SIMULATION STUDY ON COMBUSTION CHARACTERISTICS OF WATER TUBE BOILER WITH DIFFERENT TYPE OF FUEL

by

SITI SUHAILI BINTI SHUIB

16280

Bachelor of Engineering (Hons.)

(Mechanical)

JANUARY 2016

Universiti Teknologi Petronas,

32610, Seri Iskandar,

Perak Darul Ridzuan.

January 2016

CERTIFICATION OF APPROVAL

Simulation Study on Combustion Characteristics of Water Tube Boiler with Different Type of Fuel

By

Siti Suhaili Binti Shuib

16280

A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS
In partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL)

Approved by,

…………………….
(IR. DR. SUHAIMI HASSAN)

UNIVERSITI TEKNOLOGI PETRONAS
SERI ISKANDAR, PERAK
January 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

…………………………………………….

(SITI SUHAILI BINTI SHUIB)

ABSTRACT

This paper is to study the type of boiler use in industry. Water tube type boiler is commonly used for heating and power generation in the industry. The operation of water tube boiler from fuel selection, fuel separation, combustion and generation of steam requires deep knowledge and skill in order to ensure smooth running of boiler system. Combustion, occurs in the combustion chamber is considered critical part in boiler operation in converting fuel energy into chemical energy. Therefore, simulation study on combustion phenomena in the combustion chamber is essential in determining heat transfer rate from hot gas to the boiler tubes.

The performance of the boiler hinges on how efficient is the rate of heat exported by the fluid to the heat being supplied by the fuel. Therefore the improvement of heat transfer across the boiler tube give a massive contribution on the boiler efficiency. Greatly, boiler efficiency hence is effecting by performance of combustion chamber. CFD simulation software is used to investigate the combustion phenomena inside the combustion chamber for water tube boiler existed in MLNG PETRONAS, Bintulu. By using different type of fuel, it is obvious that each fuel manifest different temperature contour that give different characteristic for the fuel reaction as well as the fuel performance.

Based on the simulation result, it is proven that using different type of fuel will result in different temperature distribution as well as affect the performance of the combustion chamber. Using natural gas gives less effective contour compared to diesel. However, there are some other factors that need to be considered in choosing the fuel for industry usage.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my highest praise and gratitude to Allah SWT for His mercy, permission and guidance to myself, His humble slave throughout the Final Year Project phase by Universiti Teknologi PETRONAS. I would like to express my biggest gratitude to all the people around me that have helped me in every single way they could possibly do. First and foremost, I would like to thank my supervisor, Ir. Dr. Suhaimi bin Hassan, for his persistent determination to guide me, his commitment to support me and also his words of wisdom that give me strength to continue develop this project and hit the goals that we have set to achieved. On top of that, he consistently gives constructive comments and allow me to work in my own way to develop the project and ensure it is a success.

It would also not have been possible to execute the project without the support given from Universiti Teknologi PETRONAS and its dedicated staff and also faculty members of Mechanical Engineering Department for providing the necessary tools for me to proceed with the development of the project. I would like to express my biggest thank you for giving myself the opportunity to learn and develop my skills in so many ways during my 5 years of study and I would not be who I am today without this opportunity. On the other hand, I would also like to thank the Head of Mechanical Engineering Department, A.P Ir. Dr. Masri bin Baharom and all the lecturers for their guidance, vast knowledge shared and also persistently give their effort to bring the very best out of me and other students.

Last but not least, I would like to express my heartfelt gratefulness to my family who gave me continuous support in every aspect of my life, whether it is mentally, monetary, spirit and so much more. Not to forget my fellow friends. They have thought me a lot of knowledge that they acquired and they also played important roles in completing this project, especially for reminding me about the dateline of any parts of the project and also giving advice in improving things. Their willingness and support had made my work easier and less burden.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL .... **ii**

CERTIFICATION OF ORIGINALITY .... **iii**

ABSTRACT .... **iv**

ACKNOWLEDGEMENTS .... **v**

CHAPTER 1 .... **1**

INTRODUCTION **1**

1.1- Background 1

1.2- Problem statement 4

1.3- Objective 4

1.4- Scope of study 5

CHAPTER 2 .... **6**

THEORY & LITERATURE RIVIEW **6**

2.1- Boilers 6

2.2- Boiler Types and Classifications 7

2.3- Key element of a boiler 7

2.4- Water-tube Boilers 8

2.5- MLNG New Boiler 10

2.6- Energy 11

2.7- Fuel type 11

2.8- Combustion 12

2.9- Combustion chamber 13

2.10- Efficiency of boiler 13

2.11- CFD Modeling 15

2.12- The eddy-dissipation model 17

CHAPTER 3 .... **18**
METHODOLOGY **18**
3.1- Project Activities 18
3.2 - The Gantt chart and Key Milestone 20
3.3 - Tools 22
CHAPTER 4 .... **23**
RESULT AND DISCUSSION **23**
4.1 – Experimental Result and Discussion 23
4.2- Simulation Parameter 24
4.3- Design of combustion chamber 25
4.4- Material Specification 27
4.5- Mesh and boundaries report 27
4.6- Temperature contour 28
4.7- Water tubing surface temperature 29
4.8- Furnace exit gas temperature 30
4.9- Combustion air and fuel flow rates 31
4.10- Heat transfer through sections 33
CHAPTER 5 .... **35**
CONCLUSION AND RECOMMENDATION **35**
5.1- Relevancy to Objectives 35
5.2 - Future work for expansion and continuation 36
REFFERENCES **37**

LIST OF FIGURES

Figure 2.1- Different Part Of The Heating System [5] 6
Figure 2.2- Water Tube Boiler [5] 8
Figure 2.3- Combustion Chamber In Typical Water Tube Boiler [1] 13
Figure 3.1- The overall project flow progress 18
Figure 3.2 – Methodology Flow Of The Project 19
Figure 4.1- Design of Combustion Chamber of boiler for simulation 25
Figure 4.2 - Sizing of combustion chamber design for simulation purpose. 26
Figure 4.3 - Temperature distribution through Y-Z burner planes firing 28
a) natural gas b) diesel 28
Figure 4.4 - Temperature distribution of water along water tubing using firing fuel a) natural gas b) diesel. 29
Figure 4.5 - Furnace exit gas temperature for fuel natural gas and diesel 30
Figure 4.6 - Typical air velocity contour for combustion chamber simulation. 31
Figure 4.7 - maximum velocity reach inside the combustion chamber for natural gas and diesel. 32
Figure 4.8 - Illustration of section inside combustion chamber 34
Figure 4.9 - Surface heat transfer profile for boiler combustion chamber firing natural gas vs. diesel. 34

LIST OF TABLES

Table 1.1- Step in Conducting the Project.. 5
Table 2.1- Tendering process and schedule for MLNG new boiler 10
Table 2.2- Summary Of CFD Simulations And Their Sub-Models For Oxy-Fuel Combustion [11]... 16
Table 3.2- Project Gantt Chart... 20
Table 3.3 – Software use for project completion 22
Table 4.1- MLNG New boiler performance data 23
Table 4.2 - Boiler data for simulation purpose.. 26
Table 4.3 - Material specification for combustion chamber... 27
Table 4.4 - Mesh and nodes design for simulation.. 27

CHAPTER 1

INTRODUCTION

1.1- Background

Boiler is a pressure vessels which produce steam and heat the water. Then it will provide the steam to a building or to some application. Heat sources for the boiler can be from heating of natural gas or fuel oil. Commonly, commercial building will used natural gas for their sources. Other than that, there are another type of boiler that can be used for example oil fired burners and electric resistance heaters. Boiler also used some application such as for laundries, steam driven equipment or for cooling absorption [1]. One of the phenomena happen inside the boiler is called combustion. This combustion will happen in combustion chamber in one boiler where the oxygen is combined with fuel elements. The efficiency of one boiler is affecting by many factor, one of the biggest factor is the combustion system. Combustion system efficiency is affecting by many factors such as the parameters used for the boiler, fuels, and the working fluid temperature. The radiative heat transfer to the water effect the ratio of CO_2 circulation, which is effecting it performance as well [2]. A comparison will be conducted between the performance of a water-tube boiler utilizing difference fuel for combustion and will be studied the combustion phenomenon. This simulation study will be based on the data gathering of one of boiler at MLNG Bintulu, Sarawak.

MLNG Bintulu

Incorporated in 1978, MLNG was Malaysia's first billion Ringgit project. The scope of the project was huge. In addition to the front-end technology of LNG plant, it included the construction of a port in Bintulu, acquisition of highly specialized LNG tankers, infrastructures, and the training of local workers. In short, it transformed a completely underdeveloped area of Bintulu into an industrial growth centre.

Despite various challenges, on 7 August 1982, the LNG plant with 3 modules was completed with a combined capacity of 6 MTPA was successfully brought on stream. Over the years, MLNG has grown in both size and stature in the LNG industry. Today, the Malaysia LNG consists of MLNG, MLNG Dua and MLNG Tiga. They have emerged as a fully integrated LNG plant, being involved in production, liquefaction and LNG shipping. We currently spread out over 276 hectares, with a combined capacity of 26 MTPA.

After more than 30 years of impeccable operations, during which MLNG acquired its enviable record of never having missed a cargo, our performance began to deteriorate. The plant ability to sustain our reputation as a reliable LNG supplier was under threat. One of the reasons was ageing equipment. Most of the reliability issues were simply due to old age. An older plant would have more asset integrity issues such as boiler vibration, heat exchanger leaks, and others. Apart from causing downtime, some of the other integrity issues such as corrosion were beginning to rise in terms of severity and frequency posing a danger to staff as well.

Steam boilers are one of the critical and important equipment in ensuring continuous process in the production of LNG. The purpose is to produce steam at a required temperature and pressure for the usage of machineries and equipment in the Utilities and Process Area. The existing 9 boilers in MLNG that have a total design capacity of 3,420 tonne/hour have been in operation for more than 30 years. Their performances and reliability are degrading.

Therefore, the boilers have to be replaced with the new one. One of the boilers has been successfully replaced in 2010/2011 while the rest are expected to follow in 2014 and completed in 2019. During these boilers replacement period, steam sparing will fall below the minimum MLNG plants operation requirements. This will increase the risk of module trips and consequently loss of LNG production. Due to this circumstances, MLNG has decided to construct a new Steam Boiler to support the production requirements in producing LNG.

1.2- Problem statement

Water tube type boiler is commonly used for heating and power generation in the industry. The operation of water tube boiler from fuel selection, fuel separation, combustion and generation of steam requires deep knowledge and skill in order to ensure smooth running of boiler system. Combustion, occurs in the combustion chamber is considered critical part in boiler operation in converting fuel energy into chemical energy. Therefore, simulation study on combustion phenomena in the combustion chamber is essential in determining heat transfer rate from hot gas to the boiler tubes.

1.3- Objective

1. To study type of boiler used in industry.
2. To investigate combustion phenomenon using CFD simulation software
3. To understand the differences in temperature contour between different fuels.

1.4- Scope of study

The simulation work will be carry out using suitable CFD simulation software. Operation data for water tube boiler will be based on the data gathering from a new boiler that tested commissioned this year at MLNG, Bintulu. The project will be focused on the combustion phenomena in the boiler combustion chamber with varying certain parameters. The findings from this simulation work is temperature distribution, hot air velocity and heat transfer to the boiler tubes in the boiler combustion chamber. In experimental work, the boiler is being operated in normal pressure condition with different type of fuel.

Table 1.1- Step in Conducting the Project

Steps In Conducting The Project
1. Identify the propose project topic, objectives and scope of study
2. To study on the fundamental knowledge. Done some research on water tube boiler and combustion phenomenon in combustion chamber of boiler, CFD simulation software and effect on efficiency of boiler with different type of fuel.
3. To study on the best fuel for water tube boiler for combustion phenomenon in combustion chamber.

CHAPTER 2

THEORY & LITERATURE RIVIEW

2.1- Boilers

Boiler is providing heat to a facility which heat is needed. The benchmark for ideal size of one boiler is it must be heat adequately on the coldest day of the year. For the size of the boiler, the way systems used to be calculated with card calculator were always over-calculated “to be on the safe side”. Hence, most boilers are oversized by at least 30%. The size of boiler is chosen regarding to the size of the facility. The oversized boiler will give the excessive bills for fuel, but if it undersized, the heat generation could be inadequate especially during the winter, the coldest day.

The boiler is actually only one part of the global heating system, not the heating system [5]. A heating system consists of four main parts, shown in “figure 2.1”. Other than boiler, part of the heating system including piping, pumps, valves, radiators, convectors and also the control equipment such as room thermostat and temperature control at the outside.

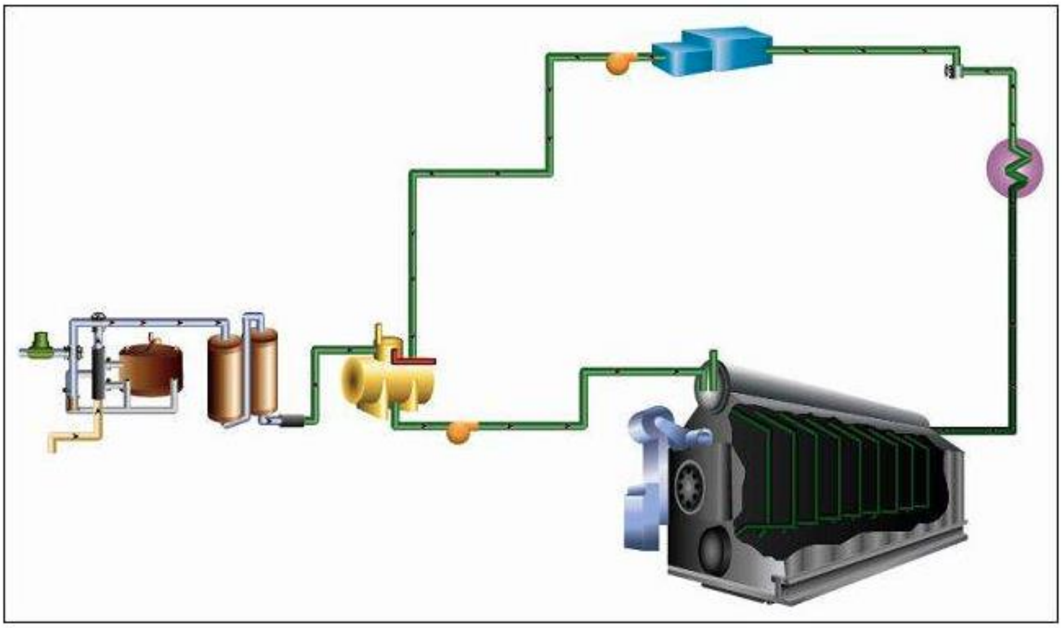


Figure 2.1- Different Part Of The Heating System [5]

2.2- Boiler Types and Classifications

There are two types of boiler generally; fire-tube and water-tube boilers. The classification of boiler is differentiated under “high-pressure” or “low-pressure” and “steam boiler” or “hot water boiler”. For boilers that operate larger than 15 psig are called “high-pressure” boilers [1].

A hot water boiler usually called a fuel-fired hot water heater, strictly speaking, is not a boiler. Due to its similarities to a steam boiler in many ways to a steam boiler, the term “hot water boiler” is used.

- ‘high temperature hot water boiler’ – temperature > 250° Fahrenheit or pressures > 160 psig
- ‘low temperature hot water boiler’ - temperature < 250° Fahrenheit or pressures < 160 psig

For heating boiler, the method of manufacture used is varies. Due to its variety, heating boilers are also classified based on that i.e., by casting or by fabrication. There are boilers, which are called steel boilers due to its fabrication. In their construction via casting are usually use iron, bronze, or brass. Meanwhile, for those that are fabricated are mostly using steel, copper, or brass, with steel as common material [1][5].

2.3- Key element of a boiler

The key elements of a boiler include the burner, combustion chamber, controls, exhaust stack and heat exchanger. Flue gas economizer is including in the accessory of boiler. It is commonly used as one of the effective method to recover heat from the boiler [1].

2.4- Water-tube Boilers

'Figure 2.2' shown is an example of water tube boiler. Water tube boiler works when the water inside the tube the boiler is heated and hot gas surround it. It is different from fire-tube boiler where the operation work with tube surrounded by the water and hot gas passes through it. Water tube boiler can achieve higher pressure smoothly up to 140 $kg/cm2$. Compared to fire-tube boiler, water-tube boiler has higher efficiency. This is because the movement of water is faster in water-tube boiler due to the convectional flows where not in the fire-tube boiler. The rate heat transfer for the water tube boiler also high makes the boiler takes less time for steam pressure to raise. Furthermore, Water-tube boilers are suitable for high rates steam generator.

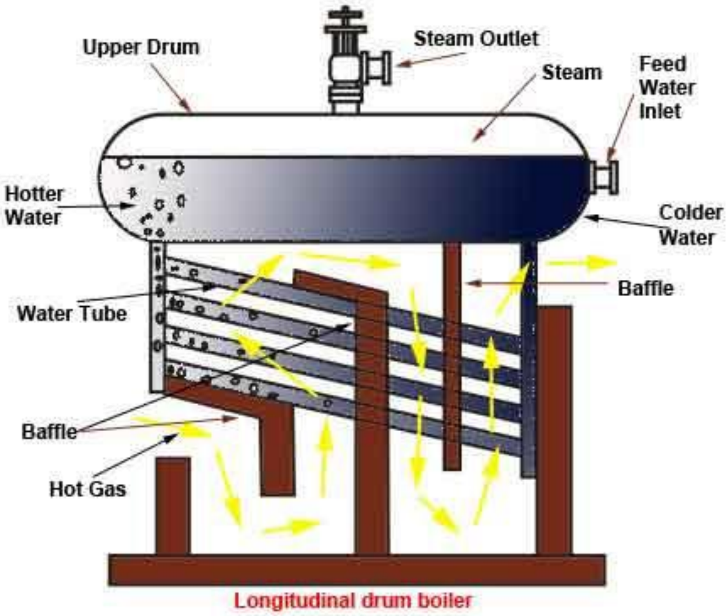


Figure 2.2- Water Tube Boiler [5]

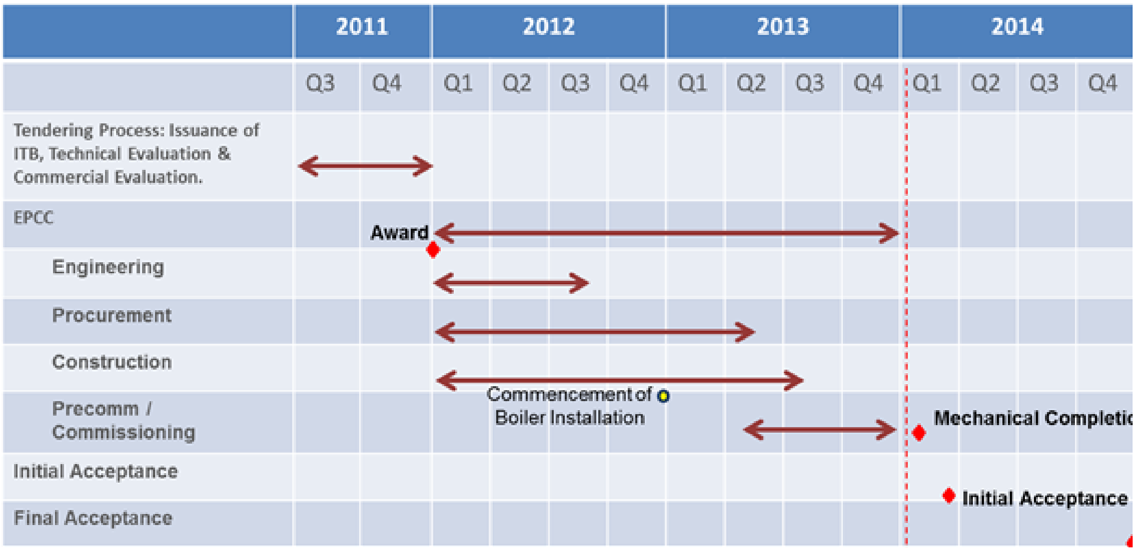
A water tube boiler usually consists of two drums. The upper drum is called steam drums and lower part is called mud drum. A steam drum and a mud drum are connecting with these tubes. From the basic principal, colder water is heavier than hot water. This makes the steam and hot water will go to upper side. Steam is lighter than hot water will separate itself from hot water. Hence, steam will rise into the upper drum or well known as steam drum. The more the steam is produced, the higher the pressure in the boiler as it is function as closed system.

The water-tube design is suited base on the capacity of the steam. In the industry, water-tube boiler typically produces steam primarily for industrial process applications [5]. Compared to fire-tube design, water-tube boilers are available in many greater sizes. Water-tube boiler also has the ability to handle higher pressures up to 5 thousands psig and will recovered faster than fire-tube type of boiler. The availability of water-tube boiler to reach very high temperature is also the great reason for users to pick this type of boilers for their uses either in industry or personal. But, there also disadvantages of the water-tube design. Due to the complex design of the boiler, this makes the boiler is hard to clean. Specialist is required for cleaning this boiler. There are no commonalities between tubes. For some, physical size could be an issue especially for confined space. Water-tube boiler is also expensive to purchased. These disadvantages are included into consideration for users to choose and to analyse the future worth of this type of boiler.

2.5- MLNG New Boiler

The installation of the new boiler includes Boiler package, Water treatment package, Deaeration package, and New Field Auxiliary Room (FAR) and substation building. The scope covers the design and installation of the boiler, associated equipment, piping, interconnection, instrumentation, electrical and control system, construction of infrastructure and civil work, testing and pre-commissioning of new equipment & associated works, tie ins and integration with existing utilities piping system, electrical system, instrumentation and control system, and commissioning, start up and performance test.

Table 2.1- Tendering process and schedule for MLNG new boiler



The tendering process for the EPCC contract was started on the 3rd Quarter of 2011. The issuance of ITB, technical and commercial evaluations was completed by the end of 2011. This EPCC contract was awarded in early 2012 and the engineering, procurement and construction activities have started in the first quarter of 2012. Boiler installation commenced in Quarter 1 of 2013 and completion date was on the 9th January 2014. Mechanical Completion was revised to 28th January 2014 while Initial Acceptance was on the 28th March 2014. The boiler was commissioned starting from the 4th October 2014 and successfully ended on 11th October 2014.

2.6- Energy

The combustion of any fuels is the source of heat. Fuels that usually used for combustion are for example wood, coal, oil, or natural gas. Heating elements has many type. Commonly, electric steam boilers uses resistance type of heating element. Other heat source for generating steam is nuclear fission, either directly (BWR) or, in most cases, in heat exchangers called 'steam generators' (PWR). Heat recovery steam generators (HRSGs) use the rejected heat from other processes. Example of HRSGs is gas turbine which uses the heat rejected [12].

2.7- Fuel type

There are many type of fuel largely used in boiler industry such as natural gas, solid fuels, renewable energy, electricity, propane and many more. Natural gas is one that used widely especially in Europe region due to its availability, cheaper price compared to electricity and oil, and it burns cleanly. Natural gas contains of methane gas and small amount of other gasses. In liquid state, natural gas can be transported easily, either via pipeline or storage tank.

However, the combustion of natural gasses emitted sulphur dioxide,SO_2 , NO_x and less greenhouse gasses which are contribute largely in global warming. This is not only harmful for our global but also harmed our atmosphere, surrounding and human health. Hence, better fuel substitution considering this issues must take place before it is too late. Not for us but for our future generation, who we lend this earth from. Each of fuel has different combustion characteristic which yields difference in performance and efficiency. Until now, millions researches still going in order to find the best fuel substitution.

Other than that, there are also fuel that modify to burn more than one fuel. This is called dual fuel boiler (DFB). DFB are designed for boiler to switch the fuel. For example, one DFB applicable to burn natural gas and oil. So, user can switch to which one he intended to burn. Due to price of oil and natural gas fluctuated through times, it gives advantage for user to switch to the cheaper one without replacing with new boiler [6]. Hence, DBF is economically justified.

2.8- Combustion

Combustion is a process of burning something. In a boiler case, combustion is generally a process of burning it fuels. It is a chemical process which involve light and heat as product. It happen when oxygen is react with elements of fuels used. The elements involve in the combination of combustion process are oxygen, hydrogen, sulphur and carbon. But there are also elements will result in product known as impurities of fuel. They are usually exist in compact amount such as iron. These substances often called impurities will remain in the form of ash. These ashes stored in the ash pit of steam boiler furnace. For the completion of this combustion process of fuel including coal requires three stages [9].

Combustion for boiler happens in combustion chamber.

Combustion process general equation;

$$C + H + O_2 + N_2 \rightarrow CO_2 + H_2O + N_2 \qquad (2.1)[9]$$

The simple word equation ;

Fuel + oxygen + nitrogen → water + carbon dioxide + nitrogen

2.9- Combustion chamber

The combustion chambers are usually made of steel or cast iron, houses for the combustion process and the burners. Inside the combustion chamber, temperature can be approaching several hundred degrees very rapidly.

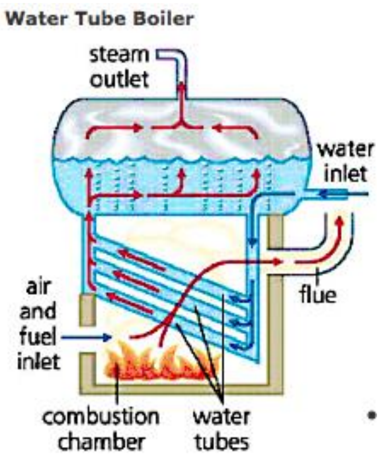


Figure 2.3- Combustion Chamber In Typical Water Tube Boiler [1]

2.10- Efficiency of boiler

The efficiency of boiler is directly proportional to rate of heat transfer and combustion efficiency. Efficiency of combustion is greater when it achieve complete combustion where the burning of hydrocarbon produced only water, carbon dioxide and heat. Insufficient oxygen will result to incomplete combustion where drop the efficiency of the combustion as well as the performance of the boiler. The mixing reaction of oxygen and fuel also drops its efficiency.

Incomplete combustion will not make used of 100% of fuel, hence, there will be unburned fuel and it is such a waste. Furthermore, unburned fuel could trigger the ignition in the stack and can cause an explosion. Boilers must be tuned to achieve complete combustion not only for the best efficiency but also for safety purpose. Other than that, carbon monoxide might form and release as well resulting to the incomplete combustion. It stand to that carbon monoxide is poisonous and harmful. Combustion efficiencies of 80% or higher are usually practicable for low-pressure steam boilers and hot water boilers for commercial buildings [4].

Combustion system efficiency is affecting by many factors such as the parameters used for the boiler, fuels, and the working fluid temperature. The radiative heat transfer to the water effect the ratio of CO2 circulation, which is effecting it performance as well [2]. In the water tube boilers, the ratio of circulated CO_2 affects the radiactive heat transfer to the water [7]. A comparison will be conducted between the performances of a boiler utilizing different type of fuel.

Boiler efficiency general equation;

$$boiler\ efficiency\ (\%) = \frac{heat\ exported\ in\ the\ system}{heat\ provide\ by\ the\ fuel} \times 100 \quad (2.2)\ [7]$$

2.11- CFD Modeling

CFD is a powerful tool for bestowing details of the temperature, velocity and concentration variations that are hardly to obtain through the experimental measurements [8]. CFD techniques have become the third dimension in combustion studies and fluid dynamics alongside experimental diagnostics and analytical modelling. Validation and development of the sub models were necessary for fuel conditions. As validation data, that detailed measurement data from well-defined flames in different scale are needed [10].

CFD simulation can gives many advantages. There are no need physical experiments to justify the parameters we desire for. Also, numerical simulation can provide detailed information on the fuels characteristic such as temperature distribution, total heat flux and soot percentage, which is not easily obtained by physical experiments. CDF is relatively cheap and also indispensable tool to perform comprehensive studies about combustion.

Currently, Chen et. al. have done some research on utilizing different fuel parameters; oxy-coal and air fired condition. He stated that CFD modelling of oxycoal combustion utilize approaches and sub-models that are similar to those developed under air-fired conditions. With the accumulated knowledge on the fundamental differences between oxy-fuel and air-fuel combustion, some effort has gone into validating and developing sub-models for the new combustion environment [2][10].

A selection of the CFD simulation studies on oxy-fuel combustion is summarized in Table 2.1, which includes the sub-models used for turbulence, radiation heat transfer, char combustion and homogenous reactions.

Author	Simulated object		Modeling approaches					
	Facility	Fuel	Code	Turbulence	Radiation	Char combustion	Homogeneous Reaction mechanism	Chemistry-Turbulence
Wang et al. [32]	BCL Subscale combustor	Wage coal	1-DICOG (1-D)	N/A	Zone Method [252], transparent gas	$C + O_2$ $C + CO_2$ $C + H_2O$	Volatiles combustion	Chemical Equilibrium
Khare et al. [207]	IHI 1.2 MWth vertical pilot scale test facility	Coal A	Fluent	$k - \varepsilon$	P-1 WSGG	$C + O_2$	Volatiles combustion	Chemical Equilibrium
Nozaki et al. [95]	IHI 1.2 MWth horizontal combustion test facility	Coal A/B	VEGA-3	$k - \varepsilon$	Multi-flux Radiation model [253] Three-gray-gas model	$C + O_2$ $C + CO_2$ $C + H_2O$ [254]	Volatiles combustion	EBU
Chui et al. [201]	CANMET 0.3 MWth VCRF	Western Canadian sub-bituminous coal	CFX-TASCflow	Standard $k - \varepsilon$	N/A	$C + O_2$	Volatiles combustion	EBU
Rehfeldt et al. [189]	E.ON 1 MWth horizontal firing facility and IVD 500 kWth down firing facility	Tselentis coal and Lausitz lignite coal	Fluent	Standard $k - \varepsilon$	DO	$C + O_2$ $C + CO_2$	N/A	N/A
Toporov et al. [162]	RWTH Aachen *U* test facility	Rhenish lignite	Fluent	$k - \varepsilon$	DO WSGG	$C + O_2$ $C + CO_2$ $C + H_2O$	Volatile breakup CO and H_2 burning [255]	Finite Rate/Eddy Dissipation
Chen et al. [80]	ISOTHERM PWR® 5 MWth pressurized test facility	Bituminous coal	Fluent	Realizable $k - \varepsilon$, $k - \omega$	DO WSGG	$C + O_2$ $C + CO_2$ $C + H_2O$	Modified JL	Finite Rate/Eddy Dissipation
Andersen et al. [233]	100 kW down-fired furnace [85]	Propane	Fluent	Realizable $k - \varepsilon$	P-1	N/A	WD [229] and Modified WD [233], JL [230] and Modified JL [233]	EDC
Vascellari et al. [227]	IFRF 2.4 MW furnace	Gottelborn hvBp coal	Fluent	Standard $k - \varepsilon$	P-1	$C + O_2$ $C + CO_2$ $C + H_2O$	Volatile decomposition, tar partially oxidation, Modified JL [239]	EDC
Muller et al. [215]	IFK 0.5 MWth test facility	Lausitz lignite	AIOLOS	Standard $k - \varepsilon$	DO Leckner's model [256]	$C + O_2$ $C + CO_2$ $C + H_2O$	JL [230]	EDC
Nikolopoulos et al. [224]	330 MWe PC boiler in Meliti power plant, Greece	Lignite from Achlada mine	Fluent	Standard $k - \varepsilon$	DO EWBM	$C + O_2$ $C + CO_2$	Volatile combustion and CO burning	Finite Rate/Eddy Dissipation
Edge et al. [217]	0.5 MWth Air- and oxy-fired combustion test facility with Doosan Babcock triple-staged low NOx burner and IFRF Aerodynamically air-staged burner	Coal A and B	Fluent	RNG $k - \varepsilon$ and LES	DO WSGG/FSK	NA	Volatile combustion and CO burning	EDM

Table 2.2- Summary Of CFD Simulations And Their Sub-Models For Oxy-Fuel Combustion [11]

2.12- The eddy-dissipation model

A model for the mean reaction rate of species i, Ri based on the turbulent mixing rate. Assumes that chemical reactions occur much faster than turbulence can mix reactants and heat into the reaction region (Da >> 1). A good assumption for many combustors: most useful fuels are fast burning. For fast reactions the reaction rate is limited by the turbulent mixing rate. The turbulent mixing rate is assumed to be related to the timescale of turbulent eddies that are present in the flow. Concept originally introduced by Spalding (1971) and later generalized by Magnussen and Hjertager (1976). The timescale used for this purpose is the so-called eddy lifetime, $\tau = k/\varepsilon$, with k being the turbulent kinetic energy and ε the turbulent dissipation rate. Chemistry typically described by relatively simple single or two step mechanism [15].

Finite-rate/eddy-dissipation model

The eddy-dissipation model assumes that reactions are fast and that the system is purely mixing limited. When that is not the case, it can be combined with finite-rate chemistry. In FLUENT this is called the finite-rate/eddy-dissipation model. In that case, the kinetic rate is calculated in addition to the reaction rate predicted by the eddy-dissipation model.

The slowest reaction rate is then used:

– If turbulence is low, mixing is slow and this will limit the reaction rate.
– If turbulence is high, but the kinetic rate is low, this will limit the reaction rate.

This model can be used for a variety of systems, but with the following caveats:

– The model constants A and B need to be empirically adjusted for each reaction in each system. The default values of 4 and 0.5 respectively were determined for one and two-step combustion processes.
– The model always requires some product to be present for reactions to proceed. If this is not desirable, initial mass fractions of product of 1E-10 can be patched and a model constant B=1E10 used [15].

CHAPTER 3

METHODOLOGY

3.1- Project Activities

Figure 3.1 shows the overall project flow. The first half of the project (FYP 1) is mainly focus on the collection of data while the second part of the project (FYP 2) involved the simulation work as well as analysis and interpretation of result.

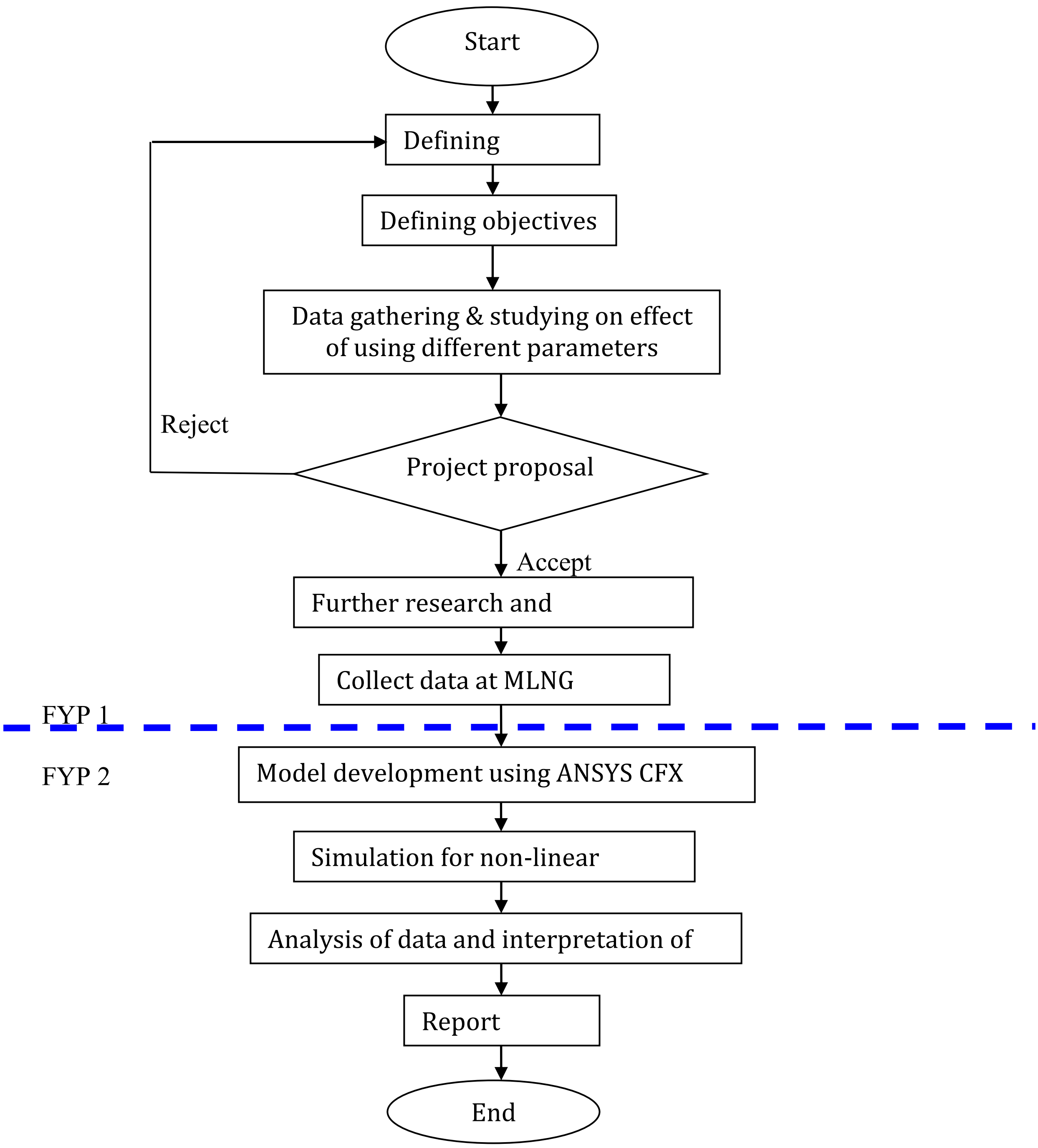


Figure 3.1- The overall project flow progress

Design methodology of combustion chamber in water tube boiler is discussed in this chapter to identify overall stages at which the process can be assessed. The main objective of identifying combustion characteristic is by comparing the different parameter set for different fuels in each simulation using ANSYS CFX. In order to carry out this project, the process required is proposed as shown in the design methodology below in Figure 3.1.

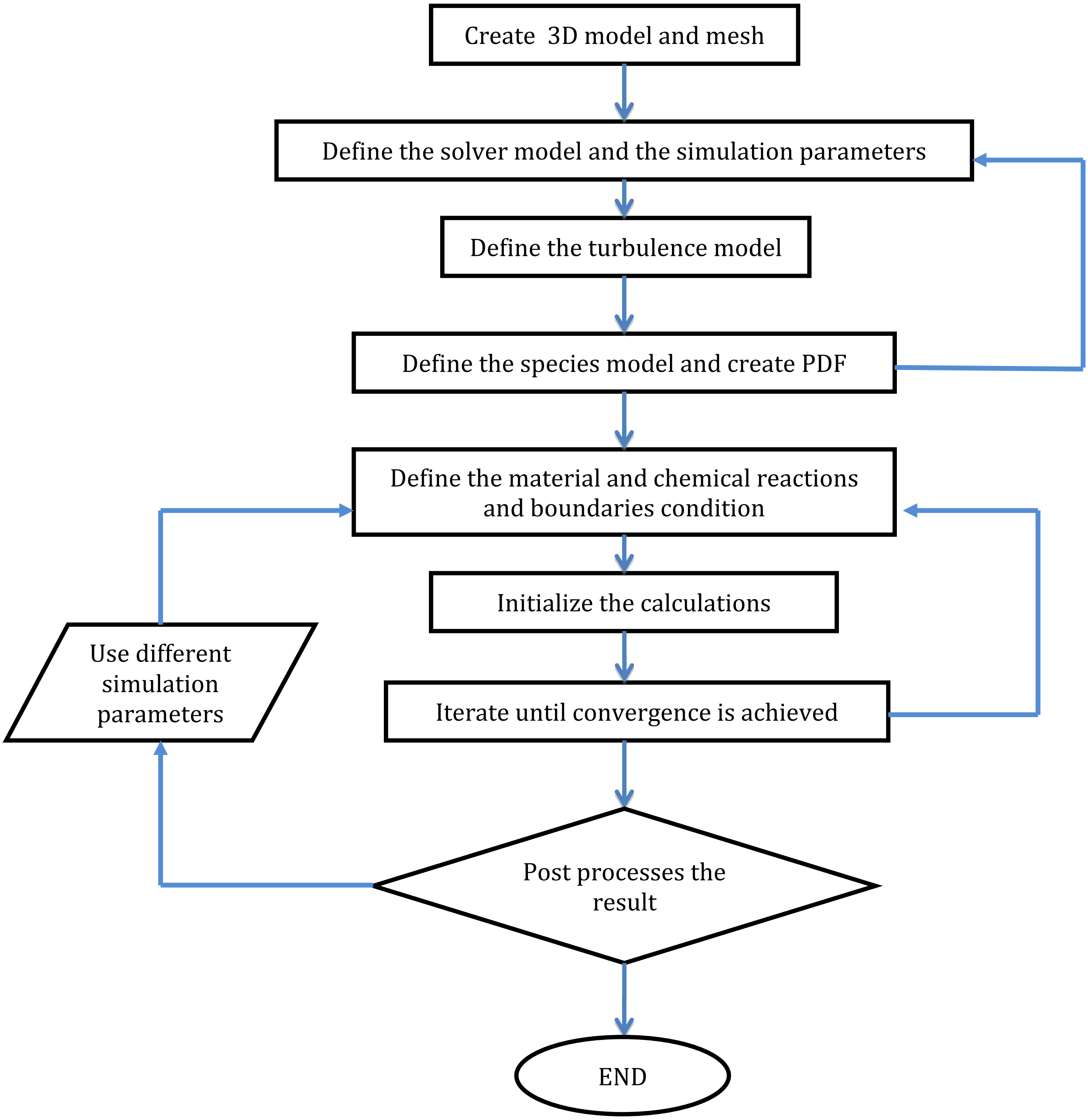


Figure 3.2 – Methodology Flow Of The Project

3.2 - The Gantt chart and Key Milestone

Table 3.2- Project Gantt Chart

Project work	Week																											
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Title Selection																												
Feasibility study																												
Develop project proposal							**1**																					
Approve project proposal								**2**																				
identify governing equation																												
In detail requirement																												
3D Solid modeling														**3**														
Defining meshing and boundary																												
Develop simulation parameters																												
Simulation with different fuel parameters																					**4**							
Result gathering and interpretation																									**5**	**6**		
Project Demonstration and Conclusion																										**7**	**8**	

Key Milestone

1. Submission of extended proposal
2. Defense proposal
3. Submission of interim report
4. Submission of progress report
5. Submission of final report
6. Submission of dissertation
7. Submission of technical paper
8. Viva Presentation

3.3 - Tools

In conducting the project, several software have been utilized. The lists of the software are as follows:

Table 3.3 – Software use for project completion

Software
1. CFD – ANSYS CFX
2. Microsoft Word
3. Microsoft Excel
4. AutoCAD

CHAPTER 4

RESULT AND DISCUSSION

This chapter presents the results obtained from comprehensive numerical simulation which covers operation of boiler using different parameter.

4.1 – Experimental Result and Discussion

Data gathering MLNG Bintulu's Boiler:

The new boiler was manufactured by NEM Energy (Netherlands) and used a design code of ASME I Ed. 2010 add. 2011. The maximum allowable working pressure is 85.2 bar(g). Hydrostatic test was done on the 10th February 2014 with a pressure of 135.2 bar(g). The boiler has a heating surface of 11,617 m2 and a maximum designed steaming capacity of 418 tonne/hour.

MLNG New Boiler (MNB) has a design capacity of 380 tonne/hour of High Pressure Steam (65 bar(g) and 480 °C) at 100% MCR. MNB forms an integral part of the Utilities plant. It produces superheated steam that is fed into the existing MLNG HP Steam Header at the following normal operating conditions:

Table 4.1- MLNG New boiler performance data

Steam flow (minimum)	190 t/h at 50% MCR
Steam flow (normal)	380 t/h at 100% MCR
Steam flow (maximum)	418 t/h at 110% MCR (For 2 hours per day)
Steam outlet pressure	68 bar(g)
Steam outlet temperature	480 °C (475°C at the tie-in point)

The new boiler coded F4140 with a permit number of SW PMD1285 is a D-type water-tube boiler with two super heaters (Primary Super heater and Platen Super heater) and two-drum design.

Protection in abnormal operating conditions was in placed in the form of safety relief valves. There are 3 relief valves installed; 2 nos. in the steam drum and 1 nos. in the super heater section. These relief valves coded 41-RV-101A, 41-RV-101B and 41-RV-102 have a set pressure of 85.2 bar(g), 87.7 bar(g) and 76.3 bar(g) respectively.

4.2- Simulation Parameter

The actual size of boiler is very huge is made for industry. For running the simulation on this actual size is possible. However, the time constraint forces author to reduce the size to make this project feasibility followed. The sizes and parameter are reduced at 90% for running the simulation on the combustion chamber.

4.3- Design of combustion chamber

For the simulation purpose, a design of combustion chamber has been carry out. below is the suitable design for running the simulation with reduced parameters and sizing. this design has been carry out using AutoCAD software.

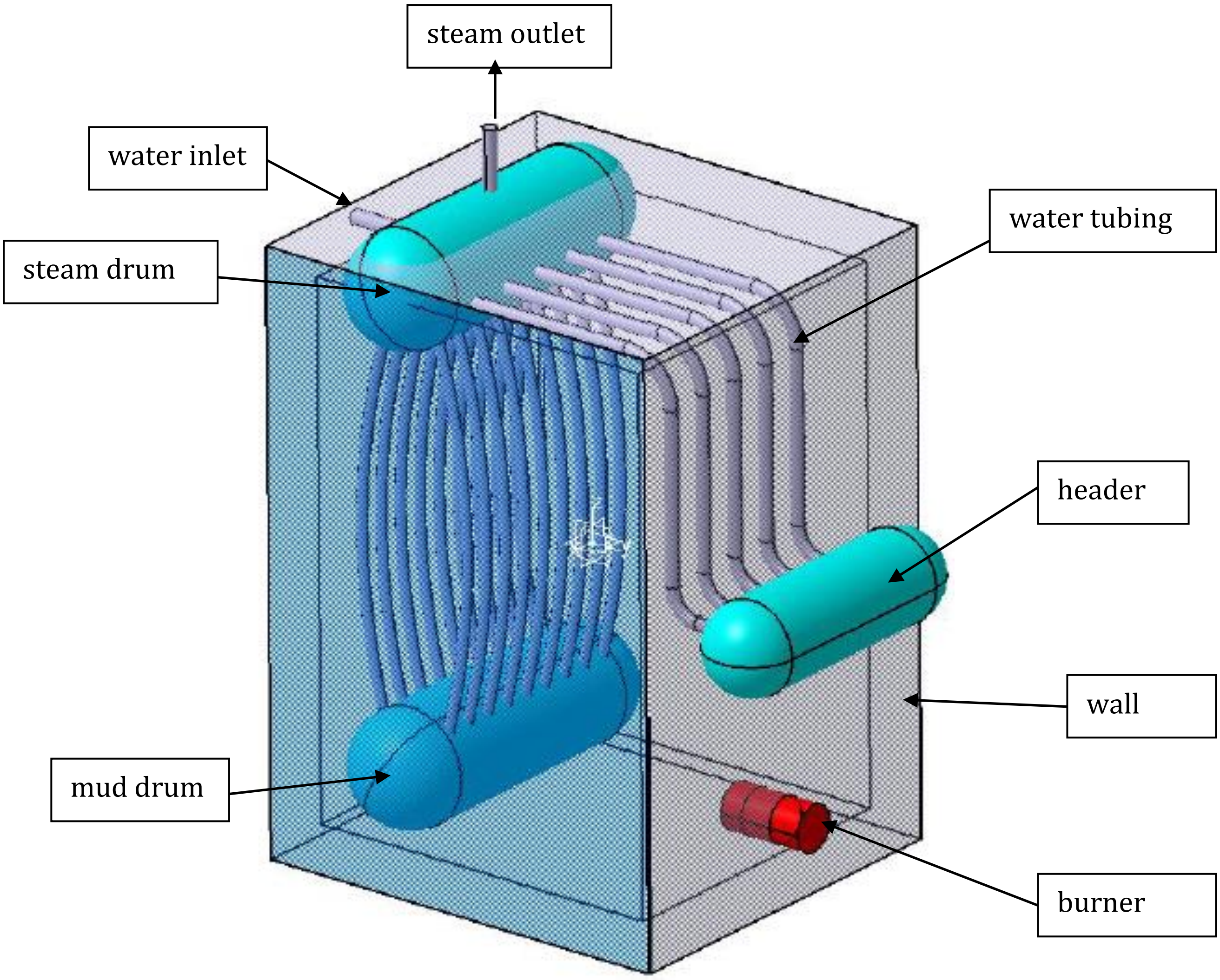


Figure 4.1- Design of Combustion Chamber of boiler for simulation

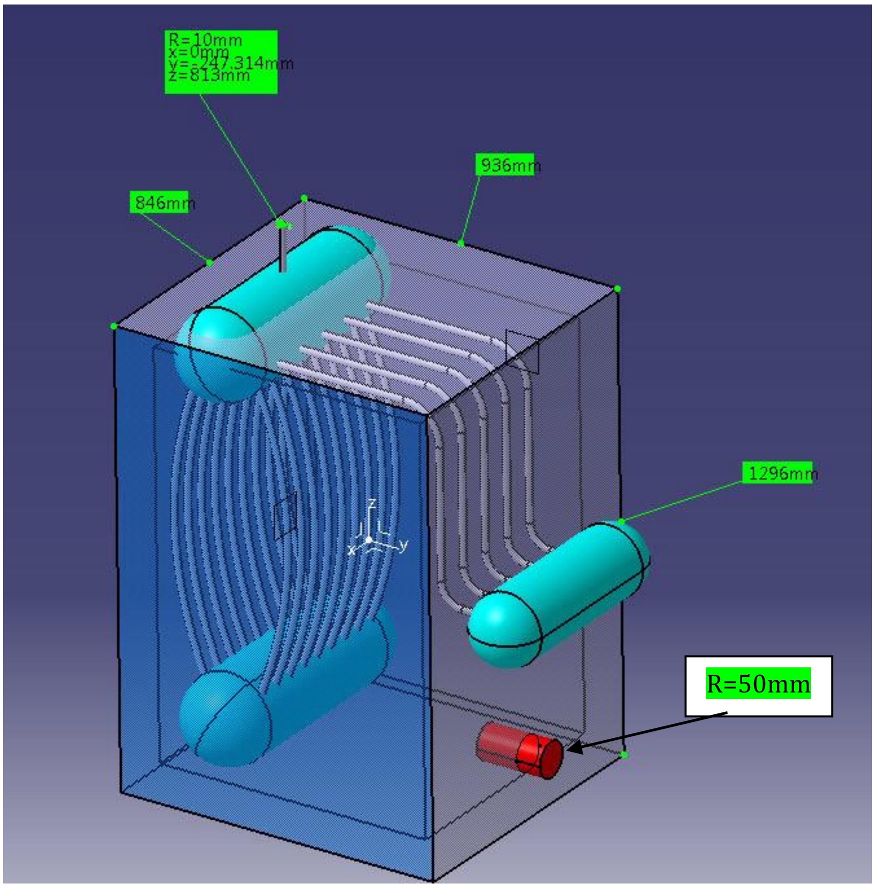


Figure 4.2 - Sizing of combustion chamber design for simulation purpose.

Table 4.2 - Boiler data for simulation purpose

Parameter	**Value**
Steam flow	Normal = 38 tonne/hour Min = 19 tonne/hour Max = 41.8 tonne/hour
Steam temperature	163.5 $℃$
Steam pressure	6.8 barg
Superheat	Yes
Max allowable working pressure	85.2 barg
Boiler heating surface	1161.7 m^2
Max steaming capacity	41.8 tonne/hour

4.4- Material Specification

Table 4.3 - Material specification for combustion chamber.

Part	Material
Wall	Fire-brick
Water tube	Medium carbon steel
Drums & header	Medium carbon steel

4.5- Mesh and boundaries report

For the simulation, 2 solid and 2 fluid volume have been defining in the domain setting.

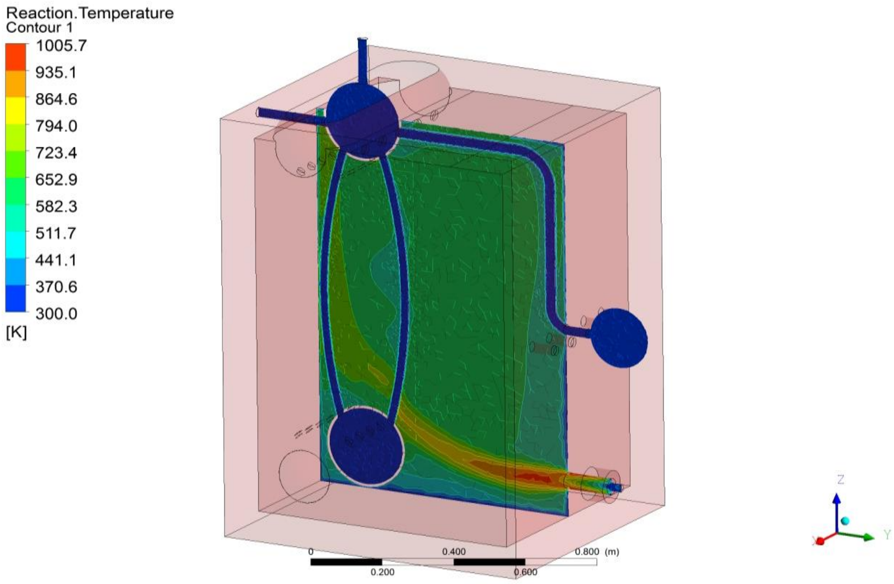
Table 4.4 - Mesh and nodes design for simulation

Domain	Nodes	Elements
Brick	52159	250497
Solid	286009	883650
VolAir	827340	4559356
VolWater	390034	1859252
All Domains	1555542	7552755

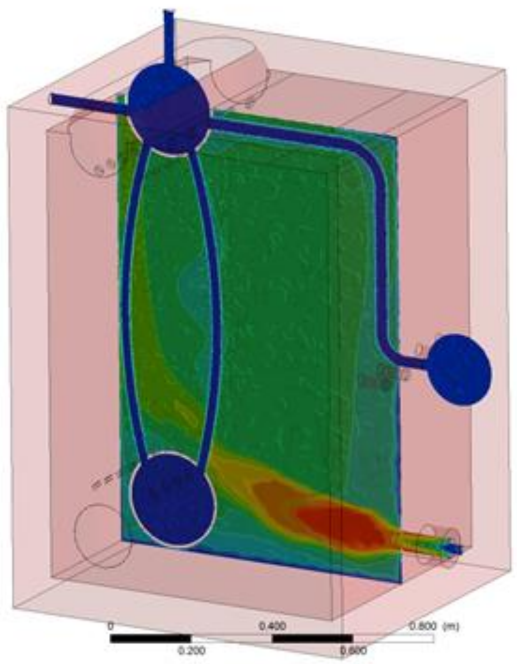
-Eddy-dissipation Model (EDM) reaction model used to model the combustion.

- Eulerian multiphase defined for the air and water

4.6- Temperature contour



a)

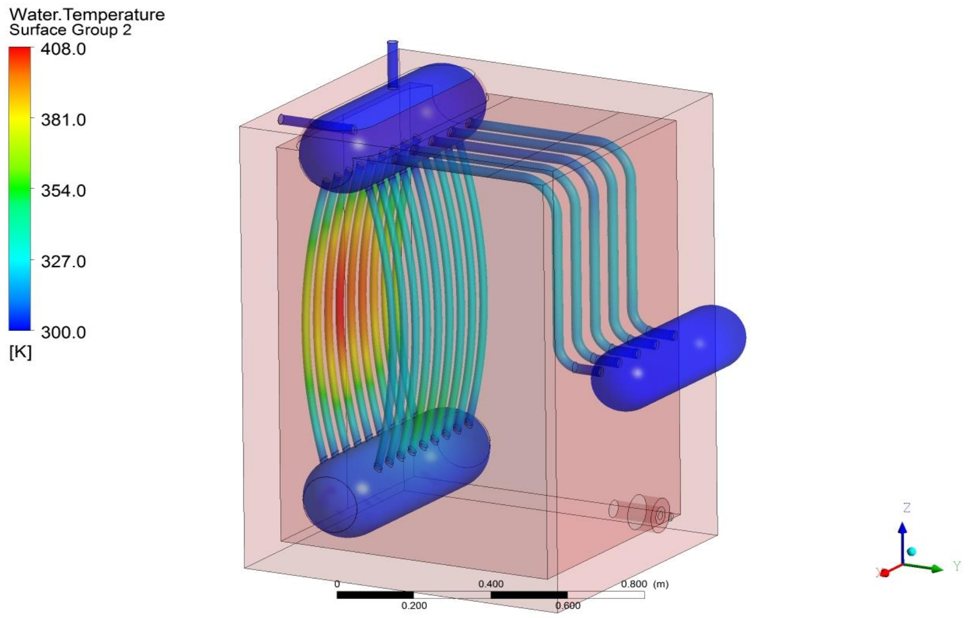


b)

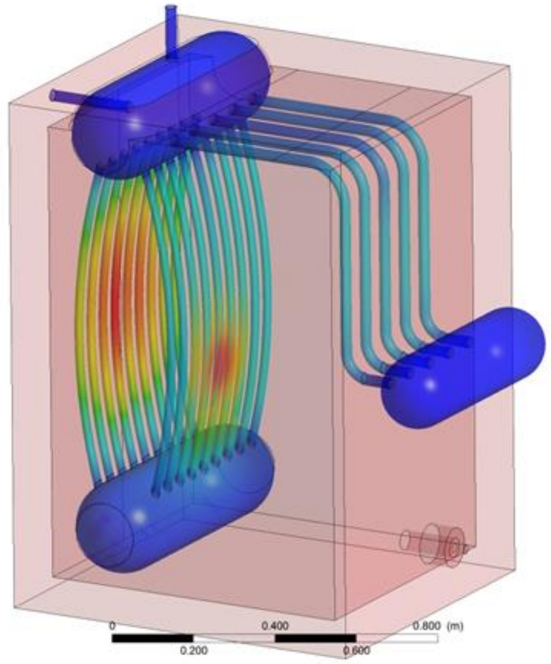
Figure 4.3 - Temperature distribution through Y-Z burner planes firing

a) natural gas b) diesel

4.7- Water tubing surface temperature



a)



b)

Figure 4.4 - Temperature distribution of water along water tubing using firing fuel a) natural gas b) diesel.

4.8- Furnace exit gas temperature

Furnace exit gas temperature is the temperature of fuel leaving the furnace and entering the convective of the boiler. This is an important factor to determine, as it affects many aspects of boiler performance.

When compared diesel with natural gas, it is typical the temperature of diesel is higher. the reason this occurs is because the emissivity of the flame from the natural gas firing is lower than diesel. The heat from combustion that is not absorbed by the furnace water walls produces a higher furnace exit gas temperature entering the back pass.

The furnace exit gas temperature for simulation boiler; for natural gas and diesel displayed in Figure 4.5. It is very important to understand how this temperature changes when switching the fuel. An increase of furnace exit gas temperature will affect final steam temperatures, requiring attemperator flow rates, or other means of steam temperature control.

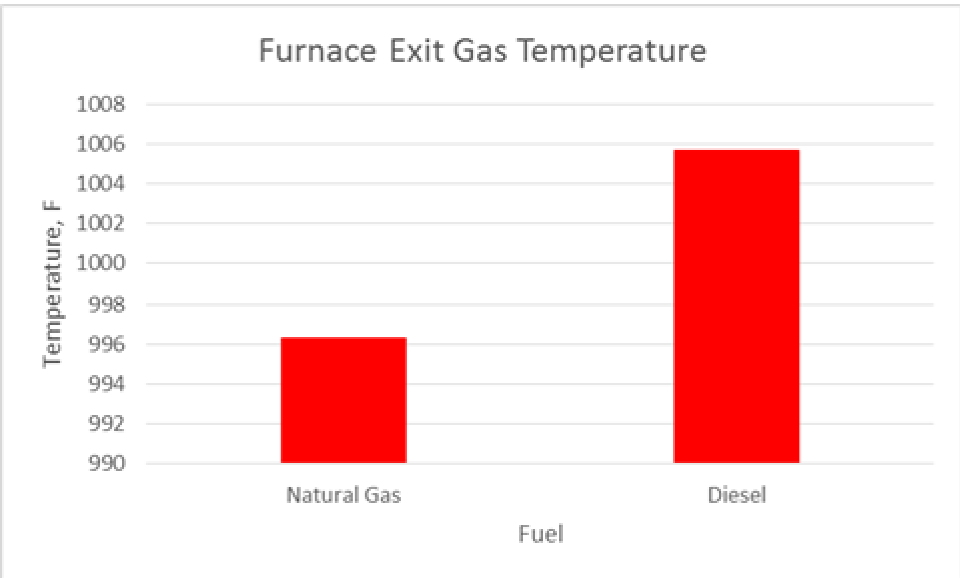


Figure 4.5 - Furnace exit gas temperature for fuel natural gas and diesel

4.9- Combustion air and fuel flow rates

It should be observing that diesel fuel has much higher BTU content than natural gas as a fuel when compared to weight basis. That is mean less fuel is required. However, it also means that there is a greater dry air requirement per pound of fuel for stoichiometric conditions.

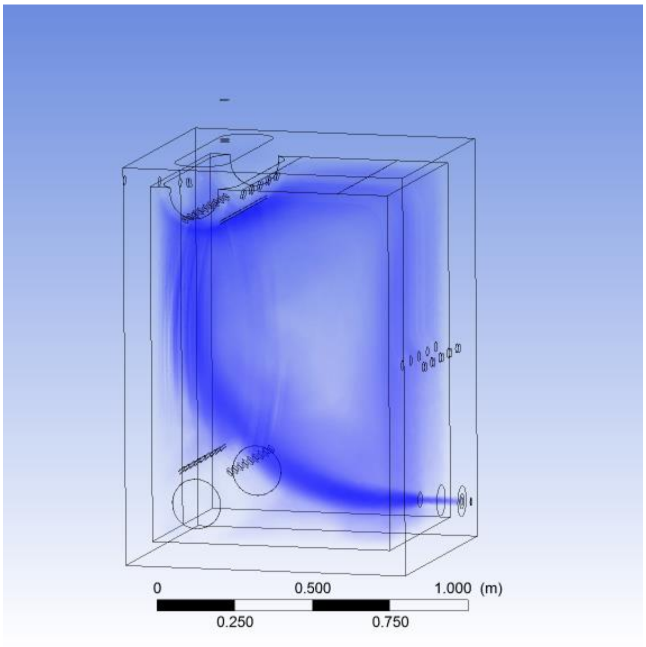


Figure 4.6 - Typical air velocity contour for combustion chamber simulation.

From simulation,

fuel inlet velocity $= 6.18\, m/s$

air inlet velocity $= 1.45\ m/s$

flow rate , $Q = VA$

V= velocity pass through the burner, m/s

A= area or burner , m^2

Fuel flow rate, $Q_{fuel} = 6.18\ \times\ \pi 0.05^2$

$= 0.049\, m^3/s$

combustion air flow rate, $Q_{air} = 1.45\ \times\ \pi 0.05^2$

$= 0.0114\, m^3/s$

Throughout this study of simulation, flow rates for fuel and combustion air are remained the same for both fuel, natural gas and diesel. This is because to compare their emissivity of flame and fuel performances. However, the maximum velocity reach for both fuels are different. This is may due to different reaction for different particles. Figure shows the maximum Velocity reached inside the combustion chamber.

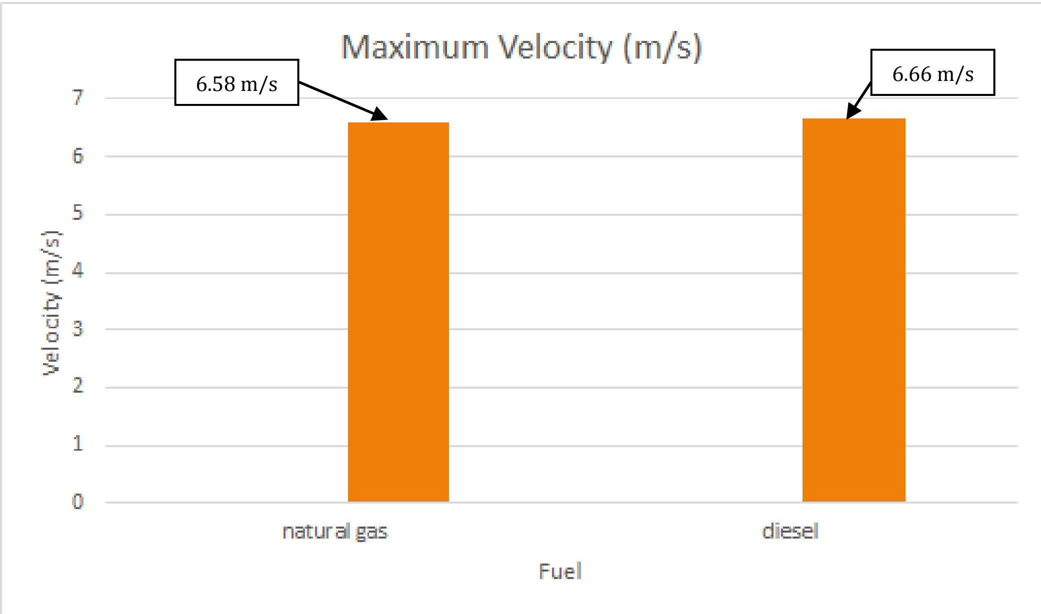


Figure 4.7 - maximum velocity reach inside the combustion chamber for natural gas and diesel.

4.10- Heat transfer through sections

The heat transfer profile through the various boiler sections can be impacted when changing the parameters of the boiler such as fuel. When switching natural gas to diesel, furnace exit gas temperature increase. It will automatically provide a boost in heat content of the fuel entering the combustion section.

A change in the fuel flow rate entering the combustion chamber due to changes in dry airflow requirements, excess air, and boiler efficiency, will also have an impact on the heat transfer profile. A general decrease in flue gas flow rate will offset the increase in flue gas heat content due to higher furnace exit gas temperature values. Some of fuel for example coal, contain ash. For this kind of fuel, the convection heat transfer will be less effective when firing compared to natural gas and diesel (both contain no ash). Different coals will have varying propensities to foul the heat transfer surfaces with this ash. This reduces the heat transfer in these sections and is the main reason cleaning devices such as soot blowers are used in pulverized coal boilers. Natural gas and diesel doesn't contain ash, and does not foul the heat transfer surfaces. Therefore, the surface heat transfer effectiveness will be higher when firing, allowing the surfaces to absorb more heat.

A side by side comparison of the surface heat transfer profile through combustion chamber for both natural gas and diesel, is provided in figure 4.9. at section a and b, the heat transfer rate likely to decrease for both fuel. this is due to reduced fuel flow at those sections. therefore, resulting the fuel gas temperature was likely to lower. The air heater absorption was lower which was due to lower air and flue gas flow rates through the heater.

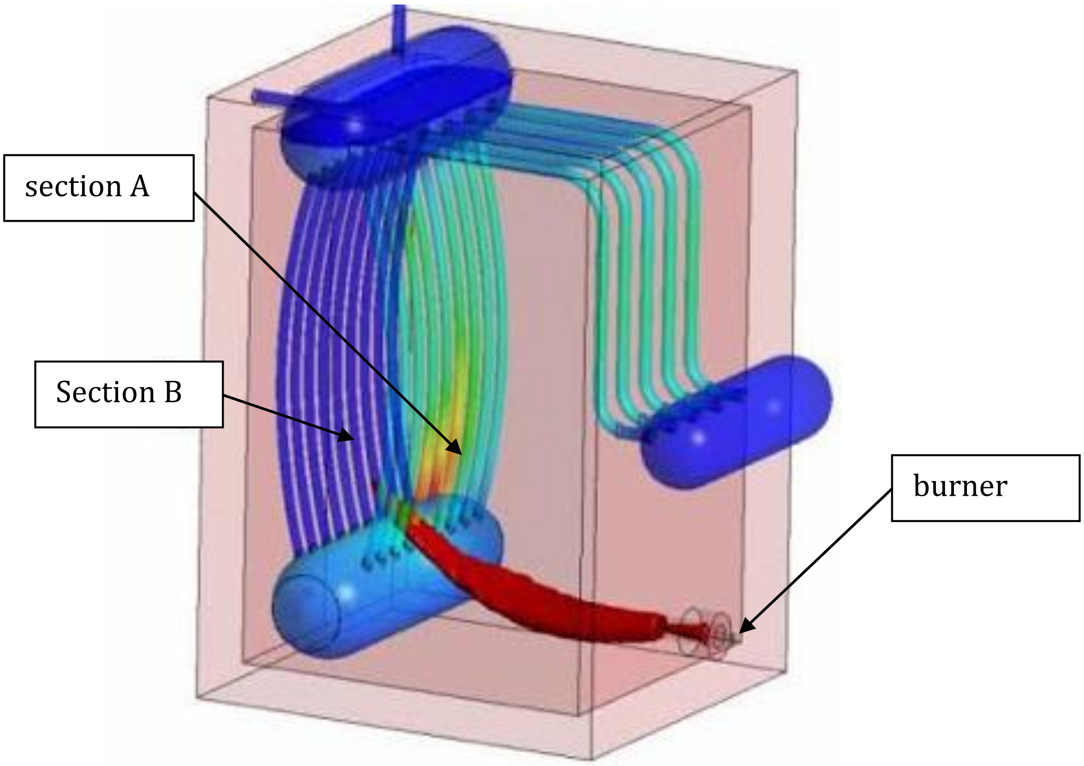


Figure 4.8 - Illustration of section inside combustion chamber

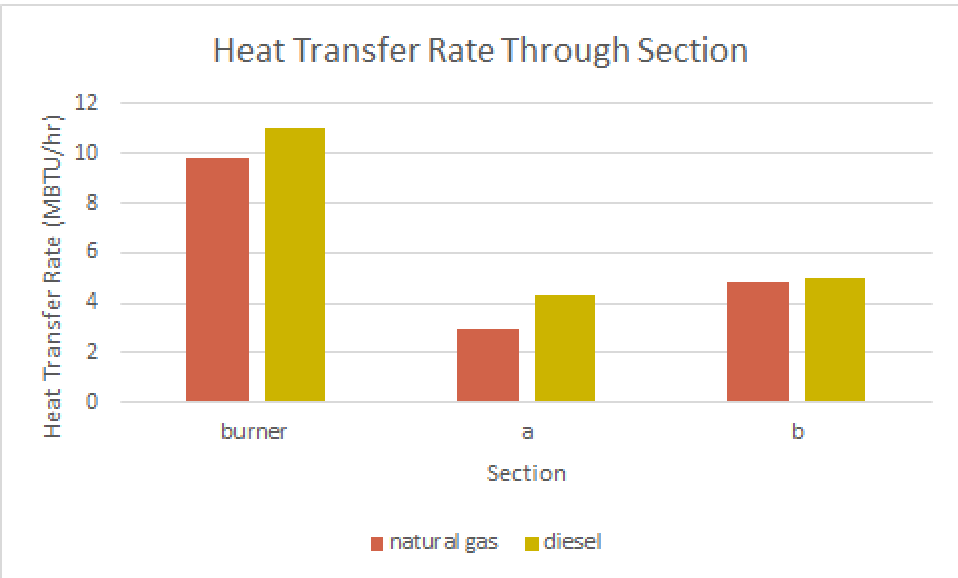


Figure 4.9 - Surface heat transfer profile for boiler combustion chamber firing natural gas vs. diesel.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1- Relevancy to Objectives

For FYP 1, deeper knowledge and understanding about type of boiler used in industry are gained as well as the characteristics of combustion phenomenon through some research works. By using CFD simulation software clearly seems to be the best way with many advantages for this study and research. By previous candidates, it is proven that combustion process can be optimised by varying boiler parameters.

With the assistance by supervisor, Ir. Dr. Suhaimi, this project considered feasible. It is feasible regarding the time constraint and the capability of final year student. It is a big hope for the accomplishment of this study. Based on the research done, different fuel used to heat up the boiler with bring difference performances. Based on the recent result, it is proven that by changing the boiler parameter, the performance of the boiler will change.

5.2 - Future work for expansion and continuation

As far as mention in this project, this simulation had to reduce their actual sizing to 90%. The reason is because time constrain. simulation process using ANSYS will consume a lot of time for running. Therefore, the sizing is reduced to ensure this project is feasible. it is highly recommended for future simulation using actual sizing and data to get the best result and performance of the boiler.

For further work, it is suggested to use more variety of fuel despite only natural gas and diesel. It is recommended to used coal or any fuel with ash contained so it can compared the soot concentration and also variety the performance comparison between firing different fuel.

Further study and deeper knowledge is highly recommended for further work. this will give advantage for the report and also a lot of thing can be explained, studied and compared. For example, this can be a go green project where running the simulation and compare the emission rate of various gases. For example $NO_x and\ SO_2$ which widely known they are harmful for our environment. Other than that, using variety of fuel will give advantages for study about boiler performance. For example, by knowing the soot concentration, the modification of part of boiler can be pointed. this soot also harm to the boiler for example lead to corrosion and more.

REFFERENCES

[1] Om of Boiler,
http://betterbricks.com/sites/default/files/operations/om_of_boilers_final.pdf

[2] M.A. Habib, R. Ben-Mansour, H.M. Badr, S.F. Ahmed, A.F. Ghoniem, "Computational Fluid Dynamic Simulation of Oxyfuel Combustion in Gas-Fired Water Tube Boilers," Computers & Fluids, pp. 153, 2011.

[3] N.S. Harding, D.C. O'Connor, "Ash Deposition Impacts in the Power Industry," Fuel Process Technology, 88 (11–12) (December 2007), pp. 1082–1093.

[4] "Energy Efficiency Guide for Industry in Asia," 2006. Retrieved from http://www.energyefficiencyasia.org/energyequipment/typesofboiler.html

[5] "Boiler Type and Specifications." Retrieved from
https://www.myodesie.com/wiki/index/returnEntry/id/3061

[6] Steam Boiler Furnace Grate Firebox Combustion Chamber of Furnace, 2011, http://www.electrical4u.com/steam-boiler-furnace-grate-firebox-combustion-chamber-of-furnace/

[7] Efficient Boiler Operations Sourcebook, Fourth Edition, F. William Payne and Richard E. Thompson, 1996.

[8] E. Croiset, K.V. Thambimuthu, A. Palmer, "Coal combustion in O_2/CO_2 mixtures compared with air,"Can J Chem Eng, 78 (2000), pp. 402–407.

[9] K. Andersson, F. Johnsson, "Flame and radiation characteristics of gas-fired O_2/CO_2 combustion," Fuel, 86 (2007), pp. 656–668.

[10] Versteeg HK, Malalasekera W. "An introduction to computational fluid dynamics; the finite volume method," Longman Scientific and Technical; 1995.

[11] Lei Chen, Sze Zheng Yong, Ahmed F. Ghoniem, "Oxy-fuel combustion of pulverized coal: Characterization, fundamentals, stabilization and CFD modeling," Progress in Energy and Combustion Science,pp. 156-214, 2012.

[12] "Boiler," retrieved from https://en.wikipedia.org/wiki/Boiler.

[13] J.-K. Park, S. Park, M. Kim, C. Ryu, S. H. Baek, Y. J. Kim, H.H. Kim, H.Y. Park. "CFD Analysis of Combustion Characteristics for Fuel Switching to Bioliquid in Oil-Fired Power Plant." Fuel. 2015. p. 324-333.

[14] S. Black, D. Bielunis. " Challenges when Converting Coal-Fired Boilers to Natural Gas." Babcock Power. Presented at Council of Industrial Boiler (CIBO) Industrial Emissions Control Technology Conference & Natural Gas Conversion Workshop, Portland, Maine. August 2013.

[15] Bakker. "Modelling Chemical Reactions with CFD." Retrieved at http://www.bakker.org/dartmouth06/engs199/10-react.pdf.