DESIGN AND HEAT TRANSFER ANALYSIS OF A FINNED INNER TUBE DOUBLE PIPE HEAT EXCHANGER

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14611

DISSERTATION

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CERTIFICATION OF APPROVAL

Design and Heat Transfer Analysis of a Finned Inner Tube Double Pipe Heat Exchanger

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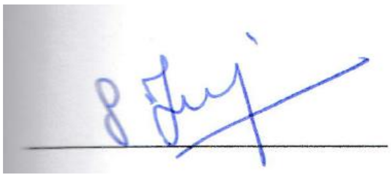

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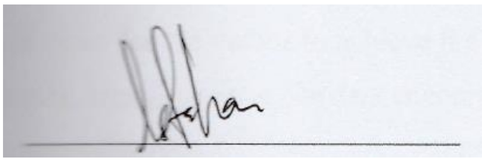
CERTIFICATION OF ORIGINALITY

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 reference and acknowledgements, and that the original work contain herein have not been undertaken or done by unspecified sources or persons.



ISFAHAN AMIN SULAIMAAN

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ABSTRACT

In this study, a double pipe heat exchanger is to be modelled using a 3D modelling software which is Solidworks software. The overall heat transfer coefficient and properties of heat transfer is numerically studied and calculated for a simple double pipe heat exchanger. The properties of water and palm oil is gathered to be used as the medium of fluid for heat transfer. By finding relevant literatures regarding heat transfer enhancement, the author finds some useful information regarding the enhancement of the design of the inner tube such as using dimpled tubes whether circular or ellipsoidal tubes. The previous article shows that the dimpled tubes would give a good heat transfer coefficient and also the effectiveness of the heat exchanger. Other than that, some articles also shoes the tubes can also be enhanced by using porous fins attached to the outer layer of the inner tubes. Previous articles discussing the porous fins discussed the optimum spacing distance and height of fins for maximum heat transfer. The author would use this idea which is the fins in order to design the double pipe heat exchanger and then analyse the heat transfer profile of the heat exchanger using ANSYS Workbench Simulation software. The results and findings is then discussed and compared with the normal tubed double pipe heat exchanger.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The project title given for the Final Year Project (FYP) is Design and Heat Transfer Analysis of a Finned Inner Tube Double Pipe Heat Exchanger. Heat exchanger is a device built for efficient heat transfer from one medium to another, whether the media are separated by a solid wall so that they never mix, or the media are in direct contact. They are widely used in space heating, refrigeration, air conditioning, power plants, chemical plants, petrochemical plants, petroleum refineries, and natural gas processing. One common example of a heat exchanger is the radiator in a car, in which a hot engine-cooling fluid, like antifreeze, transfers heat to air flowing through the radiator. To design a heat exchanger, many criteria have to be taken before making any decision. The important parameters of heat exchangers are to be collected and put a major consideration on it such as the fluid properties to be used. In this project, the software two softwares will be utilized for the design and simulation which are the Solidworks for the design and ANSYS Workbench software for the simulation. The results from the simulation will be compared for both models the finned inner tube and the normal tube in order to see the improvements in term of heat transfer profiles, rates and outlet temperatures for both fluids.

1.2 PROBLEM STATEMENT

This project is mainly focusing on designing of one type of a heat exchanger which is double pipe heat exchanger. Step by step on designing two types of heat exchanger. One heat exchanger is to be designed with normal inner tubes and the other will have an additional circular fins attached to the inner tubes to enhance the heat transfer of the heat exchanger. Heat transfer in a heat exchanger is very important because the required temperature of the fluids that is desired must be met all times without failure. Thus by designing the heat exchanger to have fins the author will analyse the heat transfer of the fluids in comparison with the normal tubed heat exchanger.

A lot of previous article tackles the problem of heat transfer rate or the overall heat transfer coefficient of the heat exchanger. Thus it is the author’s ambition to use the previous article ideas and combine them so that after the modelling work to analyse the heat exchanger using a simulation software.

1.3 OBJECTIVES

Like any other projects, there must be some sort of objectives in order to achieve the goal of the project. The main objectives for this project are:

1. To perform designing and simulation works of the double pipe heat exchanger
2. To study and analyse the heat transfer enhancements between mediums by adding fins to the heat exchanger

1.4 SCOPE OF STUDY

In this project, the author’s main scope is to make research about the double pipe heat exchangers that is available in the market and also the various usage of it whether commercially or even industrially. The research will help the author in understanding the key concepts of the double pipe heat exchanger and thus help the author in designing a double pipe heat exchanger with any types of fluid for heat transfer purposes. The scope of study is only the double pipe of the heat exchanger and the author will disregard the involvement of other systems such as pumping systems and others during the designing works. However, the pressure drop calculation is included to see how much pumping power is needed to drive the fluids. This project gives the author a lot of challenges because there is no heat exchangers provided by the University for the Author to make hands-on research. Another challenge is the time frame. The author is given 2 semesters which is 8 months for the project from start to finish. The first 4 months is dedicated to the obtaining information, researching, and do a lot of study for the double pipe heat exchanger. The other 4 months is dedicated for the designing as well as doing simulation analysis of the heat exchanger.

CHAPTER 2: THEORY & LITERATURE REVIEW

2.1 DOUBLE PIPE HEAT EXCHANGER OVERVIEW

Heat is defined as the amount of energy a substance has. A heat exchanger is a heat transfer device whose purpose is the transfer of energy from one moving fluid stream to another moving fluid stream [1]. The transfer of heat is done with a separation of a wall to avoid mixing of the two fluids of different properties.

Transfer of heat happens by three principles means which are Radiation, Conduction and Convection. Conduction occurs as the heat from the higher temperature fluid passes through the solid wall. To maximise the heat transfer, the wall should be thin and made of a very conductive material. Forced convection in the other hand allows for the transfer of heat of one moving stream to another moving stream [2]. The thermal circuit with its respective thermal resistance can be seen as:

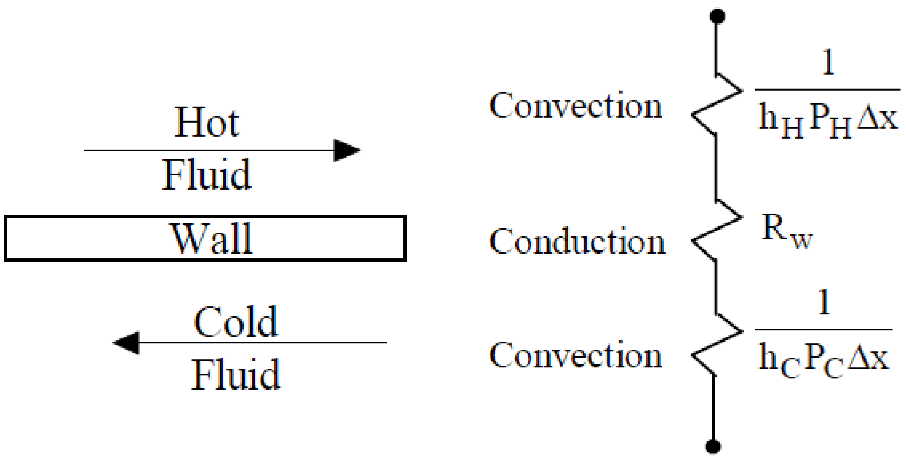

Figure 1: Thermal Circuit [1]

The convection and conduction each has its own thermal resistance and can be calculated by the formula after finding the enthalpy and the cross sectional area of the tube.

Double Pipe Heat Exchanger can be classified into 2 types which are Parallel Flow and Counter Flow. The counter flow pattern is the more efficient of the 2 because it will give a higher overall heat transfer coefficient. Also, hairpin and double pipe heat exchangers can handle high pressures and temperatures well. When they are in counter flow, they can operate with a temperature cross, that is, where the cold side outlet temperature is higher than the hot side outlet temperature [3]. This can be seen in the figure below:

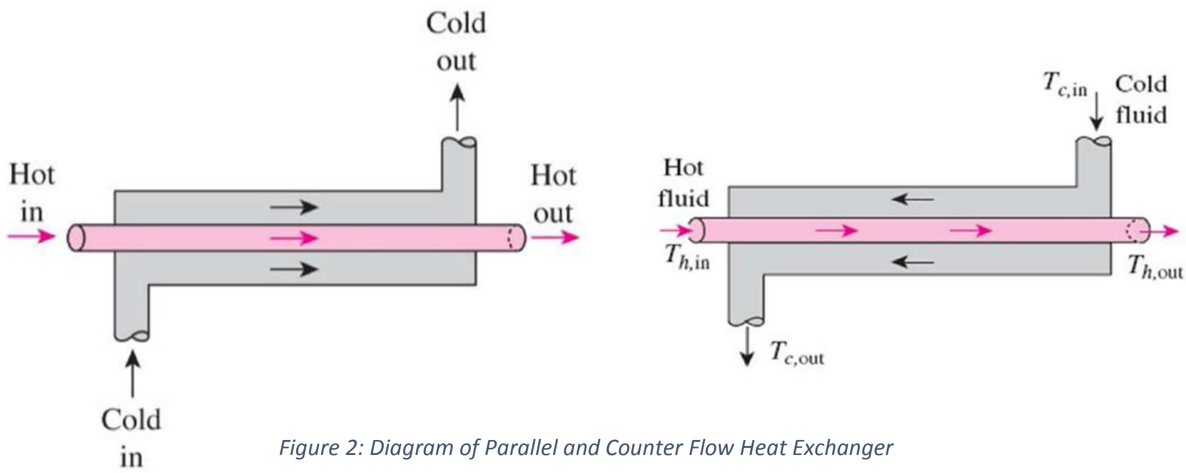

Figure 2: Diagram of Parallel and Counter Flow Heat Exchanger

2.2 FOULING

One generic problem of heat transfer is the effect of surface contamination on heat-transfer rates, that may be due for instance to chemical attack at the interface between solids in heat conduction, crust build-up at walls in heat convection flows, or dust deposition in heat radiation surfaces. Fouling (i.e. dirt and depositions) is detrimental within heat exchangers because it adds a thermal resistance to heat, it adds a fluid-dynamic resistance to flow, and it is difficult (sometimes impossible) to clean [4].

Fouling is typically due to algae growth on cold surfaces, to salt deposition on hot surfaces, and to unfiltered dirt clogging. All industrial circuits cooled with natural fresh or sea water, are subjected to biological fouling (a bio-film settlements of living organisms). Although physical screening, physical cleaning and chemical dosing can manage to get a long trouble-free operation, nowadays environmental restrictions may impinge on that; e.g. chemical dosing with chlorine concentrations up to 10 mg/L were common in the past, but now chlorine discharge to the water environment have been severely restricted [4].

2.3 HEAT EXCHANGER ANALYSIS THEORY

Two types of analysis for parallel flow heat exchangers to determine temperature drops are the log mean temperature difference and the effectiveness-NTU method. Each method is dependent upon the conditions provided or being solved for [5]. The equation for heat transfer using the log mean temperature difference becomes:

$$\dot{q} = UA\Delta T_{LM} = UA \times \frac{\Delta T_2 - \Delta T_1}{LN\left({}^{\Delta T_2}/_{\Delta T_1}\right)} \qquad (1)$$

In order to determine the amount of heat to be transferred in a heat exchanger or the intensity at which the heat from fluid flow will be transferred, the log mean temperature difference is calculated. As the name suggests, it is the logarithmic average of the hot and cold fluid channels of a heat exchanger at both the inlet and outlets. The log mean temperature difference is defined in terms of ΔT_1 and ΔT_2 which are defined depending on whether flow is concurrent or counter current. The larger the temperature difference, the larger the value of heat that is transferred [5]. The log mean temperature difference represents the effective, average temperature difference between the two heat transfer fluids over the length of the heat exchanger. For the overall heat transfer coefficient calculation, the two mediums that are flowing in counter flow of each other each will have a convective heat transfer. The separating wall of the inner tube will then have a conduction heat transfer. Calculating the total thermal resistance will have:

$$R = \frac{1}{UA} = \frac{1}{h_\iota A_\iota} + R_{wall} + \frac{1}{h_o A_o} \qquad (2)$$

However, when the thickness of the wall is very thin and the wall itself have a very high heat conduction coefficient, this will make the thermal resistance of the inner tube wall to be approximately zero. Then, the overall heat transfer coefficient formula can be simplified as:

$$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o} \qquad (3)$$

In general the heat flux is comprised of three factors: the temperature difference, the characteristic area, and an overall heat transfer coefficient. An approximate value for the transfer coefficient U ($^{W}/_{m^2K}$) is 110-350 for water to oil [5]. R_f is defined as the fouling factor with units of $^{m^2K}/_{W}$. An approximate value of .0009 is used for fuel oil, while .0001 - .0002 is used for seawater and treated boiler feedwater [5].

2.4 PRESSURE DROP

In any fluid flow systems, there must be some pressure drop that is present in the pipe. The fluid flow depends on the types of flow which is either Laminar or Turbulent flow. To determine the type, we use the Reynolds number which is also a dimensionless parameter which depends on the velocity of fluid, diameter of pipe (in case of annulus flow is hydraulic diameter), and the kinematic viscosity of the fluid. The formula is:

$$Re = \frac{VD}{v} \qquad (4)$$

The resulting number determines the flow type. When the Reynolds Number is less than 4,000 the flow is Laminar, and when it is more than 10,000 the flow is Turbulent. Other than determining the fluid flow type, this Reynolds number is also important when determining the Nusselt number which is another dimensionless parameter used in finding the convective heat transfer coefficient of the desired fluids. The Nusselt number depends on the type of flow of the fluid. The Nusselt number, other than being the ratio of convective and conductive heat transfer coefficient times the diameter, is also a function of Reynolds Number and Prandtl Number. Prandtl number is also a dimensionless parameter from the formula:

$$Pr = \frac{C_p\mu}{k} \qquad (5)$$

The Prandtl is unique to each fluid and depends on the fluid properties which are the heat capacity, dynamic viscosity and the thermal conductivity. Thus for a Laminar flow heat transfer scorrelation, the resulting average Nusselt Number for a certain tube length is calculated by [11]:

$$Nu_{average} = 3.66 + \frac{0.065(Re)\,(\mathrm{Pr})(\frac{D}{L})}{1 + 0.04((Re)(\mathrm{Pr})(\frac{D}{L}))^{2/3}} \quad (6)$$

For the case of Turbulent flow, a common formula used for the calculation of Nusselt number for turbulent flow is [11]:

$$Nu = 0.023\, Re^{0.8} Pr^{0.4} \quad (7)$$

Thus from the calculation of the Nusselts number we can in turn determine the convective heat transfer coefficient for both fluids depending from the flow type. The pressure drop calculation is included in the analysis because a highly effective heat exchanger will in turn have a high pressure drop. This is due to the high velocity and flow rate of the fluids. Although pressure drop does not directly related to the heat transfer, it is important in finding the pumping power to drive the fluid and finding the right pump. Thus, the double pipe heat exchanger only use the pressure drop formula of a normal pipe flow. The formula is [9]:

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

The friction factor, f for laminar flow is equal to:

$$f = \frac{16}{Re} \quad (9)$$

For a turbulent flow, we can use either the Colebrook or the Zigrang-Sylvester equation. However, the formula itself is hard to compute easily and have to use excel spreadsheet for an example. Another equation is the Swamee-Jain equation which is the approximation of the implicit of the Colebrook equation [12]. This equation is used to solve directly the friction factor and the formula is:

$$f = 0.25[log_{10}\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{Re^{0.9}}\right)]^{-2} \quad (10)$$

Thus from the pressure loss calculations, the power required to overcome the friction related to the pressure drop is:

$$Power = \Delta P(Q) \tag{11}$$

2.5 EFFECTIVENESS NTU

Effectiveness is another dimensionless parameter which quantifies how efficient the heat exchanger is in terms of transferring energy from one stream to another and is defined as the ratio of the actual energy transferred to the maximum possible energy transfer between the two streams. For the effectiveness of the double pipe heat exchanger, the calculation of the effectiveness is calculated by the formula:

$$\text{Parallel Flow:} \quad \varepsilon = \frac{1 - \exp[-NTU(1 + C_r)]}{1 + C_r} \tag{12}$$

$$\text{Counter Flow:} \quad \varepsilon = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]} \quad \text{for } C_r < 1 \tag{13}$$

The NTU (Number of Transfer Units) is a dimensionless parameter that is used to ease the calculation of the effectiveness. The heat capacity ratio C_r however, is the ratio of the two medium's heat capacity. These values are arranged into different equations depending upon the type of heat exchanger as shown in both equations above [5]. The NTU is given by:

$$NTU = \frac{UA}{C_{min}} \tag{14}$$

The minimum heat capacity is the heat capacity that is lowest in between the two mediums used to transfer heat. Since the effectiveness ε is also the ratio of the actual heat transfer rate to the maximum possible heat transfer rate, the formula can also be given as:

$$\varepsilon = \frac{\dot{Q}_{actual}}{\dot{Q}_{max}}, 0 \leq \varepsilon \leq 1 \qquad (15)$$

Whereby the maximum heat transfer can be calculated from:

$$\dot{Q}_{max} = C_{min}(T_{h,in} - T_{c,in}) \qquad (16)$$

By calculating the effectiveness of the heat exchanger, with the known inlets of both hot and cold fluids, we can determine the outlet temperatures of both fluids from the calculation of heat transfer rate for both fluids.

2.6 TUBE ENHANCEMENT IDEAS

Dimpled Tubes

A numerical study had been done on flow analysis and characteristics comparison of double pipe heat exchanger using enhanced tubes. The study had used dimpled tubes as compared to the more general flat surfaced tubes. The dimpled tubes provide heat transfer rates that are higher than the rates found in smooth tubes under similar conditions. This is an important development for the energy conversion and process industries. It was demonstrated that more heat transfer and an earlier transition to high heat transfer can be accomplished through the use of dimpled tubes. Tubes have been evaluated and can be designed to produce more heat transfer than smooth tubes under fouling conditions [6]. An example of the dimpled tubes are as follows:

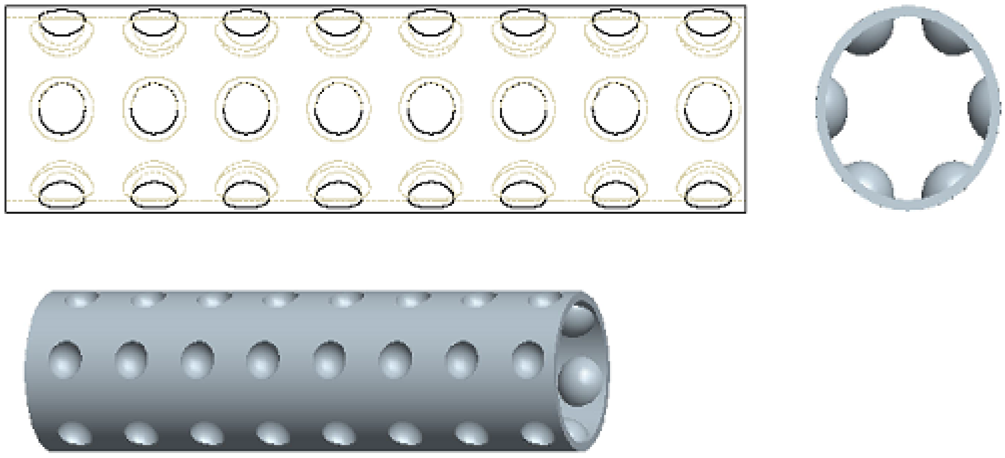

Figure 3: Dimpled Tube [6]

According to the article, the dimpled surfaces can create one or more combinations of the following conditions that are favourable for increasing the heat transfer coefficient with a consequent increase in the friction factor, which are [6]:

- Interruption of the development of the boundary layer and increase of the degree of turbulence
- Effective heat transfer area increase, and
- Generation of rotating and/or secondary flows

The dimpled surface can be classified into two different shapes which are [6]:

- Spherical dimpled tube
- Ellipsoidal dimpled tube

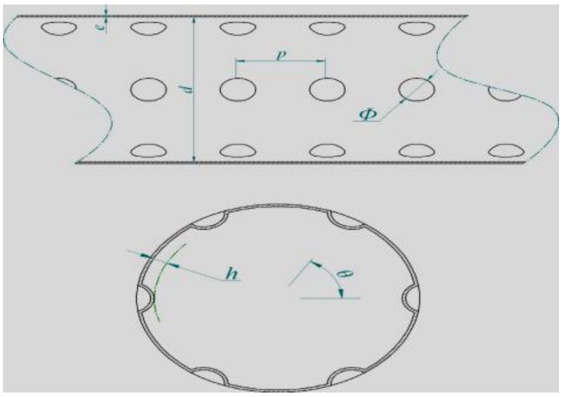

Figure 4: Spherical Dimpled Tube [6]

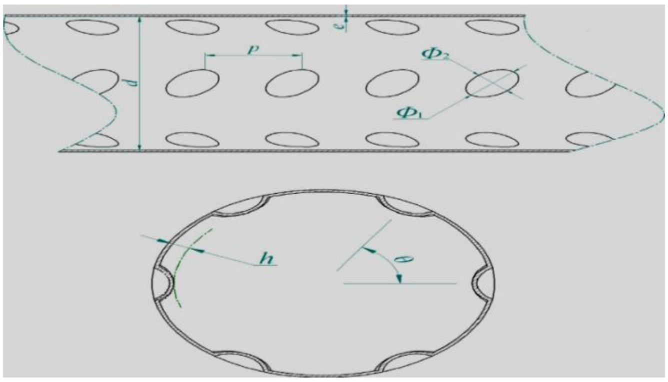

Figure 5: Ellipsoidal Dimpled Tube [6]

Porous Fins

The use of solid fins to increase the heat transfer rates between two different fluids in tubular heat exchangers is one of the most effective and widely employed methods. The insertion of porous material as another technique to enhance heat transfer in these thermal systems seems to be promising. In this context, several studies have been conducted during the recent decades. The use of porous fins to augment heat transfer rate is more interesting than the conventional solid ones due to their larger effective surface area and the lower pressure drop generated in comparison to the latter ones. However, their cleaning, after a long operating time, is more difficult due to the filling of the pores with dirt [7]. One of the articles mentioned a study using laminar flow. The effects of dimensionless parameters such as Reynolds number, Darcy number, baffle spacing and thermal conductivity ratio on the fluid and temperature fields were examined in the article and it was found that the average Nusselt number ratios for the solid baffles were higher than those for corresponding porous baffles.

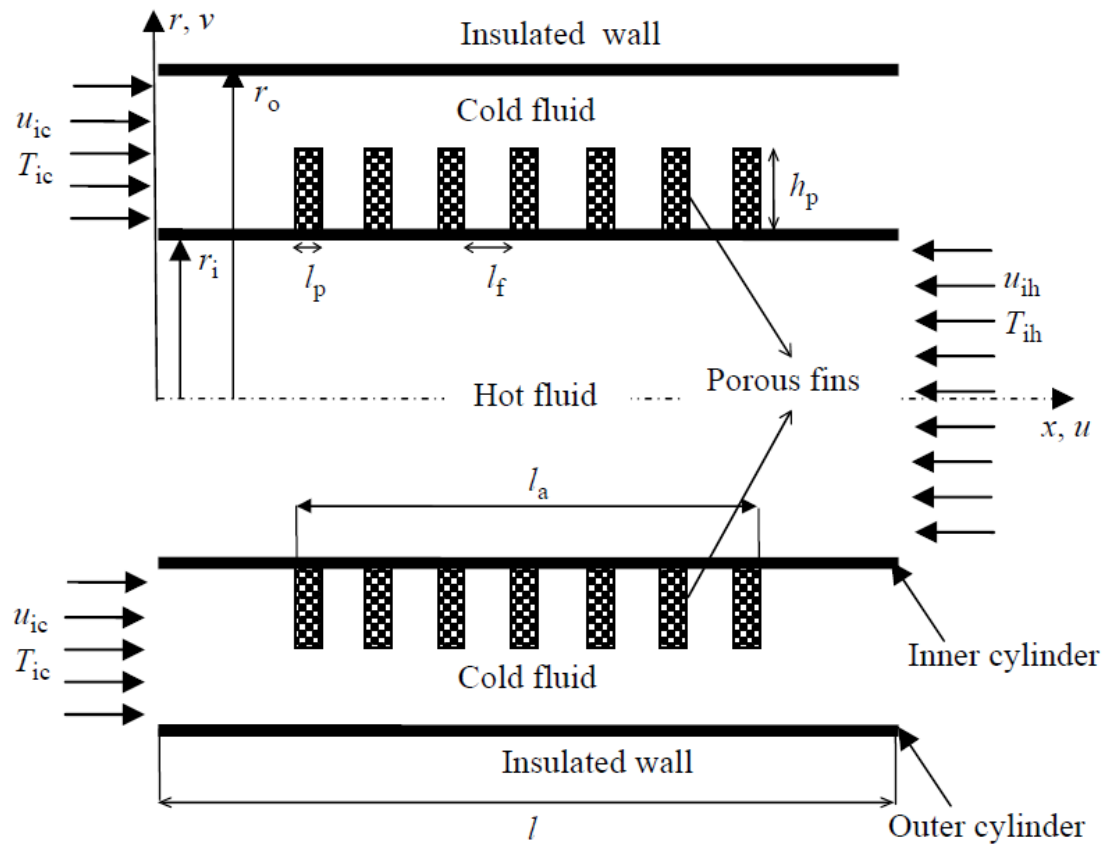

Figure 6: Schematic of the physical domain [7]

Some mathematical equations were discussed in the article such as the Continuity Equation, Momentum Equation of the annular gap and inner cylinder, and Energy Equation. Other than that, other properties of the fluid such as the Nusselt Number is calculated and shown in the results of that study.

CHAPTER 3: METHODOLOGY & PROJECT WORK

3.1 PROJECT GANTT CHART (FYP1 & FYP2) & PROJECT FLOW

Project activities	WEEK NUMBER													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of project topic (proposed by lecturers)														
Research work commenced - Look for references, resources - Study the literatures - Prepare extended proposal														
Submission of Extended Proposal						★								
Preparation for proposal defense - Rework and refine proposal - Further look for references - Preparing materials for proposal defense														
Proposal Defense														
Research work continuation - Further look for references - Identify room of improvements of the proposed project procedures - Prepare Interim report														
Submission of Interim Report draft													★	
Corrections for Interim Report draft														
Submission of final Interim Report														★

Project activities	WEEK NUMBER														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Commencement of project work - Continuing the research work - Creating 3D model for the FEA simulation	■	■	■	■	■	■	■								
Finite Element Analysis - Utilizing FEA to conduct analysis - Obtaining heat profiles and outlet temperature information for both models - Preparation of Progress Report							■	■	■						
Submission of Progress Report							★								
Continue Analysis and Pre-SEDEX preparation -Continue simulation work and collecting data -Preparation for Pre-SEDEX							■	■	■	■	■	■			
Pre-Sedex										★					
Preparation of Final Report											■	■	■	■	
Submission of Draft Final Report												★			

Submission of Dissertation (soft bound) and Technical Paper												★			
Viva													★		
Submission of Final Project Dissertation (hard Bound)															★

Legend:

- marked the process

★ - marked the Project milestone

The proposed project flow is visualized in the following flowchart

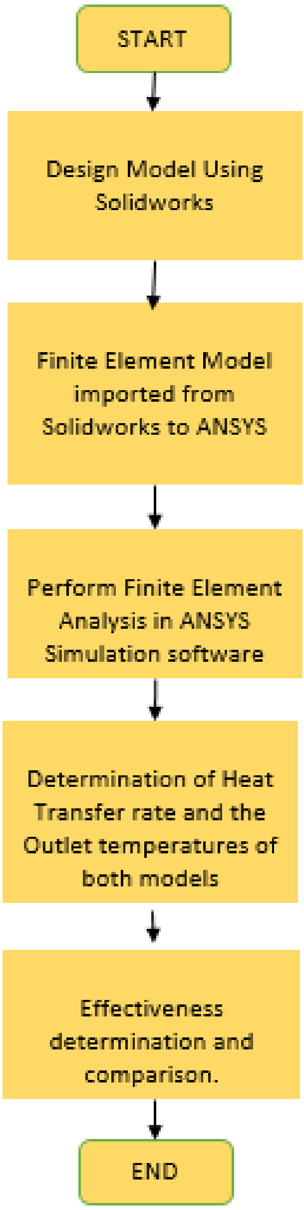

Figure 7: Flow Chart of Project

The key project objectives and tasks are further described in the following sections entitled Literature Review Work, Modelling Work, Analysis, Project Deliverables and Project Documentations. These sections will describe further of the project at hand.

3.2 LITERATURE REVIEW WORK

Literature review work involves reading, understanding, and comparing existing literature on double pipe heat exchangers. The fundamentals of the heat exchanger and its components, how types of fluid effects heat transfer and heat exchanger performance should be studied. Multiple heat exchanger models would have to be studied, especially how tubing parameters for the fluid flows are modelled. Furthermore the fundamentals of heat exchanger analysis is to be studied and understand for theoretical analysis of the double pipe heat exchanger.

3.3 THEORETICAL CALCULATIONS

In this chapter, it is to be discussed about the results and findings of the numerical studies of heat transfer of double pipe heat exchanger and how to improve it. The fluid properties obtained for water and palm oil is as shown in the table below:

Fluid data:

Hot Palm Oil	Cold Water
Copper inner tubes (Diameter = 2cm)	Shell tube (Diameter = 3cm)
Flow rate = 0.5kg/s	Flow rate = 0.8 kg/s
Temperature Inlet = 80°C	Temperature Inlet = 45°C
Density = 860 kg/m^3	Density = 990.1kg/m^3
k = 0.1675 W/m.K	k = 0.637 W/m.K
Pr = 120.3	Pr = 3.91
v = 1.161 × 10^{-5} m^2/s	v = 0.602 × 10^{-6} m^2/s
C_p = 2.018 $kJ/kg.K$	C_p = 4.181 $kJ/kg.k$

Table 1: Fluid Properties [10]

The fluid properties can be found from the table of properties at their respective temperatures. The overall heat transfer coefficient can be calculated from the equation (3). U is the overall heat transfer coefficient and h is the convection heat transfer coefficients for the inside and the outside of the tube. Using the forced convection relations, the hydraulic diameter for an annular tube is the difference in diameter of the tubes itself, $D_h = D_o - D_i = 0.01\ m$. The average velocity of the water and the Reynolds number are:

$$V = \frac{\dot{m}}{\rho A} = \frac{0.8}{(990.1)(\frac{1}{4}\pi(0.03)^2 - (0.02)^2)} = 2.06\, m/s$$

$$Re = \frac{VD}{v} = \frac{(2.06)(0.01)}{0.602\ \times 10^{-6}} = 34{,}219$$

Since the Reynolds number is greater than 10,000 therefore the flow is turbulent. Assuming that the flow is fully developed flow, the Nusselt number can then be calculated by Equation (7):

$$Nu = \frac{hD}{k} = 0.023 Re^{0.8} Pr^{0.4} = 0.023(34{,}219)^{0.8}(3.91)^{0.4} = 168.27$$

Therefore, the convection heat transfer coefficient can be calculated by:

$$h_o = \frac{k}{D_h} Nu = \frac{0.637}{0.01}(168.27) = 10{,}718.8\ W/m^2.K$$

Next, we repeat the calculation for palm oil. The hydraulic diameter for circular tube is the diameter of the tube itself. $D_h = D = 0.02m$. The average velocity and Reynolds number is calculated by:

$$V = \frac{\dot{m}}{\rho A} = \frac{0.5}{(860)(\frac{1}{4}\pi(0.02)^2)} = 1.85\, m/s$$

$$Re = \frac{VD}{v} = \frac{(1.85)(0.02)}{1.161 \times 10^{-5}} = 3187$$

Since the Reynolds number is less than 4000, the flow is said to be Laminar. Assuming developed flow, the Nusselt number for laminar can be found using the Equation (6):

$$Nu_{average} = 3.66 + \frac{0.065(3187)\,(120.3)(\frac{0.02}{0.12})}{1 + 0.04((3187)(120.3)(\frac{0.02}{0.12}))^{2/3}} = 67.6$$

Therefore, the convection heat transfer coefficient is:

$$h_i = \frac{k}{D} Nu = \frac{0.1675}{0.02}(67.6) = 566.15\, W/m^2.K$$

The overall heat transfer coefficient can be calculated from earlier Equation (3):

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} = \frac{1}{\frac{1}{566.15} + \frac{1}{10{,}718.8}} = 537.75\, W/m^2.K$$

Next is the effectiveness calculation for the normal tubed double pipe heat exchanger. The calculation for effectiveness we use the Equation (14) for the NTU and Equation (13) for the effectiveness.

$$NTU = \frac{(537.75)(7.54 \times 10^{-3})}{1.009} = 4.02$$

The calculation of max heat transfer can be yielded from Equation (16) to get:

$$\dot{Q}_{max} = 1.009(80°C - 45°C) = 35.315\ kW$$

We move then to the calculation of the effectiveness from the Equation (13) to get:

$$\varepsilon = \frac{1 - \exp[-4.02(1 - 0.302)]}{1 - 0.302 \exp[-4.02(1 - 0.302)]} = 0.96$$

Knowing the effectiveness, we can therefore calculate the actual heat transfer rate knowing the maximum heat transfer rate possible for the heat exchanger from the Equation (15).

$$\dot{Q}_{actual} = \varepsilon(\dot{Q}_{max}) = 0.96(35.315) = 33.9\ kW$$

Thus, to calculate the outlet temperatures for both fluids. The heat transfer rates for both fluids will be the same from the idea of conservation of energy. Therefore, the outlet temperatures for both fluids are:

$$\dot{Q}_{actual} = 33.9 = 3.34(T_{c,out} - 45°C) = 1.009(80°C - T_{h,out})$$

$$T_{c,out} = 55.14°C$$

$$T_{h,out} = 46.4°C$$

Since the pressure drop is also included for analysis, we therefore can calculate the pressure drop along the pipe and also along the annular tube from the equations shown before. For the inner tube side which contains hot palm oil, we had calculated before that the flow type is laminar. Therefore, to find the friction factor for the pressure drop equation, we use Equation (9) which yields:

$$f = \frac{16}{3187} = 5.02 \times 10^{-3}$$

Then we can find the pressure drop along the inner tube from the Equation (8) to get:

$$\Delta P = 2(5.02 \times 10^{-3})(\frac{0.12}{0.02})(860)(1.85)^2 = 177.3\ Pa$$

For the pressure drop along the turbulent annular tube side containing water as the fluid, using the roughness condition of a common PVC pipes which is 0.0015×10^{-3} metre [13], we can calculate the friction factor using the Equation (10) to get:

$$f = 0.25[log_{10}\left(\frac{0.0015 \times 10^{-3}}{3.7(0.01)} + \frac{5.74}{(10718.8)^{0.9}}\right)]^{-2} = 0.03066$$

Computing the pressure drop along the annular tube using the same Equation (8) yields:

$$\Delta P = (0.03066)\left(\frac{0.12}{0.01}\right)\frac{(990.1)(2.06)^2}{2} = 772.9\ Pa$$

3.4 MODELLING WORK

Modelling work involves developing a 3-D model of a double pipe heat exchanger. Getting into account the fluid properties that is going to use and also the materials for the heat exchanger body itself, for the required maximum overall heat transfer rate. The modelling work is done for two types of models which are used for comparison. Since the author is considering a finned inner tube design for heat transfer enhancement, two models are to be designed which are one without the fins and one with the fins. The modelling work is done with a 3-D modelling software which is Solidworks.

Modelling work is done for both the normal inner tube double pipe heat exchanger and the finned inner tube double pipe heat exchanger. As said previously the modelling work is done on a 3D modelling software which is Solidworks. The model of the tube is on a small scale which is around 12cm long only. The author would like to have a small control volume of the heat exchanger so that the simulation of the heat transfer will not have any other errors along the pipes. Furthermore the circular fin height and distance between the fins is placed at an approximate distance along the 12cm pipe. Since the aim is to see the heat transfer profiles and heat transfers along the tube in comparison with the normal tube, the author will not go into detail about the optimum fin height and fin space along the pipe. The models for the simulation work can be seen below.

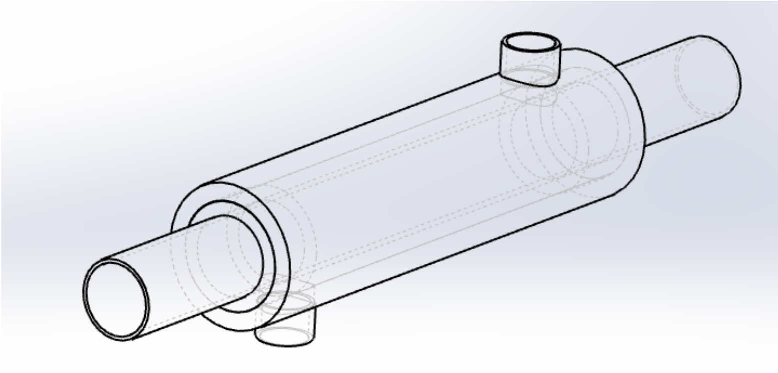

Figure 8: Normal Inner Tube Double Pipe Heat Exchanger

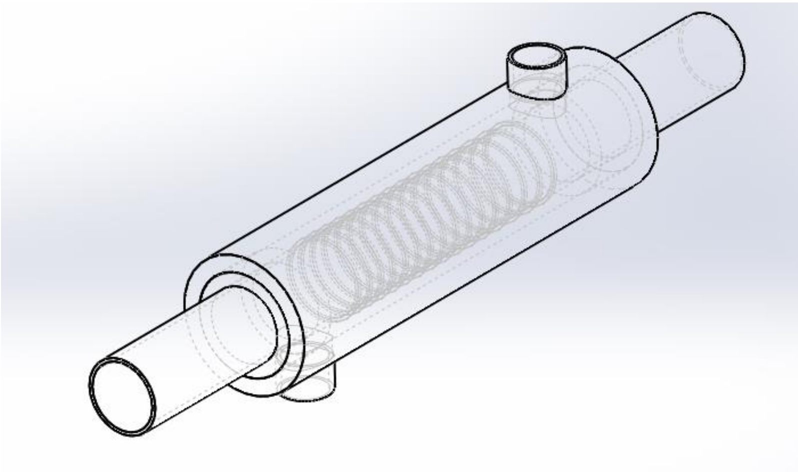

Figure 9: Finned Inner Tube Double Pipe Heat Exchanger

From the models, the next step in analysis is to do simulation on the models using ANSYS Workbench tool that had been mentioned earlier. The required results obtained such as heat transfer profiles along the tube, heat transfer rates and also the outlet temperatures will be compared with the theoretical along with the errors. The comparison of the two model's results is discussed further. Furthermore, the simulation results for the normal tube double pipe heat exchanger shall be compared with the theoretical calculation for finding the accuracy of calculation and the reliability of it.

3.5 ANALYSIS

Analysis is done after the modelling and can be used by a simulation software to provide with the data of heat transfer properties of the modelled work. The analysis is then discussed and can be compared with previous findings and calculations done earlier. ANSYS Workbench software is one of several Finite Element-capable software that are vastly available for many kind of applications. In short, like any other finite element software, this software is capable of conducting simulations and analysis in various principles of engineering such as the structural analysis (involving stress, deformation, etc.), computational fluid dynamics (CFD), heat transfer analysis, and many more. The author considers this software as an analysis tool to get the desired data of the heat transfer profiles of the double pipe heat exchanger as well as the outlet temperature of the fluids. Both models will be compared the heat transfer profiles and the temperatures. The results can also be compared with the theoretical calculations to get the desired accuracy and reliability of the result.

The finite volume method is a particular finite differencing numerical technique, and is the most common method for calculating flow in CFD codes. This section describes the basic method and procedures regarding the finite volume calculations. For this project, a fully developed laminar and turbulent incompressible fluid flow is to be simulated and analysed for the counter flow double pipe heat exchanger. The resulting temperature difference is to be compared with the finned inner tube with the same fluid properties and inlet temperatures. The meshing process also involves in creating and selecting parts of the body that is liquid and solid. Furthermore the meshing type for the whole body will is selected to be fine type so as to create more detailed meshing and thus more accurate solution. The selection of inlet and outlet faces for both outer and inner fluid is named for the purpose of selecting boundary conditions later in the simulation process. The meshing is done in Ansys Fluent and can be seen below:

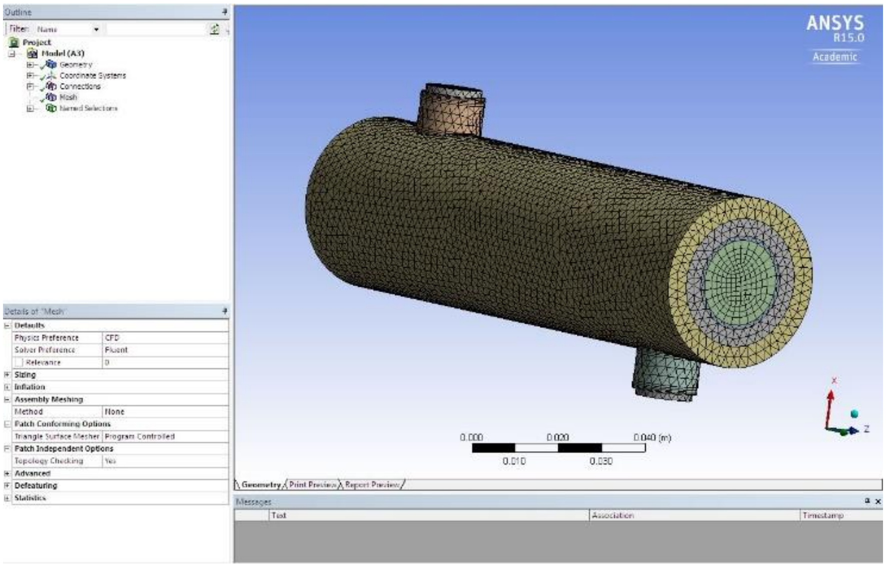

Figure 10: Meshing Process in Ansys Fluent

The finite volume method is a method where it creates a system of algebraic equations through the process of discretising the governing equations. The meshing of the geometry creates points or nodes in order to solve this equations either mass, temperature or energy in each points along the body. But before doing so, the material properties is to be selected and also the boundary conditions of inlet and outlet points must be set according to the numerical calculations such as the inlet temperatures and the velocities of fluids. The material for the pipe wall is to be slected also which are copper for the inner tube and PVC for outer tube for minimum heat loss to surrounding. The setup of materials done in Ansys is illustrated as shown:

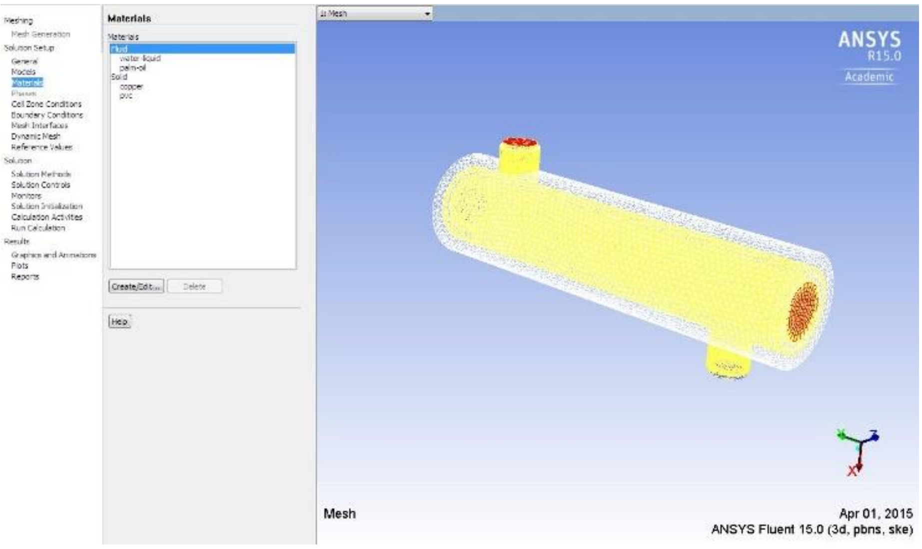

Figure 11: Setup Properties and boundary conditions in Ansys Fluent

After the specification of the boundary conditions, the initialization and the solution controls must be given before can start the iteration. Thus the next step is to obtain the solution after the 650 iteration is done. The solutions will be discussed in the Results and Discussion chapter.

3.5 PROJECT DELIVERABLES

Project deliverables is what can be achieve from the project. Thus, a clear list of the project deliverables is as listed below:

1. Design of the model and the tube of the Double Pipe Heat Exchanger for both the finless inner tube and the finned inner tube.
2. Theoretical calculation for the Double Pipe Heat Exchanger. Collecting the required information regarding the fluids used which are water for the cold outer shell and palm oil for the hot inner tubes.
3. Analyse of both models using ANSYS simulation and get the required data such as heat transfer profiles and rates as well as the outlet temperatures for both fluids.
4. Comparing the results for both models from the simulation and find the effectiveness. Results can also be compared from theoretical calculations for finding the result accuracy of the model.

3.6 PROJECT DOCUMENTATION

Project work documentations are to be submitted throughout the final year semesters. Below are the documents that are to be submitted throughout the course of this project;

1. Extended Proposal *(submitted 6th July 2014)*
2. Interim Report *(to be submitted in week 14 of FYP 1)*
3. Progress Report *(to be submitted in week 7 of FYP 2)*
4. Final Report (draft) *(to be submitted in week 11 of FYP 2)*
5. Dissertation *(to be submitted in week 12 of FYP 2)*
6. Technical Paper *(to be submitted in week 12 of FYP 2)*

CHAPTER 4: RESULTS AND DISCUSSION

The solutions can be obtained after the 650 iterations had been done for both types of heat exchanger designs. The data obtained and the observations from the CFD simulations using Ansys Fluent software is discussed below for the given selected boundary conditions. The contours and graphs obtained from the simulations are divided into their respective heat exchangers which are the finless and the finned inner tube. The temperature contours for the temperatures for the finless and the finned inner tube is shown below:

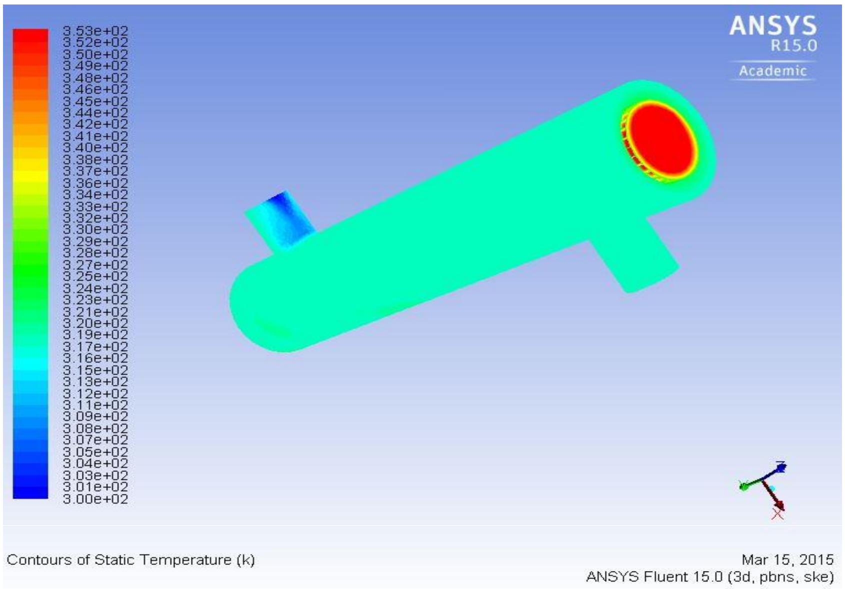

Figure 12: Finless inner tube temperature profile

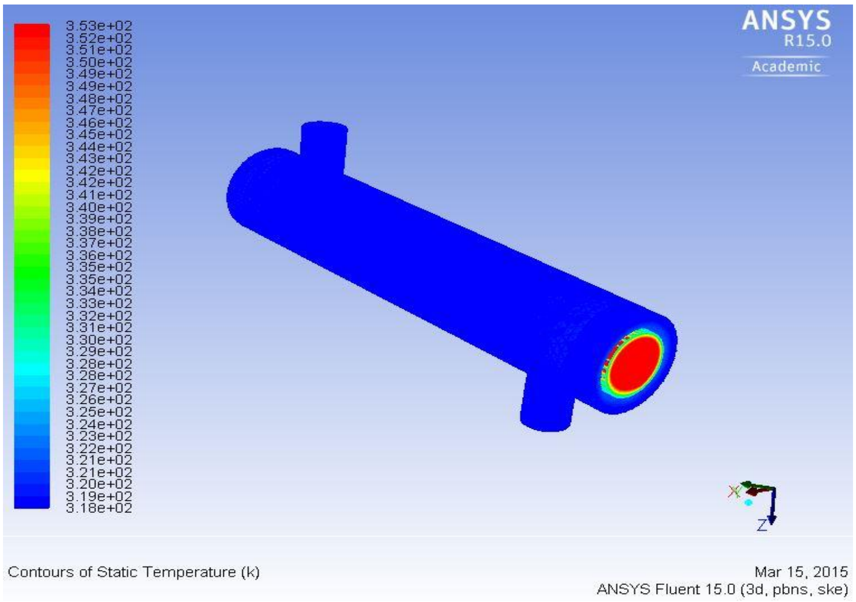

Figure 13: Finned inner tube temperature profile

The difference in the temperature profiles for the heat exchangers can be seen. The finless inner tube provides in overall higher in temperature along the outer fluid which is the water compared to the finned type. The darker blue colour for the outer fluid in the finned inner tube heat exchanger shows that the temperature is lower. The graph for the inlet and outlet temperatures for the inner fluid and outer fluid as well as temperature along the tube can be shown below:

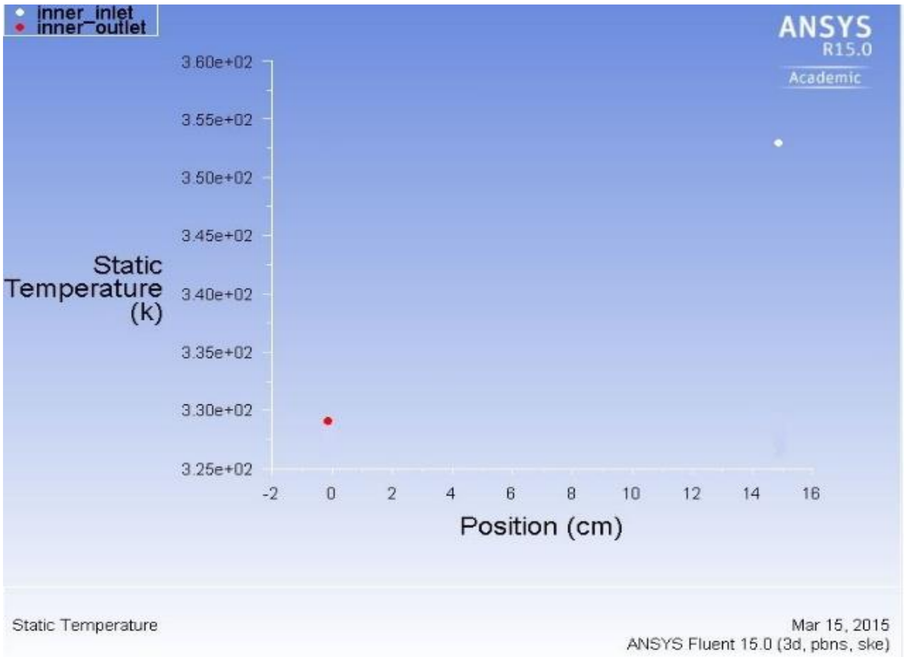

Figure 14: Finless tube inner fluid inlet/outlet temperatures

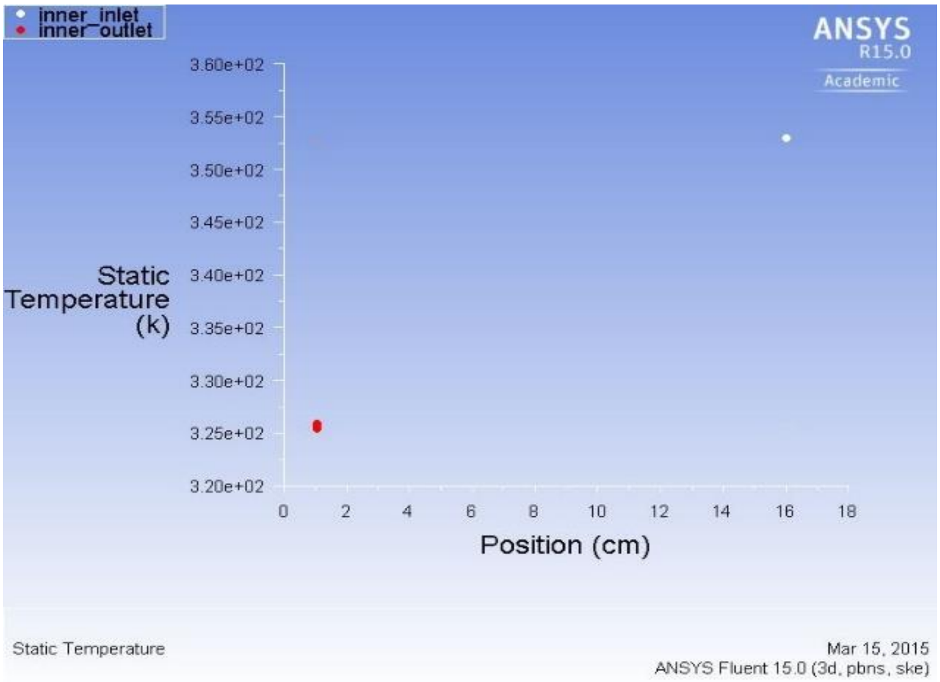

Figure 15: Finned tube inner fluid inlet/outlet temperatures

From the graphs shown for the inlet and outlet temperatures for the inner fluid which is the hot palm oil (working fluid), it can be pointed out that the outlet temperature for the finned inner tube have a slight decrease compared to the finless inner tube. The initial temperature of the inlet is the same which is 80°C because that is the starting parameter provided when doing the simulation. The outlet temperature that had been calculated for the finless inner tube is $T_{h,out}$= 46.4°C or 319.4K. The simulated finless tube outlet temperature for inner fluid is around 329K which corresponds to about a difference of 9.6K which is an acceptable range. The simulated results for the finned side however is about 326K which is closer to the numerical calculation temperature. This temperature is also lower than the finless simulated outlet temperature which is the desired objective of this simulation. The simulation shows that the finned inner tube have a significant increase in performing heat transfer because of the fin geometry that provides more heat transfer surface area. This in turn let the inner fluid to have better heat transfer and thus make the simulation results close to the theoretical calculations. Next is the inlet and outlet temperature profiles for the outer fluids which is water is as shown:

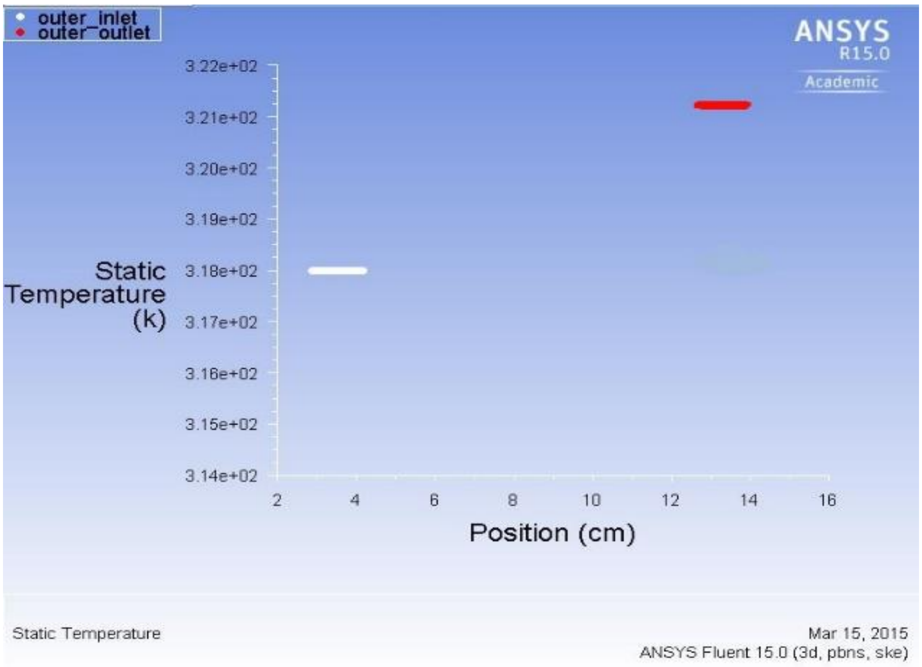

Figure 16: Finless tube outer fluid inlet/outlet temperature

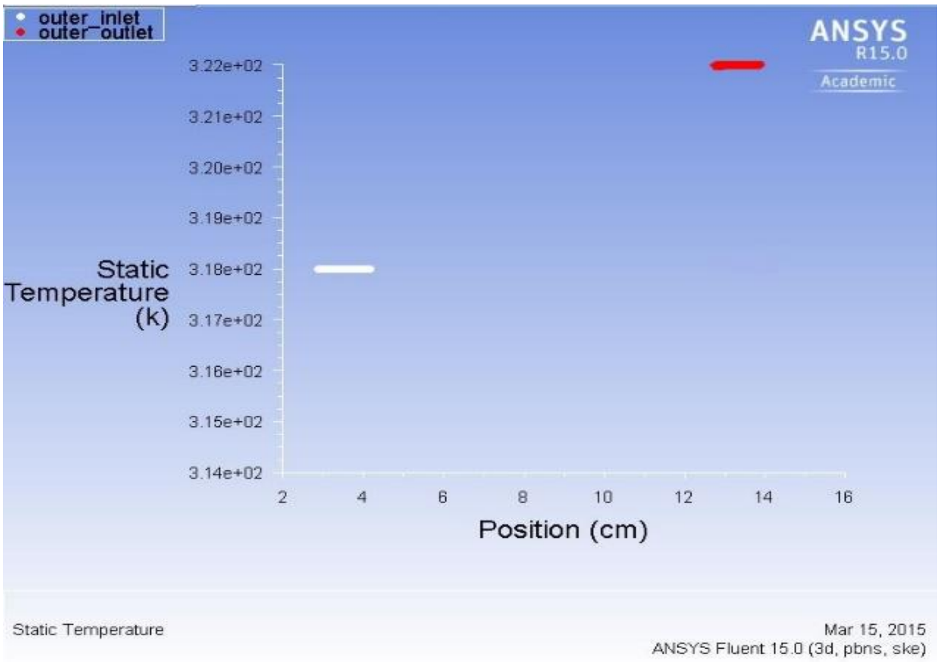

Figure 17: Finned tube outer fluid inlet/outlet temperature

From the graphs shown, the outer fluid (water) inlet and outlet temperature is seen to be higher when added fins compared to the finless inner tube one. The initial temperature for both designs are the same which is 45°C because it is the provided inlet temperatures provided for doing simulations. The outlet temperature that had been calculated for the outer fluid is $T_{c,out} = 55.14°C$ or 328.14K. The finless inner tube simulated results for the outlet temperature of outer fluid is around 321K which corresponds to about 6.14K difference which is an acceptable range. However, the simulated results for the finned tube is about 322K which is relatively close to the numerical calculation compared to the finless inner tube. This shows that the addition of fins would also have positive improvements towards the heat transfer of both hot and cold fluid sides. This is due to the extended surface provided by the fins that helps in the heat transfer process. This extended surface provides a larger surface area and thus increase in heat transfer between those fluids. Both simulation data for the inner and outer fluid shows promising results although it has few errors probably due to the design and simulation software in use. Furthermore, the numerical calculations are only theoretical and acts as the maximum possible heat transfer of those fluids. Thus, the amount of difference in temperature when doing simulation is expected to be happened and accepted because it is within acceptable range.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

After reading and obtaining information from various sources, the double pipe heat exchanger is a type of heat exchanger that is the most simple. However, basic concepts of heat transfer must be thoroughly understood in order to design the required optimum double pipe heat exchanger with various type of liquid streams. The performance and the CFD analysis of the double pipe heat exchanger for the finned and finless inner tube were investigated. The variable involves are the design of the inner tube to be taking into consideration which are the fins attached to the outer wall of the inner tube to enhance the heat transfer. Other parameters such as inner fluid (palm oil) and outer fluid (water) is used as a constant parameter taking the properties of fluids at 80°C and 45°C respectively. The conclusions of this project can be summarised as follows:

- The main objective is to study and analyse the fluid flow in the double pipe heat exchangers for finless and finned inner tube design
- In order to do the analysis, the Ansys Fluent finite volume analysis program was used to perform the simulation calculations.
- Before doing analysis, the model was design using a 3D modelling software which is Solidworks. Both models which are finless and finned inner tube double pipe heat exchanger is imported to Ansys software for simulation process.

- The temperature profiles for outlet for both inner and outer fluids were obtained from the simulations for both finless and finned inner tube. It is found that for the finless double pipe heat exchanger, the outlet temperature for inner fluid is 329K compared to the finned which is 326K. The finned results were shown to have closer value to the numerical calculations which is 319.4K. The values for outlet temperatures for outer fluid for finless type is 321K and for the finned is about 322K. The finned design again shows a closer value to the numerical calculation which is 328.14K.
- The Ansys results for both types are found to be fairly within 5% of the numerical calculation values.
- This finding provides some understanding of the counter flow double pipe heat exchanger enhancements at the inner tubes which is using fins.
- Some recommendations for improvements of the simulation is to use more various flowrates for each fluids in order to find better heat transfer profiles along the tubes.
- Since the author is limited in time frame of the project, it is recommended for this type of simulation to be done more thoroughly and more precise. Furthermore, the author have limited knowledge on Ansys Fluent and thus it is recommended to find more efficient ways to do simulation.

To conclude, in order to improve the overall heat transfer coefficient heat transfer rates of the heat exchanger, there is various methods to enhance it such as using enhanced surface, finning the tubes or even add tube inserts such as turbulators to the heat exchanger. It can be concluded for this project that adding fins to the outer wall of the inner tube will have some positive impact towards the heat exchanger performance and heat transfer of fluids.

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