DEVELOPMENT OF A 5KG CAPACITY INDUCTION FURNACE FOR MELTING ALUMINIUM

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M.ENG/SEET/2017/6766

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JANUARY, 2022

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF ENGINEERING IN MECHANICAL ENGINEERING (INDUSTRIAL AND PRODUCTION ENGINEERING OPTION).

JANUARY, 2022

Aluminium in Nigeria is a popular metallic element. Widely used to produce single domestic appliances and even industrial engine components. These components display a decrease in performance level after many years of service are discarded and they become waste that tend to be a problem to manage. Furnaces are required for student practice to improve their technical skills, to reduce stress of local blacksmiths and the reduce delays due to frequent power interruption. This project is aimed at developing a 5kg capacity induction furnace solely used to melt aluminium at a faster rate. The design was considered in two phases, the geometrical and the electrical consideration. The crucible used in this project is made of graphite and the charge material (aluminium) was locally sourced for in the environment. The heating process is fundamentally based on electro-magnetic means, where heat energy is transferred directly from the induction coil into the metal to be melted without having contact directly with the metal through the electromagnetic field produced by the induction coil. The fabrication was achieved by cutting with manual hack saw, drilling and joining with electric arc wielding machine. A maximum temperature of 720 °C was achieved in 48 minutes with a power rating of 2800 watts and 220 volts, which was satisfactory as the temperature attained from the project is higher than the conventional standard aluminium temperature which is 660.4 °C and was able to melt aluminium at a faster rate.

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CHAPTER ONE

1.0   INTRODUCTION

1.1   Background of Study

In Nigeria institutions today, there are several production machines used as model for the enhancement of student knowledge and technical skills but we hardly can find induction furnace being used in institutions. Perhaps because of the poor availability of electricity power stability situation we are facing in the country, most of the furnace used in institutions are locally made, using charcoal as the main source of heat, which is not the best and most efficient method of melting metals.

Aluminium is a metallic element that has numerous uses especially in Nigeria. It is used for the production of machine components and even in cooking utensils. It is used to primarily used to produce pistons, engine and body parts for cars, beverage cans, door and window (frames), bars wires and also for aircraft components.

Aluminium is primarily produced from bauxite ore. Bauxite is a rock formed from a reddish clay material called laterite soil and is most commonly found in tropical or subtropical regions. Bauxite is primarily comprised of aluminum oxide compounds (alumina), silica, iron oxides and titanium dioxide. Approximately 70 percent of the world's bauxite production is refined through the Bayer chemical process into alumina. Alumina is then refined into pure aluminum metal. (Ekpe *et al*., 2016).

However, the element is rarely available as rich ores, which leads to countries relying on its importation to satisfy demand (Bala, 2005). Another method of obtaining Aluminium is through secondary production, i.e, recycling. This method according to (Ekpe *et al.,* 2016) saves up to 95 % of energy compared to the primary refinement from ore and is also cheaper.

This research work is centred on developing a small size model of furnace for use in our institutions and outside the institution for learning purposes, enrichment of knowledge, technical skill, small scale production of metals in a short limited (20 minute to 60 minutes) time range before the power goes off again and also empower the student to be self-employed.

1.2   Statement of the Research Problem

Aluminium in Nigeria is a popular element used in various components, and these components displayed a decrease in performance level after many years of service and are discarded (Bala, 2005). These components can be used as raw materials for secondary aluminium production rather than loitering and becoming waste that will become problem to manage. Recycling is a cheaper way of reusing the materials that constitute wastes as environmental pollutants. Most furnaces available for recycling are manually operated and make use of charcoal, which in turn causes deforestation. The development of a new electric induction furnace is conceived to reduce the use of charcoal, protect the environment and also reduce intake of smoke produced from the charcoal.

1.3   Aim and Objectives of the Study

The aim of this project is to develop a 5kg induction furnace for melting aluminium scrap metals. The objectives are to:

1. Design a 5kg induction furnace for melting aluminium scrap metals.
2. Fabricate a 5kg induction furnace for melting aluminium scrap metals.
3. Carryout performance evaluation on the furnace.

1.4   Significance of the Study

The development of a 5kg induction furnace for melting aluminium scrap can be a learning model in our institutions to improve students' knowledge and technical skills on the subject and a fast, simple method of melting.

1.5   Scope of the Study

The furnace is developed to a maximum capacity of 5kg and it is solely to be used to melt aluminium scarps to a pouring temperature of $720^{o}C$, but no casting is to be carried out.

1.6   Limitation of the Study

This project is limited to the development of a 5kg induction furnace.

CHAPTER TWO

2.0   LITERATURE REVIEW

2.1   Historical Development of Induction Furnace

An induction furnace is an electrical furnace where heat energy is transferred directly from the induction coil into the metal to be melted without having contact directly with the metal through the electromagnetic field produced by the induction coil. Historically, the early development of induction furnace started as far back as Michael Faraday, who discovered the principle of electromagnetic induction. However, it was not until the late 1870's when De Ferranti, began experiments on Induction furnaces in Europe. In 1890, Edward Allen Colby patented an induction furnace for melting metals and produced his first steel in the United States in 1907 (Anaidhuno *et al*., 2014).

 The first practical usage was in Gysinnge, Sweden, by Kjellin in 1900 and was similar to the Colby furnace. In Germany 1906 the first induction furnace for three phase application was built by Rochling - Rodenhauser. During World War II, the technology grew rapidly to satisfy pressing wartime demands for a quick and authentic method of hardening metal engine parts. In advanced manufacturing processes, induction heating provides an appealing assemblage of speed, consistency and control, it also has a good heating efficiency, high production rate, clean working environment, 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 more iron foundries are replacing cupolas with induction furnace to melt cast iron, as the former emit lots of dust and other pollutants. Induction furnace capacities range from less than one kilogram to one hundred tonnes capacity and are used to melt iron and steel, copper, aluminium and precious metals. The two basic designs of induction furnaces are the core type or channel furnace and the coreless, which are certainly not new to the industry. The channel furnace is useful

for small foundries with special requirements for large castings, especially if off-shift melting is practiced and widely used for duplexing operations and installations where production requirements demand a safe cushion of readily available molten metal, while the coreless induction furnace is used when a quick melt of one alloy is desirable, or it is necessary to vary alloys frequently. The coreless furnace may be completely emptied and restarted easily and makes it perfect for one-shift operations (Duncan *et al.,* 1985). The coreless induction furnace is also considered as the most popular type of the induction furnace because of tis suitability for all metal industries (Hastingds *et al*., 1983).

The coreless induction is also a simple unit consisting of a helically wound coil surrounding a refractory crucible containing the molten charge and connected to an alternating excitation system (Edgerley, 1977). The coreless induction furnace is commonly used to melt all grades of steels and irons as well as many non-ferrous alloys. A modern coreless induction furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1450 °C using less than 600 kWh of electricity. Typically, Specific Energy Consumption (SEC) of coreless induction furnace varies from 500 to 800kWh per tonne depending on the type and grade of casting.

Thus, the development of an induction furnace essentially requires careful selection of materials, working principles, safe operation, method of fabrication, installation and maintenance of both the machine and the water-cooling system, which is efficient and essential in coreless induction furnace.

Aluminium being the most abundant metallic element, forming about 8% of the solid portion of the earth's crust, is rarely available as rich ores. Hence most countries are dependent on supplies of it being imported. Nigeria, for instance, uses aluminium in all aspects of human endeavour (Abubakre, 2001). The metals to be melted are aluminium

scrap, which are also called secondary aluminium. Generally speaking, there are two types of aluminium scraps which are new or production scrap and old scrap. The new scrap comes directly from the manufacturing and fabrication processes. They are easy to recycle and are almost 100% directly remelted with little preparation while the old scrap comes from various sources and is normally contaminated with foreign elements and organics. According to (Goldstick *et al., 1986)*, secondary aluminium production (recycling) saves 95% energy needed to produce aluminium from its ore. Hence, it is more of economic importance that aluminium recycling becomes a major source of aluminium production (Joshi, *et al.,* 2002). Aluminium is primarily used to produce pistons, engine and body parts for cars. Beverages cans, doors, sliding door and aluminium foil. It may also be used as sheet metal, aluminium plate and foil, Rods, bars and wire, aircraft components, windows and door frames. The leading users of aluminium include the container and packaging industry, the transportation industry, building and construction industry (Kazantsev, 1977). Aluminium can either be produced from bauxite ore (primary aluminium refining) or from aluminium scrap (secondary aluminium refining). Refinement of aluminium ore is sufficiently expensive that the secondary production industry commands much of the market. It is recorded that about 40% of aluminium in the US is recovered from secondary refining. The re-melting of these scrap product of aluminium will go a long way to enhance the availability of the product without over reliance on the foreign market, and thereby improving the foreign reserve. Similarly, the acquisition of melting equipment for this purpose has also become a very difficult thing such that there is a need to look inward for fabrication of some vital components for our technological growth. It is in view of this, that different methods of melting aluminium are being used in the country, such as crucible furnaces, either on industrial or local small scale, by burning of fossil or organic fuels. These have the disadvantage of

producing low quality products as a result of the impurities present in the fuel (Bala, 2005).

Ferranti, in 1887 designed a melting furnace and the induction heating was applied firstly in the industry for melting metals. This idea was applied successfully by Dr. F. Kjellin Sweden, around 1903, who designed and built an open channel induction furnace. It was in 1915 when the American J.R. Wyatt develops the idea of the vertical channel. In 1918 the American Professor Dr. E.F. Northrup patented an induction furnace without core of high frequency based on the oscillating discharge of a circuit consisting of a capacitor (which is charged to 50Hz in a phase of the cycle), a reactance and resistance of the coil of the furnace that surrounds the crucible without magnetic core between primary and secondary.

In 1927 the first furnace of medium frequency was installed in a factory of Sheffield (England). Since then, the number, size, design, fabrication and installations has not stopped growing over the years.

2.2   Previous Works

According to Bala (2005), the advancement of any nation technologically has been influenced and elevated by the extent to which it can usefully harness and convert its mineral resources. The productions of metal in foundries and in all human lives have also become a general practice. Different melting techniques are in practice with different energy sources. The cleanliness and availability of electrical energy sources in Nigeria is of paramount importance to its use in foundries, hence the need for this design. Bala (2005) work deals principally with the mechanical and electrical requirements for induction furnace production. The mechanical aspect gives consideration to the geometrical components, cooling system, and the tilting mechanism. The electrical aspect

deals with the furnace power requirement to make it functional. The design was achieved through consideration of relevant theories and their practical application.

Yang *et al* (2005), researched that Aluminium recycling was an excellent example in the efficient utilization of secondary material resources. During secondary aluminium recovery, the aluminium scraps were melted and refined often in a rotary melting furnace under a molten salt layer, which is how European practiced. The feed was normally a complex combination of aluminium scraps with different types, sizes, shapes, compositions, and contaminations. Efficient melting of the scrap was a critical issue in order to achieve higher metal recovery, lower energy and salt consumption, and less environmental impact. Yang *et al* (2005) stated that the melting behaviour of various types of aluminium scraps was investigated in laboratory furnaces. The recyclability of different scraps was examined. It confirms that scrap type, surface conditions, size and contaminants have significant influence on the metal yield and scrap recyclability. Based on the experimental results and industrial operational data, a Computational Fluid-dynamics CFD based process model was developed, coupled with user-developed sub-models for scrap-melting and metal burn-off. The distributed melting behaviour of different aluminium scraps was evaluated and the modelling results were used to analyse the melting process in industrial furnace, and to estimate the energy flow and distribution, and finally contribute to process optimisation.

Ahmed *et al* (2009)*,* deals principally with the design of coreless induction furnaces for melting iron. Both mechanical and electrical requirements for induction furnace was presented. To verify the design results, a comparison between the design results and those of an actual induction furnace was carried out.

Gandhewar *et al* (2011), remarked that a new generation of industrial induction melting furnaces was developed during the last 25 years. Present practices followed in Induction

Furnaces were discussed. Through a literature review account of various practices presently being followed in steel industries using Induction Furnaces was carried out. They provided some recommendations for the productivity improvement. They asserted that to non-availability of the proper instrumentations, the effect of the ill practices cannot be precisely judged. If this was properly measured, the percentage of productivity improvement in steel melting Induction Furnace can be calculated. The review was carried out from the literature in various journals and manuals.

Alshaikhli *et al* (2014) designed and constructed a coreless induction furnace. They stated that many analytical methods could be applied to induction heating and melting problems. The most suitable method used by the researchers was the equivalent circuit method, a second approach was the superposition method, which was to check the results of the first method in one step of the design. Prior to the use of these two methods the dimensions of the furnace, the operating frequency and the required power was determined as a prerequisite. A design procedure was developed as computer programs, these programs accomplished a general design which would be utilized to design coreless furnaces of variable specifications. Then, a design, meeting certain specification was prepared, taking into consideration the available facilities. Ultimately, the furnace was constructed and the final aim, which is melting the metal, was achieved.

Kulkarni *et al* (2014), designed an Induction Furnace with better controllability and power efficiency. The hardware implementation considered the following points while designing i.e. the solid state power sources used to drive induction heating loads are very efficient when the load was driven at its natural resonant frequency. These allowed zero voltage (ZVS) and zero current (ZCS) switching of the converter, resulting in reduced power losses in the semiconductor switches. Another advantage of driving a load at resonance was to enable an input power factor close to unity allowing minimal KVA

consumption. Environmental cleanliness was another added advantage. The process consists of three phase rectifier to convert three phase AC to filtered DC. Then using an H-Bridge inverter, it was converted back to high frequency single phase AC, with control circuitry. The furnace coil and a capacitor form a resonant tank circuit. The metal to be heated was placed in the coil, resulting in shift in the frequency. The resonant tank circuit was returned via frequency control circuit to achieve resonance and to enable maximum power transfer to the load at all time as remarked by the researchers.

Muhammad and Muhammad (2014), stated that Induction melting could be a potential fabrication method for aluminum matrix nanocomposites, owing to its characteristics stirring action and rapid heating. The induction coil for small scale composite fabrication was designed through geometric, thermal, and electromagnetic analyses. Subsequently, the designed coil was simulated for its thermal efficiency and stirring force using finite element method magnetics software. The designed coil yielded more than 60% of the total energy supplied into thermal efficiency with a stirring force.

Anaidhuno and Mgbemena (2015), developed a 3kg capacity Electric induction furnace with a power rating of 2500W for heat treatment of ferrous and non-ferrous alloys. The furnace was made from mild steel sheet, monolithically lined with fire clay refractories and designed to attain a temperature of 1200 ºC on the automatic control panel. The authors opined that project was primarily undertaken to build local capacity in foundry practice in Nigeria and to encourage the demonstration of fundamental foundry practice for undergraduates of a Nigerian University.

Abdulbaqi *et al* (2015), opined that the design of a certain induction furnace for a certain application depends mostly on empirical formulas and experience. The purpose of Abdulbaqi *et al* (2015), work was to use the Finite Element Method (FEM) approach to perform an electromagnetic-thermal coupled analysis for a suggested coil with certain

billet and studying its performance during the heating period. This will lead to the ability of expecting the required coil current and its frequency, to heat certain part of a certain billet to a certain temperature at the predetermined time. The researchers remarked that simulation results can be used to build the coil and which lead to designing the power supply for the induction furnace. The practical measurement of the designed system agrees with that of the theoretical design results. Hence, this approach was to reduce the design cost, time and efforts for any other required induction furnace.

According to Dhiman and Bhatia (2015) heat treatment was the linked process for treatment of machine and forging components. Furnaces can be used for heat treatment process. They have observed that the major problems in oil-fired furnace were non-uniform flame distribution, oxidation of metal, scale formation, carbon loss of metals and emission of pollutants. Oil fired furnaces have low productivity and long start-up time. They remarked that to avoid these problems the new technology induction furnace should be used. By using the induction furnace instead of oil-fired furnace, the productivity may be increased and production cost may be reduced.

Ekpe *et al* (2016), stated that the increasing demand for aluminium scrap (as waste constituent) in our environment cannot be over emphasized. Hence, an improved system of continuous aluminium recycling as a secondary aluminium production was designed and constructed for melting scrap aluminium. This furnace was a modified model suitable for laboratories and workshops. The furnace was designed and fabricated using locally available materials and butane gas as the thermal energy source in heating up the system to the melting point of aluminium (660.4 °C). The molten aluminium was casted to a desired shape and size either as ingot or end product.

Patil and Ghatge (2017), provided some recommendations for the productivity improvement. Due to non-availability of the proper instrumentation the effect of the ill

practices cannot be precisely judged. If this was properly measured, the percentage of productivity improvement in steel melting Induction Furnace could be calculated as remarked by the researchers. The review was carried out from the literature in the various journals and manuals. The aim of the researchers was to study the overall performance of induction furnace and to suggest the method to improve melt rate with optimum use of electricity. There work mainly put attention on induction furnace as these were main consumer of electricity in foundry. In case of induction furnace, efficiency was sensitive to many controllable features lie in operational practices, coil height; charge mix, furnace utilization etc. So with the help of recommendation, it is easy to find out the ways to lower the specific energy consumption in this furnace.

Grachev (2017), described the trend towards increased use of induction crucible furnaces for cast iron smelting. The use of gas cupola's duplex process – induction crucible furnace – has proved the effective direction of scientific and technical advance in the foundry industry as opined by the researcher. Gas cupolas and induction furnaces were used for cast iron smelting at the Penza Compressor Plant where in the 1960s the author developed and introduced gas cupolas for the first time in the world. Grachev (2017), represented the findings of the investigation on thermodynamics of crucible reduction of silicon, which was pivotal when choosing the technological mode for cast iron smelting in induction furnaces. The author proposed a new reaction crucible diagram with due account of both partial pressure and activity of the components involved into the process. For the first time ever, the electrochemical mechanism of a crucible reaction has been studied and the correctness of the proposed diagram has been confirmed.

Odeh (2017), designed and fabricated a 1kg capacity induction furnace for melting aluminum which was fabricated with mild steel sheet and lined with fire clay refractories which attained a temperature of 700 ºC.

Dejaeghere *et al (2018),* presented the first step concerning the design of a very high temperature inductive furnace dedicated to the characterization of molten metals in the 1600 ºC – 2800 ºC temperature range. One major constraint was to provide homogeneous temperature within the tested sample and thus avoided thermal gradients as well as magnetic fields. For that, the choice of materials for the furnace design has been made and validated through both a magneto-thermal simulation and some in situ temperature measurements of the sample with both thermocouples until 1600ºK, and with a visible-Near Infrared NIR pyrometer used for the upper temperatures. Experimentally, the pyrometer was calibrated using the melting temperature measurement of a pure nickel sample placed in the furnace. Finally, the furnace heated capacity limit was tested and reached during the niobium sample melting. During the test, technical difficulties occurred due to physico-chemical contamination from the crucible as remarked by the researchers.

Patil *et al (2018)* asserted that large innovation in heating, and electrical systems have progressed from low voltage to high voltages or multilevel to multiphase system as a result of energy crisis. Induction furnaces employed for the melting metals was well implicit and optimized electromagnetically. Still a novel challenge ascends, when the entire device was considered. The vibrations and acoustic noise were of predominant importance, as the frequency of operation and the rated power of the devices were rapidly raised. A clean, energy-efficient and well-controlled melting process was of an advantage when the induction furnace was electrified to heat up the materials that are electrically conductive in nature. As it was a non – contact heating process, it did not pollute the material being heated. It is also very efficient as the heat is actually produced within the work-piece. This lead to differ with other heated element, which was then supplied to the work-piece. Hence an induction heating offers itself some unique applications in industry.

A finite-element analysis of the furnace was presented and compared with the results from the experimental furnace in order to design the induction furnace. The Power supplies was in ranges from 10kW to 42 MW, with melt sizes of 20kg to 65 tonnes of metal respectively.

Melwyn and Bhagyanathan (2019), reported that Aluminium was extracted from the chief ore bauxite due to its abundance in nature, but the gas emissions produced by the process made researchers and industrialists to look for alternatives. Since then the aluminium was reprocessed and have been accessible in the secondary form with similar characteristics from its antecedent. A lot of recycling methods was followed, this research work gave a detailed account of the induction (electrical) method used to obtain secondary aluminium alloys. To accomplish this, machined aluminium scrap (He9) alloy was melted in the induction furnace. The recycling efficiency of the furnace, its performance compared to the combustion process (coal, natural gas and oil) were also closely analyzed. The exertion also involved monitoring of the energy ingestion of the induction furnace and the best furnace that was appropriate for the industry was also determined through the work.

2.3   Types of Electric Melting Furnace

Maung (2005), stated that in electric melting furnaces, energy is introduced by radiation, convection, or induction directly to the metal to be melted. Raw ferrous materials consist mostly of scrap and some cold pig iron. For this reason, the electric furnace plays an important role in the recovery and recycling of waste iron resources. Electric melting furnaces are usually divided into three main classes according to the method of pouring the metal from the crucible, which are:

1. Arc Furnace

2. Resistance furnace

3. Induction furnace

2.3.1 Arc furnace

Electric arc furnaces are widely used in steel industry for melting and refining of iron. They are also used in the smelting of non-ferrous metals. The principle of operation of Electric arc furnace is that the air in the air gap gets ionized under the influence of electrostatic forces and becomes conducting medium on the application of high voltage across an air gap and the current flows in the form of a continuous spark, called the arc. Depending on the formation of arc, the Electic arc furnace are classified as direct arc furnace, indirect arc furnace and submerged arc furnace. Direct arc furnace is mainly employed for making alloy steels such as stainless, high speed steel. Indirect arc furnace is used for melting nonferrous metals. Submerged arc furnace is used for the production of Ferro-chrome and Ferromanganese. Awagan and Thosar (2016). In the direct heat arc furnace the positive pole and negative pole of the furnace are contacted so that heat arises. Whereas in the indirect heat arc furnace, the contact between the two poles is not direct but the relationship between the two poles is through the charge (charge). Hermawan *et al* (2019).

2.3.2 Resistance furnaces

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 electrical energy transformed into heat in the resistors is used in part to raise the temperature of the charge and in part to heat the walls of the chamber and to compensate for the furnace heat losses. After a description of the different constructive types of

furnaces (batch, continuous, for low, medium or high temperature, with protective atmosphere or in vacuum), heating cycle, criteria and materials for wall design and test methods of this type of furnace are analyzed. In the final paragraphs, we will describe the different types of resistors, characteristics of materials used for their construction and design criteria of resistors for classical radiation or convection furnaces. At the end, furnaces with high specific power resistors are briefly discussed, making also reference to the energy balance of this type of furnaces (Lupi, 2017).

2.3.3 Induction furnaces

Induction furnace is an electrical furnace in which the heat is applied by induction heating of a conductive medium (usually a metal) in a crucible placed in a water-cooled alternating current solenoid coil Akash (2010).

2.3.4 Types of induction furnace

1. Coreless Induction Furnace
2. Channel Induction Furnace

2.3.4.1 *Coreless induction furnaces*

The heart of the coreless induction furnace is the coil, which consists of a hollow section of heavy duty, high conductivity copper tubing which is wound into a helical coil. The Coil shape is contained within a steel shell to protect it from overheating, the coil is water-cooled, the water being recirculated and cooled in a cooling tower. The crucible is formed by ramming a granular refractory between the coil and a hollow internal. The coreless induction furnace is commonly used to melt all grades of steels and irons as well as many non-ferrous alloys. The furnace is ideal for remelting and alloying because of the high degree of control over temperature and chemistry while the induction current provides good circulation of the melt. Dhiman and Bhatia (2015).

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2.3.4.2 *Channel induction furnace*

The channel induction furnace consists of a refractory lined steel shell which contains the molten metal when it is attached to the steel shell and connected by a throat is an induction unit which forms the melting component of the furnace. The induction unit consists of an iron core in the form of a ring around which a primary induction coil is wound. This assembly forms a simple transformer in which the molten metal loops comprises the secondary component. The heat generated within the loop causes the metal to circulate into the main well of the furnace. The circulation of the molten metal effects a useful stirring action in the melt. Channel induction furnaces are commonly used for melting low melting point alloys and or as holding and superheating unit for higher melting point alloys such as cast iron. These furnaces basically consist of a vessel to which one or more inductors are attached. The inductor is actually a transformer where by the secondary winding is formed with the help of a loop of liquid metal confined in a closed refractory channel. In the furnace the energy is transformed from the power system at line frequency through a power supply to the inductor and converted into heat. Dhiman and Bhatia (2015).

2.3.5   Advantages of induction furnaces

The following are the advantages of Induction furnace:

1. **Quick heating**: development of heat within the work piece by induction provides much higher heating rates than the convection and radiation processes.

2. **Less scale loss**: Rapid heating significantly reduces material loss .

3. **Energy savings**: when not in use the induction power supply can be turned off because of quick restarting. With furnaces, energy must be supplied continuously to maintain temperature during delays in processing and to avoid long start-ups.

4. **High production rates**: As heating time is less, induction heating often allows for the increase in production and reduction of labour costs.

Besides these the induction furnace provides other advantages such as-

i.   Less requirement of floor space

ii.   Quick, safe and clean working conditions

iii.   Requirement of less maintenance

iv.   Well defined melt temperature

v.   Simple automatic process control

vi.   High quality of the melt even with cheap charge material (scrap)

vii.   High throughput because fast melting and fast heating up of the melt

viii.   High furnace efficiency

ix.   Simple handling of the furnace and the process

x.   Well defined controlling of the power input

xi.   Good working conditions for the workers at the furnace

xii.   Environmentally friendly (small dust emission, no exhaust gas)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Design Method, Materials and Fabrication

This project work is carried out with the intention of making an induction furnace using locally made materials. Materials selections for each component, operating descriptions, operating sequences for the fabrications and estimated cost are outlined.

This design analysis of Bala (2005) was adopted in this research work. The design analysis is based on a 5kg capacity and the shape of the crucible is cylindrical. The internal diameter of the crucible and the height of melt is determined by the furnace capacity (melt volume), with considerations that the ratio:

$$F_c = \frac{H_m}{D_c} \tag{3.1}$$

$$\frac{0.13}{0.08} = (1.625)$$

Where:

H_m is height of molten metal, m;

D_c is diameter of crucible, m;

H_m is 0.13m

D_c is 0.08m

3.1.1 Determination of the volume of metal charge

Volume of metal charge is given by:

$$V_m = \frac{\pi d_m^2 H_m}{4} \tag{3.2}$$

Where:

V_m is Volume of Metal Charge.

d_m is diameter of molten metal.

$$V_m = \frac{3.142\ (0.08)^2\ x\ 0.13}{4}$$

$$V_m = \frac{2.00145\ x\ 10^{-3}}{4}$$

$$V_m = 6.003635\ x\ 10^{-4} m^3$$

$$V_m = 0.0006 m^3$$

3.1.2 Determination of thickness of refractory lining

The thickness of the refractory lining (Voskoboinikov, *et al.*, 1985), as stated by Bala (2005) of the crucible in the middle of the crucible can be determined from the relation:

$$B_r = 0.084\sqrt{T} \tag{3.3}$$

Where:

T is furnace capacity in tonnes.

The furnace capacity is 5kg in Tonnes is equal to 0.005t

Where:

 T is capacity of furnace 5kg = 0.005 Tonnes

$$B_r = 0.084\sqrt{0.005}$$

$$B_r = 0.084 \times 0.0707106$$

$$B_r = 5.9396 \times 10^{-3}$$

$$B_r = 0.0059396 m$$

$$B_r = 5.94 mm$$

3.1.3 Estimation of internal diameter of the inductor

The internal diameter of the inductor can be calculated from the equation:

$$D_{in} = D_C + 2(B_r + B_{ins}) \tag{3.4}$$

B_{ins} is thickness of insulation layer.

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(B_{ins} is such that $5 \leq B_{ins} \leq 6$ [mm]).

$D_{in} = 70 + 2 \, (5.94 + 6)$

$D_{in} = 70 + 2 \, (11.94)$

$D_{in} = 70 + 23.88$

$D_{in} = 93.88 \text{mm}$

$D_{in} = 0.09388 \text{m}$

3.1.4 Evaluation of the height of inductor coil

The Height of inductor coil is given by:

$$H_{in} = (1.2 - 1.5)H_m \qquad (3.5)$$

$H_{in} = (1.2) \, 130$

$H_{in} = 156 \text{mm}$

$H_{in} = 0.156 \text{m}$

3.1.5 Evaluation of the height of furnace from bottom of the bath to the pouring spout

The height of furnace from bottom of the bath to the pouring spout is:

$$H_f = (H_m + H_s + b_t) \qquad (3.6)$$

Where:

H_s is height of slag formed, m;

b_t is thickness of bottom refractory lining,

   ($b_t = 25.5 \text{mm}$ for 5kg capacity).

Where:

V_s is volume of slag in one heat, taken as 8% of total charge, m^3.

$V_s = 8\% \; of \; V_m$

$V_s = \dfrac{8}{100} \times 6.003635 \times 10^{-5}$

$$V_s = 0.08 \times 6.003635 \times 10^{-5}$$

$$V_s = 4.802908 \times 10^{-6} m^3$$

3.1.6 Determination of height of slag formed

The slag height is calculated thus:

$$h_s = \frac{4V_s}{\pi d_m^2} \tag{3.7}$$

$$h_s = \frac{4 \times 4.802908 \times 10^{-6}}{3.142(70)^2}$$

$$h_s = \frac{1.921163 \times 10^{-5}}{3.142 \times 4900}$$

$$h_s = \frac{1.921163 \times 10^{-5}}{15398.8}$$

$$h_s = \frac{1.921163 \times 10^{-5}}{15398.8}$$

$$h_s = 103.99 mm$$

3.1.7 Evaluation of the height of inductor holding poles

$$H_P = H_{in} + 2T_f \tag{3.8}$$

Where, T_f is flange thickness, taken as 3mm.

$$H_P = 156 + 2(3)$$

$$H_P = 162 \text{mm}$$

Hence;

From equation (3.6)

$$H_f = (H_m + H_s + b_t)$$

$$hf = 130 + 103.99 + 25.5$$

$$hf = 165.89 mm$$

3.1.8 Heat energy and electrical parameters

The required theoretical heat energy (Ilori 1991), as stated by *Bala (2005)* consumed during the first period of melt is given by:

$$Q_{th} = Q_m + Q_{sh} + Q_s + Q_{en} - Q_{ex} \qquad (3.9)$$

Where:

$$Q_{th} = Q_m + Q_{sh} + Q_s \qquad (3.10)$$

and

Q_{th} is Heat Energy

Q_m is Amount of heat energy to melt 5kg of charge material, J;

Q_{sh} is Amount of heat energy to superheat the melt to temperature of superheat, J;

Q_s is Heat required to melt slag forming materials, J;

Q_{en} is Energy required for endothermic process, J;

Q_{ex} is Amount of heat energy liberated to the surroundings as a result of exothermic

    reactions, J.

3.1.9 Heat energy required

Theoretically $Q_{en} = Q_{ex}$.

3.1.10 Determination of amount of heat energy to melt 5kg of charge material

$$Q_m = MC(\theta_1 + \theta_0) + L_{pt} \qquad (3.11)$$

$Q_m = 5 \times 1100\,(660 - 25)$

$Q_m = 5500\,(635)$

$Q_m = 3492500\text{J}$

$Q_m = 34925\text{kg}$

Where:

M is mass of charge, kg;

C is specific heat capacity of charge material, (for aluminum, C = 1100J/kg K);

L_{pt} is amount of heat to accomplish phase transformation, (for pure aluminum $L_{pt} = 0$,

phase transformation);

θ_1 is melting temperature of charge, (for aluminum θ_1 = 660°C);

θ_0 is ambient temperature, 25°C;

Similarly,

3.1.11 Evaluation of amount of heat energy to superheat the melt to temperature of superheat

$$Q_{sh} = MC_m\theta_{sh} \tag{3.12}$$

Where:

C_m is average heat capacity of molten Aluminum, (= 992J/kg K);

θ_{sh} is amount of superheat temperature, taken as 40°C.

$$Q_{sh} = 5 \times 992 \times 40$$

$$Q_{sh} = 198400J$$

$$Q_{sh} = 1984KJ$$

3.1.12 Determination of the heat required to melt slag forming materials is given as:
$$Q_s = K_sG_s \tag{3.13}$$

Where:

K_s is quantity of slag formed in (kg), taken as 8% of furnace capacity;

G_s is heat energy for slag = 18kJ/kg.

$$Q_s = 0.08 \times 18$$

$$Q_s = 1.44KJ$$

From equation (3.10)

$$Q_{th} = Q_m + Q_{sh} + Q_s$$

$$Q_{th} = 34925 + 1984 + 1.44$$

$$Q_{th} = 36910.44 KJ$$

$$Q_{ec} = \frac{Q_{th}}{t} \qquad (3.14)$$

$$t = 26 sec$$

$$Q_{ec} = \frac{4037.43}{26}$$

$$Q_{ec} = 155W$$

3.1.13 Number of turns (N) of the Inductor

The number of turns (N) of the inductor can be determined from:

$$B_{max} = \frac{\mu_r \mu_o NI}{L}$$

Where:

N is Number of turns of inductor coil;

I is Current in coil in amperes, A;

L is length of coil in metres, m;

μ_o is Permeability of free space = $4 \pi \times 10^{-7}$ Hm^{-1};

μ_r is Relative permeability of charge material, (for non-magnetic

material $\mu_r = 1$).

$$N = \frac{B_{max}L}{\mu_o I} \qquad (3.15)$$

3.1.14 Determination of total heat energy induced

Total heat energy induced (Hammond, 1978), as stated by *Bala (2005)* in charge due to

eddy current is given by:

$$Q_{ec} = \frac{\pi^3 f^2 H_m B_{max}^2 d_m^2}{8\rho}$$

Where:

$Q_{ec=155W}$

$$B_{max}^2 = \frac{8\rho Q_{ec}}{\pi^3 f^2 H_m d_m^2} \tag{3.16}$$

where,

    f is Frequency of power supply, 50Hz;

    B$_{max}$ is Maximum flux density, H;

    ρ is Resistivity of charge metal, (for aluminum, ρ = 2.83 x 10^{-8} Ωm).

Therefore:

$$B_{max}^2 = \frac{8 \times 2.83 \times 10^{-8} \times 155}{3.142^3 \times 50^2 \times 0.130 \times 0.07^4}$$

$$B_{max}^2 = \frac{3.5092 \times 10^{-5}}{31.018 \times 2500 \times 0.130 \times 0.00002401}$$

$$B_{max}^2 = \frac{3.5092 \times 10^{-5}}{0.242041}$$

$$B_{max} = \sqrt{0.0001449}$$

$$B_{max} = 0.012$$

Now to get the number of coils, from equation (3.16)

$$N = \frac{B_{max}L}{\mu_o \ I}$$

$$N = \frac{0.012 \times 0.156}{\mu_o \ I}$$

Therefore,

Also

$$Q_{ec} = \frac{Q_{th}}{t}$$

where,

t is time in seconds to attain maximum flux.

3.1.15 Determination of allowable current density in the inductor

The allowable current density in the inductor is given by:

$$J = \frac{I}{A_t} \tag{3.17}$$

(J ranges from 20 to 40A/mm^2).

where,

I   is Current in inductor in (A)

A$_t$ is the Cross sectional area of conducting tube (mm^2), J ranges from 20 to 40A/ mm^2

d_{t2} is 6mm external diameter of inductor coil,

d_{t1} is 3mm internal diameter of inductor coil,

I is current of inductor ampere

$$A_t = \frac{\pi}{4}(dt_2^2 - dt_1^2) \tag{3.18}$$

$$A_t = \frac{\pi}{4}(6^2 - 3^2)$$

$$A_t = \frac{\pi}{4}(36 - 9)$$

$$A_t = \frac{\pi}{4}(27)$$

$$A_t = 0.7855(27)$$

$$A_t = 21.2 mm^2$$

$$J = \frac{I}{A_t}$$

For J $= 30/mm^2$

Therefore

$$I = JA_t$$

$$I = 30 \times 21.2$$

$$I = 636A$$

Now to get the number of coils, from equation (3.16)

$$N = \frac{B_{max}L}{\mu_o \, I}$$

$$N = \frac{0.012 \times 0.156}{4 \, \pi \, x10^{-7} \, \times 636}$$

$$N = \frac{0.001872}{0.0000012568 \times 636}$$

$$N = \frac{0.001872}{0.0007993}$$

$$N = 23.42$$

3.1.16 Determination of resistance of the copper coil inductor at ambient temperature

The resistance of the copper coil inductor at ambient temperature is given by:

$$R_\theta \; = \frac{\rho_c l}{A_t} \qquad\qquad (3.19)$$

Where:

ρ_c= Resistivity of copper

$$\rho_c = 1.72 \times 10^{-8} \Omega m \; at \; 25^o C$$

Length, l is total length of copper tube, $= \pi D_{in} N$

$$R_\theta \; = \frac{1.72 \times 10^{-8} \times \pi \times 0.09388 \times 23}{2.1 \times 10^{-5}}$$

$$R_\theta = \frac{1.166905 \times 10^{-7}}{2.1 \times 10^{-5}}$$

$$R_\theta = 5.56 \times 10^{-3} \Omega$$

3.1.17 Evaluation of resistance at any temperature

The resistance at any temperatrue θ is given as:

$$R_\theta = R_\theta[1 + \propto \theta_o(\theta - \theta_o]$$ (3.20)

$where$:

$\theta \ is$ temperature coefficient of copper at 60^oC

$\theta_o \ is$ temperature coefficient of copper $at \ 25^oC$

$\propto = 3.9 \times 10^3 K^{-1}$

$$R_\theta = 5.56 \times 10^{-3}[1 + 3.9 \times 10^{-3}(60 - 25)]$$

$$R_\theta = 5.56 \times 10^{-3}[1 + 3.9 \times 10^{-3}(35)]$$

$$R_\theta = 5.56 \times 10^{-3}[1 + 0.1365]$$

$$R_\theta = 5.56 \times 10^{-3}[1.1365]$$

$$R_\theta = 6.32 \times 10^{-3}$$

3.1.18 Determination of coil loss due to resistance

$$P_c = I^2 R_\theta$$ (3.21)

$$P_c = (636)^2 \times 6.32 \times 10^{-3}$$

$$P_c = 404496 \times 6.32 \times 10^{-3}$$

$$P_c = 2556.4W$$

3.1.19 Determination of heat loss through conduction, from furnace walls to copper coil

Heat loss through conduction (Shrets *et al.* 1987), as stated by *Bala (2005)* from furnace walls to copper coil:

$$Q_L = \frac{\pi H_{in}(\theta_2 - \theta)}{\frac{1}{2}\left[\frac{1}{\lambda_{zi}}in\frac{d_2}{D_c} + \frac{1}{\lambda_{as}}in\frac{D_{in}}{d_2} + \frac{1}{\lambda_{cu}}in\frac{d_3}{d_{in}}\right]} \tag{3.22}$$

where

λ is the thermal conductivity, with subscripts for zircon, asbestos, and copper respectively;

$\lambda_{zi} = 2.093$W/mk

$\lambda_{as} = 0.117$W/mk

$\lambda_{cu} = 380$W/mk

d_2 = outer diameter of crucible = $D_c + 2B_r$, m;

d_3 = inductor diameter surrounding crucible + 2 thickness of coil, m;

$\theta_2 = \theta_1 + 40°C$ = superheat temperature °C

$\theta_2 = 660°C + 40°C = 700°C$ superheat temperature °C

$D_c = 0.07$m

$d_2 = D_c + 2B_r$

$d_2 = 0.07 + 2(0.00594)$

$d_2 = 0.07 + 0.01188$

$d_2 = 0.08188m$

$d_3 = 0.09 + 2(0.02)$

$d_3 = 0.09 + 0.04$

$d_3 = 0.13m$

$$Q_L = \frac{0.156\pi(700 - 60)}{\frac{1}{2}\left[\frac{1}{2.093}\text{ in }\frac{0.08188}{0.07} + \frac{1}{0.117}\text{ in }\frac{0.09388}{0.08188} + \frac{1}{380}\text{ in }\frac{0.13}{0.09388}\right]}$$

$$\frac{0.4902(640)}{\frac{1}{2}\left[0.4778\text{ in }1.1697 + 8.5470\text{ in }1.1466 + 0.00263\text{ in }1.3847\right]}$$

$$\frac{313.69}{{}^1\!/_2\left[0.07489 + 1.1692 + 0.000856\right]}$$

$$\frac{313.69}{{}^1\!/_2\left[1.245\right]}$$

$$Q_L = \frac{313.69}{0.6225}$$

$$Q_L = 503.92W$$

3.1.20 Determination of total heat loss per second

$$Q_p = Q_L + P_C \tag{3.23}$$

$$Q_p = 503.92 + 2556.4$$

$$Q_p = 3060.32W$$

3.1.21 Discharge rate of water for coil cooling: from heat balance equation

$$Q_P = VA_w \rho_W C_w (\theta - \theta_o) \tag{3.24}$$

V is the Velocity of heat carrying fluid, m/sec

A_w is cross – sectional area of flow, m^2

ρ_W is density of heat carrying fluid, Kg/m^3

C_w is specific heat capacity of fluid at constant pressure

θ is the outlet temperature of fluid

θ_o is the inlet temperature of fluid

3.1.22 Determination of velocity of heat carrying fluid

$$V = \frac{Q_p}{A_W \rho_W C_W \ (P\theta - \theta_o)} \tag{3.25}$$

Where:

$\rho_W = 1000\text{kg/m}^3$

$C_w = 4.186\text{kJ/kg}$

$A_w = \frac{\pi}{4} \times (0.006)^2$

$A_w = 2.83 \times 10^{-5}\text{m}^2$

$$V = \frac{3060.32}{2.83 \times 10^{-5} \times 1000 \times 4186(60 - 25)}$$

$$V = \frac{3060.32}{0.0283 \times 4186(60 - 25)}$$

$$V = \frac{3060.32}{0.0283 \times 4186(35)}$$

$$V = \frac{3060.32}{0.0283 \times 146510}$$

$$V = \frac{3060.32}{0.0283 \times 146510}$$

$$V = \frac{3060.32}{4146.23}$$

$V = 0.74 m/sec$

3.1.23 Estimation of discharge of water from tube or flow rate (m³/sec)

$Q = VA_w \tag{3.26}$

$Q = 0.74 \times 2.83 \times 10^{-5}$

$Q = 2.09 \times 10^{-5}\text{m}^3/\text{sec}$

3.1.24 Tilting mechanism

To be able to pour molten metal easily a tilting mechanism is incorporated to the design.

3.1.25 Determination of total weight of furnace

$$W_t = F_w + R_w \tag{3.27}$$

If, F_w = weight of furnace material including charge;

R_w = unrecognized weights $0.5F_W$

$$W_t = F_w + R_w$$

$$w_t = (430.59 + 216)$$

$$w_t = 646.7N$$

The supporting shaft is subjected to both bending and torsional moments. Shaft diameter, d, is given (Hall, et al 1980), as stated by *Bala (2005)* by:

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \tag{3.28}$$

Where:

M_t is torsional moment, Nm;

M_b is bending moment, Nm;

K_t is combined shock and fatigue factor applied to torsional moment;

K_t is 1.0 for load applied gradually to rotating shafts;

K_b is combined shock and fatigue factor applied to bending moment;

K_b is 1.5 for load applied gradually to rotating shafts;

S_s is the allowable shear stress;

$= 55MN/m^2$ for shaft without key way;

$= 40MN/m^2$ for shaft with key way;

$R_A = R_B$ = reactions from bearing support

$$R_A = \frac{646.7}{2}$$

33

$$R_A = 323.35N$$

$$M_b = R_A \; \frac{L}{2}$$

$$M_b = 323.35 \; \frac{0.264}{2}$$

$$M_b = 42.68Nm$$

$$M_t = W_t \times x$$

$$M_t = 646.7 \times 0.12$$

$$M_t = 77.6Nm$$

3.1.26 Determination of shaft diameter

$$d^3 = \frac{16}{\pi \times 40 \times 10^6} \sqrt{(1.5 \times 42.68)^2 + (1 \times 77.6)^2}$$

$$d^3 = \frac{16}{1.27 \times 10^{-7}} \sqrt{4098.6 + 6021.76}$$

$$d^3 = 1.27 \times 10^{-7}\sqrt{10120.36}$$

$$d^3 = 1.27 \times 10^{-7}(100.6)$$

$$d^3 = 1.2776 \times 10^{-5}$$

$$d = 3\sqrt{1.2776 \times 10^{-5}}$$

$$d = 0.02337m$$

$$d = 23.4mm$$

The tilting is effected by the use of mating gears in which the induced bending stress of gear tooth must be less than the allowable stress of gear material, given by the Lewis equation (Hall *et al* 1988) as:

$$S = \frac{2M_t}{m^3 K\pi^2 YN} \tag{3.29}$$

where,

M$_t$ is torque on pinion, Nm;

K is constant (K < 4);

N is the minimum number of teeth on pinion (N=16);

m is the module;

Y is the form factor which depends on tooth system and N, (for pressure angle φ

=20°, N = 16, Y = 0.094).

For approximate value of m in equation (28), S is taken as one third of ultimate tensile

stress of material i.e. for carbon steel of 0.5% carbon, UTS = 620MN/m^2.

$$S = \frac{2 \times 77.6}{m^3 \times 4 \times \pi^2 0.094 \times 16} \tag{3.30}$$

$$S = \frac{155.2}{59.4m^3}$$

$$S = \frac{2.61}{m^3}$$

For carbon steel of 0.5% carbon, UTS = 620MN/m^2.

$$S_a = \frac{1}{3} UTS$$

$$S_a = \frac{1}{3} \times 620 \times 10^6$$

$$S_a = 260.67 \ MN/m^3$$

$$m^3 = \frac{2.61}{206.67 \times 10^6}$$

m^3 = 1.263 x 10^{-8}m^3

$$m = \sqrt[3]{1.263 \times 10^{-8}}$$

$$m = 0.00233m$$

$$m = 2.33mm$$

Inputting the value of (m) into Equation 3.30

$$S = \frac{2 \times 77.6}{0.00233^3 x\ 4\ x\ \pi^2\ x\ 0.094\ x\ 16}$$

$$S = \frac{155.2}{59.4 \times 0.00233^3}$$

$$S = \frac{155.2}{7.5137 \times 10^{-7}}$$

$$S = 206.56 MN/m^2$$

Hence induced stress $S < S_a$ the allowable stress

Now, $K = 4\left(\frac{S}{S_a}\right)$

$$K = 4\left(\frac{206.56}{260.67}\right)$$

$$K = 3.17$$

3.1.27 Determination of gear tooth width

$$b = mk\pi$$

$$b = 3 \times 3.17 \times \pi$$

$$b = 29.9mm$$

$$b = 30mm$$

3.1.28 Velocity ratio

$$V.R = \frac{D_g}{D_p} = \frac{N_g}{N_p}$$ 　　　　　　　　　(3.31)

where,

D$_g$ is diameter of gear. M;

D$_p$ is diameter of pinion, m;

N$_g$ is the number of teeth of gear;

N$_p$ is the number of teeth of pinion.

Length of tilting handle,

For velocity ratio of 3

N$_g$ = N$_P$ × 3

N$_g$ = 16 × 3

N$_g$ = 48 teeth

3.1.29 Diameter of gear

Diameter of gear = m × N$_g$ 　　　　　　　　　(3.32)

Diameter of gear = 3 × 48

Diameter of gear = 144mm

Let an average force (Fa) be applied to tilt the furnace.

Average mass of 55Kg

Fa = Mg = 55 x 9.81

Fa = 539.55N

3.1.30 Length of tilting handle

$$L_t = \frac{M_t}{F_a}$$ 　　　　　　　　　(3.33)

where,

F_a is the average force to be applied for tilting, 539.55N

$$L_t = \frac{163 Nm}{539.55 N}.$$

$$L_t = 0.302m$$

$$L_t = 302mm$$

3.2 Material Selection

Selection of the materials was done based on the following factors considered.

    i.   The availability of the materials

    ii.   The cost of the material

    iii.   Suitability to design

    iv.   Reliability, machinability and maintainability

The materials selected for this fabrication of an induction furnace were gotten from the local market and constructed under local conditions. The materials require for the fabrication of the furnace are specified here.

3.3 General Description

A mild steel sheet was chosen for the construction of the furnace unit housing and the transformer seat. The thermal conductivity of mild steel is $40.1W/m^o/\,^oC$.

A 10 litres jerrican containing water was conjoined to the transformer for easy flow of water into the induction coil and air-cooling using fan for the control board for heat absorption.

A high pressure 360 micro pump was used to pump water from the tank into the coil. The pump was selected because of its ability to lift water at a distance of 2.5 meters and transfer of 2 liters/min.

The design of an Electric Induction Furnace considers the following important factors as guides:

  i. The geometrical shape of the furnace

  ii. Furnace capacity

  iii. The composition of the charge trial

  iv. The electrical power consumption.

3.4 Components of Induction Furnace

The components of induction furnace are:

a. Crucible

b. Induction coil

c. The shell

d. Cooling system

e. Tilting mechanism

f. Furnace transformer

a. The Crucible: The crucible was formed from refractory material, which the furnace coils were lined with. This crucible holds the charge material and subsequently the melt. The choice of refractory material depends on the type of charge, i.e. whether acid basic or neutral. For non-ferrous metals like Aluminum neutral refractory shall be used in this design. The durability of the crucible depends on the grain size, ramming technique, charge analysis and rate of heating and cooling the furnace.

b. Inductor Coil: The inductor coil is a tabular copper coil with specific number turns. An alternating current (A.C) pass through it and magnetic flux is generated within the inductor. The magnetic flux generated induces Eddy currents in the metal charge. It was these eddy current that enabled the heating and subsequently the melting

process in the crucible. The inductor was used in a spiral from, fixed to the lower and the upper supporting asbestos cement base plates. In order to eliminate electrical breakdown the turns are insulated by rapping with mica tape, this serves as a good insulator.

c. **Cooling System:** As a result of the power supplied to the furnace, its circuit appears resistive, and the real power was not only consumed in the charge material but also in the resistance of the coil. This coil loss, as well as the loss of heat conducted from the charge through the refractory crucible requires the coil to be cooled, with water as the cooling medium - this was to prevent undue temperature rise of the copper coil. To achieve effective cooling, a through-one-way flow system was used. The tubular copper coils were connected to water source through flexible rubber hoses, which were being supplied under particular pressure. The Inlet was at the top, while the outlet was at the lower end. The water flow arrangement was much that after every eight turn the water is discharged and a fresh supply starts immediately, The cooling process was a very important aspect of the furnace, this was because, failure to cool the coil when the furnace was in operation will results in the melting of the coil and total malfunctioning of the entire furnace. Therefore, a continuous circulation of water must be ensured before operation starts and after the operation in complete, until the furnace is finally brought to room temperature

d. **Tilting Mechanism:** Tilting of the furnace is to effect pouring of the melt as a last operational activity before casting. Due to the small capacity of this furnace, manually operated tilting mechanism was adopted. The furnace is hinged at the spout edge with a shaft and bearings. And at one side to the bearing is a pinion and gear system to give a gear reduction, so that when the handle is turned clockwise, the

furnace is tilted to achieve a maximum angle of 90°C for complete pouring of the molten metal by tilting the furnace upwards.

e. **Furnace Transformer:** The Electric Induction furnace has its power source from electricity. It therefore needs some basic electrical equipment for maximum power utilization. A step-down voltage transformer with various voltage steps tap is required. It has a three-phase primary terminal and single-phase output at the secondary terminal. A voltage supply of 415V, 50Hz frequency is used as the primary power supply. The nominal power output of the transformer ranges from 7kVA to 15kVA. The single-phase secondary terminal of the transformer is connected to the furnace inductor coil by means of a water-cooled Flexible copper coil embedded in a rubber hose. The transformer tap positions are used to select the desired voltage and current values depending on the Furnace condition.

f. **Furnace Capacitors:** The presence of induced reactance in furnaces with alternating current give time to phase shift or phase difference in which the value of the current now flow lags behind the voltage. This lowers the power factor (Cosφ) of the whole system. In order not to increase the power of the transformer when the furnace is in operation capacitors are installed and switched on to compensate the induced reactance of the inductor. A combination of Load coil and tuning capacitors is known as the tank circuit and the capacitors involved are subsequently known as furnace capacitor.

g. **Control Panel:** The monitoring of the furnace, transformer and capacitors conditions at intervals of operation is achieved through a control panel. This gives indications either through a lightered signal or indicator. The following parameters are monitored on the control panel: furnace temperature, voltage and current value of the furnace, power consumption, switch buttons for capacitor OFF and ON, pressure gauges for

water, Lining current leakage and inductor current leakage. Also the high voltage switch for OFF and ON with the transformer over-load are controlled through the panel. The relay for these parameters is achieved through the installation for sensors within the furnace.

Other important component materials are as follows.

i. Stainless plate: which is used to house the tesla induction coil

ii. Mild steel sheet

iii. rubber hose

iv. Flexible copper cable

v. round head screw

vi. roller bearings

vii. shaft made from commercial steel

viii. gear and pinion

ix. water pump

x. tyres

3.5 Fabrication of Induction Furnace

The design and fabrication of his furnace comprises of three units under which the fabrication carried out under various stages. The three (3) units are:

1. Transformer (power control unit)

2. Cooling system

3. The induction unit

   The various constructions

   i.   Induction coil housing

   ii.   Steel casting for the induction unit

iii.   Furnace stand

iv.   Fabrication of a water tank using brass testing to avoid leakage

v.   Steel casing for transformer and other electrical components

vi.   Electrical works and installation

3.5.1   Induction coil housing

The induction coil was housed so as to reduce the escape of excess heat to the atmosphere and also to help the crucible attain and maintain its maximum heat so as to enable the fast melting of the aluminum scraps. The tesla coil is housed inside an aluminum plate surrounded with refectory materials. The refractory material is made with a white Portland cement.

Table 3.1: Coil Housing Specification

S/N	Component	Dimensions (mm)
1.	Height of stainless plate	145.2mm
2.	Internal diameter	133.1mmØ
3.	Refractory thickness	83.31mm
4.	Diameter of coil	50mm
5.	Internal diameter for coil sitting	52mm

3.5.2   Steel casting for the induction unit

The steel sheet selected is a mild steel of composition: 0.15% C. 0.45% Mn. 0.18%Si, 0.031% S. 0.001%P, 0.005% Al, .0008% Ni and 0.1867& Fe. It was selected for the fabrication of the furnace casting because of its light weight, good strength, excellent formability, weld ability, availability, and low cost of purchase (Anaidhuno &

Mgbenuna., 2015). The furnace casting houses all the components of the furnace including the crucible, the coil and lining.

3.5.3   Steel for transformer and cooling unit

The fabrication was done, taking into consideration that the control box, transformers (for both control box and cooling system), water tank, water pump, cooling fans, control switches and all other electrical work are all packaged, and the power box should have holes for easy wiring. The body was made from a 1.5mm thick flat sheet of mild steel. The entire body of this unit were joined with the use of screws, and bots and nuts. This unit was sub divided into two unit, the transformer, and the water tank.

3.5.4   Furnace stand

The furnace stand was done putting to consideration that the induction unit can be detached from it without any form of difficulties, rollers were also attached at the top two sides to allow proper move of the induction unit during tilting. The materials used for this is a 1 x 1 angle bar. The entire joints were joined with arc welding.

3.5.5   Electric installation

The figure 3.1 below gives illustration of the performance of the electrical system from the main source to the transformer, from transformer to the cooling system and down to the induction unit. A very good effort was made to prevent every form of electric shock thereby ensuring a proper insulation. the switching frequency achieved using electrical circuit in ZVS topology is 20kHZ (main power supply is 220V AC/50HZ).

3.6   Refractory Lining and Operational Sequence

The refractory lining of an induction furnace is a very essential part of the furnace. It forms the crucible and its deterioration will cause very severe damage to the furnace.

Therefore, to enhance efficient production of the melt and furnace 1ife, the choice of the refractory material is based on the following factors:

i. Ability to withstand high temperature without using or slumping.

ii. Resist slag attack which dissolve the lining or penetrate the surface.

iii. Resist wear due to erosion and movement of solid charge

iv. Resist thermal shock as a result of uneven contraction and expansion when refractory temperature changes rapidly. The effect is that stresses are set up within the refractory and cause it to crack and pieces become detached resulting in spalling of the lining.

v. It should have low porosity and permeability.

vi. The refractory should have low thermal conductivity, to act as an insulating material.

In order to obtain best lining for effective utility of the furnace, a neutral lining will be more satisfactory; and based on effective and practical application in Nigerian foundries, Zirconium Oxide (ZrO_2) is used. In this regard the furnace can be used for melting in both acidic and basic atmospheres without changing the lining. Zirconium Oxide has an atomic weight of 123.22 g, melting point at about 2700 °C, low thermal conductivity and poor spalling resistance. Zircon sand is available in Nigeria, (Jos) and its application has proved to be effective compared to silica or magnetite. This is also cheaper than the imported to type.

Having the following composition:

Table 3.2: Composition of Chemicals

Chemical	Percentage
ZrO_2	60.47%
SiO_2	29.62%
Al_2O_3	4.46%
MgO	2.24%
CaO	1.25%
Fe_2O_3	CaO
LOI (Lost on ignition	0.88%

Source: Odeh (2017).

3.6.1 Preparation refractory lining

The preparation of the refractory lining involves the mixing of Zircon sand with iron powder, liquid glass (sodium metasilicate, Na_2, SiO_3, as a binder, and water. This has an atomic weight of 122.03g and melting point of about 1027 °C. For a 5Kg capacity furnace, the following proportions of the mixes were used:

Table 3.3: Composition of Preparatory Refractory Lining

Composition	Quantity
Zircon sand	5kg
Zircon powder	0.5kg
Liquid glans	0.5 litres
Water	0.5 litres

In forming the refractory crucible, the copper coils were first Lined inside with insulating materials, (Asbestos). This was followed with a layer of asbestos content, after which the tape of the crucible in predetermined by a formed metal pattern. Thin was inserted into

the insulated coil. The mixture of the refractory rammed round it; this was then allowed to set, the 20 pattern was withdrawn and the furnace was then ready for the first operation. Bala (2005).

3.6.2   Wear of refractory lining

The maximum lining life is affected by many factors, such that in subsequent use, replacement of lining has to be carried out. The pattern of wear depends on the operating practice. Odeh (2017).

3.6.3   Cause of lining wear

1. **Slag Attack:** most slags cause gradual fluxing of refractory: Slag containing large amounts of Calcium Carbide, lime Iron Oxide and Manganese Oxide are particularly harmful.

2. **Mechanical Stressing**: caused by rapid heating and cooling of the lining.

3. **Erosion**: this results from poor charging practice or vigorous bath turbulence.

4. **Attack from Melt:** certain alloying elements such as Lead, Chromium, Manganese and Titanium cause severe attack on the refractory lining.

3.6.4   Repair of lining

The repair of lining is effected depending on the type of wear. Small hairline type cracks, which appear on cooling, will normally close when the furnace is heated. however, larger cracks, grooves and spoiled areas can be effectively patched with a plastic zirconium refractory. Erosion of the crucible bottom can be repaired by pouring Lining material into the furnace bottom, and ramming with a flat rammer.

3.6.5   Obtaining maximum lining life

The lining like tray be improved by;

1. Raining the melt to a high temperature only when ready to tap the furnace.

2. Avoiding impact of charge materials on the refractory lining.

3. Avoiding dirty or heavily oxidised charge materials.

4. Removing slag as soon as possible.

3.7   Method of Charging

The charging of the furnace can be accomplished mechanically or manually. In the case of this project it was accomplished manually. The machine was switched on and allowed to raise to temperature of 40 ºC before the scarp aluminium was charged into the crucible then the transformer which powers the heater is switch on for melting operation to take place.

3.8   Temperature Determination

The measuring of the temperature of the melt during the melting process, was done with a calibrated temperature gauge of 0 ºC to 1300 ºC range, and a RKC REX-C700 PID/On-Off Digital Temperature Controller thermocouple. The thermocouple acts as a sensor whose resistance increases with temperature. Its tip was dipped into the molten metal and the equivalent temperature attained at that instance was read from the calibrated gauge. Temperature determination enables the furnace operator to know whether the pouring temperature required for a particular melt has been reached. This temperature is however, based on the theoretical melting temperature of the charge material. Aluminium has a melting point of about 660 °C, when in a pure form, but due to the addition of some alloying elements and other impurities, it is necessary to superheat the melt to about 40 °C higher than the melting point. This also compensates heat lost during pouring and

48

casting processes; especially when the ladle is to be held for long time before completion of casting and also to ensure uniform.

3.9   Slag Removal

The constant impurities present in Aluminium scrap are iron silicon, titanium, copper and zinc. These are added as alloying elements. During the melting process in Induction furnace, due to the high stirring condition, the slag was starred and mixed with the molten metal. Therefore, slag removal was effected only when the equipment was OFF and ready for pouring. The slag raised up and formed a strong film of oxide on the surface due to aluminium reactivity with air. This slag was scrubbed off with a metal spade before casting begins.

Plates I and II depict the fabrication process as the calculated dimensions are realised for the machine. The diameters of the crucible and the necessary allowance for the coils made within the crucible housing.

PLATE I: Frame and Crucible Housing for Induction Furnace

PLATE II: Assembled Frame and Crucible Housing for Induction Furnace

The coil is wound round the crucible to a 156 mm height as obtained analytically as shown in Plate III.

PLATE III: Heating Coil for Induction Furnace and Crucible

PLATE IV: Flexible Heating Coil Hose and Shift Heating Coil Input and Output

PLATE V: Complete Assembly for Induction Furnace

3.10   Material Specifications, Costing and Specifications

The materials required for the Fabrication of the Induction furnace are specified here, based on their desirable properties such as thermal and electrical conductivities, refractory insulation properties, cheapness, strength and available. A flexible copper tubing inductor

coil is selected because of its electrical conductivity hence heat generated due to resistance is less compared to aluminium.

A low carbon steel sheet was selected for the construction of furnace shell due to its strength and high melting point, which may not occur as a result of heat lost to the surroundings. The refractory material is zircon sand, with liquid glass zircon powder as binders.

3.10.1   Costing

The costing of all these materials was based on the prevailing market prices of the different components of the furnace, as shown in table 3.4.

The cost of production is listed below:

$$\text{labour cost} = \frac{40}{100} \times 163{,}600$$

$$= N65{,}440$$

$$\text{Overhead cost} = \frac{10}{100} \times 163{,}600$$

$$= N16{,}360$$

The overhead cost includes the cost of transportation and other expense made apart from the material cost (taken as 10% of materials cost).

Therefore, total production = material cost + Labour cost + overhead cost

$$= 163{,}600 + 65{,}440 + 16{,}360$$

$$= N247{,}400$$

Table 3.4: Bills of Engineering Measurement and Evaluation (BEME)

S/No.	Materials	Specifications and Dimension	Qty	Unit (₦)	Total (₦)
1.	Local crucible casting and fabrication		1	15,000	15,000
2.	Crucible	5kg	1	10,000	10,000
3.	Tesla induction coil	Diameter = 50mm^2	1	13,000	13,000
4.	Transformer (for main control board)	220v$_{ac}$/7.5kva	1	25,000	25,000
5.	Transformer (for cooling system)	220v$_{ac}$/100ma	2	6,500	13,000
6.	Copper clad board	165.1×112.4×16mm	1	4,500	4,500
7.	Gearbox		1	22,000	22,000
8.	Filer capacitor	100μf/100v	1	1,300	2,600
9.	Bridge rectifier	Kbpc 5010	1	4,200	4,200
10.	Switches	15amps/250v$_{ac}$	2	200	400
11.	Cooling fan	12vdc	2	600	1,200
12.	Resistance		1	3,000	3,000
13.	Voltage Regulator	Lm7812	2	1,500	3,000
14.	Induction capacitor	0.3μf/1200vdc	8	500	4,000
15.	Magnetic inductor coil	200μf/5A	2	1,500	3,000
16.	Copper Screw Accessories	2packets	2	250	500
17.	Red and black flexible wires	4 meters each	1	2,000	2,000
18.	Pressure water pump		1	3,000	3,000
19.	Control board etching		1	8,000	8,000
20.	Cement for cast	White Portland cement and cement		4,000	4,000
21.	Angle iron	1inch	1	5,800	5,800
22.	Water hose		2	700	1,400
23.	Sheet of mild steel		1	8,000	8,000
24.	Stainless plate		1	2500	2500
25.	Painting			4500	4500
26.	**TOTAL**				**N163,600**

3.11 Maintenance and Safety

The effective performance and safety of induction furnace depends on proper maintenance. Therefore, the following must be ensured during operation of on furnace:

1. Adequate and constant supply of water for cooling the coil must be ensured at all times when the furnace is in operation.

2. Inspection of lining material for wear must be carried out after every twenty melting operations. Wear and crack must be repaired and replaced to avoid electrical breakdown of the furnace.

3. The temperature of the molten metal should not be allowed above its superheat temperature.

4. Bearing must be lubricated when necessary.

4.0   **RESULTS AND DISCUSSION**

4.1   **Results**

After complete compilation of analysis and its calculations, the obtained parameters were used for fabrication of the induction furnace. The parameters are shown in the Table 4.1.

Table 4.1: Result for Design Analysis

S/No.	Parameters	Symbol	Values	Units
1.	Height of metal	H	0.156	M
2.	Volume of metal charge	V_m	5×10^{-4}	m^3
3.	Refractory lining thickness	B_r	5.94	Mm
4.	Internal diameter of inductor	D_{in}	0.0938	M
5.	Height of furnace	H_f	165.89	Mm
6.	Volume of slag	V_s	4.00291×10^{-5}	m^3
7.	Height of slag	h_s	103.99	Mm
8.	Amount of heat to melt charge materials	Q_m	34925	KJ
9.	Amount of heat to superheat	Q_{sh}	1984	KJ
10.	Heat consumed during melt	Q_{th}	36910.44	KJ
11.	Heat required to melt slag	Q_s	1.44	KJ
12.	Maximum flux density	B_{max}	0.012	H
13.	Total heat induced	Q_{ec}	155	W
14.	Resistance of copper coil			
15.	Copper coil Inductor at ambient temperature	$R\Theta_\Theta$	5.56×10^{-3}	Ωm
16.	Resistance at any temperature	$R\Theta$	6.32×10^{-3}	Ωm
17.	Coil loss due to resistance	P_c	2556.4	W

Table 4.1: Continuation

S/No.	Parameters	Symbol	Values	Units
18.	Heat loss through conduction	Q_L	503.92	W
19.	Total heat loss	Q_p	3060.32	W
20.	Current in inductor	I	633	AMP
21.	Discharge rate of water	Q	2.09×10^{-5}	m^3/sec
22.	Velocity of heat carrying fluid	V	0.74	m/sec
23.	Shaft diameter	D	23.4	mm
24.	Stress of gear tooth	S	206.56	MN/m^2
25.	Gear tooth width	B	29.9	mm
26.	Velocity Ratio of Gear	N_g	43	
27.	Diameter of Gear	G	144	mm

A total of two tests were carried out in the 5kg induction furnace which was fabricated in order to ensure its efficiency and working condition. Aluminium scarps were deposited into the crucible and melted, from the first test the maximum temperature attained was 670°C in 48 minutes, while the second test carried out attained a maximum temperature of 720°C under 48 minutes. The results of both tests have been represented graphically in Figure 4.1.
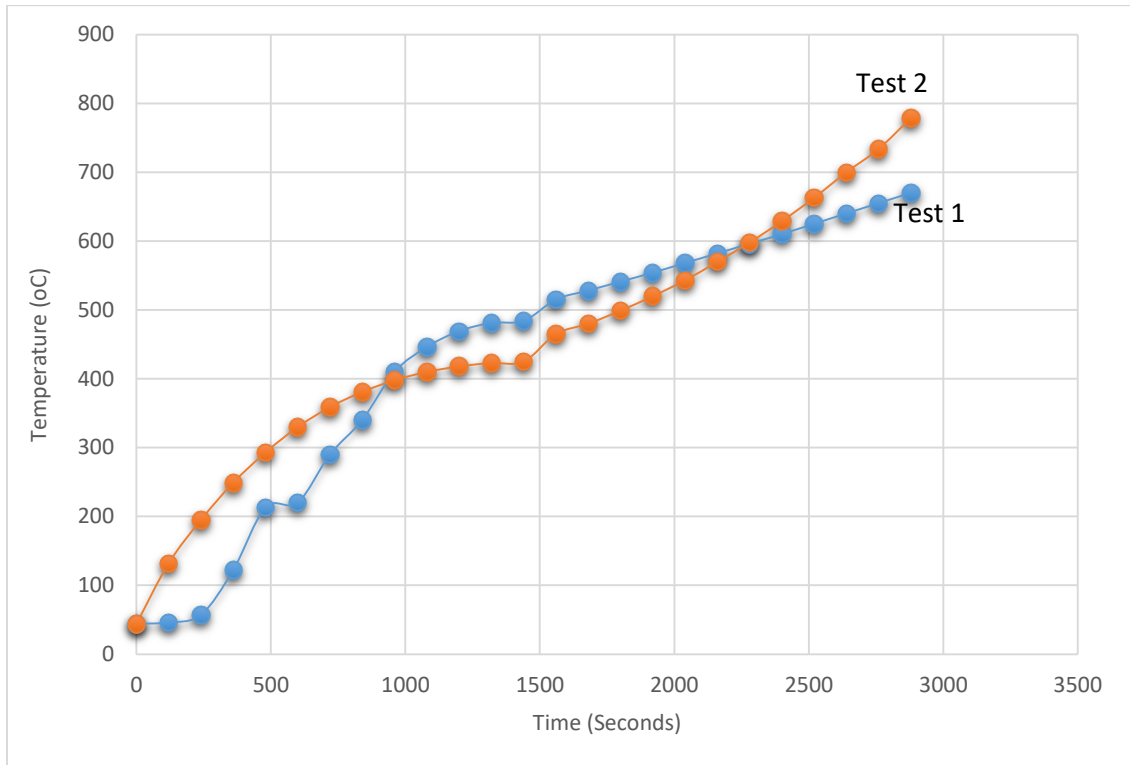
Figure 4.1: Variation of Aluminium Melting Temperature with Time for Test 1 and

Test 2

4.2   Discussion

It can be seen from Figure 4.1 in Test 1, that the melting temperature of aluminium

increased with time. The furnace temperature increased from 44 ^{o}C to a maximum

temperature of 670 ^{o}C in 48 minutes (2880 seconds). The rise in temperature for this test

was categorised with two distinctive arrest points; 48°C and 220 ^{o}C. This may be as a

result of power fluctuations during the operation but as the power stabilised the

temperature rate continued on a steady increase as intended.

For the Test 2 however, only one arrest was recorded. This was at 410 ^{o}C. This clearly

shows that the furnace is highly sensitive to power fluctuations and the furnace efficiency

reduces with them. A stabilizing unit might be required to smoothen the power supply to

the furnace. The temperature rose from 44 ^{o}C to a maximum of 720 ^{o}C in 48 minutes

which makes the melting rate higher and faster than Test 1, this was because the aluminium scrap deposited into the crucible had been melted already and later solidify, recharging the material made the melting process faster.

The rate of temperature rise is considerably higher when compared to the result obtained from furnaces developed by Gottmyers (2019), which takes about 6 hours to attain 754 ^{o}C temperature. Although the starting temperature and the charge weight contributes to the time it takes the furnace to attain maximum temperature. The curve attained from the test results shows similar characteristics to that obtained by Anaidhuno (2005) and Gottmyers, (2019).

Economically the machine is less expensive compared to imported machines as local materials were utilised in the fabrication process. It can be beneficial to metal production companies and our institutions to improve student's knowledge and technical skills on the subject.

CHAPTER FIVE

5.0   CONCLUSION AND RECOMMENDATION

5.1   Conclusion

The development of a 5kg induction furnace for melting aluminium scraps was successfully fabricated and tested. The machine was able to heat and melt the metal (aluminium scrap), in other to obtain the required work piece.

The development of this machine helped to reduce aluminium scrap in the environment by increase the awareness of waste management and the recycling of the metal. Air pollution was reduced to the minimal when in operation of the machine and the cost of maintenance and labour was low. The metal (aluminium scrap) was melted in a shortest possible period of time with great reduction in energy consumption.

Therefore, this fabricated induction furnace can be encouraged to be used in our local foundries, companies and institutions in Nigeria and overseas as a medium for learning, faster production and to encourage local production.

5.2   Recommendations

Since the development of 5kg Induction furnace cost less in maintenance and labour, ability to melt fast, reduction in air pollution and user friendly compared to other types of furnace. Therefore;

1. It is recommended that these method and design should be adopted in our companies in Nigeria, mode of learning in our universities and polytechnic.

2. It is recommended that mass production of this machine should be considered in order to reduce the high rate of imported furnace machine to encourage the use of made in Nigeria product that is, locally made induction furnace which will also help improve the economy of the country.

3. Improvement of this machine should be highly considered in the area of control system automation, mostly by Electrical Engineering department.

5.3   Contribution to Knowledge

Based on the result on the development of 5kg induction for melting scrap metals, my contribution to knowledge is that it can be used as a learning model to improve student knowledge, technical skills on related subject and also introduce a new, faster, cleaner method of melting aluminium.

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APPENDICES

Appendix 1: Results for Test 1

Time (Seconds)	Temperature (^{O}C) Test 1
0	44
120	46
240	57
360	122
480	213
600	220
720	290
840	340
960	410
1080	446
1200	469
1320	481
1440	484
1560	515
1680	528
1800	541
1920	554
2040	568
2160	582
2280	596
2400	610
2520	625
2640	640
2760	655
2880	670

Appendix 2: Results for Test 2

Time (Seconds)	Temperature (^{O}C) Test 2
0	44
120	132
240	195
360	249
480	293
600	330
720	359
840	381
960	398
1080	410
1200	418
1320	423
1440	425
1560	465
1680	480
1800	499
1920	520
2040	543
2160	570
2280	598
2400	629
2520	663
2640	700
2760	734
2880	779

MECHANICAL ENGINEERING DEPARTMENT
SCHOOL OF INFRASTRUCTURE PROCESS
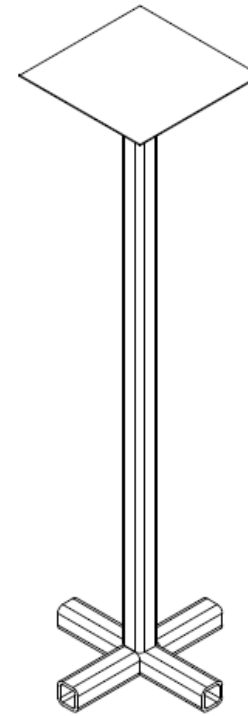AND ENGINEERING TECHNOLOGY
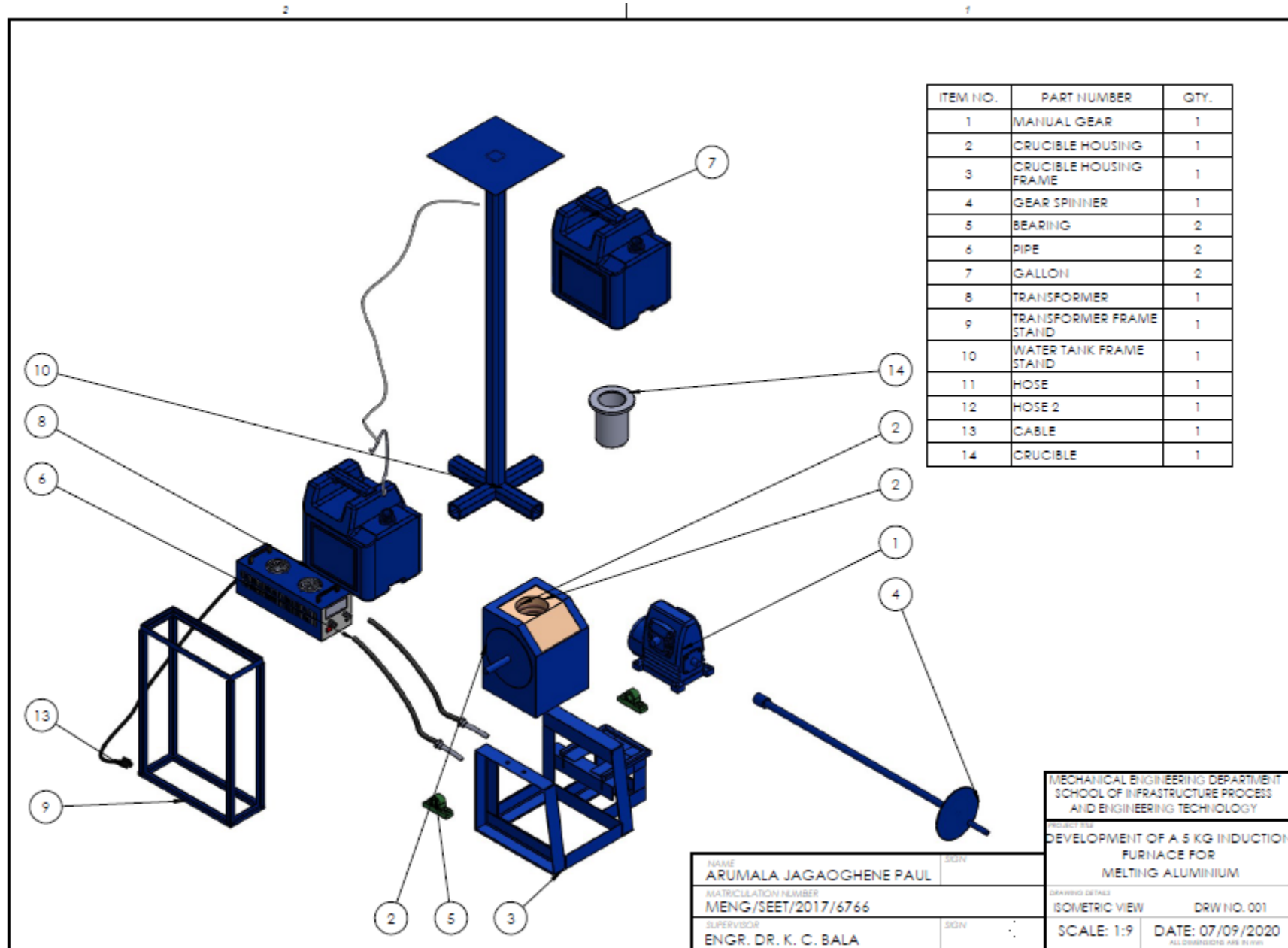
DEVELOPMENT OF A 5 KG INDUCTION
FURNACE FOR
MELTING ALUMINIUM
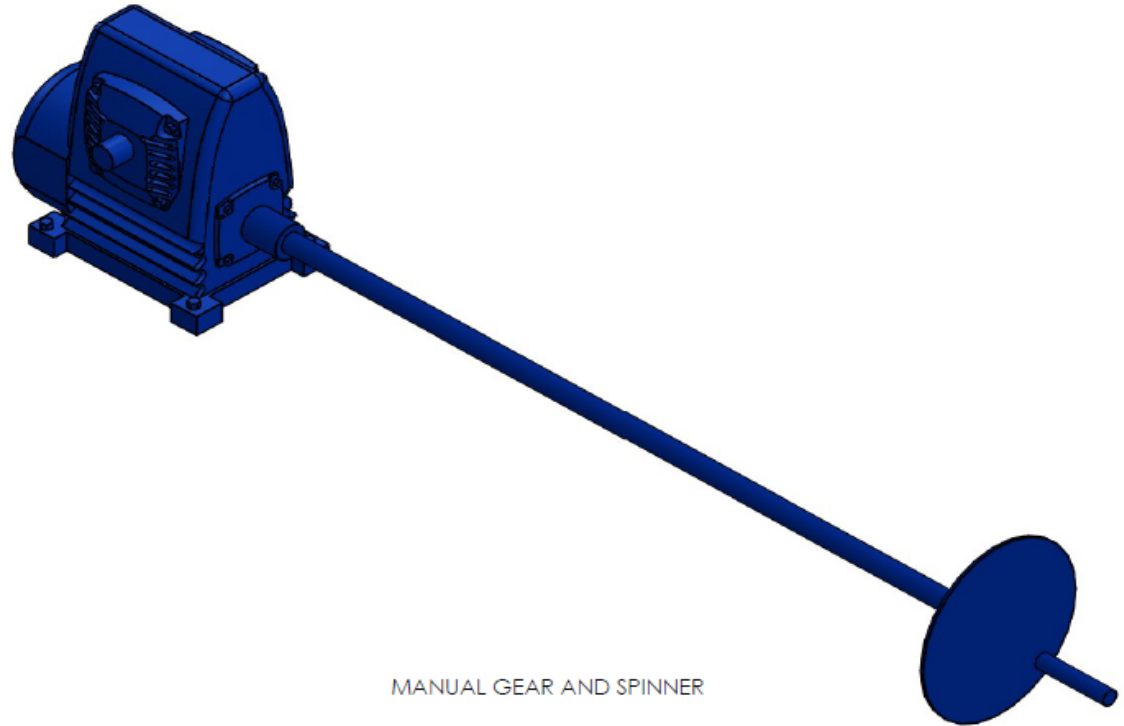
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ENGR. DR. K. C. BALA				ALL DIMENSIONS ARE IN mm

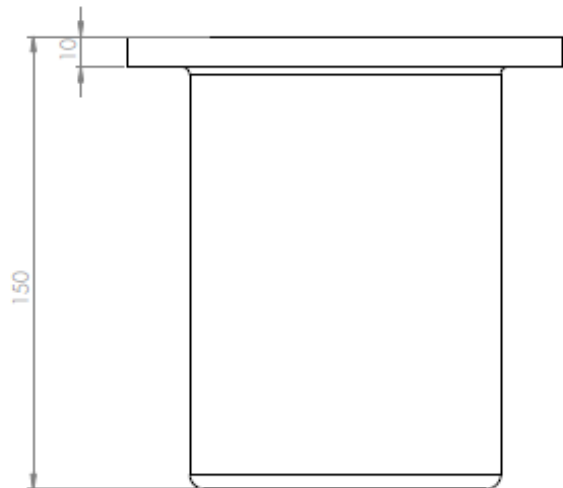| ITEM NO.	PART NUMBER	QTY.
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2	CRUCIBLE HOUSING	1
3	CRUCIBLE HOUSING FRAME	1
4	GEAR SPINNER	1
5	BEARING	2
6	PIPE	2
7	GALLON	2
8	TRANSFORMER	1
9	TRANSFORMER FRAME STAND	1
10	WATER TANK FRAME STAND	1
11	HOSE	1
12	HOSE 2	1
13	CABLE	1
14	CRUCIBLE	1

NAME
ARUMALA JAGAOGHENE PAUL

MATRICULATION NUMBER
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SUPERVISOR
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MECHANICAL ENGINEERING DEPARTMENT
SCHOOL OF INFRASTRUCTURE PROCESS
AND ENGINEERING TECHNOLOGY

PROJECT TITLE
DEVELOPMENT OF A 5 KG INDUCTION
FURNACE FOR
MELTING ALUMINIUM

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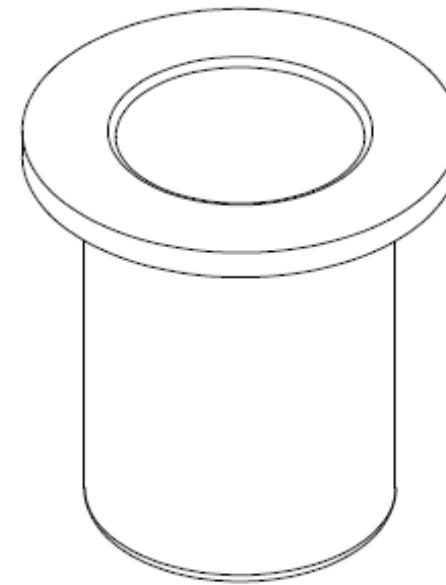ALL DIMENSIONS ARE IN mm

MECHANICAL ENGINEERING DEPARTMENT
SCHOOL OF INFRASTRUCTURE PROCESS
ANDENGINEERING TECHNOLOGY

PROJECT TITLE
DEVELOPMENT OF A 5 KG INDUCTION
FURNACE FOR
MELTING ALUMINIUM

NAME
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MATRICULATION NUMBER
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SUPERVISOR
ENGR. DR. K. C. BALA | SIGN

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ALL DIMENSIONS ARE IN mm

198

198

PLAN

340

50

345

300

50

300

190.00

345

FRONT VIEW

ISOMETRIC PROJECTION

PLAN

300

300

FRONT VIEW

1275

50

360

ISOMETRIC PROJECTION

70

PLAN

Ø140
Ø85
Ø70

10

150

FRONT VIEW

ISOMETRIC PROJECTION

PROJECT TITLE
DEVELOPMENT OF A 5 KG INDUCTION
FURNACE FOR
MELTING ALUMINIUM

NAME
ARUMALA JAGAOGHENE PAUL

SIGN

MATRICULATION NUMBER
MENG/SEET/2017/6766

DRAWING DETAILS
CRUCIBLE

DRW NO. 005

SUPERVISOR
ENGR. DR. K. C. BALA

SIGN

SCALE: 1:1.5

DATE: 07/09/2020
ALL DIMENSIONS ARE IN mm

BEARING

MANUAL GEAR AND SPINNER

TRANSFORMER

	SIGN		MECHANICAL ENGINEERING DEPARTMENT

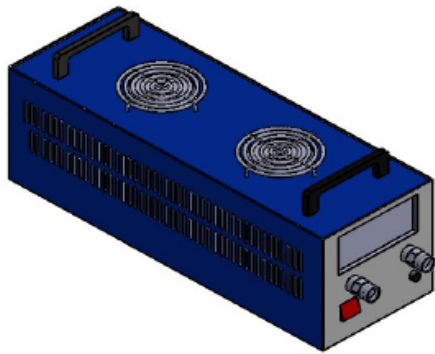BEARING

MANUAL GEAR AND SPINNER

TRANSFORMER

MECHANICAL ENGINEERING DEPARTMENT
SCHOOL OF INFRASTRUCTURE PROCESS
ANDENGINEERING TECHNOLOGY

PROJECT TITLE
DEVELOPMENT OF A 5 KG INDUCTION FURNACE FOR MELTING ALUMINIUM

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ENGR. DR. K. C. BALA				ALL DIMENSIONS ARE IN mm

HEATING ELEMENT (COIL)

15

40

PITCH 8

50

Ø 7,5

85