

**THE EFFECTS OF TWO DIFFERENT MATERIALS (ALLOY STEEL T91 &  
CARBON STEEL) OF BOILER TUBE**

**SAIFUDDIN BIN OMAR**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

SAIFUDDIN BIN OMAR      BACHELOR OF MECH. ENG. (PLANT & MAINTENANCE)(HONS)      2015      UTeM

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CARBON STEEL) OF BOILER TUBE**

**SAIFUDDIN BIN OMAR**

**This report submitted to Faculty of Mechanical Engineering  
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In partial fulfilment for Bachelor of Mechanical Engineering (Plant &  
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**Faculty of Mechanical Engineering  
Universiti Teknikal Malaysia Melaka  
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## **SUPERVISOR DECLARATION**

“I hereby declare that I have read this draft report and in my opinion this draft is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Plant & Maintenance)’

Signature:.....

Supervisor:.....

Date:.....

## DECLARATION

“I hereby declare that the work in this draft is my own except summaries and quotation which have been duly acknowledged”

Signature :.....  
Supervisor : En. Omar Bin Bapokutty  
Date :.....

Dedicated to my  
Mother/ Rohana Bte Johar  
Father /Omar Bin Ahmad  
Siblings and my Niece and Nephew  
Lastly my whole family

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I would like to take this opportunity to thank Allah for giving me the strength and the knowledge for me to carry out these projects smoothly and finish it in time . Thanks to the lecturers who has been supporting me and giving me so many advice in creating this thesis and making this project possible. For my housemate, thank you for the morale support that you all have given me. Without it, I might not be able to finish this thesis. And lastly, my beloved parents who have not lose hope on seeing his son succeed in life. For that, this is you for mom and dad.

## ABSTRACT

Computational Fluid Dynamic (CFD) is said to mimic the actual result of an experiment data. Because of that, we might say that CFD is a simulation of an experiment that can be done in a lab. The simulation is based on a steady state formulation. It focus is to assess the capabilities of a Computational Fluid Dynamics tool for aerodynamic development of a coach. The material that will be investigating is only two, which is Carbon Steel or Mild Steel and High-Alloy Steel or we call it as T91 steel. The software that will be using is the ANSYS© software which are capable of simulating fluid flow inside material. Some knowledge about the Carbon Steel and High-Alloy T91 Steel is needed in order to develop the simulation. All the information will be collected and will be compared with my simulation inside the ANSYS. By that, we can see where the high turbulence will occur and the effect of heat transfer on two different materials. Recent study has been done on tube temperature distribution in a water tube boiler using CFD and also on the leakage of boiler tube. It is expected to see a conclusive result as the two materials have very different characteristics.



## **ABSTRAK**

Computational Fluid Dynamic (CFD) dikatakan menyerupai sebuah eksperimen kerana data keputusan yang di perolehi hampir sama dengan apa yang didapati ketika membuat eksperimen di makmal. Dengan itu, dengan teknologi yang begitu canggih telah memudahkan kita dengan hanya melakukan simulasi dikomputer sama sahaja melakukan eksperimen di makmal. Simulasi ini adalah berdasarkan perumusuan keadaan mantap dimana ia menumpukan kepada kupayaan CFD untuk membangunkan aerodinamik. Bahan yang akan di uji adalah hanya dua iaitu Carbon-Steel dan High-Alloy Steel T91. Perisian yang akan digunakan adalah ANSYS© dimana ia berkebolehan untuk mensimulasikan pergerakan medium seperti air dan wap di dalam sesebuah bahan. Semua maklumat daripada keputusan ANSYS© akan dikumpul dan dibandingkan dengan keputusan makmal yang telah dilakukan di seluruh dunia. Dengan itu, kita akan ketahui dimana tenaga golakkan yang kuat akan muncul dan kesan pemindahan haba antara dua bahan yang berbeza. Kajian lepas telah dilakukan terhadap pembiasan suhu tiub boiler menggunakan CFD dan juga kajian mengenai kebocoran yang berlaku didalam tiub boiler. Dijangka keputusan yang muktamad di mana bahan yang di bandingkan mempunyai ciri-ciri yang amat jauh sekali berbeza.

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## CHAPTER 1

### INTRODUCTION

A watertube boiler is a tube in which water circulates in tubes heated externally by the fire inside a boiler. Fuel is burned inside the furnace, creating hot gas which heats water in the steam-generating tubes. Boiler tube is a tube where water circulates in tubes heated externally by the fire whether from a burning coal, oil or gas. Fuel is burned inside the furnace, creating heat to heat the water inside the steam-generating tube. Usually, boiler tube is used inside a boiler where steam is generated in a power plant. There are three main types of water tube boiler which is horizontal straight tube boiler, bent tube boiler and cyclone fired boiler.

Commonly known as materials science and engineering or we call it as material science, is a discipline field which deals with the discovery and design of new material. It is a new scientific field which involves studying materials through materials paradigm and its intellectual origin reach back to the emerging fields of chemistry. Using Computational Fluid Dynamic as a method used in this study, the aim is to determine the effects of material on the flow of high heat transfer in which the case is between Alloy Steel T91 and Carbon Steel.

## **1.1 PROBLEM STATEMENT**

Different material have different characteristic. To know if this statement is true, I will be doing some research on the material by using CFD as the medium for research. This research require me to know about the characteristics of the material Carbon Steel and High-Alloy Steel T91 such as specific heat and thermal conductivity of the material which is currently used in the industry for boiler tube. I will also need to know how the effects of the steam flow rate will be affecting the boiler tube and see where the highest turbulence energy will occur in order to know where the area of defect expected to occur. To reach the conclusion, I will need to compute the effects of heat transfer (convection) between Carbon Steel and High-Alloy Steel T91 in the boiler tube to define which material can store energy the longest.

## **1.2 OBJECTIVES**

1. To find the area where the highest turbulence energy occurred inside the boiler tube using the Fluid Flow(CFX) inside the ANSYS©
2. To compute which material will reach room temperature the longest in order to determine their ability to store heat energy using Transient Thermal application inside ANSYS© and using 'newton law of cooling'.

## **1.3 SCOPE**

This final year project is assigned to investigate which material reaches the normal room temperature and finding where wills the highest turbulence energy will appear. By that information, we can predict which material is good for containing the steam which requires heat. We need to know whether it is the High-Alloy Steel T91 material or the carbon steel material which is good to store energy. Investigation on other material is not required as because two materials are commonly used in the generating electricity in the industry. These projects require for me to know a certain way using computational fluid dynamic (CFD) to achieve those two objectives which is finding the area of the highest turbulence energy and which material is good for restoring energy. For this project, Fluid Flow (CFX) and Transient Thermal is the suitable method to achieve the objective for these projects.



## 1.4 PROJECT PLANNING

### 1.4.1 GANTT CHARTS

		GANTT CHART															
NO.	ACTIVITY	PSM 1															
		WEEK															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	Briefing for PSM1	■										S					
2	Collecting Information and Data		■	■								E					
3	Introduction		■	■								M					
4	Literature Review			■	■	■						B					
5	Methodology					■	■					R					
6	Preliminary analysis on the design using CFD(ANSYS)								■	■		E					
8	Poster Submission											A	■	■			
9	Report PSM 1 submission											K		■	■	■	■

Figure 1.4-1 Shows a Gantt chart for the Final Year Project 1

No	Activity	Week															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14		
1	3D Modelling	■	■														
2	Do analysis using ANSYS© software		■	■	■	■											
3	Progress Report Submission						■										
4	Data collecting from analysis							■	■	■	■	■	■				
5	Final Seminar												■	■	■	■	
6	Final Draft report submission																■

Figure 1.4-2 Shows a Gantt chart for the Final Year Project 2

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 INTRODUCTION TO BOILER

According to (Rayaprolu, 2009) boiler is a device that boils water to produce steam. On scientific perspectives, a boiler changes the chemical energy in fuel into the heat energy in steam. In other words, heat energy of hot gases change in heat energy of steam where no firing is involved. Some of the earliest application can be found in boiling water in a kettle. It is also known as steam generators which have been around for more than 150 years. It can be classified as first classification in which the cases have three types. The first one is Fire tube boilers which flues gases flow through the inside and outside of the tube. Next is the water tube boiler which we will be investigating. Water will flow inside the tube and flue gases flow outside. For the third one, combination (combo boiler) where flue gas and water flow both outside and inside the tube of the boiler. Figure 2.1-1 shows some example of boiler used in the industry.



**Figure 2.1-1 Example of Boiler in industries**

## 2.2 BOILER TUBE

The core boiler without the firing equipment is built with several high-temperature material. Some of them are namely steel and refractories. Structural steels used for support and sheet materials for air and gas transport. (Rayaprolu, 2009) Rise of circulating fluidized bed combustion (CFBC) boilers that require large quantities of furnace and cyclone lining. Material used to construct boiler comprise of variety of steels and refractories. For little nonferrous, they are in the form of tubes, pipes and headers. For tubes and plates, there are plates and strips, castings and forgings, and structural rolled and flat section. (Avallone & Theodore, 1987) state that boiler tube or water tube boiler was recognized for more than 100 years ago. Figure 2.2-1 shows some example of boiler tube in the industry. It succeeded the fire tube boiler except in small package-boiler designs and waste heat boiler. Fire tube boiler is design for medium and low pressure application. Boiler tube are available in various type of capacities, from as low as 5,000 lb(2.3 tonne) to as high as 9,000,000 lb(4082 tonne) of steam per hour.

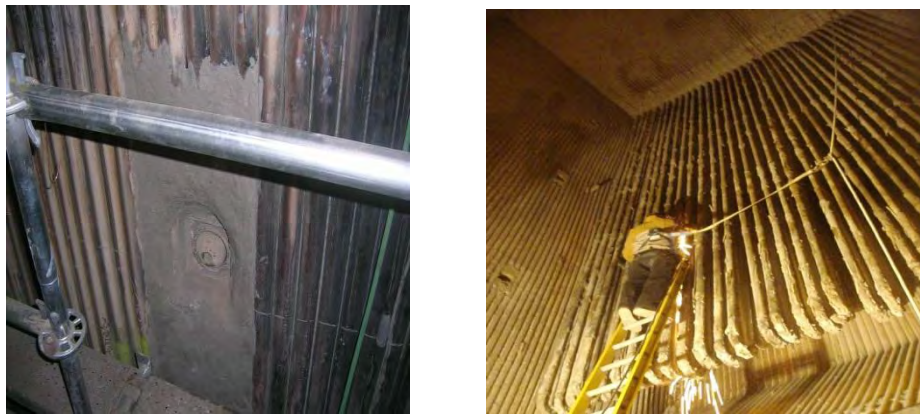


Figure 2.2-1 Example of boiler tube in industries

### 2.3 TUBE MATERIALS

Carbon steel is a combination of Fe and C. Carbon Steel is formed when the alloying element is only C. The minor element such as Mn, Si and C may be presents when carbon steel is formed. There are three type of Carbon Steel based on percentage of carbon. The first type is Low-Carbon Steel or Mild Steel where carbon content ranging from 0.008% to 0.3%. This type of steel is soft, ductile, malleable and tough.

It is easily Machinable and weldable. It is also non-hardenable, but surface hardness can be increased through carburising. The second type is medium-Carbon steels, where carbon ranging from 0.3% to 0.6 %. This type of steel are called machinery steels. The characteristics for this steel are that their weldability is low and is considered shallow hardening type. They need to be hot worked as cooled working is very difficult. For the third type, which is High-Alloy steel where the carbon content ranging from 0.62% and above. It is also called tool steel or T91. T91 is the part of ASTM (American Society for Testing and Materials) Standard Specification which is for Seamless Ferritic and Austenitic Alloy. These materials are usually found in Steel Boiler, Superheater and in Heat-Exchanger Tubes. This type of steel is hard, brittle and wear resistant. It is difficult to machine and weld. High-Alloy steel are hardened by heat treatment to high hardness levels with good depth of hardening (Rayaprolu, 2013)

### 2.4 TUBES VERSUS PIPES

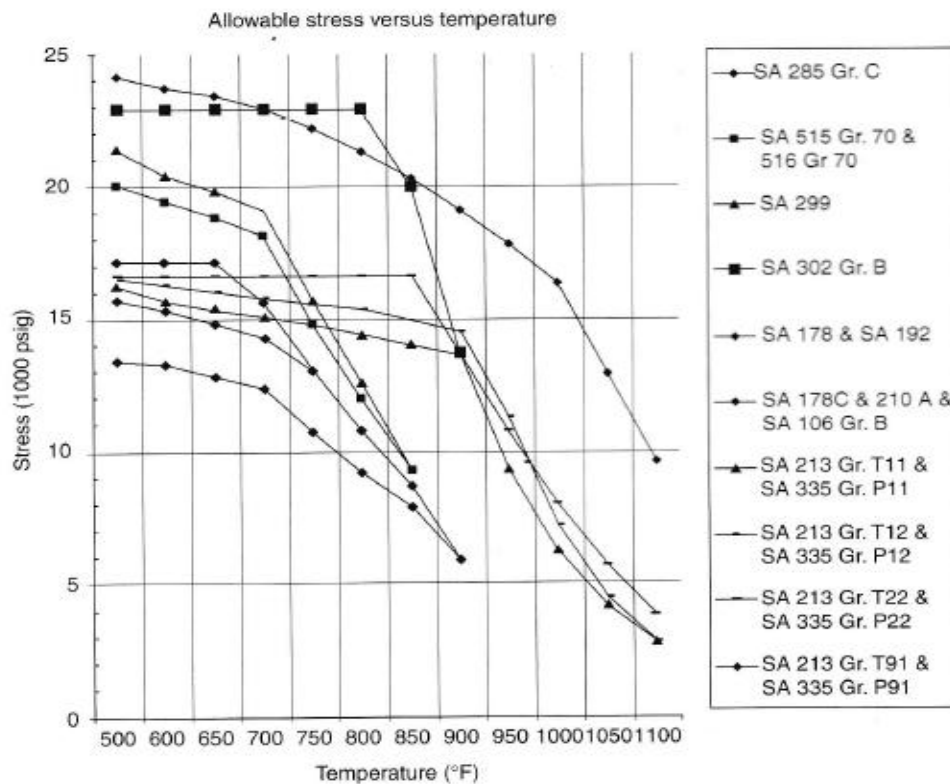
Tubes and pipes are not the same identical work purposes (Rayaprolu, 2009). Pipes do not transfer heat while tubes transfer the heat. The differences are stated in Table 2.4.1 below:

Table 2.4.1 shows the comparison between tubes and pipes

Tube	Pipe
Can Transfer heat and conveyance	Cannot transfer heat but conveyance
Easy to be bend because of low carbon	Material is limited for bending
Easy to be weld as to low Carbon	Minimum size is 1000mm
The largest size is 125mm in outer diameter	Nominal bore(NB) upto 12in(304.8 mm)
Closer tolerance on thickness	Have larger tolerance

## 2.5 RECOGNIZING OF TUBE MATERIALS

(Rayaprolu, 2009) states that to determine any basic application of any material, we need to know the temperature limits based on accelerated oxidation.



**Figure 2.5-1 Shows Graph Allowable Stress Versus Temperature of Material**

Referring to figure 2.5-1 graph, it can be seen that as the stress value decreases, the temperature becomes higher. We can also say that deterioration is more marked with carbon steel which limiting its usage elevated temperatures ranging from 450°F and above. T91 is very well suited for high-temperature tubes and pipes due to its much higher stresses resistance compared to 178 A(Carbon Steel) which decrease until 900°F.

## 2.6 MATERIAL SPECIFICATION

Referring to the Table 2.6.1 below, we can see that the temperature limit for Carbon Steel is 510 °C while for High Alloy Steel which is T91 is 649 °C which is higher compared to Carbon Steel. For the Ultimate Tensile Stress (UTS) the highest was 414 Mpa for Carbon Steel while for T91, the value is 586 Mpa which is also higher than Carbon steel. For Yield Strength (YS) value, Carbon Steel highest value was 276 Mpa while T91 is 414 Mpa which is also higher than Carbon Steel.

**Table 2.6.1 Shows the table for ASME Tube Specification**

Material	ASME Tube Specification			
	Nominal Composition	Temperature Limit (°C)	UTS (Mpa)	YS(Mpa)
<b>1. Carbon Steel</b>				
Low tensile				
178 A (ERW)	C(<0.18)	510	324	179
192	C(<0.18)	510	324	179
Medium tensile				
210 A-1	C(<0.27)	510	414	255
High Tensile				
210 C	C(<0.35)	510		276
178 C (ERW)	C(<0.35)	510	414	255
178 D (ERW)		510		276
<b>2. High Alloy Steel</b>				
213 T91	9Cr-1Mo-V	649	586	414

Referring to the table 2.6.2 below , we can see that the density for AISI 178A (Carbon Steel) is  $11 \text{ kgmm}^{-3}$  higher than AISI 213 T91(High-Alloy Steel). But for the tensile yield strength and tensile ultimate strength, T91 value is higher than the Carbon Steel. For thermal conductivity, T91 is higher than Carbon Steel for about  $92.95 \text{ Wm}^{-1}\text{C}^{-1}$  and also for the specific heat for a about  $410.31 \text{ Jkg}^{-1}\text{C}^{-1}$ . From these data we can already see which material is better.

Table 2.6.2 shows Engineering data of the two material which is Carbon Steel(AISI 178 A) and T91(AISI 213). (Anon., n.d.)

	AISI 178 A
Density	$7861 \text{ kgmm}^{-3}$
Tensile Yield Strength	$179 \text{ MPa}$
Tensile Ultimate Strength	$324 \text{ MPa}$
Isotropic Thermal Conductivity	$623.07 \text{ Wm}^{-1}\text{C}^{-1}$
Specific Heat	$485.67 \text{ Jkg}^{-1}\text{C}^{-1}$
	AISI 213 T91
Density	$7850 \text{ kgmm}^{-3}$
Tensile Yield Strength	$414 \text{ MPa}$
Tensile Ultimate Strength	$586 \text{ MPa}$
Isotropic Thermal Conductivity	$716.02 \text{ Wm}^{-1}\text{C}^{-1}$
Specific Heat	$895.98 \text{ Jkg}^{-1}\text{C}^{-1}$

## **2.7 COMPUTATIONAL FLUID DYNAMIC ANALYSIS (CFD)**

### **2.7.1 Theory of CFD**

CFD is a new branch of integrating in fluid mechanics with mathematics and computer science application. It is a study of fluid mechanics which is the study of which either in motion or at rest. CFD is dedicated to help user to study the fluid flow that influence the process which include heat transfer and chemical reaction in combusting flows. It is also one of 3 basic methods that can be employed to solve problem in fluid dynamics and heat transfer (Jiyuan Tu, 2008).

### **2.7.2 CFD in Chemical and Mineral Processing**

In Chemical and mineral processing industry, CFD can be a helpful tool which mould essential products for food and health as well as vital advanced technological equipment's in computing and bio-technology (Jiyuan Tu, 2008). It contributes into making operational process more energy efficient, safer and flexible while better containing and reducing emissions. Information on transport of fluid and gases through the use of CFD ensure that engineer have the best data to work on. Data which can be used to increase yield by improving fluid flows. Therefore reduce operating cost and increase system efficiency. In manufacturing, it involves complex fluid flow, heat and mass transfer phenomena inside aggressive and hostile environment. By that, CFD can provide a design with greater efficiency and significant production output such as choosing the right material for a boiler tube.

### **2.7.3 Eddy Viscosity**

The eddies turbulent which causing the transfer of momentum is often modeled with an effective eddy viscosity which is similar as the momentum transfer caused by molecular diffusion (for example friction) is modeled with a molecular viscosity. The hypotheses that the effect of turbulent eddies on the flow can be modeled in this is often refered to