DESIGN & FABRICATION OF A MODEL ELECTRIC-ARC FURNACE

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DEDICATION

This project is dedicated to my loving parents Col. & Mrs Olode and my wonderful brothers and sisters, Tolu, Dotun, Abe, Bukky, Tope, and Jumoke.

CERTIFICATION

This is to certify that this project titled "Design and Fabrication of a Model Electric-arc furnace" was carried out by Olode Lanrewaju under the supervision of Engr. Dr. Adgidzi and submitted to Agricultural Engineering Department, Federal University of Technology Minna, in partial fulfilment of the requirements for the award of Bachelor of Engineering (B.Eng) degree in Agricultural Engineering.

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ρ	-	density (kg/m^3)
A	-	area (m^2)
L	-	length (m)
h	-	height (m)
V	-	volume (m^3)
θ_1	-	Initial temperature (^0C)
θ_2	-	final temperature (^0C)
K	-	thermal conductivity (kg/kJ)
m	-	mass (kg)
Q	-	quantity of heat (J/kg)
F	-	force (N)
V	-	voltage (volt)
P	-	power (watt)
I	-	current (amps)
R	-	resistance (ohms)
g	-	gravitational force 10m/s
t	-	time (sec)

ABSTRACT

The electric-arc furnace design and fabrication was done to carry out foundry operation using a very low amount of energy in he form of electricity. It's size, structure, principle of operation and maintenance are simple and understandable. This makes it easy to use by any workshop practitioner. The total capacity of the furnace is 5kg/charge. The voltage supply rating is 219v. Temperature range of the electric arc furnace is controlled between 200^0C and $1,106^0$C

CHAPTER ONE

1.0 INTRODUCTION

A furnace in a closed structure in which heat is applied to a load or charge. The term is derived from the latin word fornus meaning oven (Historically, it grew out of the fireplace & stove). The purpose for which furnaces are used varies and this reflects the structural design of the furnace.

Presently, the industries using melting furnaces are those producing iron and steel and they mostly use blast furnace, bessemer converters, electric arc and induction furnaces. Cement manufacturers are interested in rotary kilns while glass manufacturers are more interested in tanks and pot furnaces. On the other hand, the economic industries are interested in various types of kilns.

Furnaces are designed for either intermittent (batch) operations or continuos use. In batch operation, the charge is placed in the furnace when cold, fired to required temperature, cooled and unloaded. A continous furnace generally consist of a number of zones; pre-heat, firing and cooling.

The type of bricks used in furnace constructions depends on various factors such as the maximum firing temperature, atmospheric conditions and the reaction of molten metal, slag, combustion gases with the refractory lining. The furnace structure must remain stable under the prevailing heating and cooling conditions so that expansion and contraction can be accounted for. Due to rapid change in temperature, refractories that are highly resistive to thermal shock are required. In this century, cement-like lining, which can be sprayed on the refractory for give monolithic layer and ceramic fibre blankets pinned to the supporting brick work are used. Examples of materials are China clay (kaolin), ball clay, and fire clay.

1.1 TYPES OF FURNACES.

In the past times, different kinds of furnaces have been developed from one stage to the next. Today, there are various kinds of furnaces ranging, from very little size and process to large ones.

- **The blast furnace**: usually lined with a kind of brick that can stand great heat. It is often charge (loaded with metals) with layers of coke, ore and limestone. Air is heated for hot blast and forced through the flues (chimneys) of the heat source to produce high temperatures.

  The heat then melts the ore and impurities are remove by the flux or limestone.

- **Basic-oxygen process**: in this furnace a metal tube is lowered after the furnace is charged. The tube blows oxygen down from the top. This mixes with the carbon and other unwanted element and starts a high-temperature action. This temperature is achieve to melt the charge and a good quality steel is resulted.

- **Open-hearth furnace**: In the open hearth furnace, heat is directed over the metal instead of through it. The hearth is usually a large rectangle basin holding several tons of metal. A charge of limestone and scrap is placed in the furnace. The lit fuel burns directly downwards the charge when the scrap metal is nearly melted, hot metal from the blast furnace is added and refinement of the metal continues.

– **Electric furnace**: steel is made in an electric furnace the same way as it is made in the open-hearth. But it is usually made in smaller amounts, and electricity is used for heating. The electric furnaces are used to make special kinds of steel. Other furnace structures exists such as the converters, oven and kilns.

1.2 ELECTRIC FURNACES.

These are furnaces that requires no combustion process but as the name implies, relies on electrical energy from the grid system being converted directly into heat energy. Electric furnaces provide very high temperature.

They are used to heat materials such as steel, glass, Aluminum, copper etc. in certain manufacturing processes. The material heated is called the charge.

There are three main types of electric furnaces. These are:

i. Resistance furnace

ii. Induction furnace

iii. Arc furnace.

i. **Resistance Furnaces**: There are two types of resistance furnaces: the direct heated type and indirect heated type. In the indirect heated resistance furnace, the heat in produced by passing an electric current through resistors made of a Nickel-chrome alloy, Graphite or Molybdenum. These resistors are usually

ii. located with a material capable of withstanding high temperatures. Indirectly heated resistance furnaces are used to heat-treat metals and fuse vitreous enamels. In the directly heated resistence furnace, the heat is produced by passing the current directly through the charge. Phosphorous and fused alumina are produced in the directly heated resistence furnace.

iii. **Induction Furnace**: In the induction furnace there is no direct connection between the source of electricity and the charge. The vessel containing the charge in surrounded by a will, inducing a current either in the charge or in the vessel containing it. It is this induced current that heats the materials. there are two principal types of induction furnace; the core type and the coreless type. In the core type induction furnace, the coil is wound around an iron core that passes through a hole in a v-shaped crucible. The charge in the crucible is heated by the induced current. This furnace is meant for heating non-ferrous metals. The coreless induction furnace uses high-frequency electric current and the charge is contained in a crucible placed inside the coil. The heating current is induced in the charge. Its advantages are it's ability to concentrate heat in the charge and to produce rapid increase in temperature.

iv. **Air Furnaces**: In the arc furnace, heat is generated by an arc. There are two classification of Arc furnaces. These are the indirect-arc furnace and direct arc furnace. In the indirect-arc-furnace, the electric arc is formed between two electrodes placed above the charge. In the direct-arc furnace, one type consist of the three electrodes arranged in a triangular form above the charge. The arc is formed between the electrode placed and the charge. In another type of direct arc furnace, called the submerged arc furnace, the electrode is buried in the charge. The indirect arc furnace operates on a single phase alternating current while the direct furnace usually uses three phase alternating current. The arc furnace can be used to melt scrap metals of various types ranging from lead to steel.

1.3 JUSTIFICATION OF THE PROJECT:

The modern workshop lacks foundry equipment to carry out simple operations in maintenance and repairs.

This project is intended to produce a major foundry equipment (An electric-arc furnace) of low cost with simple design, and ease of operation and maintenance.

1.4 OBJECTIVES

i. The project is aimed at designing and fabricating an electric-arc furnace capable of carrying out modern foundry operations in small and medium scaled workshops.

ii. To carry the test performance of the electric arc furnace.

CHAPTER TWO

2.0 LITERATURE REVIEW.

2.1 HISTORICAL BACKGROUND.

As early as 3000 B.C. the sumerians of mesopotamians were using closed furnaces (kilns) with controlled draught for firing fine pottery at temperature up to 1200 °C (2192 °F) for metal extraction. The pot furnace which is buried in the ground replaced the primitive stone or clay lined hollow. during the bronze age a more advance type of furnace evolved known as the shaft furnace. the shaft furnace is widely used for smelting and probably derived from the pottery kiln.(New science encyclopedia Vol 4 Pg 462)

Ancient Egyptians, during the iron age, extracted iron from its ores and made it into various utensils. Many eastern nations knew how to prepare alloy steel in furnace around 500 B.C.

Towards the middle of the sixteenth century Gorgeous Agricola worked on various types of smelting furnaces in considerable detail and later published a book 'de re metallica' (concerning metals).

The invention of the bessemer process bessemer in the 1850's by a U. S. citizen Wailliam Kelly and a British subject Henry bessemer led to the awareness and use for furnaces for this made melting process organized and quantified for subsequent uses. The bessemer steel provide much of metal used for the early rail roads and the first skyscrapers.(encyclopedia Britannica Vol 2 pg. 271) skyscrapers.(encyclopedia Britannica Vol 2 pg. 271)

The open hearth process was introduced in the 1860's which was the next development. The 20th century saw the introduction of electric furnace after the development of electricity and its application.

Early steel work machinery: Object of iron and steel have been worked by hand hammering since antiquity. With development and product of wrought iron on a large scale water driven hammers came into use. A mill of this type for the production or rods and bars used in the manufacture of nails was installed at iron works at saugus, Massachusetts, 1648. in England in 1786 watts steam engine was first used to drive a slitting and rolling.

In 1856 William and Frederich Siemens German born scientist who also lived in England, invented a regenerative system for preheating the air supplied to a furnace so that flames of very high temperature could be produced.

As soon as the dynamo became a practical reality chemist and metallurgist put electricity to work as an energy for steel making. William Siemens is credited with having first used electric power to make steel (1878).

Heroutt in France operated the first commercial electric furnace steel production in 1899. His design was the forerunner of the modern high powered arc furnace. the furnace was enlarged in 1904 in an installation in the united states with a capacity of 4 tons (3600 kg) per charge. (encyclopedia of science vol 6 pg. 713)

The electric arc furnace in well situated to the production of high quality special and alloyed steels and it rapidly replaced the crucible process for making these steels

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2.2 DEVELOPMENT OF FURNACES.

The development of furnaces in recent times has been characterized by the emphasis on the quality of various ferrous metals in general and steel production and this have played an enormous role in the workshop, industries and the national economy. The economic power of a country is determined by its output of metal and steel especially in the agricultural branch. Though the output of non-ferrous metals, especially of aluminum has risen many times during the last 60-100 years

In 1973, the world output of steel approached the figure of 700 million tonnes annually. (encyclopedia Britannica). The time of transition from the "Bronze age" to the "Iron age" cannot be established with certainty. Man knew from the far antiquity how to produce iron and make tools with them. Excavations of structures built at the time of Egyptians, Pharaohs provided evidence that the ancient Egyptians were familiar with iron melting process as far back as 4200 B.C.

In 1830 Joseph Hall proposed to make the hearths of paddling furnaces from materials high in iron oxides. The hearths of the earliest furnaces were made from materials high in Silicon Oxide or sand and this led to high losses of iron due to formation of iron silicates. In 1855, Henry Bessemer an English mechanic, proposed a simple and inexpensive process for marking cast steel in large quantities by blowing molten pig iron with air. The metal was blown in a special vessel (converter) lined with an acid refractory material.

The process has been called the bessemer process.

In 1878-79 S.G. Thomas of England developed a version of the Bessemer process to be a carried in a converter lined with dolomite, a material possessing basic properties. The process is known as the basic Bessmer in great Britain and sometimes called the Thomas process in some other countries.

In 1865, Emile and Pierre Martin of France succeeded in melting steel from pig iron and scrap in a reverberatory (open-hearth) furnace. A high temperature sufficient for melting steel was attained in the furnace owing to the pre-heating of gaseous fuel and air. The principle of preheating the fuel and air by heat of the waste gases in regenerators has been developed by C. W. siemens.

2.3 PROGRESS OF ELECTRIC FURNACE.

In the second half of the past two century, a number of proposal were made on utilizing electric energy for furnaces. At the end of the 19^{th} and beginning of the 20^{th} century, various electric furnaces were built and put into operation. Electric melting has been developing rapidly especially in a few past decades. Electric arc steel-making furnaces having capacity of 200-350 tones have appeared with unit power of transformers. raised up to 700 - 800 KV. High efficient electric arc furnaces often replace older open hearths.

The replacement of air, which is supplied to steel making plants for fuel combustion and the oxidation of iron impurities, by pure oxygen was for many years the dream of metallurgists. The idea however, could not be implemented for a long time in view of the high cost of oxygen. Only after the second world war, efficient and relatively inexpensive method of producing oxygen were developed. In only 10 year (from 1960 to 1970) the world output of steel work increased from 364 million ton to 603 mill ton. The idea of making cast steel on hearth of a reverberating furnace was proposed by a number of scientist (by R. Reaumur of France in 1722). In 1856; W. Siemens suggested the principle of regeneration, that is, of utilizing heat of exhaust gases of a furnace for heating up the air for combustion in an arrangement called a regenerator.(steel making, Kudrin 1976)

The principle of heat regeneration was soon employed practically by Pierre and Emile Martin of France for making steel. The open-hearth process is considered to come to existence on April 8^{th} , 1864, when Martins seceded in melting in an open hearth furnace in Sireuil, France.(steel making, Kudin 1976)

2.4 TYPES OF ELECTRIC ARC FURNACES.

Electric arc furnaces in modern days, comes in various designs based on their shape, sizes and arrangement of the electrodes.

On the basis of the arrangement of electrodes in an electric are furnace, the major types of furnace includes:

- Submerged arc furnace

- Direct arc furnace
- Indirect arc furnace

The direct arc furnace is that which has its electrode in direct contact to the metal to be melted or fused. One terminal of current flow is the electrode while the metal acts as the second terminal. Most Industrial foundries accept this method for use due to it's efficient advantage both in time and power consumption.

- **Submerged arc furnace**: Three large carbon electrode project vertically downwards into the hearth with their tips well immersed in the furnace charge. Furnaces of this nature may not have roots. The electrodes are made in place by filling thin steel cylindrical shells with a tar-coke mix. This mix is packed as it passes into the hot zone of the furnace. Heat for the process is generated by current from the electrodes passing through the change.
- **Indirect arc furnace**: Here two electrodes each of different terminal are bridged together to discover a spark which when separated produces an electric arc between them. The arc then generates heat enough to melt scrap metals when the atmosphere is controlled.

Based on method ofheating, electric furnace are classified as resistance furnace, arc furnace, plasma-arc furnace and high-frequency furnaces. [B. Linchevsky (1982)].

Bulavin et al (1982) proposed the following classification.

I. By the direction of production flow relative to the charge in the furnace.

a. Vertical furnaces, in which the direction of production flow coincides with that of the charge melting.

b. Horizontal furnaces, in which the production flow is perpendicular to the horizontal charge melting process.

II. By the position of the electrode relative to the production flow. There are electric furnace with longitudinal arrangement of electrodes, those with transverse arrangement and also with combined longitudinal/transverse arrangement.

III. By the position of electrodes relative to enclosing furnace walls. It may be distinguished between furnaces with rod-type electrodes, those with wall electrodes and those with vertically arranged electrodes.

2.5 ADVANTAGES OF THE ELECTRIC ARC FURNACE.

- It permits greater flexibility therefore can be used with variety of scrap metals.
- Any desired temperature may be obtained since the rate of heat application can be closely controlled.
- The electric arc furnace has a very high thermal efficiency, usually about 70%.
- There are rarely contaminations in metals to be melted.
- Steel that are to contain particularly high percentage of various alloy metals are made almost exclusively in the electric furnace. Some plain carbon steel and low alloy steel are produced by this process.
- In electric furnace, steel is melted by the heat of an electric arc. No fuel or air

is needed in the furnace. As a result, it is possible to control the amount of oxygen. Entering the furnace.

- Expensive alloying elements can be added without much loss through oxidation, or combining with oxygen. therefore operations such as annealing or crystallization can be achieved in the electric-arc furnace.

2.6 THE AVERAGE DIRECT ELECTRIC ARC FURNACE.

The furnace is a circular steel shell resembling a huge tea kettle, lined throughout with heat resisting brick. Its capacity ranges from 5 to over 90 metric tones. Three carbon rod (electrodes) extends through the dome-shaped top into the furnace carrying the current to the steel charge. Each electrode can be raised or lowered Independently of the others. In general the closer the electrodes are to the charge, the more heat is produced. On one side of the furnace is the charging door and the other side has the tapping sprout. The furnace can be tilted to pour out the molten steel and slag through this sprout.

The method most frequently used in the operations of an electric furnace is the cold, melt process. It is called so because cold steel scraps make up the charge, with the furnace charged, the current is turned on. As each electrode is lowered, electric current jumps a gap between the electrode and scrap forming an arc. A violent noise is heard within the furnace as the gap leaps and breaks. The Intense heat generated melts the charge until entire mass is seething.

Fluxing materials are added by a charging machine through the swivel door and alloying materials are charged in the same way as required.

Compared with conventional flame-contact furnaces, electric furnaces are generally simpler in design and smaller in dimension due to the absence of regenerators. The thermal efficiency is usually as high as 60-70%. This is usually due to low heat loss to the surroundings. Also the thermal condition can easily be controlled automatically. Consequently, very high quality of product is achievable.

Owing to the nation's economic state, electric furnaces are in affordable; and this has immensely stagnated the national technological development. This project is embarked upon to increase thermal efficiency for the power consumed per kilograms of charge.

2.7 PRINCIPLES OF MELTING TECHNOLOGY.

The process of melting always involves metal losses, so that the mass of the final metal Invariably turns out to be smeller than that of the metal charged into the furnace or crucible. These losses in melting may range from a few tenths of a percent to a few percent and are associated with oxidation and evaporation of the metal and its Interaction with the refractory lining.

All the metals introduced into a furnace for melting is called the charge. The charge may contain pure metals; purchased scraps, return scraps from the workshops, metal chips, rejected casting, gates and risers. All these charge materials are usually contaminated with sand. Another loss is associated with evaporation of the metal and its Interaction with the refractory lining. This loss known as the melting loss can be estimated by the difference between the mass of the initial charge and that of the final metal and the loss to slag.

Before carrying out a heat charge specified quantity of charge is introduced into the furnace. This can be based on the capacity of the furnace.

The materials constituting the largest fraction of the charge and also high melting additions should be charged into the furnace in the first place. Volatile, oxidizable and minor additions should preferable be introduced as special alloys. The melt should be agitated for reliable dissolution of all additions.

At the final stage, the melt is modified by special additions or holding it at a specified temperature. Just before tapping. The melt is kept quiet for 10-20 minutes, which is needed for separation. (faulting up) of slag particles, oxides and gas bubbles. The temperature of molten metal at tapping usually exceeds the liquideous temperature by 100-200 °C.

2.8 METAL REFINING.

Because of its Interaction with atmospheric air or moisture, the molten metal may get contaminated with dissolved oxygen, nitrogen and hydrogen. It may also be contaminated with insoluble oxides formed in the process and with slag droplets, fluxes and particles of the refractories. The charge usually contains a large amount of contaminants which can pass over into the melt. Thus, the removal of dissolved metallic and non-metallic impurities from molten metal is an important procedure in melting.

Refining of the melt is its purification from non-metallic inclusions and dissolved gasses and this is a specific procedure in foundry practice. .

One simple method of removing non-metallic Inclusions in by setting. Since non-metallic inclusions are lighter than the metal, they float up to the metal surface and pass over to the slag.

Table 2.1 Table melting temperature of selected metals that can be melted with EAF model (low-melting point metals)

METAL	TEMPERATURE	
	^0F	^0C
Tin	449	232
Babbit metal	462	239
Lead	621	327
zinc	788	420
Aluminium	1220	660
Bronze	1675	913
Brass	1706	930
Silver	1761	960
Gold	1945	1063
Copper	1981	1083

These compound are based on a blend of high purity raw materials, selected to form spiral bonding at high temperatures for optimum performance.

The materials react to a neutral state at temperature and can be used in furnaces for the melting of steels and high-alloyed, non-ferrous metals. additionally, for lower temperature work, the use of alternative bonding systems are incorporated into the standard mixes for copper based alloy and aluminum alloy melting.

Component/Chemical analysis of aluminum magnesia lining.

By weight,

Al_2O_3	-	83.0	-	96.5%
Mgo	-	13.0	-	15.5%
SiO_2	-	0.7 max.%		
Fe_2O_3	-	0.7 max.%		

The lining which has a dry bulk density of 2800 - 2950 Kg/m^3 can be used for heat application limit of 1725^{0}C in continuos operations and 1775^{0}C in short time operation.

Basic dry rammed linings:

A dry, basic ramming mixes of certain compounds of purity blended to give a dry powder. The compounds consists of Al_2O_3, Mgo, SiO_2, Fe_2O_3 and CaO.

Unbounded refractoriness can withstand heat of up to 1600^{0}C. A temperature of 1700^{0}C is resisted for short period operation.

Silica lining:

Dry silica, and acidic lining are produced from high purity quartzitic silica and are blended with basic oxide or basic acid to produce a full range of sintering agent concentrations. Silica lining is known to be the most effective form of lining among others.

At 99.0% silica composition, temperature of 1650^{0}C is workable. Wide range of alloys can be melted in the silica lining. These includes:-

a) Carbon and low alloys steels

b) High speed magnet

c) Stainless steels

d) Grey and alloy irons

e) Cupro-based alloys

It must be noted that rapid erosion of lining will occur when melting carbon or low alloy steels and stainless steels.

Refractoriness:

Refractories are classed into three groups by their refractoriness index: common, which withstands temperature up to 1580 - 1770^{0}C, high refractory(1770 - 2000^{0}C) and those of the highest refractoriness (above 2000^{0}C). The refractoriness index is determined by standard test, which essentially consist of a specimen usually in form of a truncated pyramid placed in a furnace for heating, on reaching a definite temperature.

Table 2.2 Refractoriness of common linings

Refractory type	Ultimate compressive strength at room temp.KN/Cm^2	Softening temp. under load 20N/cm^2,^{0}C	Refractoriness ^{0}C
Fine clay	0.98 - 6.88	1350	1730
Silica	2.45 - 29.4	1630	1730
Magnesite	2.94 - 4.90	1500	2000
Chrome- Magnesite	2 - 5	1500 - 1630	2000
Periclose-spinal	4.8	>1550	2000

Based on chemical properties two types of oxides are used

i) acids such as silica(SiO_2) and Phosphorous pentoxide(P_2O_5)

ii) Bases such as lime(CaO), magnesia(MgO)

Ferrous oxide (FeO) and alumina(Al_2O_3) are essentially neutral.

2.9.1 Interaction of metals with Refractories:

The material for lining melting furnace and melting crucibles should posses a wide range of mechanical strength and chemical stability at elevated temperature so as to withstand the action of metallic melt, oxides, slags, and fluxes.

The common refractory materials consists of various oxides such as SiO_2, Al_2O_3, MgO, Cr_2O_5, ZrO_2 etc in which the most popular among them are fine clay (60-75%

SiO_2, balance Al_2O_3), silica (at least 95% SiO_2 balance impurities), magnesite (80% MgO balance CaO), chrome magnesite (45 - 50% MgO, 30 - 35% Cr_2O_3, balance SiO_2), Zircon (65% Zro_2 35% SiO_2) and high-alumina refractories (at least 50% Al_2O_3, balance SiO_2). Fire clay is the cheapest and most available among them.

The chemical stability of refractories is determined by the probability of the reaction between the Molten metal, Me and the Refractory Oxide, RO:

$$Me + RO \longrightarrow MeO + [R]Me \quad (R= \text{Reaction})$$

$$Me + RO \longrightarrow [Me + O + R]$$

These reaction may result in the destruction of the lining and contamination of the metal with impurities (oxides and R or oxygen and R).

The probability of this reaction is estimated by a decrease of Gibb's energy.

Refractory oxides can react not only with the metal proper but also the metal oxides which leads to their mutual dissolution.

All above mentioned refractories are suitable for melting of low-fusible metals e.g tin, lead, zinc, as can be seen in table 2.1.

In the melting of lead and lead alloys in a fire clay-lined furnace with superheating to 750^{0}C, fusion of the lining is possible because the PbO-SiO_2 system forms a stability with the melting point as low as 715^{0}C.

If only refractoriness were considered, magnesium and magnesium alloys with the working temperature up to 850^{0}C would be melted in fire clay-lined furnace. However, molten magnesium actually, intensively reduces silicon from silica, because magnesium alloys are only melted in magnesite-lined furnaces or steel crucible. In melting of aluminum & aluminum alloys, reduction of silicon from silica of the lining also takes place, but fire clay, as the least expensive and most easily available refractory material and therefore widely used in the manufacture of aluminum alloys provided silicon is present in the alloy in tolerable limits.

Fire clay has a sufficiently high mechanical strength and chemical stability to be used as lining the furnaces for melting the copper and copper alloys.

Common fire clay is unsuitable for melting of iron and nickel-base alloys in view of its low refractoriness. Therefore, silica, magnesite, Zircon and chrome magnesite are employed for this purpose.

Metals with the working temperature up to 900^{0}C can be prepared in steel or cast iron crucibles. The main risk in this case is that the melt may get saturated with iron.

Clay is a mixture of extremely fine particles of several related minerals mostly hydrous aluminum silicates, with minor organic matter and non-clay minerals.

China clay or Kaolin so named from "Kauling", a hill in China from which it was mined for use in porcelain, is a white clay of high purity. It has a high firing temperature of about 1300^{0}C.

The temperature at which vitrification starts and the range within this point and complete fusion to a viscous mass are properties of the greatest importance in refractory materials.

CHAPTER THREE

3.0 METHODOLOGY.

3.1 SITUATION FOR DESIGN.

In modern workshops of small and medium-scaled sizes, certain foundry operations are carried out to ensure a satisfactory result in total work input.

The operation are usually omitted and skipped due to the unavailability of the rear and expensive furnace in the workshop. Therefore a result of poor finishing and improper procedures of working activities is achieved.

In cases where purification is a priority, a poor case is also resulted due to lack of purifying equipments. Worn-out parts capable of being recycled into use are predominantly abandoned and disposed whereas they could become useful articles.

All these problems give rise to the need for an urgent solution in modern workshops to complete activities and operations generally omitted.

3.2 DESIGN INFORMATIONS.

To design and fabricate an electric arc furnace that is capable of carrying out modern foundry operations in a small/medium scale production workshop. The design should carry out the following secondary operations:

i) Melting/fusing of metals, non-metals and alloyed-metals.

ii) Heat treat (forging).

iii) Reconditioned by casting/dipping operation.

iv) Purification of substances including metals.

v) Firing

vi) Metal joining (Welding) and casting.

3.3 TECHNICAL CONCEPTS AND MAJOR COMPONENTS OF THE MODEL ELECTRIC-ARC FURNACE.

The design of the electric arc-furnace is determined mainly by these factors.

1) The diameter of the melting shell (vessel).

2) The weight of the charge.

3) The electric power supply required.

While electric power consumed is a measure of the melting performance, the diameter of the shell is a decisive factor for furnace serviceability because of its association with lining life.

One important component is the furnace vessel containing the melt. The vessel was formed from the refractory material This is held on a structural frame which can be lifted and tilted fr tapping and dis-lagging.

3.3.1 Vessel & Roof Cover:

The vessel have the function of containing the melt for processing and shielding it against heat losses to the surroundings. The vessel has a cylindrical flat bottom

(Hearth) and a cylinder wall with opening for the tapping sprout. The bottom is made of thick shell plates welded with appropriate stiffness. The root is a structured form of the refractory shaped to fit the vessel top. It covers the melt in the vessel preventing loss of heat and entrance of oxygen into the chamber.

3.3.2 Tilting device:

The purpose of the tilting device is to tilt the furnace accurately for dis-lagging and tapping. This is done by the means of the tilting handle. The handle is rigidly fastened to the shaft carrying the vessel . The shaft is then passed through designated bearing for support. The force necessary for tilting are usually transmitted manually by hand.

In the normal (zero tilt) position, the vessel is held balanced by gravity.

3.4 ELECTRICAL COMPONENTS OF THE ELECTRIC-ARC FURNACE

3.4.1 The boiler:

The boiler is that major part of the electrical circuit of the furnace. This was made to work with the principle of semi-conduction. Two cylindrical metals are connected in a circuit and separated by a semi-conductive material such as wood soaked in water. The resistance in the circuit can be reduced by increasing the conductivity of the solvent or increasing the salt concentration in water. Thus, an increase in the conductivity brings about an increase in current and power of the circuit, or vise versa.

The electrical circuit is completed when the boiler is totally immersed into water.

Arc furnace electrical equipment:

The electrical equipment comprises of the following placed on the electrical control board to sufficiently control and observe the working operation of the furnace.

These equipments on the control board, are listed as follows:

1) Furnace main switch.

2) Temperature regulator

3) Boiler switch

4) Furnace light-indicator.

The circuit diagram of the control board is shown in fig. 3.0

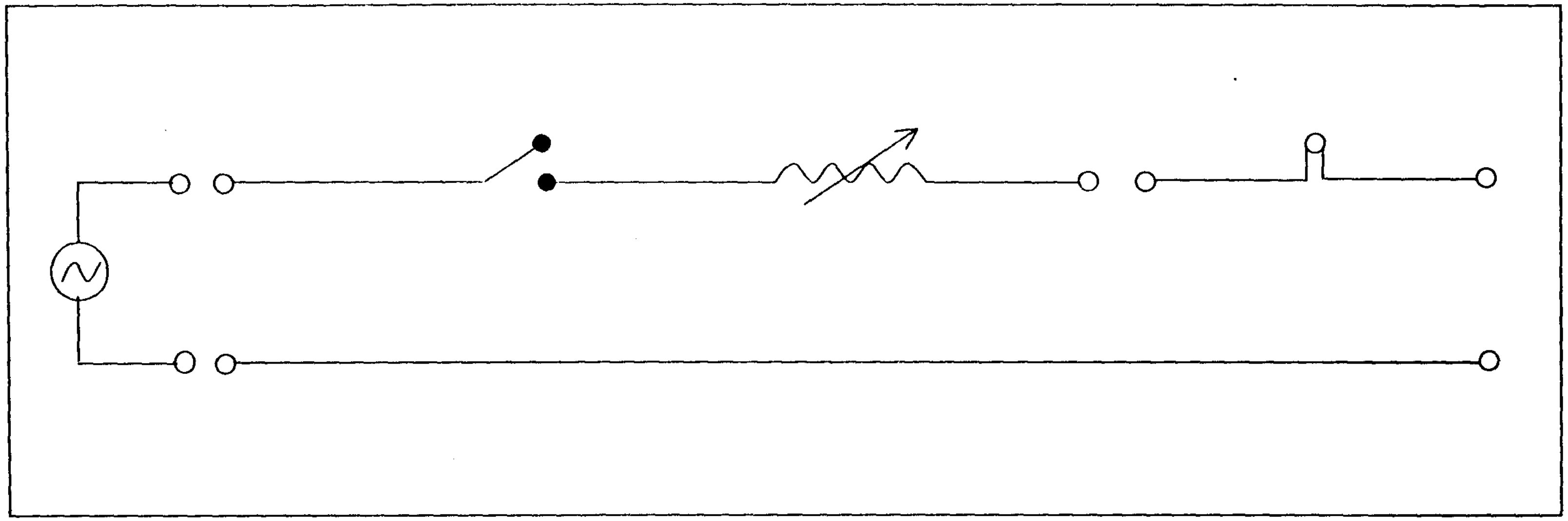
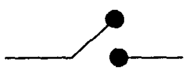


Fig. 3.0 Circuit diagram of the control board for the EAF.

 — A.C. Source

 — Switch

 — Variable resistor (temperature regulator)

 — Socket

 — Indicator Lamp.

3.4.2 Electrode holder tubes:

(Chucky's electrode holder)

The function of this is to move the attached electrode close and away from each other. This also functions as an agent of bringing power to the carbon/graphite electrode. The Chucky electrode can be moved mechanically, by hand. Current is fed through the circuit to the electrode holder and to the carbon electrodes. To achieve the lowest possible reactance, the conductors must among other things be as short as possible.

3.4.3 The Electrodes:

These are cylindrical length of graphite or carbon inserted into a pipe of high fusing temperature. The electrode should have a reasonably high conductivity of heat and electricity and also should be able to withstand a very high temperature of at least 3000^0 C. Though the size (diameter & length) of the electrode is determined by the furnace size the design was based on the electrode size and length readily available. Either carbon or graphite electrodes may be used. Carbon electrodes are cheaper but the best quality graphite electrodes are required to meet the severe operating condition especially in large capacity modern furnaces.

The electrodes are consumed by oxidation, by the action of the arc and by breakage.

From experiment the weight of electrode consumed is 0.4 to 0.75% of melted iron.

3.5 BASIC PRINCIPLE OF ELECTRIC FURNACE.

High Current Circuit: The high current circuit of an arc furnace using the Herold system has three phase star connecting to the three phase main supply. With a 220-240v supply a reliable amount of current can be achieved with the aid of the constructed water boiler. This takes the place of the 3-phase transformer in the Herold system. The reactance is determined by the conductivity of the boiler at work when in water.

3.6 ENERGY AND POWER IN THE CIRCUIT.

Power which is defined as the rate of doing work or the rate at which energy is converted into other forms. enters the circuit in form of electrical energy. An electric heater which is designed by the principle of semi-conductivity imbibes power into the circuit. As the current flows through, the electrical energy is converted in to heat energy with the aid of the carbon electrode while current jumps from one electrode to the other producing an arc. The power in the circuit can be given as:

$$P = VI$$

Where V = Voltage in circuit (volts)

I = Current flow (amps)

The furnace circuit is closed by striking the electrodes together and withdrawing

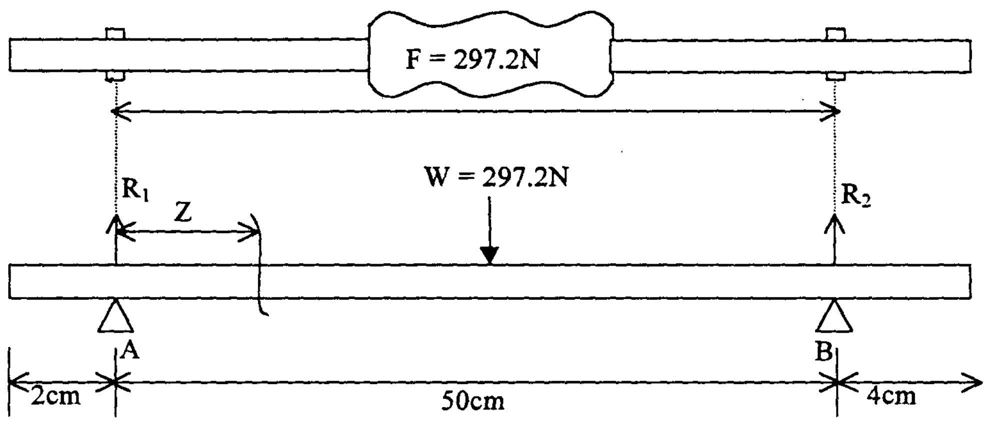


Fig.3.3 Diagram showing the reactions on the shaft

∴ Force acting at the point of the case fitting

$F = mg$

$F = 29.72 \times 10$

$= 297.2N$

Composition of the various materials used for the refractory in the EAF:

(Handbook in chemical engineering pg. 406)

1) Fire clay:

SiO_2 - 52%

Al_2O_3 - 43%

Fe_2O_3 - 1%

TiO_2 - 2%

2) Kaolin

SiO_2 - 52%

Al_2O_3 - 45.4%

Fe_2O_3 - 0.6%

TiO_2 - 1.7%

CaO - 0.1%

MgO - 0.2%

3) Silica sand Aggregate

SiO_2 - 96%

Al_2O_3 - 1%

Fe_2O_3 - 0.3-1%

CaO - 2%

4) Cement

SiO_2 - 21.92%

Al_2O_3 - 6.91%

Fe_2O_3 - 2.91%

CaO - 62.92%

MgO - 2.54%

SO_3 - 1.72%

– To calculate for shaft size:

length of shaft = 56cm

Distance from one support to the other = 50cm.

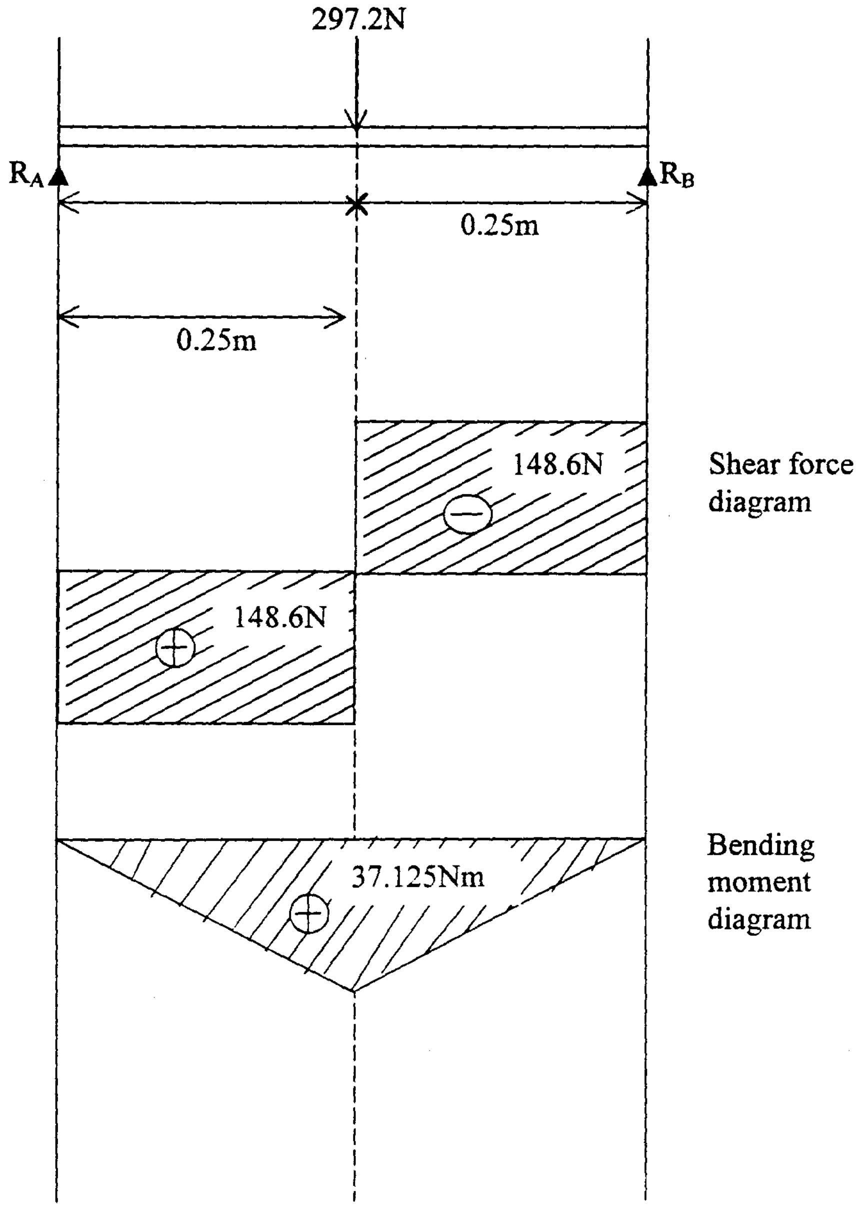


fig.3.4 Bending Moment and share force diagram for the shaft

Calculating for the reactions at point A & B

$$\sum fx = \sum fy$$

Taking moments about point A,

A $297.2 \times 25 - 50 \times R_2 = 0$

$R_2 = 297.2 \times 25/50$

$R_2 = 148.6N$

Since load is at centre of shaft

$R_2 = R_1 = 148.6N$

– Maximun bending moment is given by

$M_{max} : R_1Z$

$M_{max} = 148.6 \times 25$

$M_{max} = 3712.5N.cm$

$M_{max} = 37.125N.m$

3.10.1 HEAT CALCULATION.

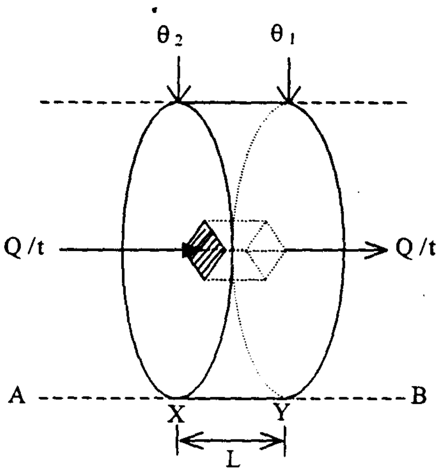


Fig.3.5 Heat conduction through the refractory wall.

Figure 3.5 represents a slice of the refractory lining with temperature θ_1 and θ_2 on the outer and inner walls respectively.

Temperature gradient over slice of refractory

$$= \frac{\theta_2 - \theta_1}{L}$$

heat flow per sec = Q/t

Since Q/t depends on temperature gradient and coefficient of conductivity

$$\frac{Q}{t} = \frac{k(\theta_2 - \theta_1)}{L}$$

∴ for a slab of refractory with

Area - A

Thickness - L

Quantity of heat - Q

temperature of it's faces θ1 and θ_2

Thermal conductivity - K

Heat flow per second = $\frac{Q}{t} = \frac{KA(\theta_2 - \theta_1)}{L}$

Heat flow per m^2 per second

$$\frac{Q}{At} = \frac{K(\theta_2 - \theta_1)}{L} = \text{conductivity x temperature gradient.}$$

Heat quantity.

i. Heat absorbed by the charge metal

$q_1 = mc\theta$

$q_1 = \rho vc\theta$

m = Mass of metal to be melted (kg)

C = Specific heat capacity of metal (J/kg.k)

ρ = Density of metal

θ = Temperature rise (k)

V = Volume of metal

ii Heat absorbed by the refractory

$q_2 = \rho_r V_r C_r \theta$ (J)

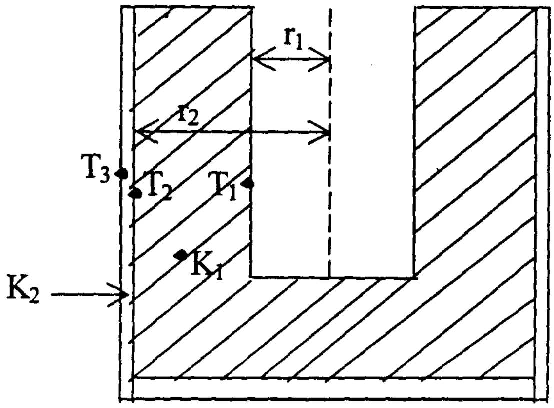
where

ρ_r = Density of refractory (kg/m^3)

V_r = Volume of refractory sheet (m^3)

C_r = Specific heat capacity of refractory (J/kg.k)

Heat Losses:



$r_1 r_2$ -Internal & External diameter (m)

r_3 -External radius of the entire furnace wall (m)

$K_1 k_3$ -Thermal conductivity of the refractory wall (w/m.k)

Fig. 3.6 Heat loss diagram

Figure 3.6 shows how heat is lost through the refractory walls from it's inner surrounding.

The heat loss Q_3 (W) can be determined using the equation:

$$Q_3 = \frac{T_1 - T_3}{\sum RT}$$

$$\text{Where } \sum RT = \frac{\ln\left(\frac{r_2}{r_3}\right)}{2PK_1L_1} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{2PK_2L_2}$$

3.10.2 ELECTRIC POWER REQUIREMENT.

Provided the voltage supply from the mains is V(volts) and power rating of the boiler is P(watt) then the resistance of the heating element is

$$R = \frac{V^2}{P} \ (\Omega)$$

$$\text{But } I \propto \frac{1}{R}$$

$$\Rightarrow P = \frac{V^2}{R} = IV^2$$

calculation of heat loss through furnace wall:

material	r(H)	K[Btu/(ft.hr.°f)]	r/k
refractory wall	0.1572	0.41	0.3725
mild steel	0.0039	17	0.0002
			0.3727

From the chart, 3.2 inside temperature = 1733°F (Heat transfer handbook. pg. 220)

By extrapolation,

Heat loss Q_3,

$$\frac{Q_3}{1000} = \frac{1733}{800}$$

$$Q_3 = \frac{1733 \times 1000}{800} = 2166.25 \text{ Btu/ft.hr}$$

By converison

$$Q_3 = 6833.5\, w/m^2$$

$$= 6833.5\, \pi\left(\frac{0.245}{2}\right) + \pi(0.245)(0.310)$$

$$Q_3 = 2274.8w$$

Total heat transfer

$= 110910.9 + 2274.8$

$Q_4 = 14185.7w$

Heat absorbed by load

Heat absorbed by the charged aluminum will be

$q_1 = 2643 \times 0.75 \times 2/4(0.125)^2 \times 0.2 \times 962.78 \times 640$

$q_1 = 2997818.69J$

Design of frame.

Beam design: The total weight on each vertical beam is given by

W_c = weight of casing

W_r =weight of refractory

W_s =weight of shaft

W_L = weight of handle

Total weight of furnace

$W_f = W_B + W_{fr}$

W_{fr} = weight of frame stand

Density of mild steel = $7840kg/m^3$

3.11 TEST PROCEDURE OF THE MODEL ARC FURNACE.

The electric arc furnace has a very simple mode of operation in the sense that anyone with little or no idea of workshop practices can operate it to working process.

The most important aspect to consider in the test procedure of the model electric arc-furnace is the safe of the operator.

The arc-furnace must be in a well spacious and ventilated area. This and the following must be ensured before operation commences.

i. As an operator, ensure to put on safety clothing which must include a hand glove and a safety goggle.

ii. Ensure that all tools needed to set the electric arc furnace for work agree readily available.

Those tools includes pliers, tester, tongs, crucible and the charge to be melted.

iii An electric socket should be located within the area at which the furnace is to be operated.

iv All necessary electrical connection alone. These connections includes,

- Fixing the carbon rods (electrodes) into the electrode holder.
- Fixing the electrode holder into the holes located on the furnace shell.
- Clipping the electrode holder with the crocodile clips attached to the electrical control panel.

To start the electric arc-furnace to work, a step by step procedure is needed to guide the operator of its use.

1. After all connecting have been made, the furnace plug is put into the socket available.

2. Before the main switch is put on, the boiler is plugged in the socket of the electric control panel and put in a plastic bowl of water.

3. The main switch, control/regulator switch and the boiler switch are then put on respectively.

4. The electrodes are joined to make contact in the furnace. This is done to close the circuit. The carbon electrodes remains in contact until the water in the plastic bowl begins to boil.

5. The electrodes are then slightly separated from each other with the use of a plier. This created an arc hot enough to melt-off the incoming charge.

   Usually, the gap of the arc should not exceed 30mm.

6. The metal to be melted can now be dropped in bits into the furnace after which the furnace lid covers the furnace.

7. Whenever the furnace goes off, the electrodes can just be contacted and separated to regain its arc.

   To collect the molten charge,

a) Put off all switches, from the mains to the control panel switches.

b) Stir the molten charge with stirring rod.

c) Remove the electrode holder from the furnace.

d) Tilth the furnace casing with the aid of the handle for its tilting mechanism and collect or pour out molten metal into mould or a tong-held crucible.

With particular reference to Fig 3.7, a pictorial layout of the furnace connection in operation can be seen with a representation of the various parts.

A - Furnace casing

B - Chucky electrode holder

C - Control board panel

C_1 - Main switch

C_2 - Temperature regulator

C_3 - Boiler socket

D - Boiler

E - Water bowl.

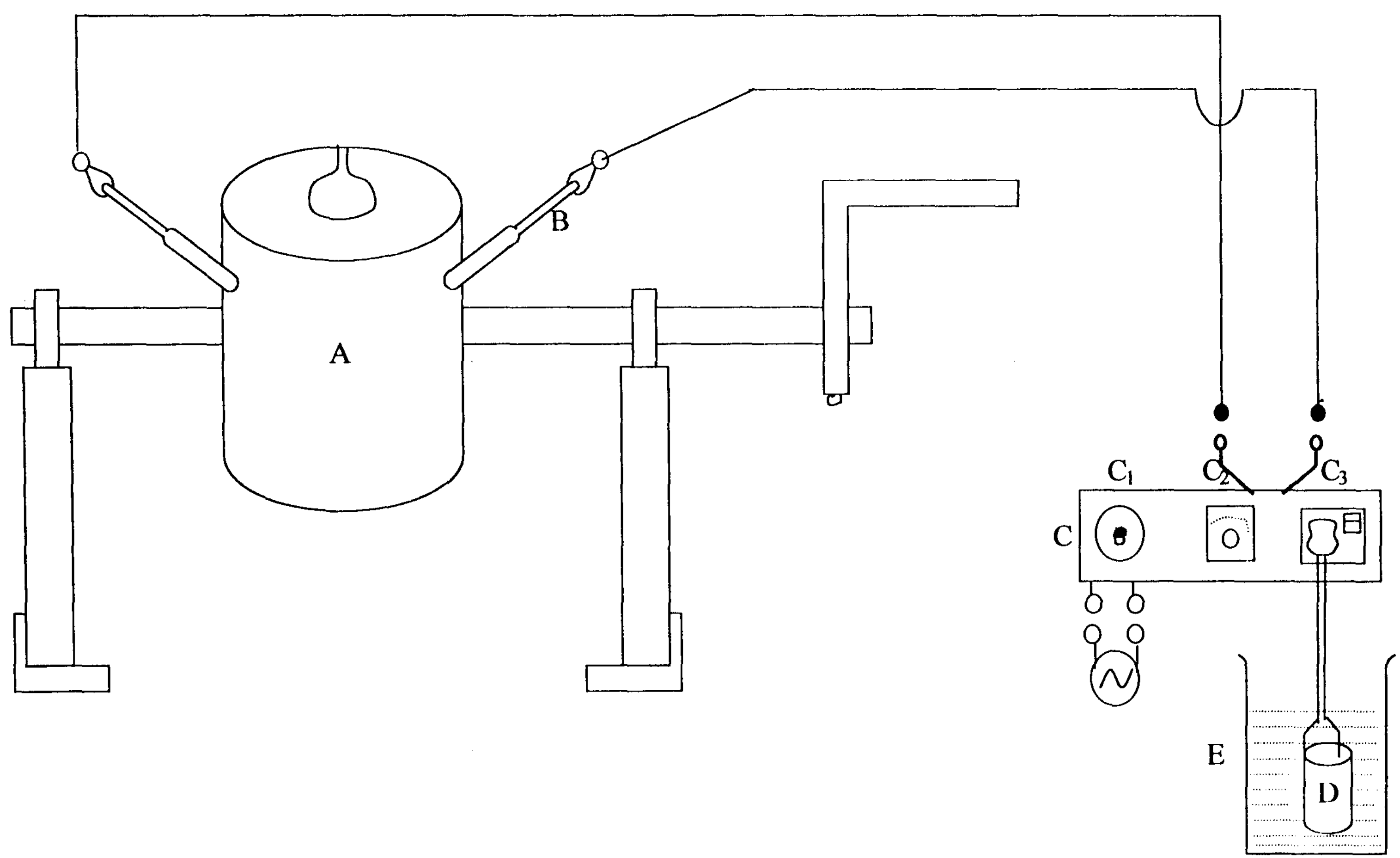


Fig 3.7 Pictorial layout of components of the EAF in operation.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION OF RESULTS

4.1 RESULTS

In the testing of the electric arc furnace, the following observations were made:

- Voltage across the circuit of the EAF when boiler is not in water

  = 213v

- Resistance of circuit boiler = $1.4 \times 10^3 \Omega$

- Current flow along circuit when boiler is not in water

  A= 0.152 Amps.

With the boiler immersed in water the following electrical parameters were recorded.

- Voltage across the circuit = 193v

- Resistance of circuit = $0.02 \times 10^3 \Omega$

- Current flow along circuit when boiler is completely immersed in water

  = 9.65Amps

All important parameters were measured using the digital multimeter.

TEMPERATURE RISE

The temperature in the furnace atmosphere was recorded at regular intervals starting from the zero minute, for 1 hr. Table 4.1 Shows the record of the results taken.

Table 4.1 Results of the Performance test of the E.A.F.

Time in min	°C Temp. of atmosphere	Vol. of water added to boiling waste (Litre)
0	35 °	0.35
10	225 °	0
20	438 °	0.35
30	678 °	0.35
40	891 °	0.50
50	1,109 °	0.50
60	1,106 °	0.70

The higher the current the stronger the arc formed. salt was used to increase the conductivity of the water and thus reduce the resistance of the circuit. The current in the circuit was eventually raised. This principle was used to start the furnace to work.

4.2 DISCUSSION OF RESULTS.

In the analysis of the properties of the charge in solid and fusing stage, it was discovered that the particles in external and deeper layers were subjected to different effects from the surrounding particles. For this reason, the properties in the surface layer of the charge are different from those below in terms of oxidation reaction and time of melt.

Continuos dryness of the roof lid resulted to a decrease in volume which limits the optimum control of the furnace atmosphere. Oxidation of aluminum took place during the attempt to melt it, forming Aluminum oxide. This increased the time taken for aluminum to fuse. With an oxidizing atmosphere existing in the furnace during operation, the process of iron melting inevitably involved the oxidation of iron and impurities making fumes released into the open vent.

Further, the refractory lining of the furnace was gradually eroded during its operation. The load on the refractory lining were attached by a number of factors which includes

1. Physical deterioration through radiation.
2. Chemical deterioration.
3. Thermal shock.
4. Mechanical stressing.

4.3 MAINTENANCE AND SAFETY.

Certain safety operations must be carried out before, during and after the use of the workshop electric arc-furnace.

- It should be noted that the furnace must be operated in well-ventilated area with lot of space to the operator's access.
- Safety gloves should be put on as well as safety goggle for the eye protection against extremely bright light from the arc.
- Water must be readily available to maintain the level of water in the boiler's container.

- To pour out the molten metal, the tilting of the furnace should be done at slow speed rate with the crucible directly below the furnace sprout.
- Refractory wall should relined as soon as wearing becomes obvious.
- All workshop safety rules are applicable in the use of the electric arc-furnace. Protection against the basic source of accidents must be well administered.

These basic sources are:

- Radiation from the arc (infra-red and ultra-voilet).
- Flying sparks or globules.
- Electric shock.
- Burns.

4.4 MATERIALS.

The materials used are those readily available and which are suitable for the job they have to do. They are also appropriate to the environment in which they are used.

Each material have their function and limitations to the choice of use.

The materials used for the construction include:

I. Metal sheet (4 x 4)ft

II. Carbon/graphite electrodes (25 mm dia)

III. 2 metal tins (70 & 90 mm dia)

IV. Wood (80 x 10 mm)

V. Copper cable

VI. Bearing (2)

VII. Metal pipe (2 x 4")

VIII. Angle iron bar (11/2 x 11/2")

IX. Clay

X. Silica oxide

XI. Kaolin

XII. Cement

XIII. Water

XIV. Temperature regulator

XV. Crocodile clips (2)

4.5 COSTING.

The costing of the above specified material is based on the present market price and its steadiness is not guaranteed in any way due to non-stability of the market prices. The table below shows the material specification and cost.

Table 4.2 costing of materials.

S/No	Material	Quantity	Unit cost (₦)	Total cost (₦)
1	mild steel sheet (18'guage)	1	900.	900
2	graphite rod	4	100	400
3	copper cable	10(m)	70	700
4	bearing	2	400	800
5	steel pipe	20(ft)	30	600

Table 4.2 Costing of materials (cont'd)

6	angle iron	20(ft)	30	600
7	angle pipe	4(ft)	175	700
8	clay	10(kg)	50	500
9	cement	10(kg)	60	600
10	kaolin	10(kg)	100	1000
11	temp. regulator	1	300	300
12	crocodile clips	2	100	200
Total				₦7000

4.5.1 Labor cost:

The labor cost is taken as 20% of the material cost for a direct labor.

Therefore,

$$\text{Labour cost, LC} = \frac{\text{material cost x 20}}{100} = \frac{7000 \times 20}{100} = 1400$$

4.5.2 Over head Cost:

This includes other expenses incurred which are different from material and labor cost. This is taken as 10% of the material cost.

$$\text{Over head Cost, O.C.} = \frac{\text{material cost x 10}}{100}$$

$$= \frac{7000 \times 10}{100} = 700$$

4.5.3 Waste Cost:

The waste cost is taken as 5% of total cost : $\frac{7000 \times 5}{100} = 350$

4.5.4 Total Cost:

Total cost = material cost + Labour cost + Overhead cost

= ₦(7000 +1400 + 700 + 350)

= ₦9450.00.

CHAPTER FIVE

5.0 RECOMMENDATION AND CONCLUSION.

5.1 RECOMMENDATION.

The main trend in the development of ferrous metallurgy in the present day workshop and the country in general are increased production of effective types of metal produces with improved metal quality.

Preferable development is expected for the process which can save starting materials fuel and energy, increase labour productivity and improve labour condition.

Simple automatic systems can be deviced to monitor the production process, state and conditions of the equipment. This will save materials and labor expenditure, increase the efficiency and improve quality of melts.

A reliable measurement of metal temperature allows a continuos melting with a very low super heating (not more than 20 °C).

The boiler is another source of energy when in function. The realized steam could also be collected and used to turn small forced turbines for a mechanical energy result.

5.2 CONCLUSION.

Furnace as it was defined in chapter one has more to do with efficiency and reliability. Electric arc furnace is presently the most efficient and reliable in the process of steel making. It is also seen to be the simplest in design and operation. However, it's design and improvement is highly necessary for the technological growth of the workshop and the nation as a whole. There is no doubt that before the end of this century, electric furnaces will replace almost all other furnaces in the existing steel industries. Therefore in view of this, the design of an electric arc furnace is greatly needed.

Since Nigeria as a country is yet to be fully established with steel production, there is no doubt that the melting aggregate for such a plant will be an electric arc furnace. Due to the fact that special alloys are to be used, which can only be use deficiently and to specification via the electric furnace.

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Plate 1: Model Electric Arc Furnace.