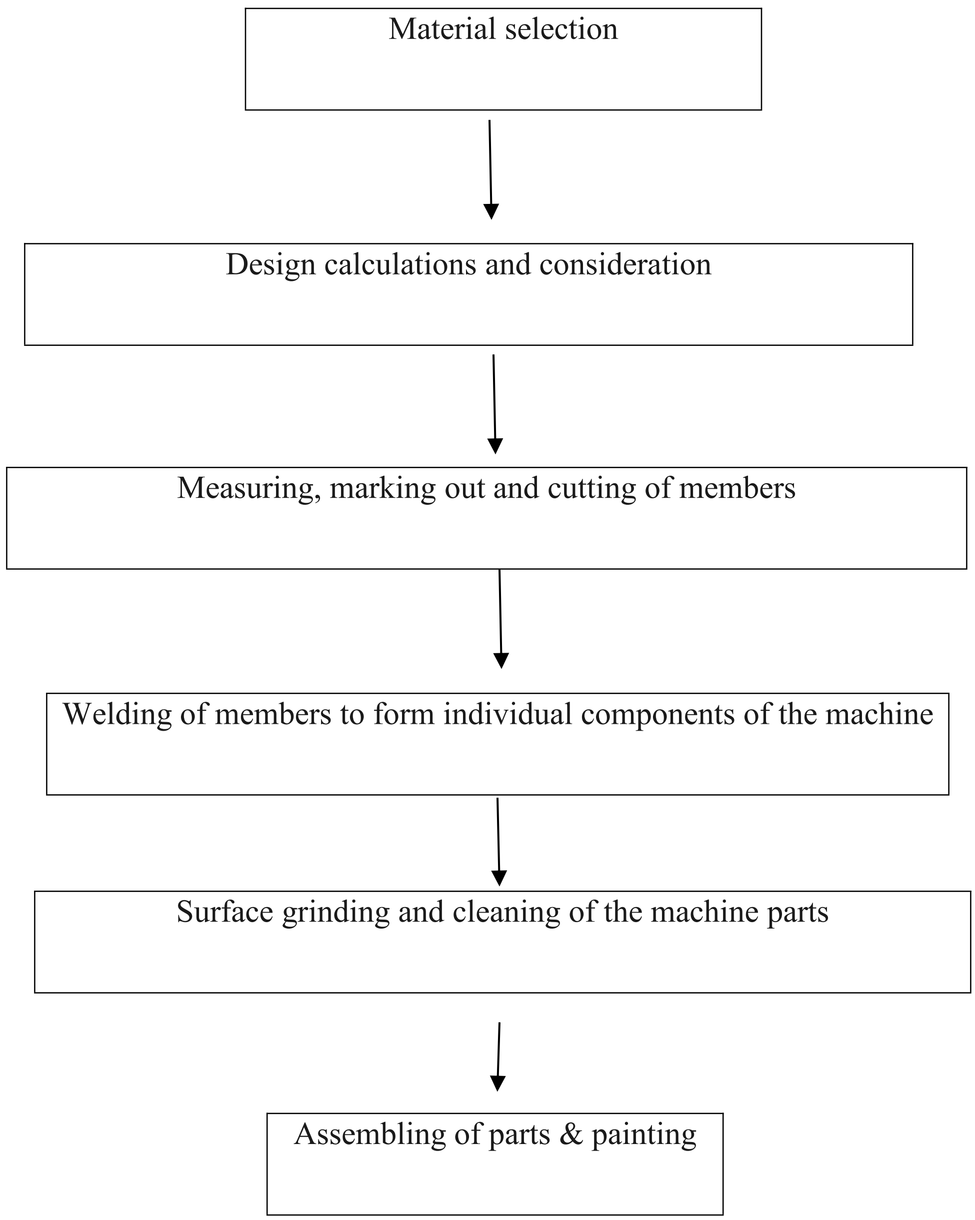


Fig 3.1 Design flow chart

3.2 Material Selection

This is based on the fact that a furnace with improved efficiency, minimum heat losses and minimum amount of impurity in the molten aluminium produced is required to reduce inefficiency and low quality (as regards to physical and mechanical quality) of aluminium produced by local blacksmiths in Nigeria. The choice of materials for the development of the furnace was based on the following engineering requirements:

a) Weldability: This is the ability of the material to be welded.

b) Toughness: This is the ability of the material to withstand shock and absorb energy due to impact.

c) Fatigue: This is the ability of the material to withstand cyclic stresses.

d) Ductility: This is the ability for the material to be drawn into wire.

e) Durability: This is the ability to stay strong and in good condition over a long period of time.

f) Availability: This is the state of the material being readily accessible.

The mild steel plate used for fabricating most components of the furnace is ductile, thus making it possible for it to be rolled, folded and bent without cracks or fractures.

The under listed materials were specified for the design of the gas fired crucible furnace and were all obtained within Benin.

- Firebricks

- Angle bar
- Welding electrode
- Mild steel rod
- Firebrick cement(durax)
- Bolts and nuts

The selected materials for the different components of the furnace are as stated in Table 3.1

COMPONENT	**FUNCTIONS**	**MATERIAL USED/TYPE**	**REASONS**
Casing	Houses the refractory, pot and combustion chamber	Mild Steel	Strength, low cost
Refractory Wall	Prevents heat loss due to conduction, retains heat within the combustion chamber and maintains high temperature needed for complete fuel combustion	Firebrick cement, sheet metal, Clay	Poor thermal conductivity and high temperature resistant composite
Crucible pot	Contains the aluminum to be melted	High carbon steel	High thermal conductivity
Cover	Withstands the internal heat and pressure	Mild steel	Increases the efficiency of the furnace.

Table 3.1: Material selection table

3.3 Methodology

The gas fired crucible furnace was designed majorly to melt aluminum. However, the gas fired crucible furnace can also be used to melt other metals whose melting temperatures falls within its designed operation temperature range. Some of the equipment used in fabricating the various parts of the furnace are as follows:

(a)Folding/Rolling Machine

(b) Drilling Machine

(c) Welding Machine

(d) Cutting Tools

(e) Marking/Measuring tools etc.

3.4 Components of The Furnace

The gas fired crucible furnace consists of the following components:

(I) The Furnace Casing

(II) The Furnace Cover

(III) Fire Bricks

(IV) Burner

(V) Opening/Closing Mechanism of Furnace Cover

(VI) Base Stand

3.5 Components Design

3.5.1 The Furnace Frame

Mild steel angle bar of 50mm x 50mm x2mm was used to construct the frame, which is the main support of the furnace that carries the whole load of the furnace comprising the weight of the furnace housing, the gas burner and the weight of the refractory material inside the furnace housing. Mild steel angle bar will be selected over other materials because of its strength, availability and low cost.

3.5.2 The Furnace housing or casing

Mild steel sheet of 2mm thickness was used in order to get the required geometry and dimensions of the furnace housing. The selection criteria favours this grade of mild steel because of its ability to be formed into different shapes coupled with its ability to retain these shapes in service. It houses all the component of the furnace including firebricks, refractive lining, the burner and the crucible.

Fig 3.2 Furnace Housing

3.5.3 Burner

This component was mounted on the burner support which will be bolted to the support using M13 bolt, making the nozzle of the gas burner to be able to enter the 60mm diameter hole to be made on the furnace housing body.

Fig 3.3 Oxygen and Butane Burner

3.5.4 Refractory Materials/Liners

The refractory lining for the furnace was made by mixing firebrick cement with sodium silicate. The thoroughly blended mixture will then be used in the lining of the furnace.

3.5.5 Flooring

This was done by first making the surface of the base of the furnace wet with a mixture of water and sodium silicate before pouring a very thin layer (2mm thick) of the refractory mixture before arranging the firebricks into the base of the furnace. The mixture of the castable refractory and sodium silicate will be poured in and allowed to set.

Fig 3.4 Floored Furnace

3.5.6 Furnace Cover

The furnace cover-opening/closing mechanism was made of a mild steel flat bar, mild steel rod and a threaded rod. The mild steel flat bar was cut into rectangular shape of appropriate dimensions and welded together with the chimney on top.

Fig. 3.5 Furnace cover and opening mechanism

3.6 Engineering Design of The Furnace

The general layout and profile of the crucible furnace consist of a gas burner, blower unit, crucible furnace unit and fuel unit. The furnace will comprise of a crucible pot to which the aluminum to be melted is fed into, a burner which burns the oxygen and the butane gas in equal proportion and the crucible furnace cover. LPG Butane gas and oxygen cylinders are connected with a Y-shaped regulator to maintain a proper supply of both gases, a rubber pipe and a gas burner with regulators to control the air/fuel ratio to the gas burner.

3.7 Design Consideration

The following factors is considered in carrying out the design; production cost, type of fuel used (gas) and its availability, material selection and their availability, flexibility in fabrication, ease of assembly, durability, cost of selected material, availability and tool for fabrication, production capacity of furnace and shape of furnace.

3.8 The Crucible Furnace Specification

The furnace with its cover will be 500mm high with a width of 500mm. The furnace lining forms an internal diameter of 250mm and include mechanism to insert the burner. The furnace will be potable and easy to move around for easy operation. The design crucible furnace assembly has the following component.

- The furnace casing
- The refractive lining
- Opening/closing mechanism
- Burner hole and its pipe

Fig 3.6 Assembled design of the crucible furnace

3.9 Design Calculations

3.9.1 Design Parameters

The Detailed dimensions of the furnace drum are as follows:

a) Height of the furnace drum before laying bricks (h) = 450mm

b) Height of combustible space of the furnace drum after laying of bricks (h_1) = 400mm

c) Height of the cover = 50mm

d) Total height of the drum = height of drum + height of cover = 450+ 50 = 500mm.

e) Diameter of the chimney hole (on cover) = 60mm

f) Thickness of the metal sheet = 2mm

g) Internal diameter of drum after laying bricks = 250mm

3.9.2 Calculations of internal and external diameter of the crucible furnace.

External height = Height of furnace from base + height of cover

= 450mm + 50mm

= 500mm

Internal height = thickness of base lining + internal height of combustion chamber

50mm + 400 = 450mm

3.9.3 Size of Charge (Aluminum)

Length of the furnace (interior) = 0.305m

Width of the furnace (interior) = 0.305m

Height = 0.15m

Density of aluminum = 2700kg/m^3

V = L x W x H

= 0.305 x 0.305 x 0.15

= 0.01395m

Mass of Aluminium = Density x Volume

= 2700 x 0.01395

= 38kg

3.9.4 Velocity of the Butane Gas

Pressure of the gas in the gas cylinder, P = 70lb/ft^2 =3351.56N/m^2

Density of butane gas ρ = 2.59kg/m^3

$$\text{Velocity, } V = \sqrt{\frac{P}{\rho}}$$

$$= \sqrt{\frac{3351.56}{2.59}}$$

= 35.97m/s

3.9.5 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:

$$t = \frac{PD}{2\sigma J - P} + C$$

Where t = minimum thickness of the furnace walls

P = Design Pressure gotten from table = 7.5 x 10^5 N/m^2

D = 250mm = 0.25m

$C = 1.5 \times 10^{-3}$

$J = 0.70$

$\sigma = 250 \times 10^{6}$

$$t = \frac{7.5 \times 10^{5} \times 0.25}{2 \times 250 \times 10^{6} \times 0.70 - 7.5 \times 10^{5}} + 1.5 \times 10^{-3}$$

$t = 0.00203m$

$t = 2mm$

3.9.6 Maximum 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)

$$p = \frac{\sigma J t}{R + 0.6t}$$ R = Radius of the furnace = 0.125m

$$p = \frac{250 \times 10^{6} \times 0.70 \times 0.002}{0.125 + 0.6(0.003)}$$

$$p = 24.5 \times 10^{5} \, N/m^{2}$$

3.9.7 Thermal stresses setup 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;

$$\sigma t_a = \frac{-\alpha E(T_a - T_b)}{2(1-v)} = \frac{-\alpha E \Delta T}{2(1-v)} \qquad inside\ wall$$

$$\sigma t_b = \frac{\alpha E(T_a - T_b)}{2(1-v)} = \frac{\alpha E \Delta T}{2(1-v)} \qquad outside\ wall$$

$$\sigma t_a = \frac{-11 \times 10^{-6} \times 206 \times 10^{9} \times (933 - 299)}{2(1-0.3)}$$

$$\sigma t_a =- 1.03 \times 10^{9} N/m^2 \qquad (Compressive)$$

$$\sigma t_b = \frac{11 \times 10^{-6} \times 206 \times 10^{9} \times (933 - 299)}{2(1-0.3)}$$

$$\sigma t_b = 1.03 \times 10^{9} N/m^2 \qquad (Tensile)$$

3.9.8 Changes in the furnace dimensions due to internal pressure

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.

Change in length, $\Delta L = \frac{pd}{4tE}(1 - 2v)L$

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

Change in the volume of the crucible, $\Delta V = \frac{pd(5-4v)V}{4tE}$, $\quad V = \frac{\pi}{4}d^2L$

$$\Delta L = \frac{7.5 \times 10^5 \times 0.25}{4 \times 0.002 \times 206 \times 10^9}\big(1 - (2 \times 0.3)\big)0.5$$

$$\Delta L = 0.00002275m$$

$$= 0.02275mm$$

$$\Delta d = \frac{7.5 \times 10^5 \times 0.25^2}{4 \times 0.002 \times 206 \times 10^9}(2 - 0.3)$$

$$\Delta d = 0.0000483m$$

$$= 0.048mm$$

$$V = \frac{\pi}{4} \times 0.2^2 \times 0.35$$

$$V = 1.1 \times 10^{-2}m^3$$

$$\Delta V = \frac{7.5 \times 10^5 \times 0.2(5 - (4 \times 0.3)}{4 \times 0.002 \times 206 \times 10^9} \times 1.1 \times 10^{-2}$$

$$\Delta V = 3.805 \times 10^{-6} m^3$$

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.

3.9.9 Determination of the sensible heat of aluminium

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

Mathematically it is given as:

$$Q_1 = MC_{p1}(T_m - T_A)$$

where: M = mass of the metal (kg)

C_{p1} = specific heat of the metal solid (J/Kg/K) = 0.91×10^3

T_m = melting point temperature

T_A = ambient temperature

For 1kg of Aluminium,

$$Q_1 = 1 \times 0.91 \times 10^3 \times (933 - 299)$$

$$Q_1 = 576.94KJ$$

3.9.10 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:

$$Q_2 = ML$$

where: M = mass of the metal

L = latent heat of fusion = $398 \times 10^3 Jkg^{-1}$

For 1kg of Aluminium,

$$Q_2 = 1 \times 398 \times 10^3$$

$$Q_2 = 398KJ$$

3.9.11 Determination of the super heat value (Q3)

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:

$$Q_3 = MC_{p2}\left(T_p - T_m\right)$$

where:

C_{p2} = specific heat of the melt (J/Kg/K) = $0.96 \times 10^3 J/Kg/K$

T_p = pouring temperature of the molten metal(aluminium) = 700ºC + 273 = 973K

For 1kg Aluminium,

$$Q_3 = 1 \times 0.96 \times 10^3 \times (973 - 933)$$

$$Q_3 = 38.4KJ$$

3.9.12 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:

$$Q_n = Q_1 + Q_2 + Q_3$$

The total heat required to melt 1kg aluminium becomes:

$$Q_n = 576.94 + 398 + 38.4$$

$$Q_n = 1013.34KJ$$

3.10 Fabrication Procedure

3.10.1 Furnace Casing and Burner Housing

3.10.2 Marking Out and Cutting

This is the first fabrication stage which involves the marking out and cutting out of the required dimension of 450mm by 500mm from the mild steel for the furnace casing. The burner housing was also marked out and cut from steel metal plate to produce two flat plates of dimension 200mm by 350mm and 200mm by 450mm and a hole of diameter 60mm was marked out and cut on the 200mm by 450mm plate. The furnace base was also cut from the steel plate to produce a square sheet plate of width 500mm.

3.10.3 Welding process

This process was used to produce the casing of the furnace by welding the cut sheet metal to produce a square housing for the furnace frame of width 500mm and height 450mm. The burner part was also welded to the furnace casing. Stainless steel of diameter 60mm was cut and was aligned with the burner housing hole. This was welded together to form the burner housing completely.

3.10.4 Refractory lining

The refractory lining for the furnace was made by mixing refractory cement (durax) with sodium silicate $Na_2(SiO_2)$ in the proportion of 1 litre of Na2(SiO2) to a bag of durax of weight 25kg. The thoroughly blended mixture was used in lining the furnace which involves three stages:

3.10.4.1 Flooring

This was done by first making the surface of the base of the furnace wet with a mixture of water and sodium silicate before pouring a very thin layer (2mm thick) of the refractory mixture before arranging fire bricks into the base of the furnace. The mixture of the castable refractory and sodium silicate was then poured on it and allowed to set.

3.10.4.2 Setting of bricks

The wall was also damped with sodium silicate before the surface was plastered with the mixture of the refractory cement and sodium silicate to form a layer of 10mm thickness before the 60mm thick bricks was glued to the first layer while it was still wet before a final layer (26mm thick layer of the refractory and sodium silicate) was used to cover the bricks and the final thickness of the wall is 195mm leaving us with the furnace internal diameter of 305mm. A total number of 40 bricks was used to produce the wall.

3.10.4.3 Drying

The furnace body was allowed to dry for 28 days and any crack duly observed was repaired as it dried.

3.10.5 Furnace cover and stand

The fabrication of the cover was based on the internal diameter of the furnace and a cover of width of 500mm and height of 50mm was made from steel rim using purely the same mixture of durax and sodium silicate with a hole in the rim which serves as the exhaust. The furnace cover support was fabricated from steel plate cut out to the required dimensions which was inclined at an angle of 37^0 to form the support.

3.10.6 The Burner System

Two pipes of 15mm diameter were welded to the ends of the two 25mm diameter pipes meant for the burners. Then, the Y - shaped gas tap with regulators was joined to the pipes with a PVC hose using adjustable clips in order to supply gas to the furnace burner. Another PVC hose was used to join the gas outlet of the gas cylinder to the gas inlet of the Y - shaped gas tap. Then, two rectangle holes of 50mm by 25mm were cut on the underside of the burner pipes using cutting stone affixed in a filling machine. This is where the air inlet pipes will be joined to the burners. After the connections, the two burner pipes were introduced into the body of the furnace and the whole joints were welded to avoid air and gas leakages.

3.10.7 Grinding and Smoothening

This was carried out to improve the appearance of the furnace by using grinding stone fixed in the filling machine. It was done also to check whether there are defects in the welded joints and every defect detected was welded to avoid air and gas leakages.

3.11 Assembly Process

The parts assembled include: The casing, cover, the crucible stand, crucible, the cover stand and the burner. The cover stands which has a support for the cover and serves as a holder for the cover is first welded to the body of the furnace body before the cover is carefully placed in an anchor and it is held in place using a pin. Then the burner is placed in the 60mm hole drilled in the burner housing at an angle 45^0 on the horizontal plane.

3.12 COST ANALYSIS

Table 3.2 Break down of the production cost, materials and their dimensions.

S/N	Component	Material	Dimension	Qty	Unit Price Cost ₦	Total Cost ₦
1.	Furnace	Mild steel	1000 x 800 x 2 mm	$1\frac{1}{2}$ sheet	14,500	21,500
2.	Combustion chamber	Fire bricks	60mm	40	1,500	56,000
3.	Crucible pot	Steel	Ø = 200mm L = 370mm	1	2,500	2,500
4.	Gas supply pipe	PVC	Ø = 10mm	1	1,500	1,500
5.	Insulator	Refractory cement and sodium silicate	-	Bulk	3,000	3,000
6.	Bolts and Nuts	Mild steel	10mm	10	50	500
7.	Angle bar	Mild steel	1 length	1	2,500	2,500
8.	Welding electrode		Gauge 10	2 pckts	750	1,500
9.	Welding and fabrication work					5,000
10.	Spraying/Painting					2,000
11.	Transport and miscellaneous expenses					4,000
12.	**Total**					**₦100,000**

CHAPTER FOUR

4.0 Result, Discussion and Performance Evaluation

4.1 Results

After fabrication, the system was tested to determine the time required to completely melt the aluminium scrap while taken the temperature readings at regular intervals using a thermocouple and stopwatch to monitor the time taken for 38kg of aluminium to melt completely. The test was conducted on the furnace to determine the time taken to raise the temperature of the aluminium to its melting temperature using two (2) different ways; a no-load test and continuous method of melting 38kg of aluminium metal at 4 minutes interval each. The results obtained are shown below;

Time (minutes)	**Temp. attained (^0C)**	**Heat rate ($^0C/min$)**
4	241	60.25
8	532	66.50
12	633	52.75
16	774	48.38
20	1020	51.00
24	1386	57.75
Average		56.11

Table 4.1: Result of the Test Carried Out on the Fabricated Crucible Furnace

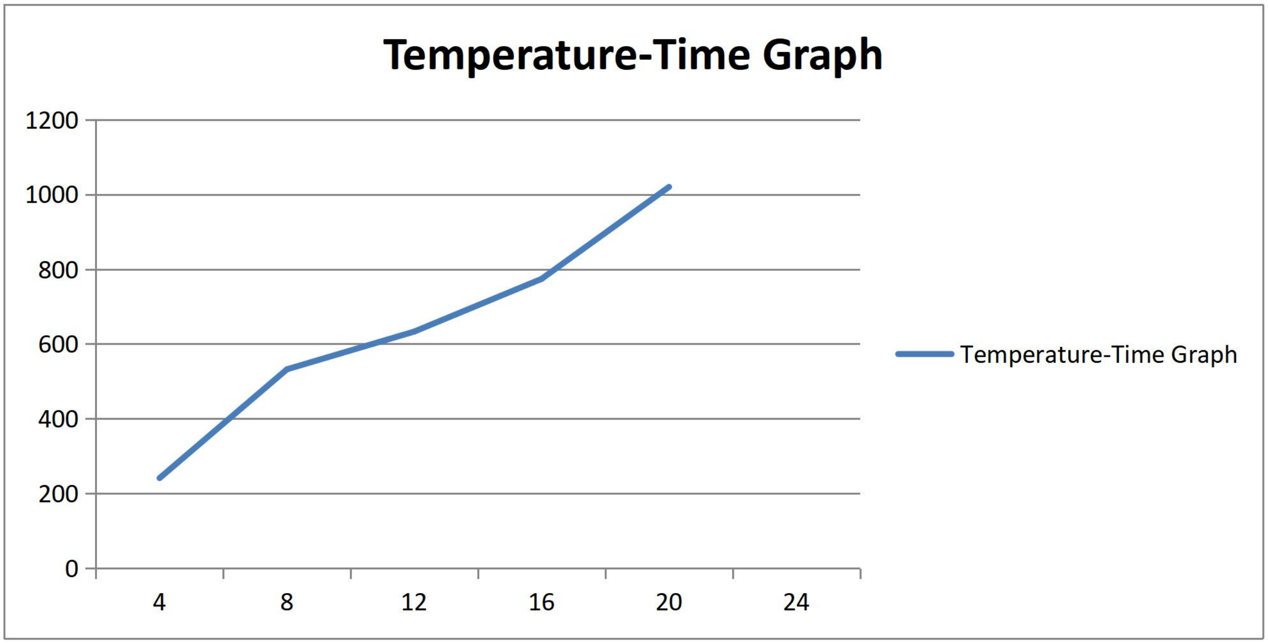


Figure 4.1: Representation of Temperature-Time Graph

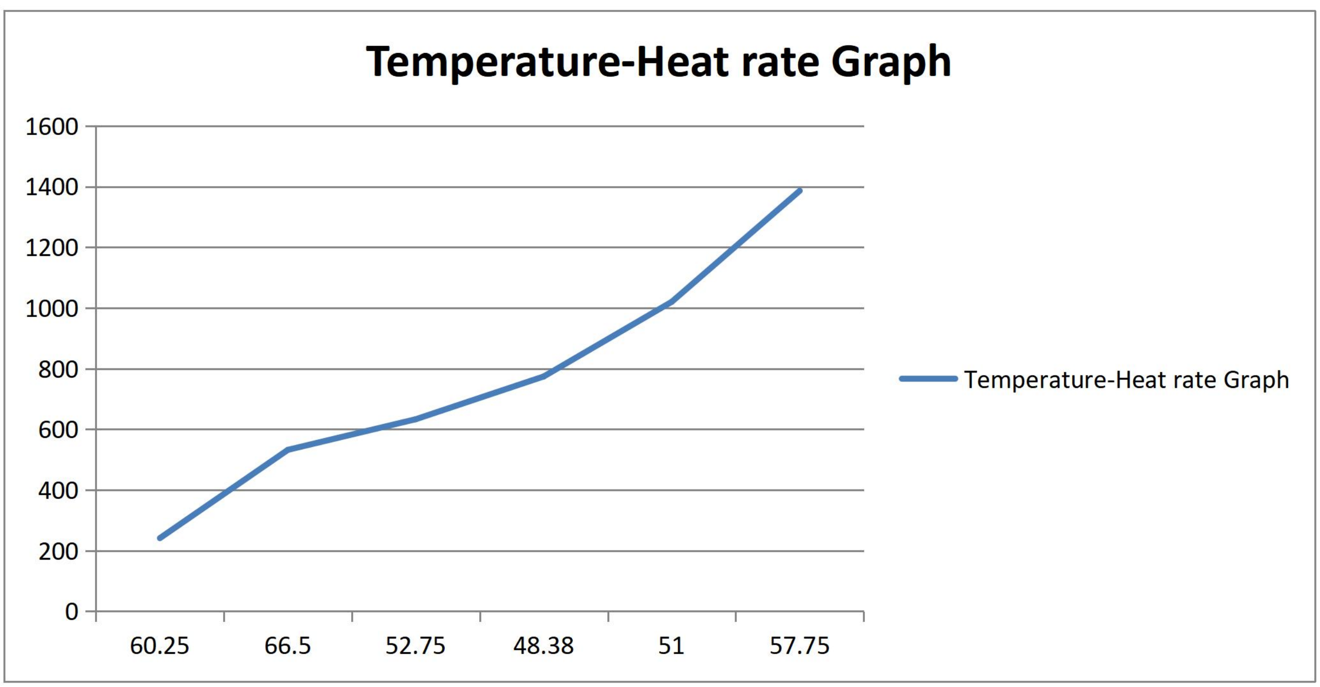


Figure 4.2: Representation of Temperature-Heat rate Graph

4.2 Performance Evaluation

The furnace parameter and the result obtained as shown in table 4.1 above are;

The ambient temperature (T_a) = 26°C

The melting temperature of the aluminium (T_m) = 660°C

Furnace Maximum Design Temperature (T_d) = 700°C,

Total mass of charge (Kilogram) =38kg

Total time is taken to melt charge (minutes) =24minutes

Mass of the aluminium metal= 38Kg

Specific heat capacity of the solid aluminium = 0.91KJ/KgK

Specific heat capacity of the molten aluminium = 1.18KJ/KgK

Latent heat of fusion of aluminium = 321KJ/Kg

The melting rate of the furnace can be determined below;

Melting rate = $\frac{\text{Total mass of charge}}{\text{Total time taken to melt charge}}$

Melting rate= $\frac{38}{24} = 1.58kg/min$

The theoretical energy content to melt 38Kg of aluminium metal at 660°C when assuming its initial temperature at standard temperature and pressure of 26°C is calculated below:

Temperature rise to melting point $(\Delta\theta) = Tm - Ta$

$(\Delta\theta) = 660 - 26 = 634^0C$

Energy content required to raise the temperature of the metal to the melting point (Q_h) is given by;

$Q_h = MC_P\Delta\theta$

$Q_h = 38 \times 0.91 \times 634 = 21923.72KJ$

Temperature rise to reach the superheated stage

$(\Delta\theta) = T_D - T_M$

$(\Delta\theta) = 700 - 660 = 40^0C$

$Q_S = MC_{PS}\Delta\theta$

$Q_S = 38 \times 1.18 \times 40 = 1793.6KJ$

Energy content required to change metal from solid to liquid (QL);

$Q_L = ML$

$Q_L = 38 \times 321 = 12198KJ$

Then, the total energy content of Aluminum (Q_T) can be determined by adding the energies above, thus

$Q_T = Q_h + Q_S + Q_L$

$Q_T = 12198 + 1793.6 + 21923.72 = 35915.32KJ$

This means that the heat required in melting the aluminum (theoretical energy) = 35915.32KJ

The total amount of energy consumed in the furnace can be determined;

Recall; that the energy content of the fuel is rated as 139000KJ/gallon

1gallon= 4.6litres

1litre= 1kg

This implies that the energy content of the gas is $\frac{139000}{4.6} = 30217.3913kj$

From the test carried out, the amount of fuel used to melt the 38kg of aluminium metal is 3kg of LPG butane gas. Therefore, the total amount of energy used by the furnace is:

$$= 3 \times 30217.3913 = 90652.1739kj$$

This means that the heat used by the furnace (experimental heat energy) = 90652.1739KJ

The efficiency of crucible furnaces ranges from a low 3.5% to a high 28%, the common commercial average being around 15%. The efficiency of the crucible furnace when melting aluminium metal is calculated as follows

$$\text{Efficiency } (n) = \frac{heat\ required\ to\ melt\ thealluminium}{heat\ used\ to\ melt\ the\ alluminium} \times 100$$

$$\text{Efficiency } (n) = \frac{35915.32}{90652.1739} \times 100 = 39.6\%$$

The efficiency of the furnace increases with increased volume or mass of metal, this implies that the higher the melting capacity, the higher the efficiency.

4.3 Discussion

The result obtained from the two (2) tests carried out on the furnace shows that; For the No-load test/empty furnace test (furnace tested without loading the aluminum); the temperature of the crucible rose from room temperature of 26^0C to 660^0C in 3minutes while for the continuous method of melting process was undergone to determine the time taken to melt 38 kilograms of aluminium and holding time for steering the molten aluminium to ensure complete melting of aluminium. Table 4.1, Figure 4.1 above shows the trend of the temperature rise and drop in the crucible while monitoring a 4minutes time interval to melt aluminium and the temperature dropped to a certain level before it rose back to 660^0C. Figure 4.2 further shows the holding time required for 38kilograms of aluminium to melt and the heating rate after monitoring the melting process at 4minutes interval and continuous firing of the furnace to reach the melting point. Therefore, the total time taken for melting of 38kilograms of aluminium was 24 minutes and consumes 3 kilograms of LPG butane gas. From the performance evaluation above, the average heating rate is 56.11^0C/min, melting rate of 1.58kg/min.

CHAPTER FIVE

5.0 Conclusion and Recommendation

5.1 Conclusion

The gas-fired crucible furnace was fabricated to melt aluminium scraps with specific objectives of achieving high melting efficiency by effectively minimizing heat losses and maximizing heat generation through the use of available local materials with good insulating properties for the refractory wall. The crucible inside was loaded with scraps from aluminium roofing sheets, offcuts and canned drinks weighing 38kg. Then it was heated for about 24 minutes and the aluminium scraps melted completely indicating that the furnace can attain temperatures ranging from 660^0C to 700^0C which is the melting temperature range of aluminium. The successful melting of the aluminium scrap by the furnace shows that this project objectives were successful. The material used for the development of the crucible furnace where all procured locally around Edo State to encourage indigenous industries and encourage further research. The developed crucible furnace has a fast heating rate, efficient in fuel economy as it is capable of consuming 3kg of gas, can melt 38kg aluminium scraps in 24 minutes, the heating rate is 56.11^0C/min , melting rate of 1.58kg/min and efficiency of the furnace were calculated to 39.6% . This is quite impressive considering that efficiency of the furnace increases with increased volume or mass of metal, this implies that the higher the melting capacity, the higher the efficiency.

It was also observed that the furnace has a good heat-retaining capacity, can be easily maintained and safe to use. Thermocouple was used to measure the melting point of aluminium between temperature ranges of 29^0C to 1386^0C and can also be used to melt other materials with a melting point up to 1386^0C.

From the results above, it can be concluded that the crucible furnace can be effectively used in melting non-ferrous metal such as aluminium scrap of automobiles, used cans and kitchen utensils. This fabrication will contribute immensely in assisting local foundry industries, it is economical and time-saving during operation when compared to foreign ones and it is suitable for use in small scale foundries and in conducting practical in tertiary institutions. In developing countries like Nigeria, where the level of unemployment is high and job opportunities are very scarce, it is very important not to allow the few operating foundry industries and workshops to close down. Hence the fabricated furnace can conveniently replace the conventional imported crucible furnace as a means of improving the Nigerian local production, provide an alternative means for the foundry industry, provide employment opportunities and saves a lot of foreign currencies used in importing the equipment to the country.

5.2 Recommendation

Based on the observations while testing the gas fired crucible furnace, these recommendations are made for a better and more efficient functioning of the crucible furnace.

- Gas crucible furnace should be incorporated in small foundry industries in Nigeria to serve as an alternative to the oil fired and electric crucible furnaces.
- Due to the heavy nature of the crucible furnace, it should be positioned permanently in a particular place and should not be moved about frequently unless when it is necessary to do so.
- Inspection and maintenance should be conducted periodically on the crucible so as to repair cracks.

REFERENCES

Amstead, B.H., Oswald P.F. and Begeman M.L. (1979). Manufacturing Processes (7th Ed). John Wiley and Sons Inc, New York.

Allen.D,K.(1979):Working group report 1995, second report of Institute Working Group TIO-NF Melting and molten metal treatment of non-ferrous materials.

Agontu J,A. (2009) Design and development of low pressure charcoal fired steam Generating unit for Sterilizing surgical tools in hospitals, Unpublished. M.Sc Thesis Department of Mechanical Engineering, ABU Zaria.

Adeleke, A.F. (2003) Investigation into Charcoal Production Techniques (unpublished) B.Eng. project Report, Department of Mechanical Engineering, ABU Zaria

Beeley, P. (2001) Foundry Technology (2nd ed). Oxford, U.K: Butterworth- Heinemann.

Charles, H. (2000) Crucible Melting furnace, (Brief Article) on modern Casting, June1, 2000.

Folayan, J.D. (2001) Design of a coal fired crucible type furnace, undergraduate project, Department of Mechanical Engineering, ABU Zaria.

Incropera F.P. and Dewitt D.P (1990). Fundamentals of heat and mass transfer, John Wiley and Sons, Inc, New York.

Komolafe, A.J. (1992), Design and construction of a gas fired crucible type furnace, Undergraduate Project, Department of Mechanical Engineering, ABU Zaria.

Kulla, D.M. (2007) Technology Improvement for safety and economy in wood burning devices in Nigeria, Ph.D. Proposal seminar, Department of Mechanical Engineering, A.B.U Zaria.

Kulla, D.M. (2004) Development of an improved charcoal stove: A step to energy Recovery. M.Eng. Thesis, Department of Mechanical Engineering, B.U.K.

Megyesy, E.F. (1977) Pressure Vessel Hand Book (4th ed) Pressure Vessil Hand Book Publishing, Inc. Tulsa, U.S.A

OA Ighodalo, Egbodion, H. Omondiagbe, A. Ogbeide, I. Development of a cylindrical gas fired furnace for recycling Aluminum in small scale foundries. International Journal of Natural & Applied Sciences. Published 2013-03-14 Vol.7 NO3 (2011)

Okada,Sasaki and Yashikawa (2004); www.osha.gov accessed on 21/11/2012.

Osarenmwendia J.O. Fabrication and Performance evaluation of an oiled fired crucible furnace using locally sourced materials. International Journal of Engineering Research and Application. Vol 5. Issue 3. 2015 PP 29-33

Roffel, B.J. Rijnsdorp, J.E. Dynamics and Control of a Gas Fired Furnace
Engineering & Technology Institute Groningen 1974-01-01

Rajan, and Ashok, F.J. (1988) the Heat treatment of steel, Sir Isaac Pitman and Sons Ltd London.

Rajput, R.K. (2008-2009), an Integrated Course in Mechanical Engineering.

Sinha, K.P and Joel D.B. (1973) “Foundry technology” 1st edition London ILIFFE Books Ltd.

Singh, S. (2003) (Ed) Mechanical Engineers Hand Book Khana Publishers, New Delhi,India

Singh, S. (2004). Machine design (3rd ed). Khana Publishers, 2-B Nath market, Naisarak, Delhi, India. pp.86-241.

Sham and Ashok P.C.(1988) Production Engineering, Great Britain.

Snow, D.A. (1991) (ed) plant engineering reference book, Butter worth Heinman, Linacre House, Jordan –Hill Oxford England.

Tyler, G.H and Hicks P.E. (Eds). Standard hand Book of Engineering Calculations. Mc-Graw Hill Book company Inc. New York, USA pp3.187-3.201, pp3.259-3.289.

Town of Woodside, California: (2004) Geotechnical - Reportssoils - Reports. www.woodsidetown.org/building accessed on 5/12/2011.

Umar, B. (1988). Design construction and testing of a manually operated blower for Reactivation of Departmental forging furnace. Unpublished. M.Sc thesis Department of mechanical Engineering, ABU Zaria.

University of Minnesota Department of Soil, Water and Climate: (2007) Soil Testing. www.soiltest.cfans.umn.edu accessed on 5/12/2011.

Wilton, E, and Smith, J. (2006), Real life emissions testing of pre 1994 wood burners in New Zealand, for environment Waikato, ISSN: 1172-4006, Document 1052491V2

Young, P, (1992), Smoke Measurement, in boiling point, August 1992, No.28, Intermediate Technology Development Group, Great Britain 12-15.

Yaws, D.S. (2003) Performance evaluation of an improved Three- Burner Wood Fired stove NSE Technical Transactions, Volume 38 Journal of Nigerian society of engineers.

Yawas, D. S (2004) The development and performance evaluation of an efficient rice husk stove Nigerian Journal of Renewable Energy Vol. 12. Nos. 1 and 2 pp 92-99