EXPERIMENTAL AND SIMULATION STUDY ON THE EFFECTS OF TUBE COIL PLATES ON THE PERFORMANCE OF STEAM PACKAGED BOILER

By

KHAIRIN EZZATY BINTI ABDUL RAHMAN

Dissertation submitted in partial fulfillment

of the requirements of the

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CERTIFICATION OF APPROVAL

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Approved:

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TRONOH, PERAK

September 2012

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

KHAIRIN EZZATY BINTI ABDUL RAHMAN

ABSTRACT

Enhancement of heat transfer intensity in thermo technical apparatus especially boiler is a great significance for industry. Besides the savings of primary energy by increase the boiler efficiency, it is also led to a reduction in size and weight. The performance of the boiler is depend 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 contributes greatly to the boiler efficiency.

The rate of heat transfer to the water depends on heat combustion temperature, operating pressure, total surface area of the coils as well as the material of the coils inside the tubes. However, coil plate is one of the most important members of enhancement technique which is employed extensively in heat exchangers.

Based on the experimental and simulation result, it is proven that the tube coil plates will increase the performance of the boiler by disrupting the fire flow from laminar to turbulence flow thus reducing the speed and allowing more heat transfer across the tube.

ACKNOWLEDGEMENTS

First and foremost, I thank and praise God, for His guidance and blessings, for without it, I would not have been able to complete my final year project.

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CHAPTER 1
INTRODUCTION

1.1. Background of Study

A boiler is an enclosed vessel in which fluid or water is heated. Generally, boilers work by heating water/fluid by means of a heat source such as the combustion of fuels or heating elements. The steam or vaporized liquid generated by the boiler is then used for various processes and/or heating applications such as power generation. Early boilers were very simple, usually a shell or cylinder full of water suspended over a brick-enclosed fire. Heat was applied on the bottom of the shell, and there were no tubes or flues (Stephen, 1973). But as sciences of heat transfer become better known, designers began to apply this knowledge to the simple shell vessels so as to produce more efficient and economical boilers.

Currently, boilers can be classified based on the tube types which are fire tube boiler and water tube boiler. A fire tube boiler is a boiler in which the products of combustion pass through the tubes, which are surrounded by water (Malek, 1998). The body of the boiler is called the shell and it contains water. Steam is generated by the heat transfer through the walls of the tubes, transferring their heat to the water. However, the drawback of fire tube boiler is the entire tank is under pressure. Therefore if the tank bursts it creates a major explosion (Marshall, 2008)

Different from fire tube boiler, a water tube boiler is a boiler in which the water passes through the tubes and products of combustion surround the tubes. The tubes are encaged in a furnace that the burners fire into. The water is heated and steam is produced in the upper drum (Malek, 2007). This subdivision of pressure parts in water tube boiler also make it possible for large capacities and high pressure. The water tube boiler is safer, largely because most of the water at the hottest part of the furnace is in small components (tubes). Thus if a tube ruptures, only a comparatively small volume of water is instantly release to flash into steam (Stephen, 1973). Figure 1.1 describe the working principle of fire tube and water tube boiler.

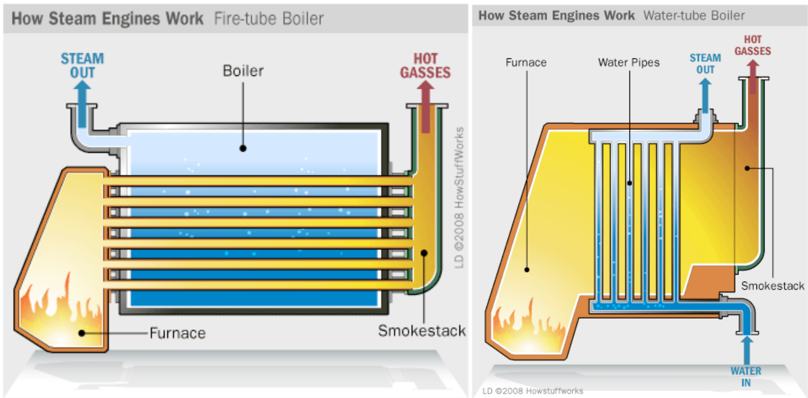

Figure1.1: The working principle of fire tube and water tube boiler (Marshall, 2008)

Steam package boiler is a variation of fire tube boiler. The American Boiler Manufacturers Association (ABMA) defines a package fire tube boiler as *"a modified scotch-type boiler unit, engineered, built, fire tested before shipment, and guaranteed in material, workmanship, and performance by one firm, with one manufacturer furnishing and assuming responsibility for all components in the assembled unit, such as burner, boiler, controls and all auxiliaries"*. Today's steam packaged fire tube boilers are available in wide variety designs which are available in single pass, 2 pass, 3 pass and 4 pass patterns.

Figure 1.2 shows the Bradley Steam Package Boiler in UTP which features a full wetback design for maximum efficiency. It comes complete with combustion and control equipment, water level controls, feed water pump and all necessary valves and fittings. It designed working pressure is 8.9 bar and maximum temperature is 250^{o}C. The theoretical efficiency of the boiler ranges from 70% to 80% (Bradlee Boilers Ltd, 2002). UTP steam packaged boiler is currently using a conventional diesel as fuel for burner. Figure 1.2 shows the steam packaged boiler in UTP. The specification of the boiler is shown in Table 3.5.

Figure 1.2: UTP Bradlee Steam Package Boiler

1.2. Problem Statement

1.2.1. Problem Identification

UTP steam package boiler is a heat exchanger that has been used to demonstrate its function in generating steam and power through steam turbine. The generating tube in steam packaged boilers uses coil plates to enhance the rate of heat transfer from the combustion chamber to the water container through the tubes walls, and later converting it into steam.

The rate of heat transfer to the water depends on heat combustion temperature, operating pressure, total surface area of the coils as well as the material of the coils inside the tubes. Even though there are many ways to increase the heat transfer rate as stated above, the range of the combustion temperature and the design operating pressure have already been fixed by the manufacturer. Besides that, significant reduction in boiler operating pressure may cause the boiler circulation to be interrupt without some modification on the existing piping, tubes etc (Steam Pressure Reduction: Opportunities and Issues, 2005).

Therefore, the most reasonable solution to increase the efficiency of UTP steam package boiler is by using coil plates inserts to enhance the rate of heat transfer from the combustion chamber to the water container through the tubes. Investigating the effect of coil plate surface on the boiler performance is essential in order to determine to the minimum total surface area required and how to increase the boiler performance by manipulating the surface area of the coil plates.

1.2.2. Significance of the Project

Enhancement of heat transfer intensity in all types of thermo technical apparatus is of great significance for industry. Besides the savings of primary energy, it also leads to a reduction in size and weight. Coil plate is one of the most important members of enhancement techniques, which is employed extensively in heat exchangers.

1.3. Objective and Scope of Study

1.3.1. Objective

The objectives of the project are:

i. To compare the performance of boiler operation with and without coil plates.

ii. To study the effect of surface area of the coil plates on heat transfer rate in boiler.

iii. To develop a simulation work on coil plates to increase the rate of heat transfer in the boiler tube.

1.3.2. Scope of Study

In the experimental work, the boiler is being operated in normal pressure condition with 0%, 50% and 100% tube coil plate inserts. Boiler operation is guided by technician. The performance of the boiler is investigated by varying low and high burner setting, then compared as an overall result of this project. Not only that, various researches, journals as well as experiment results will be referred and analyse for data interpretation during the literature study of the effect of surface area of the coil plates on heat transfer rate in heat exchanger. In simulation work, Ansys Fluent 6.3.26 software will be used to determine and identify the most suitable width ratio and twist ratio of the coil plate and to increase the rate of heat transfer in the boiler.

1.4. The Relevancy of the Project

Increasing the efficiency of boilers significantly reduces the amount of energy required to generate the same amount of steam of a given temperature. This is crucial in reducing the cost of steam generation, by decreasing the required amount of fuel/electricity needed, especially with the ever increasing price of fossil fuel (which is to be directly fed into the boiler or as means of generating electricity).

1.5. Feasibility of the Project within the Scope and Time Frame

Total of 28 weeks are given to complete the project. The overall project has been successfully completed without any problems. The project deadline is reasonable with high surveillances along the project progress.

CHAPTER 2
LITERATURE REVIEW

2.1. Theory

2.1.1. Coil Plate Inserts

Coil plate inserts, as one of the passive heat transfer enhancement technology, have been extensively studied due to their advantages of simple configuration without any use of external power source, steady performance, and ease of installation. The heat transfer in tubes with coil plates could be enhanced by generating swirls which enhance the fluid mixing of the near-wall and central regions (Guo et al. 2011) Most of the coil plate inserts for fire tube boiler in the market are fabricated with a ceramic material since it has high temperature resistant properties (Thomas, 2002). Figure 2.1 shows the UTP steam packaged boiler coil plate inserts while example of coil plate inserts with different width ratio is depicted at Figure 2.2.

Figure 2.1 : UTP steam packaged boiler coil plate inserts

Figure 2.2: Coil plate inserts with different twist ratio (Halit et al., 2011)

2.1.2. Laminar and Turbulent Flow

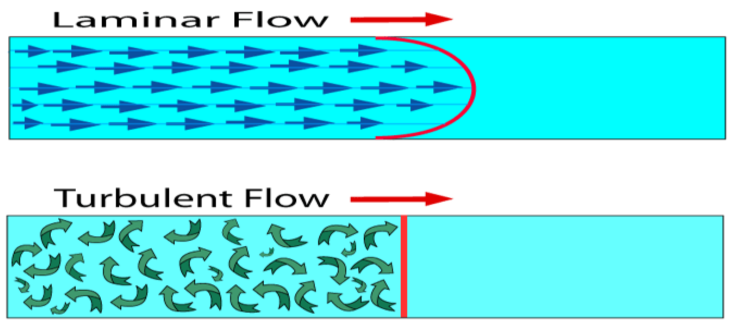

Figure 2.3: Laminar and turbulent flow

(http://www.equipmentexplained.com/physics/fluids/flow/flow.html)

Without coil plate inserts, the hot gases inside the tubes will be in laminar flow mode. The flow occurs in parallel layers, with minimal disruption between these layers. However the friction of the surface of the tubes will cause the flow rate of the hot gases to become slower at boundary layer between tubes and steam. The flow is greatest at the centre and diminishes towards the periphery describe the bullet shaped “velocity profile” shown in Figure 2.3 (Manglik, 1993). Since there is a temperature difference between the hot gases and the tube, the slower moving layers near the tube edge change temperature more readily than the layers near the center.

Difference from laminar flow, the turbulent flow layers are continuously and chaotically changing. Based on Figure 2.3, some of the hot gases moving backward, which it does not, but some flow forward more slowly. The intense mixing of the fluid in turbulent flow as a result of rapid fluctuations enhance heat and momentum transfer between fluid particles, which increases the friction force on the surface and the convection heat transfer rate. Since heat transfer happens as a function of temperature difference, the turbulent flow mode is more efficient than laminar flow, because the 'particles' of the gases get exposed to particles of pipe and are more subject to temperature (Manglik, 1993). Also, the idea that slowing down the gas flow rate will result in increased heat transfer doesn't hold up either. While it is true that if the gas flows more slowly, its temperature will be higher when it exits, there is less total heat exiting with a lower speed.

The idea of slowing down the fluid flow rate to increase the heat transfer also proven based on the friction factor equation (Cengel, 2007) :

$$f = \frac{\Delta P}{\left(\frac{\rho u^2}{2}\right)\left(\frac{L}{D_i}\right)} \quad \text{-----------------} \quad (1)$$

As the flow layers of the hot gases being disrupt by the coil plates, the friction between the hot gases and the surface of the tube increases thus causing the increment of the pressure drop and overall heat transfer across the tube. Because of this, referring to Figure 2.4 the coil plate is inserted into the tube to generate a turbulence flow thus enhance the heat transfer between the tube and fluid.

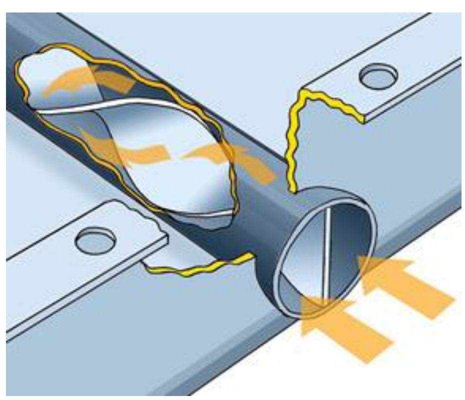

Figure 2.4: Turbulence flow inside tube with the presence of coil plate inserts

(http://kaserafintube.com/finned-terbulator.asp)

2.2. Critical Analysis of Literature

Tube coil plates are utilized as passive heat transfer enhancement devices which work without any external power source. Therefore ways to optimize the thermo hydraulic performance of tubes fitted with coil plates has gained increasing attention.

Saha et al. (1989) experimentally studied the heat transfer and pressure drop characteristics of laminar flow in a circular tube fitted with regularly spaced coil plate elements connected with rod. The results showed that the pressure drop of the tube fitted with the segmented coil plate elements is 40% smaller than that of the tube fitted with a continuous coil plate, and the former has a better thermohydraulic performance. Later, Saha et al. (2001) further investigated the effects of width of the coil plates and the diameter of the connecting rod on heat transfer and pressure drop characteristics. This work indicated that a narrower width of tape elements led to a worse thermohydraulic performance, while a thinner connecting rod resulted in a better one.

In 2006, Naphon compared tubes with coil plates with those without tube coil plates, and proposed non-isothermal correlations for predicting the heat transfer coefficient and friction factor of the horizontal tube with coil plate insert. Eimsa-ard et al. (2009) numerically studied the swirling flow and convective heat transfer in a circular tube fitted with loose-fit coil plates. They found that it was beneficial to reduce the pressure drop by reducing the width of coil plate.

Other researcher, Liu et al. (2012) conducted a numerical investigation on heat transfer behaviors of laminar and turbulent flows in a circular tube fitted with short-width coil plates. Their results of laminar flow also showed a worse overall performance of this method.

CHAPTER 3
METHODOLOGY

3.1. Flow Chart of FYP

Figure 3.1 shows the overall project flow. The first half of the project (FYP1) is mainly focus on the collection of experimental data while the second part of the project (FYP2) involved the simulation work as well as analysis and interpretation of result.

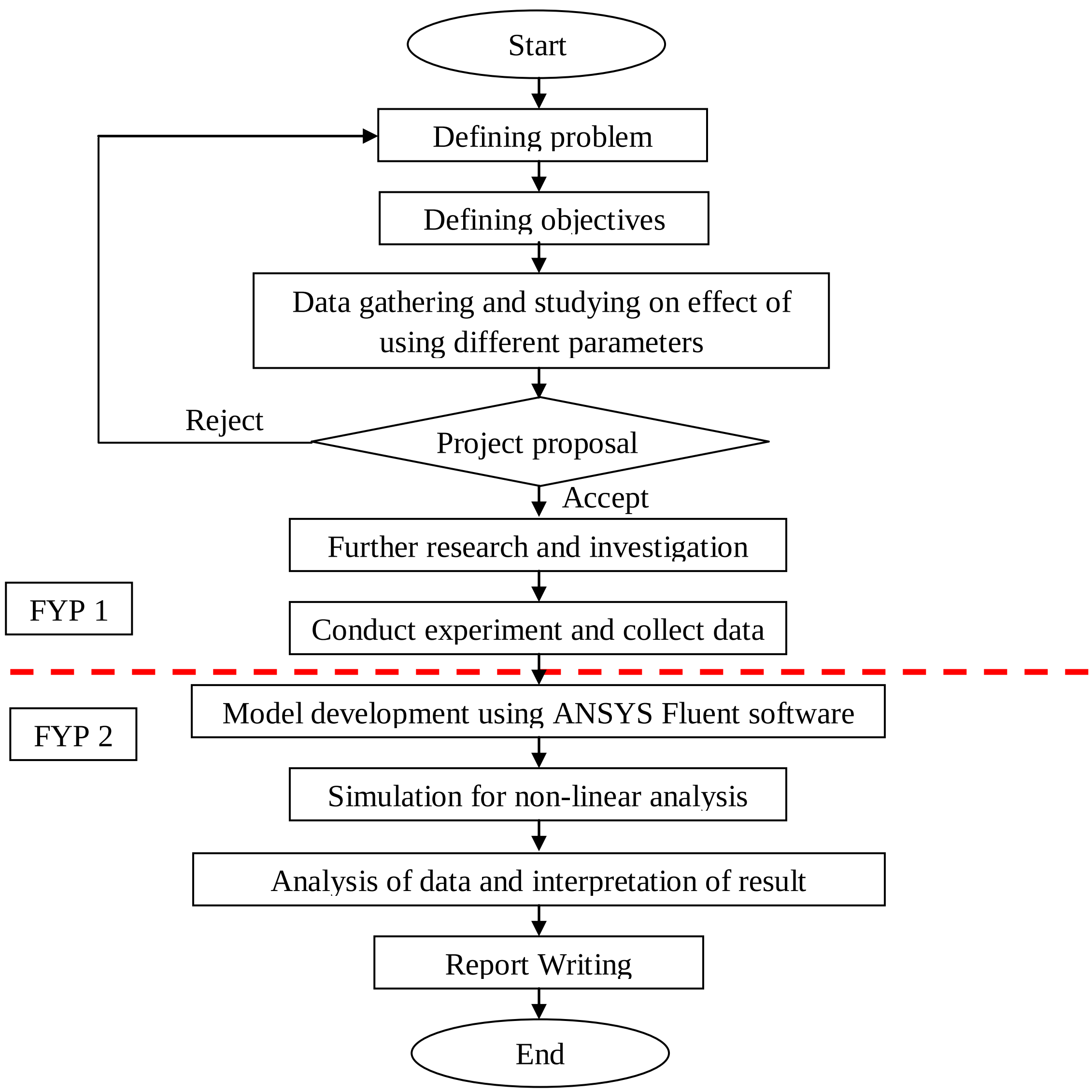

Figure 3.1 : The overall project flow progress

3.2. Project Gant Chart and Milestone

3.2.1. Final Year Project 1

Table 3.1: Final Year Project 1 Gantt Chart

No	Activity	Duration	Week													
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	FYP1 Briefing	1week	23/5													
2	Selection of project title	2 weeks														
3	Investigation of coil plate inserts on the enhancement of steam packaged boiler	5 weeks														
4	Submission of Extended Proposal Defense draft	1 day					22/6									
5	Submission of Extended Proposal Defense	1 day						29/6								
6	FYP Viva (Proposal Defense & Progress Evaluation)	1 day														
7	Further study and investigation	3 weeks														

8	Experiments on the performance of boiler with and without coil plates	2 weeks														
9	Analysis of results and discussion	4 weeks														
10	Submission of Interim Draft Report	1 day													17/8	
11	Submission of Interim Report	1 day														24/8

Legend

Key Milestone

Process

Actual

3.2.2. Final Year Project 2

Table 3.2: Final Year Project 2 Gantt Chart

No	Activity	Duration	Week														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	FYP2 Briefing	1day															
2	Study on the effect of surface area of coil plates insert on heat transfer rate in heat exchanger	4 weeks															
3	Continuation of experiment on the performance of steam packaged boiler with and without tube coil plates insert	4 weeks															
4	Simulation work on coil plates to increase the rate of heat transfer in the boiler																
5	Analysis of simulation result	4 weeks															
6	Progress report draft submission	1 day							31/10								

7	Progress report submission	1 day								11/ 11							
6	Provide simulation discussion and conclusion	2 weeks															
7	Prepare final report	3 weeks															
8	PRE-SEDEX	1 week															
9	Draft Report submission	1day												3/12			
10	Dissertation submission (soft bound)	1 day															
11	Technical paper submission	1 day															
12	Oral Presentation	1 day														19/12	
13	Project Dissertation submission	1 day															

3.3. Experimental Procedure

The UTP Steam Packaged Boiler Instrumentation is shown in Figure 3.2 and the instrumentation parts are listed in Table 3.3. The experiments are conducted as follows:

1. The performance of UTP Steam Packaged Boiler was observed with 0%, 50% and 100% tube coil plate inserts (refer to Figure 3.3) and the boiler was set to run with low fire and high fire burner setting for each set of experiment.
2. The data was collected with initial operating pressure of 0 bar until the operating pressure was build up to 7 bar.
3. The time, temperature of the air, feed water, fuel oil, steam and exhaust fuel gas were taken for each 1 bar increment of the operating pressure.
4. The performances of the boiler were being compared.
5. The efficiencies of the boiler were calculated by using direct method.

Figure 3.1: UTP Steam Packaged Boiler Instrumentation

Table 3.3: UTP Steam Packaged Boiler parts

No	Parts
1	Bradlee steam packaged boiler
2	Pressure meter
3	Pressure relief valve
4	Boiler operating data reader
5	Thermocouple sensor for air temperature
6	Thermocouple sensor for feedwater temperature
7	Thermocouple sensor for fuel oil temperature
8	Thermocouple sensor for steam temperature
9	Thermocouple sensor for fuel gas temperature

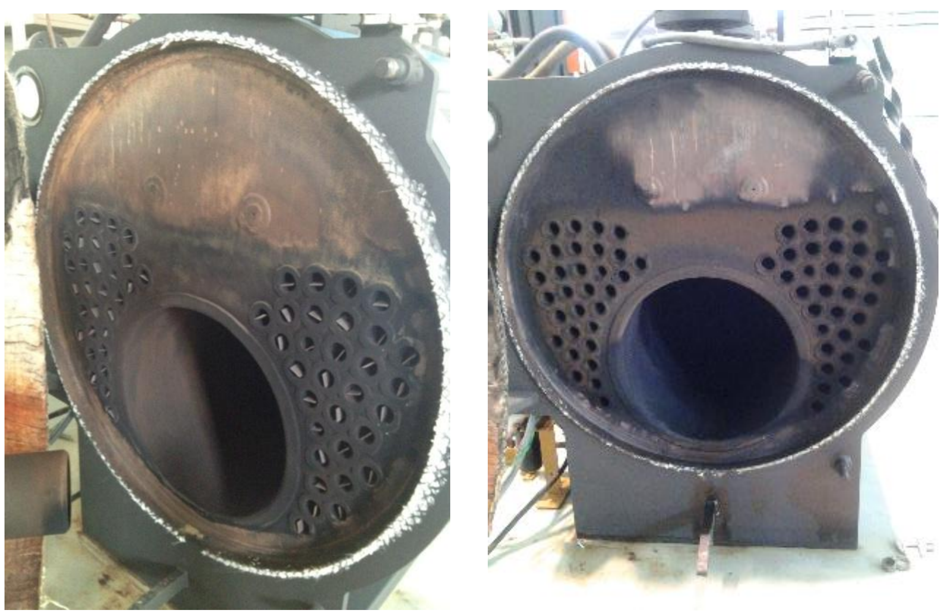

Figure 3.2: Boiler with 100% (left) and 0% (right) tube coil plate inserts

3.3.1. Methods for Determining Boiler Efficiency

The performance of the boiler operation with and without coil plates will be compared by using the direct method as proposed by Rckonsul, 2011.

For a steam-generating unit, efficiency is defined as the heat absorbed by the boiler fluid, divided by the fuel fired. In equation form, this is:

Efficiency, η = $\frac{Heat\ exported\ by\ the\ fluid}{Heat\ provided\ by\ the\ fuel}$ x 100 = %

Efficiency, η = $\frac{Steam\ flow\ rate\ (heat\ of\ steam - heat\ of\ feedwater)}{(Weight\ of\ fuel)(Calorific\ Value\ of\ fuel)}$ x 100%

Efficiency, η = $\frac{\dot{m}_s(h_s - h_{fw})}{\dot{m}_f\ (CVF)}$ x 100%----------------- (2)

Where	$\dot{m}_s$	=	mass flow rate of steam produced per hour (kg/hr)
	$\dot{m}_f$	=	mass flow rate of fuel (kg/hr)
	h_s	=	enthalpy of steam leaving boiler (kJ/kg)
	h_{fw}	=	enthalpy of feed water entering boiler (kJ/kg)
	CVF	=	calorific value of fuel (kJ/kg)

3.4. Simulation Procedure

Ansys Fluent 6.3.26 has been chosen as the CFD tool to simulate the effect of width ratio and twist ratio of the coil plate with the performance of heat transfer across the tube side of the boiler.

3.4.1. Physical Model

The geometric cross section of coil plate inside UTP steam packaged boiler tube used for the numerical simulation is depicted in Figure 3.4. Coil plate with thickness 1mm is fitted in the full length (L) 17cm of tube. The original diameter (D) of tube and width (w) of coil plate is 3.2cm and 2.46cm respectively with width ratio of 0.8. The 180^o twist pitch (y) is 8.5cm thus the relative twist ratio is 3.5. The effects of the surface area of the coil plates to the rate of heat transfer from the hot air inside the tubes to the water container of UTP steam packaged boiler will be simulated using Ansys Fluent 6.3.26 by varying the width ratio and twist ratio.

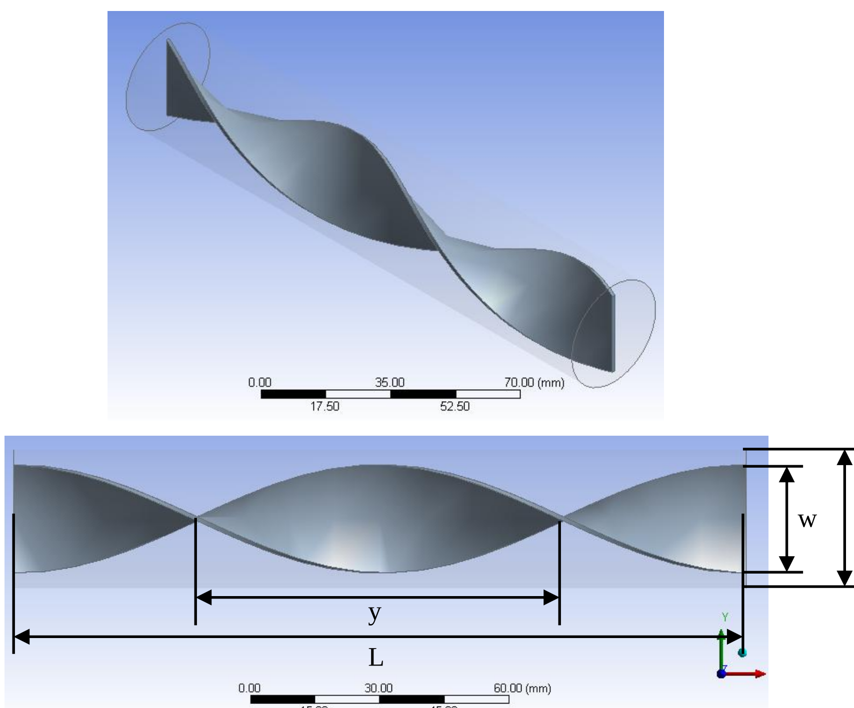

Figure 3.3: Geometry of round tube with coil plate inserts

The formula of width ratio and twist ratio are shown below.

Width ratio = $\frac{w}{D}$ ---------- (3)   Twist ratio = $\frac{y}{w}$ ---------- (4)

3.4.2. Governing Equations

The Reynolds numbers used for the computation are 750, 1000, 1250, 1500, 1750 and 2000 by varying the inlet velocity of the hot air. The equation use to compute Reynolds number (Re) is (Cengel, 2007):

$$Re = \frac{\rho u D}{\mu} \quad ---------- (5)$$

where	ρ	=	density of air at 433K (0.815kg/m^3)
	μ	=	kinematic viscosity of air at 433K (2.433 x 10^{-5} kg/m^3)
	D	=	0.032m
	u	=	inlet velocity of air (m/s)

The hot air flow inside tube is analyse to be incompressible, laminar, steady and three-dimensional. It is assumed that there's no heat conduction in the coil plate. Constant heat flux and no slip condition are also imposed on the surface of coil plate and inner tube wall while outer tube wall has been set under adiabatic condition. The inner tube wall and inlet tube temperature is kept constant at 453 K and 433 K respectively.

Navier-Stokes equations are being used along the process and can be written in the following form (Cengel, 2001)

Continuity equation:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \quad ---------- (6)$$

Momentum equations:

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial \rho}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right] \quad \text{----------} \ (7)$$

Energy equation:

$$\frac{\partial}{\partial x_j}\left(\rho u_j C_p T - k\frac{\partial T}{\partial x_j}\right) = 0 \quad \text{----------} \ (8)$$

There are 2 parameters of interest for the simulation result which are Nusselt number (Nu) and friction factor (*f*). The Nusselt number and friction factor of each width ratio and twist ratio at different Reynolds number (Re) will be compared with one another. A larger value of Nusselt number and friction factor corresponds to more active convection with greater turbulent flow. The Nusselt number and friction factor of the air flow can be compute by using the following equations.

The convection of heat transfer at pipe wall (Mullen, 2012):

$$q_w^{"} = h\,(T_w - T_m) \quad \text{----------} \ (9)$$

Nusselt number expression (Mullen, 2012):

$$Nu = \frac{hD}{k} = \frac{q_w^{"}\,(2R)}{k(T_w - T_m)} \quad \text{----------} \ (10)$$

where	h	=	convection coefficient (W/m^{2}K)
	k	=	thermal conductivity (W/mK)
	D	=	inner diameter of the tube (0.32m)
	$q_w^{"}$	=	heat flux at the heated surface (W/m^2)
	T_w	=	tube wall temperature (K)
	T_m	=	mean temperature of the tube (K)

Friction factor can be defined as (Cengel, 2007):

$$f = \frac{\Delta P}{\left(\frac{\rho u^2}{2}\right)\left(\frac{L}{D}\right)}$$

where ΔP = Pressure drop along the tube (Pa)

ρ = density of air at 433K (0.815kg/m^3)

u = inlet velocity of air (m/s)

L = length of the tube (0.17m)

D = inner diameter of tube (0.32m)

3.5. Tools Required

Table 3.4: Software used along the project

No	Software	Description
1	Microsoft Office Word	Write report and information safe form.
2	Microsoft Office Excel	Organize data for comprehension and calculation.
3	Ansys Fluent 6.3.26	To model flow, turbulence and heat transfer inside the tube of heat exchanger with the presence of coil plates for further research.

Table 35: Hardware used along the project

No	Hardware	Description
1	Bradlee Steam Packaged Boiler	- Heat exchanger with a 3-pass horizontal, return flame, wet-back type. - Ratings : From 50kg/hr to 6800 kg/hr (F&A 100^{o}C) - Working Pressure : 8.9 Bar
2	Coil Plates	To investigate the effect of coil plate insert on heat transfer rate in heat exchanger.
3	Measuring Tape & Vernier Caliper	To measure the dimension of the tubes, coil plates and other parameters.

CHAPTER 4
RESULT AND DISCUSSION

This chapter presents the results obtained from comprehensive numerical simulation and experimental investigation which covers operation of boiler at different burner setting with 0%, 50% and 100% tube coil plate inserts.

4.1. Experimental Result and Discussion

4.1.1. Data Gathering

Below are the experimental result obtained during data gathering for the boiler operation performance. Since there is no steam produced at the beginning of the experiment, no steam temperature data is collected at 0 min with the initial operating pressure of 0 bar.

Table 4.1: Data for running steam packaged boiler with 0% tube coil plate inserts at low fire burner setting

Pressure (bar)	Time (min)	Temperature (^{o}C)				
		Air	Feedwater	Fuel Oil	Steam	Flue
0	0	21	21	22	-	69
1	42	24	24	23	119	194
2	49	24	23	24	134	205
3	55	25	24	24	143	212
4	60	25	24	24	148	218
5	64	25	24	24	153	224
6	69	25	24	24	160	228
7	73	25	24	24	168	234

Table 4.2: Data for running steam packaged boiler with 50% tube coil plate inserts at low fire burner setting

Pressure (bar)	Time (min)	Temperature (°C)				
		Air	Feedwater	Fuel Oil	Steam	Flue
0	0	23	23	24	-	69
1	35	24	23	24	116	177
2	43	24	24	24	133	190
3	50	24	24	24	128	198
4	54	25	24	24	148	204
5	59	25	24	24	153	210
6	63	25	24	24	157	215
7	67	25	24	24	170	220

Table 4.3: Data for running steam packaged boiler with 100% tube coil plate inserts at low fire burner setting

Pressure (bar)	Time (min)	Temperature (°C)				
		Air	Feedwater	Fuel Oil	Steam	Flue
0	0	24	27	24	-	69
1	30	24	26	25	118	123
2	38	24	26	24	130	136
3	43	24	26	24	143	145
4	48	24	26	24	153	153
5	53	25	26	24	160	161
6	57	25	26	24	161	165
7	61	25	26	24	172	169

Table 4.4: Data for running steam packaged boiler with 0% tube coil plate inserts at high fire burner setting

Pressure (bar)	Time (min)	Temperature (^oC)				
		Air	Feedwater	Fuel Oil	Steam	Flue
0	0	21	22	22	-	199
1	6	22	22	23	123	263
2	10	22	22	23	136	277
3	12	22	23	24	146	286
4	15	23	23	24	152	292
5	18	23	23	24	154	298
6	20	23	23	24	158	302
7	22	23	23	24	165	297

Table 4.5: Data for running steam packaged boiler with 50% tube coil plate inserts at high fire burner setting

Pressure (bar)	Time (min)	Temperature (^oC)				
		Air	Feedwater	Fuel Oil	Steam	Flue
0	0	24	23	24	-	182
1	4	24	23	24	122	232
2	8	24	24	24	136	246
3	10	24	24	24	147	255
4	13	24	24	24	152	260
5	16	24	24	24	155	265
6	19	24	24	24	165	269
7	22	24	24	24	171	273

Table 4.6: Data for running steam packaged boiler with 100% tube coil plate inserts at high fire burner setting

Pressure (bar)	Time (min)	Temperature (^oC)				
		Air	Feedwater	Fuel Oil	Steam	Flue
0	0	22	23	24	-	114
1	3	22	23	26	118	158
2	8	23	23	27	139	171
3	10	23	23	27	151	180
4	13	23	24	27	157	186
5	15	23	24	27	163	192
6	19	23	24	27	171	195
7	21	24	24	28	177	200

4.1.2. Discussion and Analysis

The data gathered were tabulated into graph form for further analysis. Figure 4.1and 4.2 show the time taken of the boiler operation with respected to the boiler operating pressure at low and high fire burner setting.

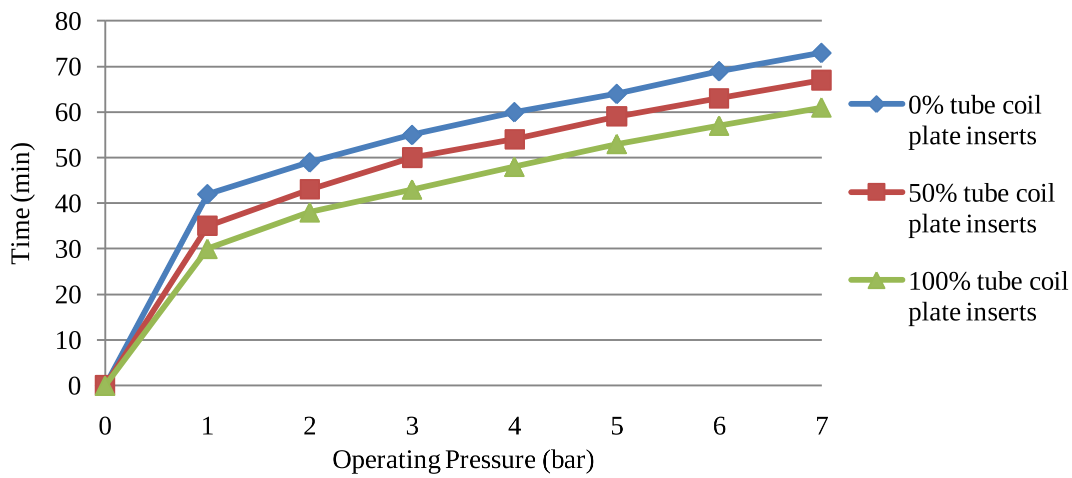

Figure 4.1: Graph of time taken versus boiler operating pressure for low fire burner setting.

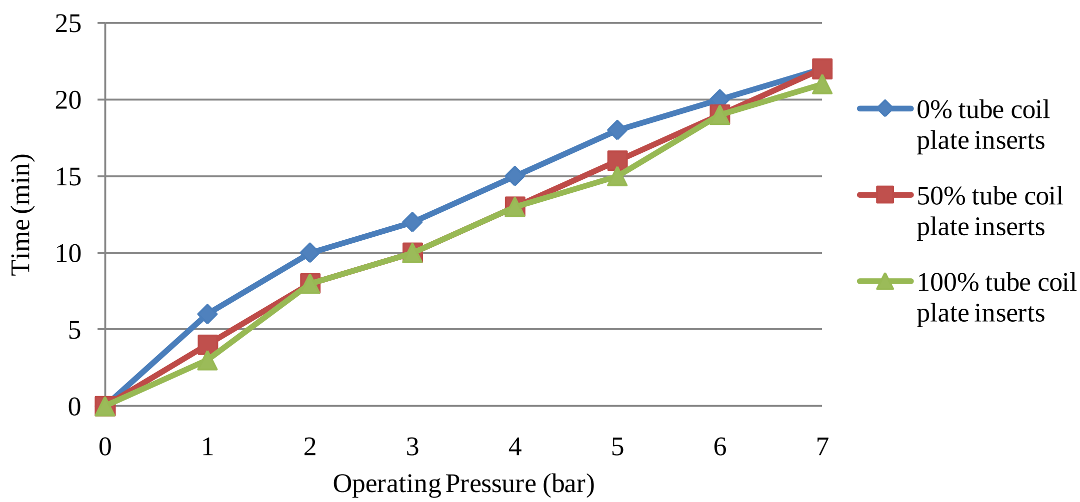

Figure 4.2: Graph of time taken versus boiler operating pressure for high fire burner setting.

Based on Figure 4.1 and 4.2, the time taken for the boiler operating pressure to increase is the fastest for 100% tube coil plate inserts followed by 50% and 0% tube coil plate inserts for both fire burners setting. The time taken for 0%, 50% and 100% tube coil plate inserts under low fire burner setting to reach 7 bar are 73, 67 and 61 minutes respectively. For high fire burner, it takes 22 minutes for both 0% and 50% coil plates while 100% tube coil plates only takes 21 minutes to build up pressure until 7 bar. With coil plate as passive heat transfer enhancement, more steam can be produced at a faster rate and increase the boiler operating pressure at a faster time.

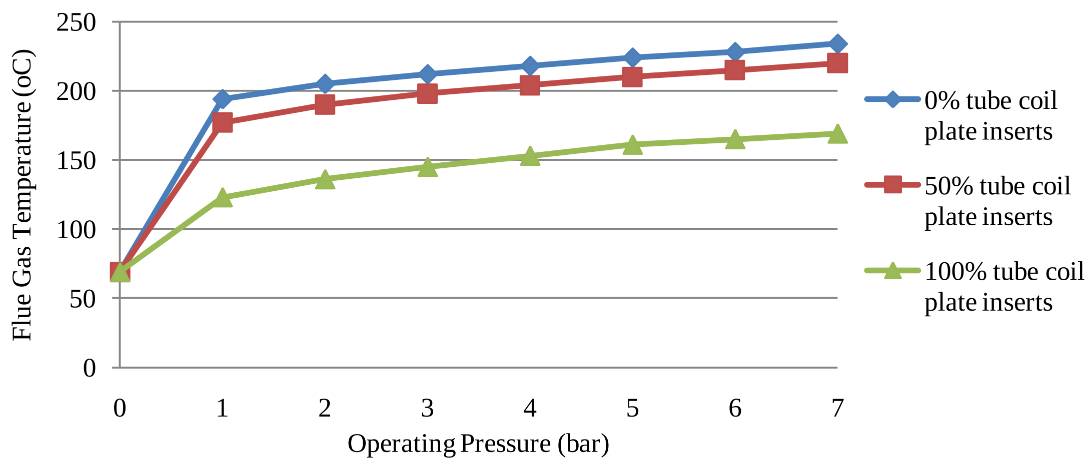

Figure 4.3: Graph of exhaust flue gas temperature versus boiler operating pressure for low fire burner setting

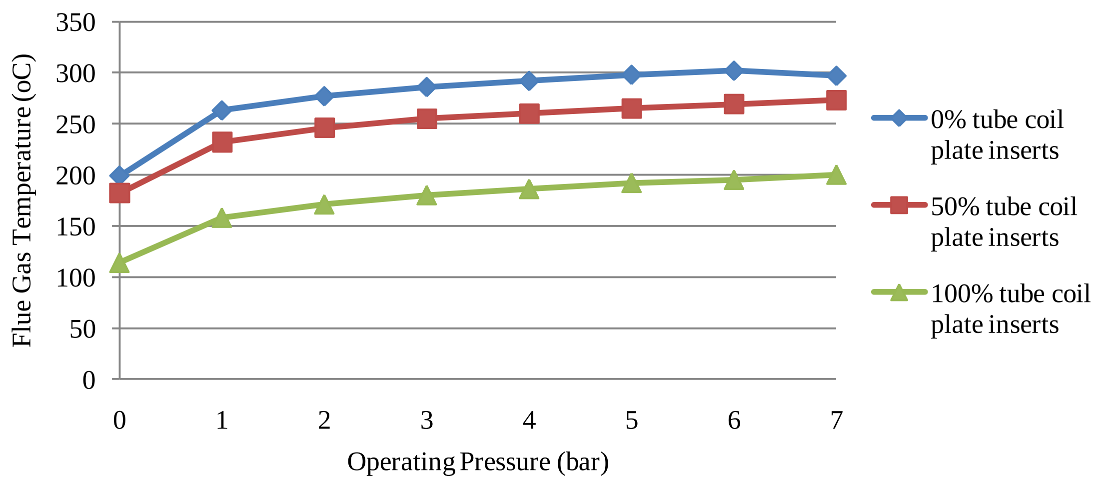

Figure 4.3: Graph of exhaust flue gas temperature versus boiler operating pressure for high fire burner setting

Figure 4.3 and 4.4 show the graphs of exhaust flue gas temperature versus boiler operating pressure for low fire burner and high fire burner setting. 0% tube coil plate inserts indicates the highest exhaust flue gas temperature for both fire burner setting followed by 50% and 100% tube coil plate inserts.

For low fire burner setting, the flue gas temperatures for 0%, 50%, 100% coil plates inside tubes to reach 7 bar are 234^{o}C, 220 ^{o}C and 169 ^{o}C while for high fire burner setting the flue gas temperatures are 297 ^{o}C, 273 ^{o}C and 200 ^{o}C.

In general, the temperature of the flue gas is an indication of how effective the heat from the combustion gas being transferred to the water. Low temperature of exhaust flue gas for 100% tube coil plate inserts signify better energy and heat transfer from the combustion gas across the tubes to the water along the process and less energy is being wasted to the stack. This correlates with the purpose of coil plate which is to enhance the heat transfer and increase the overall efficiency of the boiler.

It is approximately 30% - 33% difference between 0% and 100% tube coil plate inserts for low fire burner setting and 36% - 40% difference for high fire burner setting, thus showing high fire burner setting for boiler give more significant enhancement of heat transfer with the usage of coil plates. Besides that, reducing half the number of coil plates inside tubes cause almost 80% of heat loss to the stack for low burner and 70% for high burner.

Figure 4.5 and 4.6 below show the temperature of the steam at each operating pressure for low and high fire burner setting while Figure 4.7 and 4.8 are the steam temperature with respective to the time taken for both fire burner settings.

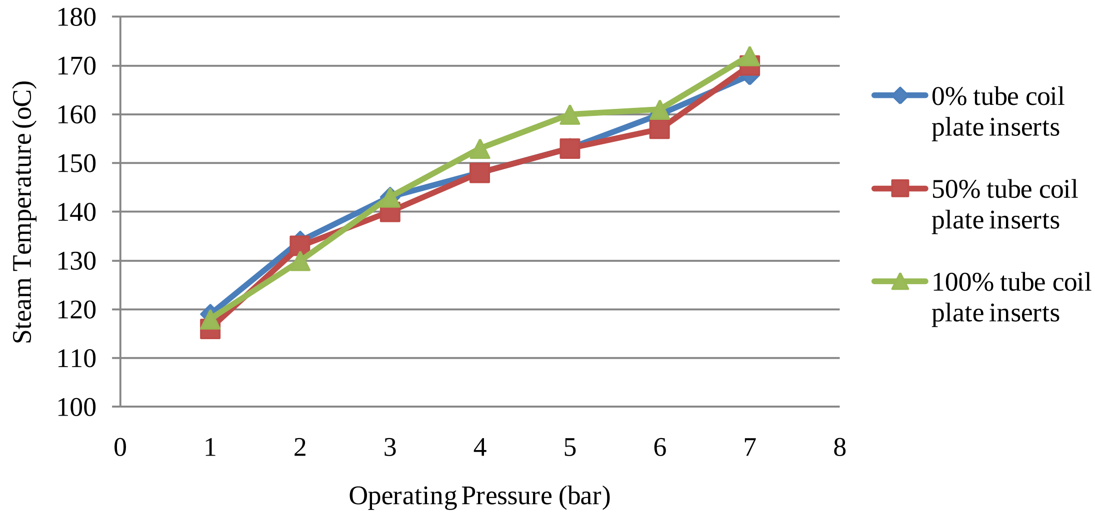

Figure 4.5: Graph of steam temperature versus boiler operating pressure for low fire burner setting.

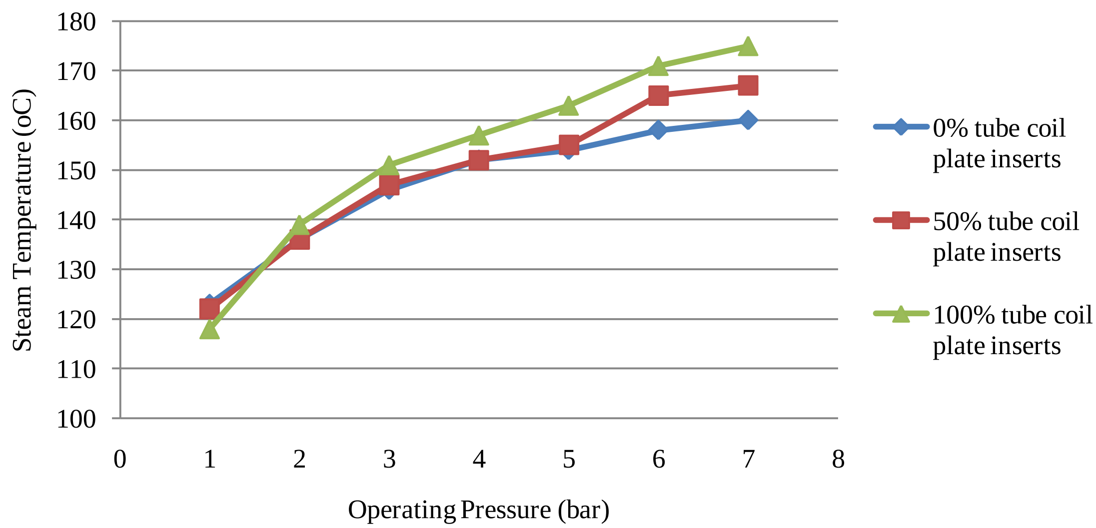

Figure 4.6: Graph of steam temperature versus boiler operating pressure for high fire burner setting.

From Figure 4.5 and 4.6, it can be observed that 100% tube coil plate inserts produce highest steam temperature for each increment of boiler operating pressure however there's only a small difference of steam temperature between each set of experiment. Both 50% and 100% coil plate inside tubes for low fire burner show the final temperature of 168°C at 7 bar operating pressure and temperature of 170 °C for 0% tube coil plate inserts. Besides that, for the 2nd set of experiment (high fire burner setting), the steam temperature for 0%, 50% and 100% tube coil plates are 160 °C, 167 °C and175 °C respectively.

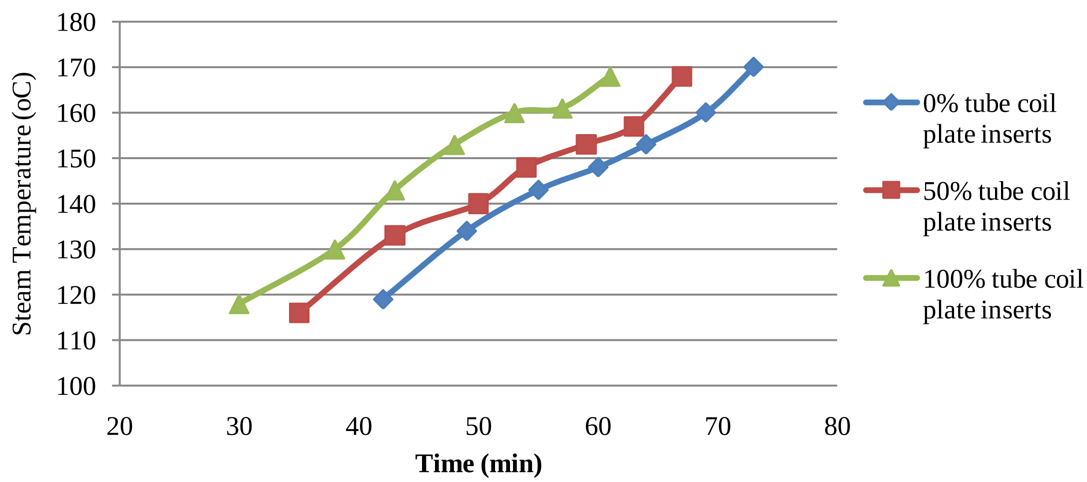

Figure 4.7: Graph of steam temperature versus time for low fire burner setting.

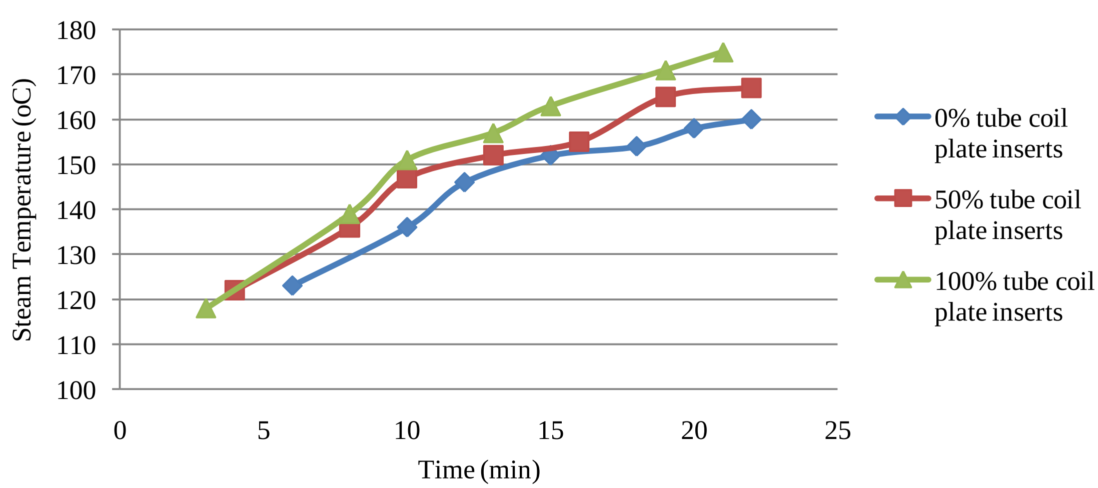

Figure 4.8: Graph of steam temperature versus time for high fire burner setting.

To justify more clear relationship between steam temperature and the percentage of tube coil plates, the steam temperatures for each set of experiment were being compared with the time taken to build up the operating pressure until 7 bar. Even though there are no significant differences between steam temperatures at each operating pressure, in Figure 4.7 and 4.8, it clearly show 100% tube coil plate inserts takes the shortest time to increase the steam temperature while the longest would be 0% tube coil plate.

This characteristic proves that coil plate improves the heat transfer from the combustion gas in tubes to the water in the shell side of the boiler that later will be transformed into steam. For low fire burner setting, 0% tube coil plates takes the longest time (73 minutes) to increase the operating pressure until 7 bar with steam temperature of only 145 ^{o}C. 50% and 100% take 67 and 61 minutes each to increase their temperature to 168 ^{o}C.

Moreover, for high fire burner setting, the time taken is 22 minutes at 7 bar operating pressure for both 0% and 50% coil plate inserts with 150 ^{o}C and 167 ^{o}C steam temperatures. 100% coil plates inside tubes shows temperature of 175 ^{o}C with time taken only 21 minutes at 7 bar. As expected, high fire burner setting will provide better rate of heat transfer than low fire burner setting.

4.1.3. Boiler Efficiency

The boiler efficiency for 0%, 50% and 100% coil plates inside tubes are being compared. Boiler efficiency is presented as a percentage ratio of heat supplied to the boiler and the heat absorbed in the boiler water. A method called direct method or also known as input-output method as shown in equation 2 is used to calculate the boiler efficiency. Figure 4.9 and 4.10 describe the UTP Rankine mini steam power plant cycle and T-s diagram for easy understanding.

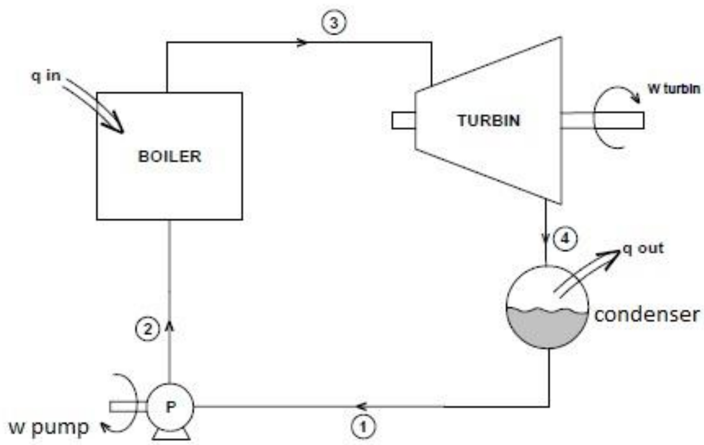

Figure 4.9: UTP Rankine mini steam power plant cycle (http://steamofboiler.blogspot.com/2011/06/thermodynamic-analysis-in-steam-boiler.html)

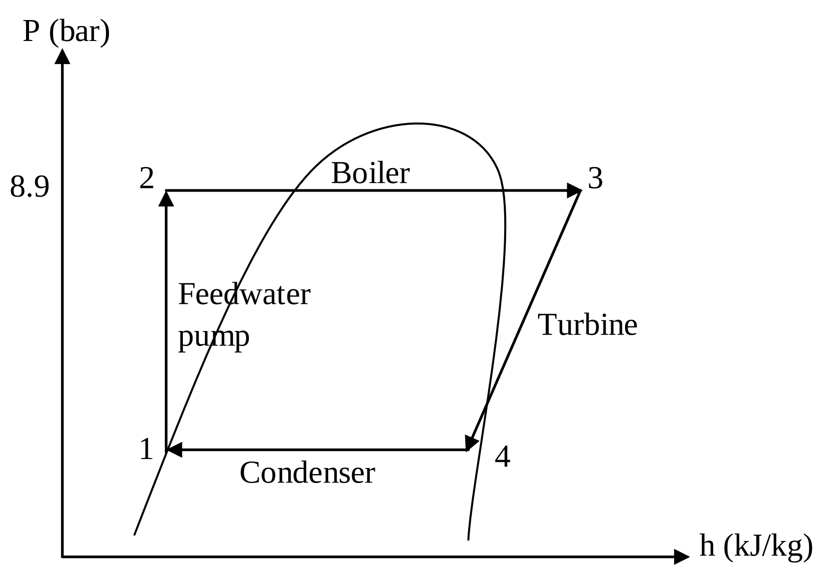

Figure 4.10: UTP Rankine mini steam power plant P-h diagram

The operating pressure of the boiler is 7 bar and the maximum temperature is 250^oC. The average temperature of the feedwater is 24^oC. The theoretical efficiency of the boiler ranges from 70% and 80%. Therefore, its average is 75%. For conventional diesel, the calorific value, CV_f is around 45,000 to 47,000 kJ/kg. The average value is taken which is 46,000 kJ/kg.

At point 2, (saturated water)	$T_2 = T_1$	=	24^oC
	P_2	=	7 bar
	$h_2 (h_{fw)} = h_1 = h_{f@24oC}$	=	100.647 kJ/kg
At point3, (superheated water)	T_3	=	250^oC
	P_3	=	7 bar
	$h_3 (h_s)$	=	2954 kJ/kg

Theoretically using equation 2, the ratio of mass flow rate of steam produced over mass flow rate of fuel can be calculated as below

$$\text{Efficiency, } \eta = \frac{\dot{m}_s(h_s - h_{fw})}{\dot{m}_f\ (CVF)}$$

$$0.75 = \frac{\dot{m}_s(2954 - 100.647)}{\dot{m}_f\ (46{,}000)}$$

$$\frac{\dot{m}_s}{\dot{m}_f} = 12.09$$

Therefore, 1kg of fuel will produce about 12.09 kg of steam.

Next, the h_s and h_{fw} for 0%, 50% and 100% coil plate insert will be find out to compare the boiler efficiency and performance for each cases.

a) 0% Tube Coil Plate Inserts (Low Fire Burner)

At point 2, (saturated water)	$T_2 = T_1$	=	23.5^oC
	P_2	=	7 bar
	$h_2\,(h_{fw}) = h_1 = h_{f@23.oC}$	=	98.6 kJ/kg
At point3, (superheated water)	T_3	=	168^oC
	P_3	=	7 bar
	$h_3\,(h_s) = h_g$	=	2770.5kJ/kg

b) 50% Tube Coil Plate Inserts (Low Fire Burner)

At point 2, (saturated water)	$T_2 = T_1$	=	23.75^oC
	P_2	=	7 bar
	$h_2\,(h_{fw}) = h_1 = h_{f@23.75oC}$	=	99.6 kJ/kg
At point3, (superheated water)	T_3	=	170^oC
	P_3	=	7 bar
	$h_3\,(h_s)$	=	2774 kJ/kg

c) 100% Tube Coil Plate Inserts (Low Fire Burner)

At point 2, (saturated water)	$T_2 = T_1$	=	26.125^oC
	P_2	=	7 bar
	$h_2\,(h_{fw}) = h_1 = h_{f@26oC}$	=	109.53 kJ/kg
At point3, (superheated water)	T_3	=	172^oC
	P_3	=	7 bar
	$h_3\,(h_s)$	=	2778.05kJ/kg

d) 0% Tube Coil Plate Inserts (High Fire Burner)

At point 2, (saturated water)	$T_2 = T_1$	=	22.6^oC
	P_2	=	7 bar
	$h_2\,(h_{fw}) = h_1 = h_{f@22.6oC}$	=	94.79 kJ/kg

At point3, (saturated steam)	T_3	=	165°C
	P_3	=	7 bar
	$h_3\ (h_s) = h_g$	=	2763.5kJ/kg

e) 50% Tube Coil Plate Inserts (High Fire Burner)

At point 2, (saturated water)	$T_2 = T_1$	=	23.75°C
	P_2	=	7 bar
	$h_2\ (h_{fw)} = h_1 = h_{f@23.75oC}$	=	99.6 kJ/kg
At point3, (superheated water)	T_3	=	171°C
	P_3	=	7 bar
	$h_3\ (h_s)$	=	2775.75kJ/kg

f) 100% Tube Coil Plate Inserts (High Fire Burner)

At point 2, (saturated water)	$T_2 = T_1$	=	23.5°C
	P_2	=	7 bar
	$h_2\ (h_{fw)} = h_1 = h_{f@23.oC}$	=	98.6 kJ/kg
At point3, (superheated water)	T_3	=	177°C
	P_3	=	7 bar
	$h_3\ (h_s)$	=	2791.05kJ/kg

By using equation 2 and the theoretical value of $\frac{\dot{m}_s}{\dot{m}_f} = 12.09$, the boiler efficiency for each cases are shown in the table below.

Table 4.7: Boiler efficiency for 0%, 50% and 100% tube coil plates

Percentage of tube coil plates (%)		0	50	100
Boiler efficiency (%)	High Fire Burner	69.24	70.34	72.76
	Low Fire Burner	69.10	70.29	70.48

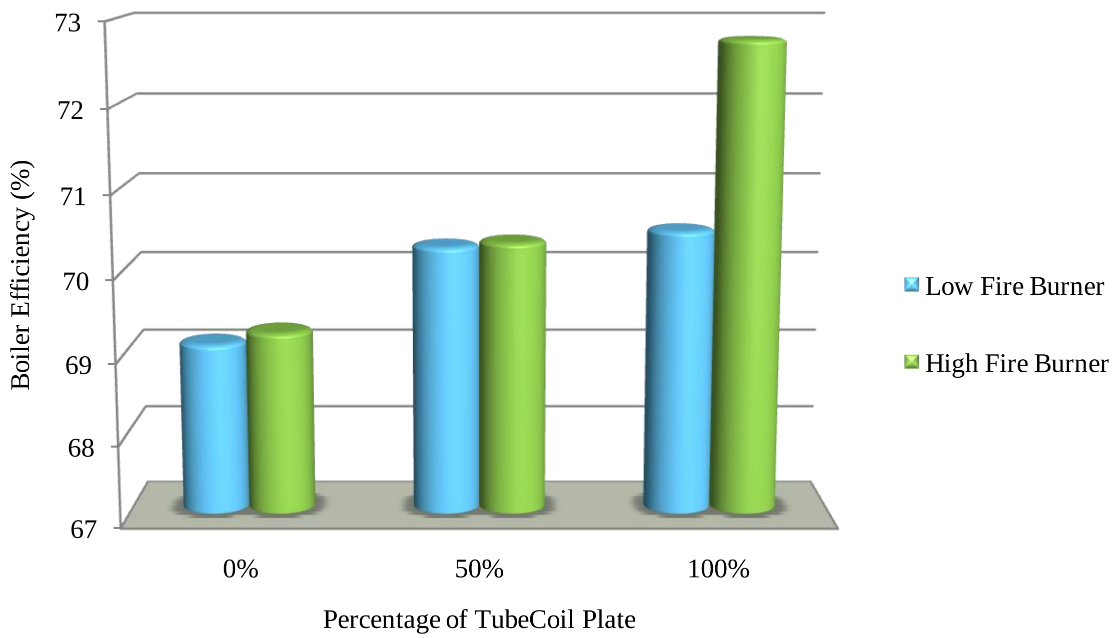

Figure 4.11: Graph of boiler efficiency versus the percentage of tube coil plate

Based on the result in Table 4.7 and Figure 4.11, it is proven that the coil plates inside tubes increase the efficiency of the boiler. The efficiency of the boiler becomes greater as the number of the coil plates increases. High fire burner setting shows a more significant efficiency increase compared to the low fire burner setting.

4.2. Simulation Result and Discussion

For validating the accuracy of the numerical result, the Nusselt number (*Nu*) of a plain tube is compared with the theoretical data (Thirumaleshwar, 2006) under fully developed flow in smooth, circular pipe.

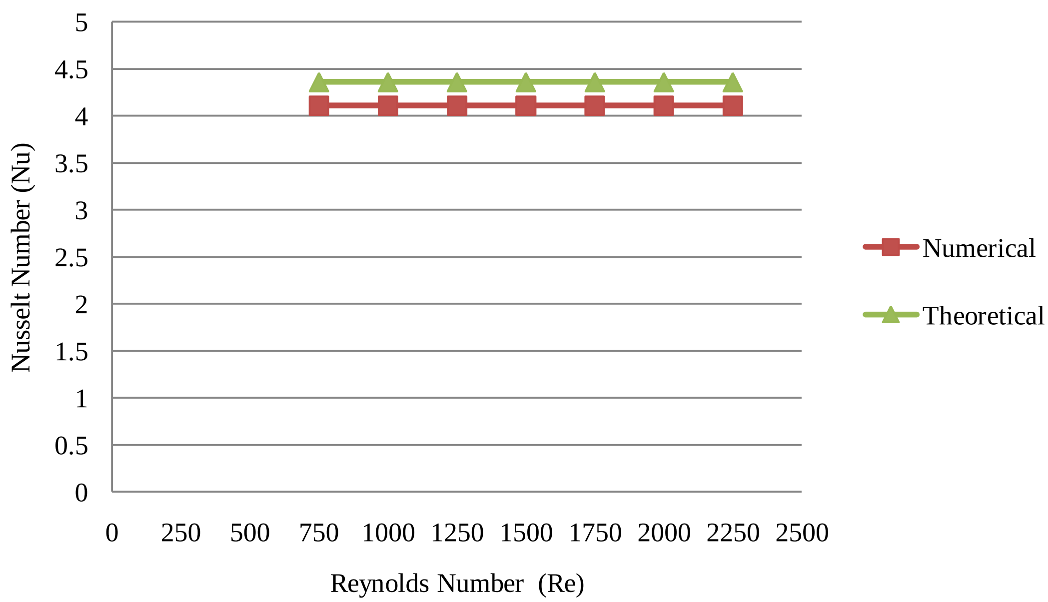

Figure 4.12: Graph of numerical and theoretical Nusselt Number versus Reynolds Number of a plain tube.

From Figure 4.12, the deviation between numerical result (Nu = 4.11) with theoretical data (Nu = 4.36) is only 5.7% which is relatively very low and can be considered as reasonably accurate.

4.2.1. Effects of Tube Tube Coil Plate Width Ratio and Twist Ratio to the Nusselt Number

The comparison of Nusselt number for each width ratio and twist ratio of tube coil plate insert at different Reynolds numbers are shown in Figure 4.13 and 4.14.

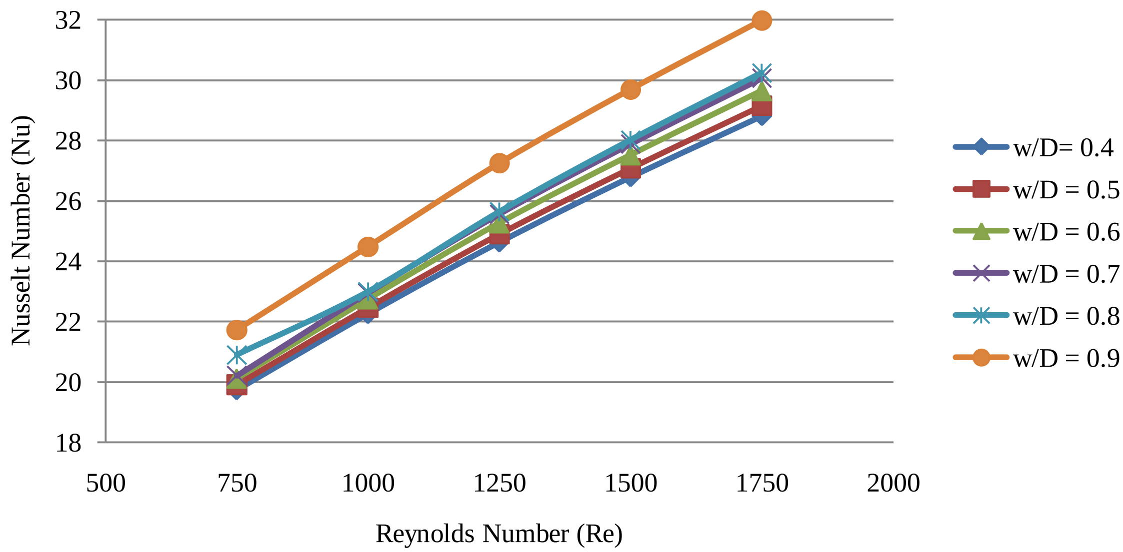

Figure 4.13: Variation of Nusselt number (Nu) versus the Reynolds number (Re) of the coil plate at different width ratio (w/D).

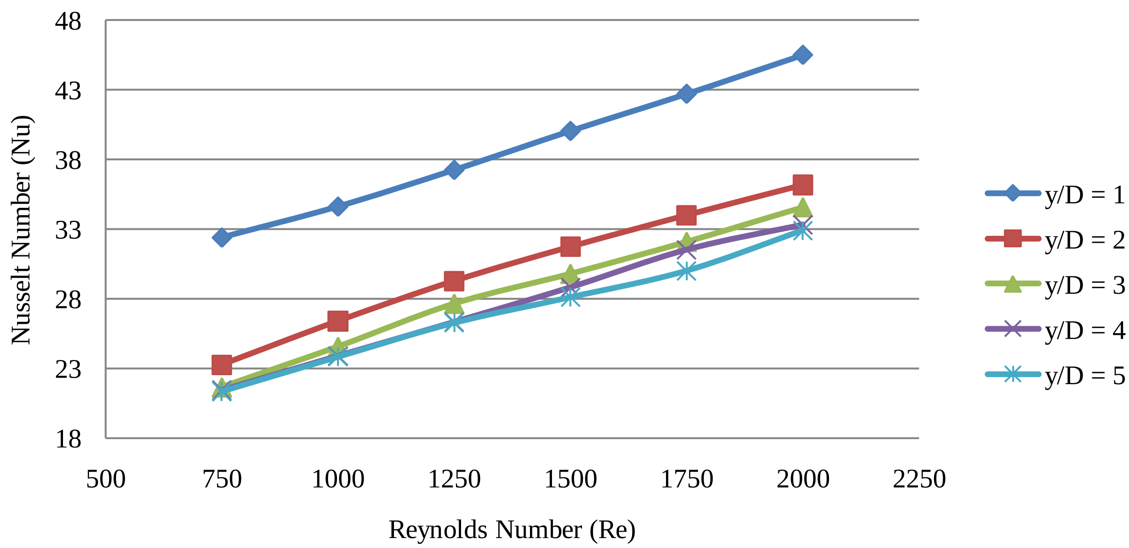

Figure 4.14: Variation of Nusselt number (Nu) versus the Reynolds number (Re) of the coil plate at different twist ratio (y/D).

Nusselt number represents the enhancement of heat transfer through a fluid layer as a result of convection relative to conduction across the same fluid layer. The larger the Nusselt number, the more effective the convection (Cengel, 2007).

It can be seen that for each Reynolds number, the Nusselt number will increase as the width ratio is increases and the twist ratio is decreases. Besides that, the heat transfer enhancement for each Re is greatest for the largest width ratio 0.9 and the smallest twist ratio of 1. However, the nusselt numbers decrease together with the reduction of width ratio and the increment of twist ratio.

The reduction in heat transfer for low width ratio and high twist ratio might be due to the weakening of disturbance at the boundary layer of the air flow. Not only that, the decrement of width ratio will also lead to the increment of twist ratio which results in weaker swirls generated by coil plate.

4.2.2. Velocity Contours

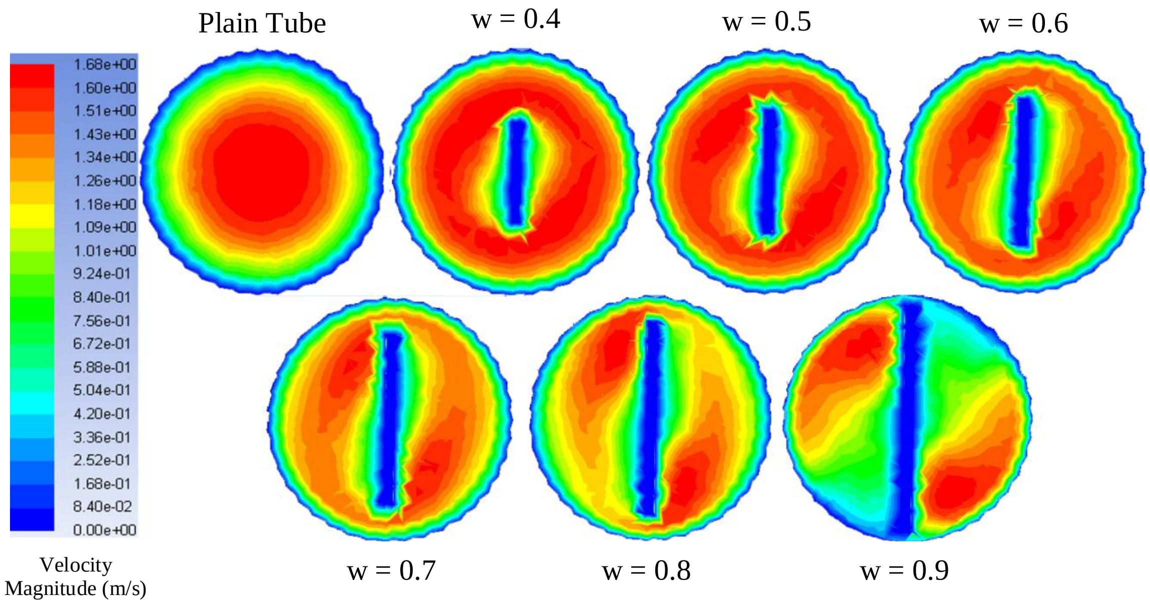

Figure 4.15: Contour plots of velocity magnitude at different width ratio (w/D) with twist ratio (y/D) = 3.5 for Re = 1000

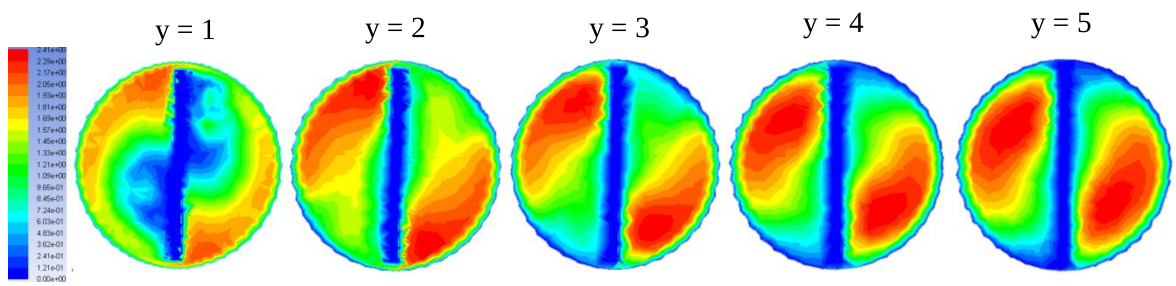

Figure 4.16: Contour plots of velocity magnitude at different twist ratio (y/D) with width ratio (w/D) = 0.9 for Re = 1000

The velocity fields shown in Figure 4.15 demonstrate that the swirl of air near the tube wall remains almost unchanged in the plain tube which can be considered as a laminar flow. The flow is greatest at the centre and diminishes towards the tube wall surface. Moreover, the hot air flow rate is also much greater inside plain tube.

Referring to the contour plots of velocity in Figure 4.15 and 4.16, it can be observed that as the coil plate width ratio increases and the twist ratio decreases, more reversed flow between the tube wall and the coil plate surface. The hot air flow starts to change chaotically in different direction. This correlates with the theory stated beforehand whereby the coil plate will induces a turbulent flow of air inside tube thus reducing the flow rate of air allowing more heat transfer across the tube.

4.2.3. Temperature Contours

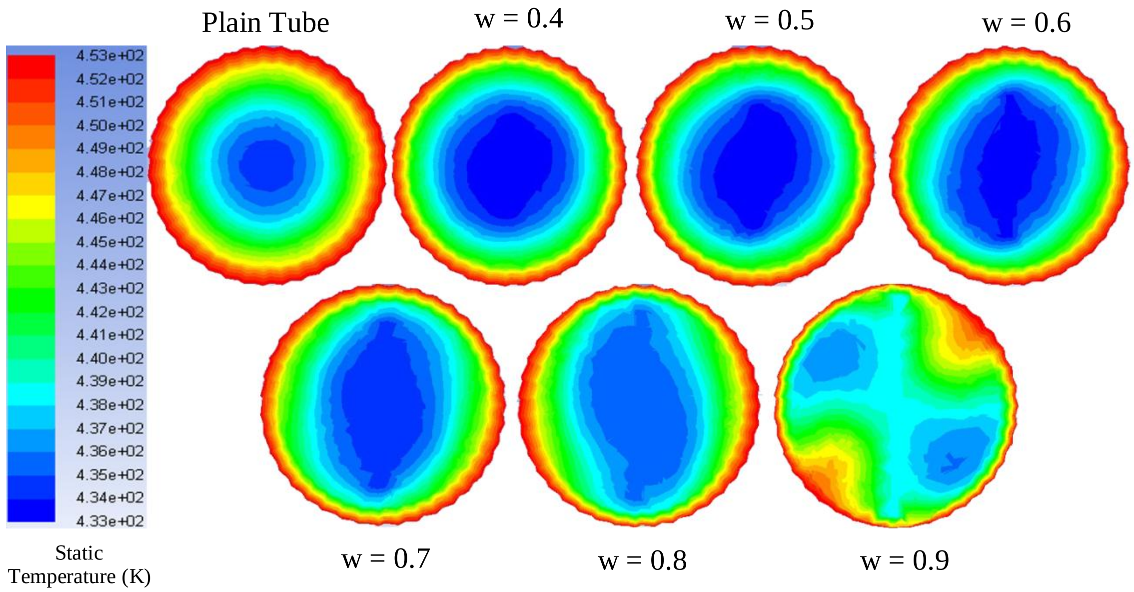

Figure 4.17: Contour plots of static temperature at different width ratio (w/D) with twist ratio (y/D) = 3.5 for Re = 1000

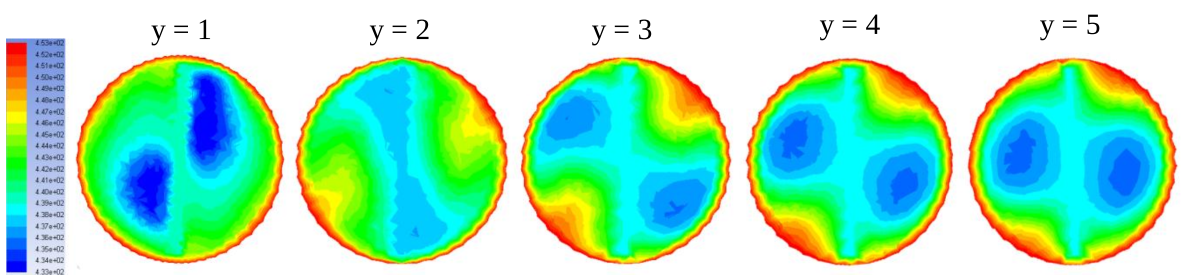

Figure 4.18: Contour plots of static temperature at different twist ratio (y/D) with width ratio (w/D) = 0.9 for Re = 1000

Based on Figure 4.17 and 4.18 the temperature fields' shows that as the coil plate width ratio increases and the twist ratio decreases, the thermal boundary at the wall tube surface becomes thinner. In other words, the temperature gradient near the tube wall becomes greater especially for width ratio of 0.9 and twist ratio of 1 which provides better temperature distribution around the tube. This contributes to more efficient mixing of hot air inside the tube with higher coil plate width ratio and better performance of heat transfer.

4.2.4. Static Pressure Contours

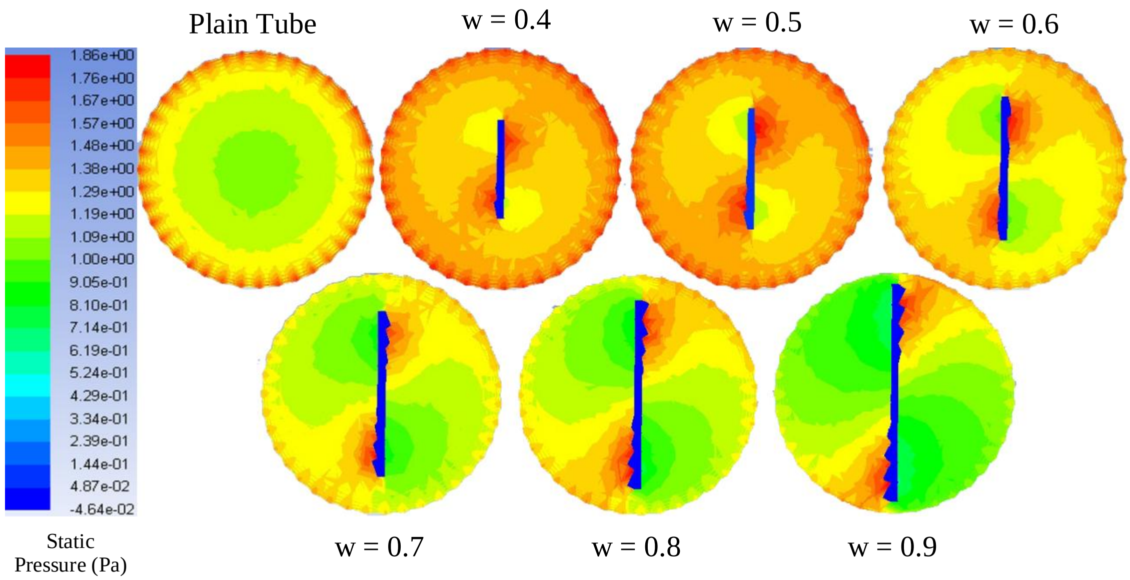

Figure 4.19: Contour plots of static pressure at different width ratio (w/D) with twist ratio (y/D) = 3.5 for Re = 1000

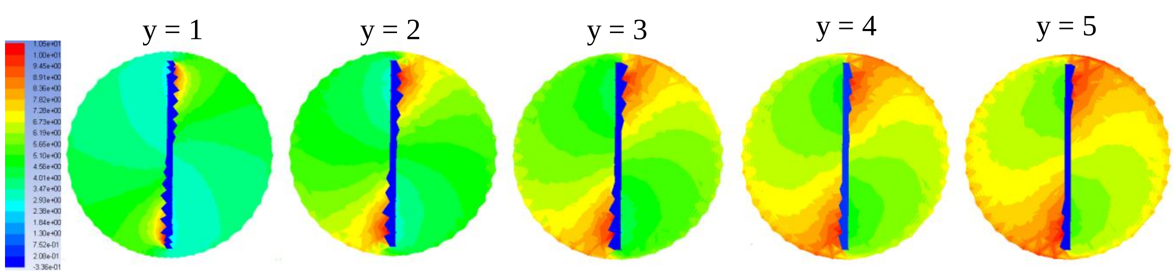

Figure 4.20: Contour plots of static pressure at different twist ratio (y/D) with width ratio (w/D) = 0.9 for Re = 1000

Contour plots of static pressure for coil plates with different width ratio and twist ratio are shown in Figure 4.19 and 4.20. Obviously for width ratio of 0.4 to 0.6, the static pressure appeared to be the most intense at the tube wall and the contact area of the coil plate. The static pressure start to diminish slowly as the width ratio increases provide higher pressure drop.

Coil plate with width ratio of 0.9 and twist ratio 1 shows the lowest overall static pressure especially at the tube wall. Moreover, increment in width ratios and decrement in twist ratio are found to weaken the effect of static pressure which is attributed to the reduction of swirl flow intensity and higher friction factor. By enhanced the friction factor characteristic, the overall heat transfer performance will be improved.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1. Relevancy to the Objectives

In the project, the study of the effect of tube coil plates on the performance of UTP steam packaged boiler has been successfully carried out with the aim to increase the steam packaged boiler overall performance.

Studies on the effect of tube coil plates on the performance of steam packaged boiler are going to be beneficial for the industry. The understanding upon this subject will help the boiler system become more efficient throughout the industry. Not only it can reduce annual plant energy costs by several billion dollars, the environmental emissions can also be diminished by millions of metric tons.

Based on the recent result, it is proven that tube coil plates will increase the efficiency of the boiler by disrupting the fire flow from laminar to turbulence flow thus they are highly recommended to be insert in every boiler tubes. Moreover, any reduction in the numbers of coil plates inside boiler will reduce their efficiency greatly.

Besides that, the Ansys simulation work of scope which is to investigate the effect of width ratio and twist ratio to the heat transfer performance inside tubes is successfully completed. The larger the width ratio and the smaller the twist ratio of the coil plate, the better the heat transfer across the tube. At the end of the project, all the objectives are successfully achieved.

5.2. Future Work for Expansion and Continuation

Below are the suggestion for the future work expansion:

1. To fabricate the new design of coil plate to replace the existing tube coil plate. The dimension of the exisiting and new design coil plate is described in Table 5.1 and being potrayed in Figure 5.1.

Table 5.1: The existing and new design coil plate dimension

	Existing	New
Thickness	1 mm	1 mm
Full length	159 cm	159 cm
Width (w)	2.46 cm	2.88 cm
Twist pitch (y)	8.5 cm	3.2 cm
Width ratio (w/D)	0.8	0.9
Twist ratio (y/D)	3.5	1

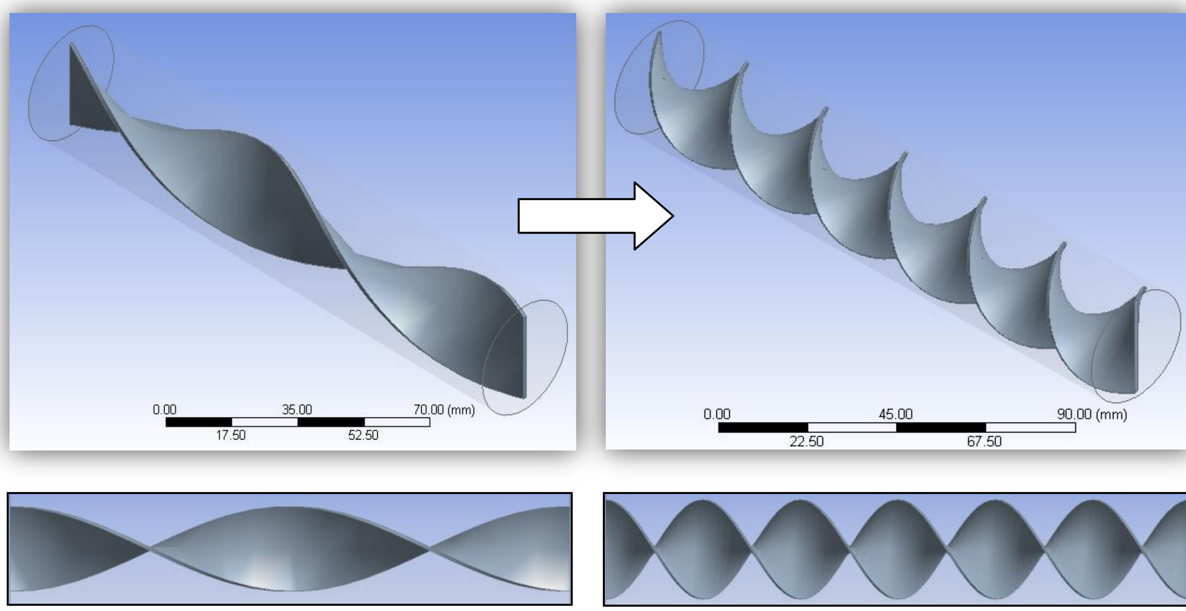

Figure 5.1: The existing design coil plate (left) and the new design coil plate (right).

2. To run UTP steam packaged boiler with 100% new design tube coil plate inserts in the near future.

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