INVESTIGATING THE EFFECT OF COIL PLATES ON THE PERFORMANCE OF FIRE TUBE STEAM PACKAGED BOILER USING SIMULATION SOFTWARE

By

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Dissertation submitted in partial fulfillment

of the requirements of the

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2013

CERTIFICATE 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.

Mohamad Haziq Faiz Bin Mohd Hashim

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ABSTRACT

In recent years, the study of increasing the heat transfer rate in a boiler had been conducted widely. Boiler is a type of heat exchangers which can be categorized as; Fire-tube boiler and Water-tube boiler. The project was entitled as "Investigating the effect of coil plates on the performance of Fire-tube steam packaged boiler using the simulation software”. The previous study had found out that to increase the heat transfer rate, the coil plates had been used as an insert into the generating tube inside the boiler. Nevertheless, the amount that heats energy produced by the furnace is still not been fully utilized. The heat transfer from the generating tube to the water still can be increased by increasing the surface area of the coil plate inserts into the generating tube. In this project it will determined the effects by varying the surface area towards the heat transfer rate of the Fire-tube boiler by using the ANSYS FLUENT simulation software . The coil plates are proposed to have several numbers of holes and diameters which can differentiate the surface area of coil plates. All the results were recorded to compare and determined which design of coil plates gives the maximum heat transfer rate. From the first hypothesis, the coil plate will have a greater surface area when the hole is created. But from the result obtained, a surface area of coil plates is decreasing when the hole is created. Nevertheless, the heat transfer rate is still increasing due to the increasing velocity. The lower the size of holes, the higher the velocity hence it will increase the heat transfer rate. The creation of holes on the coil plate will lead to a higher velocity and change the type of flow to approach turbulence. In a nutshell, the creation of holes on the coil plate will increase the heat transfer rate inside the generating tube.

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ABBREVIATIONS AND NOMENCLATURES

A	Area
A_s	Surface area
d, D	Diameter
f	Friction Factor
h	Convection heat transfer coefficient, $W/m^2.K$
k	Thermal conductivity, $W/m.K$
L	Length
Nu	Nusselt number
ΔP	Pressure drop, Pa
Pr	Prandtl number
$\dot{Q}$	Heat transfer rate, W
Re	Reynold number
T_s	Surface temperature, K
T_∞	Fluid temperature, K
V	Velocity, m/s
μ_b	Average dynamic viscosity, $kg/m.s$
μ_s	Surface dynamic viscosity, $kg/m.s$
ν	Kinematic viscosity, m^2/s
ρ	Density, kg/m^3

1.0 INTRODUCTION

1.1 Project Background

Boiler is a type of heat exchanger that converting water to steam through boiling process. It has been used in industrial application in various processes such as power generation, central heating and sanitation. As it is a heat exchanger, the heat is transferred from the combustion chamber to the water and converts it into steam. According to Amori and Insayif (2011) [1] the efficiency of this process is low, only up to 70% and the previous study has found the solution to increase the rate of heat transfer by inserting the coil plate into the heat exchanger. In this case, the heat exchanger will be the Fire-tube Boiler. Zimparov and Penchev (2000) [2] had stated that the main objective of enhancing the heat transfer rate is to encourage or increase the heat fluxes. Encouraging the heat fluxes will reduce the size of the heat exchanger and as well as the capital cost. Prajapati et al. (2012) [3] stated another advantage of enhancing the heat transfer rate is that the heat exchanger can operate at low velocity but the performance will be the same or better than the heat exchanger that did not use the inserts into the tubes. This will lead to a pressure drop and low operating cost.

In this project, the passive technique of enhancing heat transfer was used because it does not require any external input power. The inserts that is the coil plates is installed into the generated tube to promote higher heat transfer coefficient by disturbing the existing fluid flow behavior (Kumar and Murugesan, 2012) [4]. The heat that been generated from the combustion chamber inside the Fire-tube Boiler using the plain twisted coil plates, still not been fully utilized to convert the water into steam. The enhancement of heat transfer technique can be improved by increasing the surface area of the coil plate because the larger the surface area, the greater the heat transfer rate. The surface area of the coil plate can be increase by creating set of holes throughout the coil plate. The surface area of the coil plate is depends on the diameter of the holes. Investigation on the effect of coil plate surface area towards the performance of the Fire-tube Boiler will be conducted using the ANSYS software. By manipulating the surface area of the coil plate, the minimum total surface area to increase the performance of the boiler will be determined.

1.2 Problem Statement

The generating tube inside the boiler used coil plates insert to enhance the heat transfer rate from the combustion chamber to the water. The rate of heat transfer can be increase by increasing the surface area of the coil plate. The effect of the coil plate surface area towards the performance of the boiler have to be investigated using ANSYS simulation software and the minimum total surface area have to be determined to increase the efficiency of the boiler.

1.3 Objectives

The objectives of this project are as follows:

1. To study the effect of the coil plates surface area in enhancement of heat transfer using simulation software
2. To propose new design of coil plate using simulation software
3. To simulate the overall performance of boiler with the new design of coil plates and without coil plate

1.4 Scope of Study

The scope of study in this project will be within the Fire-tube Boiler. The coil plates will be designed to have a set of holes and each coil plates have different diameter of holes that shows different surface area. With the new design of coil plates, then it will be simulated using the ANSYS software to compare the overall performance of the boiler.

Figure 1: Fire-Tube Boiler

1.5 Relevancy of Study

From this project, the investigation of the effect of coil plate's surface area may give significance in enhancing the heat transfer rate inside the fire tube steam packaged boiler. With the investigation of the effect of increasing the coil plate's surface area, the efficiency of the boiler will predicted to increase significantly.

1.6 Feasibility of Study

This project is analyzed to be feasible where the simulation software which is ANSYS Fluent is provided in the University. The simulation parts of the project follow the theories, which become the critical part to complete the project. The allocation of financial cost is sufficient for this project. Moreover, the project is conducted with the help of postgraduate student where this become the medium to share some data and information in order to achieve the project completion successfully. Therefore, author could ensure the feasibility of this project within the given period.

2.0 LITERATURE REVIEW

Boiler has been used in industrial application to generate steam to produce power. There are two types of boiler which are Fire-tube Boiler and Water-tube Boiler. The concept that been used between these two boilers are the same but the way they operate it is difference. In Fire-tube Boiler, the hot gases will pass through the tube that been surrounded by water. The heat is transferred from the wall of tubes to the water through thermal conduction process. The water will confine in the outer shell of the boiler. Fire-tube Boiler usually been used in low pressure that is up to 50 mbtu per hour or less to avoid the need of bigger thickness for the outer shell (U.S. Department of Energy, 2010) [5]. But nowadays, the size of the Fire-tube Boiler has increased so that it can withstand with the higher pressure. In Water-tube Boiler, the water been heated in the other way around. The water will pass through the bundle of tubes while it been heated externally. Water-tube Boiler usually been used in high pressure because the pressure is confined inside the tube (U.S. Department of Energy, 2010). The previous Fire-tube Boiler that been created have a low efficiency which is only up to 70% with high fuel consumption (Amori and Insayif, 2011). The amount of heat energy used to boil the water is high due to low efficiency of heat transfer rate.

The augmentation technique has been used recently to increase the heat transfer rate. Kumar and Murugesan had described the augmentation technique of heat transfer which can be divided into three techniques; active technique, passive technique and compound technique. The active technique required external power input to improve the heat transfer rate. This technique is complex and not all applications can adapt this kind of technique. The passive technique did not require any external power, only use the power from the system itself and create higher fluids pressure drop. It used geometrical modifications by installing the inserts to the flow channel. This will create a disturbing from the original flow, hence, it increase the heat transfer coefficient. The compound technique is the combination between the active and passive technique. It is proven that by using the passive technique, the rate of heat transfer can be improved. Sarada et al. (2010) [6] studied the frictional and heat transfer characteristics in turbulent flow using various widths of twisted tape inserts under constant wall heat flux. The result is that the highest Nusselt number (Nu) obtained with full width of twisted tape. The mean heat transfer gain is increase varied from 4% to 20% compared to plain tube. Dewan et al. (2004) [7] described the effect toward the flow after implemented the augmentation techniques. The passive technique use inserts such as wire coil, twisted tape or coil plate is installed in the flow channel and will reduce the hydraulic diameter of the flow channel. This will result in increasing of heat transfer due to the flow blockage that increases the pressure drop, viscous effect and fluid flow velocity. Furthermore, by installing the inserts also will result the formation of secondary flow that can enhance the heat transfer. It provides better thermal contact between the surface and the fluid due to the swirl created by the secondary flow and lead to a better mixture of fluid. Based on Mohapatra and Sahu (2007) [8], the type of active technique and passive technique can be described in the **Table 1** and **Table 2** below.

Table 1: Description for various type of active technique

Type	**Description**
Mechanical aids	The fluids were stirred by mechanical devices or rotating the surface.
Surface vibration	It is been applied to increase the convection heat transfer coefficients at low or high frequency in single phase flow.
Fluid vibration	With the frequency of vibration ranging from 1.0Hz – 1.0MHz used in single phase flow.
Electrostatic fields	The sources of electric is from alternative current (AC) or direct current (DC) that been applied to heat exchange systems involving dielectric fluid.
Injection	Is been used only in single phase flow. Injecting the fluid into the main bulk fluid through the porous zone or upstream heat transfer section.
Suction	Removing the vapor or fluid through the porous heated surface.
Jet impingement	Direction of heating or cooling is perpendicular to the heat transfer surface. Single or multiple jets may be used in single phase flow.

Table 2: Description for various type of passive technique

Type	Description
Treated surface	Surface that have fine scale altercation to their coatings.
Rough surface	Modified surface that create turbulence in the flow field. The geometric features range from sand-grain roughness to discrete three dimensional surface.
Extended surface (finned surface)	It creates an effectively heat transfer rate. Usually, plain fins is been used in most heat exchangers. Nowadays, the new development of fin has improved the heat transfer rate by disturbing the flow field.
Displaced enhancement devices	It used the inserts to improve the energy transport indirectly at the heat exchanger surface by changing the heated or cooled surface with the bulk fluid from the core flow.
Swirl flow devices.	It used inserts to create a secondary recirculation to the fluid flow. Examples of inserts are helical strip, cored screw-type tube, and twisted ducts.
Coiled tubes	The tube shape creates a secondary flow which can increase the heat transfer coefficient.
Surface tension device	Includes the wicking or grooved surfaces which it can improve the flow of liquid to boiling surfaces as well as from the condensing surfaces.
Additives for liquids	Addition of solid particles, soluble traces additives and gas bubble in single phase-flow.
Additives for gases	Introduced the additives for example liquid droplets or solid particles to the single-phase fluid flow in dilute or dense phase.

Numbers of experiment have been conducted to study the effect of inserts towards the enhancement of heat transfer. The enhancement of heat transfer in passive technique is depends on the type of fluid flow; laminar flow or turbulent flow. The wire coil inserts is perform better in turbulent flow (Dewan et al.) meanwhile in laminar flow the twisted tape inserts give a better result in heat transfer enhancement (Kumbhar and Sane, 2010) [9]. Various experiments had been conducted to study the performance of heat exchanger with wire coil inserts in turbulent flow. For example, Kim et al. (2001) [10] had conducted the experiment to study the flow pattern of the fluid in vertical round tube using wire coil insert. The observation is that the void fraction is higher than a smooth tube in turbulent flow. Hence, the performance of wire coil in the turbulent flow is higher than any other inserts. Arici and Asan (1994) [11] conducted the experiment to enhance the turbulent flow by introducing the wire coil inserts. They found out that by increasing the pitch of the wire coil will increase the heat transfer rate. Other than that, Rahai et al. (2001) [12] also studied the effect of wire coil on mixing enhancement turbulent jet from Bunsen burner. The wire coil have a constant $p/D = 1$. The result shows that there is a significant increase in the mixing process near the discharge region of the jet. There are also experiments been conducted to show the effect of twisted tape inserts in laminar flow towards the performance of the heat exchanger. Yadav (2009) [13] had conducted an experiment to investigate the influences of the half length twisted tube inserts on pressure drop and heat transfer characteristics in U-bend double pipe heat exchanger. The result is the heat transfer coefficients was increased 40% with half length twisted tube inserts compared to the plain tube. Naphon (2006) [14] carried an experiment to investigate the heat transfer characteristics and pressure drop with twisted tape inserts in the horizontal double pipes. The result obtained showed that with twisted tape inserts, the heat transfer rate is increase compared to those pipes without twisted tape inserts.

Although the solution to increase the heat transfer rate had been found, but the heat energy from the combustion chamber is not fully utilized to boil the water in the water container. According to Çengel and Ghajar, (2011) [15] the total heat transfer in conduction, convection or radiation is depends on the surface area of the object. This can be expressed as below:

$$\dot{Q}_{cond} = kA \frac{T_1 - T_2}{L} \quad (1)$$

Where k = Thermal conductivity, A= Area, L = Length

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) \quad (2)$$

Where h = Convection heat transfer coefficient, A_s = Surface area, T_s = Surface temperature, T_∞ = Temperature the temperature of the fluid sufficiently far from the surface

$$\dot{Q}_{rad} = \varepsilon\sigma A_s({T_s}^4 - {T_{surr}}^4) \quad (3)$$

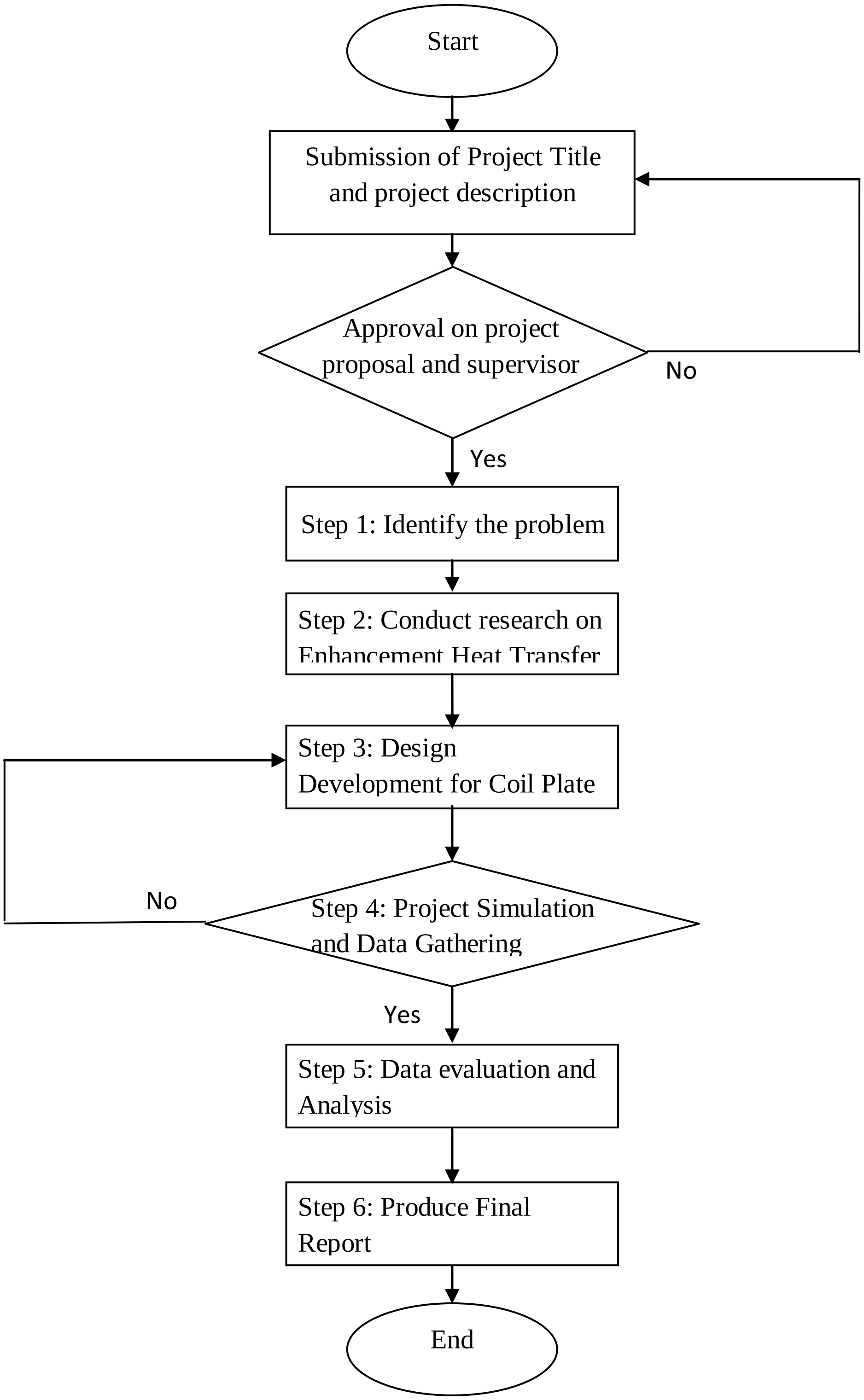
Where ε = emissivity of the surface, σ = Stefan-Boltzmann constant, A_s = Surface area,

T_s = Surface temperature, T_{surr} = Surrounding temperature

Based on the expressed formula, the heat transfer in conduction in equation (1) is depends on the area whereas heat transfer in convection in equation (2) and radiation in equation (3) is depends on the surface area of the object. Since the hot gas is flowing inside the tube in Fire-tube Boiler, the heat transfer can be classified as convection heat transfer. As the formula shown that convection heat transfer is depends on the surface area, hence by increasing the surface area of the coil plate it can be predicted that the heat transfer also will be increases.

3.0 METHODOLOGY

3.1 Research Methodology



Step 1: Identify the Problem

The problem for the project should be identified first which is how to increase the heat transfer in the Fire-tube Boiler with coil plates inserts into the tube. After identifying the problem, then the objectives of the project can be determined which is to design new sets of coil plates and compare the overall performance of the Fire-tube Boiler with the new sets of design as well as without the coil plate.

Step 2: Conduct research on Enhancement Heat Transfer

Conduct a research regarding the enhancement technique for the heat transfer. The enhancement technique is called augmentation technique which can be divided into three types; active technique, passive technique and compound technique. Gather the important information regarding those techniques based on the previous study and experiment to carry out the project. Produce a literature review based on the information obtained.

Step 3: Design Development for Coil Plate

Produce several designs of coil plates that can increase the heat transfer. Based on the theory, to increase the heat transfer, the surface area of the coil plate should be bigger. Hence, the coil plates should have set of holes to increase the surface area of the coil plates. The diameter and number of holes should be varied in order to see the difference of the heat transfer rate.

Step 4: Project Simulation and Data Gathering

The new design coil plate were simulate using the ANSYS software and collect the important data for example temperature distribution, velocity distribution, and the heat transfer rate. If the simulation part is fail to simulate, so step 3 should be repeated. After simulating all the new design of coil plates as well as the tube without the coil plate, the result and data should be recorded.

Step 5: Data evaluation and Analysis

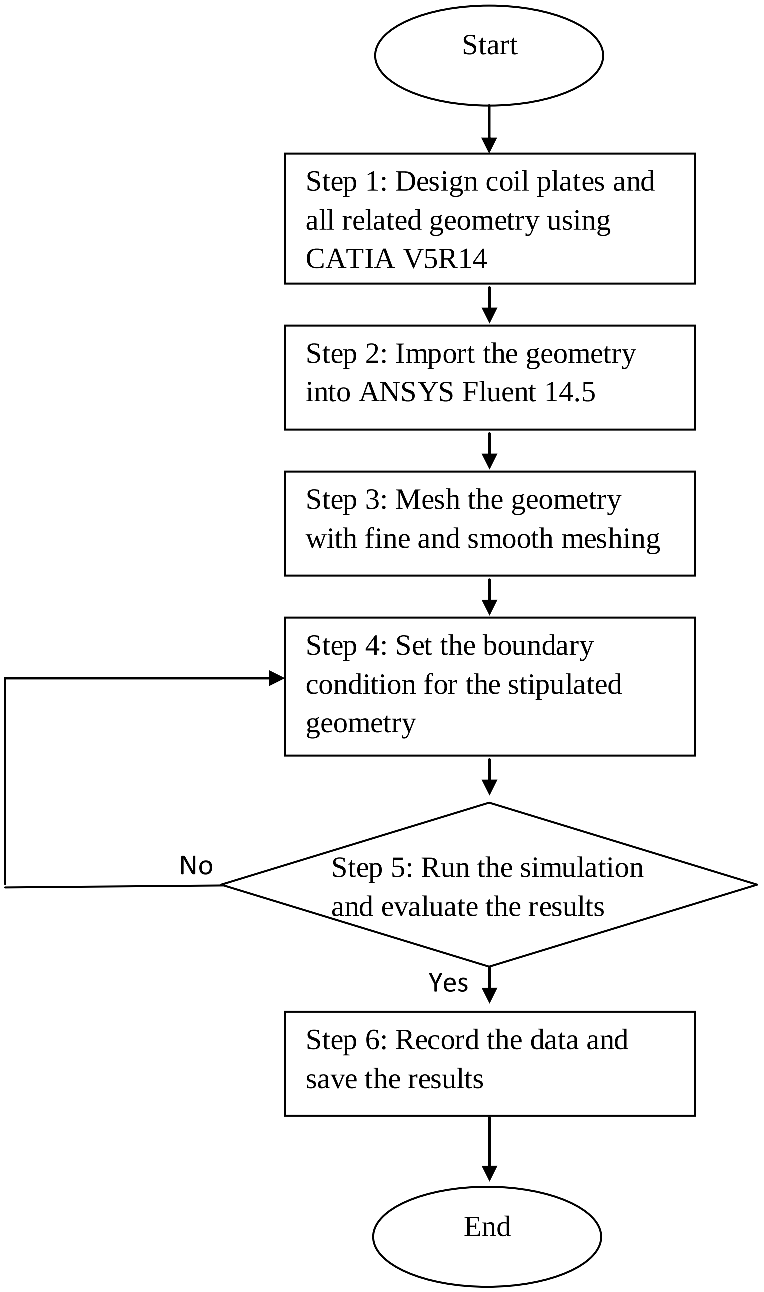
Evaluate and analyze the data by comparing the results that been recorded based from the simulation. Compare the heat transfer rate between the tube that have coil plates insert and the plain tube. Study the effect of coil plate surface area towards the performance of boiler. Specify the design of the coil plates that produce highest heat transfer rate.

Step 6: Produce Final Report

Prepare final report to propose the new design of coil plate with the data obtained. Produce some recommendations towards the project so that it can be improves and obtain better result in enhancing the heat transfer rate of Fire-tube Boiler.

3.2 Project Methodology

In the simulation work, there are six step involves in order to obtain the results. The step is been summarized in the flowchart shown as below.



Step 1: Design Coil Plates and All Related Geometry using CATIA V5R14

The coil plates should be design first using the design software which in this case is the CATIA V5R14. The proposed design is to have the holes been punched to the coil plates to increase the surface area. The holes diameter are varied from 4mm, 8mm, 10mm, and 15mm and the number of holes been created are one, two and three holes.

Step 2: Import the Geometry into ANSYS Fluent 14.5

The geometry that been designed should consists of the coil plates which is the inserts, the air, and the generating tube of the Fire-tube boiler.

Step 3: Mesh the Geometry with Fine and Smooth Meshing

Meshing is the critical parts in the simulation work. Meshing is an integral part of the computer-aided engineering (CAE) simulation process. With proper meshing, the results will be much more accurate and precise. Other than that, meshing also will determine the boundary from one object to another which in this case there are three different objects; the inserts, air and the generating tube. The help of meshing will distinguish the three objects and ease the simulation work.

Step 4: Set the Boundary Condition for the Stipulated Geometry

The hot air flowing inside the generating tube is assumed to be laminar with 160°C. The air is incompressible, and steady. The hot air is also assumed to have a constant heat flux with no slip condition. There is also no heat conduction occur at the surface of the coil plates. The hot air is flowing from the inlet at certain velocity and goes out through the outlet. The constant and varied parameters are shown in the **Table 3** below.

Step 5: Run the Simulation and Evaluate the Results

Before running the simulation the calculation should be initialized based on the inlet condition. After it has been initialized, run the simulation and evaluate the results obtain. If the result is not according as the expected, repeat Step 4. Make sure that the boundary condition has been set up according to the real situation.

Step 6: Record the Data and Save the Results

After evaluating the results, the data were recorded and saved. Simulate another design that has been created using the same step mentioned above. Repeat the simulation if the result is not according to the theory. Ensure all the boundary conditions have been set according to the real situation.

Table 3: Parameters for the simulation work.

Parameters	Value	Constant /Varied
Inlet Velocity	1 m/s	Constant
Inlet Tube Temperature	433 K	Constant
Inner Tube Wall Temperature	453 K	Constant
Twist ratio	0.25	Constant
Width ratio	0.84	Constant
Number of Holes	0, 1, 2, 3, 4	Varied
Diameter of Holes	4mm, 8mm, 10mm, 15mm	Varied

3.3 Project Gantt-Chart

Table 4: Gantt-Chart for FYP I

Detail	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Selection of FYP topics	■	■												
Preliminary Research regarding boilers			■											
Meeting with Master Students				■										
Gather Literature Review and Articles relating to Augmentation Technique				■	■									
Preparing Extended Proposals				■	■									
Submission of Extended Proposals						■								
Preparation for Proposal Defence							■							
Proposal Defence								■	■					
Preliminary Simulation using Ansys										■	■	■		
Obtain Preliminary Results												■		
Preparing Interim Report													■	
Submission of Interim Report														■

Table 5: Gantt-Chart FYP II

Detail	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14
Data Collection	■	■	■	■	■	■	■							
Preparing Progress Report					■	■								
Progress Report Submission							■							
Obtain Final Results								■	■					
Pre-SEDEX										■				
Preparing Final Report and Technical Report											■			
Submission of Disertation (Softcopy)												■		
Submission of Technical Paper												■		
Oral Presentation													■	
Submission of Disertation (Hard Bound)														■

3.4 Key-Milestone

Table 6: Table for Key-milestones

No.	Milestone	Date
1	Submission of Extended Proposals	June 2013
2	Proposal Defense	June 2013
3	Preliminary Simulation	August 2013
4	Data Collection	September 2013
5	Submission Progress Report	November 2013
6	Final Results of Simulation	November 2013
7	Pre-SEDEX	December 2013
8	Submission of Disertation (softcopy)	December 2013
9	Submission of Technical Report	December2013
10	Oral Presentation	December 2013
11	Submission of Disertation (hardbound)	January 2014

4.0 RESULTS & DISCUSSION

4.1 Proposed Design of Coil Plates

The coil plates will have five segments and in **Figure 2** it only shown one segment out of the five segments. The coil plates have been designed with twist ratio, y/L of 0.25 and width ratio, w/D of 0.84. These two parameters are kept constant throughout the simulation and the diameter as well as the number of the holes that been created were varied. The geometry of the coil plates can be described below.

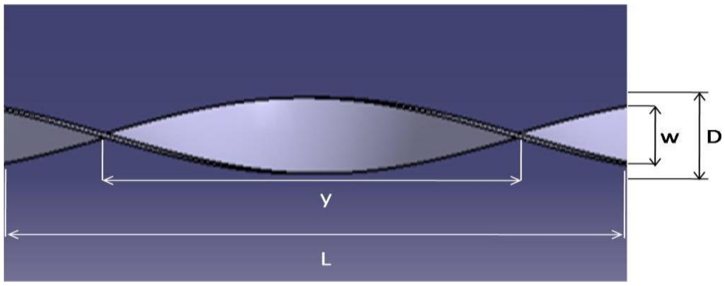
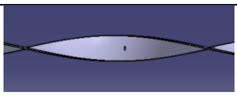
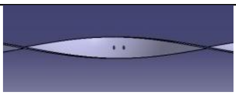
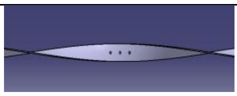
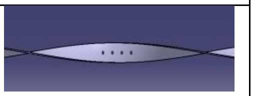
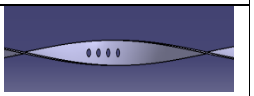
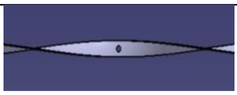
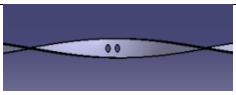
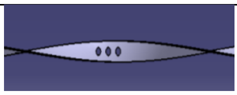
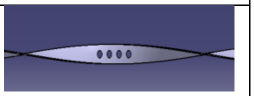
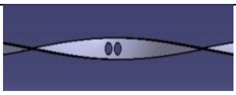
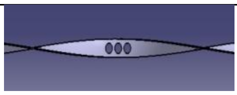


Figure 2: The geometry of coil plates

The diameter of the holes is varied from 4mm, 8mm, 10mm and 15mm and the number of holes is consists of one, two, three and four holes. The proposed designs were simulate using ANSYS Fluent and the result is compared with the insert without holes. The design that been described is been illustrated in the table below.

Table 7: The proposed design of coil plates

Number Diameter	1 hole	2 holes	3 holes	4 holes
4mm				
8mm				
10mm				
15mm				

4.2 Static Temperature Contour Plots

The simulation had been conducted for the tube with inserts as well as without the inserts. The simulation for the tube with inserts had been conducted for all the design. The results had been recorded and shown as below:

Coil plates with 4mm diameter:

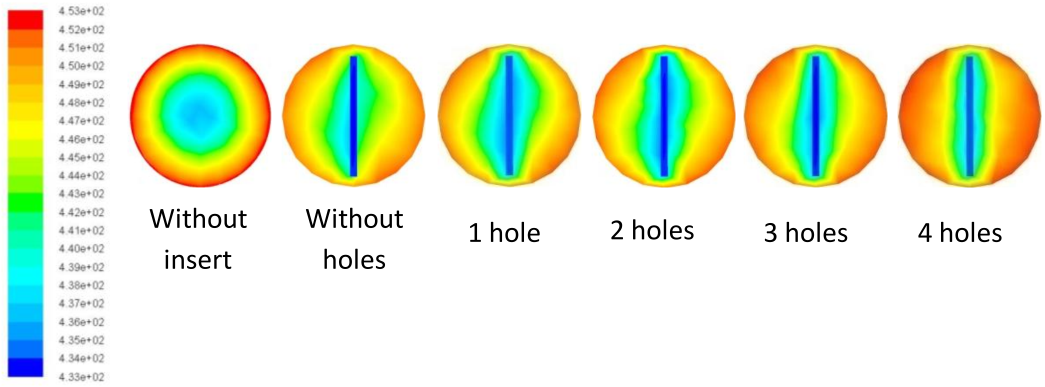


Figure 3: Static temperature contour plots with 4mm diameter and the number of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is different with different design of coil plates. The design of coil plate with 4 holes has the highest hot temperature distribution as it shows a lot of red color. It followed by the 3 holes design coil plates, 2 holes design, 1 holes design and lastly the lowest hot temperature distribution is without the hole design coil plate. Nevertheless, the 4 holes design coil plates have greater red region that indicates that the hot region is greater than any other coil plate designs. All the contour plots are compared with the tube without the coil plates. The tube without the coil plates has the normal distribution of temperature. This is because, there is no secondary flow that been created when there is no disturbance towards the flow of the fluid that can affect the temperature distribution.

Coil plates with 8mm diameter:

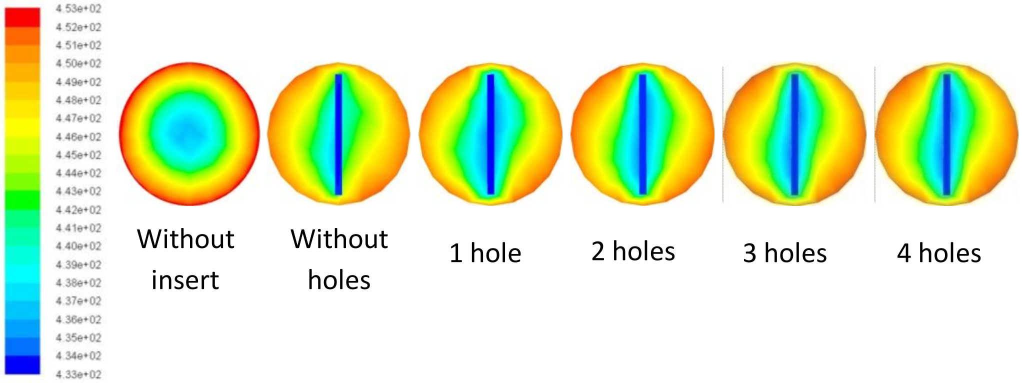


Figure 4: Static temperature contour plots with 8mm diameter and the number of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is different with different design of coil plates. The design of coil plate without holes has the highest hot temperature distribution as it shows a lot of yellow color. It followed by the 4 holes design coil plates, 3 holes design, 2 holes design and lastly the lowest hot temperature distribution is 1 hole design coil plate. Nevertheless, the 3 holes and the 4 holes design coil plates have greater red region that indicates that the hot region is greater than the coil plates without the hole. All the contour plots are compared with the tube without the coil plates. The tube without the coil plates has the normal distribution of temperature. This is because, there is no secondary flow that been created when there is no disturbance towards the flow of the fluid that can affect the temperature distribution.

Coil plates with 10mm diameter:

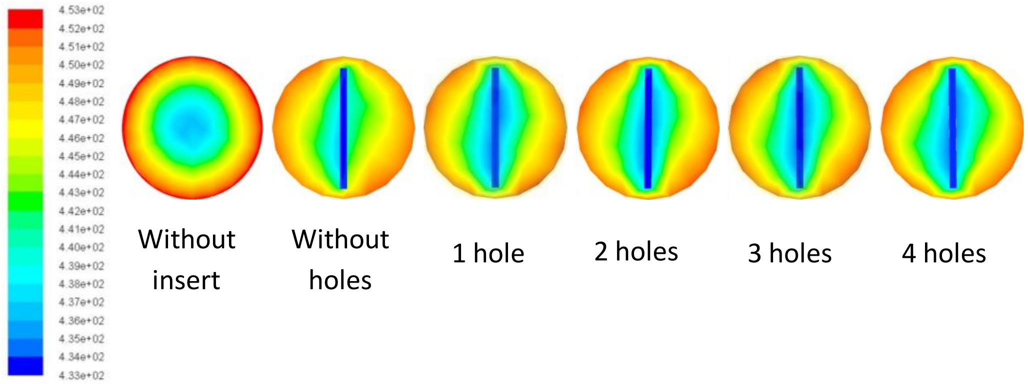


Figure 5: Static temperature contour plots with 10mm diameter and the number of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is not much different between the four designs. The red region which indicates the hottest region clearly can be seen between the four designs. This indicates that the design for 10mm diameter with variety number of holes did not affect much towards the temperature distribution of the hot air flowing inside the generating tube. Meanwhile, the tube without insert has the normal distribution of temperature because there is no formation of secondary flow due to the absence of coil plates.

Coil plates with 15mm diameter:

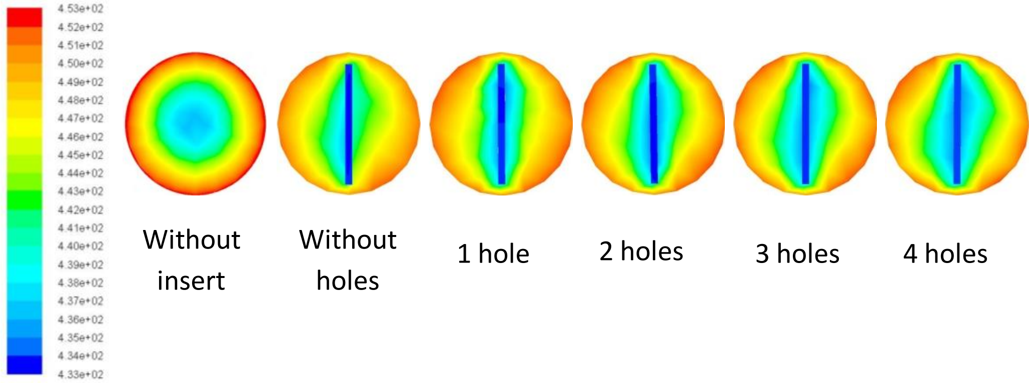


Figure 6: Static temperature contour plots with 15mm diameter and the number of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is different with different design of coil plates. The design which does not drill with the holes has the highest hot temperature distribution as it shows a lot of yellow color. It followed by the 1 hole design coil plates, 2 holes design, 3 holes design and lastly the lowest hot temperature distribution is 4 hole design coil plate. Increasing number of holes will affect the fluid flow. The fluid will flow easily with bigger diameter and large number of holes. Hence it will affect the heat transfer rate inside the generating tube.

Coil plates with 1 hole:

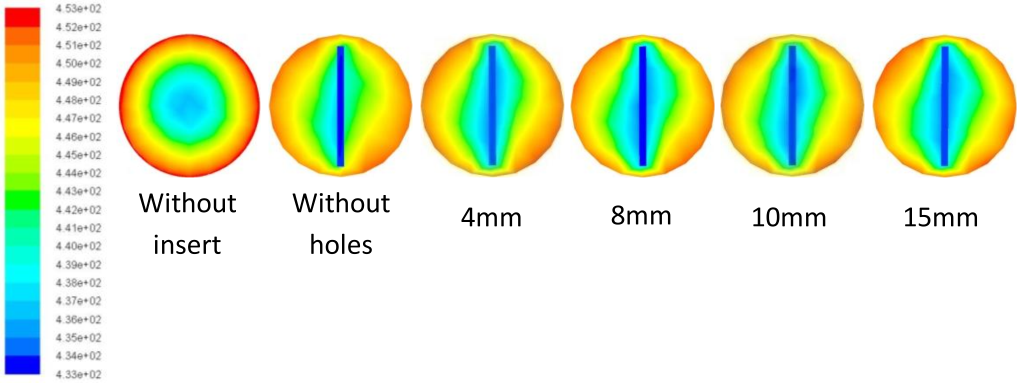


Figure 7: Static temperature contour plots with 1 hole and the diameter of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is not much difference between the four designs. The 4mm holes diameter has the highest hot temperature distribution as it the red color clearly can be seen. It followed by the 8mm holes diameter, 10mm holes diameter and lastly the lowest hot temperature distribution is 15mm holes diameter coil plate. Nevertheless, the 8mm holes diameter coil plates have slightly the same temperature distribution compared to 10mm holes diameter. The red region which indicates the hotter part can be seen clearly at the tip of the hot air as shown in the figure. All the designs are compared with the tube without insert. It shows that the design without insert has a normal distribution of temperature as the formation of secondary flow did not occur. The larger the diameter size will cause the fluid to flow easier and reduce the heat transfer rate.

Coil plates with 2 holes:

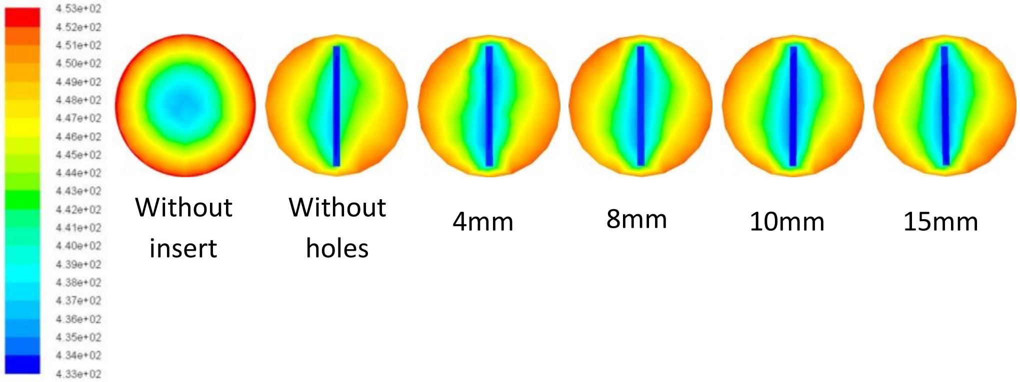


Figure 8: Static temperature contour plots with 2 holes and the diameter of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is different with different design of coil plates. The design which has 4mm diameter holes has the highest hot temperature distribution as the red color clearly can be seen. It followed by the 8mm holes diameter, 10mm holes diameter and lastly the lowest hot temperature distribution is 15mm holes diameter coil plate. The 4mm holes diameter coil plate have greater yellow and green region which indicates the temperature is slightly higher compared to other design. The 15mm diameter coil plate has the lowest hot temperature distribution as the red region cannot be seen clearly compared to the other designs. Nevertheless, the 8mm diameter also has slightly the same temperature distribution with the 10mm diameter coil plate. This shows that, the larger the diameter size will cause the fluid to flow easier and reduce the heat transfer rate.

Coil plates with 3 holes:

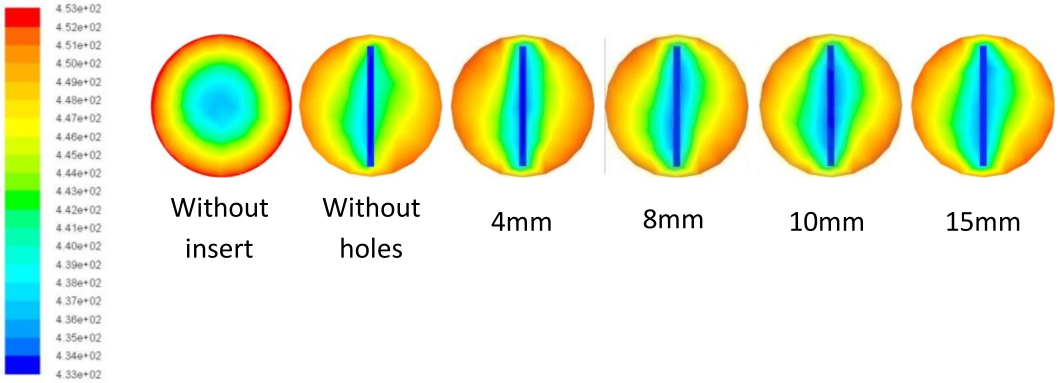


Figure 9: Static temperature contour plots with 3 holes and the diameter of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is different with different design of coil plates. The design which has 4mm diameter holes has the highest hot temperature distribution as the red color clearly can be seen. It followed by the 8mm holes diameter, 10mm holes diameter and lastly the lowest hot temperature distribution is 15mm holes diameter coil plate. The 4mm holes diameter coil plate have greater yellow and red region which indicates the temperature is higher compared to other design. The 15mm diameter coil plate has the lowest hot temperature distribution as the red region cannot be seen clearly compared to the other designs. Nevertheless, the 8mm diameter also has slightly the same temperature distribution with the 10mm diameter coil plate. This shows that, the larger the diameter size will cause the fluid to flow easier and reduce the heat transfer rate.

Coil plates with 4 holes:

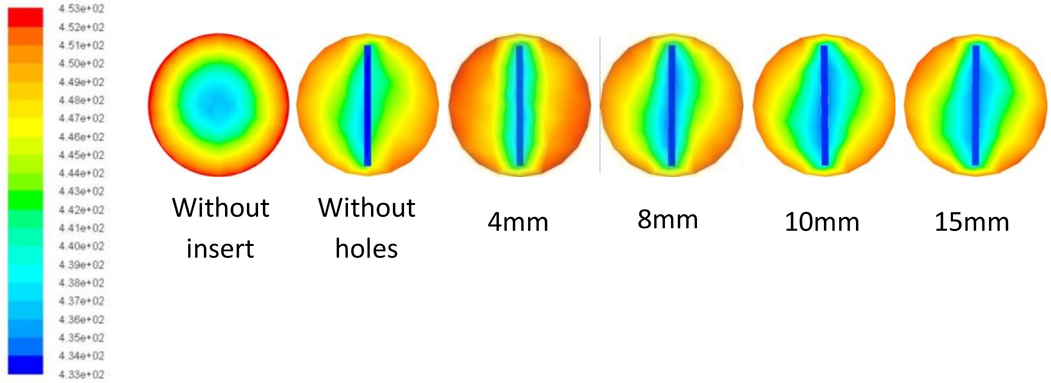


Figure 10: Static temperature contour plots with 4 holes and the diameter of holes are varied

Based on the figure above, the minimum temperature is 433K (blue region) which is mostly at the center of generating tube. The temperature is slightly increased towards the tube wall and reaches the maximum of 453K (red region). The temperature distribution according to the figure is different with different design of coil plates. The design which has 4mm diameter holes has the highest hot temperature distribution as the red color clearly can be seen. It followed by the 8mm holes diameter, 10mm holes diameter and lastly the lowest hot temperature distribution is 15mm holes diameter coil plate. The 4mm holes diameter coil plate have greater yellow and red region which indicates the temperature is the highest compared to other design. The 15mm diameter coil plate has the lowest hot temperature distribution as the red region cannot be seen clearly compared to the other designs. Nevertheless, the 8mm diameter also has slightly the same temperature distribution with the 10mm diameter coil plate. This shows that, the larger the diameter size will cause the fluid to flow easier and reduce the heat transfer rate.

4.3 Velocity Contour Plots

Coil plates with 4mm diameter:

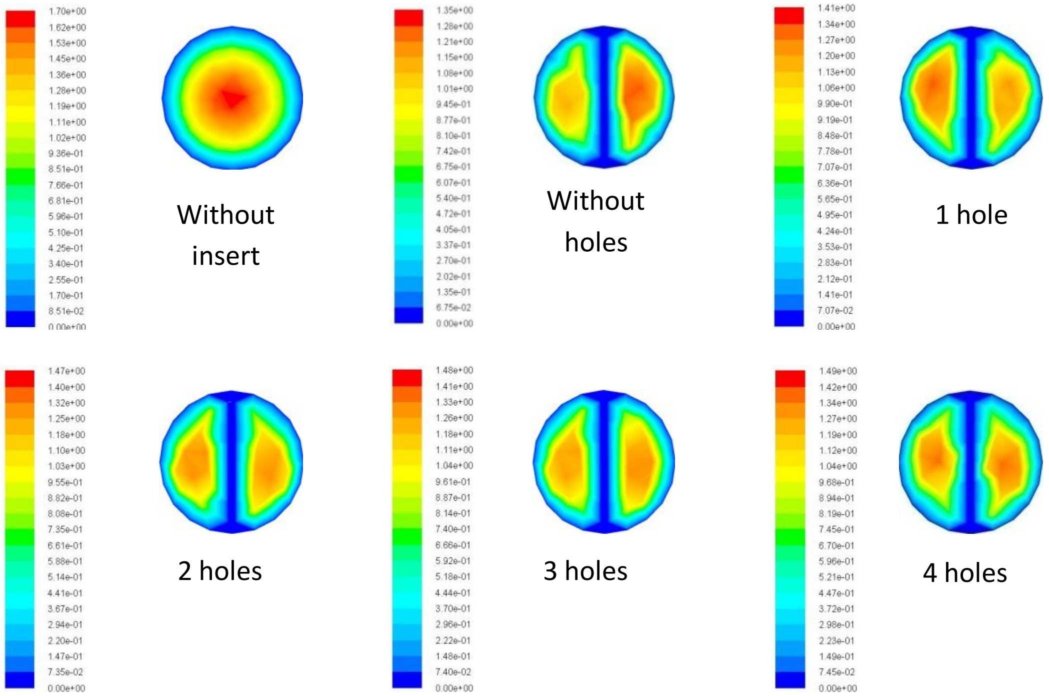


Figure 11: Velocity contour plots with 4mm diameter and the number of holes are varied

Based on the figure above, each of the design has different maximum velocity recorded. The highest value of maximum velocity is 1.49 m/s which are for the 4 holes design coil plates. This design has the highest value of maximum velocity because it contains greater number of holes which allows the hot air to flow through it with more than one path than the other designs. The second highest value of maximum velocity is 1.48 m/s which are for the 3 holes design coil plates. The value is slightly lower than the 4 holes design. Next, the values of the maximum velocity are 1.47 m/s and 1.41 m/s for 2 holes design and 1 hole design respectively. The lowest value of maximum velocity recorded is 1.35 m/s which are for the design without the holes. According to the figure above, the maximum velocity is accumulates at the center of the generating tube. This is because the maximum velocity is mainly focused on the center of the tube. The coil plates separate the flow of the hot air hence creating the secondary flow to create a better heat transfer rate.

Coil plates with 8mm diameter:

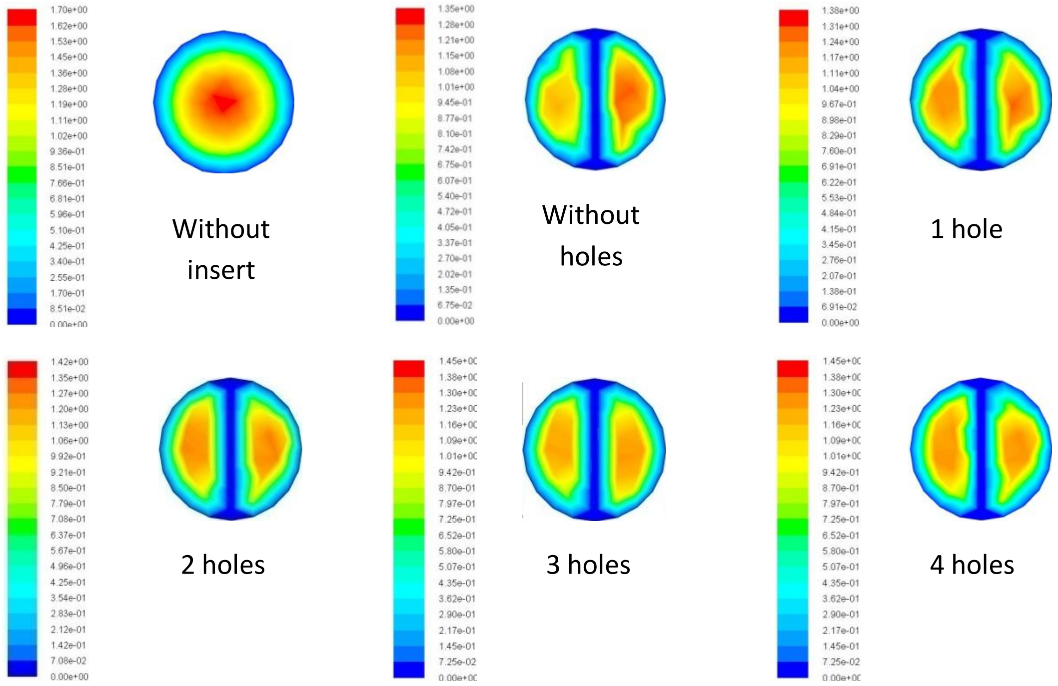


Figure 12: Velocity contour plots with 8mm diameter and the number of holes are varied

Based on the figure above, each of the design has different maximum velocity recorded. The highest value of maximum velocity is 1.45 m/s which are for the 3 holes design and 4 holes design coil plates. This design has the highest value of maximum velocity because it contains greater number of holes which allows the hot air to flow through it with more than one path than the other designs. The second highest value of maximum velocity is 1.42 m/s which are for the 2 holes design coil plate. The value is slightly lower than the 3 holes design because the number of path for the hot air to flow through the coil plate is lower. For 1 hole design coil plate, the value of maximum velocity is 1.38 m/s. The lowest value of maximum velocity recorded is 1.35 m/s which is for the design without the holes. According to the figure above, the maximum velocity is accumulates at the center of the generating tube. This is because the maximum velocity is mainly focused on the center of the tube. The coil plates separate the flow of the hot air hence creating the secondary flow to create a better heat transfer rate.

Coil plates with 10mm diameter:

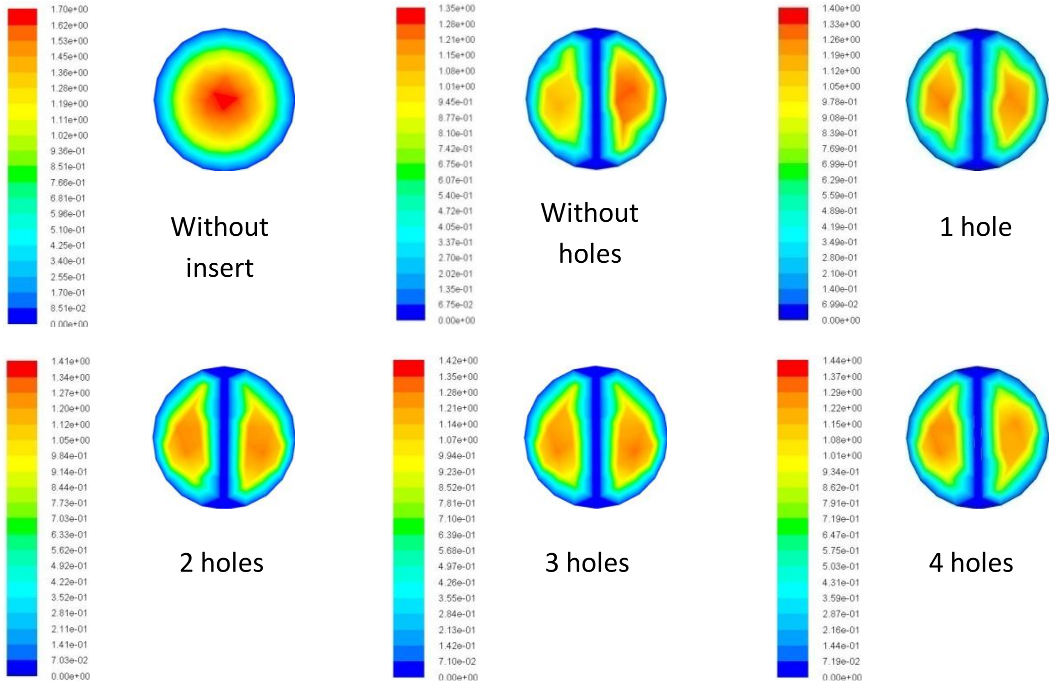


Figure 13: Velocity contour plots with 10mm diameter and the number of holes are varied

Based on the figure above, each of the design has different maximum velocity recorded. The highest value of maximum velocity is 1.44 m/s which are for the 4 holes design coil plates. This design has the highest value of maximum velocity because it contains greater number of holes which allows the hot air to flow through it with more than one path than the other designs. The second highest value of maximum velocity is 1.42 m/s which are for the 3 holes design coil plates. The value is slightly lower than the 4 holes design because the number of path for the hot air to flow through the coil plate is lower. Next, the values of the maximum velocity are 1.41 m/s and 1.40 m/s for 2 holes design and 1 hole design respectively The lowest value of maximum velocity recorded is 1.35 m/s which is for the design without the holes. According to the figure above, the maximum velocity is accumulates at the center of the generating tube. This is because the maximum velocity is mainly focused on the center of the tube. The coil plates separate the flow of the hot air hence creating the secondary flow to create a better heat transfer rate. The velocity also increases when the number of holes increases but the velocity decreases with increasing diameter.

Coil plates with 15mm diameter:

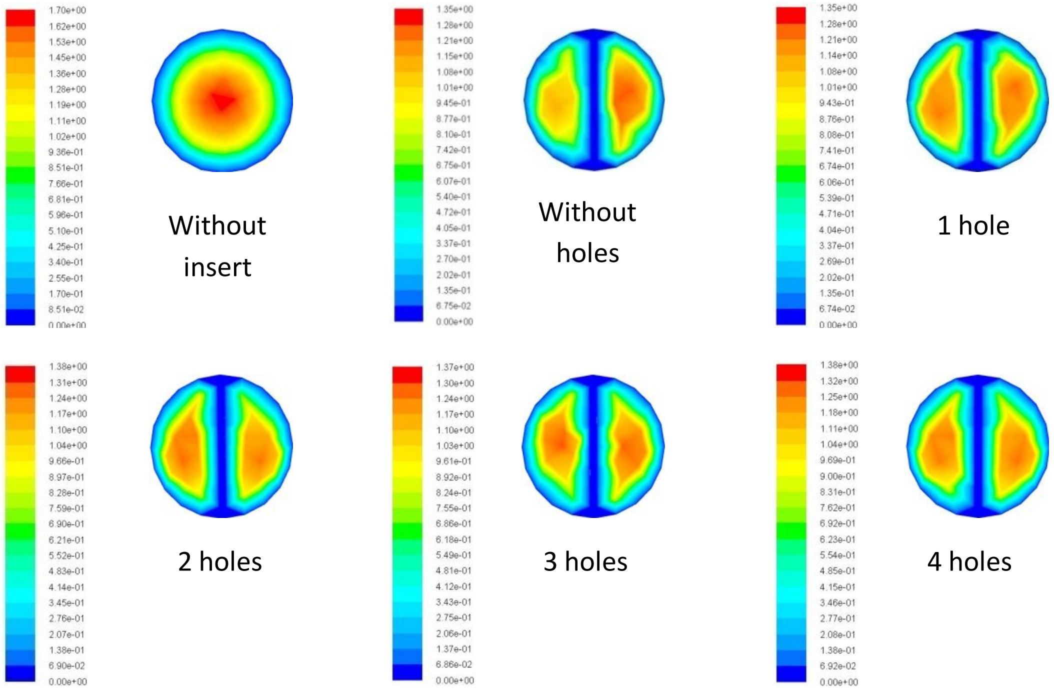


Figure 14: Velocity contour plots with 15mm diameter and the number of holes are varied

Based on the figure above, each of the design has different maximum velocity recorded. The highest value of maximum velocity is 1.38 m/s which is for the 3 holes and 4 holes design coil plates. These designs have the highest value of maximum velocity because it contains greater number of holes which allows the hot air to flow through it with more than one path than the other designs. The second highest value of maximum velocity is 1.35 m/s which is for the 2 holes design coil plates. The value is slightly lower than the 3 holes design because the number of path for the hot air to flow through the coil plate is lower. The maximum velocity for the coil plates without holes is same as 1 hole design coil plates. This shows that the velocity is decreasing with increasing diameter of holes. Nevertheless, the velocity is increasing with increasing number of holes due to the flow that become easier with greater number of holes. According to the figure above, the maximum velocity is accumulates at the center of the generating tube. This is because the maximum velocity is mainly focused on the center of the tube. The coil plates separate the flow of the hot air hence creating the secondary flow to create a better heat transfer rate.

4.4 Relationship between Velocity with Number of Holes

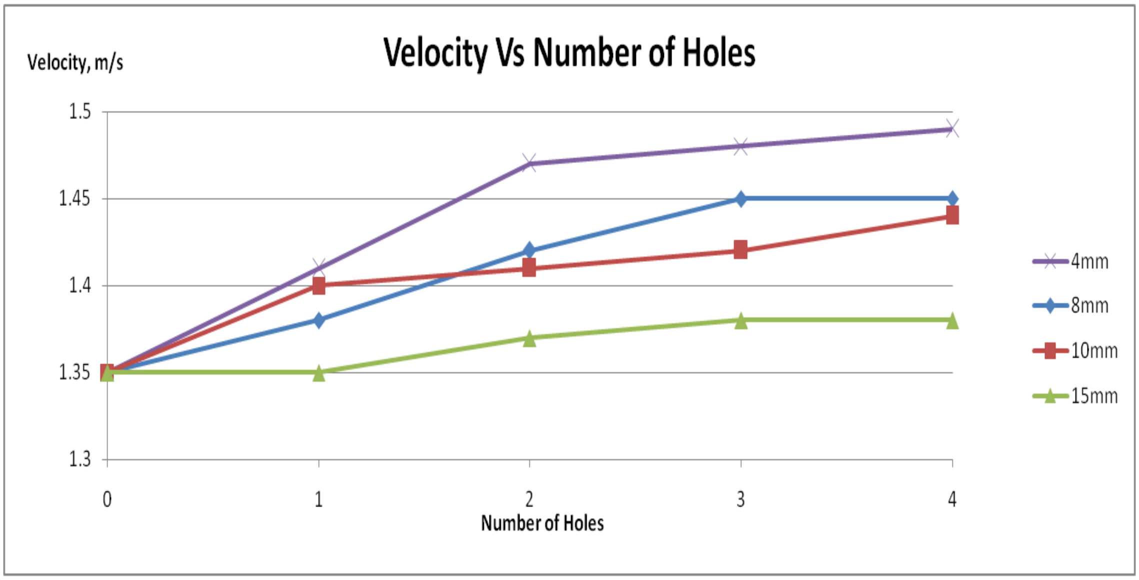


Figure 15: Relationship between Velocity with Number of Holes

Based on the graph above, it can be seen that the velocity is increasing with increasing number of holes. Nevertheless, the increment of velocity is not constant for different designs of coil plate. For example, the steepness of the graph for 4mm diameter design is different. The steepness for 0 to 2 numbers of holes is different with the line from 2 to 4 numbers of holes. Other than that, the 8mm diameter design has the same velocity for 3 numbers of holes and 4 numbers of holes. Prajapati et al. (2012) stated that by using the inserts, the heat exchanger can operate at low velocity but the performance will be the same or better than the heat exchanger that did not use the inserts into the tubes. From the above graph, it can be seen that the velocity is increasing instead of decreasing. The velocity of the tube without coil plate is 1.75 m/s which is the highest one compared to the all coil plate designs. The coil plate that been inserted into the generating tube will cause the formation of the secondary flow to increase the heat transfer rate. This formation was formed due to the disturbance of the fluid flow inside the generating tube. The holes that been created is allow the fluid which is the hot air to flow through the coil plate so that it can increase the velocity of the fluid to approach turbulence flow from laminar flow. The increasing of velocity will affect the Reynold number for the fluid flow inside the generating tube. Based on the equation (4), increasing number of velocity will increase the Reynold number.

$$Re = \frac{VD}{\nu} \tag{4}$$

Where Re = Reynold number, V = Velocity, D = Diameter, and $\boldsymbol{\nu}$ = kinematic viscosity

4.5 Relationship between Reynold Number with Number of Holes

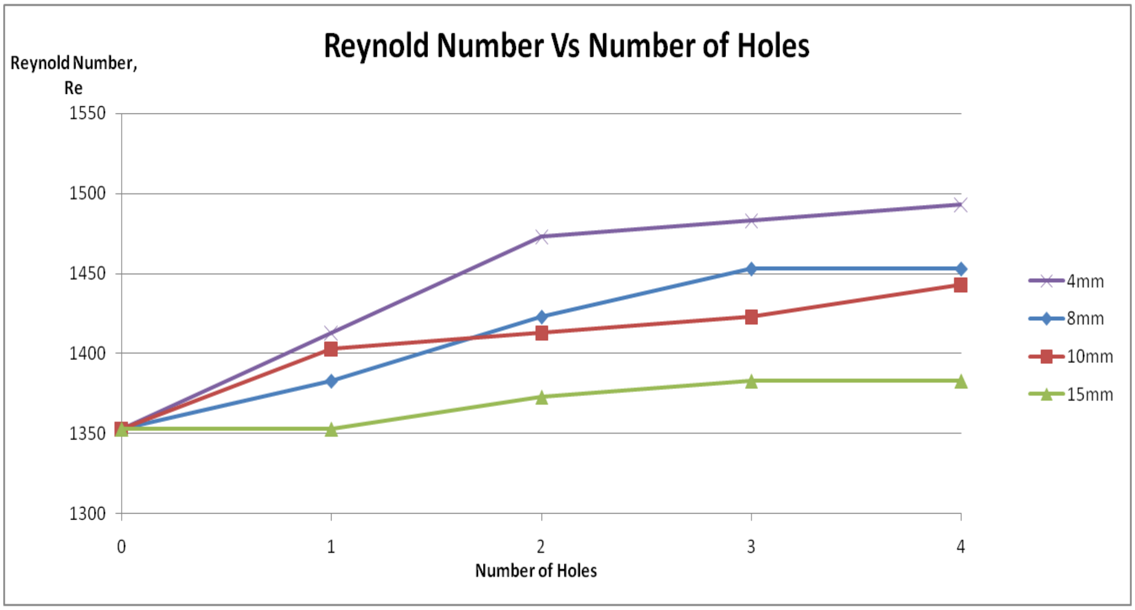


Figure 16: Relationship between Reynold Number with Number of Holes

Based on the graph above, the Reynold number is increase with increasing number of holes. This is the same as the relationship between velocities with the number of holes. It is because, the velocity affect the value of the Reynold number; high velocity will result in high Reynold number. The value of Reynold number will indicate the type of flow that occurs inside the generating tube. Most of the flow in tube can be categorized as follow:

Table 8: Type of Flow Based on Reynold Number (Çengel and Ghajar, 2011)

Reynold Number, Re	Type of flow
Re < 2300	Laminar
10,000 ≤ Re ≤ 2300	Transition
Re > 10,000	Turbulence

From the graph obtain, the value of Reynold number is between 1350 and 1500. Hence, it indicates that the type of flow inside the generating tube is a Laminar flow. The Reynold number is increasing with increasing number of holes which indicates that the flow is approaching to the turbulence flow with greater number of holes.

The Nusselt number can be obtained based on the Reynold number using Sieder and Tate equation. The relationship between Nusselt number and Reynold number is shown in the equation (5). The Nusselt number is one of the important parameter in this project to determine the heat transfer coefficient, h. Equation (6) shows the relation between Nusselt number and heat transfer coefficient, h.

$$Nu = 1.86(\frac{Re\ \mathrm{Pr}\ D}{L})^{\frac{1}{3}}(\frac{\mu_b}{\mu_s})^{0.14} \tag{5}$$

Where Nu = Nusselt number, Pr = Prandtl number, $\boldsymbol{\mu_b}$ = Average dynamic viscosity, $\boldsymbol{\mu_s}$ = Dynamic viscosity at surface

$$Nu = \frac{hD}{k} \tag{6}$$

Where Nu = Nusselt number, k = Thermal conductivity, h = Heat transfer coefficient,
D = Diameter

From the equation (6), it can be seen that the greater the Nusselt number will lead to higher value of heat transfer coefficient, h. This heat transfer coefficient value was used to determine the heat transfer, $\dot{Q}$ inside the generating tube.

4.6 Relationship between Nusselt Number with Number of Holes

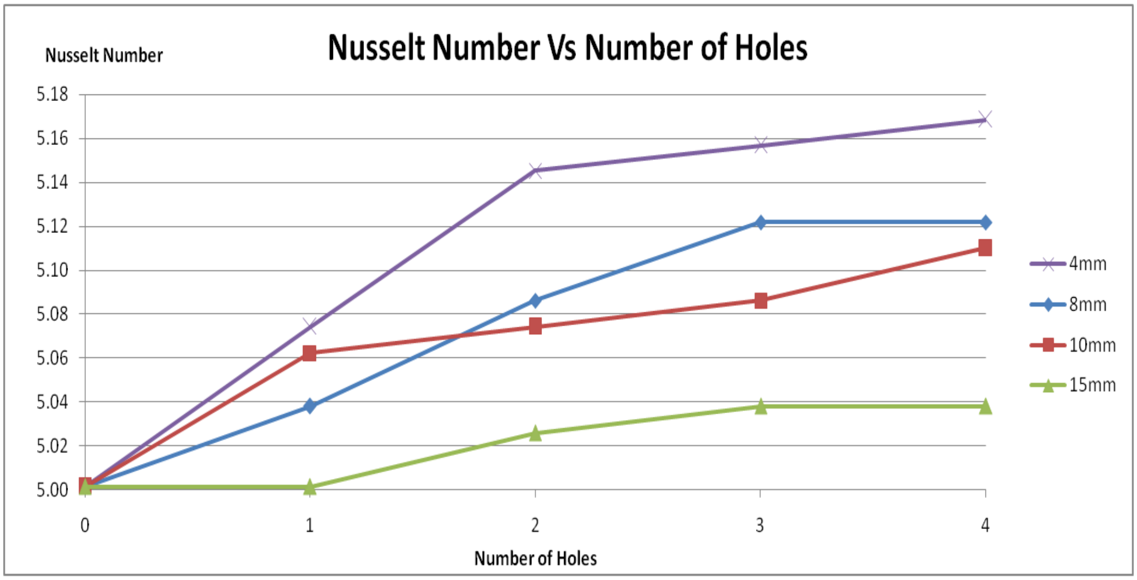


Figure 17: Relationship between Nusselt Number with Number of Holes

Based on the graph above, the Nusselt number is increase with increasing number of holes. The steepness for each of the designs is not the same. For example, 4mm diameter design coil plate has higher steepness compared to other designs. The number of holes also does not affect the steepness of the graph but it affect the Nusselt number. But in overall, the higher number of holes the greater the Nusselt number.

Based on the equation (5), if Reynold number is increase, the Nusselt number also will increase. The 4mm diameter design coil plate has the highest value of Nusselt number due to the maximum velocity that is also the highest one compared to other designs. It followed by the 8mm diameter design coil plate, 10mm diameter design coil plate and lastly is the 15mm diameter design coil plate. Based on the graph it can be seen that the bigger the diameter, the lower the value of Nusselt number. With lower value of Nusselt number, it will affect the heat transfer rate, $\dot{Q}$ inside the generating tube.

By obtaining the value of Nusselt number, the heat transfer coefficient, h also can be determined using equation (6). Hence, the heat transfer also can be determined as well. Most of the parameter such as diameter, D, inlet temperature, T, and the length of the tube, L, are kept constant throughout the experiment.

4.7 Relationship between Surface Areas of Coil Plate with Number of Holes

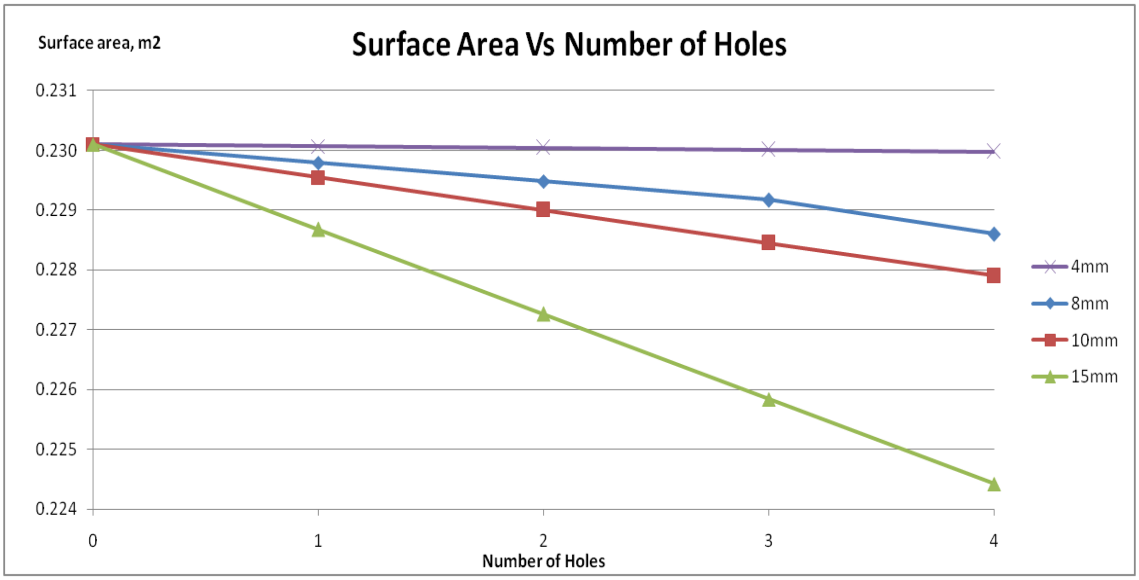


Figure 18: Relationship between Surface Areas of Coil Plate with Number of Holes

Based on the graph above, it can be seen that the surface area of the coil plate is decreasing with increasing size of holes. The surface area of the coil plate also decrease with increasing number of holes. From the first hypothesis, it is stated that the surface area of the coil plate will increase when the holes is created on it. But from the graph shown above, the surface area is decreasing when the holes is created.

The 4mm diameter design coil plate has the highest value of surface area while the 15mm diameter design coil plate has the lowest. The decrement line for 4mm diameter design coil plate is too low because the value difference is not too big. While the decrement line for 15mm diameter design coil plate is the highest due to the value drop is too big.

Although the surface area is decreasing, the velocity is increase with decreasing size of holes. With this factor, the heat transfer rate can be increase. It is because when velocity is increase, it will affect the Nusselt number that also will increase. The velocity also increases with increasing number of holes.

4.8 Relationship between Heat Transfer Rate with Number of Holes

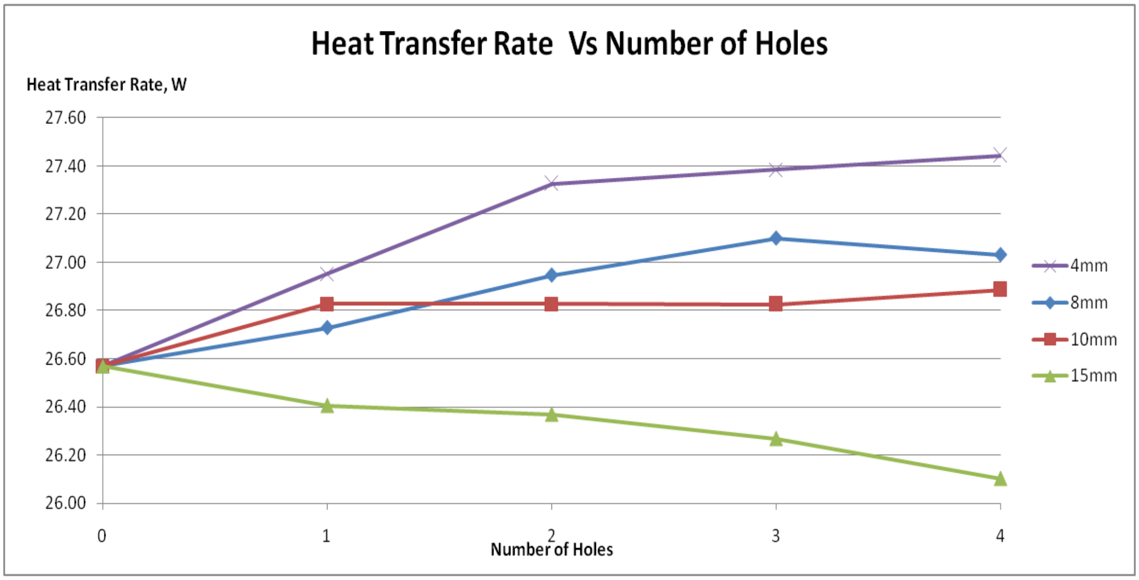


Figure 19: Relationship between Heat Transfer Rate with Number of Holes

Based on the graph above, the 4mm diameter design coil plate has the highest value of heat transfer rate, $\dot{Q}$. For 1 number of holes, the 10mm diameter design coil plate has slightly higher value of heat transfer compared to 8mm diameter design coil plate. But after that, the 8mm diameter coil plate has the higher value compared to 10mm diameter design coil plate. The value of heat transfer is increasing for the 4mm diameter design coil plate as well as 8mm diameter design coil plate. But at 4 numbers of holes, the heat transfer is decreasing for 8mm diameter design coil plate. For 10mm diameter design coil plate, the value of heat transfer is constant from 1 number of holes to 3 numbers of holes. But at 4 numbers of holes, the value is slightly increasing. For 15mm diameter design coil plate, the value of heat transfer is decreasing from without holes to 4 numbers of holes. It can be seen that 15mm diameter design is not the best design to increase the heat transfer rate inside the generating tube.

The heat transfer rate inside the tube can be determined from the equation (7). Note that the temperature difference between the surface and the fluid is kept constant throughout the simulation work.

$$\dot{Q} = hA_s(T_s - T_\infty) \tag{7}$$

Where $\dot{Q}$ = Heat transfer rate, h = heat transfer coefficient, A_s = Surface area, T_s = Surface temperature, T_∞ = Fluid temperature

The heat transfer coefficient is obtained based on the Nusselt number using the equation (6). The surface area of the coil plate is actually decreased when the hole is created. The surface area without the holes has the highest value compared to other designs. The parameter that increases the value of heat transfer rate, $\dot{Q}$ is the heat transfer coefficient, h which is affected by the velocity of the fluid. Although the surface area is decreased, the velocity of the fluid is increasing and will increase the value of heat transfer coefficient.

The heat transfer rate, $\dot{Q}$ is increased due to the increasing value of velocity. The holes that been created on the coil plate will leads to the higher velocity. The fluid is initially in laminar flow when there is no hole created on the coil plate. But after the hole is created, the velocity is increase and as well as the Reynold number, Re. The increasing value of Reynold number indicates that the flow is approaching to the turbulence flow to create a better heat transfer rate.

4.9 Relationship between Pressure Drop with Number of Holes

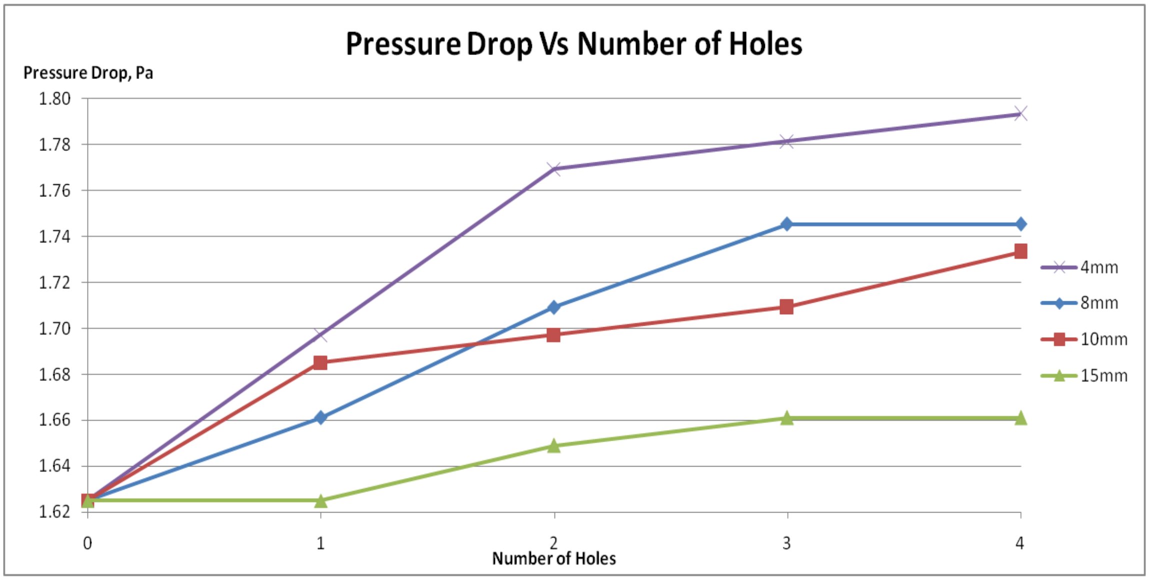


Figure 20: Relationship between Pressure Drop with Number of Holes

Based on the graph above, the 4mm diameter design coil plate has the highest value of pressure drop, $\Delta \boldsymbol{P}$, which is approximately 1.90 Pa for 4 numbers of holes. The gradient of this design is steep from 0 number of hole to 2 numbers of holes then it decreases. But still has the highest value compared to other designs. The 8mm diameter design coil plate has higher steepness compared to 10mm diameter and 15mm diameter design coil plate. From the graph, it can be seen that the lower the diameter of holes, the higher the pressure drop. Increasing number of holes also will increase the pressure drop.

Prajapati et al. (2012) has stated that by inserting the coil plate into the generating tube, it will leads to a pressure drop. It has been proved in the graph that is shown above. The pressure drop has occurred when inserting the coil plate into the generating tube. The pressure drop also increase with increasing number of holes and decreasing size of holes diameter. The pressure drop can be calculated using the equation (8) shown below:

$$\Delta P = f \frac{L}{D} \frac{\rho V^2}{2} \tag{8}$$

Where ΔP = Pressure drop, f = friction factor, ρ = density of fluid, L = Length of tube, D = Inner diameter of tube, V = Velocity of the fluid.

And the friction factor, f, for laminar flow in circular tube can be calculated by equation (9):

$$f = \frac{64}{Re} \tag{9}$$

Where Re = Reynold number.

From the equation (8) and (9), it can be seen that the velocity affect the pressure drop, ΔP. Increasing velocity will increase the pressure drop inside the generating tube. For 4mm diameter design coil plate, it has the highest velocity compared to all other design. Hence, the pressure drop, ΔP, is also the highest.

5.0 CONCLUSIONS & RECOMMENDATIONS

The conclusion that can be made based on the project that been done by the author for this Final Year Project are:

- The coil plate surface area is decrease with increasing size of holes. The coil plate surface area also decrease with increasing number of holes. But the heat transfer rate is increase with increasing velocity due to greater number of holes and low size of diameter.
- The proposed design of coil plate in this project is 4mm diameter with 4 numbers of holes. This is because this design results in high heat transfer rates.
- The overall performance of boiler is increase with inserting the coil plate into the generating tube compared to the one without the coil plate.

The objective of the project have been achieved by studying the effect of the coil plates surface area in enhancement of heat transfer using simulation software and propose new design of coil plate using simulation software. The overall performance of boiler also has been compared with boiler with and without the coil plate inside the generating tube.

For the future works, it would be good if the result for the simulation work can be compared to the experimental data. It is because it can verify the results from the simulation work with the experimental data. The result from the experiment is according to the real case situation while the simulation work is only virtual work that has some limitations. Due to the limitations, the assumptions have to be made and the result may not be the same as the experimental result. Below are some recommendations that could be made for further research to improve the heat transfer rate.

- Improve the flow of the hot air inside the generating tube to change the laminar to turbulence flow. Hence, it can increase the heat transfer rate.
- Conduct a research on how the width ratio and twist ratio will affect the heat transfer rate with different design of coil plate.

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APPENDIX

Appendix – I

Sample calculation for 4mm diameter with 4 numbers of holes design coil plate

Based on the simulation, the maximum velocity is 1.49 m/s. Based on this velocity, the Reynold number can be calculated. From equation (4):

$$Re = \frac{VD}{\nu}$$

$$Re = \frac{(1.49)(0.031)}{0.000030935}$$

$$Re = 1493.13$$

To calculate the Nusselt number based on the Reynold number, equation (5) was used.

$$Nu = 1.86(\frac{Re\,\mathrm{Pr}\,D}{L})^{\frac{1}{3}}(\frac{\mu_b}{\mu_s})^{0.14}$$

$$Nu = 1.86(\frac{(1493.13)(0.7003)(0.031)}{1.5})^{\frac{1}{3}}(\frac{0.00002462}{0.00002504})^{0.14}$$

$$Nu = 5.17$$

Based on the Nusselt number obtained, the heat transfer coefficient, h, also can be determined by using equation (6):

$$Nu = \frac{hD}{k}$$

$$h = \frac{Nu.k}{D}$$

$$h = \frac{(5.17)(0.035785)}{0.031}$$

$$h = 5.97\ W/m^2.K$$

The heat transfer rate can be identified based on the heat transfer coefficient using the equation (7):

$$\dot{Q} = hA_s(T_s - T_\infty)$$

$$\dot{Q} = (5.97)(0.22998)(453 - 433)$$

$$\dot{Q} = 27.44\ W$$

The pressure drop inside the generating tube also can be calculated using equation (8):

$$\Delta P = f\frac{L}{D}\frac{\rho V^2}{2}$$

Where, $f = \frac{64}{Re}$

$$f = \frac{64}{1493.13}$$

$$f = 0.04$$

Hence, the Pressure drop inside the generating tube is;

$$\Delta P = (0.04)\frac{1.5}{0.031}\frac{(0.779)(1.49)^2}{2}$$

$$\Delta P = 1.79\ Pa$$

Note that, all the properties of air at 160°C can be obtained from Table A-15 in Çengel Y.A., & Ghajar A.J. (2011), "Heat and mass transfer; Fundamentals and Application". McGraw-Hill, New York.