

**DESIGN, CONSTRUCTION AND TESTING OF A CRUCIBLE FURNACE**

**BY**

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**CERTIFICATION**

This is to certify that this project titled "Design, Construction and Testing of a Crucible Furnace" was carried out by SHITTU IBRAHIM OLUWATOSIN (MME/12/0880) and has been submitted and approved in partial fulfilment of the requirements for the degree of Bachelor of Engineering (B.Eng.) in Materials and Metallurgical Engineering of Federal University Oye-Ekiti, during the academic year 2016/2017, is a bonafide record of work carried out under our guidance and supervision.

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Date

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Prof. A. Oni  
**Head of Department**  
.....

Date



## **DEDICATION**

I dedicate this project to the Almighty Allah who saw me through the course of my study, and also to my late father Alh Saminu Shittu may Allah (SBWT) forgive his short comings and grant him Al-Jannah Firdaus (ameen).

## ACKNOWLEDGEMENT

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## ABSTRACT

This research work presents the design concept, construction and testing of portable crucible furnace which uses diesel oil as fuel. The diesel fired crucible furnace was designed, constructed using locally available engineering materials mild steel sheet of 1.5 mm, The materials used in this work were obtained from the local markets within Akure and Lagos. They include: mild steel sheet of 1.5mm thickness, compressor pot, stainless steel pipe of 60mm diameter, refractory material (kaolin). A weighing scale with model No ek5055 and thermocouple with model No Kane-may km 340 were used to measure the temperature and heat generated respectively. The furnace is suitable for use both in the rural and urban areas for melting of different types of aluminum cast iron. The furnace is environmental friendly without health hazards to the workers and can be moved from one place to another unlike the local one.

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## CHAPTER ONE

### 1.0 INTRODUCTION

Crucible furnace is one of the oldest and simplest type of melting unit used in the foundry. The furnace uses a refractive crucible which contains the metal charge. The charge is heated via conduction of heat through the walls of the crucible. The heating fuel is typically coke, oil, gas or electricity. Crucible furnaces are commonly used where small batches of low melting point alloy are required. The capital outlay of these furnaces make them attractive to small non-ferrous foundry. Crucible furnaces are typically classified according to their method of removal which are the tilting furnace, lift-out furnace, bale-out furnace([www.atlasfdry.com](http://www.atlasfdry.com)).

A crucible is a pot that is used to keep metals for melting in a furnace. Furnace crucibles are designed to withstand the highest temperatures encountered in the metal casting works. Crucible should essentially be made of materials with a much higher melting point than that of the materials to be melted. It should also have good strength even when extremely hot. Crucible furnaces are made up of metal constructions, clay graphite, silicon carbide etc. These materials can resist the extreme temperatures in typical foundry operations.

#### 1.1 Foundry Practice in Nigeria.

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. Figure 1.1 shows the shape of the local furnace used in local foundries.



Plate 1.1 A typical Furnace

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

### **1.2 Background of the Research**

A foundry is a factory that produces metal castings. Metals are cast into shapes by melting them into a liquid, pouring the metal in a mold, and removing the mold material or casting after the metal has solidified as it cools. The most common metals that are produced by casting process are aluminum and cast iron. However, other metals such as bronze, brass, steel, magnesium, and zinc are also used to produce casting in foundry. In this process, parts of the desired shape and sizes can be formed.

### **1.3 Challenges facing Foundry Practice in Nigeria.**

The foundry practice were having challenges working with local type of crucible furnace due to 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 Adewale, (1998).

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 was noticed that gas as a source of energy can be very hazardous and so the use of non-hazardous fuel must be put into consideration. The gas furnace is found in big industries only and ordinary foundry men do not know much about gas. Also, gas is not readily available and cheap in every part of the country compared to charcoal. Nigeria is readily blessed with oil; this is readily available with little cost.

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). Due to the emission of gases which leads to air pollution, oil fired crucible is preferred. Oil is readily available and easily stored. This is less dangerous than gas which can fill a room and ignite. Oil burners do not need any equipment like gauges that cannot be easily be built.

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 modern crucible furnace is shown in Plate 1.2



**Plate 1.2: An Oil Fired Crucible Furnace**

#### **1.4 Statement of the Problem**

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

#### **1.5 Aim**

The aim of the work is to design and construct a portable laboratory crucible furnace.

#### **1.6 Objectives**

The objectives of the work are to:

- i. design a portable oil fired crucible furnace;
- ii. construct the furnace using locally available materials; and
- iii. carry out performance evaluation of the furnace.

### **1.7 Significance of the Project Work**

This work will contribute to:

- i. development of indigenous technology especially in the production industries.
- ii. improved working conditions of foundry men and encourage youths to venture into foundry work.

### **1.8 Scope of the Work**

The scope of the research work will be limited to the designing, construction, and assemblage of the components that make up the diesel oil fired crucible furnace of an area of  $237613.75\text{mm}^2$  and a height of 500mm with furnace cover size of height 80mm with an area of  $237613.75\text{mm}^2$  for melting aluminum. These include: the furnace shell, refractory lining (wall of the furnace), burner and its pipe, fuel tank and the crucible pot.

## CHAPTER TWO

### 2.0 LITERATURE REVIEW

#### 2.1 Overview of Furnaces

In any foundry practices, 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).

Furnace is also a term used to identify a closed space where heat is applied to a body in order to raise its temperature. The source of heat may be fuel or electricity. Commonly, metals and alloys and sometimes non-metals are heated in furnaces. The purpose of heating defines the temperature of heating and heating rate. It is an apparatus in which heat is generated and transferred directly or indirectly to a molten or solid mass for the purpose of effecting a physical, chemical or metallurgical change in the mass. Furnace equipment is isolated from the surrounding by an insulated wall and is used to transfer heat to the material to be melted or heat treated within the furnace. An ideal furnace is one in which all energy produced is utilized, this practically is unachievable and there is no thermal processing equipment with efficiency of 100%. A furnace of high efficiency is therefore a system in which energy losses are minimal. In practice however, a lot of heat is lost in several ways. The losses include energy conversion losses, furnace wall losses, furnace opening losses and the likes. In order to prevent these losses, materials that can retain and conserve heat known as refractory materials are therefore used as lining materials for the furnaces. Refractories are porous, multi-component and heterogeneous materials composed of thermally

stable mineral aggregate, a binder phase and additives. Refractory wall of furnaces is the key to efficiency of a furnace Yoshikawa, (2004).

## **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).

### **2.2.1 Types and classification 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:

1. Fuel fired furnaces, and
2. 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).

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).



- I. **Electric Arc furnace** – It is a furnace that heats charged material by means of an electric charge. Industrial arc furnace ranges in size from approximately 1 tonne capacity up to 400 tonnes units. It is commonly used for secondary steel making. Industrial electric arc furnaces temperatures can be up to 1800°C, while laboratory units can exceed 3000°C.
- II. **Induction Furnaces** – An induction furnace is an electrical furnace in which the heat is applied by induction heating of metal. Induction furnace capacity range from 1kg to 100 tonnes capacity and are used to melt iron and steels, copper, aluminium and precious metal.  
[https://en.wikipedia.org/.../induction\\_furnace](https://en.wikipedia.org/.../induction_furnace).
- III. **Cupola**– A cupola furnace is a melting device used in foundries that can be used to melt cast iron, Ni-resistant iron and some bronzes. The cupola can be made almost any practical size. The shell of the cupola, being usually made of steel, has refractory brick and plastic refractory patching material lining it. ([https://en.wikipedia.org/.../cupola\\_furnace](https://en.wikipedia.org/.../cupola_furnace)).
- IV. **Reverberatory Furnace** – This is a furnace that isolates the material being processed from contact with the fuel, but not from contact with combustion gases. It is used for smelting or refining in such a way that the fuel is not in direct contact with the ore but heats it by a flame blown over it from another chamber. [www. Britannica.com](http://www.Britannica.com).
- V. **Crucible Furnace** -This is among the oldest and simplest furnaces used in the foundry; it is primarily used to melt smaller amounts of non-ferrous metals but can also be used for ferrous metals. It is mostly used in small foundries. The crucible or refractive container is heated in a furnace, typically fired with natural gas or liquid propane, although coke, charcoal, oil, or electricity can be used ([industrialmetalcasting.com](http://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). The work of Charles, (2000) centered on the construction of an 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 *et al*, (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. 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).

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 and the appliances for removal of the flue gases The broad classification of furnaces is presented in Plate 2.1

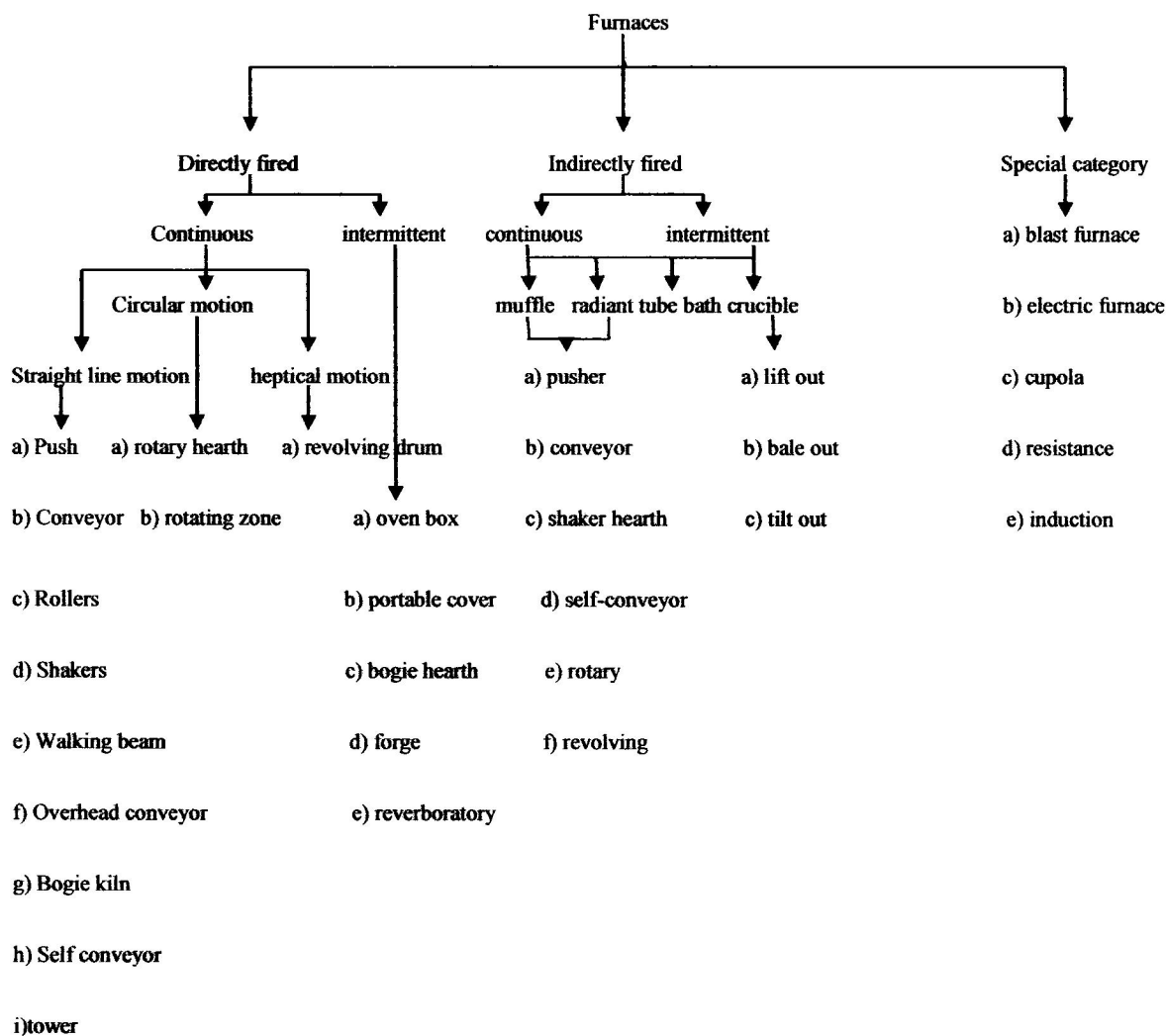


Figure 2.1: Classification of Furnaces based on their Firing Methods and Processing Conditions.

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### 2.2.2 Crucible

Crucible furnaces are furnaces used for the melting of mostly non-ferrous metals. Its capacity may be up to 150 kg. The types of crucible furnace are:

- 1) Pit furnace
- 2) Coke fired stationary furnace
- 3) Oil fired tilting furnace
- 4) Pot furnace

A crucible is a container that can withstand the very high temperatures necessary to melt glass, metal, pigments and some laboratory materials. Bronze and Iron age crucibles were shallow clay vessels and the air for the heat was blown from above. They often had small handles to aid in transport from the furnace to the mold. 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](http://www.britanica.com/Crucible%20furnace)). 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. 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 of kg. These include lift-out, tilting, bale-out, rotary and immersed crucible furnaces Folayan, (2001).

- 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: rotary crucible furnace and 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 Design parameters**

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. The physical properties of the materials were used as the basic parameters guiding the selection. The factors, properties to be considered include cost effectiveness, availability, high or low tensile, strength as may be required, rigidity and/or flexibility, heat and corrosion resistance, etc.

The function, objective and the constraint of each unit in the furnace must be known for the selection of the candidate material. This will be used in selecting appropriate material for the construction of the fuel fired crucible furnace.

#### **2.3.1 The Furnace Shell**

The function of the furnace shell was to provide housing for the refractory lining and the crucible pot. It is to provide rigidity, strength, ability to carry its own weight and ability to retain high strength even after shaping. The constraint considered was cost.

The furnace shell requires a material that is durable, moderately strong and that can withstand its own weight, the refractory, and its container. It must possess good fabricability, readily available and not expensive. The following mechanical as well as thermal properties should be put into consideration and they served as a basis for the choice of material that was eventually recommended for the design of the outer shell of the furnace.

**Density:** The density of the material to be chosen must be quite low so that the entire Furnace will not be too heavy.

**Cost Price:** The price of the material that will be chosen must be relatively cheap.

**Weldability:** To enhance proper joining of the flat sheets as well as fabricability the material must be easy to weld.

**Young's Modulus:** A material that is durable, moderately strong and which can withstand its own weight and that of the refractory bricks.

**Melting Point:** The melting point of the material must be quite high so as to prevent any phase changes during the course of the operation of the furnace.

**Thermal Conductivity:** The desired material must have a low thermal conductivity so as to prevent the rapid dissipation of heat to the environment.

### **2.3.2 The Refractory Lining**

The function of the furnace refractory was to reduce heat loss in the furnace. This is determined by considering some factors such as environmental condition, furnace requirement and the expected length of service. Environmental conditions that affects effectiveness of refractories include chemical attack by slags, fumes, gases etc. The furnace requirement and operating conditions include the working temperatures and mechanical forces like abrasion, erosion and physical impact. Design factors that influenced the selection include refractory strength (exposure to varying stress conditions) and thermal functions (insulation, dissipation or transmission of heat). Other factors considered are resistance to fusion at working temperature, resistance to thermal shock, low thermal conductivity to prevent heat loss from the furnace, impermeability to gases, high resistance to abrasion and good thermal resistance for adequate insulation. The major constraints considered were cost and availability. Silicon carbide, carbon and graphite refractories

are very expensive and unless condition demands their usage, alternatives are always sought for. Since cost is a crucial factor, locally available candidate materials must be given consideration.

The term “Refractory” means “Hard to Fuse”. High temperature operations are involved in almost all the industries dealing with the treatment of ores and other materials for the manufacture of metallurgical, chemical, and ceramic products. Refractories are, therefore the class of materials, which withstand high temperatures, resist the action of corrosive liquids and hot gases, etc. Refractories are heat resistant materials that can withstand high temperature without rapid physical and chemical deterioration ([https://en.wikipedia.org/.../refractory\\_lining](https://en.wikipedia.org/.../refractory_lining)).

In selection of refractory lining for the design of the crucible furnace some factors are needed to be considered such as environmental condition, cost, furnace requirement and the expected length of service. Environmental conditions that affects the effectiveness of the lining of the furnace is chemical attack from slags, fumes, gases and molten metal that may pour on the linings etc.

Cost is another major factor to be considered when selecting refractory for the crucible furnace; silicon carbide, carbon and graphite refractories are expensive and unless condition demands their usage, alternatives are always sought for. Another factor that influences the selection of the refractory is the design factor which includes refractory function, refractory strength (exposure to constant or variable stress conditions), thermal functions, and heat environment.

The furnace requirement and operating conditions include the working temperatures and mechanical forces like abrasion, erosion and physical impart John, (1992). General, mechanical as well as thermal properties were put into consideration and they served as a basis for the choice of material that was eventually recommended for the design of the lining of the furnace.

**High refractoriness:** resistant to fusion at working temperature.

**Resistance to thermal shock:** it must be able to withstand sudden change in temperature.



**Low thermal conductivity:** the thermal conductivity must be low to prevent heat loss from the furnace.

**Melting point:** the refractory should be of a high melting temperature so that it will not fail during service. The temperature at which the action results in failure of a test pyramid (cone) to support its own weight is called melting point of refractory.

**Bulk Density:** It is a useful property, which defines the material present in a given volume. An increase in bulk density of a given refractory increases its volume stability, its heat capacity as well as resistance to slag penetration ([https://en.wikipedia.org/.../refractory\\_lining](https://en.wikipedia.org/.../refractory_lining)).

### **2.3.3 The Crucible Pot**

The purpose of the crucible pot is to contain the charge to be melted. The objectives require that the crucible pot must be durable, wear resistant to chemical effect and must be able to withstand temperatures higher than the operating temperature of the furnace. The crucible should be durable, wear resistant, and resistant to chemical effect and be able to withstand temperatures higher than the operating temperature of the furnace.

Generally, Cost should be a major constraint considered in selecting the appropriate candidate material because the furnace must be affordable for the local industry especially the small and medium scale industries to buy.

### **2.3.4 Oil Burner Design**

There are a wide variety of designs for oil drip burners, but the basic principles remain the same. Drip oil or pressurized oil are or gravity fed into a reaction chamber, where it is ignited and the resulting flames pushed out through a burner tube. Some designs are fairly simple and others incredibly complex pressurized systems with filters for the oil.

## **2.4 Process involved in Constructing the Crucible Furnace**

### **Construction of metallic frame of the crucible**

- **Cutting**
- **Boring**
- **Welding**
- **Trimming and grinding**

**2.4.1 Cutting:** This operation involves the physical separation of the metal sheet along a straight line between two cutting edges. It is typically used to cut large sheets into smaller sections for subsequent press working operations. The iron sheet was cut and dimensioned into pieces to be welded together.

**2.4.2 Boring:** Boring operation is the process of enlarging a hole that have already been drilled by means of a single point cutting tool or of a boring head containing several of such tools. It is used to achieve greater accuracy of the diameter of a hole and can be used to cut a tapered hole, boring can be viewed as the internal diameter counterpart to turning which cuts external diameter. In this work boring is used to bore the hole for the blower and fuel pipe to pass through.

**2.4.3 Welding:** This is the process of similar metals by the application of heat, with or without application of pressure or filler metal, in such a way that the joint is equivalent to a composition and characteristics of the metals.

**2.4.4 Trimming and grinding:** The essence of trimming the frame part is to remove all the rough edges or slag formed by welding on the joint thereby making the joint smooth and neat.

**2.4.5 Lining of the crucible:** Lining of the crucible furnace requires the use of refractory materials which is used as a protective layer installed inside the furnace to insulate the furnace steel structure from high temperatures. It also protects it from thermal shock and chemical attack and abrasion wears.

## **2.5 Fuels**

In engineering, any material which on combustion is capable of generating heat energy that can be utilized for industrial purpose is called fuel. 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.

### **2.5.1 Types of fuels used in crucible furnace**

1. coke
2. oil
3. Gas or electricity

**Coke-** Coke fired furnaces are one of the easiest furnaces to build and run on a small scale

**Oil-** oil fired furnaces are very fast furnaces that are inexpensive to operate. Oil is readily available and easily stored. Oil burners do not need any equipment like gauges that cannot be easily built.

**Electricity-** It is environmental friendly, produces only waste gas from the metal itself.

### **2.5.2 Properties of Liquid Fuels**

Liquid fuels like furnace oil and LSHS (low Sulphur heavy stock) are predominantly used in industrial application. The various properties of liquid fuels are given thus:

i. **Density:** This is defined as the ratio of the mass of the fuel to the volume of the fuel at a reference temperature of 15°C. Density is measured by an instrument called hydrometer. The knowledge of density is useful for quantity calculations and assessing ignition quality. The unit of density is kg/.

ii. **Specific Gravity:** This is defined as the ratio of the weight of a given volume of oil to the weight of the same volume of water at a given temperature. The density of fuel, relative to water, is called Specific Gravity. The specific gravity of water is defined as 1. Since specific gravity is a ratio, it has no units. The measurement of specific gravity is generally made by a hydrometer. It is used in calculations involving weights and volumes. The specific gravity of some fuel oils is given in the Table 2.1

Table 2.1: Specific Gravity of different liquid fuel

<b>Fuel Oil</b>	<b>L.D.O Light Diesel Oil</b>	<b>Furnace oil</b>	<b>L.S.H.S Low Sulphur Heavy Stock</b>
<b>Specific Gravity</b>	<b>0.85-0.87</b>	<b>0.89-0.95</b>	<b>0.88-0.98</b>

iii. **Viscosity:** The viscosity of a fluid is a measure of its internal resistance to flow. Viscosity depends on temperature and decreases as the temperature increases. Any numerical value for viscosity has no meaning unless the temperature is also specified. Viscosity is measured in Stokes /Centistokes. Sometimes viscosity is also quoted in Engler, Saybolt or Redwood. Each type of oil has its own temperature - viscosity relationship. The measurement of viscosity is made with an instrument called Viscometer. Viscosity is the most important characteristic in the storage and use of fuel oil. It influences the degree of pre-heat required for handling, storage and satisfactory atomization. If the oil is too viscous, it may become difficult to pump, hard to light the burner, and

tough to operate. Poor atomization may result in the formation of carbon deposits on the burner tips or on the walls. Therefore, pre-heating is necessary for proper atomization.

iv. Flash Point: It is the lowest temperature at which the fuel can be heated so that the vapour gives off flashes momentarily when an open flame is passed over it. Flash point for diesel oil is  $66^{\circ}\text{C}$ .

v. Pour Point: It is the lowest temperature at which it will pour or flow when cooled under prescribed conditions. It is a very rough indication of the lowest temperature at which fuel oil is readily pumpable.

vi. Specific Heat: It is the amount of kcal needed to raise the temperature of 1 kg of oil by  $1^{\circ}\text{C}$ . The unit of specific heat is kcal/. It varies from 0.22 to 0.28 depending on the oil specific gravity. The specific heat determines how much steam or electrical energy it takes to heat oil to a desired temperature. Light oils have a low specific heat, whereas heavier oils have a higher specific heat.

vii. Calorific Value: It is the measurement of heat or energy produced, and is measured either as gross calorific value or net calorific value. The difference being the latent heat of condensation of the water vapour produced during the combustion process. Gross calorific value (GCV) assumes all vapour produced during the combustion process is fully condensed. Net calorific value (NCV) assumes the water leaves with the combustion products without fully being condensed. Fuels should be compared based on the net calorific value.

The calorific value of coal varies considerably depending on the ash, moisture content and the type of coal while calorific value of fuel oils are much more consistent. The typical Gross Calorific Values of some of the commonly used liquid fuels are given in Table 2.2 and general properties of a diesel oil is given in Table 2.3

**Table 2.2: Gross Calorific Values of some Liquid Fuel**

<b>Fuel oil</b>	<b>Gross calorific value (kCal/kg)</b>
Kerosene	11,000
Diesel oil	10,800
L.D.O (light diesel oil)	10,700
Furnace oil	10,500
LSHS	10,600

**Table 2.3: Properties of a Diesel Oil**

<b>Properties</b>	<b>Diesel</b>
Oxygen content, %	0
Lubricity	Good
Cetane number	41-48
Sulphur, ppm	1-10
Viscosity at 40	2.04-3.23
Density(kg/L)	0.84-0.86
Energy content(MJ/L)	35.7-36.7
Cloud point	0 – (-55)
Flash point	68 – 94
Distillation	307 – 352
Stability	Good

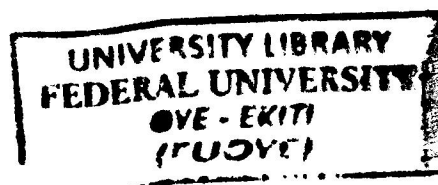
## 2.6 Review of Past Works on Diesel fired furnace

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

In most third world nations, one of the cheapest ways to melt non-ferrous metal commercially in a crucible furnace is by using combustion fuel. Furnace design may vary according to its function, heating duty performed, heating method applied or type of fuel used UNEP, (2006). The work of Musa, (2012) and Bello, (2004) compared diesel and butane gas as fuel in firing crucible furnace for melting aluminium scraps. It was discovered that butane gas brought the aluminium scraps to its pouring temperature within 45 minutes while diesel fuel spent 50 minutes with lower cost.

Asibeluo and Ogor (2015), designed a 50-kilogram capacity Cast-iron crucible furnace that is fired with diesel fuel. The furnace drum has an overall combustion capacity of  $0.1404m^3$ . It is fitted with a chimney to allow for the easy escape of combustion gases. The air blower discharge air into the furnace at the rate of  $0.3m^3/s$  with an air/fuel ratio of 400:1. The cast-iron crucible furnace is designed to consume four gallons of diesel fuel with a rating of 139000kj/gallon which is required to completely melt 50-kilogram of cast iron over a period of 90min. The designed operation temperature range of the cast-iron crucible furnace is  $1300^{\circ}C$  to  $1400^{\circ}C$ .

A furnace fired with diesel was considered by Govardhan *et al.*, (2011) showing computer based experimentation and computational fluid dynamic analysis indicating the temperature distribution during oscillating combustion in a crucible furnace. Alaneme and Olanrewaju, (2010) worked on diesel fired stationary pot crucible furnace for both heat treatment and salt bath with the use of diesel oil as the liquid fuel. The literature review of fuels for combustion in a crucible furnace indicates that the need to obtain a fuel that is readily available and cheap remains a major challenge affecting the foundry practice in Nigeria.



## **2.7 Heat Transfer**

**Heat Transfer:** - This can 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: the designs of heat exchanger systems, evaporators, steam generators, condensers, boilers, automobile engines, furnaces e.t.c

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:** This 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 is governed by Fourier's law of conduction. It is an empirical law based on observations which 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 2.1 and 2.2 according to Sinha and Goel, (1973).

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

$$Q = -kA \cdot \frac{dt}{dx} \dots\dots\dots 2.2$$

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

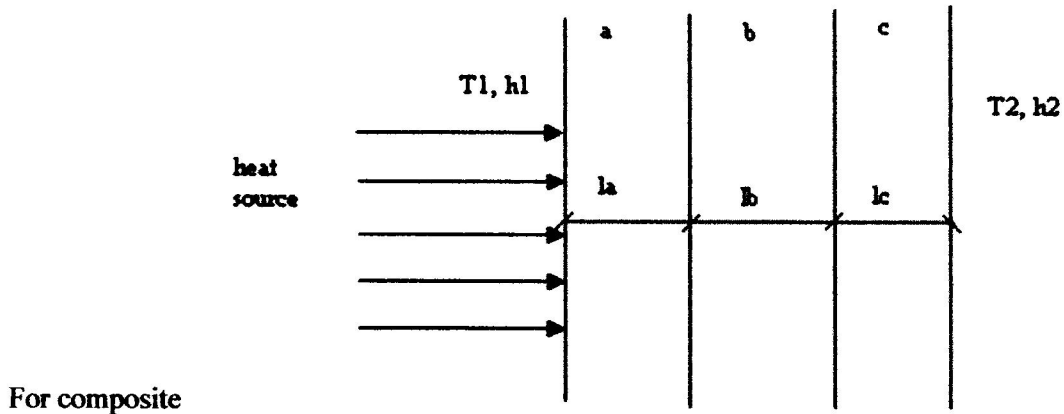
Consider a flow of heat through a composite material as shown in Figure 2.2

1. Heat flow (Q) is proportional to the temperature difference ( $T_1 - T_2$ ) across the specimen  
i.e.  $Q \propto (T_1 - T_2) \dots\dots\dots 2.3$

i. Heat flow (Q) is proportional to increase in area of material i.e.  $Q \propto A$ .

ii. Heat flow (Q) increases as the block thickness decreases i.e.  $Q \propto 1/l$

Hence,  $Q \propto \frac{-KA(T_1-T_2)}{L}$  .....2.4



**Figure 2.2:** Conduction of heat through slabs of different materials

Hence the total heat flow is given by

$$Q = \frac{dT}{\sum R} = \frac{T_2-T_1}{\sum R} \dots\dots\dots 2.5$$

Where

$$\sum R = \frac{1}{h_1A} + \frac{1}{h_0A} + \frac{L_a}{K_aA} + \frac{L_b}{K_bA} + \frac{L_c}{K_1A} \dots\dots\dots 2.6$$

Therefore,

$$Q = \frac{T_2-T_1}{\frac{1}{h_1A} + \frac{1}{h_0A} + \frac{L_a}{K_aA} + \frac{L_b}{K_bA} + \frac{L_c}{K_1A}} \dots\dots\dots 2.7$$

where

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

H = Conductive heat transfer co-efficient

### 2.7.2 Convection

Thermal convection is a process of energy transport affected by the circulation or mixing of a fluid medium (gas, liquid or a powdery substance). It is possible only in a fluid medium and is directly linked with the transport of medium itself. The effectiveness of heat transfer by convection depends largely upon the mixing motion of the fluid. With respect to origin, two types of convection are distinguished; forced and natural or free convection. It is generally based on newton's law of cooling.

#### Newton's Law of Cooling

$$Q = hA(t_s - t_f) \dots\dots\dots 2.8$$

Where Q is the convective heat flow rate,

A is the area exposed to heat transfer,

$t_s$  and  $t_f$  are the surface and fluid temperatures respectively.

The heat transfer coefficient  $h$  depends upon the thermodynamic and transport properties (e.g. density, viscosity, specific heat and thermal conductivity of the fluid), the geometry of the surface, the nature of fluid flow, and the prevailing thermal conditions. Convection mechanism involving phase changes leads to the important fields of boiling(evaporation) and condensation

### 2.7.3 Radiation

Thermal radiation is the transmission of heat in the form of radiant energy or wave motion from one body to another across an intervening space. Unlike heat transfer by conduction and convection, transport of thermal radiation does not necessarily affect the material medium between the heat source and the receiver. An intervening medium is not necessary and the radiation can be affected through vacuum or a space devoid of any matter. Radiation exchange, in fact, occurs most

effectively in vacuum. A material present between the heat source and the receiver would either reduce or eliminate entirely the propagation of radiation energy.

The mechanism of the heat flow by radiation consists of three distinct phase:

a) Conversion of thermal energy of the hot source into electromagnetic waves: All bodies above absolute zero temperature are capable of emitting radiant energy. Energy released by a radiating surface is not continuous but is in the form of successive and separate (discrete) packets or quanta of energy called photons.

b) Passage of wave motion through intervening space: the photons, as carriers of energy travel with unchanged frequency in straight paths with speed equal to that of light.

c) Transformation of waves into heat: when the photons approach the cold receiving surface, there occurs reconversion of wave motion into thermal energy which is partly absorbed, reflected or transmitted through the receiving surface.

The basic rate equations for radiation heat transfer are based on Stefan-Boltzmann law which states that the emissive power of a block of body is directly proportional to fourth power of its absolute temperature.

i.e.  $Q \propto T^4$  .....2.9

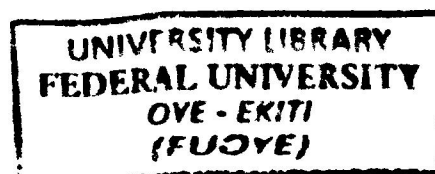
$Q = \delta AT^4$  .....2.10

where Q = Rate of heat emission

A = Radiation area of black body

$\delta$  = 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

$$Q = \delta A_1 T_1^4 - \sigma A_2 T_2^4 \dots\dots\dots 2.11$$

$$Q = \delta A (T_1^4 - T_2^4) \dots\dots\dots 2.12$$

## CHAPTER THREE

### 3.0 Materials and Methods

#### 3.1 Materials

The materials used in this work were obtained from the local markets within Akure and Lagos. They include: mild steel sheet of 1.5mm thickness, compressor pot, stainless steel pipe of 60mm diameter, refractory material(kaolin).

#### 3.2 Equipment

The equipment used in this research include: electric arc welding machine Denver d12, cutting machine, grinding machine, drilling machine, measuring tape, blower of 1hp (horse power) capacity

#### 3.3 Design of the furnace

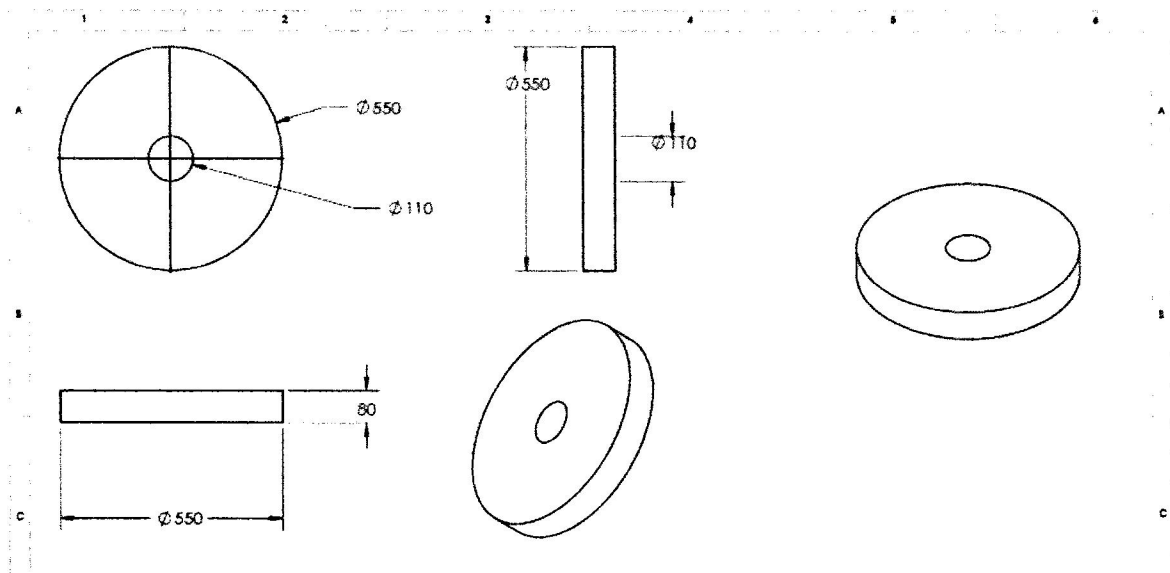


Figure 3.1: 2D Design of the Furnace Cover and Its Dimension

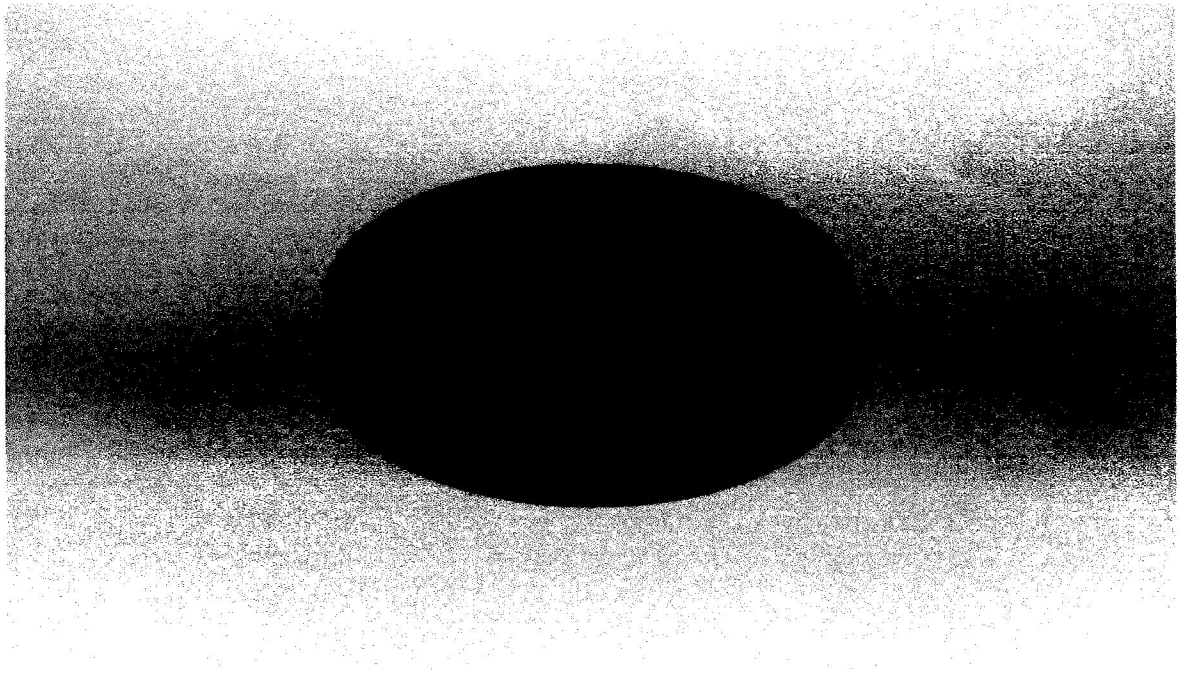


Plate 3.1:3D Design of the Furnace Cover

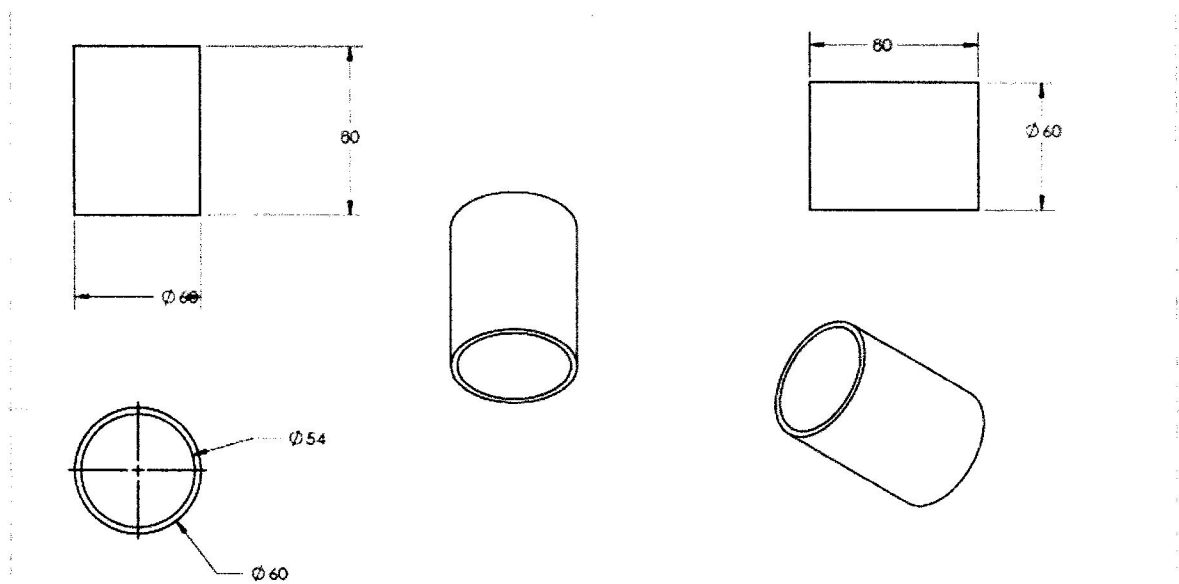


Figure 3.2: 2D Design of the Blower Pipe and Its Dimension

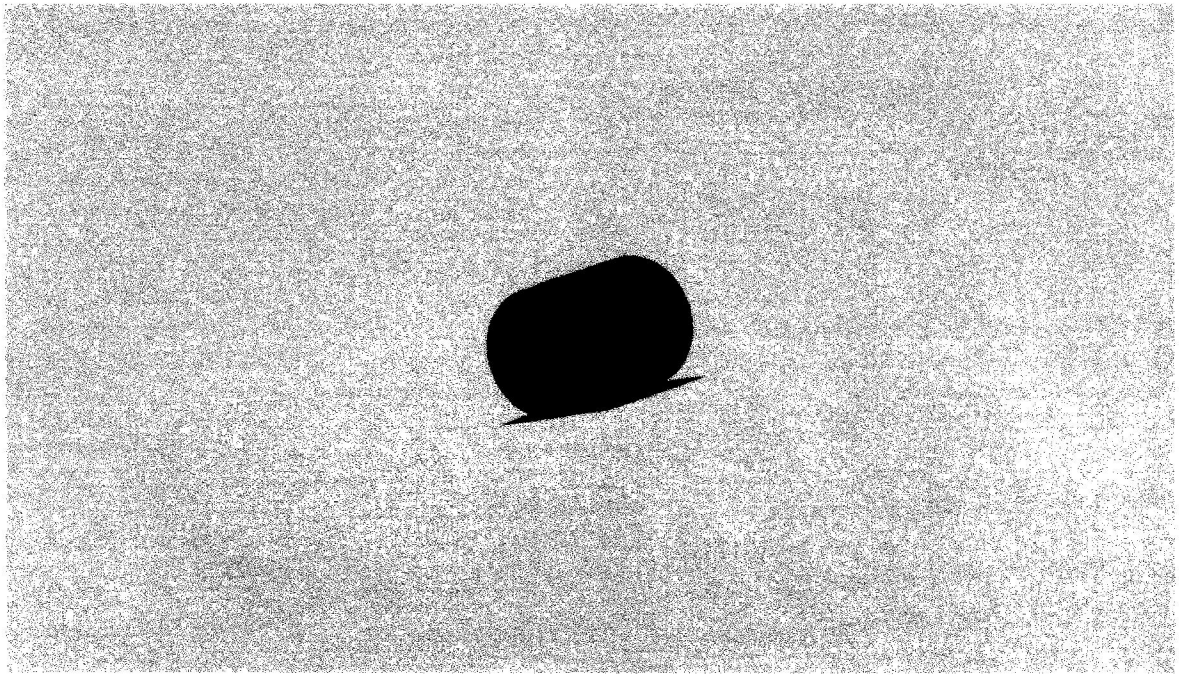


Plate 3.2: 3D Design of the Blower Pipe.

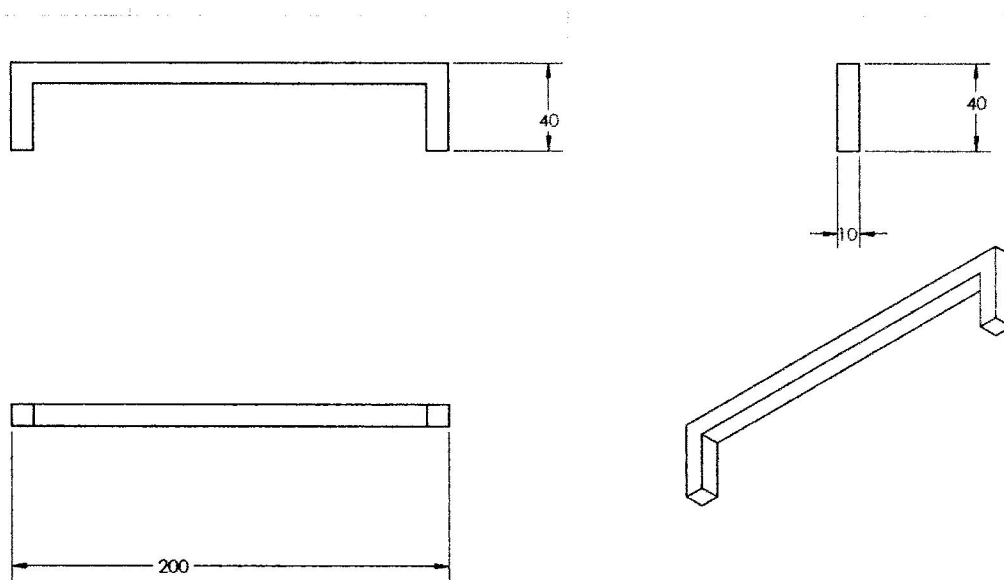
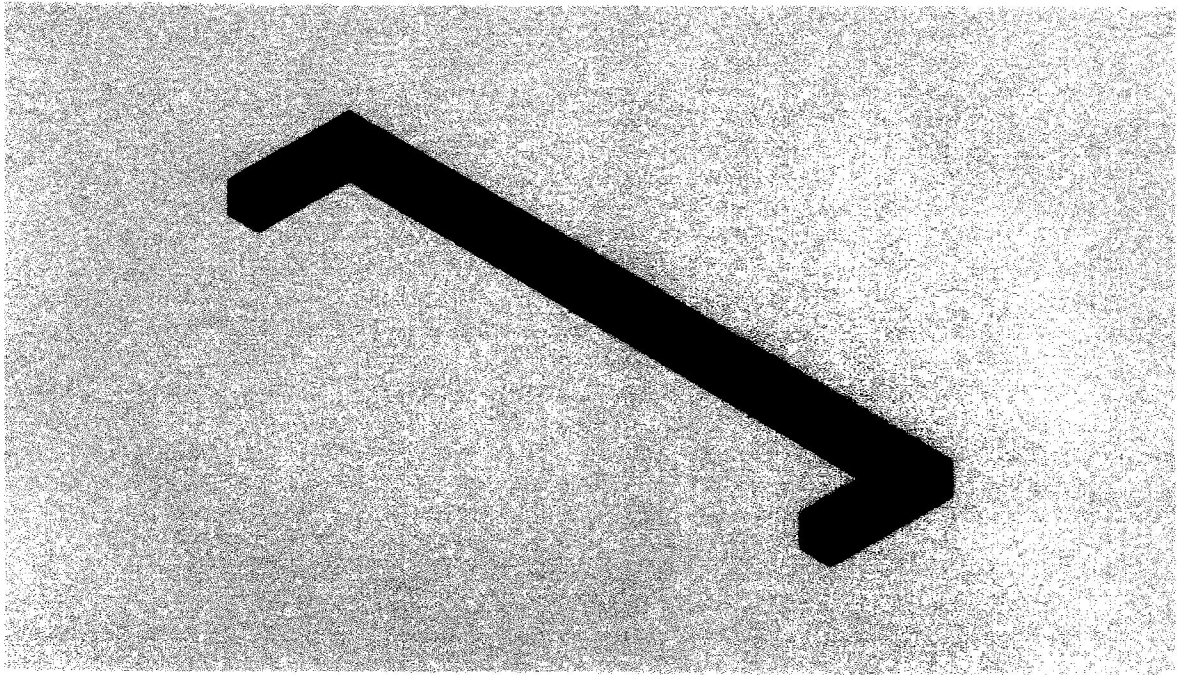
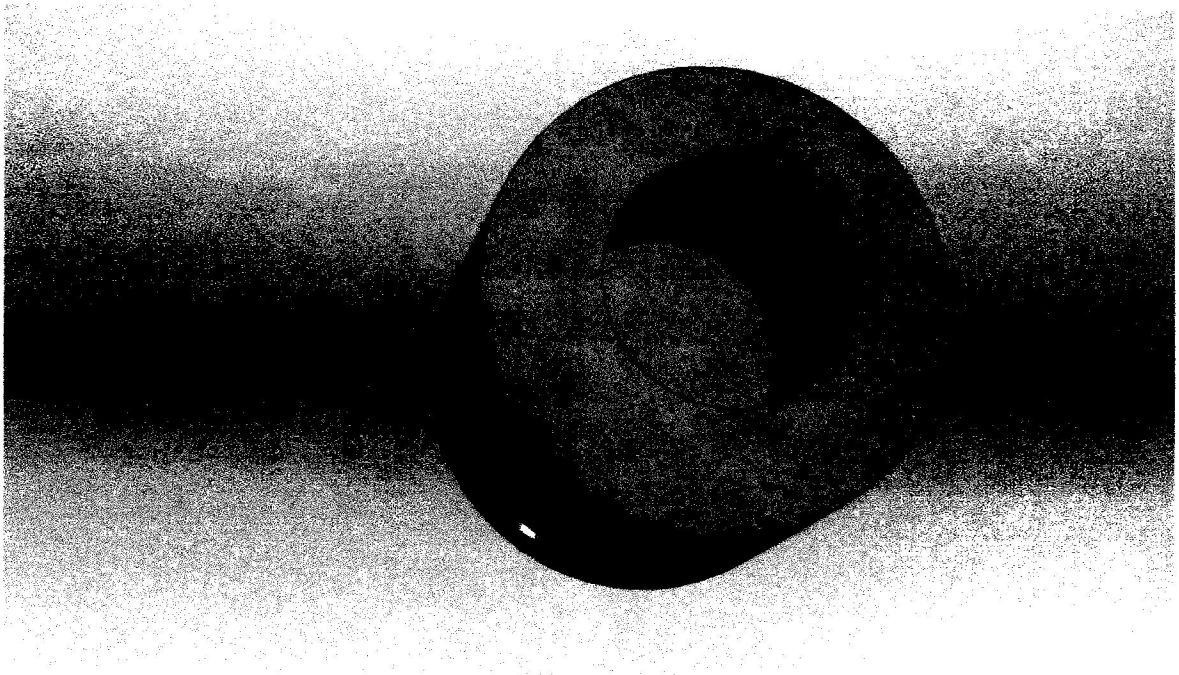


Figure 3.3 :2D Design of the Furnace Cover Handle in (Mm)





**Plate 3.3: 3D Design of the Furnace Cover Handle**



**Plate 3.4: 3D Design of the Furnace Shell and the Refractory Lining**



Plate 3.5: The Crucible Pot

### **3.4.0 Furnace Construction**

#### **3.4.1 Fabrication of Furnace Shell**

A 1.5 mm mild steel sheet of dimension 600 mm x 650 mm was cut using cutting machine and rolled to shape using rolling machine to dimension 500mm x 550 mm. The rolled plate was joined at the edges by welding using electric arc machine to form a cylindrical shape which serves as the body of the cylinder. The tolerance was cut away to give the actual dimension of 500 mm x 550 mm. The base of the furnace was also made from the mild steel sheet that was cut into a circular shape of diameter 550 mm; the circular plate was welded to the body of the furnace to give a solid base. A crucible cover of 80 mm x 550 mm was also fabricated from the mild steel plate with a hole of 115 mm made on the cover to serve as an exhaust for the fumes and gases. Handles were

attached to the crucible cover to allow for easy removal of the cover from the body of the furnace during loading of charges into the furnace and during removal of crucible pot from the furnace.

### **3.4.2 Refractory Lining**

The raw refractory material (alumino silicate) was crushed into a uniform size about 25mm, which was further grinded into the size of 200 mesh ,then the undesirable materials are removed from the raw materials through hand screening, the screened raw material were been tempered with water and binder was added which enhances the plasticity of the refractory material which enables it to be pounded or rammed into the circumference of the furnace shell forming a jointless lining, then dried and heated to obtain high strength, high density and chemical resistant.

### **3.4.3 Crucible pot**

The container of a refrigerator compressor was made use due to cost and availability. The refrigerator compressor container is made of pressed alloy steel. Therefore, the crucible pot was made of boiler plant pressed alloy steel, the weight of the crucible pot is 2kg.

## **3.5.0 Methodology**

The following methods were adopted for this project work:

### **3.5.1 Engineering Design of the Furnace**

The general layout and profile of the crucible furnace consists of an oil burner, blower unit, fuel tank and its stand, and crucible furnace unit. The furnace comprises a crucible pot to which the charge to be melted is fed into, a burner which burns the diesel oil and the crucible cover.

### **3.5.2 Design Consideration:**

The following factors were considered in carrying out the design; production cost, type of fuel used (diesel oil) 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

### **3.5.3 Crucible and Furnace specifications**

The furnace with its cover is 580mmhigh, the circular base having 550mm base diameter, the furnace lining forms an inner diameter of 300mm 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 five main components as listed below.

1. The Furnace Shell
2. The refractory lining (wall of the furnace).
3. The Burner and its pipe.
4. The fuel tank.
5. Crucible pot.

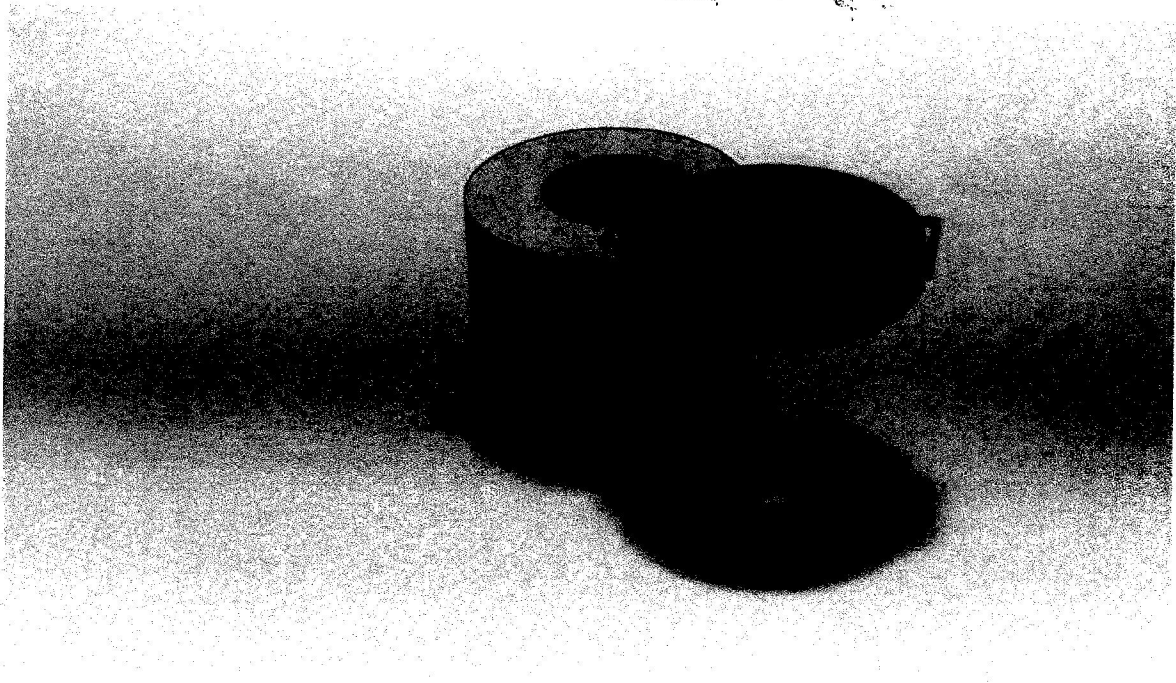


Plate 3.6: A Typical Design of a Crucible Furnace

### 3.5.4 Design Calculations

#### i. Calculations for the Internal and External Height of the Furnace

Internal height of the furnace = height of crucible + height of refractory lining uncovered by crucible

Therefore,  $= 200 + 210 = 410\text{mm}$

External height = internal height of the furnace + thickness of the base lining

Therefore, external height =  $410 + 90 = 500\text{mm}$ .

#### ii. Circumference of the furnace

The circumference of the furnace =  $2\pi r$

Where  $r$  = radius of the internal diameter of the furnace =  $\frac{300}{2} = 150\text{mm}$

Hence, the Circumference =  $2 * \frac{22}{7} * 150 = 942.86\text{mm}$ .

**iii. Calculation of the Weight of the Metal Sheet of the Furnace**

Recall that the volume of a cylinder =  $\pi r^2 h$

$$\text{Volume} = (\pi r^2 h)_{\text{external}} - (\pi r^2 h)_{\text{internal}}$$

$$\text{Volume} = \frac{22}{7} \times 0.275^2 \times 0.500 - \frac{22}{7} \times 0.150^2 \times 0.410 = 0.041 m^3$$

**iv. Calculating Weight of the Crucible**

Since the crucible to be used is 2kg

$$\text{Hence, its weight} = 2 \times 9.81 = 19.62.4kn$$

**v. Calculation of Weight of the Molten Metal**

Let mass of charged materials equals mass of the molten metal let's say= 5kg

$$\text{Therefore, its weight} = 5 \times 9.81 = 49.05kn$$

## CHAPTER 4

### 4.0 RESULTS AND DISCUSSION

#### 4.1 RESULTS

After the furnace had been fabricated the furnace was tested by melting of 5kg aluminium scraps which was used to produce a spanner and kerosene stove stands through the following process

A pattern of a spanner and electric stove stand was first made through floor molding process, 5kg of aluminium scrap is being weighed and charged into the crucible, the charged crucible is then placed in the furnace the furnace was then covered and the furnace was started, at about 25 minutes from the start of the furnace the aluminium scrap turned molten completely at a temperature of  $700^{\circ}\text{C}$ , the crucible containing the melt was then removed with a tong and poured into the already made mold and allowed to solidify.

During the test it was observed that heat was well dissipated and there was less heat loss during the melting of the aluminium scrap. The furnace was found to melt 5kg of Aluminium within 25 minutes. The furnace diesel fuel consumption rate was found to be 0.15 L/min.



**Plate 4.1: Assemblage of the Furnace during Testing**





**Plate 4.2: Layout of the constructed Furnace during Testing**

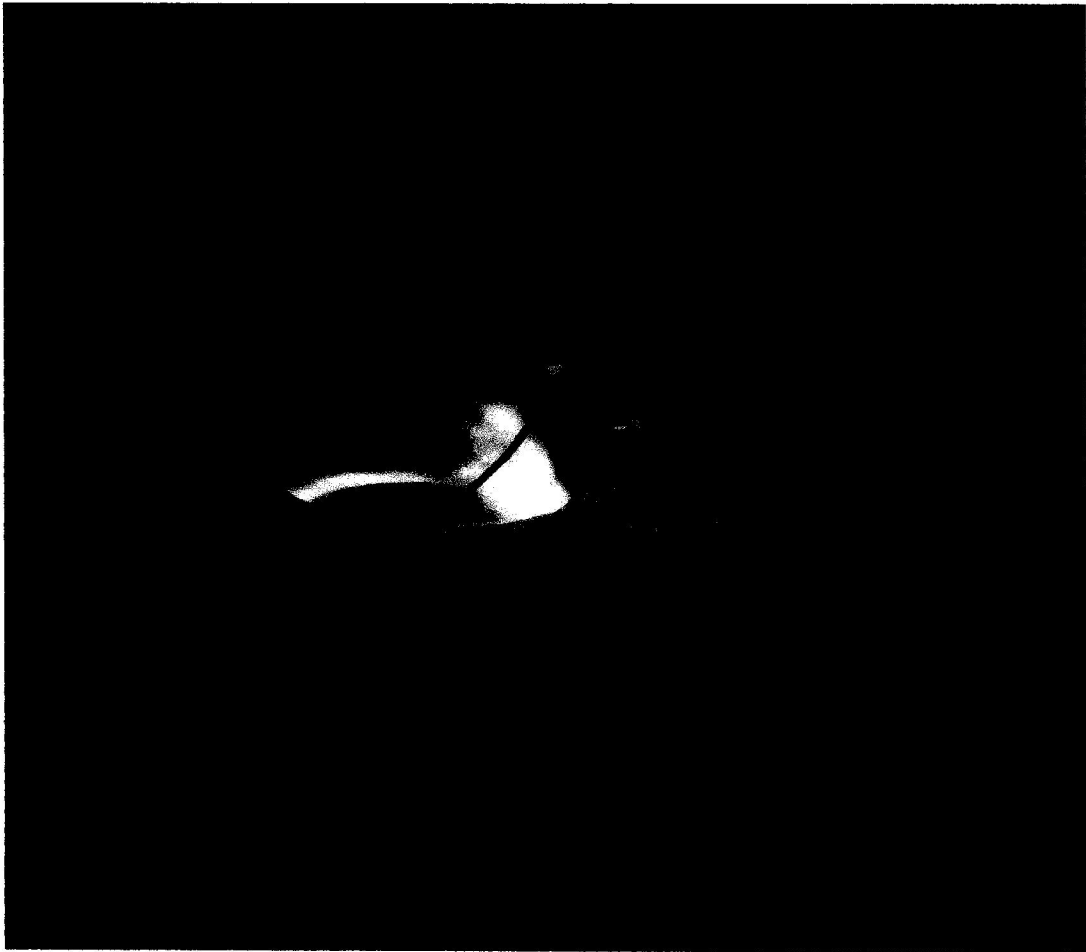


Plate 4.3: A Picture of the Furnace During the Removal of the Melt from the Furnace

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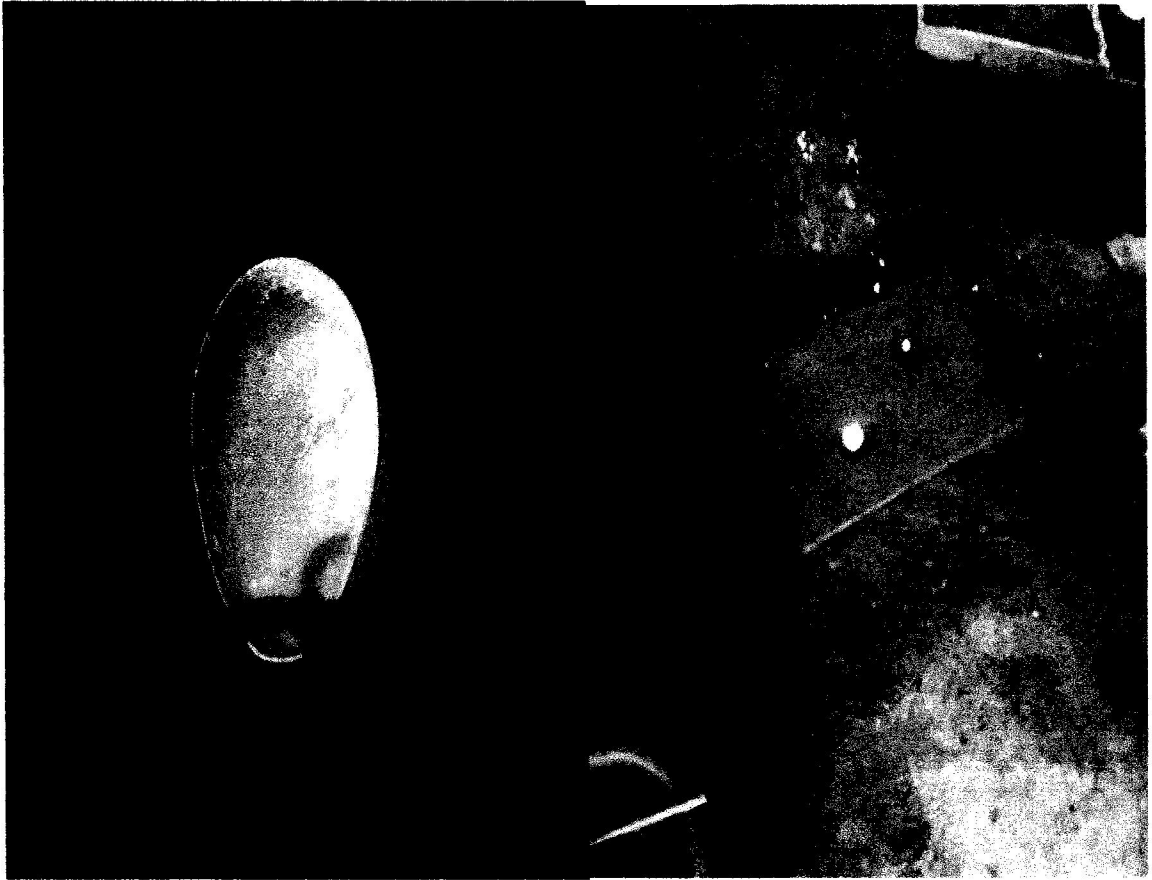


Plate 4.4: A Picture of the Melt during Pouring of the Melt into Mould



Plate 4.5: A Picture of the Casted Spanner and Stove Stands

## **CHAPTER 5**

### **5.0 CONCLUSION AND RECOMMENDATION.**

#### **5.1 CONCLUSION**

Based on the results obtained from the performance test carried out on the fabricated crucible furnace, the objectives of the research were achieved, such as fuel economy, health hazard reduction and time required for the operation, the furnace melts the aluminium scrap, which was used for casting some specimens for testing. The crucible has the ability to conduct heat and so transfers heat to the aluminium scrap without much loss. Molten metal is easily poured out from the furnace due to its design which permits it to be lifted out. The following conclusions was also 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.

#### **5.2 RECOMMENDATION**

Further research is recommended to ease the operation of the system. The capacity of the fuel tank should also be increased to accommodate more fuel for longer operation period. An awareness campaign should be undertaken to encourage the use of crucible furnace.

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