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A REVIEW OF THE DESIGN AND ANALYSIS OF A FIRE TUBE BOILER

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Abstract: A boiler is a closed vessel in which water under pressure is transformed into steam by the application of heat. In the boiler furnace, the chemical energy in the fuel is converted into heat, and it is the function of the boiler to transfer this heat to the contained water in the most efficient manner. The boiler must be designed to absorb maximum amount of heat released in the process of combustion. This heat is transferred to the boiler water through radiation, conduction and convection. The relative percentage of each is dependent upon the type of boiler, the designed heat transfer surface, and fuel. This review from related literature focus on the design and analysis of a fire tube boiler which are internally fired, horizontal and natural circulation boiler. Example is the Lancashire boilers which are reliable and bear over load. However, they are bulky and initially raise steam very slowly. Efficiency of the boiler is about 65%–70%. This research discuss the increase in the efficiency of a fire tube boiler through 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 emission reduction through usage of high grade fuel and incorporating heat exchangers that will utilize the flue gasses.

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INTRODUCTION

Fire tube boilers consist of a series of straight tubes that are housed inside a water-filled outer shell. The tubes are arranged so that hot combustion gases flow through the tubes. As the hot gases flow through the tubes, they heat the water surrounding the tubes. The water is confined by the outer shell of boiler. To avoid the need for a thick outer shell fire tube boilers are used for lower pressure applications. Generally, the heat input capacities for fire tube boilers are limited to 50 mbtu per hour or less, but in recent years the size of fire tube boilers has increased.

Fire tube boilers are subdivided into three groups. Horizontal return tubular (HRT) boilers typically have horizontal, self-contained fire tubes with a separate combustion chamber. Scotch, Scotch marine, or shell boilers have the fire tubes and combustion chamber housed within the same shell. Firebox boilers have a water-jacketed firebox and employ at most three passes of combustion gases.

Most modern fire tube boilers have cylindrical outer shells with a small round combustion chamber located inside the bottom of the shell. Depending on the construction details, these boilers have tubes configured in either one, two, three, or four pass arrangements. Because the design of firetube boilers is simple, they are easy to construct in a shop and can be shipped fully assembled as a package unit.

These boilers contain long steel tubes through which the hot gases from the furnace pass and around which the hot gases from the furnace pass and around which the water circulates. Firetube boilers typically have a lower initial cost, are more fuel efficient and are easier to operate, but they are limited generally to capacities of 25 tonnes per hour and pressures of 17.5 kg per $cm.^2$ Boilers mix air with fuel to provide oxygen in the combustion process. For safety reasons, a small amount of additional or "excess air" is always provided to assure that all fuel is burned inside the boiler [Stultz, S.C. and J.B. Kitto. (1992]. By operating a boiler with a minimum amount of excess air, stack heat losses can be decreased and the combustion efficiency can be increased. But, unnecessary amount of excess air can lead to [S. Krishnanunni (2012]:

A fire tube boiler is a type of boiler in which hot gases from a fire passes through one or more tubes running through a sealed container of water. The heat of the gases is transferred through the walls of the tubes by thermal conduction, heating the water and ultimately creating steam. The fire-tube boiler developed as the third of the four major historical types of boilers low-pressure tank or "haystack" boilers, flued boilers with one or two large flues, fire tube boilers with many small tubes, and high-pressure water-tube boilers. Their advantage over flued boilers with a single large flue is that the many small tubes offer far greater heating surface area for the same overall boiler volume. The general construction is as a tank of water penetrated by tubes that carry the hot flue gases from the fire. The tank is usually cylindrical for the most part being the strongest practical shape and this cylindrical tank may be either horizontal or vertical.

The process of designing the Lancashire boiler involves developing a conceptual physical geometry, making necessary calculations from which dimensions and other deductions can be made, and finally, developing a working drawing , analyzing with software. There are several researchers working on fire tube boiler and its efficiency. As per the present market condition, there are few fire tube which can be used for steam generation. So the efficiency of Lancashire boiler can be analyzed with the help of performance parameters and this analysis can be used for improvement of boiler efficiency.

Lancashire boiler is one of the type of fire tube boiler, it is horizontal smoke tube boiler with single furnace and three pass boiler. It is placed in horizontal position over a brick work or saddle support it is partly filled up with water. The water level inside the shell is well above the furnace tubes. Fire-tube boilers are widely used for modest steam output at low and medium pressures. They can either deliver hot water or steam for heating and technological purposes. In the past few years, improvement in boiler designs and more efficient fire-tube layout have resulted in more compact, less costly packages which are more accessible for cleaning and inspection [D. Annaratone2008]. Accurate prediction of heat transfer in the boiler is of significant importance for safe and economic operation [J. Taler,1992]. Several numerical and experimental studies [B.J. Huang,1998] have been performed to understand the thermal-hydraulic characteristics of conventional boilers. In the past, traditional methods relied heavily on expensive experimentation and the building of scaled models, but now a more flexible and cost effective approaches are available through greater use of mathematical modeling and computer simulation [M. Orstnerhof,2006]. The purpose of this work is the elaboration of a calculation program in order to estimate the heat transfer between the combustion gases and the boiler internal surfaces in 4-pass fire-tube boiler under different operating conditions. At these surfaces, an energy balance is established considering both radiation and convection heat transfer. Therefore, a set of simplifications may be considered in order to reduce the boiler complexity [B. Leckner,2000]. The boiler passes are sliced into elementary sections in the gas flow direction. Each element represents isothermal gas volumes enclosed by isothermal surfaces. The plug-flow furnace model [Truelove,1993] is used to simulate the heat transfer characteristics in the boiler. This model is judged more appropriate to predict the peak heat flux density and thermal parameter profiles. At the water side, a set of empirical correlations are selected in order to simulate the boiling heat transfer. The modeling validation has been made by comparing the calculated gas temperatures exiting the boiler with the measured ones for steady-state operating conditions. The comparison shows that the calculated results are in good agreement with the boiler operating data. In addition, a qualitative analysis has been made to investigate the operating pressure effect on the boiler thermal behavior.

METHODOLOGY

A boiler shall satisfactorily withstand such pressure without appreciable leakage or undue deflection or distortion of its parts for at least ten consecutive minutes. If the test is not satisfactory, the working pressure allowable by calculation shall be suitably reduced,

Factors considered in the design methodology are:

1. Suitability of the material for the working conditions in service, considering characteristics such as; appearance, thermal conductivity, rate of emissivity, strength, stiffness, creep, etc.
2. Availability of the material: the ease at which the materials are seen or purchased in the market.
3. Workability of the material: considering possible methods of processing material selected into desired shape such as; weldability, machinability, formability, and workability.
4. Expected load or force as well as adequate strength in conformity so as to function satisfactorily without failure.
5. Cost of the material (economic consideration).

Detailed Design

Having completed the material selection for the fire-tube boiler, the design of the various parts of the boiler is typified by the following features;

- The volumetric boiler pressure vessel (tank or shell).
- The furnace.
- The lire-tube.
- The return chamber.
- The smoke stack.
- Actual volumetric capacity of the boiler.
- Pressure gauge.
- Temperature gauge.
- Safety valve.
- Thermal stresses and creep analysis.

Review of Related Literatures

F.J. Gutiérrez Ortiz Developed a model for the analysis of a fire tube boilers performance, The model is based on the principle of mass, energy and momentum conservation. In the model he considered economizer, the super heater the firepart and the water/steam part. In his design a 800HP fire tube boiler burning fuel was simulated to test the boilers performance by varying the operating conditions using a pulse and step change in fuel and steam flow-rate as well as simulating a start up from the beginning up to achieve a steady state. To build a model for a system by physical principles, it is necessary to define inputs and outputs. For a fire-tube boiler, the inputs are design parameters (boiler geometry and elements optionally incorporated as an economizer, a superheater or a degasifier) and operational parameters, such as the feed water, fuel and air flow-rates and the steam valve position), fuel and ambient temperature and pressure. The outputs are performance parameters such as temperatures (boiler water, flue gas, saturated and superheated steam), pressures (inside water phase boiler and steam phase boiler), steam flow-rate, level or liquid volume, composition of flue gas and global boiler efficiency. Moreover, there may be other outputs depending on the complementary elements disposed as heat recovery by flashing of blowdown, degasifier, heat exchanger, conditioning of the steam through a superheater or the feed water by an economizer. These other parts of the fire-tube boiler are after taken into account. Next, the modeling will be focused on the aforementioned two parts of the fire-tube boiler. He concluded that his proposed model predicted a dynamic performance that are in qualitative agreement with data obtainable from literature.

G.A. Ikechukwu fabricated a fire tube boiler and tested it 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 or norms. It is an indicator for tracking day-to-day and season-to-season variations in boiler efficiency and energy efficiency improvements. The result in his work is a torque produced at a steam pressure of 1.5bar and a steam temperature of 111.40C also raising the temperature of the water from 300C to a generated steam quantity of 61.34kg/hr, with a diesel quantity of 5.2Htres/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%. Good boiler design practices must take into account the operation of the boiler and not simply the heat transfer, parameters that a good boiler design addresses include; a. sample furnace volume must be included to absorb a) significant portion of Radiative heat transfer and allow the low NOx burner designs to function. b.) Optimized pressure drop across the boiler convective passes, the pressure drop determines the fan size required for the boiler application. c.) Ample steam storage and steam height.

A.Rahmani et al In this paper, the heat transfer in 4-pass 500HP fire-tube steam boiler is numerically investigated. A calculation program is carried out in order to simulate the heat transfer characteristics between the hot gases and the boiler tube internal walls. Especially, the heat flux densities and the corresponding wall temperatures for different operating conditions. On these surfaces, an energy balance is established taking into account the radiation and the convection heat transfer. The model validation consists in comparing the predicted outlet gas temperature with the operating data of the 500HP fire-tube boiler for several steady-state conditions. The comparison shows that the calculation results are in good agreement with the boiler operating data. Furthermore, a sensitivity study has been carried out to investigate the operating pressure effect on the boiler thermal performances.

In his study a numerical simulation of a 4-pass fire-tube boiler was performed using a coded computer program. The modeling approach consists of subdividing the boiler tubes into elementary volumes in the gas flow direction. The gas fuel combustion and heat transfer laws from hot gases to the boiling water are taken into account according to adequate correlations. The heat exchange between the combustion gases and the boiler internal walls is therefore estimated according to a numerical scheme. The calculated results have been compared to the boiler operating data for different steady-state regimes, and good agreement is generally obtained. The operating pressure effect on the boiler heat transfer characteristics has been investigated. The calculation shows that, the prevailing mechanism of heat transfer in the 4-pass fire-tube boiler is convection, which accounts for over 80%.

J. Ganan et al explain in his work that thermal power installations emit various polluting matter to the atmosphere that contribute to the greenhouse effect and the deterioration of the environment. The main pollutants emitted to the atmosphere in these equipment are Carbon monoxide (CO), Hydrocarbon (HC), Nitrogen Oxides (NOx), Carbon dioxide (CO2) and Sulphur Oxide (SO2). Due to the high contamination of these gases, environmental agencies impose some maximum emission levels. The emission of pollutants has its origin in the resulting gases of the combustion process. Three fundamental elements can be found in this process: fuel, comburent and activation energy. In this study the evaluation of the optimum operation conditions for two three-pass fire tube boilers, connected in parallel and using gasoil C was developed address the problem.

Apasi et al analyzed the heat losses on a fire tube boiler as it affects the efficiency of the fire tube boiler,The various losses are

(1)**Percentage of heat loss in dry flue gas per kilogram of fuel**

The temperature of flue gas is above 150^{0}c,But excess of it will amount to heat loss.

$$\frac{m\,c[Tg - Tb]X\,100}{GCV\ of\ fuel}$$ ……………………………………………[1]

(2) **Percentage heat lost in moisture present in fuel**

$$\frac{m[hsup - h]X\,100}{GCV\ of\ fuel}$$ but hsup = enthalpy of superheated steam ………………[2]

(3)**Percentage heat lost to steam formed by combustion of hydrogen per kg of fuel.**

$$\frac{(9H_2 + M)[h + cp(tg - t) - h]X100}{GCV\ of\ fuel}$$ ………………………………………[3]

(4) Percentage heat lost due to incomplete combustion of carbon to carbon monoxide

This usually occur due to insufficient supply of oxygen

$$= \frac{mc\,X100}{GCV\ of\ fuel}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[4]$$

where m = mass of carbon monoxide in flue gas per kg of fuel and c = calorific value of carbon monoxide

(5) Percentage of heat loss due to Blow down

Water evaporates continuously leaving behind the salts in the boiler. This leads to continuous increase in the concentration of these salts in the boiler drum which requires regular blow down and results in wastage of fuel.

$$= \frac{m\,X0.02\,X\,h\,X\,100}{Mf\,X\,CV} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots[5]$$

(6)Heat lost due to radiation is the differences between heat supplied per kilogram of fuel and heat utilized/heat lost, It occur due to the transfer of heat from the side walls of the boiler to outside. These are fixed losses and are assumed to be 1% or 2% as per BS 845,They also the unaccounted heat losses.

(7) Mass of dry flue gas

= mass of $[C_3 + H_6 + O_2] + N_2$ in air supplied for combustion.

Net efficiency of the boiler

= 100% − **TOTAL LOSS**% [in percentage]

In his analysis he explained that the maximum heat lost is obtained from losses in flue gas and losses from unburnt fuel ,this cannot be unconnected with poor supply of oxygen. The efficiency of the boiler at less than 70% shows a low efficiency, Therefore the introduction of zirconium oxygen sensor was suggested to reduce these losses and increase the boiler efficiency.

M. A. Waheed et al., The laboratory steam boiler designed was 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 subjected to temperature and pressure variations were conducted in the theoretical framework of the laboratory fire-tube steam boiler. Dimensions of major and secondary parts were estimated from computations from the theoretical framework and 3D modelling process for the steam boiler was then carried out to present various working drawings of the steam boiler for possible construction. Conclusively, a simple laboratory fire tube steam boiler is herein presented for fabrication, testing and further improvement. Production of a simple steam boiler of this sort will enable the availability of portable and affordable steam boilers for steam generation processes, especially in school laboratories.

P. Kumar et al. According to him Pressure vessels are always works under certain pressure and temperature along with contain sometime lethal substances which are hazardous for both human and environment. Considering this, safety implications and hazards arising from the operation of pressure vessels, there is an obvious need to standardize engineering and fabrication practices. To assure minimum safety standards, several design codes have prepared and developed. Design of pressure vessel can be finished quickly by applying numerous calculations in software. The drawing process was simpler associated to the software. This study only investigated a part of parameters design. There are other parameters that are not considered such as thermal loads, wind loads, seismic load, transportation load, erection load and fabrication methods etc. however this insufficiency can be overcome by mastering software.

Mechanical design of pressure vessel had been done using graphical based software. Drawing process was very easy and input can be entered in the same screen. The result fully complied with standard code and had been employed on practical design of pressure vessel.

DESIGN PROCEDURE FOR A FIRE TUBE BOILER

In the design of multitude fire boiler in this report, many things
were considered when analyzing the system:

• Design specification
• Design consideration
• Detailed design
• Technological details.

Design Specification

The diesel burner used to heat up the furnace of the fire-tube must have a known specification as following specification.

• Mass firing rate
• Orifice diameter for exit
• Motor rating

The burner is connected to the furnace by the means of both external and internal circular flange (a projecting collar, rim, or rib on an object for fixing it to another object, holding it in place or strengthening it. Flanges are often found on pipes and shafts) of both the burner and furnace respectively. The flange specifications are given as follows;

• Outer diameter of circular flange
• Inner diameter of circular flange

• Number of opening for bolts and nuts of flange
• Diameter of the bolts and nuts used.

Design Consideration for Material Selection.

For an intelligent design to be done, the knowledge of the materials available as well as the properties they posses are very important For the selection of the proper material to be used for the design of the fire-tube boiler, we shall consider the factors which affect the choice of material selected and used for design and there reasons.

Thermal Design Calculation

The thermal design calculation involves the heat transfer from all heat sources located in the boiler as outlined:

Fire Tubes Heat Transfer Calculation

• Furnace heat transfer calculation.
• Fire-tubes heat transfer calculation
• Return chamber heat transfer calculation.
• Smokestack calculation

The furnace heat transfer analysis involves the following. The sensible heat loss of flue gas at furnace exit are:

Radiation heat transfer from furnace

Convective heat transfer from furnace

Conduction heat transfer from furnace

Efficiency of furnace

Thermal efficiency of the furnace by direct method;

Thermal efficiency of the furnace =

$$\frac{\text{Heat output from the burner}}{\text{Heat in the fuel consumed heat input}}$$

x

100.................................[6]

RESULTS AND DISCUSSIONS

According to Apasi et al, His analysis has shown that maximum heat lost is obtained from losses in flue gas and losses from unburnt fuel ,this cannot be unconnected with poor supply of oxygen. The efficiency of the boiler at less than 70% shows a low efficiency, Therefore the introduction of zirconium oxygen sensor was suggested to the Department to reduce these losses and increase the boiler efficiency. F.J. Gutiérrez Ortiz Developed a model for the analysis of a fire tube boilers performance, The model is based on the principle of mass, energy and momentum conservation He concluded that his proposed model predicted a dynamic performance that are in qualitative agreement with data obtainable from literature. From the reviewed literature it is observed that the performance of firetube boiler has improved with time and advancement in technology and this is achievable through minimizing heat lost and emission, and the use of high grate fuel, different types of fuel and simulation of inputs and outputs parameters in a design model for a better boiler design.

CONCLUSION

This present review of design and analysis of a fire tube boiler draws the following facts. Comparison between the fire-tube boiler performances when running with different fuels, especially when considering the firing of a new fuel in given equipment. Another application may be the tests facilities used in research projects dealing with oxy-combustion process. The results showed an absolute improvement of the overall thermal efficiency which is important for plants of that size since the resulting benefits were lower fuel consumption. Boilers and components in hot conditions, such as wall tubes, cylinders, valves and channels have a limited lifespan; therefore preventive condition monitoring is very important. To take the right action at the right time and to optimize the use of boilers means preventing leaks, accidents and interruptions for the sake of safety. Past literature have discuss the need to improve the efficiency of a fire tube boiler through minimizing heat lost and emission, this is achievable through the use of high grate fuel, different types of fuel and simulation of inputs and outputs parameters in a design model for a better boiler design.

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