MODIFICATION OF FURNACE DESIGN FOR THE PRODUCTION OF COKE FROM PALM KERNEL SHELLS FOR METALLURGICAL PROCESSES

A Project Report

Presented to the

Department of Materials and Metallurgical Engineering

College Of Engineering

Kwame Nkrumah University of Science and Technology, Kumasi

BY

AMOAKO EBENEZER VIFAH

APLERH-DOKU DAVID-DEREK BORTEY

ASARE-BAFFOUR ALBERT

In Partial Fulfillment of the

Requirements for a degree in Bachelor of Science in Metallurgical Engineering

MAY, 2016

DECLARATION

We declare without any reservation that we undertook this project under the supervision herein submitted and that this work has not been submitted anywhere for an award.

………………………..   ………………………..

Amoako Vifah Ebenezer   Date

………………………..   ………………………..

Aplerh – Doku David – Derek Bortey   Date

………………………..   ………………………..

Asare – Baffour Albert   Date

Supervisors

I declare that I personally supervised the students in undertaking the project submitted herein and confirm that they have the permission to present it for assessment.

………………………..   ………………………..

Prof. F.W.Y. Momade   Date

………………………..   ………………………..

Mr. Donald Amrago   Date

ABSTRACT

Palm kernel shells is produced as waste from palm oil and are utilized by blacksmiths after they have been charred to burn off the remaining oils in them. Charred shells have been exposed to temperatures ranging from 900°C to 1200°C and the product has been observed to have properties similar to coke. The products have calorific values in the ranges of 27,000kJ/kg to 32,000kJ/kg which is very similar to the calorific value range of coke which is between 28,000kJ/kg and 31,000kJ/kg. The product remained solid after the firing periods which is averaged to be 120minutes (2hours). It is observed that the higher the firing temperature, the lesser the calorific value.

ACKNOWLEGDEMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND

Coke is solid fuel which is made by heating coal in the absence of air to drive off volatile components. Coke can also be defined as fuel with few impurities and a high carbon content, usually made from coal. It is the solid carbonaceous material derived from destructive distillation of low-ash, low sulfur, bituminous coal. Coke can alternatively be formed naturally. (Wittcoff, 2003)

Local coke production has been found necessary due to the increased need for coke by small scale foundry companies in Ghana. The unavailability of a coal mine for coke production in Ghana has influenced the alternative search for ways of producing coke for foundry purposes in Ghana. In most common uses in Ghana, blacksmith at Suame in Kumasi burn palm kernel shells as fuel to enhance the temperature of the hearth.

Palm kernel shells is a waste material after the production of palm oil. It is hard and burns longer compared to charcoal. With the abundance of Palm Kernel shells in Ghana from Oil Palm Plantations, it can be considered for coke production for use by small scale foundry companies for various metallurgical purposes.

Coke could either exist as Petroleum Coke or Metallurgical Coke based on its properties, uses and how it is made. Metallurgical Coke, which is used by foundry companies in Ghana to convert metal solid material to molten form for other metallurgical purposes must meet some specified requirements. The coke reactivity index (CRI) and Coke Strength after Reaction (CSR) are typical requirements. Coke properties and its performance could be influenced by moisture content, density and coal weathering

Most modern day large scale foundries use electric and induction furnaces due to high temperatures required for melting metals and metal scraps. Such furnaces are quite expensive for small scale foundry companies who have resorted to the use of locally manufactured cupola furnaces. Locally manufactured cupola furnaces use coke as a source of fuel, therefore a source of coke production will be beneficial for such small scale foundries and cost effective.

"Palm Kernel Shell has a higher calorific value compared to regular coke from coal and a high carbon content which are important characteristics for good fuel. The ash content is less than 15% of the total mass when fired."("Palm Kernel Shell - Biomass Renewable Energy," n.d.)

1.1 PROBLEM STATEMENT

Currently in Ghana, there is importation of coke from overseas for fuel in cupola furnaces at a high cost. This is as a result of scarcity in source of coke as a result of shutdown of industries which had coke as waste. Every metallurgical industry desires to have cost effective raw materials therefore creating the need for alternative solutions since coke is a very important raw material for fuel. Producing coke from Palm Kernel Shells has become necessary to help save cost and increase profits of small scale metallurgical industries.

From the previous year, a furnace was designed to solve this problem, but it could not meet its requirements due to its orientation and stoking mechanism and shortcomings with its mechanism of operation. It was considered ineffective, thus creating the need for a modification in design for effective firing.

| (a) | (b) | (c) |

Figure 1.1 (a) Palm kernel shells   (b) A local blacksmith using coal   (c) Cupola Furnace

1.2 AIM

The aim of this project is to modify an already designed furnace for the production of coke from palm kernel for metallurgical processes.

1.2.1 OBJECTIVES

The objective is to produce a better, environmentally safe and lighter user-friendly furnace to produce coke from palm kernel shells.

Specific objectives include:

1. Modify furnace design
2. Modify refractory material in the furnace.
3. Minimize the external temperature of the furnace.
4. Improve the energy efficiency of the furnace.
5. Efficiently produce coke from palm kernel shells with the modified furnace.

1.3 JUSTIFICATION

It was realized from the designed furnace that the bricks used made the entire furnace heavy therefore a lighter refractory material is considered. The external temperatures measured were high and design calculations would be adjusted to minimize it and improve energy efficiency.

Figure 1. 2 (a) Opened previous furnace design   (b) closed old furnace

1.4 METHODOLOGY

As part of achieving our stated objectives, the following will be undertaken:

- Review of relevant literature.
- Design considerations of the furnace

1.5 SCOPE OF STUDY

The scope of study will include:

- Relevant literature in Coke and its Properties, Palm Kernel and Reasons for its use for Coke Production, Castable refractory material and Furnace Designs
- Design of construction
- Testing
- Report Preparation

CHAPTER TWO
LITERATURE REVIEW

2.0 COKE

2.1 DEFINITION OF COKE

Coke is the solid carbonaceous material derived from destructive distillation of low-ash, low sulfur, bituminous coal. In the process, volatile components are driven off resulting in fuel with few impurities and a high carbon content. Coke can also be formed naturally (Wittcoff & Green, 2003).   Figure 2.1 – 2.3 shows a pile of metallurgical coke.

Figure 2. 1 (a) Coal   *(b) Heap of coal*   *(c) Fine coal pile*

2.2 BRIEF HISTORY OF COKE

The earliest history of coke production could be traced back to the 4th Century in ancient China. Coke then was produced for cooking and heating till about the ninth century (Wertime, 1962). By the eleventh century its use became commercial when Chinese ironworkers in the Yellow River Region began to use coke in fueling their furnaces to solve fuel problems in that region. (Mcneil, 1982).

Great Britain also has a history with coke production, patents were granted to some citizens of Great Britain on coke and its use for commercial basis. In 1589 Thomas Proctor and William Peterson acquired a patent for iron and steel making and melting lead with "earth coal, sea-coal, turf and peat". The Dean of York also acquired a patent in 1590 to purify pit coal and get rid of its foul smell. A patent was granted to a company owned by St. John and other knights in the use of

coke for smelting ores and manufacturing metals (A.Hovenac & Skomra, 1991). The method of rendering sea-coal and pit-coal useful as charcoal for burning in houses without producing offensive smells or smoke also gained a patent, this was granted to Sir John Hacket and Octavius de Strada in the year 1627 (Peckham, 1880).

Hugh Plat in 1603, suggested that coal might partially burn so as to blacken the surface in a way comparable to charcoal production from wood. This was never put into practice till about 1642 when coke was used for roasting malt in Derbyshire, Before then, brewers resorted to the use of wood, as a result of uncoked coal producing foul taste to the beer from sulfurous fumes when used in brewing (Nersesian, 2010). Coke use in brewing was seen as an advancement in technology and embraced by England, the coke process which allowed for a lighter roast of the malt led to what by the end of the seventeenth century was called "pale ale" (Peckham, 1880).

In 1709, a coke-fired blast furnace to produce cast iron was established by Abraham Darby I. Coke has a superior crushing strength which introduced increase in height and size of blast furnaces in which coke was used (Cooper, 1993). Before then, iron-making made use of large quantities of charcoal from burnt wood. Coke substitution for charcoal became common as forests reduced drastically in Great Britain. The manufacturing process then was by burning heaps of coal on the ground in a way to expose only the outer layer for burning, leaving the interior of the pile in a carbonized state. To further advance and control the burning process, brick beehive ovens were developed in the 18th Century (Cooper, 1993).

John Wilkinson in 1768, with the aim of advancing coal burning to produce coke built a more practical oven (Wittcoff & Green, 2003). He improved the process by building the coal heaps around a low control chimney built of loose bricks and with openings for combustion gases to enter, which resulted in a higher yield of better coke. Yields increased from about 35% to 65% by the middle of the 19th Century as a result of improved skills in firing, covering and quenching of the heaps. In the 2nd quarter of the 19th century, the Scottish iron industry employed the use of hot blast process in its coalfields and this caused a tremendous expansion in the industry (Beaver, 1951). In later years, between 1802 and 1850, the use of battery beehives in coke production became widely used in West Durham coalfields. In the early years of steam railway locomotives, coke was used as fuel. With its use, a legislation was passed that every locomotive had to consume its own smoke, technically this was unachievable until the introduction of the firebox arch.

The coke production history will be incomplete without the mention of the contributions of the United States of America because in the 1885 there was the construction of the largest string of coke ovens in Pennsylvania by the Rochester and Pittsburgh Coal and Iron Company. (S.B.Elliot, 1896)

Coke's first use in an iron furnace was recorded around 1817 at Isaac Meason's Plumstock puddling furnace and rolling mill in Fayette County (DiCiccio, 1996). Between 1870 and 1905 there was a massive increase of number of beehive ovens from about 200 to almost 31000 which produced nearly 18million tons of coke in Pittsburgh alone.

2.3 TYPES OF COKE

Different types of coke exist, characterized by the variations in formation and composition. The commonly known are metallurgical coke and petroleum coke. Metallurgical coke is produced as a result of destructive distillation of coal in coke ovens, whiles petroleum Coke is a carbonaceous solid material produced from oil refinery cracking processes. Petroleum Coke is further sub-divided into four basic types, namely; needle coke, sponge coke, honeycomb coke and shot coke. These differences are also visible in their microstructures as a result of variations in operating variables and feedstock nature (Ibrahim, 1990).

2.3.1 METALLURGICAL COKE AND ITS USES

Metallurgical Coke is a carbon product made from coal, it is usually refined and produced using extremely high temperatures. Using very good coals produces good coke after the coking process. The quality of coke is influenced by moisture content, density and weathering of coal. (Smith, 2001) This is because it has a high calorific value which is able to produce heat high enough to reach the melting temperature of iron .Metallurgical coke has varied uses in the smelting industry. It is used as fuel since it provides heat for the endothermic requirements of chemical reactions and the melting of slag and metal, it also serves as a chemical reducing agent, because it produces gases for the reduction of iron oxides. It serves as a permeable support, it acts as the only solid material in the furnace that supports the iron bearing burden and provides a permeable matrix necessary for slag and metal to pass down into the hearth and for hot gases to pass upwards into the stack. (Diez, 2002)

2.3.2 PETROLEUM COKE

Petroleum Coke is a carbonaceous solid which is obtained from oil refinery coker units or other cracking processes. It is classified into fuel grade (high sulfur and metals) or anode grade (low sulfur and metals). It is over 90% carbon and emits about 5-10% carbon-dioxide than coal on a per-unit-of-energy basis when burned. Types of Petroleum Coke include: needle coke, honeycomb coke, sponge coke and shot coke (Ibrahim, 1990). Other types of coke exist such as calcined Petroleum Coke which is petroleum coke which has undergone calcination to change its structure for uses such as anode material in aluminium, steel and titanium smelting industries. Marketable coke which is relatively pure carbon is sold as fuel and used in manufacturing dry cells and electrodes. (Ibrahim, 1990)

2.3.3 NEEDLE COKE

Needle coke is a type of petroleum coke used in the manufacture of graphite electrodes for arc furnaces in steel manufacturing industries. Needle Coke can also be called acicular coke (Ibrahim, 1990).

2.3.4 HONEY COMB COKE

Honey comb coke is an intermediate kind of coke, with pores ellipsoidal in shape. Honey comb coke has a lower coefficient of thermal expansion and a lower electrical conductivity in comparison with needle coke (Ibrahim, 1990).

2.3.5 SPONGE COKE AND SHOT COKE

Shot coke and Sponge coke are as well classified under fuel grade coke. Researchers have not been able to accurately identify the mechanism for formation of sponge cake or shot coke. (Ibrahim, 1990).

2.4 SOURCE OF COKE

Coke is a carbon material with high strength produced by coal carbonization at temperatures of up to about 1400K (Diez, 2002). From research coal has been proven to be the source of Metallurgical coke. Petroleum coke has its source from catalytic cracking processes or from oil refinery coker units. Coal has essential properties such as heat content and pure carbon content which have made it the best option in coke production. With respect to the types of coal there is Anthracite coal which has a high carbon content and highest heat values between 31401 KJ/Kg and 36285.6 KJ/Kg. whiles Bituminous coal has a relatively lower carbon content and lower heat values between 19305.8 KJ/Kg and 36285.6KJ/Kg. Bituminous Coal is soft coal which is usually used for metallurgical processes. Anthracite Coal is harder compared to Bituminous Coal with a higher carbon content and energy density, for domestic/industrial uses, including smokeless fuel.

2.4.1 COKE PRODUCTION

Metallurgical coal is heated to about 2000^0F in ovens for about 12-36 hours to complete one cycle. It is then taken out to be either water or air cooled and then stored or directly put into use in a blast furnace (Smith, 2001).

The quality of coke made depends of the quality of the coking coals. Quality coals do not generate high pressure on the coke oven wall and should easily shrink to enable easy removal from the coking oven. Moisture content, density and weathering of coal amongst others influence the properties and performance of coke, according to a report from the American Iron and Steel Institute (Smith, 2001).

2.5 COAL

Coal is a combustible sedimentary rock composed mostly of carbon and hydrocarbons, usually in a swamp environment. It is known to be the most abundant fossil fuel on the planet (M.A.Diez, R.Alvarez, & Bariocanal, 2002). . Fossils are nonrenewable resources. They have been formed million years ago including oil and natural gas. Coal has been used to produce energy both in the form of heat and electricity (Stopes, 1919).

2.5.1 HOW COAL IS FORMED

Over a period of time plant debris accumulated in a swamp environment dies and falls into the swamp. The water of the swamp protects it from decay. Swamp waters are usually deficient in oxygen. Oxygen will react with the plant debris and cause it to decay. The plant debris will persist in a lack of oxygen environment. Any insect and organism that might consume the plant debris on land will not survive well under water in an oxygen deficient environment. The plant debris must be buried after accumulation to form thick layers in mud or sand. They move into the swamp by flooding river and compacts debris and transform it into coal. Coal is formed when dead plant matter is converted into peat, which in turn is converted into lignite then sub-bituminous, after that bituminous and lastly anthracite (Stopes, 1919)

2.5.2 TYPES OF COAL

There are four types of coal, namely peat, lignite, bituminous and anthracite. Coal can vary in composition. Due to the increased pressurization, heat and time there are differences in energy output. The properties will be different as well. Coal is ranked based on how much change that has occurred. The change is known as organic metamorphism (M.A.Diez, R.Alvarez, & Bariocanal, 2002).

2.5.2.1 PEAT

Peat is the first step in coal formation/ it is composed of over 60% organic matter. It serves as a conditioner for soil in making it more able to retain and slowly release water. It is also highly effective absorbent for fuel and oil spills on land and water. Peat contains a lot of water and this makes it have lower heat content or amount of energy. It is soft and brown in colour. When pressure and temperature increases, peat is transformed to lignite (M.A.Diez, R.Alvarez, & Bariocanal, 2002).

2.5.2.2 LIGNITE

Lignite is known to be the lowest rank of coal and still contains high amount of water. It has higher heat content than peat. It makes up almost half of coal reserves. It normally has plant structures. The carbon content is between 60 to 70%. It is very soft and brownish-black in colour with high moisture and ash content having the lowest heating value amongst the four types of coal. It can be used as ornamental stone (M.A.Diez, R.Alvarez, & Bariocanal, 2002).

2.5.2.3 SUB-BITUMINOUS

This is a form of lignite that has gone through organic metamorphism. Through metamorphism, some of the oxygen and hydrogen in the coal are driven off. This produces coal with higher carbon content of 71% -77% on a dry ash-free basis.

2.5.2.4 BITUMINOUS

Bituminous is known to be the most abundant rank of coal of about 50% and has carbon content between 77%-87% on dry ash-free basis with a higher heating value than lignite and sub-bituminous coal. It is formed when sub-bituminous undergoes organic metamorphism. It is a soft type of coal.

2.5.2.5 ANTHRACITE

Anthracite has carbon content of over 87% on a dry ash-free basis with the highest heating value per ton on mineral matter free basis. It is normally subdivided into semi-anthracite, anthracite and meta-anthracite on the basis of carbon content. It is a hard coal. It is the highest grade coal and dark black in color with light weight and little water content.

2.6 PALM KERNEL SHELL

The oil palm tree is one of the greatest economic assets for every nation. Its importance is realized and potentials fully exploited. Its products include palm oil, palm kernel oil and palm kernel cake amongst other products. All parts of the oil palm tree are beneficial and of economic value. Palm

kernel nut is a by-product from the milling of palm oil and can be sourced from oil palm plantations. The nuts are gathered in small quantities from farmers after extracting oil from the fruits in villages or oil palm producing companies. It is a seasonal product normally available during raining season. The palm kernel shells are the outer protective layer of the palm kernel nut, this shells have properties similar to coal and therefore allowing for it to be an alternative option in coke production (www.melcify.wordpress.com)

Palm kernel shell has a wide usage in industries. It is gotten from oil palm fruit which has gone through the palm oil process, the kernel is separated and the kernel oil further distilled for other uses. The shell has specific properties which make it possible for its use in the steel mills, biomass power plants, power plants, and some chemical plants.

Some of the notable properties include heat energy or calorific value which is greater than 4.000kcal/kg, inherent moisture which is supposed to be less than 20%, ash content less than 15% by mass, size of 4.20mm and, foreign materials less than 2%(www.melcify.wordpress.com).

In early years palm kernel was buried underneath the land for it to become black colour palm kernel compost without any economic value. It later gained usage as a boiler fuel supplementing the fibre which is used as primary fuel and also in biomass production. The compost served as an organic fertilizer but because of the hard shell, it always took a very long time to convert totally to organic fertilizer. (www.jonnestorconsultancylimited.com).

Due to the high calorific value of palm kernel shell, it has been one of the key biomass materials that can be used to replace fossil fuel for steam power plant. Carbonized palm kernel shell can be used for charcoal which can be pressed into bio-fuel briquette, and sold for family use. Carbonized palm kernel shell has been used in the processing of activated carbon which is used in liquid and gaseous phase filtration or adsorption. Palm kernel shell has a high dry matter content greater than 80% making it a good fuel for the boilers as it generates low amounts of ash and low potassium and chlorine content, which will lead to less ash agglomeration.

Further studies and research also revealed that palm kernel shell could be used as replacement for coarse aggregate in asphalt concrete. Furthermore, it is studied that the shells can serve as feedstock for pyrolysis. The extent to which this could happen is not known, however the high

lignin content in palm kernel shells indicates that shells are less suitable as raw material for fermentation (www.bioenergyconsult.com/trends-palm-kernel-shells).

2.7 COMPARISON OF PALM KERNEL SHELLS WITH METALLURGICAL COAL

Wood charcoal was used in the iron production up to about 1750. It was very efficient yet expensive to use in steel making. A higher amount of wood was to be used to get just small kilogram of steel. This made regular coal come into use but it also did not work well due to impurities in the coal, especially sulphur. In getting pure carbon with high calorific value to be called 'coke', the coal is passed through destructive distillation method to remove majority of the impurities out of the coal. This kind of coke is approved to be used as metallurgical coke. Formerly coke has contributed to increase in greenhouse gases in the atmosphere from 280 ppm to 390 ppm, which caused Global Warming. Charcoal was formerly used as fuel but upon further research palm kernel shell charcoal was proven to be a better fuel in electric arc furnaces. The palm kernel shell charcoal outperformed the coal because of the low sulphur and ash content and high calorific value and cheaper to acquire as well. Calorific value is the most important characteristics of a good fuel. The net calorific value depends mostly on a materials combustible components, ash and moisture content. The net calorific value of Palm Kernel shells is greater than 4.000kcal/kg as against that of Bituminous coal which is low between 4.048kcal/kg-5,536kcal/kg, Anthracite Coal which is 7,738kcal/kg-8,095kcal/kg. Moisture content of palm kernel shells has a range between 7.7-25.1% by mass. The ash residue from combustion is not considered hazardous waste. Ash is between the ranges of 1.3% to 10.8% by dry mass. Particle size is also necessary in increasing calorific value. A range of between 4-20mm is required. The dust is dumped without any environmental problem. Palm kernel shell charcoal is used also as an auxiliary energy with ratio 25kg of palm kernel shell charcoal for 1 tonne steel.

Palm kernel shell is also used as a reducing agent in steelmaking. A very high carbon content is needed and the carbon will reduce oxygen from ore in a very high temperature environment. Therefore the carbon content is mostly above 80%. The palm kernel shell is also used as a carburizer in steelmaking. Iron or steel absorbs carbon liberated when heat treated in the presence of a carbon bearing material such as palm kernel shell charcoal with the notion of making the metal

13

harder. Granulated powder form of size range 1-5 mm of palm kernel shell charcoal with high fixed-carbon is required. (supremecarbon.com/metalbriq.htm).

Coal Analysis is a technique used to determine the appropriate measures of coal for coking and for power generation. The various forms of coal which include lignite, bituminous coal, and anthracite coal all have varied parameters controlled by moisture, volatility and amount of carbon. Research has shown that coal is mined wet, thereby causing moisture content to play an important role in properties of coal. Volatility of coal is controlled under certain conditions between the ranges $900 \pm 5°C (1650 \pm 10°F)$ for 7minutes. Volatility is also an important property in determining coal quality. Ash content of coal is also another important property, this refers to the non-combustible residue after coal is burnt. This includes the whole quantity of material after sulphur, oxygen and water have been burnt off. Ash content may be determined as air dried basis and on oven dried basis. After the volatile materials have been burnt off, the carbon content of the coal is known as the fixed carbon gives an estimate of the amount of coke that will be yielded from a sample of coal. This is determined by removing mass of volatiles determined by a volatility test. Coal is generally used in furnaces and coking ovens at a certain size. This is called the particle size and allows for the determination of the crushability of coal. (Group, 1984)

2.8 COKING FURNACE DESIGNS

A furnace is a device used for high temperature heating. The name is of Greek origin from the word "*fornax*" which means oven. The name is sometimes used to refer to household heating systems and a kiln. The term also refers to direct fired heaters (Metallurgical furnaces) used to provide heat for chemical reactions for "cracking" - the breakdown of complex organic molecules or hydrocarbons into simpler ones.

2.8.1 TYPES OF FURNACES

The classification of furnaces can be made according to their function, heating duty, type of fuel and the method of introducing combustion air. Several types of specialized furnaces are available for metallurgical purposes. The list includes the popular blast furnace used in the reduction of iron ore to pig iron. The reverberatory furnace, bessemer converter, open hearth furnace, basic oxygen

14

furnace, electric arc furnace, electric induction furnace and the reheating are all considered as the steel making furnaces. There are other types used for remelting and reheating in foundries as well as vacuum furnaces.

The term reverberatory is generically used to imply rebounding or reflecting. The reverberatory furnace isolates the material being processed from contact with the fuel used. However, there is contact with the combustion gases. The disadvantage of using this furnace is that it is less efficient because the separation of the burning fuel and the material. (Lida, 1980)

The electric arc furnace heats materials by electric arcs. The operation is similar to the Induction Furnace but in this case, the charge material is exposed directly to the arcs while current passes through the material. (Boulet et al, 2003)

The induction furnace is an electrical furnace in which heat is applied by induction heating of metals. The furnace is desired because it is clean, energy efficient and it has a well-controllable melting process. There is no combustion or arcs in this furnace.

Forges are types of hearth (a brick or stone-lined fireplace, they are made with or without an oven) used for heating metals for easier shaping. Coal, coke or charcoal is used as source of fuel in the forge. There are slight variations in the construction of forges yet the basic design remains uncompromised.

The furnace type considered for the production of coke from coal in foundries and steel industries is the cupola furnace. Cupolas are usually used in the production of iron, coke and other metallurgical products. An advantage of the cupola is that, it can be used several times to produce the desired product (Kirk, 1899)

The general construction of the cupola is cylindrical shape of varying sizes usually arranged in a vertically with supporting legs. A door is fitted at the base to serve as an outlet for the desired product after heating. In the arrangement, the outer component is usually made of steel with an internal layer of refractory material which is commonly made from brick. An extra refractory plastic layer can be included to reduce external temperatures sometimes to the point where it is safe to touch during operation.

2.8.2 FURNACE DESIGN

The geometry of the furnace varies from cylindrical model to conical, rectangular and other complex shapes with an interior refractory material around the walls for insulation. A secondary refractory material thinner than the internal refractory take some thickness around the furnace to make it safe to touch during operation at high temperatures.

A door is fitted at a vantage position to trap the heat in the furnace and also to allow easy charging and removal of the final product. The position the door depends on the type, size and other design parameters.

The furnace may have a stand and can be fitted horizontally or vertically to suit desired configuration. Caution symbols and messages are placed around the operation area to prevent injury to operators. The conversion of palm kernel shells into coke in a cupola furnace can be achieved in a similar operation of a "drum" furnace with the right construction and proper selection of the refractory materials.

Some furnace types of different designs and with different refractory materials are show in figures 2.3.1 to 2.3.4.

Figure 2. 2 (a) Cylindrical furnace (b) Opened furnace (c) Closed furnace (d) Vertical furnace

2.8.3 REFRACTORIES USED IN FURNACES

A refractory according to the ASTM standard definition (ASTM C71) is a non-metallic material having those chemical and physical properties that make them applicable for structures, or as components of systems that are exposed to environments above 811K (538°C).

Refractories are heat-resistant materials that constitute the linings for high temperature furnaces, furnaces and other processing units. In addition to being resistant to thermal stress and other physical phenomena induced by heat, refractories must withstand physical wear and corrosion by chemical agents.

Refractories can be classified on chemical composition as acidic neutral or basic, method of manufacture, physical form according to their application and fusion temperature.

For the 'drum' furnace considerations, castable refractories are used. Castable refractories are made from carefully set portions of fine and coarse refractory grains with suitable binders for strong ceramic bonds.

The functions of refractories can be summed in four ways. The first is acting as a thermal media between a hot medium and the walls of a container. The second is protection of the walls by preventing the erosion of the walls by the circulating hot medium. The provision of a chemical protective barrier against corrosion is the third function and finally they retain the heat generated in the furnace (thermal insulation)

2.8.4 COMPOSITION OF REFRACTORIES.

On the chemical classification, acidic, neutral and basic refractories are discussed. The acidic refractories are those that can be attacked by basic slags. They are preferred for use in areas where the slag and atmosphere are either acidic. An example includes silica (SiO_2) composition.

Neutral refractories are chemically stable in both acidic and basic media and can be used in any of such conditions. An example is a refractory made of carbon graphite, (Diez et al. 2002).

Basic refractories are stable to alkaline slags, fumes and atmosphere at elevated temperatures but are attacked by acidic slags. Basic refractories are made mostly from magnesia (MgO) and dolomite (CaO*MgO) constituents.

The classification based on physical form can be sorted as shaped and unshaped refractories. The shaped types gets to the end user in fixed shapes whereas the unshaped do not come in any predetermined shapes. Unshaped refractories are also known as monolithic refractories.

To sum it all up the choice of a refractory material is dependent on the following factors: the area of application, the type of refractory, operating conditions, quality of the refractory and the workmanship of the installer, (Blond et al. 2007).

Figure 2. 3 (a) Furnace refractory   (b) Different types of refractory shapes

2.8.5 PROPERTIES OF REFRACTORIES

The selection of refractories for any purpose is largely dependent on the properties of the refractory material. Some of the important properties considered are melting point, porosity, bulk density, creep at high temperature and volume stability, expansion and shrinkage at high temperature.

The melting point of a material determines the material's ability to withstand high temperature without any change to its chemical and physical properties. The melting point determines the right environment and the maximum temperature to use the material.

Porosity is a measure of the effective open pore space in the refractory into which the molten metal, slag, fluxes, vapors etc. can penetrate and thereby contribute to the degradation of the structure.

The porosity of refractory is expressed as the average percentage of open pore space in the overall refractory volume. Low porosity refractories are preferred to highly porous ones. This is due to the reason that high porosity materials retain a lot of air which does not conduct heat. They are likely to shrink under high temperatures. High porosity refractory materials are usually not chosen to be in contact with molten slag as these can 'penetrate' their surfaces. (Bakker 1993)

Creep is a time dependent property which determines the deformation in a given time and at a given temperature by a material under stress. The refractory materials are normally exposed to extreme temperatures (including repeated thermal cycling) and constant corrosion from very hot liquids and gases. The material's ability to overcome all such conditions for a given application is considered. (Diez et al. 2002).

The thermal conductivity of a material is the quantity of heat that can flow through a unit surface area per unit time. Materials of high thermal conductivity are used in applications where good heat transfer is required such as coke oven walls. On the other hand, materials of low thermal conductivity are preferred in industrial applications where heat conservation is essential.

2.8.6 FUEL USED IN FURNACES

The fuel used in the furnace can be supplied by burning fuel, electricity as used in an electric arc furnace or by induction heating as used in induction furnaces.

The various fuels used to charge the blast furnace are; metallurgical coke, natural gas, a liquid mixture of oil and coal in slurry form, sinters and additions of gaseous fuels through stack injection.

CHAPTER THREE
MATERIALS AND METHODOLOGY

3.1 INTRODUCTION

The chapter introduces the various materials, equipment and tools as well as the methods used in the stages of the construction of the furnace. It elaborates on the procedures used and how everything was put together to arrive at the full construction of the furnace. The chapter concludes on the trial testing of the modified furnace design and the safety measures taken at all stages of the construction and firing.

Outline of plan for the construction

- Measure and cut out the lid
- Make glass lining in and out
- Make hinge and rest bar
- Create burner hole

- Castable refractory lining
- Brick layer for crucible seat
- Make exhaust from clay
- Make gas connectors

3.2 DESIGN OF NEW FURNACE

3.2.1 DESIGN ASSUMPTIONS

We considered changing the orientation of the furnace from its initial horizontal position to a vertical position, this was to help with effective stoking and complete burning of palm kernel shells. Also we considered using much lighter refractory linings with similar refractory properties to help make the use of the furnace more comfortable. Working height of the furnace was considered to make furnace user friendly. Palm Kernel shells was to be charged in a crucible to prevent direct contact of material with flame. Crucible should be able to withstand thermal shock and conduct heat easily and also be able to withstand temperatures of about 1400°C.

The figure below shows the design model chosen for the furnace. The outer layer shows the drum from which the furnace is made, the next layer represents the glass wool used for insulation with a thickness of about 1" (0.0254m) and the third layer represents the castable refractory with a

thickness of about 2" (0.0508m). The central portion shows the crucible placed inside the furnace with some space around it to allow for circulation of air and heat during firing.

(a)   (b)

Figure 3. 1 (a) Drawing of the base of the cylinder showing layers of refractories (b) Drawing of the lid of the cylinder showing layers of refractories

Figure 3. 2 above is the two-dimensional view of the furnace with their corresponding dimensions in inches

3.2.2 DESIGN CALCULATIONS

The thicknesses from the dimensions of the furnace are used in making the following calculation on the heat conductivities.

Drum radius = 11.5" (0.2921m).

Glass Fibre thickness = 1" (0.0254m).

Castable refractory thickness = 2" (0.0508m)

Surface Area of Drum = $2\pi rl = 2\times\pi\times0.2921\times0.635m$ = **1.165m²**

Surface Area with Glass Fibre thickness = $2\times\pi\times0.266\times0.635m$ = **1.064m²** ; r = 10.5" (0.2667m).

Surface Area with Castable Refractory = $2\times\pi\times0.2159\times0.635m$ = **0.8614m²** ; r = 8.5" (0.2159).

3.2.2.1 Mass flow rate of air

Where T_o = furnace temperature, T_1 = temperature at refractory surface, h_{air} = 5W/m²/K²,

Cp_{air} = 1.006 kJ/kg.K

Surface Area $\times h_{air}$ = m $\times$ Cp_{air} $\times$ T

1.165×5 = m×1.006 × (1473-323)

m = **4.35×10⁻⁶ kg**

3.2.2.2 Total Amount of Heat

Total Q_0 = (heat in inner container) = Q_{air} + Q_{drum} + $Q_{castable}$ + $Q_{glassfibre}$

Q_{air} = h (T_a-T_b) = 5(1473-523) = **4750kJ**

$Q_{castable}$ = A$\times$ kdT/dr = 0.258 × (1473/0.2159)×0.8614 = **1516.26 kJ**

$Q_{glassfibre} = 0.04 \times (1673\text{-}1473/0.2667) \times 1.064 = \textbf{31.9 kJ}$

$Q_{drum} = 21 \times (50/0.2921) \times 1.1654 = \textbf{4189 kJ}$

Q = 4750 + 1516.26 + 31.9 + 4189

Q = 10,487 kJ

3.3 MATERIALS

The essential materials required for the project are briefly enlisted

- Empty Oil barrel (drum)
- Glass wool
- Fired brick
- Castable refractory
- LPG gas cylinder

- LPG burner
- Metallic hinge
- Air blower
- Welding electrode (gauge 10)
- Angle irons

3.4 CONSTRUCTION

3.4.1 METHODOLOGY

The methodology was planned with an activity chart that was scheduled to carry out the various stages of the project in sequence. To successfully complete the segmented activities, an activity chart was made and crossed out as the work progressed. The activity chart is shown in table 3.1.

Table 3.1. Crossed activity chart

Months	January				February				March				April				May	
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Activity																		
Presentation				/		/		/						/				/
Furnace designs	/	/	/	/														
Purchase drum					/													
Purchase refractory								/										
Purchase crucible							/											
Purchase glass wool								/										
Purchase hinge						/												
Purchase angle iron						/												
Purchase burner													/					
Cutting of lid					/													
Lining with glass wool										/								
Make burner hole											/							
Fix angle irons							/											
Refractory lining											/							
Make exhaust									/									
Purchase gas connectors													/					
Firings														/	/	/	/	

24

3.4.2 MEASUREMENT AND CUTTING OF THE FURNACE

The dimensions of the furnace was taken with a tape measure to determine the appropriate length to cut to make the gliding lid. The considerations made in the calculations were dimensions of the crucible and the dimensions. The cut surfaces were rough and was filed off with a metal file. The internal surface of the drum was washed with soapy water and rinsed to clean the oil stained in it. The furnace used was 35" long and 25" in diameter. 10" was cut out to be the lid portion after calculating the base and height of the crucible. It was determined that the sides of the furnace will be lined with 1" of glass wool and 2" of castable refractory for both the base and lid portions. The base and lid were filled with 2.5" of castable material.

3.4.3 ANGLE IRONS

The angle iron was cut to cover the entire circumference of the drum. The cut pieces were rolled (inside rolling) by a rolling machine to attain a diameter equivalent to the drum diameter. The rolling creates ripples in the iron.

To remedy the effect to attain a smooth flat surface, the long curved iron was cut into smaller pieces and for each small piece, small portions of the iron are sawed off in V-shapes to allow easy curving. To attain the required shapes, some the cut edges were grinded with a grinding machine. This resulted in a decrease in the actual expected value of the drum radius (practical radius).

The angle irons used were 2" on both sides. To attain a smooth curve around the circumference of the base and lid, they were cut into smaller sections after being rolled. Grooves were made in the small section to allow for easy bending before they were welded to the drum.

3.4.4 WELDING

The cut angle irons were welded to the sides of the drum and the weld joints grinded to create a smooth surface. The hinges were welded to both the bottom and lid. The top portion of the hinge was made to be removable as the base is left to be permanent.

A simple stand of 10" was made at the base of the drum with four rectangular rods. The rods are welded to the base and connected at the base for reinforcement. A rest table was welded separate from the furnace to provide additional support for the lid to rest on when it is rotated (opened). The drum used for the furnace was thin and made welding difficult, the electrode used was gauge 12. The welded sections were either grinded or filed to attain smooth surfaces.

3.4.5 GLASS WOOL (FIBER BLANKET)

To attach the glass wool to the sides of the drum, spikes were to be welded to the sides at randomly spaced intervals to hold the glass wool in place. The other alternative was to make screws to hold them. The glass wool was fixed to the screws for both the bottom and the lid. The screws were alternated such that some were made shorter to hold only the glass wool to the drum while some were made longer (an inch) to extend into the area of the Castable refractory.

The glass wool remained in place secured by the screws used to hold them.

Figure 3. 3 Glass wool held in place by screws.

3.4.6 BURNER AND BLOWER INLET

The exact position of the burner and blower was marked on the drum and cut out gradually with a round saw. The space in the glass wool was also cut out. The hole was covered prior to the filling of the Castable refractory. A small inlet was left out for a thermocouple to be inserted during operation to calculate the internal temperatures during operation.

The burner inlet was carefully constructed by cutting out the desired hole, a diameter of 2.5". The hole was accounted for during the placing of the glass wool and the castable material. The hole was sealed during the casting to prevent the cutting out the hole after the material had fully set.

3.4.7 CASTABLE REFRACTORY

The dimension needed for the Castable refractory was calculated and a light-weight metal was cut and rolled to the required dimension of the space between the glass wool and the castable material.

The powdered castable refractory was mixed with water into a paste and gently poured into both the base and the lid portions. The initial pouring was done for the base portions. The light weight metal was fixed in the center of the drum allowing a thin space between itself and the glass wool and then, the sides were filled with the castable refractory paste. The paste was rammed gently to ensure that every portion was filled. The paste was allowed to dry on its own overnight.

The furnace was allowed to dry and inspected for any deviations from the plan before it was put to testing. The castable was mixed with water to form a paste for the molding process. The space required was attained by making a round light metal sheet of diameter 16" and placing it in the

center of the drum. The castable paste were placed around the light metal and rammed gently to make it compact.

<div align="center">(a)   (b)</div>

Figure 3.4 (a) The freshly molded furnace (base) with the round light metal (b) Dried furnace

3.4.8 THERMOCOUPLE SLOT

A small hole was drilled at one side of the lid portion to accommodate the thermocouple probing section. The lid portion was chosen because it was assumed that the heat from the base will gradually rise to the top and thereby the lid portion will indicate uniform temperature throughout the furnace.

3.4.9 CLAY GRAPHITE CRUCIBLE

The clay graphite crucible was selected because it can withstand high temperature firings and can stand sharp thermal shocks in the case of lifting it res-hot from a furnace to atmospheric temperature without any damage. The crucible was fitted with a fitting lid to preserve the content from any contamination.

3.5 RUN ONE

Run one was conducted as a trial firing to determine the performance of the furnace. In this case, an amount of 4.863kg charred palm kernel shells was measured into the clay-graphite crucible and firing was done at 1200°C for 192 minutes, the final product was solid but there was mass reduction of 2.236kg in the sample.

The crucible was not used in this instance and the lid of the furnace was removed. The testing was carried out for about 15 minutes and then the empty crucible was introduced into the burning chamber and the furnace lid was placed on it for another 20 minutes of firing.

During the period, the gas nozzle, blower, and flame were all gradually adjusted to acquire the best position of the burner for smooth circulation of the flame throughout the burning chamber.

Run One parameters

Date: 21st April 2016

Start time 10:30 for preheating. Temperature reached: 430°C

Time: 10:55am

Atmospheric temperature: 36 °C

LPG Cylinder nozzle operated at maximum pressure.

Gas and blower nozzles were operated at almost full capacity.

Initial mass of run one 1: 4.863 kg   Results: change in mass% $= \frac{4.863-2.2627}{4.863} \times 100\%$

Final mass of run one 1: 2.627 kg $=53.8\%$

The results of Run One; the furnace temperature profile and cooling profile are shown in figure 4.2-4.3. The product of firing is shown on figure 4.1. In order to validate the product, samples were sent for calorific value testing.

The furnace temperature and cooling profiles for the Run 2, 3 and 4 are presented in figures 4.4-4.8. It is interesting to note that the wall temperature of the furnace was around 61-73^{0}C during operation and only went up when the furnace was stopped.

It is imperative to mention that the castable lining of the completed furnace did not merge perfectly as expected because there was insufficient castable material remaining. This contributed to excessive heat losses around the lid during the firing which was observed by the external temperature readings.

3.6 PRODUCTION OF COKE

After the initial testing of the furnace, an amount of 4.654kg of palm kernel charcoal was measured into the clay-graphite crucible and furnace fired. Table 3.2 shows the conditions for firing. A third run of the furnace was conducted using different amount of palm kernel charcoal with temperature reading 1073°C.

Table 3. 2 Condition used in running the furnace

	Run 1	Run 2	Run 3	Run 4
Time Started	10:30am	4:00pm	1:30pm	10:40am
Humidity	–	–	–	–
Atmospheric Temperature	36°C	34°C	37°C	28°C
Initial Mass of Charred palm kernel shells	4.863kg	4.654kg	4.841kg	5.189kg
Final temperature	1200°C	966°C	1073°C	1073°C

Observations made on the LPG cylinder during the firing.

(a)   (b)

Figure 3.5 (a) Frozen LPG cylinder   (b) Tilted frozen LPG

The figure above shows a frozen cylinder, according to Gay-Lussac's law which states that pressure is inversely proportional to temperature. The gas in the cylinder is stored under pressure, with time the heat generated whiles the gas was placed under pressure dissipates, as the gas is used up, the pressure in the cylinder reduces thus causing a reduction in temperature. Reduction in temperature then causes the freezing.

Run two parameters

Date: 22nd April, 2016 (Run Two)

PM device turned on at 3: 45

Furnace started at 4:00 pm

Relative humidity

Atmospheric temperature 34°C

Final mass of sample 2: 2.627kg   Results: change in mass% $= \frac{4.654 - 2.2627}{4.654} \times 100\%$

Initial mass of sample 2: 4.654Kg   = 43.6%

LPG cylinder tilted at 7:25pm

Run three parameters

Date: 29th April, 2016

Furnace started at 1:30pm

Relative humidity

Atmospheric temperature 37°C

Initial mass of sample 3: 4.841Kg   Results: change in mass% $= \frac{4.841-2.775}{4.841} \times 100\%$

Final mass of sample 3: 2.775kg   = 42.7%

Run four parameters

Date: May 7, 2016

PM device turned on at 10:00

Furnace started at 10:40

Relative humidity

Atmospheric temperature 28^{0}C

Initial mass of sample 4: 5.189 Kg   Results: change in mass% $= \frac{5.189-2.900}{5.189} \times 100\%$

Final mass of sample 4: 2.900 kg   = 44.1%

3.7 SAFETY

The safety measures applied includes the wearing of nose masks during the cutting of the glass

wool and the mixing of the castable powder. Hand gloves were worn to prevent direct contact

with the glass wool. Personal protective clothing were worn throughout the manufacturing

stages. A fire extinguisher was close by during the run firings as a safety precaution. The testing was carried out away from combustible materials.

Figure 3.6 Fire extinguisher close to the firing area.

CHAPTER FOUR
RESULTS AND DISCUSIONS

4.0 FIRING AND COOLING RESULTS

Below is the table of recorded data as firing was taking place.

Table 4.1 Firing temperature readings for run one

Time (Actual)	Time (minutes)	Furnace (°C)	External (°C)	Observations
11:00	0	430		
11:25	25	571		
11:42	42	757		
12:05	65	825		
12:15	75	889		
12:25	85	941	60 – 73	
12:35	95	1000	61 – 80	
12:45	105	990		LPG cylinder surface froze.
12:55	115	1002	61 – 70	
13:05	125	1036		
13:15	135	1079		
13:25	145	1120		
13:35	155	1152		
13:45	165	1185		
13:55	175	1201		
14:02	182	1198		
14:10	192	1200	100-105	

Table 4.1 shows the temperature data taken during the firing of the palm kernel shells in the

furnace. The remarks show that at about 100 minutes of firing, reaching 990°C the LPG cylinder

froze. This is attributed to the rapid change in the internal and external temperatures of the cylinder.

To ensure smooth flow of the gas into the burning chamber, the cylinder is tilted periodically.

The gas flame, and blower were turned off at 14:10 and furnace cooling temperatures were recorded and tabulated in Table 4.2

Table 4.2 Cooling temperature readings for run one

Time(actual)	Time(minutes)	Temperature(°C)	Remarks
14:20	0	972	The material is allowed to cool gradually in the furnace
14:30	10	892	
14:40	20	832	External temperature ranges between 100 and 105 degrees on the surface of the furnace
14:50	30	777	
15:00	40	729	
15:10	50	693	
15:20	60	648	
15:30	70	597	
15:40	80	585	
15:50	90	551	
16:00	100	528	
16:10	110	491	
16:20	120	455	
16:30	130	450	
16:40	140	330	Lid is opened for cooling
16:50	150	301	

The furnace was fixed around the lid with a paste made from powdered burnt bricks, quarry dust and a little portion of cement to fill up the portions that were not merging smoothly. The fixing produced notable changes in the external temperatures observed.

Table 4. 3 Firing temperature readings for Run two

Time(actual)	Time(minutes)	Temperature	External	Remarks
4:20	0	610	40 -41	
4:30	10	690		
4:40	20	730		Furnace goes out due to power cut
4:50	30	782	60 -65	
5:00	40	858		power cut
5:10	50	853		
5:20	60	884		
5:30	70	964		
5:40	80	940	60 -67	
5:50	90	907		
6:00	100	882		Blower and gas nozzles adjusted
6:10	110	885		Gas pressure and blower is maximized
6:20	120	872		
6:30	130	938		
6:40	140	955		
6:50	150	966		
7:00	160	887		

The cooling graph is not recorded for sample 2 because there was a downpour of rain during the time. The furnace is covered and no temperature readings are taken.

Table 4. 4 Firing temperature readings for Run three

Time(actual)	Time(minutes)	Temperature	External	Remarks
2:00	0	774		
2:10	10	845		
2:20	20	886		
2:30	30	829		Power cut
2:40	40	790		LPG cylinder changed
2:50	50	730		
3:00	60	964		
3:10	70	958		Power cut
3:20	80	1014		
3:30	90	1073		

Table 4. 5 Cooling temperature readings for run three

Time	Time (minutes)	Temperature
3:40	0	761
3:50	10	668
4:00	20	641
4:10	30	568
4:20	40	525
4:30	50	487
4:40	60	459
4:50	70	422
5:00	80	390
5:10	90	370
5:20	100	350
5:30	110	320

Table 4.6 Firing temperature readings for run four

Time (actual)	Time (minutes)	Temperature	External	Remarks
10:50	0	703	28	
11:00	10	792		
11:10	20	905		Nozzles adjusted to reduce flame intensity
11:20	30	920	40	LPG cylinder freezing
11:30	40	907		LPG nozzle opened to max
11:40	50	860		LPG cylinder is tilted
11:50	60	931		LPG cylinder is tilted to freeze sides
12:00	70	985	60	
12:10	80	1040		
12:20	90	1073		
12:30	100	1048		Furnace is turned off

Table 4.7 Cooling temperature readings

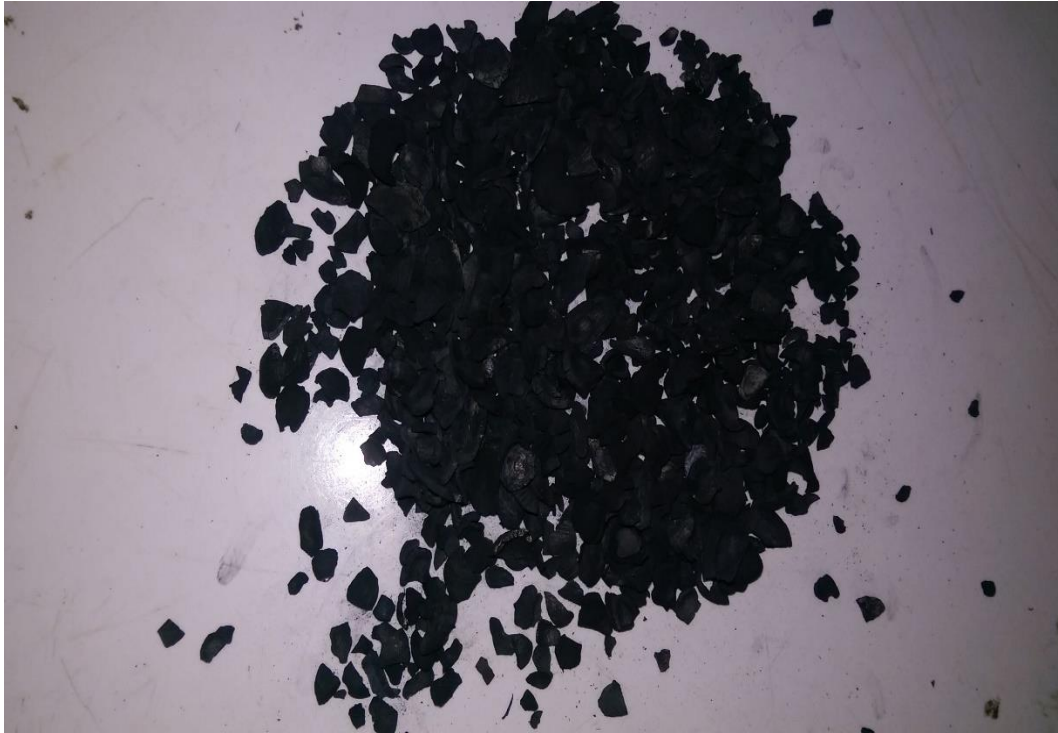| Time (Actual)	Time (minutes)	Temperature
12:30	0	1048
12:40	10	775
12:50	20	695
1:00	30	613
1:10	40	580
1:20	50	525
1:30	60	487
1:40	70	460
1:50	80	425
2:00	90	392
2:10	100	370

4.1 PRODUCT OF FIRING

Figure 4. 1 Fired palm kernel shells (final product)

It is important to note how long the furnace was kept at the highest temperature, for this reason a temperature-time graph was constructed.

The temperature-time graph was constructed for all four run firings showing their graph of firing temperature and cooling temperature.
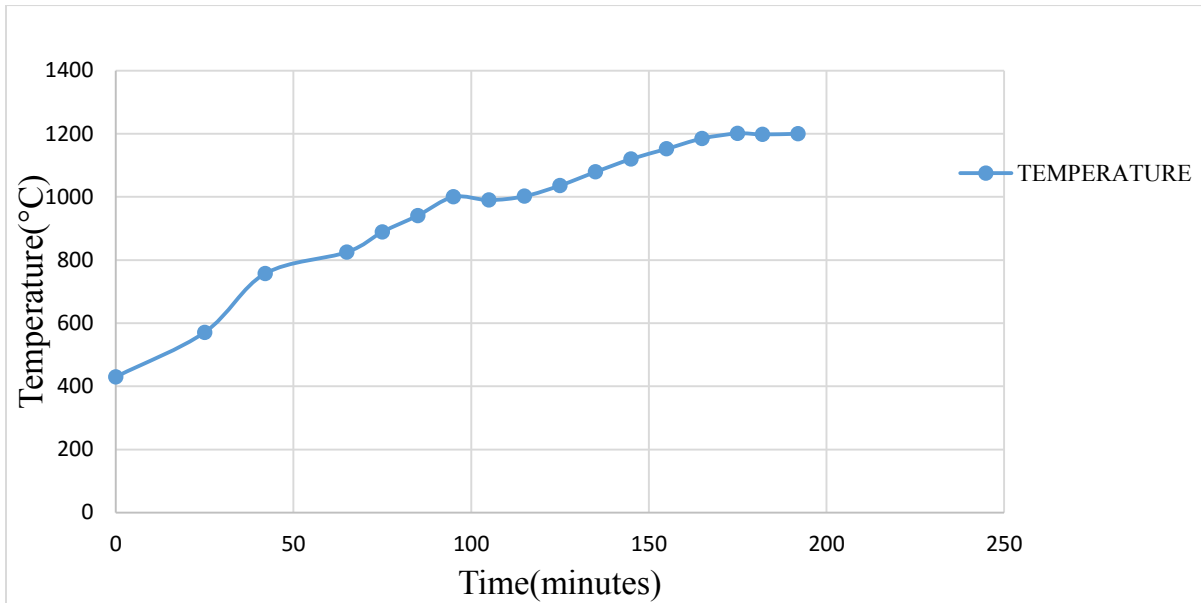
Run one

Figure 4.2 Temperature time graph of firing
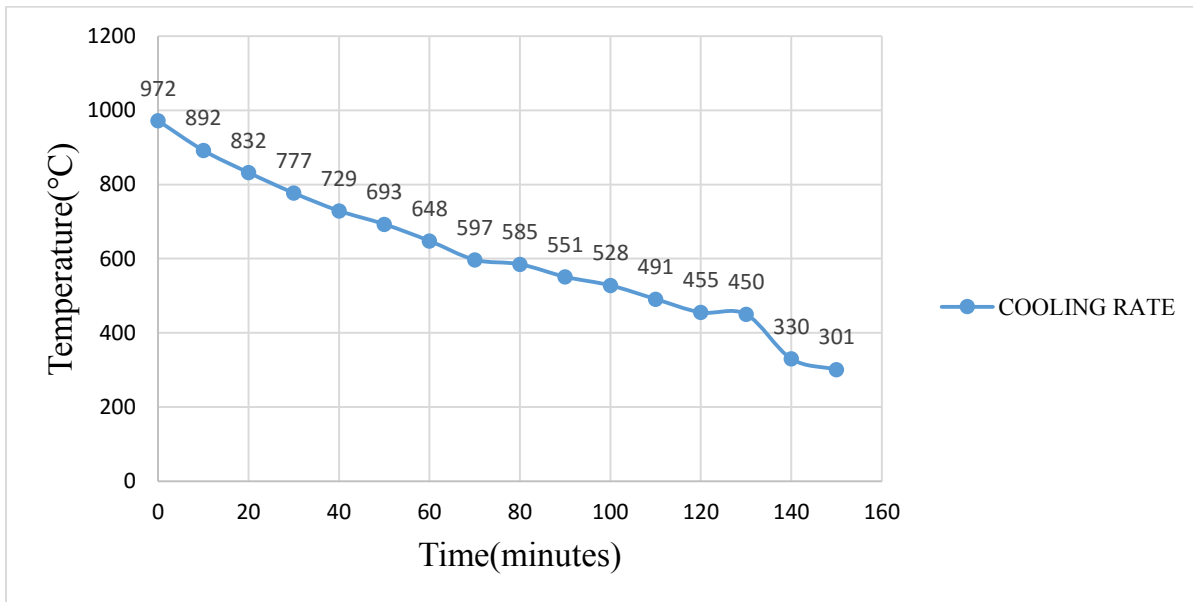
The graph starts at 400 preheating

Steady climbing

Figure 4.3 Temperature-time graph of cooling

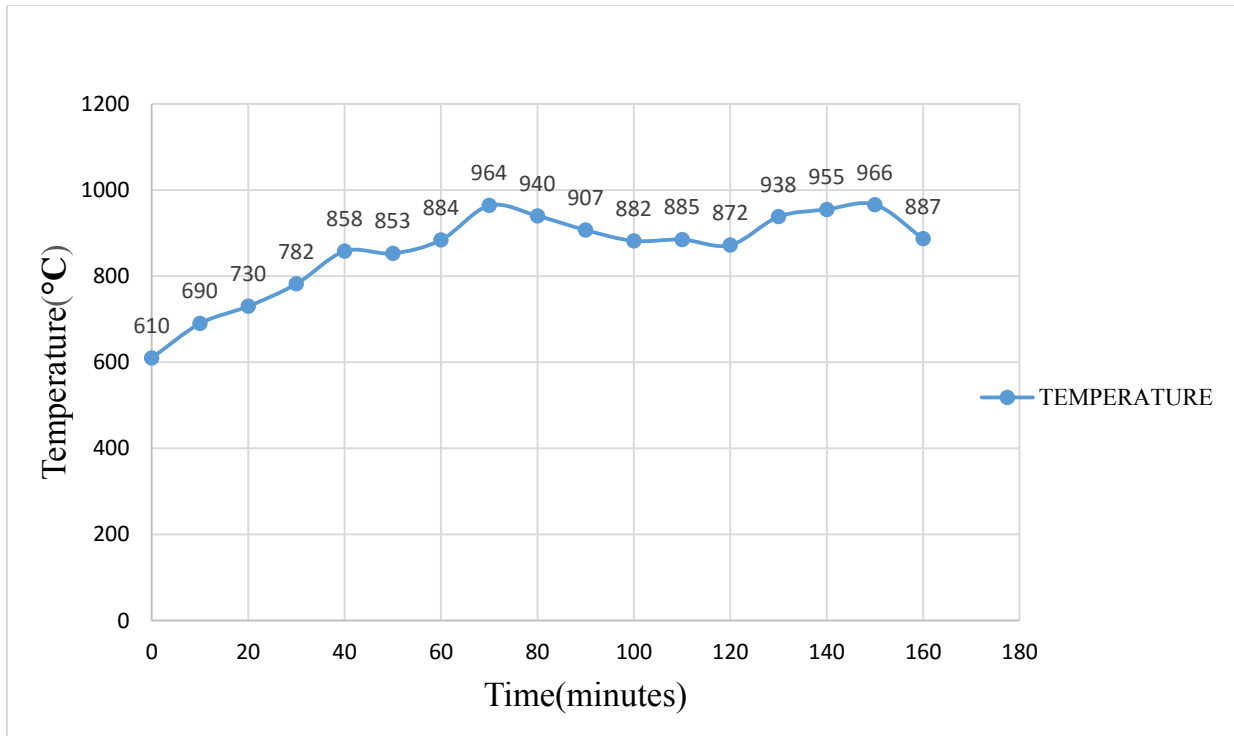The cooling was measured for 150 minutes.

Run two

Figure 4.4 Temperature time graph of firing

The graph shows portions of rise and fall in temperature

The periodic drops in temperatures is attributed to power cuts which resulted in the blower going off. This lead to inefficient burning of the gas. In effect, the gas nozzle had to be opened to minimum to prevent the emission of smoke from the exhaust.

There is no records for the cooling of the second firing.
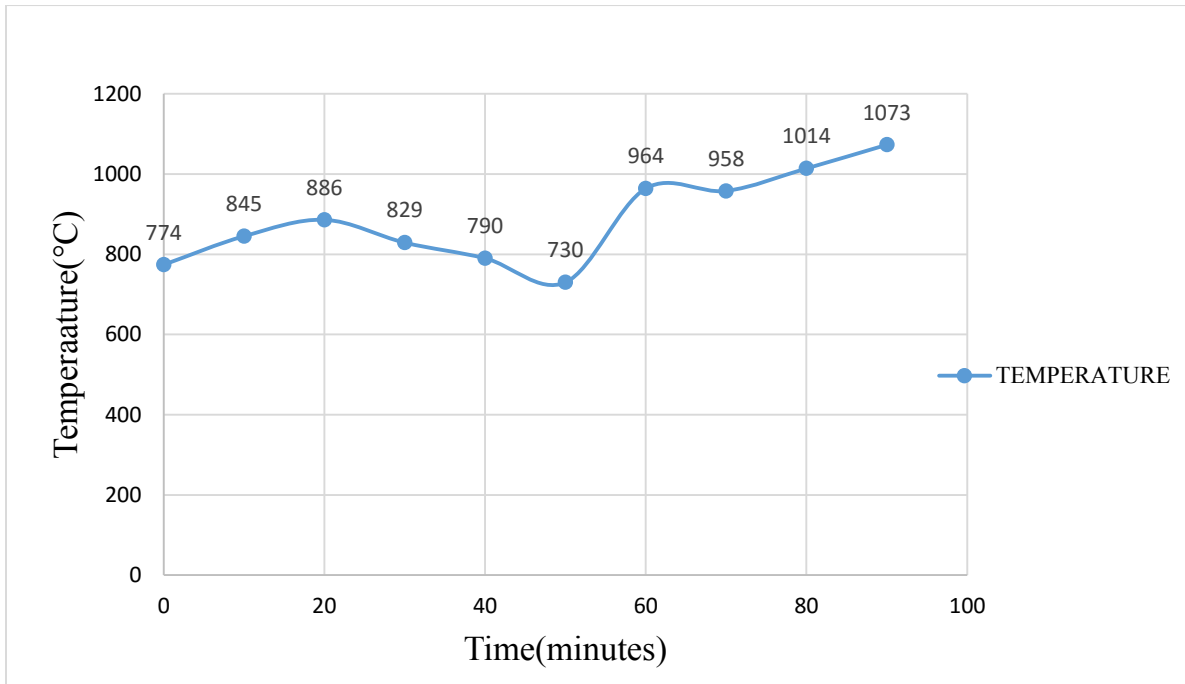
Run three

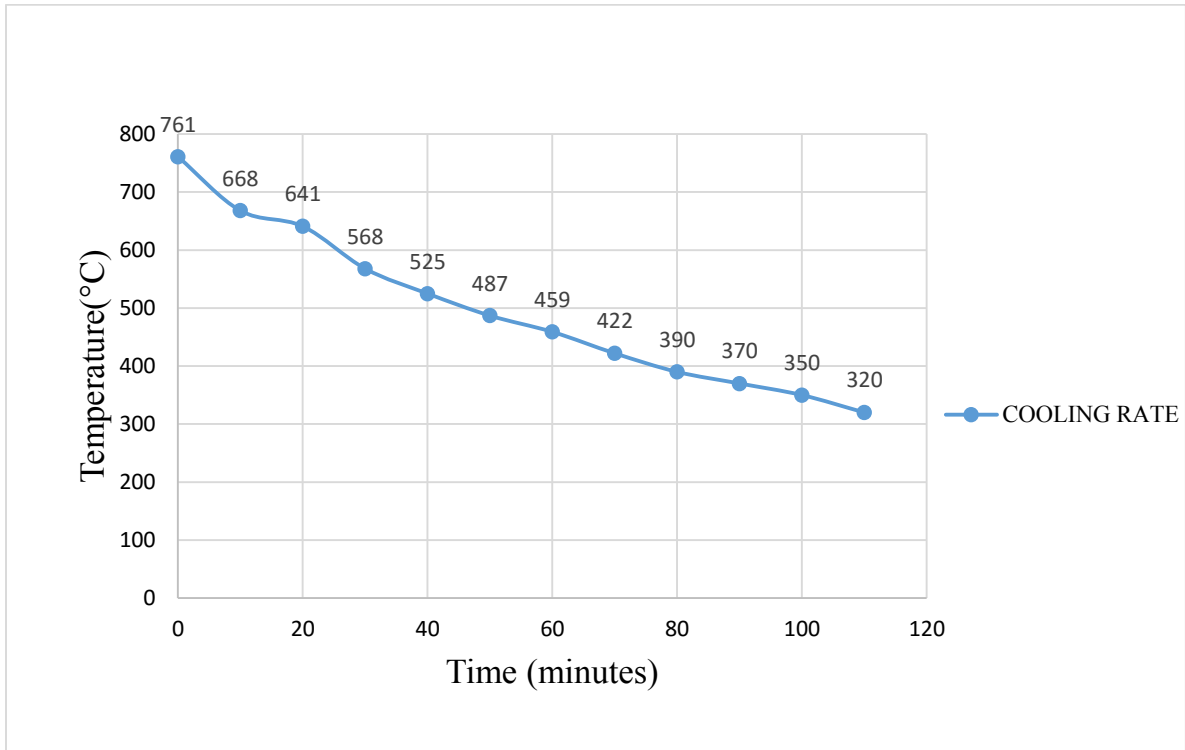

Figure 4.5 Temperature time graph of firing

Figure 4.6 Temperature time graph of cooling
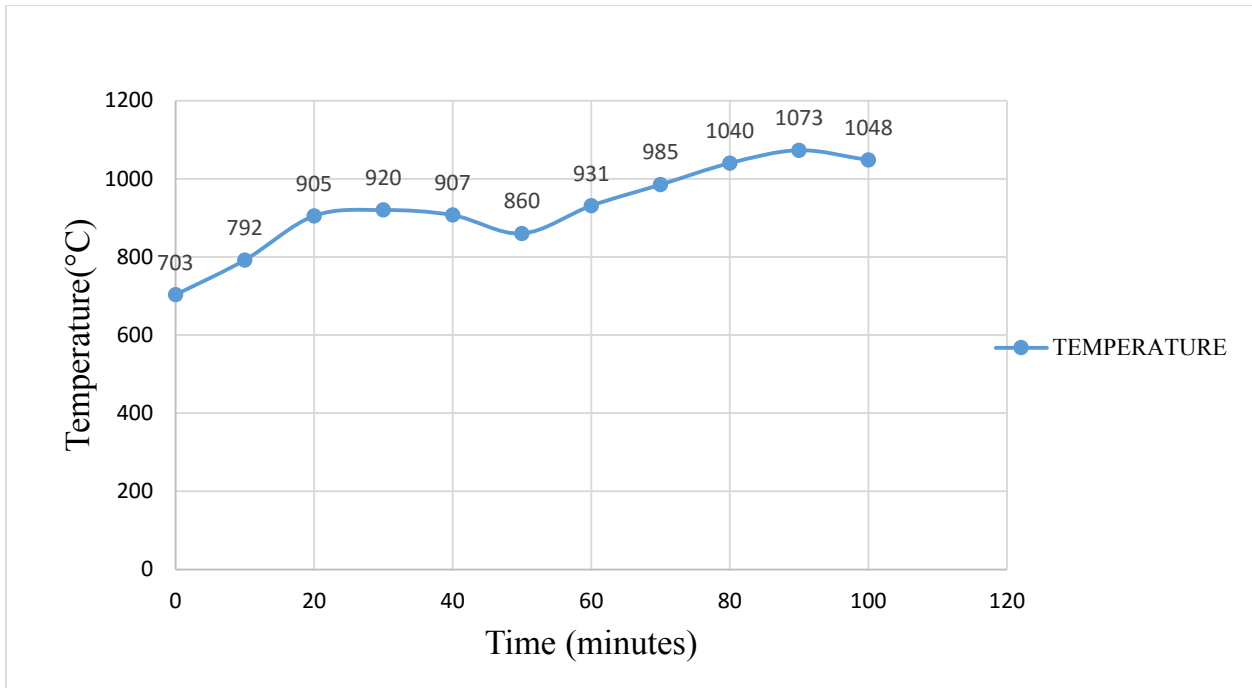
Run four

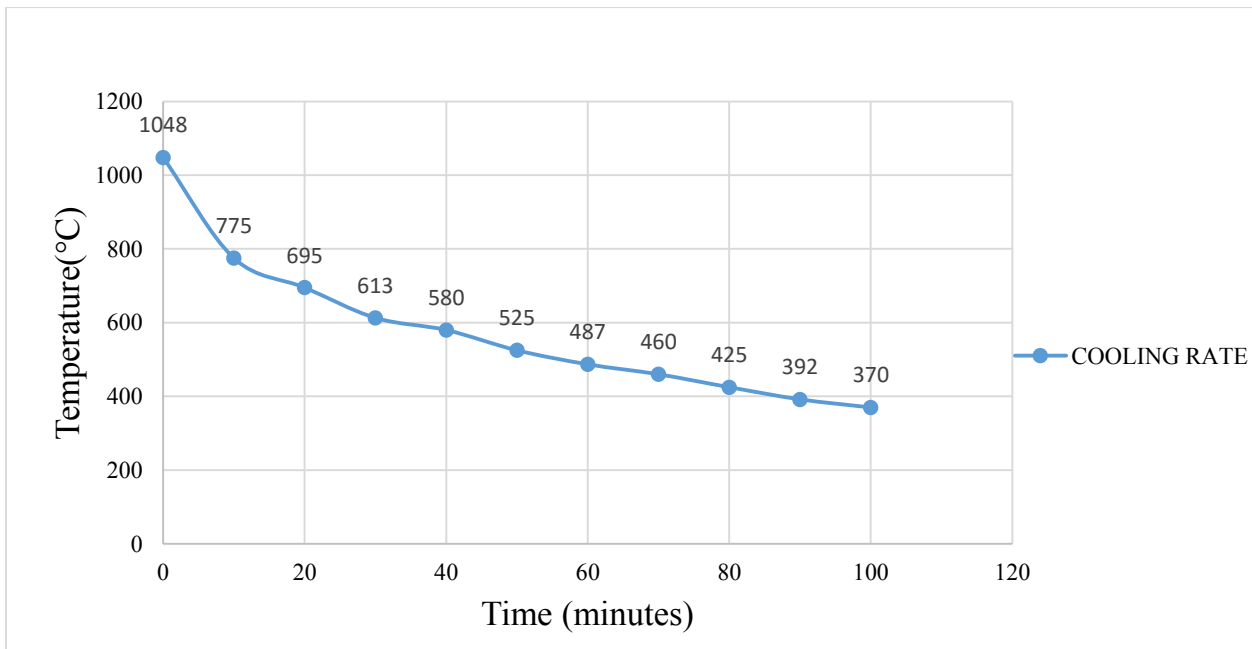

Figure 4.7 Temperature time graph of firing

Figure 4.8 Temperature time graph of cooling

4.2 CALORIFIC VALUE TESTING

The fired products were subjected to calorific tests to make legitimize the product.

Table 4. 8 Change in mass with respect to temperature

	Test 1	Test 2	Test 3	Test 4
Temperature	1200	966	1073	1073
% change in mass	53.8	43.6	42.7	44.1

Initially, the tests were done with the fired palm kernel shell as the product was intended to be preserved. In the testing two sample produced results as the rest failed. The failure was attributed to the nature of the samples in terms of hardness and size. The samples that produced results were taken from the first and third firings. They gave out the following calorific values:

After the failure of the subsequent samples, the fired products were crushed mostly to powder and tested again. This time two samples from each of the firings produced results.

The results are tabulated below.

Table 4. 9 Table of calorific values

Sample name	Calorific value (MJ/kg)	Average calorific value (kJ/kg)
Sample 1a	28.54	28,585
Sample 1b	28.63	
Sample 2a	30.08	29,520
Sample 2b	28.96	
Sample 3a	28.81	29,580
Sample 3b	30.35	
Sample 4a	26.41	27,005
Sample 4b	27.60	

The calorific values obtained are compared to the standard calorific values of coke. Coke ranges from 28,000 to 31,000 kJ/kg. From the results obtained, the fired product is very comparable to coke and further tests are required to confirm the finding.

4.1 ENVIRONMENTAL CONCERNS

Particulate Matter and carbon monoxide levels around the furnace was also determined for an environmental acceptance of the process. There was the need to know the effects of the process on the health of humans since there are fumes produced during firing.

The firing of the palm kernel shells in the furnace produces smoke and other gases. The gases of particular interest are carbon dioxide, carbon monoxide and particulate matter. Particulate matter is measured by their sizes. These were measured because the measuring instrument available during the time could only detect them. For this project, the particulate matter of the size 2.5μg and carbon monoxide are measured and the results presented in the tables and graphs below.

The data obtained is compared to guidelines on air quality set by the World Health Organization (WHO).
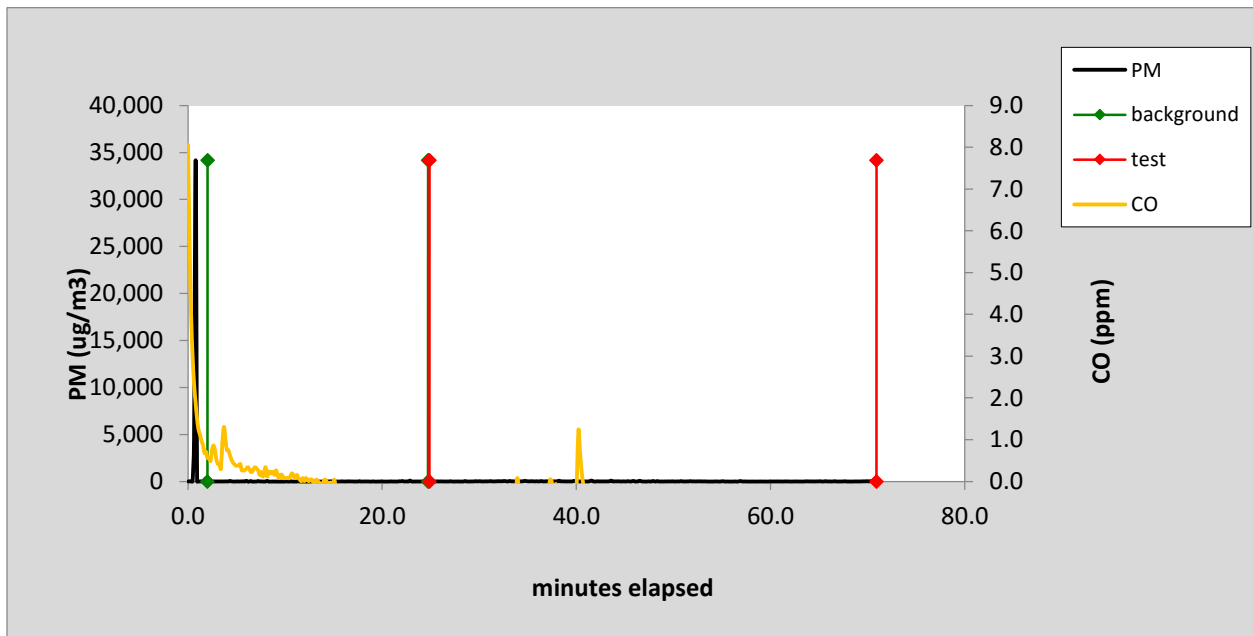

Figure 4. 9 Indoor Air Pollution measurement graph

The graph in figure 4.9 shows the background air pollution when the device was turned on and the values of the concentrations of the pollutants observed over the firing period. The table 4.2 provides the compressed data that is gathered by the indoor air pollution meter.

Average PM Concentration	**7**	**ug/m3**
Average CO Concentration	**-0.7**	**ppm**
Highest PM Concentration	92	ug/m3
Highest CO Concentration	1.2	ppm
Highest 15-minute PM Concentration	17	ug/m3
Highest 15-minute CO Concentration	-0.5	ppm
Lowest 15-minute PM Concentration (1)		ug/m3
Lowest 15-minute CO Concentration	-0.8	ppm
Average Temperature	32.6	deg C
Average Relative Humidity	61	%

Table 4.2 Indoor air pollution data

The average temperature and relative humidity are recorded from the smoke that was measured by the device. The average PM (particulate matter) concentration recorded was 7µg. The WHO standard set is 10µg. According to the standards, an average concentration below 10µg of PM reading is considered environmentally safe.
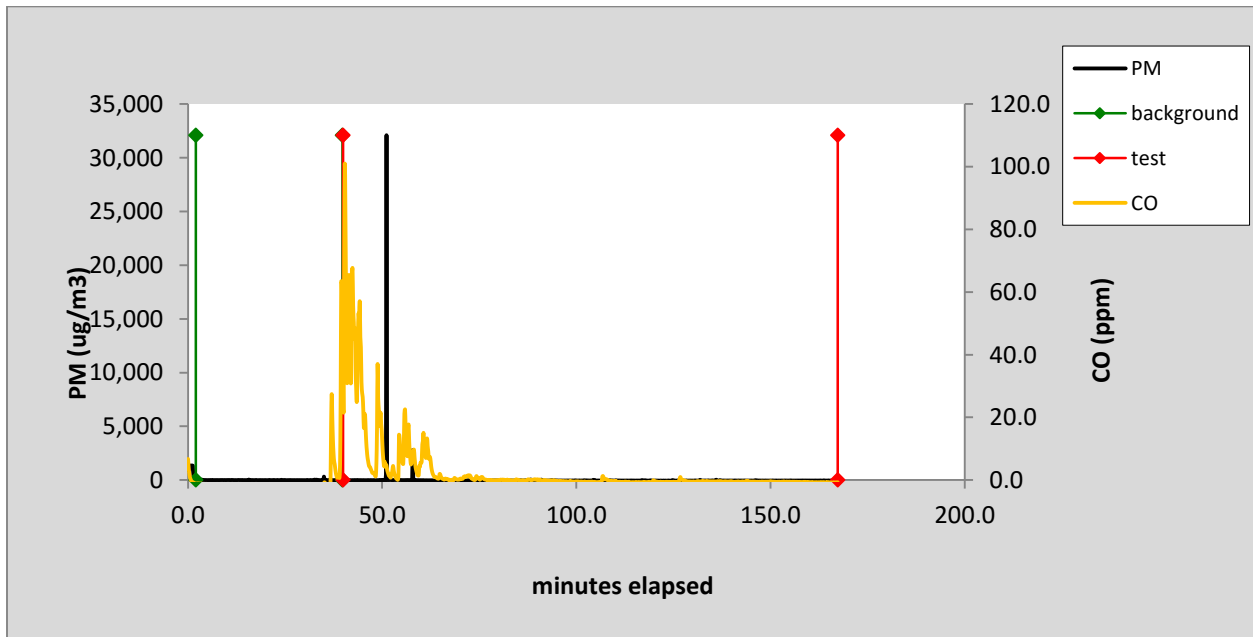

Figure 4.10 Indoor air pollution results

Average PM Concentration	**9**	**ug/m3**
Average CO Concentration	**2.8**	**ppm**
Highest PM Concentration	32,103	ug/m3
Highest CO Concentration	101.0	ppm
Highest 15-minute PM Concentration	359	ug/m3
Highest 15-minute CO Concentration	21.4	ppm
Lowest 15-minute PM Concentration	(48)	ug/m3
Lowest 15-minute CO Concentration	-0.7	ppm
Average Temperature	37.5	deg C
Average Relative Humidity	56	%

Table 4.3 Indoor air pollution results

Figure 4.10 and table 4.3 also show another result from the indoor air pollution meter. From the table, the average concentration of the particulate matter (of sizes below 2.5µg) is 9 is which is below the health hazard limit of 10µg which is being compared.

CHAPTER FIVE

5.0 CONCLUSION

The furnace design was successfully modified and constructed over a period of three months. The new design dealt with the problems identified from the previous design. The opening of the furnace was changed successfully, and the design is more efficient in utilization of heat.

The production of coke from palm kernel shells for metallurgical purposes was also attained by heating the charred palm kernel shells to 1200 degrees Celsius for about 120 minutes on the average. The product was confirmed by the properties of coke which is primarily obtained by the comparable calorific values although further tests are necessary to confirm this initial findings.

The external temperatures that were taken directly on the surface of the furnace stays below 60°C for most of the firing session. From the indoor air pollution tests, it was found that the average pollution of the entire firing process is within acceptable limits. That is below $10\mu g/m^3$ for both particulate matter of size $2.5\mu g$ and carbon monoxide.

5.1 RECOMMENDATIONS

The prototype furnace achieved the initial aim of modifying the existing furnace in terms of making it easier to open and reducing heat losses to the environment. However in this prototype, more heat can be conserved by directing the exhaust heat back into the heating chamber or even directed elsewhere for a desired heating process.

An electrical temperature controlled device could be installed in future models to automatically turn the burner off when a desired temperature or heating time is attained.

The use of angle irons around the circumference of the lid and base sections can be replaced with a cheaper material, a possible candidate is used car tired.

48

REFERENCES

1. A.Hovenac, E., & Skomra, D. F. (1991). *The Culture and Lore of a mining people*. University of Pittsburgh.

2. Archive, B. (2013). *The Coming of the ages of Steel*.

3. Beaver, S. (1951). "Coke Manufacture in Great Britain". *a Study in Industrial Geography*, 133-148.

4. Cooper, E. M. (1993). *History of Coke*. Pennsylvania, Indiana.

5. DiCiccio, C. (1996). *Coal and Coke in Pennsylvania*. Harrisburg, PA.

6. Diez, M. A. (2002). Coal for Metallurgical coke production: predictions of coke quality and future requirements for cokemaking. *International Journal of Coal Geology*.

7. Group, T. a. (1984). Coal Preparation . *Coal Analytical Methods*.

8. Ibrahim, H. A.-H. (1990). *Desulfurization of petroleum coke*. Pittsburgh.

9. Kirk, E. (1899). Cupola Management. *A Practical Treatise on the Construction and Management of Foundry Cupolas*.

10. M.A.Diez, R.Alvarez, & Bariocanal. (2002). *International journal of coal geology*.

11. Mcneil, W. H. (1982). *The Pursuit of Power: Technology, Armed Force and Society*. Chicago: University of Chicago Press:1427 E. 60th Street, Chicago, IL 60637.

12. Nersesian, R. L. (2010). *"Coal and the industrial revolution", Energy for the 21st Century*. New York.

13. Peckham, S. (1880). *Special Reports on Petroleum, Coke and Building Stones*. United States Census Office.

14. S.B.Elliot. (1896). *Reports on Mines, Rochester and Pittsburgh Coal and Iron Company*. Railway Equipment and Publication company.

15. Smith, B. (2001). What is metallurgical coke?

16. Stopes. (1919). COAL PETROGRAPHY. *Coal structure*.

17. Wertime, T. A. (1962). *The coming of the Ages of Steel*. Chicago: University of Chicago Press.

18. Wittcoff, M., & Green, H. (2003). *Organic Chemistry Principles and Industrial practice*. Weinheim:Wiley-VCH.

19. Palm Kernel Shell - Biomass Renewable Energy. (n.d.). Retrieved from http://www.biofuelresource.com/palm-kernel-shell/

20. Wittcoff, M. M. G.; H. A. (2003). *Organic chemistry principles and industrial practice* (1. ed., 1. reprint.). Weinheim: Wiley-VCH.

21. Valia, H. S. (1994) Coke Production for blast furnace ironmaking. *American Iron and Steel Institute*.

22. Bakker, W.T. (1993, August) Refractories for present and future electric power plants. In *Key Engineering Materials (Vol. 88 pp.* 41-70).

23. Blond, E, Schmitt, N., Hild, F., Blumenfeld, P., & Poirier, J (2007) Effects of slag impregnation on thermal degradation in refractories. *Journal of the American Ceramic Society*, *90*(1), 154 - 162

24. Lida, Ken'ichi (1980) Origin and development of iron and steel technology in Japan (http://d-arch.ide.go.jp/je_archive/society/wp_unu8.html) Retrieved 13th November 2015

25. Benoit Boulet, Gino Lalli and Mark Ajersch, *Modeling and Control of an Electric Arc Furnace*. Accessed 13/11/2015

26. Metallurgical coke: http://www.e-reful.com/products/pr_pic_874.html Retrieved: 13th November 2015

27. http://vacaero.com/information-resources/vac-aero-news-and-training/news-announcements/1363-vac-aero-commissions-a-vacuum-furnace-to-a-university-r-d-center-in-south-korea.html Retrieved: 13th November 2015

28. http://www.amg-nv.com/Products/Vacuum-Furnaces/ Retrieved: 13th November 2015

29. http://www.ru.all.biz/en/metallurgical-furnaces-bgg1046118 Retrieved: 13th November 2015

30. Harper, Douglas. "coal". Online Etymology Dictionary.

31. **[**geology.com/rocks/coal.shtml][Hobart King] Retrieved: 13th November 2015

32. International energy annual 2006 Energy information administration. 2008.

33. Archived from the original on 23 may 2011. Retrieved: 13th November 2015

34. "EIA International Energy statistics: Coal: Recoverable reserves". Retrieved 31 May 2012.