DEVELOPMENT OF LABORATORY FIRE TUBE STEAM BOILER

BY

AKINDELE PETER ORIMISAN

MEE/13/1148

BEEN A PROJECT SUBMITTED TO DEPARTMENT OF MECHANICAL ENGINEERING

IN PARTIAL FULFILMENT OF THEREQUIREMENTS FOR THE AWARD OF BACHELORS OF ENGINEERING IN MECHANICAL ENGINEERING

FEDERAL UNIVERSITY OYE EKITI, EKITI STATE

SUPERVISED BY: PROF. B.O BOLAJI & DR. O. A OYELARAN

FEBRUARY, 2019

CERTIFICATION

This is to certify that this project was carried out by **AKINDELE PETER ORIMISAN** with matriculation numbers **MEE/13/1148** in the department of **Mechanical Engineering,** Federal University Oye-Ekiti, Ekiti state, Nigeria in partial fulfillment of the requirements for the degree of Bachelor of Engineering (Mechanical Engineering).

.... 08-03-2019

Dr. O.A. OYELARAN Date

(Supervisor)

....

Prof B.O BOLAJI Date

(Co-Supervisor)

.... 08-03-2019

Dr.O.A OYELARAN Date

(Head of Department)

.... 12/03/2019

Dr T.A.O Salau

(External Examiner)

DECLARATION

I, AKINDELE PETER ORIMISAN with matriculation number **MEE/13/1148** declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other university for a similar or any other degree award.

....

Signature

ACKNOWLEDGEMENT

First and foremost, I acknowledge Almighty God for his infinite goodness and mercies. Also, I will like to specially express my gratitude **To Mr Mathew Akindele And Mrs Akindele Idowu** and the members of my families whose moral, financial and physical support did not wane throughout the course of undertaking this project.

Special thanks to, **Dr. O.A Oyelaran**, for his apt corrections, support and encouragement, **Prof B.O Bolaji** for taking his time enlighten us on vital concepts regarding this study.My profound gratitude goes to **Dr T.A.O Salau,** the external supervisor for apt correction . And my project team, **Ajilore Jacob And Azeez Babatunde** for their good spirit ofn team work.

I also appreciate all my wonderful an brilliant lecturers, technologist, the Non Academic Staff of the Department in the Department of Mechanical Engineering for imparting and impacting my life. Also the students and the executives that served with me during my tenure in office as the president of National Association Of Mechanical Engineering Students(NAMES), FUOYE Chapter.

Special thanks to Gofamint Students Fellowship (GSF) brethren , ikole Campus,the Good Success Family, the executives during my tenure as the pioneer President, workers and members for their love, care, unity through my service in God's vineyard in FUOYE and my Zonal Coordinator, Pastor Isaac Ajiboye, for his support and advise.

Also our inner circle of friends and acquaintances, I celebrate you all.

DEDICATION

This work is dedicated to my parents and siblings for their unwavering support.

ABSTRACT

This project report discusses the design and fabrication of a laboratory steam boiler. The step and process used to achieve the steam boiler. Steam is needed for diverse purposes in homes, laboratories and industries hence the need to develop a low cost, functional steam boiler using locally sourced materials.

The process of designing the laboratory steam boiler involves developing a conceptual physical geometry, making necessary calculations from which dimensions and other deductions were made, and finally, developing a working drawing.

The steam boiler involves the design, fabrication and testing of stainless steel cylinder used to generate steam for laboratory applications. It involves cost analysis, modifications and the selection of suitable materials which fulfill the design requirements for the fabrication. It also covers the design description, analysis and calculations as well as the history of steam generation and applications.

The fire tube concept was used for this steam boiler and it generates steam at a temperature of 309°C. The heat used is typically produced deliberately for the production of steam for laboratories purposes. One of the step involves in steam generation is to transfer the heat gotten from the heat source (gas) into clean water in the boiler. This is achieved by having the heat source elevate the temperature in the combustion chamber. This heat produced, heats up the water with the help of hot tubes by convection.

This project presented a successful design and fabrication of the steam boiler. The burner used produced sufficient heat at a temperature of to convert water into pure steam. The steam is delivered at a pressure of 1.52bar .The efficiency of the boiler obtained is 75.8% at.

Table of content

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

In our everyday lives, the importance of steam cannot be over emphasized. It is basically water in the gas state which is found applicable in both domestic and industrial setting either as a direct source of heat or as a source of power to steam engines. Steam is an important resource in today's industrial world. It is used in the production of goods and food, the heating and cooling of large buildings, then running and the production of electricity. The system in which steam is generated is called a boiler (Woodruff *et al.*, 2004).

In an enclosed vessel in which water is heated and circulated, either as hot water or steam, to produce a source for either heat or energy is known as Boiler. Essentially, the boiler provides a means for combustion and consequently transfers the heat energy to the water until it becomes hot water or steam. In engineering and laboratories, there is sometimes the need to utilize steam to generate power, to carry out tests or for other heating applications. It has been in use for a very long time and over the course of time, various inventors and engineers have developed and modified them for the purpose of academic study, as well as to suit the needs of the modern man. As a result of their continuous success, many industries today depend greatly on steam for the operation of their equipment and the production of their goods.

Steam is an invisible gas that is generated by heating water to a temperature that brings it to the boiling point. It can be obtained using boilers. It is the gas formed when water passes from the liquid to the gaseous state. At the molecular level, this is when molecules manage to break free from the hydrogen bonds keeping them together. In liquid water, molecules are constantly being joined together and separated. As the water molecules are heated, however, the bonds connecting the molecules start breaking more rapidly than they can form (Ubi *et al.*, November 2010)

1.2 Boiler classification:

i. Tube content: (i) Fire tube boiler and (ii) water tube boiler
ii. Axis of shell: (i) Horizontal, (ii) vertical, (iii) inclined
iii. Location of furnace: (i) Externally fired, (ii) internally fired
iv. Method of circulation: (i) Natural, (ii) forced
v. Mobility: (i) Stationary, (ii) portable
vi. Usage: (i) Packaged, (ii) unpackaged
vii. Pressure: (i) High, (ii) low
viii. Tubes: (i) Single-tube, (ii) Multi-tube

1.3 STATEMENT OF THE PROBLEM

Steam is needed for diverse purposes in homes, laboratories and industries hence the need to develop a low cost, functional steam boiler using locally sourced materials. To develop a device that will serve as a suitable teaching aid and research tool in the laboratory, the steam boiler must be:

i. able to produce steam effectively at a relatively low cost.

ii. less hazardous (in terms of surface temperature).

iii. able to produce steam efficiently at a relatively low cost.

1.4 JUSTIFICATION

Through history mankind has reached beyond the acceptable to pursue a challenge, achieving significant accomplishments and developing new technology. The desire to generate steam in demand sparked this revolution, and technical advances in steam generation allowed it to continue. However, in modern times steam boilers have had the challenge of immobility, size (requirement of large space for installation and operation) and cost (it is expensive to build). Therefore a system that takes all these limitations into account and provides a way of minimizing them is required. Thus the concept of this steam boiler finds its roots.

1.5 OBJECTIVES AND AIMS

The objectives and aims of this project are:

i. To develop a miniature laboratory steam boiler to meet the needs of schools for practical demonstrations and teaching aid.

ii. To fabricate a steam boiler that is compact and easy to adapt in the existing laboratory arrangement.

iii. To develop a system that produces steam efficiently and effectively by generating the heat required for the conversion of water to steam and minimize heat loss to the surrounding.

1.6 METHODOLGY

The process of designing the laboratory steam boiler involves developing a conceptual physical geometry, making necessary calculations from which dimensions and other deductions were made, and finally, developing a working drawing.

1.7 SCOPE AND LIMITATIONS

1.7.1 Scope

The steam boiler involves the design, fabrication and testing of stainless steel cylinder used to generate steam for laboratory applications. It involves cost analysis, modifications and the selection of suitable materials which fulfill the design requirements for the fabrication. It also covers the design description, analysis and calculations as well as the history of steam generation and applications.

1.7.2 LIMITATIONS

The limitations of the design include:

i. Cost of materials: The most suitable material to be used for the fabrication of the steam boiler is stainless steel. However due to the cost of stainless steel, mild steel which also satisfies considerably the design requirement of the steam boiler at a lower cost was selected.

ii. Unavailability of required machinery for fabrication within the university.

iii. The pressure gauge at the outlet of the steam boiler needs a return valve to function as required this was not achieved due to cost.

CHAPTER TWO

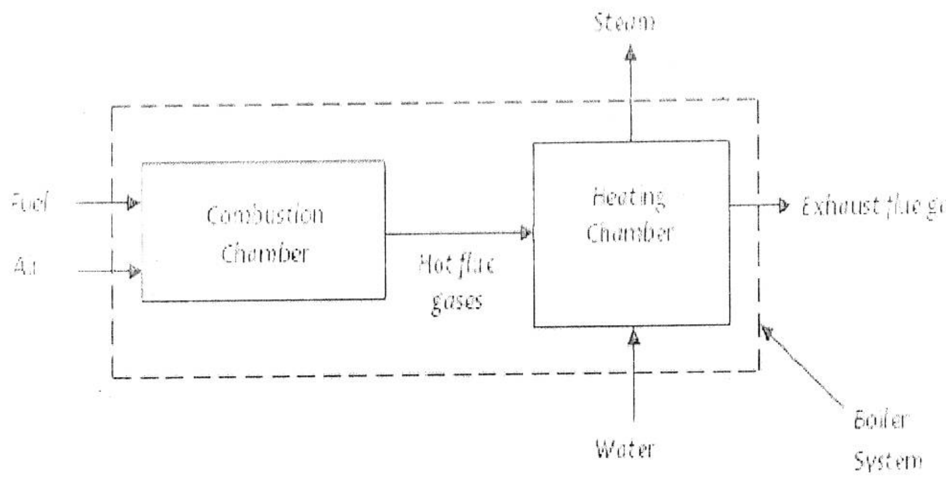
2.1 LITERATURE REVIEW

Throughout history, Steam boiler have played a vital role in the generation of electricity, sterilization of laboratory equipment, other material and products for more than 50 years. There has been rapid progress and innovation in the development of boilers throughout the industrial age. Steam Boilers have been a heat transfer apparatus that convert energy of the fuel to desired working medium such as steam. Mankind has reached beyond the acceptable to pursue a challenge, achieving significant accomplishments and developing new technology about steam boiler. One of the most significant series of events shaping today's world is the industrial revolution that began in the late seventeenth century. The desire to generate steam on demand sparked this revolution, and technical advances in steam generation allowed it to continue.

2.2 Review of literature

M. A. Waheed *et al.* , I. O. Ohijeagbon, M. A. Waheed, S. O. Jekayinfa, O. E. Opadokun, "Developmental design of a laboratory fire tube steam boiler", ACTA corviniensis-bulletin of engineering tome. Vol. VI. ISSN 2067-3809. 2013

A laboratory steam boiler was designed and projected from the conceptual physical geometry of fire-tube boiler which elucidated the primary units making up a boiler. Thermodynamics, heat transfer and strength of materials analysis was subjected to temperature and pressure variations were conducted in the theoretical framework of the laboratory fire-tube steam boiler. The dimensions of major and secondary parts were estimated from computations from the theoretical framework and 3D modeling process for the steam boiler was then carried out to present various working drawings of the steam boiler for possible construction. Conclusively, the boiler was presented for fabrication, testing and further improvement. The design and fabrication of the boiler enabled the availability of portable and affordable steam boilers for steam generation processes, especially in school laboratories. The conceptual physical geometry for the laboratory fire-tube steam boiler developed from the schematic diagram of a boiler is shown in Figure 1. The boiler consists fundamentally of the combustion and heating chambers and other parts such as: fire tubes, water container, steam trap, steam tap, exhaust pipe and boiler casing which are designed in the geometry of the laboratory fire-tube steam boiler.



Also, A theoretical framework was developed which includestheoperating temperature and pressure of a boiler to determine the effectiveness function of the boiler,Stresses induced in tubes and drums. etc

G.A. Ikechukwu (2004), A fabricated fire tube boiler was design and fabricate. It was tested to evaluate its performances, efficiency and determine its evaporation ratio. The purpose of the performance test is to determine the actual performance and efficiency of the oiler and compare it with design values. It was an indicator for tracking day-to-day and season-to-season variations in boiler efficiency and energy efficiency improvements. The result obtained was a torque produced at a steam pressure of 1.5bar and a steam temperature of 111.4°C, also raising the temperature of the water from 30°C, to a generated steam quantity of 61.34kg/hr, with a diesel quantity of 5.21ltres/hr. The efficiency of the burner after getting an adequate combustion air/fuel ratio and heat delivery from the burner resulted into 64.3%. The efficiency of the boiler was also calculated to be 69%.The following conclusions was drawn from the data and research. Dimensions of major and secondary parts were estimated from computations from the theoretical framework and 3D modeling process for the steam boiler was then carried out to present various working drawings of the steam boiler for possible construction.

. F.J. Gutiérrez *et al.*,F.J. Gutiérrez Ortiz, "Modelling of fire-tube boilers", Applied Thermal Engineering, Vol. 31, 3463-3478. 2011

A complete dynamic model of a full-scale fire-tube boiler has been developed based on the mass, energy, and momentum balances together with constitutional equations. Two parts were distinguished in fire-tube boilers: the fire/gas side and the water/ steam side. A first nonlinear physical model was presented and after that it reduced to shorten the computational

time, but providing reasonable results.. Thus, it may allow to simulate the process as well as to design a multivariable controller. Simulation was used for training and assisting in on-line decisions. A case study was simulated using an 800 HP fire-tube boiler and dynamic performances predicted by the model are in good qualitative agreement with data taken from the literature. The proposed modeling were used for an effective way of undertaking a comparison between the fire-tube boiler performances when running with different fuels, especially when considering the firing
of a new fuel in given equipment.

(Xinhui Yang 2014 Design and Research for a Boiler Steam Drum Control System Based on PLC) Introduced the composition of a boiler steam drum control system. It uses the application of a programmable PLC control unit for the boiler steam drum control system. Due to the complexity of boiler control targets, particularity the boiler control environment and the continuity of its operation cycle, S7-200 series PLC was used to form SIEMENS as the control device in our automatic control system. The S7-200 PLC contains an individual S7-200 CPU and many optional extendable modules. These could be easily combined to form controllers of different sizes. The control size could cover several ranges: from a few points, to several hundred points. Due to the number of I/O points in the boiler control system (the number of detected variables and output variables) we chose one CPU 222 module for the CPU in the S7-200 PLC. Also, EM 235 for the analog quantity input and output module. In a system composed by the selected modules, CPU 222 was able to supply all of the electric power consumed by the extendable modules. The quantity of the attached extendable module was no more than 2, which means that the hardware configuration of this system was suitable. The control system composition has been shown in Figure 1.1. Controlling boiler water level systems with PLC effectively allows us to control the combustion process in boilers. It also allows us to make sure that combustion occurs with a proper air-fuel ratio in order to improve combustion efficiency. Since industrial boilers consume large volumes of coal, every 1% increase in thermal combustion efficiency will generate huge economic benefits. Secondly, the automatic boiler control processing and friendly human-computer interface found with this monitoring software centralize the operational parameters for monitoring. Operators can modify operation parameters on monitoring computers based on control-effect in a timely manner

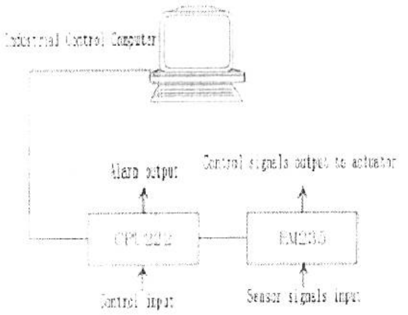


Figure 1.2 Control System Composition and Structure Diagram

P. Negi *et al.*,P. Negi, Dr. A. Gupta, V. Kumar, "A Review: Heat Transfer Enhancement in Boiler Tube Using Different Geometry", International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 9. ISSN 2348 – 7968, 2014

Boiler provides the major source in industries to burn fuel to generate process steam and electric power. It is the main device of power plant to generate steam by efficiently burning available fuels used to generation of power. There are mainly two types of boiler, water tube boiler and fire tube boiler. Water tube boiler are those types in which water flows inside the boiler tube and flue gases flows outside to heat up the water to generate steam. Most industrial purpose uses water tube boiler as it is more efficient than fire tube boiler. Today the main concern is to increase the efficiency of water tube boiler by enhancing the heat transfer rate in the boiler tube. Due to economic and environment demand, engineers must continuously focus on improving the efficiency of the boiler and reducing emission, wide variety of engineering situations, including heat exchangers for viscous liquids in chemical process and food industry. In real condition the boiler water tube are plane walled, due to this the flow inside the tube is laminar. Many studies have focused on turbulent flow, the laminar range is of particular interest in a review of corrugated geometry of boiler tubes, heat transfer studies for different geometries and other various designs are carried out. The researcher's designs going to the integration between the geometry and flow through the tube to reduce heat loss and system costs.

UBI ATEB PASCHAL, ROWLANDS DAVID OLUSINA, UCHOLA LAWRENCE AND OCHI VICTOR

DESIGN, FABRICATION AND TESTING OF A STEAM GENERATOR NOVEMBER, 2010

A steam generator was designed and fabrication. It is used to harness the energy liberated as heat in a variety of processes and converts it into a form which is useful for applications in the industry, medicine, agriculture etc. The water tube concept was used for the steam generator and generated steam at a flow rate of $0.0035\ m^3/s$and at a temperature of 509°C. The heat generated was used for the production of steam for industrial or domestic purposes. The step of steam generation was to transfer the heat gotten from the heat source (fuel) into clean water in the boiler. These were done by having the heat source elevate the temperature in the combustion chamber. This heat produced. heats up the water in the water tube without contaminating it.

Babu *et al.*, (2016) in their work "design and construction of a pressing steam boiler" listed the following classifications of boilers;

- Tube content: Fire tube boiler and) water tube boiler
- Axis of shell: Horizontal, vertical and inclined
- Location of furnace: Externally fired, and internally fired
- Method of circulation: Natural and forced
- Mobility: Stationary and portable
- Usage: Packaged and unpackaged
- Pressure: High and low
- Tubes: Single-tube and Multi-tube

In the aforementioned work, the following boiler systems were also identified

- Feed water system
- Steam system
- Fuel system

According to Babu *et al.*, each of the above system performs specific functions; the steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depend on the type of fuel used in the system.

Fig 2.1 pressing steam boilers (Babu et al., 2016)

The feed water system provides water to the boiler and regulates it automatically to meet the steam demand. The water supplied to boiler that is converted to steam is called feed water. The sources of feed water are:

1. Condensate or condensed steam returned from the processes

2. Make up water which is the raw water which must come from outside.

The above produced pressing boiler was comprised of the boiler shell, a U-tube heating coil constructed from a 20 gauge ¾ inch single wall copper tubing, the control valve amongst others.

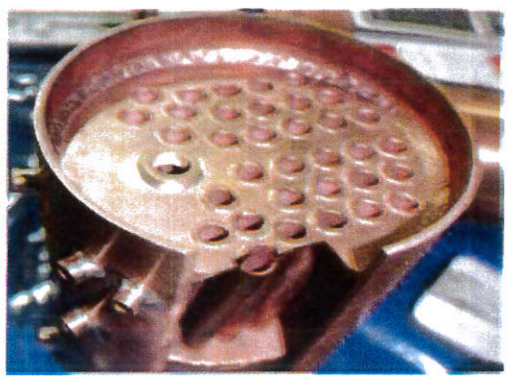


Fig 2.2 Cut section of the shell (Babu *et al.*, 2016)

2.3 DEVELOPMENT OF BOILER TYPES

2.3.1 Fire Tube Boiler

2.3.1.1 Haycock and wagon top boilers

For the first Newcomen engine of 1712, the boiler was little more than large brewer's kettle installed beneath the power cylinder. Because the engine's power was derived from the vacuum produced by condensation of the steam, the requirement was for large volumes of steam at very low pressure hardly more than 1 psi (6.9kPa) The whole boiler was set into brickwork which retained some heat. A voluminous coal fire was lit on a grate beneath the slightly dished pan which gave a very small heating surface; there was therefore a great deal of heat wasted up the chimney. In later models, notably by *John Smeaton*, heating surface was considerably increased by making the gases heat the boiler sides, passing through a flue. *Smeaton* further lengthened the path of the gases by means of a spiral labyrinth flue beneath the boiler. These under-fired boilers were used in various forms throughout the 18th Century. Some were of round section (haycock). A longer version on a rectangular plan was developed around 1775 by Boulton and Watt (wagon top boiler). This is what is today known as a three-pass boiler, the fire heating the underside, the gases then passing through a central square-section tubular flue and finally around the boiler sides. The figure shows the picture a fire tube boiler

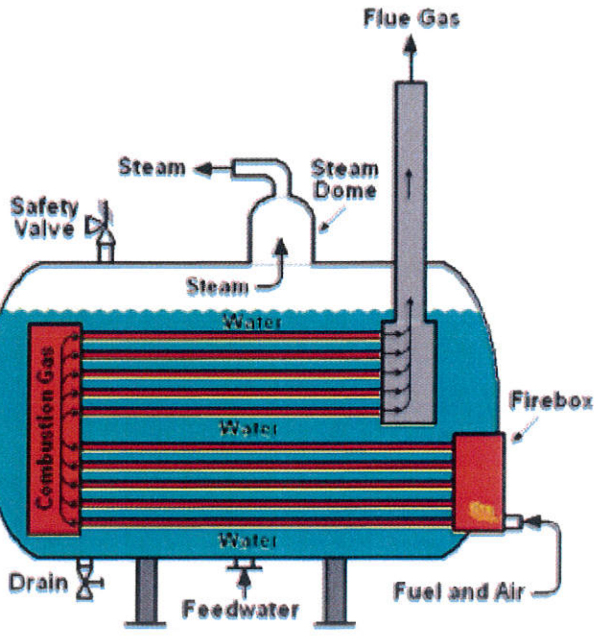


Figure 2.: *a fire tube boiler*

2.3.1.2 Cylindrical fire-tube boiler

An early proponent of the cylindrical form, was the American engineer, *Oliver Evans* who rightly recognized that the cylindrical form was the best from the point of view of mechanical resistance and towards the end of the 18th Century began to incorporate it into his projects. Probably inspired by the writings on *Leopold's* "high-pressure" engine scheme that appeared in encyclopedic works from 1725, *Evans* favored "strong steam" i.e. non condensing engines in which the steam pressure alone drove the piston and was then exhausted to atmosphere. The advantage of strong steam as he saw it was that more work could be done by smaller volumes of steam; this enabled all the components to be reduced in size and engines could be adapted to transport and small installations. To this end he developed a long cylindrical wrought iron horizontal boiler into which wide which passed longitudinally inside the tank. The fire was tended from one end and the hot gases from it travelled along the tube and out of the other end, to be circulated back along flues running along the outside then a third time beneath the boiler barrel before being expelled into a chimney. This was later improved upon by another 3-pass boiler, the Lancashire boiler which had a pair of furnaces in separate tubes side-by-side. This was an important improvement since each furnace could be stoked at different times, allowing one to be cleaned while the other was operating. Railway locomotive boilers were usually of the 1-pass type, although in early days, 2-pass "return flue" boilers were common, especially with locomotives built by Timothy Hackworth. was incorporated a single fire tube, at one end of which was placed the fire grate.

The gas flow was then reversed into a passage or flue beneath the boiler barrel, then divided to return through side flues to join again at the chimney (Columbian engine boiler). Evans incorporated his cylindrical boiler into several engines, both stationary and mobile. Due to space and weight considerations the latter were one-pass exhausting directly from fire tube to chimney. Another proponent of "strong steam" at that time was the Cornishman, Richard Trevithick. His boilers worked at 40-50 psi (276-345 kPa) and were at first of hemispherical then cylindrical form. From 1804 onwards Trevithick produced a small two-pass or return flue boiler for semi-portable and locomotive engines. The Cornish boiler developed around 1812 by Richard Trevithick was both stronger and more efficient than the simple boilers which preceded it. It consisted of a cylindrical water tank around 27 feet (8.2 m) long and 7 feet (2.1 m) in diameter, and had a coal fire grate placed at one end of a single cylindrical tube about three feet 27 wide which passed longitudinally inside the tank. The fire was tended from one end and the hot gases from it travelled along the tube and out of the other end, to be circulated back along flues running along the outside then a third time beneath the boiler barrel before being expelled into a chimney. This was later improved upon by another 3-pass boiler, the Lancashire boiler which had a pair of furnaces in separate tubes side-by-side. This was an important improvement since each furnace could be stoked at different times, allowing one to be cleaned while the other was operating. Railway locomotive boilers were usually of the 1-pass type, although in early days, 2-pass "return flue" boilers were common, especially with locomotives built by Timothy Hackworth.

2.3.2 Multi-tube boilers

A significant step forward came in France in 1828 when Marc Seguin devised a two-pass boiler of which the second pass was formed by a bundle of multiple tubes. A similar design with natural induction used for marine purposes was the popular "Scotch" marine boiler.

Prior to the Rainhill trials of 1829 Henry Booth, treasurer of the Liverpool and Manchester Railway suggested to George Stephenson, a scheme for a multi-tube one-pass horizontal boiler made up of two units: a firebox surrounded by water spaces and a boiler barrel consisting of two telescopic rings inside which were mounted 25 copper tubes; the tube bundle occupied much of the water space in the barrel and vastly improved heat transfer. Old George immediately communicated the scheme to his son Robert and this was the boiler used on Stephenson's Rocket, outright winner of the trial. The design was and formed the basis for all subsequent Stephenson an-built locomotives, being immediately taken up by other constructors; this pattern of fire-tube boiler has been built ever since.

2.3.3 Water Tube Boiler

2.3.3.1 Combined heat and power (CHP) plant

Water-tube boilers differ from shell type boilers in that the water is circulated inside the tubes, with the heat source surrounding them, because the tube diameter is significantly smaller, much higher pressures can be tolerated for the same stress.

Water-tube boilers are used in power station applications that require:

- Superheated steam (up to 550°C).
- High pressure steam (up to 160 bar).
- A high steam output (up to 500 kg/s).

However, water-tube boilers are also manufactured in sizes to compete with shell boilers. Small water-tube boilers may be manufactured and assembled into a single unit, just like packaged shell boilers, whereas large units are usually manufactured in sections for assembly on site. However, when the pressure in the water-tube boiler is increased, the difference between the densities of the water and saturated steam falls, consequently less circulation occurs. To keep the same level of steam output at higher design pressures, the distance between the lower drum and the steam drum must be increased, or some means of forced circulation must be introduced. Figure 2.8 shows the picture of a Babcock and Wilcox water tube boiler.

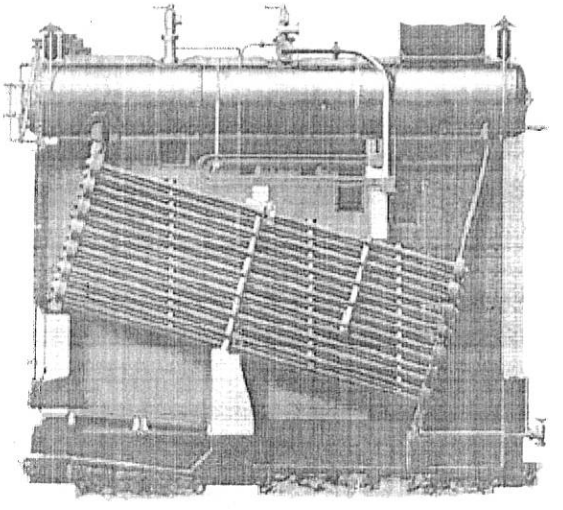


Figure 2.8: Babcock and Wilcox water tube boiler with longitudinal steam drum

Water-tube boiler sections

The energy from the heat source may be extracted as either radiant or convection and conduction.

(a) **The furnace or radiant section:** This is an open area accommodating the flame(s) from the burner(s). If the flames were allowed to come into contact with the boiler tubes, serious erosion and finally tube failure would occur. The walls of the furnace section are lined with finned tubes called membrane panels, which are designed to absorb the radiant heat from the flame.

(b) **Convection section:** This part is designed to absorb the heat from the hot gases by conduction and convection. Large boilers may have several tube banks (also called pendants) in series, in order to gain maximum energy from the hot gases.

Advantages of water-tube boilers:

- The design may include many burners in any of the walls, giving horizontal, or vertical firing options, and the facility of control of temperature in various parts of the boiler. This is particularly important if the boiler has an integral superheater, and the temperature of the superheated steam needs to be controlled.
- They have small water content, and therefore respond rapidly to load change and heat input.
- The small diameter tubes and steam drum mean that much higher steam pressures can be tolerated, and up to 160 bar may be used in power stations.

Disadvantages of water-tube boilers:

- They are not as simple to make in the packaged form as shell boilers, which mean that more work is required on site.
- The option of multiple burners may give flexibility, but the 30 or more burners used in power stations means that complex control systems are necessary.

2.3.4 Bent tube or Stirling boiler

A further development of the water-tube boiler is the bent tube or Stirling boiler. Again this operates on the principle of the temperature and density of water, but utilises four drums in the following configuration. Cooler feedwater enters the left upper drum, where it falls due to greater density, towards the lower, or water drum. The water within the water drum, and the connecting pipes to the other two upper drums, are heated, and the steam bubbles produced rise into the upper drums where the steam is then taken off.

The bent tube or Stirling boiler allows for a large surface heat transfer area, as well as promoting natural water circulation. Figure 2.9 shows a Stirling water tube boiler with four cross-drums.

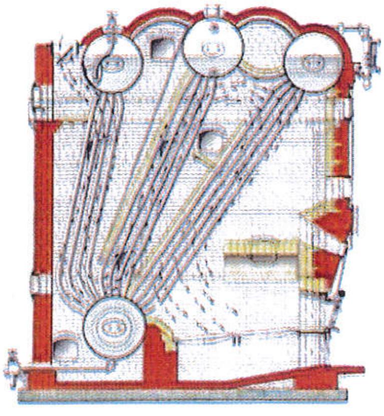


Figure 2.9: Stirling water tube boiler with four cross-drum

2.2 STEAM THEORY

The theoretical knowledge about steam and principle of steam boiler is discussed below:

2.2.1 PRINCIPLE OF STEAM PRODUCTION

Steam and water are typically used as heat carriers in heating systems. It is well known that under atmospheric pressure, water boils and evaporates at 100°C. At higher pressure, water evaporates at higher temperature - e.g. a pressure of 10 bar equals an evaporation temperature of 184°C. During the evaporation process, pressure and temperature are constant, and a substantial amount of heat is use for bringing the water from liquid to vapour phase. When all the water is evaporated, the steam is called dry saturated. In this condition the steam contains a large amount of latent heat, corresponding to the heat that was led to the process under constant pressure and temperature. So despite temperature and pressure is the same for the liquid and the vapour, the amount of heat 10 is much higher in vapor compare to the liquid. This latent heat in the dry saturated steam can efficiently be utilized to different processes requiring heat *(W.M Huitt, 2009)*.

2.2.1.1 Steam Dryness Fraction

Steam is said to be dry saturated when at that particular pressure its temperature is equal to the boiling point. Steam with a temperature equal to the boiling point at that pressure is known as dry saturated steam. However, to produce 100% dry steam in an industrial boiler designed to produce saturated 13 steam is rarely possible, and the steam will usually contain droplets of water. In practice, because of turbulence and splashing, as bubbles of steam break through the water surface, the steam space contains a mixture of water droplets and steam. Steam produced in any shell-type boiler, where the heat is supplied only to the water and where the steam remains in contact with the water surface, may typically contain around 5% water by mass. If the water content of the steam is 5% by mass, then the steam is said to be 95% dry and has a dryness fraction of 0.95. The actual enthalpy of evaporation of wet steam is the product of the dryness fraction x and the specific enthalpy h_{fg} from the steam tables. Wet steam will have lower usable heat energy than dry saturated steam because the specific volume of water is several orders of magnitude lower than that of steam, the droplets of water in wet steam will occupy negligible space. Therefore the specific volume of wet steam will be less than dry steam. *(Gordon & Yon , Engineering Thermodynamics 4th edition, pg 174)*.

2.2.1.2 Evaporation Enthalpy of wet steam h_{fg}

This is the amount of heat required to change the state of water at its boiling temperature, into steam. It involves no change in the temperature of the steam/water mixture, and all the energy is used to change the state from liquid (water) to vapour (saturated steam). The old term latent heat is based on the fact that although heat was added, there was no change in temperature. However, the accepted term is now enthalpy of evaporation. Like the phase change from ice to water, the process of evaporation is also reversible. The same amount of heat that produced the steam is released back to its surroundings during condensation, when steam meets any surface at a lower temperature. This may be considered as the useful portion of heat in the steam for heating purposes, as it is that portion of the total heat in the steam that is extracted when the steam condenses back to water. The total energy in saturated steam also known as **enthalpy of saturated steam or total heat of saturated steam is given by:** $h_f = h_g + xh_{fg}$

Where: h_f= Total enthalpy of saturated steam (Total heat) (kJ/kg)

h_g Liquid enthalpy (Sensible heat) (kJ/kg)

h_{fg}= Enthalpy of evaporation (Latent heat) (kJ/kg)

The enthalpy (and other properties) of saturated steam can easily be referenced using the tabulated results of previous experiments, known as steam tables *.(Gordon & Yon ,Engineering Thermodynamics 4th edition)*

2.2.1.3 Flash Steam.

Flash steam is produced when water pressure is reduced from high to a low pressure, then the water is at higher temperature than that of saturation temperature at low pressure. Thus this excess heat energy is released at low pressure in the foam of flashing and the steam thus produced is "Flash Steam".

2.2.1.4 Water Hammer

Water hammer is a liquid shock wave resulting from the sudden starting or stopping of flow. As steam begins to condense due to heat losses in the pipe, the condensate forms droplets on the inside of the walls. As they are swept along in the steam flow, they then merge into a film. The condensate then gravitates towards the bottom of the pipe, where the film begins to increase in thickness. The build up of droplets of condensate along a length of steam pipework can eventually form a slug of water which will be carried at steam velocity along the pipework. This slug of water is dense and incompressible, and when travelling at high velocity, has a considerable amount of kinetic energy. The laws of thermodynamics state that energy cannot be be created or destroyed, but simply converted into a different form. When obstructed, perhaps by a bend or tee in the pipe, the kinetic energy of the water is converted into pressure energy and a pressure shock is applied to the obstruction. Water hammer can significantly reduce the life of pipeline ancillaries. In severe cases the fitting may fracture with an almost explosive effect. The consequence may be the loss of live steam at the fracture, creating a hazardous situation. Water hammer is affected by the initial system pressure, the density of the fluid, the speed of sound in the fluid, the elasticity of the fluid and pipe, the change in velocity of the fluid, the diameter and thickness of the pipe, and the valve operating time *Ubi et el., 2010*

2.2.1.5 Steam Hammer

Steam hammer is similar to water hammer except it is for a steam system. *Steam hammer* is a gaseous shock wave resulting from the sudden starting or stopping of flow. Steam hammer is not as severe as water hammer for three reasons:

1. The compressibility of the steam dampens the shock wave
2. The speed of sound in steam is approximately one third the speed of sound in water.
3. The density of steam is approximately 1600 times less than that of water.

The items of concern that deal with steam piping are thermal shock and water slugs (i.e. Condensation in the steam system) as a result of improper warm up. *Ubi et el., 2010*

2.2.2 FUNCTIONS AND USES OF A STEAM BOILER

The main application of steam can be divided into humidifying/heating applications and motive/drive applications

1. Steam is used for energy storage, which is introduced and extracted by heat transfer, usually through pipes. Steam is a capacious reservoir for thermal energy because of water's high heat of vaporizations.
2. Steam is used in the generation of electricity. In most countries, about 86% of electric power is produced using steam as the working fluid.

3. In cogeneration steam is typically condensed at the end of its expansion cycle and returned to the boiler for reuse. However in cogeneration, Steam is piped into buildings to provide heat energy after it is used in the electricity generator cycle.
4. Steam is used for sterilization. Autoclaves, which use steam under pressure is used in microbiology laboratories and similar environments for sterilization.

5. Steam is used in agriculture for soil sterilization to avoid the use of harmful chemical agents and increase the soil health.

6. Steam is also used for domestic purposes like cooking of vegetables, steam cleaning of fabrics and carpet and heating of buildings.

7. In industries, a steam engine uses the expansion of steam in order to drive a piston or a turbine to perform mechanical work.

8. The superheated steam produced is used to drive a turbine for the production of electricity. *(Milton Beychok, 2009).*

CHAPTER THREE

3.0 DESIGN ANALYSIS, DESIGN CALCULATIONS AND MATERIAL SELECTION

3.1 DESIGN ANALYSIS

3.1.1 Mode of Operation

Before firing up the boiler, water is poured into the reservoir tank and flows into the heating section (water drum) through a non-return valve. The globe valve outlet controlling the water level at the heating section (water drum) is set to open. This is to ensure that water doesn't flow into the steam section (tank). When the capacity of the tank is reached, the globe valve is closed to ensure pressure build up during heating.

On firing, water in the lowermost drum(heating section) gets heated up as the fire is provided directly beneath the lower drum. The heated up water turns into steam and this steam is transferred into the steam section via internal steam tubes. The steam gets superheated in the steam section. The flow of water from the reservoir to the heating section (water drum) through a non-return valve which does not only serves the function of preventing water from flowing back to the reservoir during heating, but also ensures that water is continually fed to the heating section (main drum) by the opening of the valve when the pressure falls below a certain level as a result of depletion in the level of feed water at the heating section (water drum).

The water at the heating section (main drum) gets boiled and the steam is transferred to the steam section (middle drum) where it undergoes further heating. The chimney provides suction to the flue gases and hence aid in the successful pulling of the flue gases from the fire to the top of the top drum.

3.1.2 Features of the laboratory Steam Boiler, and it uses

The designed boiler consist of the following parts, the firing section, heating section, steam section , the reservoir, chimney(exhaust assembly) and the control panel.

1. **The Firing Section:** The design works with a gas fired unit hence, the firing unit consist of the gas burner and mountings for heating the lower section of the boiler. The base stands are also welded to this section to provide suitable support while in use.

2. **The Water drum**: This is the lowermost part of the boiler and it receives preheated water from the reservoir for onward heating. Having a diameter of 240mm and a length of 100mm, the water drum consist of flanges are welded to both of its sides. One flange comes in contact with the open flame and the other flange contains the seating arrangement for the middle drum.Water is fed to this drum by a non-return valve and a suitable outlet is provided via a globe valve to ensure water remains at the desired level and not overflow into steam drum (middle drum).

Plate 3.1 water drum

3. **Steam drum**:It is the middle portion of the boiler drum. The length of the steam is 110mm and diameter of 240mm. The steam drum consist flanges which are welded at some distance away from the edges to encourage turbidity of the flue gases that come from the lower drum before entering into the middle drum's tubes.The steam drum is fitted with suitable pressure relief valve and a pressure sensor for monitoring and regulating the pressure of the formed steam.
4. **The water reservoir:** Water is fed into the reservoir tank via the provided inlet and since during operation the flue gases flow through the tubes in this pipe, this preheat the water transferred to the main heating drum so as not to send cold water and reduce thermal shock.
5. **Flanges and Pipes:** The Flanges for inter-connecting each section of the boiler to the next is made of **0.15in** mild steel plates in which holes are drilled for the copper tubes.

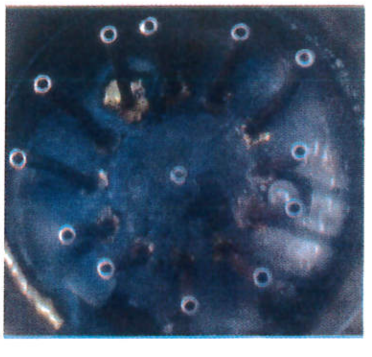


Plate 3.2 show the flanges in the water drum

6. **Non Return Valve:** This is used in the water line from the reservoir tank to the main heating section (water drum) so as to prevent entry of the boiling water from the lower drum to the preheating unit.

7. **Safety Valve:** A locally fabricated safety valve consisting basically of a spring loaded stopper with adjustable screw is used to ease out the pressure of the system when it exceeds the preset values.
8. **Globe Valves:**it is used in controlling the level of water at the lower tank and the flow of steam from the middle tank.
9. **Chimney:** It serves as a tunnel for expelling then burnt gases which is a product of combustion. The chimney is fabricated using mild steel and it is welded together to the reservoir. The length and diameter of the chimney is 250mm and 24mm respectively. The thickness of the mild steel is 1.50mm
10. **Fibre glass:** it serves as the lagging material. It is used for thermal insulation in the steam boiler to minimize heat loss.

Plate 3.3 fibre glass

11. **Pressure gauge:** It is located at the steam valve outlet of the steam boiler. It is used to measure the pressure at which the steam flows out of the steam boiler. It helps in the

investigation of the steam flow characteristic(volume, flow rate,) etc

Plate 3.4 pressure gauge

3.1.3 Design Consideration

The main and paramount objective of the steam boiler is to be able to generate the heat required for the conversion of water to steam, to serve as a suitable laboratory aids and academic teaching aid, to produce steam at a low pressure which can be used at the laboratory, minimizing the heat loss to the surrounding from the system (steam boiler) and dispose of the exhaust fumes through the chimney after utilization.

In the fabrication of the steam boiler, the design requirement includes:

- The globe valves should be provide so as to indicate the level of the water in the system(boiler)
- A temperature sensor to indicate the operating temperature.

A pressure gauge to indicate the amount of pressure in the system.

- A Safety valve to ease out the pressure of the system when it exceeds the preset values.
- The system will be lag in order to avoid heat loss

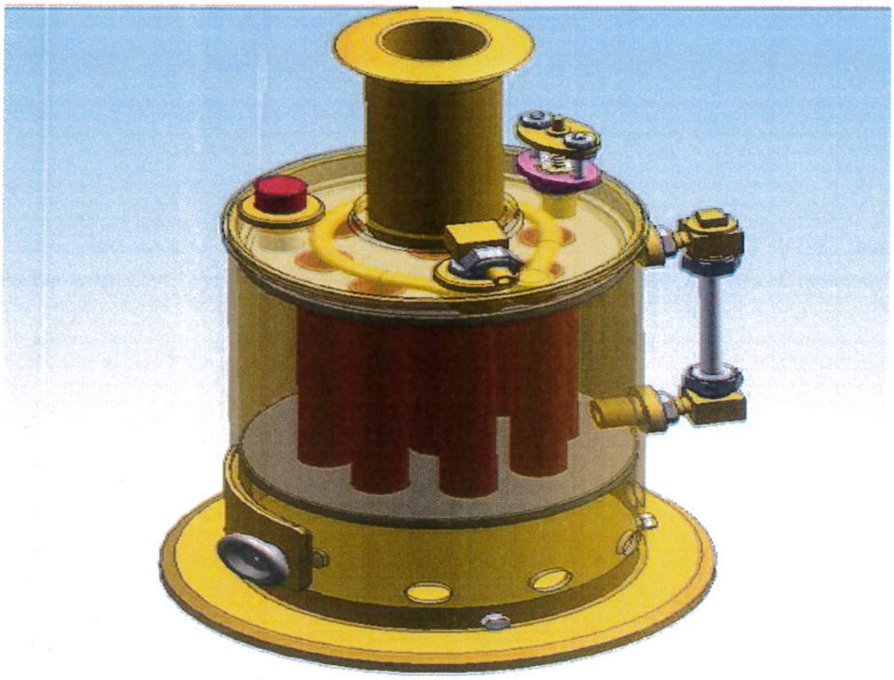


Plate 3.5 3D view of the boiler

3.2 DESIGN CALCULATION

Heat loss during conduction and convection (q)

$$Ql = dQ/dt = \frac{temperature\ difference}{Thermal\ resistance}$$

Thermal resistance R = ΔT/q = L/K

Where l=thickness

Q= heat flow rate

T= temperature

For steady heat transfer $q_c = \frac{dQ}{dt}$ which is a constant. The rate of heat conduction is given by: $Q_l = -kA\left(\frac{dt}{dr}\right)$--- (equation 1)

Where k constant thermal conductivity within the given temperature range

A(Area of a cylinder through which heat is transmiited) $= 2\pi r.L$ ....equation 1b

Considering a hollow cylinder as shown in Figure 3.1 below

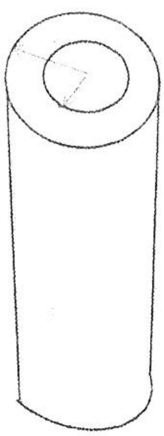


Fig 3.1

Let

r_1, r_2 = inner and outer radii respectivity T_1, T_2

= internal temperatures of inner and outer

Substitute equation 1b into equation 1

$$Q_l = -K.2\pi.r.L\frac{dt}{dr}$$

$$Q_l . dr = -K . 2\pi r . L \, dt$$

$$Q_l . dr = -2\pi r l . K \, dt$$

$$Q_l . \frac{dr}{r} = -2\pi l . K \, dt$$

$$Q_l \int_{r_1}^{r_2} \frac{dr}{r} = -2\pi l . K \int_{T_1}^{T_2} dt$$

$$Q_l In \frac{r_2}{r_1} = -2\pi l . K(T_2 - T_1)$$

$$Q_l In \frac{r_2}{r_1} = 2\pi l . K \ (T_1 - T_2)$$

$$Q_l = \frac{(T_1 - T_2)}{\frac{1}{2\pi l . K} \ In \frac{r_2}{r_1}}$$

$$Q_l = \frac{(T_1 - T_2)}{\frac{In^{r_2}/r_1}{2\pi l . K}}$$

Where $\frac{In^{r_2}/r_1}{2\pi l . K}$represents theresistance.

To obtain the heat loss of the cylinders, taking into consideration the insulation material used, we solve as follows making reference to the cylindrical section of the shells as shownin figure 3.2 below

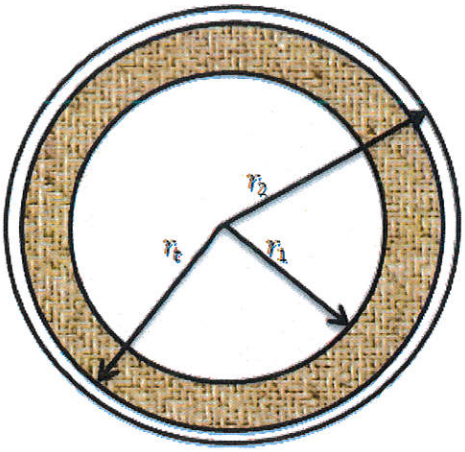


Fig3.2

Whereby:

r_1 = = radius of the inner shell(cylinder),

r_t= r_1 + thickness of the insulation material,

r_2 = radius of the outer shell,

T_1 = temperature at the surface of the inner shell,

T_2 = temperature at the surface of the fiber glass insulation,

T_3 = temperature at the surface of the outer shell,

t_{hf}= temperature of the hot fluid (water) flowing inside the cylinder,

$$k_1 = thermal\ conductivity\ of\ the\ inside\ layer\ 1,$$

$$k_2 = thermal\ conductivity\ of\ the\ outside\ layer\ 2,$$

t_{cf}= temperature of the surrounding

h_{hf}, h_{cf} = inside and outside heat transfer coefficients

For the inner part of the cylinder, the heat transfer is through convection is given by

$$q_c = h_{tf} A_1 (t_{hf} - T_1) = \frac{T_i - T_1}{\frac{1}{h_i A_1}} \; but \; A = 2\pi r . L$$

$$q_c = h_{tf} A_1 (T_i - T_1) = \frac{T_i - T_1}{\frac{1}{2\pi r_1 l h_{tf}}} \text{..............................equation 2}$$

After the inner section the heat transfer on the outside is through conduction, is given by:

$$q_c = \frac{T_1 - T_2}{\frac{1}{2\pi l k_1} ln \frac{r_t}{r_1}} \text{.............................. equation 3}$$

$$q_c = \frac{T_2 - T_3}{\frac{1}{2\pi l k_2} ln \frac{r_2}{r_t}} \text{.............................. equation 4}$$

the final heat transfer on the outside is through convection is given by:

$$q_c = h_{cf} A_2 (T_3 - t_{cf}) = \frac{T_3 - t_{cf}}{\frac{1}{2\pi r_2 \, . \, L \, . \, h_{cf}}} \text{..............................equation 5}$$

Making the temperature difference the subject of the formula in equations 2 to 5 gives:

$$t_{hf} - T_1 = \frac{q_c}{2\pi r_1 l h_{hf}} \text{.............................. equation 6}$$

$$T_1 - T_2 = \frac{q_c \, ln \frac{r_t}{r_1}}{2\pi l k_1} \text{.............................. equation 7}$$

$$T_2 - T_3 = \frac{q_c ln \frac{r_2}{r_t}}{2\pi l k_2} \text{.............................. equation 8}$$

$$T_3 - t_{cf} = \frac{q_c}{2\pi r_2 l h_{cf}} \text{............................equation 9}$$

Therefore, the heat transfer from $(t_{hf} - t_{cf})$

$$(t_{hf} - t_{cf}) = (t_{hf} - T_1) + (T_1 - T_2) + (T_2 - T_3) + (T_3 - t_{cf})$$

$$(t_{hf} - t_{cf}) = \frac{q_c}{2\pi r_1 \, l \, h_{hf}} + \frac{q_c \, In\frac{r_t}{r_1}}{2\pi l k_1} + \frac{q_c In\frac{r_2}{r_t}}{2\pi l k_2} + \frac{q_c}{2\pi r_2 \, l \, h_{cf}}$$

$$(t_{hf} - t_{cf}) = q_c\left(\frac{1}{2\pi r_1 l \, h_{hf}} + \frac{In\frac{r_t}{r_1}}{2\pi l k_1} + \frac{In\frac{r_2}{r_t}}{2\pi l k_2} + \frac{1}{2\pi r_2 \, l \, h_{cf}}\right) q_c$$

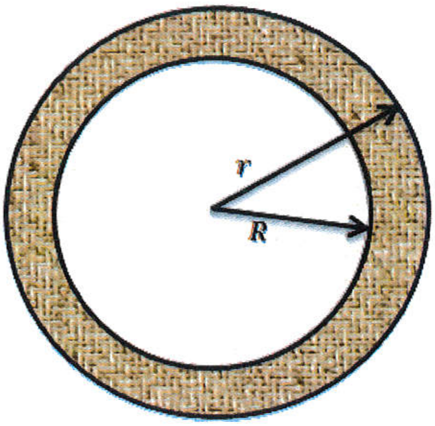
$$= \frac{(t_{hf} - t_{cf})}{\left(\frac{1}{2\pi r_1 \, l \, h_{hf}} + \frac{In\frac{r_t}{r_1}}{2\pi l k_1} + \frac{In\frac{r_2}{r_t}}{2\pi l \, k_2} + \frac{1}{2\pi r_2 l \, h_{cf}}\right)}$$

$$q_c = \frac{(t_{hf} - t_{cf})}{\frac{1}{2\,\pi\,l}\left(\frac{1}{r_1 \, h_{hf}} + \frac{In\frac{r_t}{r_1}}{k_1} + \frac{In\frac{r_2}{r_t}}{k_2} + \frac{1}{r_2 \, h_{cf}}\right)}$$

$$q_c = \frac{2\pi l \, (t_{hf} - t_{cf})}{\left(\frac{1}{r_1 \, h_{hf}} + \frac{In\frac{r_t}{r_1}}{k_1} + \frac{In\frac{r_2}{r_t}}{k_2} + \frac{1}{r_2 \, h_{cf}}\right)}$$

Insulation thickness (t)

When insulation is added to the inner shell, the outer surface will decrease in temperature and at the same time the surface area for convective heat dissipated will be increased.



where:

$$T_1 = inner\ surface\ temperature$$

$$T_0 = inner\ surface\ temperature\ of\ the\ surrounding$$

$$h_0 = convection\ at\ the\ outer\ boundary$$

$r - R$= thickness of insulation

the heat loss per unit length of the cylindrical shell through the insulation is given as:

$$\frac{q}{l} = \frac{T_{i-}T_0}{\frac{In\frac{r}{R}}{2\pi K} + \frac{1}{2\pi hr}}$$

$$= \frac{2\pi(T_{i-}T_{0)}}{\frac{In\frac{r}{R}}{K} + \frac{1}{hr}}$$

To obtain an optimum value of the heat loss, the first derivative of $\frac{q}{l}$ with respect to r to

be zero

i.e$\frac{\partial}{\partial r}\left(\frac{q}{l}\right) = 0$

$$let\ u = 2\pi(T_1 - T_0)$$

$$v = \frac{In\frac{r}{R}}{K} + \frac{1}{hr} \equiv \frac{1}{k}In\frac{r}{R} + \frac{1}{hr} \equiv \frac{1}{k}In(r - R) + \frac{1}{hr} \equiv \frac{1}{k}In\ r - \frac{1}{k}In\ R + \frac{1}{hr}$$

So that, $\frac{du}{dr} = 0$ and $\frac{dv}{dr} = \frac{1}{kr} - \frac{1}{hr^2}$

Therefore;

$$\frac{\partial}{\partial r}\left(\frac{q}{l}\right) = \frac{\left(\frac{1}{k}In\frac{r}{R} + \frac{1}{hr}\right)(0) - 2\pi(T_1 - T_0)\cdot\left(\frac{1}{kr} - \frac{1}{hr^2}\right)}{\left(\frac{1}{k}In\frac{r}{R} + \frac{1}{hr}\right)^2} = 0$$

By cross multiply, we have

$$=> -\ 2\pi(T_1 - T_0) \times \left(\frac{1}{kr} - \frac{1}{hr^2}\right) = 0$$

Dividing through by $-\ 2\pi(T_1 - T_0)$, we have

$$\left(\frac{1}{kr} - \frac{1}{hr^2}\right) = 0$$

$$\frac{1}{kr} = \frac{1}{hr^2}$$

$$kr = hr^2$$

Dividing through by r ;

$k = hr \equiv \frac{k}{h} = r$ *Whererdenotes the critical radius which is the optimum thickness to minimize heat loss.*

<u>Quantity of steam</u>

$x = \frac{h_g\ h_f}{h_{fg}}$ *from* $h_g = h_f + x\ h_{fg}\ x\ h_{fg} =$ enthalpy of vapour

3.2.1 APPLICATION OF FORMULAS AND EQUATIONS

Insulation thickness (t)

$$\frac{k}{h} = r$$

Thermal conductivity of the fibre glass, $k_1 = k = 0.0485$ w/mk

enthalpy of air surrounding h, $= 7.9 w/m^2$k (for air to mild steel)

$$therefore;$$

$$r = \frac{0.0485}{7.9}$$

$r = 0.00614$m

The thermal conductivity of mild steel is between 26 - 37.5 BTU/ (hr. ft. ° F)

Taking the average thus;

$$\frac{26 + 37.5}{2} = 31.75\ BTU/\ (hr.\ ft.\ °\ F)$$

But 1 BTU/ (hr. ft. ° F = 1.731 w/mk

$$k_2 = 1.731 \text{ x } 31.75$$

$$k_2 = 54.96 w/mk$$

HEAT TRANSFER IN THE STEAM BOILER

$$q = \frac{2\pi l\,(t_{hf} - t_{cf})}{\left(\frac{1}{r_1\,h_{hf}} + \frac{In\frac{r_l}{r_1}}{k_1} + \frac{In\frac{r_2}{r_l}}{k_2} + \frac{1}{r_2\,h_{cf}}\right)}$$

Where

$$length, l = 0.110m$$

$radius, r_1 = 0.120m$; $radius, r_2 = 0.150m$; $radius, r_l = 0.152m$

$t_{hf} = 112.84°C$; $t_{cf} = 27°C$

$$h_{hf} \equiv h_{cf} = 7.9 w/m^2 k$$

k_1 0.0485 w/m k

$$k_2 = 54.96\ w/mk$$

$$therefore;$$

$$q = \frac{2 \times \pi \times 0.120\,(385.84 - 300)}{\left(\frac{1}{0.120 \times 7.9} + \frac{In\frac{0.150}{0.120}}{0.0485} + \frac{In\frac{0.152}{0.150}}{54.96} + \frac{1}{7.9 \times 0.152}\right)}$$

$$q = \frac{64.721}{(1.054 + 4.600 + 0.0002408 + 0.833)}$$

$$q = \frac{64.721}{6.48724}$$

$$q = 9.976\ watt$$

To obtain the value for T_1, T_2, T_3

From equation 6

$$t_{hf} - T_1 = \frac{q_c}{2\pi r_1 l h_{hf}}$$

$$therefore;\quad T_1 = t_{hf} - \frac{q_c}{2\pi r_1 l h_{hf}}$$

$$T_1 = 385.84 - \frac{9.976}{2 \times \pi \times 0.120 \times 0.110 \times 7.9}$$

$$T_1 = 370.61k \quad ; \quad 97°C$$

From equation 7

$$T_1 - T_2 = \frac{q_c \, In \frac{r_t}{r_1}}{2\pi l k_1}$$

Therefore; $T_2 = \quad T_1 - \frac{q_c \, In \frac{r_t}{r_1}}{2\pi l k_1}$

$$T_2 = = \quad 370.61 - \frac{9.976 \, In \frac{0.150}{0.120}}{2 \times \pi \times 0.110 \times 0.0485} = 304.2k \quad 31.2°C$$

From equation 8

$$T_2 - T_3 = \frac{q_c In \frac{r_2}{r_t}}{2\pi l k_1}$$

Therefore; T_3 is equal to

$$T_3 = T_2 - \frac{q_c In \frac{r_2}{r_t}}{2\pi l k_1} = 304.2 - \frac{9.976 \, In \frac{0.152}{0.15}}{2 \times \pi \times 0.110 \times 54.96}$$

T_3 304.1k 31.1°C

3.3 MATERIAL SELECTION

For aneffective and successful performance, efficiency and profitability of an engineering project, it depends ultimately on the choice of materials that are used. The materials selected were based on the following design requirement.

(a) Mild steel (for construction of cylinder and chimney)

- Malleability
- Heat resistance at elevated temperatures
- Resistance to corrosion
- Weldability
- Low cost

(b) Tubes

- High thermal conductivity
- Malleability
- Resistance to corrosion
- Weldability
- Low cost

c) Insulation Material (Fibre glass)

- Low thermal conductivity
- Durability
- Low cost

3.4 COST ANALYSIS

3.41 Material Cost

S/N	MATERIAL DESCRIPTION	Quantity	Unit Price((₦)	Amount (₦)
1	Pressure and temperature Gauge	1	5,000	5,000
2	Steam Pipe	8	2,000	16,000
3	Pressure Hose	1	1,500	1,500
4	Mild steel sheet metal (2mm thickness)	Short length	9,500	19,000
5	Fibre glass	Little	4000	4000
6	Mild steel pipe	2m	5,000	10,000
7	Digital control panel	1	10.000	10.000
8	Burner	1	4000	4000
9	Aluminium sheet	Short length	4,000	4,000
10	Painting and finishing		10.000	10,000
11	Miscellaneous, transportation and others		25.000	25,000
			TOTAL	108,500

Table 3.1: table showing the material cost of the components

CHAPTER FOUR

4.0 FABRICATION AND TESTING

4.1 FABRICATION

The components of the steam boiler were fabricated and assembled one after the other. After each component was fabricated as described in item 3.1.2 of chapter three, the individual components were assembled. The assembly and fabrication were described as follows:

A three drum made of mild steel of 1.5mm thickness which form the major component of the chambers was measured and cut out. The water section of the drum is 100mm length and 240mm diameter, the drum of the steam section is 110mm with same diameter and the reservoir is 50mm. The flat plate of the same material is used for inter-connecting each section of the boiler to the next is made up of 0.15m mild steel plates in which holes were drilled copper tubes. The tubes are in the same level with the plate beneath the water chamber which pass through the steam section to the reservoir tank. It is 300mm above the plate separating the steam section from the reservoir tank. Also a non-return valve used to interconnect the plate separating the reservoir tank from the steam section to the plate separating the water section from the steam section. The valve is in the level with the plates.

A hole was punched on the plate separating the water and steam section from each other for passage of steam. A burner was welded beneath the water chamber plate. The control panel is bolted on the steam chamber and safety valve consisting of a spring loaded stopper with adjustable screw for pressure control Finishing operation such as body filing, chrome spray and painting . Fibre glass was used for lagging and aluminum was used for the covering.

Plate 4.1 The designed and fabricated steam boiler

4.1.2 Maintenance

The following maintenance tasks are to be observed regularly in the cause of the usage and operation of the steam boiler:

1. Chemical cleaning: Water treatment is necessary to aid in the removal of oxygen in the feed water and prevents corrosion. The addition of an oxygen scavenging chemical (Sodium Sulphide, hydrazine or Tannin) will remove oxygen in the feed water and prevent corrosion (Spirax Sarco website, 2009). The chemical cleaning process for a steam boiler removes pollutant and impurities that impedes the transfer of heat within the generator that may result in system failure. Hot alkaline chemical cleaning can also be used to remove oil, grease and other protective coatings that were necessary during the fabrication of the steam boiler but will act as pollutants and impurities during operation (Chris Passas, 2009)
2. Flushing with water: Residual pollutant and impurities from the fabrication of the steam boiler include metal scales, welding slag, oil and dirt. Chemical cleaning removes metal scale and corrosives, but flushing the steam boiler with water can remove simpler debris such as dirt and sand.
3. Cleaning of the burner and ensure that the valves are free from dirt.

4.1.3 Safety

During the design and fabrication stage of the steam boiler, the failure concept has been brought to a minimum taking Murphy's Law into consideration. The following safety procedures were observed in the design and fabrication of the steam boiler as well as safety during its operation:

i. The chimney was constructed in such a way that it is above an average person's height to prevent inhaling of the exhaust gases during its operation.

ii. A globe valve was incorporated to know the water level of the boiler.

iii. A safety valve consisting basically of a spring loaded stopper with adjustable screw is used to ease out the pressure of the system when it exceeds the preset values

4.1.4 Safety Measures

The safety measures to be carried out regularly upon operation include:

i. Test for methane gas linkage at the hose and burner section.

ii. Remove dirt, soot or corrosion from the burner and boiler.

iii. Check the system temperature and panel reading on the panel to ensure that it is operational so as to enable the monitoring of the temperature of the system.

iv. The globe valve (outlet valve) should be kept opened when water is poured through the chimney.

4.2 TESTING

Upon testing, the steam boiler produced steam required at an efficiency of 78.5% when the boiler was fired. The following parameters were also gotten after testing the steam boiler.

i. Temperature of the combustion chamber during operation: 169

ii. Pressure gauge reading during the discharge of steam: 1.52bar

iii. Pre-heating time before steam production: 10minutes 50 seconds

$$heat\ gained\ by\ water = steam\ generated = m_w\ C_w \Delta T = (m_w - m_r)(h_f - h_g)$$

$$m_r = mass\ of\ water\ remaining$$

$$m_w = density \times volume = 1000 \times 0.002 = 2kg$$

$$note{:}\ 2litre\ of\ water\ was\ used\ and\ was\ heated\ for\ 1hr$$

$$Heat\ gained\ by\ water = 2 \times 4.2\ (385.84 - 299)$$

$$= 729.456\ KJ$$

$$Heat\ generated\ by\ steam = = h_f\ at\ 27°C \quad and\ h_g\ at\ 112.8°C$$

$$mass\ of\ water\ remained\ after\ heating = 1.6kg$$

$$(2 - 1.6)(470 - 111.9) = 0.4 \times 358.1 =$$

$$steam\ generated = (2 - 0.4)(470 - 111.9)$$

$$= 1.6(470 - 111.9)$$

$$= 572.6KJ$$

$$Efficiency = \frac{steam\ generated}{heat\ gained\ by\ water} \times 100\%$$

$$= \frac{572.6}{729.456} \times 100\% = 0.785 \times 100\% = 78.5\%$$

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This project presented a successful design and fabrication of the steam boiler. The burner used produced sufficient heat at a temperature of to convert water into pure steam. The steam is delivered at a pressure of 1.52bar .The efficiency of the boiler obtained is 75.8% at.

5.2 RECOMMENDATION

The following are the recommendations:

i. An alternative source of flue gas expulsion.

ii. Stainless steel should be used as it possess better material property requirements that mild steel when cost is not a constraint.

iii. An alternative outlet valve installed to discharge the water remaining in the boiler after used.

iv. A water pump to be installed to pump water into the preheating section automatically.

REFECENCES

- Abubakar 2010, "Design and Fabrication of Water Heating System for Food Drinks and Pharmaceutical Industries using local material". PGD/MECH/2007/517 Mechanical Engineering Department FUT Minna.
- Babu et al., (2016) "design and construction of a pressing steam boiler"
- Boulton and Watt **Haycock and wagon top boilers**
- F.J. Gutiérrez Ortiz, "Modelling of fire-tube boilers". Applied Thermal Engineering, Vol. 31, 3463-3478, 2011
- G.A. Ikechukwu (2004), A fabricated fire tube boiler was design and fabricate
- Geometry", International Journal of Innovative Science, Engineering & Technology, Vol. 1 Issue 9, ISSN 2348 – 7968, 2014.
- Gordon and Yon, Engineering Thermodynamics, 4th Edition
- Heat and mass transfer (fifth edition) by Er R.K RAJPUT
- M. A. Waheed et al.,2016 "Developmental design of a laboratory fire tube steam boiler
- OCHI VICTOR, ROWLANDS DAVID OLUSINA, UBI ATEB PASCHAL, and UCHOLA LAWRENCE DESIGN, FABRICATION AND TESTING OF A STEAM GENERATOR NOVEMBER, 2010
- P. Negi, Dr. A. Gupta, V. Kumar, "A Review: Heat Transfer Enhancement in Boiler Tube Using Different

- Xinhui Yang 2014 Design and Research for a Boiler Steam Drum Control System Based on PLC
- Woodruff LD , Bounkeo JM, Brannon WM , Dawes KS, Barham CD , Waddell DL , Enwemeka CS.