Development of Heat Exchangers Design Tool

by

Arif Zaki Bin Ariffin

Dissertation Submitted to the Mechanical Engineering Programme

in Partial Fulfilment of the Requirements

for the Degree

Bachelor of Engineering (Hons)

(Mechanical Engineering)

SEPTEMBER 2012

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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SEPTEMBER 2012

CERTIFICATION OF ORIGINALITY

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

ARIF ZAKI BIN ARIFFIN

ABSTRACT

The main purpose of heat exchanger is to control a system's or substance's temperature either by adding or removing thermal energy. Suitable heat exchanger is essential as it can help in decreasing the operating cost and keep the efficiency of the system at the highest level possible. As there are many types of heat exchanger, a design selection tool is essential to predict and compare the performance for each type of heat exchanger. Focusing on three types of heat exchanger, Shell and Tube heat exchange, Plate Fin heat exchanger and Finned Tube heat exchanger, this project is intended to develop a tool for a design selection of heat exchanger. The developed tool worked base on four main steps. The first step in using the tool, user is required to key in the thermal properties of the system. The next step required user to key in the physical properties of the heat exchanger. With the availability of the thermal and physical properties, the tool will then calculate the performance of the heat exchanger in the third stage. Lastly, the performance of each heat exchanger will be represented graphically as to ease user to do comparison and analysis of the performance of each heat exchanger. The tool was developed using Microsoft Excel and base on the fundamental of heat transfer concepts. The performance of the heat exchanger is defined by three main elements which are heat transfer coefficient, pressure drop and effectiveness.

This report consists of four main part including introduction, problem statement, objective, literature review, methodology used in developing the standard designing tool, result and discussion and conclusion and recommendation.

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in his will and given strength, I managed to complete this Final Year Project for the Mechanical Engineering Department, Universiti Teknologi PETRONAS.

A lot has transpired during the study and I am indebt with so many people who has made this course an illuminating and enriching venture. My deepest gratitude goes to my supervisor, AP. Dr Zainal Ambri bin Abdul Karim for guiding me through this course thoroughly and giving me all the support to finish this study. Not to forget my colleague for helping and giving continuous support towards this course.

Last but not least, to all that help me directly or indirectly helped me out in completing this study.

Thank you.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Many engineering applications are related to the process of heat exchange between two fluids that are at different temperature and separated by a solid wall. The instrument used to execute the exchange process is known as heat exchanger. Heat exchangers with specific application are widely used in space heating and air conditioning, power production, waste heat recovery and chemical processing [1]. For this project, three types of heat exchanger had been selected, Shell and Tube Heat Exchanger, Plate Fin Heat Exchanger and Finned Tube Heat Exchanger.

1.1.1 Shell and Tube Heat Exchanger

Shell and tube heat exchanger consist of a series of tubes. The fluid that is going to be cool down or heat up will flow in one set of tubes. Second type of fluid will runs over the so that it can absorb or provide the heat required accordingly. The basic components of a shell and tube heat exchanger can be interprets as in Figure 1.1.

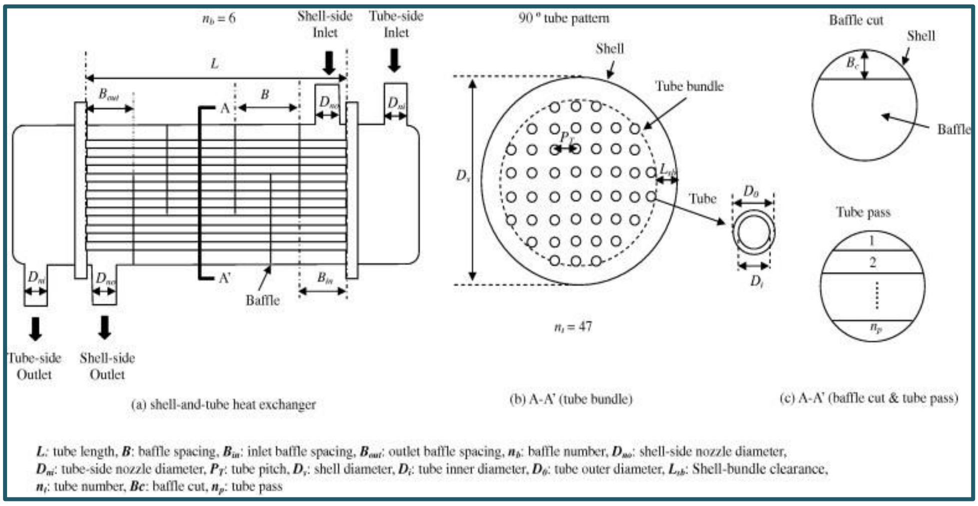


Figure 1.1: Typical Shell and Tube Heat Exchanger components [2].

In general, Shell and tube heat exchanger are the most common heat exchanger selected for the transfer of heat in industrial process applications especially in oil refineries and other large chemical process [3] [4]. This is due to the resistance toward higher pressure occurring in the heat exchanger [3]. Apart from that, shell and tube heat exchanger have the ability to transfer large amounts of heat in relative low cost and serviceable design [3]. Shell and tube heat exchanger's duties include [4]:

i. Process liquid or gas cooling
ii. Process or refrigerant vapor or steam condensing
iii. Process liquid, steam or refrigerant evaporation
iv. Process heat removal and preheating of feed water
v. Thermal energy conservation efforts, heat recovery
vi. Compressor turbine and engine cooling, oil and jacket water
vii. Hydraulic and lube oil cooling
viii. Many other industrial applications

1.1.2 Plate Fin Heat Exchanger

A plate fin heat exchanger is a form of compact heat exchanger consisting of a block of alternating layers of corrugated fins and flat separators. The basic components of a plate fin heat exchanger can be interprets as in Figure 1.2.

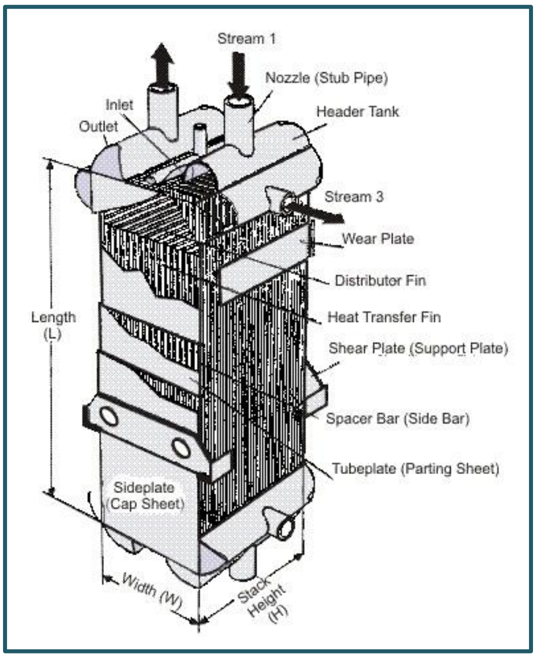


Figure 1.2: Typical Plate Fin Heat Exchanger [5].

Plate fin heat exchangers are widely used in aerospace, military and other high performance applications. This is because plate fin heat exchanger offer excellent thermal transfer capacity combined with small size and weight. Some of the typical applications include [6]:

i. Separation of air gases
ii. Hydrocarbon processing
iii. Natural gas liquefaction
iv. Industrial gas liquefaction (oxygen, nitrogen, argon, etc.)

1.1.3 Finned Tube Heat Exchanger

Define by the name, the tube for this type of heat exchanger are equip with extended outer surface. The extended surfaces are to enhance the heat transfer rate by increasing the effective heat transfer area between the tubes and surrounding fluid. Various finned tube surface configuration are as shown in Figure 1.3.

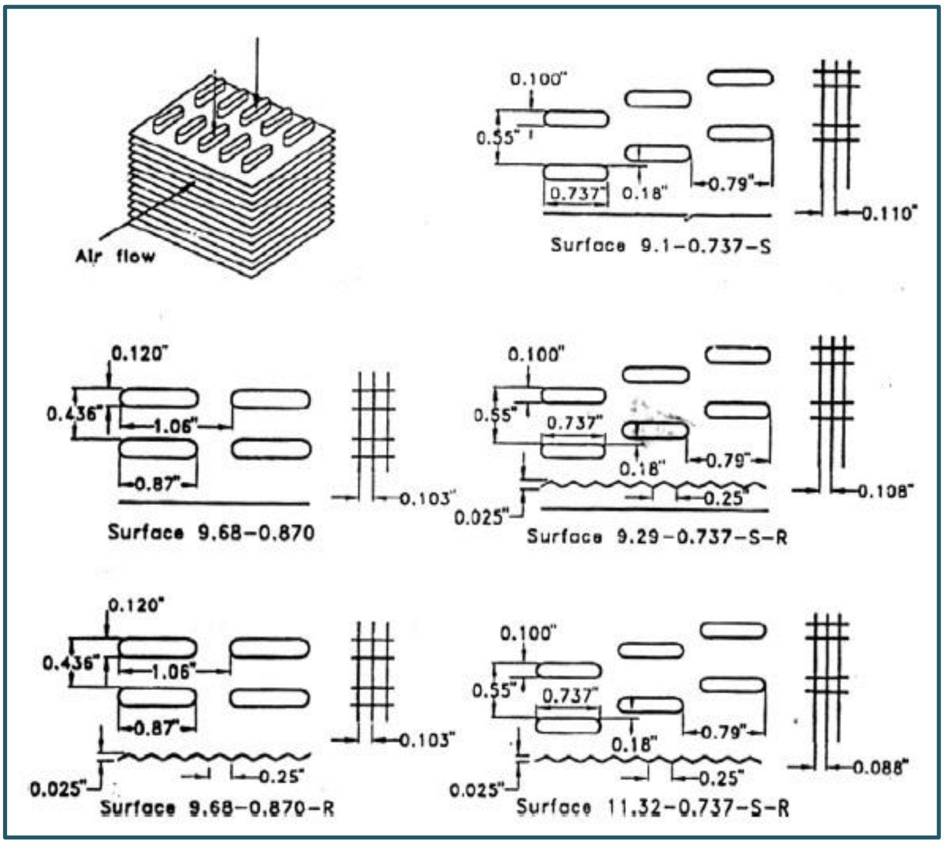


Figure 1.3 : Various finned tube surface configuration [6].

Some of the application for finned tube heat exchanger is in commercial application and as dryers for pharma equipments such as fluid bed, tray dryers and many more. Other than that, finned tube heat exchanger also suitbale to be used for air heating in process houses for drying food product or for air cooler in pneumatic conveying systems.

1.1.4 Advantages and Disadvantages for each type of heat exchanger

Table 1.1 : The advantages and disadvantages for Compact Heat Exchanger and Shell and Tube Heat Exchanger [7]

Compact Heat Exchanger	Shell and Tube Heat Exchanger
Advantages	
1) Low initial purchase cost (plate type) 2) Many different configurations are available (gasket, semi-welded, welded, spiral) 3) High heat transfer coefficients (3 or more times greater than for shell & tube heat exchangers, due to much higher wall shear stress) 4) Tend to exhibit lower fouling characteristics due to the high turbulence within the exchanger	1) Widely known and understood since it is the most common type 2) Most versatile in terms of types of service 3) Widest range of allowable design pressures and temperatures 4) Rugged mechanical construction - can withstand more abuse (physical and process)
Disadvantages	
1) Narrower range of allowable pressures and temperatures 2) Subject to plugging/fouling due to very narrow flow path 3) Gasket units require specialized opening and closing procedures 4) Material of construction selection is critical since wall thickness very thin (typically less than 10 mm)	1) Less thermally efficient than other types of heat transfer equipment 2) Subject to flow induced vibration which Can lead to equipment failure 3) Not well suited for temperature cross conditions (multiple units in series must be used) 4) Contains stagnant zones (dead zones) on the shell side which can lead to corrosion problems

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Currently, there are very limited tools that able to predict the performance of heat exchanger. Also there are still no tools that able to provide and compare many types of heat exchanger in one tool. Hence the main purpose of this project is to develop a tool for designing selection of heat exchanger. The tool developed able to demonstrate the performance of plate fin heat exchanger, finned tube heat exchanger and shell and tube heat exchanger in one tool.

1.2.2 Significant of Project

The graphical outcome of the tool provide user a better understanding on the performance of the heat exchanger as they analyze the outcome from the tool. The generated graph offer opportunity to user to easily compare and analyze the performance of each type of heat exchanger in making selection of heat exchanger.

1.3 OBJECTIVE AND SCOPE OF THE PROJECT

1.3.1 Objective

The objective of this project is to:

1. To identify the controlling parameters of the heat exchanger.
2. To analyze the parameter of three types heat exchangers.
3. To develop a tool for design selection of heat exchanger using Microsoft Excel.

1.3.2 Scope of the project

This project is closely related to designing the heat exchanger. Hence it involved the studied on fundamental and characteristic for each type of heat exchanger. The design selection tool was developed base on the interpretation of the understanding regarding the concept of designing for each type of heat exchanger.

This project is divided into two parts namely Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2). All the properties and equations related in designing the heat exchanger have been defined in the first stage of the project which is in the FYP 1. All the important parameters for the heat exchanger that have been determined include the thermal properties of the fluids and the physical properties that contribute to the performance of the heat exchanger. The performances of the heat exchanger are defined by heat transfer coefficient, pressure drop and effectiveness of the heat exchanger.

The heat exchanger design tool has been developed in the next stage of the project which is in FYP 2. Upon completion, the tool was put on test with a case study. The case study required the heat exchanger to cool down high temperature air by using chilled water.

The tool was developed as to cater three types of heat exchanger which are plate fin heat exchanger, finned tube heat exchanger and shell and tube heat exchanger.

CHAPTER 2

LITERATURE REVIEW

There are many types of heat exchanger available in the market. It is important to select the most suitable heat exchanger to be implied to the system. The compatibility of heat exchanger will affect the efficiency of the system. In every system, it is always the best to go for the optimum of the system as this will not only able to prolong the life of the system, it will also reduce the cost of operation and maintenance of the system.

There are a lot of factors needed to be taken into account in choosing the suitable heat exchanger. It is crucial to determine which type of heat exchanger to be used in the system as early as at the designing stage.

2.1 Basic Concept of Heat Transfer

In calculating any heat transfer, the overall energy balance and the equation is taken into account [8].

$$Q = \dot{m}_{hot} C_{p,hot}\left(T_{hot,in} - T_{hot,out}\right) = \dot{m}_{cold} C_{p,cold}\left(T_{cold,out} - T_{cold,in}\right)$$

$$Q = UAF\Delta T_{lm}$$

Where $F = Correction\ Factor$

$\Delta T_{lm} = Log\ Mean\ Temperature\ Different$

$A = Total\ heat\ transfer\ area$

$U = Overall\ heat\ transfer\ coefficient$

2.2 Shell and Tube Heat Exchanger

There are several factors that will influence the shell side heat transfer coefficient that in turn will determine the rate of heat transfer in the shell side [9]. Those factors are:

1. In the present of baffles, the shell's fluid flow will be redirected from axial flow to top-to-bottom flow or side-to-side flow. These changes in direction will increase the heat transfer coefficient compared to the undisturbed flow along the axes of the tubes.
2. Patterns of tube layout influence turbulence and hence heat transfer coefficient e.g. triangular pitch gives greater turbulence than square pitch. And under comparable conditions of flow and tube size the heat transfer coefficient for triangular pitch are roughly 25% greater than for square pitch.
3. The smaller the spacing between baffle, the number of times the shell-fluid change its direction will also increase, resulting in greater turbulence.
4. Tube size, clearance and fluid-flow characteristics will also affect the shell side coefficient.
5. There is no true shell side flow area where the mass velocity of the shell fluid can be computed. This is due to varies flow area across the bundle diameter with different number of tube clearances in each longitudinal row of tubes.
6. The correlation obtained for fluids flowing in tubes is obviously not applicable to fluids flowing over the tube.
7. There are particularly several terms used in heat exchanger specification problems and one of the terms is “Rating”. The term “Rating” defined the computational process in which the inlet flow rate and temperatures, the fluid properties and the heat exchanger parameters are taken as input and the outlet temperature and thermal duty or the required length of the heat exchanger are calculated as output.

The initial conditions which are the thermal properties of the heat exchanger were determined in the first step. These initial conditions include flow rate of fluids, temperature range of the fluids and length and arrangement of tubes [9].

Basically the next stage involved in calculation of physical properties of the heat exchanger. First is the calculation of total number of tubes. The next calculation is to calculate and check the heat load for U-Tube. For this part of calculation, there are two set of calculation involve namely calculation of tube side heat transfer coefficient and calculation of shell side heat transfer coefficient. Last but not least is the calculation and checking of pressure drop [9].

The performance of a heat exchanger can be determined by four properties namely number of tubes and shell diameter, heat transfer rate, overall heat transfer coefficient and tube and shell side pressure drop [9].

To demonstrate the above calculation Than et al. [9] in a case study has come out with few findings

1. Reynolds Number in tube and Heat Transfer Coefficient in tube vs. Number of Tubes.

   Reynolds Number and Heat Transfer Coefficient are gradually decreased corresponding to a high number of Tubes. This is due to a high velocity of the fluid with a constant mass flow rate.

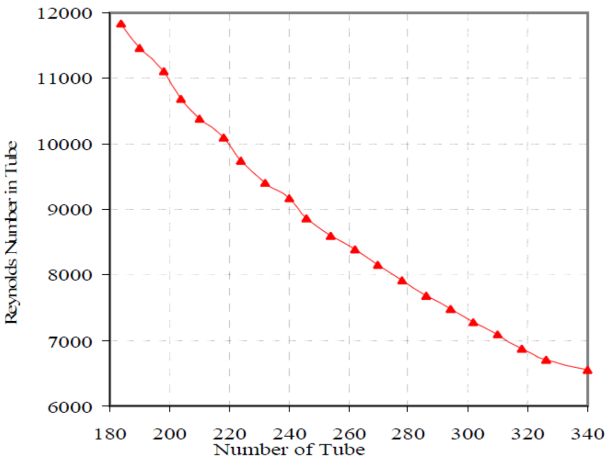


Figure 2.1: Effect of Reynolds Number on Number of Tubes [9].

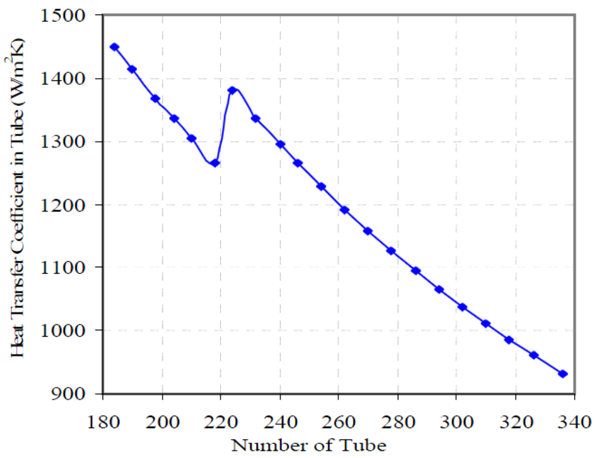


Figure 2.2: Effect of Heat Transfer Coefficient on Number of Tubes [9].

Between total number of tube 220 and 240, there are slight rise in heat transfer coefficient because of changing from turbulent flow to transition flow.

2. Reynolds Number in Shell and Heat Transfer Coefficient in shell vs. Length of Tube.

The decreasing pattern of curves of Reynolds Number *(Re)* and heat transfer coefficient *(h)* shown in the graph shows that the Re and h are gradually decreased corresponding as high as Tube Effective Length *(L)*. However, this graph also describes, due to Number of Baffles increase, Reynolds Number increase.

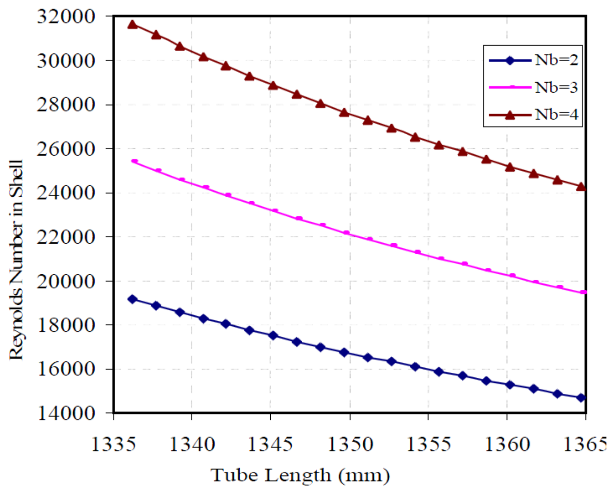


Figure 2.3: A fact of Reynolds Number on Number of Baffles and Length of Tube [9].

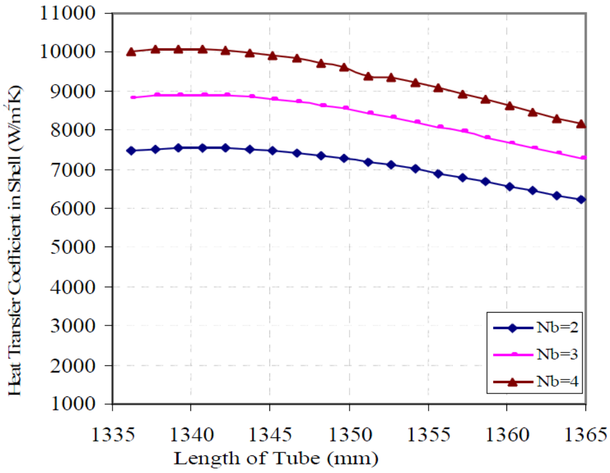


Figure 2.4: Effect of Heat Transfer Coefficient on Number of Baffles and Length of Tube [9].

3. Heat Load vs. Shell Diameter

Between shell diameter 320m and 330m, there are also a slight rise in heat transfer coefficient because of changing from turbulent flow to transition flow. The variations of the affects are as plotted in the graph below.

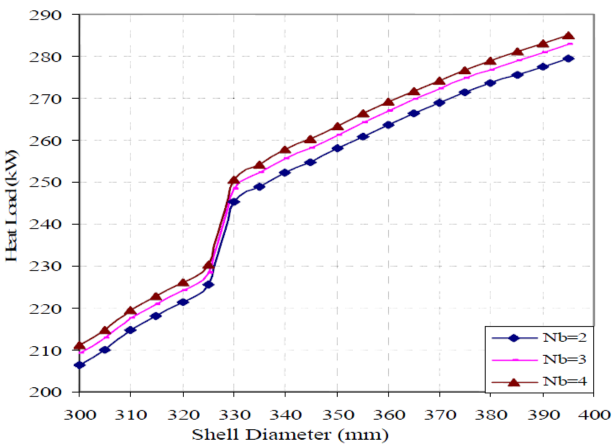


Figure 2.5: Effect of Heat Load on Shell Diameter [9].

2.3 Plate Fin Heat Exchanger

In the designing plate fin heat exchanger, the smallest units in terms of weight, volume and within the restrictions of reasonable block dimensions are always favor [1]. In producing the smallest unit, the heat exchanger must satisfy the requirement

within the specified pressure drop constrains. Smaller exchanger volumes are obtained by using surfaces that exhibit “high performance” [10].
It is important to specify the surface that will produce the unit of smallest weight or volume in the early stage of designing the plate fin heat exchanger. This surface selection can be done with the aid of performance index [11]. Performance concept is developed based on tubular exchangers where the surface area of the unit gives a clear idea of the actual size of the exchanger.

However in the case of plate-fin heat exchanger, it is the actual exchanger volume that gives a clearer indication of the actual dimension of the unit. A similar approach will be used to derive a volume performance index (VPI) [10]. The higher the VPI, the smaller the volume of the exchanger and vice versa. By plotting together the VPI for all surfaces of the same type over the Re number for which data is available, an envelope for the best surface performance can be determine. This envelope will directly indicate the particular surface that best performs in any specific Re number interval [10].

The performance of a plate fin heat exchanger is also affected by the fin geometry [8]. The three most common fin configurations are:

i. Plain fin with rectangular, trapezoidal or triangular passages
ii. Uninterrupted wavy fins
iii. Interrupted fins (offset strip, louvered, perforated and pin fin)

There are a lot if study has been conducted to analyze the heat transfer and pressure drop characteristic of plate fin heat exchanger focusing on the Off Set Fins (OSF) type of plate fin heat exchanger. This is why emphasis has been given on the prediction of j and f factor and thermal performance testing of heat exchanger [12].

Patankar and Prakash [13] presented a two dimensional analysis for the flow and heat transfer in an interrupted plate passage which is an idealization of the OSFs heat exchanger. The main objective of the study is to investigate the effect of plate thickness in a non dimensional form $t/_H$ on heat transfer and pressure drop in OSF channels. Their calculation method was based on the periodically fully developed flow through one periodic module. They used the constant heat flow boundary condition with each row of fins at fixed temperature. They made their analysis for different fin thickness ratios t/H= 0, 0.1, 0.2, 0.3 for the same fin length L/H = 1, and they fixed the Prandtl number of fluid = 0.7. For proper validation they compared there numerical results with the experimental results of London and Shah for offset strip fin heat exchangers. The result indicates reasonable agreement for the f factors, but the predicted j factors are twice as large as the experimental data. They concluded that the thick plate situation leads to significantly higher pressure drop while the heat transfer does not sufficiently improve despite the increased surface area and increased mean velocity.

H. Bhowmik and Kwan-Soo Lee [21] studied the heat transfer and pressure drop characteristics of an offset strip fin heat exchanger. For their study they used a steady state three dimensional numerical model. They have taken water as the heat transfer medium, and the Reynolds number (Re) in the range of 10 to 3500. Variations in the Fanning friction factor f and the Colburn heat transfer j relative to Reynolds number were observed. General correlations for the f and j factors were derived by them which could be used to analyze fluid flow and heat transfer Characteristics of offset strip fins in the laminar, transition, and turbulent regions of the flow.

Dong et al. [15] have done a study to include the effect of manufacturing irregularities such as burred edges, bounding imperfections and separating plate roughness. The purpose of the study is to get better thermal and hydraulic performance from the OSFs. Sixteen types of OSFs and flat tube heat exchangers were used in the experimental studies on heat transfer and pressure drop characteristics. A number of tests were made by changing the various fin parameters and all the tests were carried out in specific region of air side Reynolds number (500- 7500), at a constant water flow crate. Results showed that the heat transfer coefficient and pressure drop reduce with enlarging the fin space, fin height and fin length.

2.4 Finned Tube Heat Exchanger

A cross flow pattern form when a high pressure fluid passes through finned tube and the low pressure cold gas passes over the tube [15]. Therefore it increases the cross flow heat transfer coefficient on the shell side and provides high overall effectiveness of counter flow.

The performance in terms of thermal and pressure drop in heat exchanger is influenced by the clearances between shell and tube periphery. If there is part of the cold steam passes through the clearances without taking part in heat exchange process, it will know as ineffective part of heat exchanger. However the pressure drop performance will be increase by increasing the available cross-section area [15].

In designing process, thermal and pressure drop are the main concern. The overall heat transfer coefficient will be based on axial length of the heat exchanger instead of the heat transfer area of either fluid by applying the concept of wetted parameter of heat exchanger per unit axial length [15]. Pressure drop for the tube side, the friction factor for the turbulent flow inside a smooth tube of any crosses section was calculated by the empirical equation. For the shell side and tube side, the pressure drop is presented as dimensionless quantity and it is defined as follow [16] $\Delta P^* = \frac{\Delta P}{P_c}$. In analyzing a finned tube heat exchanger, two assumptions have to be made namely the pressure drops due to other effects are negligible in comparison to the core frictional pressure drop and all thermo physical properties have been calculated at the mean temperature of individual fluid stream [17].

In the analysis done by Gupta et al. [15] it is found that the effectiveness has increases by reducing the clearance. They concluded that the diametrical clearance between inner shell, finned surface and outer shell has to be chosen carefully. The thermal and pressure drop performance of the heat exchanger are effected significantly by the clearance.

The correction factor can be calculated with respect to the ideal finned tube bundle that is when clearance is zero. In the variation of mass flow rate, the pressure drop in shell and tube increase sharply but the sizing only increase by 15% [15].

The pressure drop is also affected by the number and diameter of the fins [14]. Lesser number of fins will lead to less pressure drop as finned tube will offer more cross-sectional area and reduce the flow velocity through the finned tube. Small diameter of the finned tube also will lead to a lower pressure drop.

Research has been done for each type of heat exchanger but still less research has been done in comparing different types of heat exchanger. It is such a tedious work to study and compare few types of heat exchanger every time information regarding the heat exchanger is needed.

Hence it is essential to have a tool that able to compare few types of heat exchanger. A tool that able to show the performance of the heat exchanger would come handy in this situation. The performances of heat exchanger are important in determining the most suitable type to be applied to a specific system.

The developed tool able to assist user to find the optimum specification of heat exchanger by allowing user to key in different input until desire outcome are achieve. Apart from that, the outputs of the tool can be use in determining which type of heat exchanger suitable for a given system by comparing the performance of each type of heat exchanger.

As a conclusion, this project is aimed to study and develop a tool to study and compare three types of heat exchanger namely plate fin heat exchanger, finned tube heat exchanger and shell and tube heat exchanger. The provided outcomes of the tool include the heat transfer coefficient, pressure drop and effectiveness for each type of the heat exchanger as the outcome.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The research done in this project is to gather knowledge in the field related to heat exchanger. The research done is aimed to determine the important characteristic and equation related to heat exchanger's design. Hence the researched done were focused on the designing stage of heat exchanger as that is where the design consideration and effects of design were put on study.

The performance of a heat exchanger is influence by the physical design. The size of the heat exchanger, number of tubes, area of heat transfer does contribute in the performance of the heat exchanger. Hence the important information and equations has been gathered from the reference books, journals and other sources such as the internet.

As mention earlier, the next stage of the project focused on developing the tool. By using Microsoft Excel, all the properties and characteristic were congregated to construct the tool.

3.1.1. Research Scope

In this project, three types of the most common heat exchanger have been selected. The tool developed for this project are based on the knowledge of the three types of heat exchanger which are plate fin heat exchanger, finned tube heat exchanger and shell and tube heat exchanger.

For each and every heat exchanger, the heat exchanger's operation are designed as to cater specific task, either to cool down or heat up a fluid with the aid of another fluid. For this project, the tool has been designed and tested for air cooled heat exchanger from chilled water system. The basic system of the heat exchanger is as illustrated as in FIGURE 3.1.

Table 3.1: Fluids properties for case study

Description	Air	Chilled Water
Inlet Temperature, $T_i(°C)$	24 - 36	7
Outlet Temperature, $T_o(°C)$	20	13
Mass Flow Rate, $\dot{m}(kg/s)$	1.665	Calculated

The aimed of the heat exchanger in this study is to cool down the air with inlet temperature range from 24□C to 36□C and cooled down to outlet temperature at 20□C. The hot air will be cooled down by chilled water. At initial, the temperature of the chill water will be at 7□C and at the end of the process, the outlet temperature of the chill water will be at most 13□C.

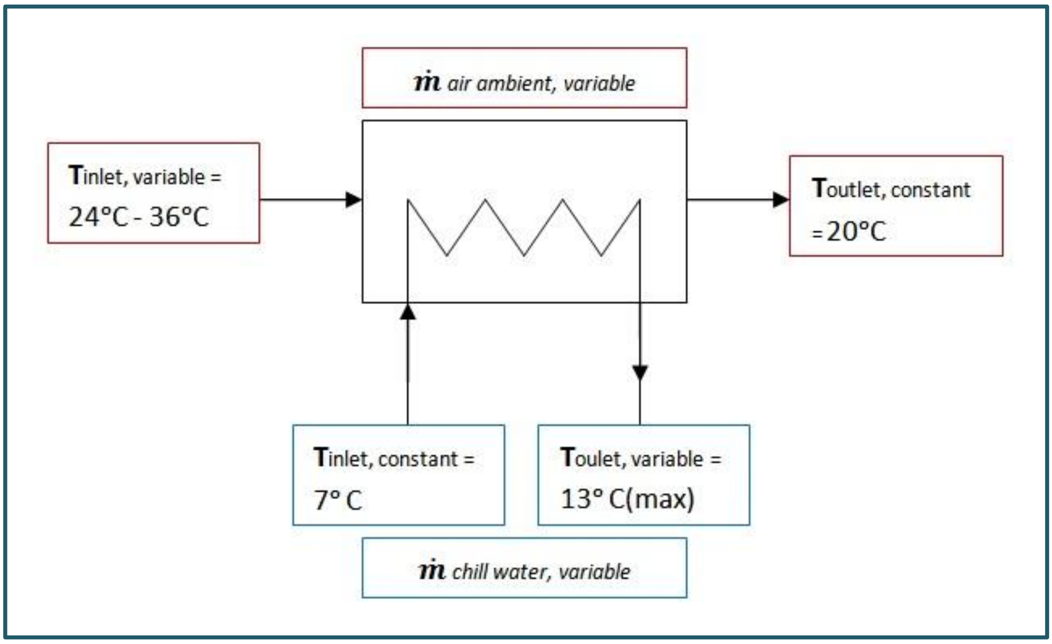
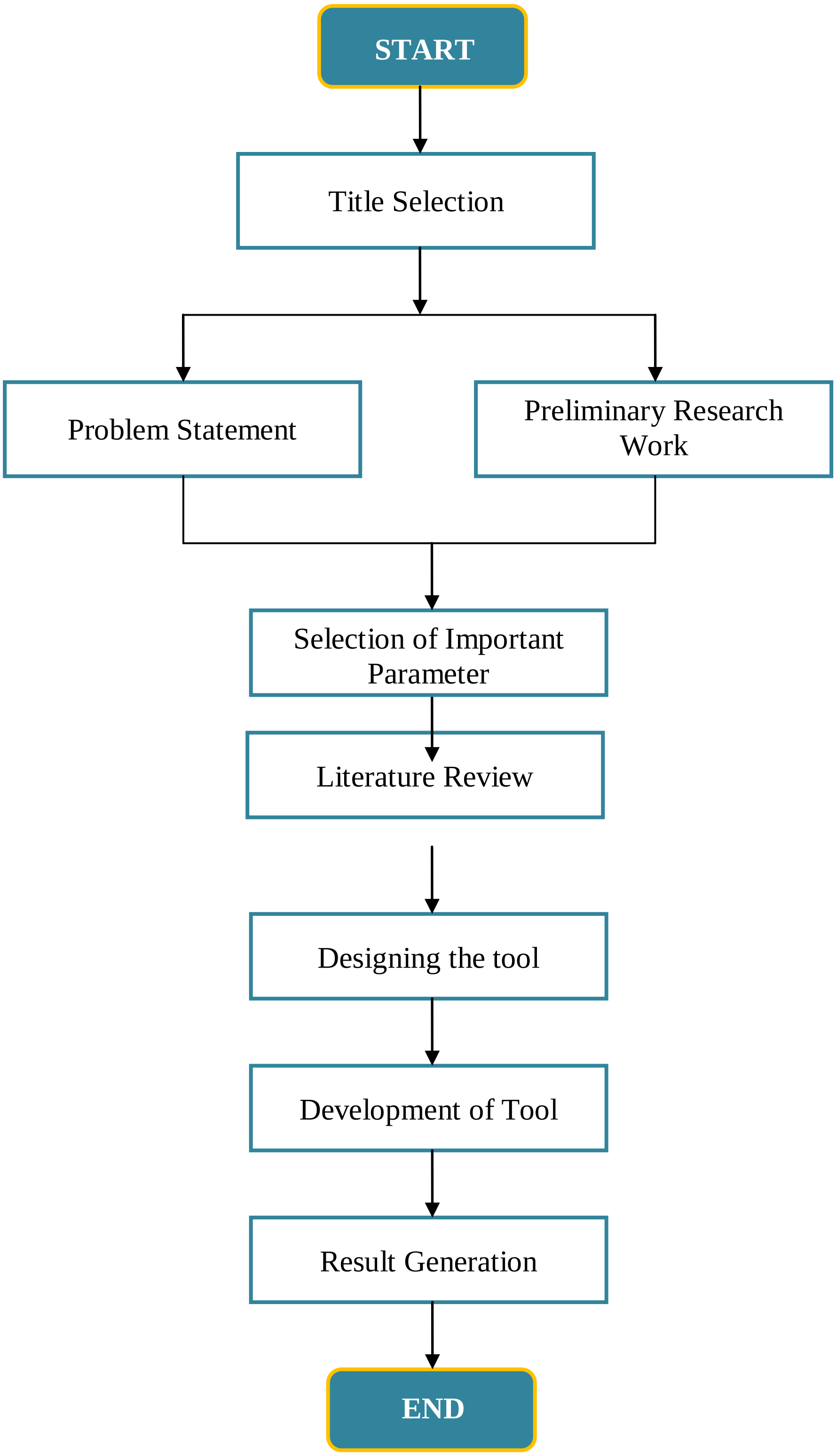


Figure 3.1: Air cooled heat exchanger from chilled water.

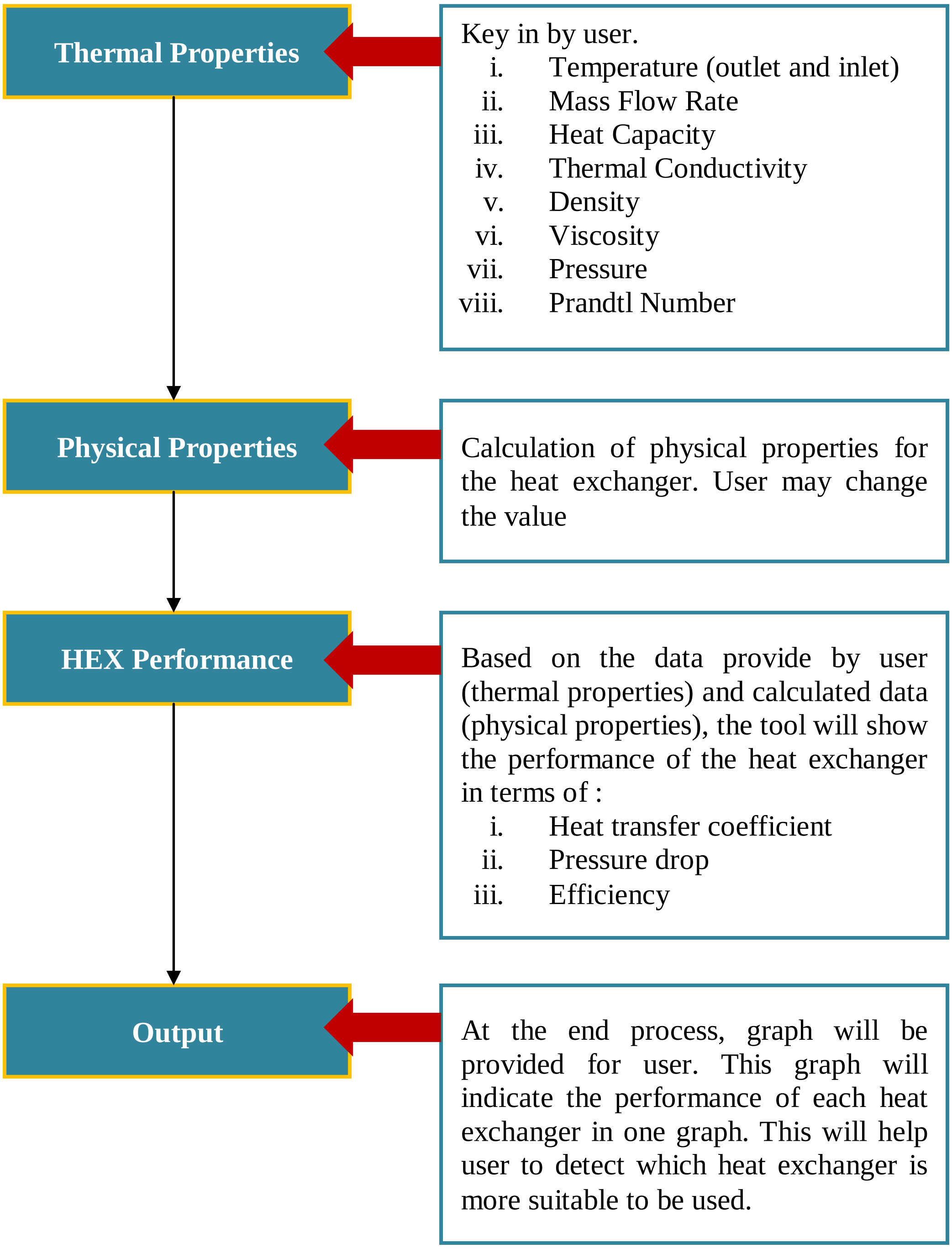
3.2 Tool Required

The design tool was developed using Microsoft Excel as it is more convenience and user friendly to the user. No specific knowledge need as to run the tool and obtain the outcome.

3.3 Project Flowchart



3.4 Work Flow of Tool (Flowchart)



3.5 Gantt Chart Final Year Project 1

No	Detail/Week	1	2	3	4	5	6	Mid Semester Break (7/02-11/02/2012)	7	8	9	10	11	12	13	14
1	Selection of Project Topic: DEVELOPMENT OF HEAT EXCHANGER DESIGN TOOL	■	■	■												
2	Preliminary Research Work: Research on literatures related to the topic		■	■	■	■										
3	Submission of Extended Proposal						■									
4	Project Work: Continue Research on related topic						■		■	■						
5	Proposal Defend										■					
6	Project work continues: Completing Interim Report										■	■	■	■	■	
7	Submission of Final Interim Report															■

3.6 Gantt Chart Final Year Project 2

No	Detail/Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Development of Selection Tool	■	■	■	■	■	■	Mid Semester Break (5/7-8/7/2012)	■	■						
2	Progress Report									■						
3	Tool Testing									■	■	■				
4	Poster Presentation											■				
5	Tool Improvement											■	■	■	■	
6	Dissertation Report (Draft)													■	■	
7	FYP 2 Viva															■

3.7 Key Milestone

Key milestone mark the end of each phase as the project work progress. It essentially monitors the project work progress and ensures the project is on schedule. The key milestone of the project is shown below.

Table 3.2: Final Year Project 1 key milestone.

No	Detail/Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Completion of Preliminary research work														
2	Submission of extended proposal **(28.2.2012)**														
3	Defense proposal presentation **(26.3.2012)**														
4	Submission of Interim report **(23.4.2012)**														

Table 3.3: Final Year Project 2 key milestone.

No	Detail/Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Development of tool														
2	Submission of progress report **(12.7.2012)**														
3	Submission of poster **(31.7.2012)**														
4	Submission of final report and technical paper • Technical paper **- 13.8.2012**														
5	Presentation • Poster - **31.7.2012** • Viva - **27.8.2012**														

3.8 The Assumptions

In developing the tool, it is crucial to identify the similarities among the three type of heat exchanger. Also, assumption need to be made as to standardize some of the properties involve. Hence in this section the similarities and assumption are stated as guidelines that are used to develop the tool for FYP 2.

1. Flow arrangement

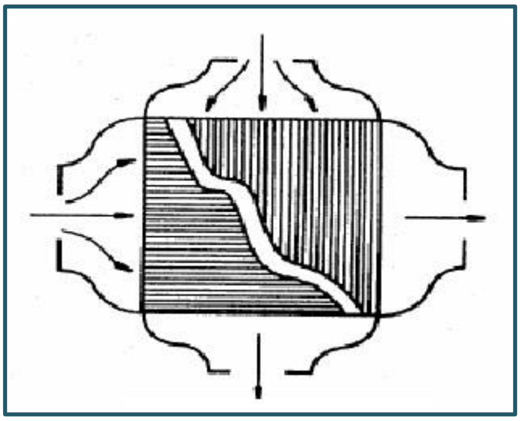


Figure 3.2: Example of cross flow in Plate Fin Heat Exchanger [2].

For all three types of heat exchanger, it is assume that the fluid flow inside the system is occurring in the form of cross flow. In a cross flow heat exchangers, usually only two streams are handled eliminating the need for distributors. The header tanks are located on all four sides of the heat exchanger core.

This arrangement is suitable for these situations:

- High effectiveness is not necessary
- The stream have large different in volume flow rate
- One or both of the stream are nearly isothermal

2. Fluid involve and material used

The tool that has been developed in FYP 2 is specifically build to serve two type of fluids, water and air. The heat exchanger is assumed to be made of Aluminum Bronzes as it is economically wise and high corrosion resistance.

3.9 Physical Properties and Performance of Heat Exchanger

The aim of this tool is to help user to select which type of heat exchanger to be used for the specified system. The tool should be able to determine the suitability of the heat exchanger towards the system. To calculate the performance of the heat exchanger the physical properties of each heat exchanger are determined as the first step.

3.9.1 The physical properties of heat exchanger

i. Plate fin heat exchanger

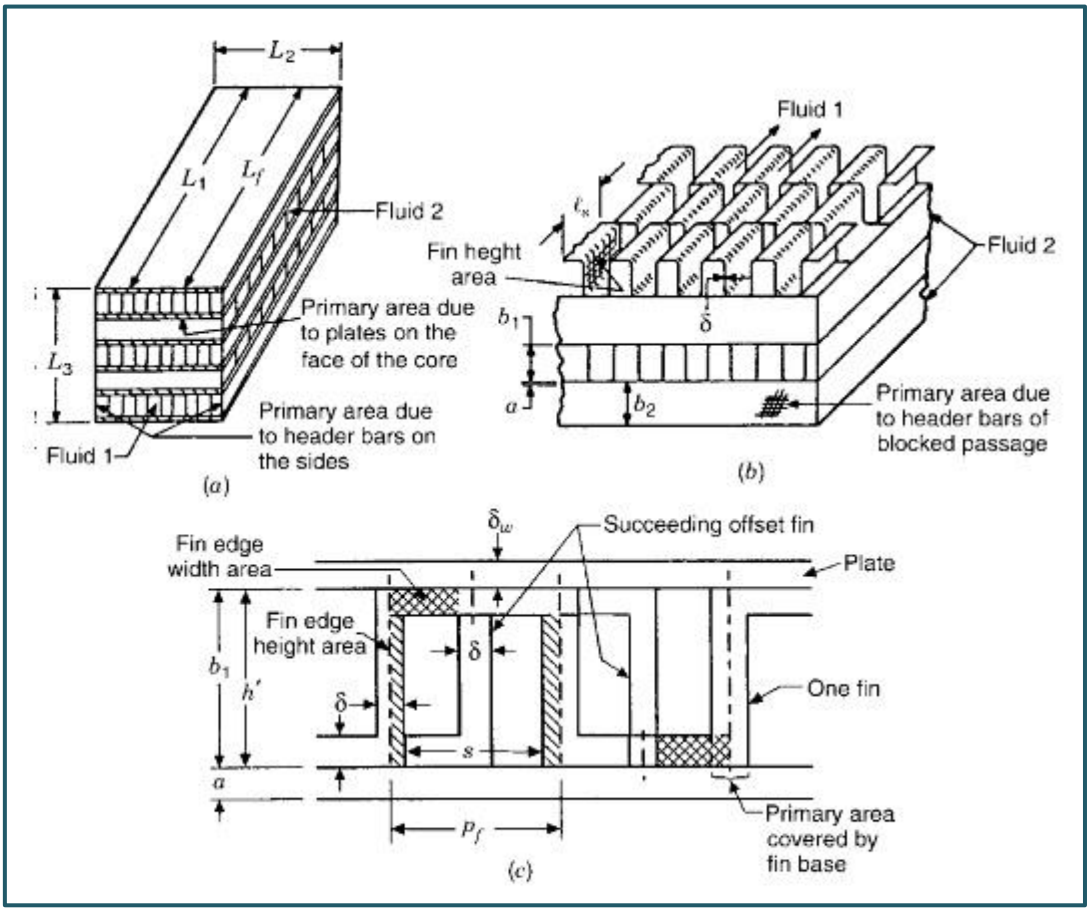


Figure 3.3: Nomenclature of plate fin heat exchanger. (a) Plate fin exchanger; (b) offset strip fin geometry; (c) small section of idealized offset strip fin geometry [2].

The physical properties of the heat exchanger can be calculated based on the following equation [18]:

Table 3.4: Equations to calculate the physical properties of Plate fin heat exchanger.

1. Exchanger height
$$\boldsymbol{H = n_{hot}(H_{hot} + b) + n_{cold}(H_{cold} + b)} \quad \textbf{(1)}$$ where $n = the\ number\ of\ stack$ $b = separation\ plate\ spacing$ $H = hight\ of\ each\ side$
2. Frontal area
$$\boldsymbol{A_f = HW} \quad \textbf{(2)}$$ where $W = width\ of\ the\ heat\ exchanger$
3. Ratio of total surface on one side to total surface on both sides
$$\boldsymbol{\alpha = \frac{H}{[H_h + H_c + 2\delta]\beta}} \quad \textbf{(3)}$$ where $\delta = fin\ thickness$ $\beta = ratio\ of\ total\ surface\ are\ to\ the\ volume\ on$ $one\ side\ of\ the\ heat\ exchanger$
4. Total surface
$$\boldsymbol{S_h = \alpha \times V} \quad \textbf{(4)}$$ where $\alpha = ratio\ of\ total\ surface\ on\ one\ side\ to\ total\ surface\ on\ both\ side$ $V = total\ volume\ of\ heat\ exchanger$
5. Ratio of flow area to the frontal area
$$\boldsymbol{\sigma = \alpha \times d_e / 4} \quad \textbf{(5)}$$ where $d_e = hydraulic\ diameter$

6. Flow areas
$$\boldsymbol{A = \sigma \times A_f} \quad \textbf{(6)}$$ where $\sigma = ratio\ of\ flow\ area\ to\ the\ frontal\ area$ $A_f = Frontal\ area$

ii. Finned tube heat exchanger

Based on the FIGURE 1.3 in C 1 S 1.1.3, the geometry of the heat exchanger can be calculated using following equation [2]:

Table 3.5: Equations to calculate the physical properties of Finned tube heat exchanger.

1. Total heat transfer area
$$\boldsymbol{A_{t,w} = 2 \times [(L_{tube} - \delta) + (W_{tube} - \delta)] \times N_{tube}} \quad \textbf{(7)}$$ where $L = length\ of\ tube$ $N_t = number\ of\ tube$ $W = witdh\ of\ the\ tube\ bundle$ $\delta = thickness\ of\ tube$
2. Total primary area
$$\boldsymbol{A_p = 2\big[(L_{tube} + W_{tube})\big\{H - \big(H \times N_{fin} \times \delta_{fin}\big)\big\}\big]N_{tube}} \quad \textbf{(8)}$$ where $H = height\ of\ heat\ exchanger$ $N_{fin} = number\ of\ fin$ $\delta_{fin} = thickness\ of\ fin$
3. Total secondary surface area
$$\boldsymbol{A_{fin} = 2L\ N_{fin}[(HW) - (L_t W_t N_t)] + 2LN_{fin}\ \delta_{fin} H + W} \quad \textbf{(9)}$$

4. Total air side heat transfer area
$$A = A_p + A_{fin} \quad (10)$$ Where $A_p = Total\ primary\ area$ $A_{fin} = Total\ secondary\ surface\ area$
5. Total free flow area
$$A_{ot,w} = (L_{tube} - \delta) \times (W_{tube} - \delta) \times N_t \quad (11)$$
6. Frontal area
$$A_{ft,w} = HW \quad (12)$$
7. Ratio of free flow to frontal area
$$\sigma_{t,w} = \frac{A_{ot,w}}{A_{ft,w}} \quad (13)$$
8. Surface area density
$$\alpha_{t,w} = \frac{A_{t,w}}{V_{total}} \quad (14)$$ where $V = over\ all\ volume$
9. Hydraulic diameter
$$d_e = \frac{4 \times \sigma_{t,w}}{\alpha_{t,w}} \quad (15)$$

iii. Shell tube heat exchanger

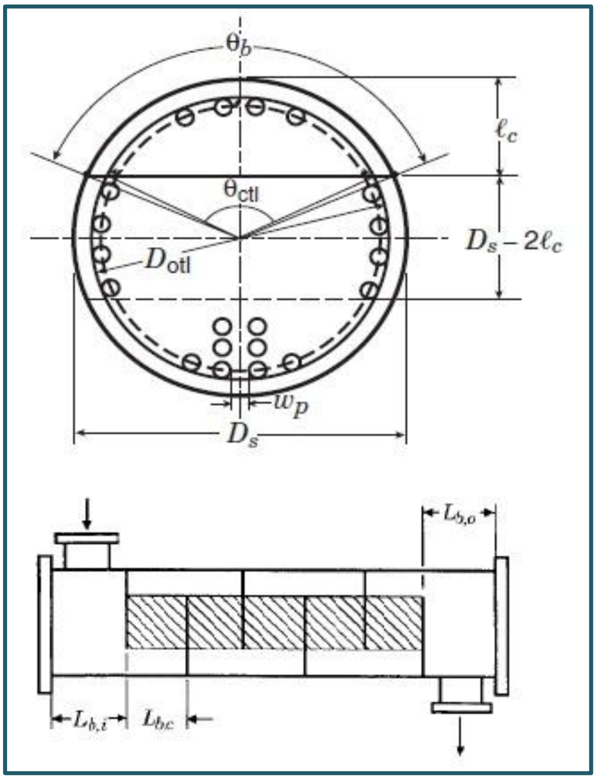


FIGURE 3.4: Nomenclature of Shell and tube heat exchanger [2].

The following equations can be used to calculate the physical properties of shell and tube heat exchanger [2].

Table 3.6: Equations to calculate the physical properties of Shell tube heat exchanger.

[1] Gross window area
$$A_{fr,w} = \frac{D_s^2}{4}\left[\frac{\theta_b}{2} - \left(1 - \frac{2l_c}{D_s}\right) \sin\frac{\theta_b}{2}\right] \quad \textbf{(16)}$$ where $D_s = shell\ diameter$ $l_c = baffle\ cut$ $\theta_b = angle\ between\ 2\ radii\ intersected\ at\ the\ inside\ shell\ wall\ with\ the\ baffle\ cut$

[2] Flow area in one window section
$$A_{fr,t} = \frac{\pi}{4} d_o^2 F_w N_t \qquad (17)$$ where $d_o = tube\ outer\ diameter$ $F_w = fraction\ of\ total\ in\ the\ window\ section$ $N_t = total\ number\ of\ tube\ in\ the\ window\ section$
[3] Flow area in one window section
$$A_{o,w} = A_{fr,w} - A_{fr,t} \qquad (18)$$
[4] Hydraulic diameter
$$D_h = \frac{4A_{o,w}}{\pi d_o N_{t,w} + \pi D_s \left({}^{\theta_b}/_{2\pi}\right)} \qquad (19)$$ where $N_{t,w} = number\ of\ tube$
[5] Number of effective tube rows in each window
$$N_{r,cw} = \frac{0.8}{X_l}\left[l_c - \frac{1}{2}(D_s - D_{ctl})\right] \qquad (20)$$ where $D_{ctl} = outer\ tube\ limit$ $X_l = longitudinal\ tube\ pitch$
[6] Crossflow area
$$A_{o,cr} = L_{b,c}\left[D_s - D_{otl} + 2\frac{D_{ctl}}{X_t}(p_t - d_o)\right] \qquad (21)$$ where $D_{otl} = outer\ tube\ limit$
[7] Number of baffles
$$N_b = \frac{L - L_{b,i} - L_{b,o}}{L_{b,c}} \qquad (22)$$ where $L = tube\ length$ $L_{b,c} = central\ baffle\ spacing$ $L_{b,i} = inlet\ baffle\ spacing$ $L_{b,o} = outlet\ baffle\ spacing$

[8] Area for flow bypass
$$A_{o,bp} = L_{b,c}\left(D_s - D_{otl} + 0.5N_p w_p\right) \quad (23)$$ Where $N_p = number\ of\ pass\ partition$ $w_p = width\ of\ by\ pass\ lane$
[9] Tube to baffle leakage area
$$A_{o,tb} = \frac{\pi d_o \delta_{tb} N_t (1 - F_w)}{2} \quad (24)$$ where $\delta_{tb} = thickness\ of\ tube$
[10] Shell to baffle leakage area
$$A_{o,sb} = \pi D_s \frac{\delta_{sb}}{2}\left(1 - \frac{\theta_b}{2\pi}\right) \quad (25)$$ where $\delta_{sb} = shell\ to\ baffle\ clearance$

3.9.2 Performance of Heat Exchanger

The performance of heat exchanger is measure base on three elements which are heat transfer coefficient, pressure drop and effectiveness of the heat exchanger.

Table 3.7: Equations used to calculate the heat transfer coefficient [2].

Heat transfer Coefficient, h
Plate fin heat exchanger
$$h = \frac{JGc_p}{Pr^{2/3}} \quad (26)$$ Where $c_p = specific\ heeat$ $J = Colburn\ factor$ $Pr = Prandtl\ number$ $G = mass\ velocity$
Finned tube heat exchanger
$$h = \frac{k}{D_i} Nu \quad (27)$$ where $D_i = tube\ inner\ diameter$ $k = thermal\ conductivity$ $Nu = Nusselt\ number$
Shell and tube heat exchanger
Shell side $$h = h_{ideal} \times J \quad (28)$$ where $h_{ideal} = ideal\ heat\ transfer\ coefficient$ $J = Correction\ factor$ Tube side $$h = \frac{Nu \times k}{D_i} \quad (29)$$ where $D_i = tube\ inner\ diameter$ $k = thermal\ conductivity$ $Nu = Nusselt\ number$

Table 3.6: Equations used to calculate the pressure drop [2].

Pressure Drop, Δp
Plate fin heat exchanger
$$\Delta p = \frac{G^2 v_1}{2g_c}\left[K_c + 1 - \sigma + 2\left(\frac{v_2}{v_1} - 1\right) + f\left(\frac{S_i}{A_i}\right)\left(\frac{v_m}{v_1}\right) + 1 - \sigma - K_e\frac{v_2}{v_1}\right] \quad \textbf{(30)}$$ where $A_i = flow\ area$, $G = mass\ velocity$, $K = loss\ coefficient$, $S = total\ surface$, $v = specific\ volume$, $\sigma = ratio\ of\ flow\ area\ to\ frontal\ area$
Finned tube heat exchanger
Hot side $$\Delta p = \frac{N_r \rho G^2 f}{2} \quad \textbf{(31)}$$ where $f = friction\ factor$, $G = mass\ flowrate$, $N_r = number\ of\ row$ Cold side $$\Delta p = \frac{N_r\left(l/D_i\right)\rho G^2 f}{2} \quad \textbf{(32)}$$ where $D_i = tube\ inner\ diameter$, $f = friction\ factor$, $G = mass\ flowrate$, $l = length\ of\ tube$, $N_r = number\ of\ row$
Shell and tube heat exchanger
Shell side $$\Delta p_s = \Delta p_{cr} + \Delta p_w + \Delta p_{i-o} \quad \textbf{(33)}$$ where $\Delta p_{cr} = pressure\ drop\ by\ tube\ bundle\ central\ section$, $\Delta p_w = pressure\ drop\ in\ window\ section$, $\Delta p_{i-o} = pressure\ drop\ in\ inlet - outlet\ section$

Tube side
$$\Delta p = \frac{\dot{m}_t^2}{2 g_c \rho_t A_{o,t}^2}\left[\frac{4fL}{d_i} + (1 - \sigma^2 + K_c) - (1 + \sigma^2 - K_e)\right] n_p \qquad (34)$$
where
$A_{o,t} = flow\ area\ per\ pass$ $d_i = inner\ tube\ diameter$
$f = fouling\ factor$ $g_c = proportional\ constant$
$K = loss\ coefficient$ $n_p = number\ of\ pass\ partition$
$\rho_t = water\ density$

Table 3.7: Equations used to calculate the effectiveness of heat exchanger [2].

Effectiveness, ε
Plate fin heat exchanger
$$\varepsilon = \frac{1 - e^{-NTU(1 - C_r)}}{1 - C_r e^{-NTU(1 - C_r)}} \qquad (35)$$
where
$C_r = heat\ capacity\ rate\ of\ regenerator$
$NTU = Number\ of\ transfer\ unit$
Finned tube heat exchanger
$$\varepsilon = 1 - exp\left[\frac{NTU^{0.22}}{C_r}\left(\exp\left(-C_r \times NTU^{0.78}\right) - 1\right)\right] \qquad (36)$$
where
$C_r = heat\ capacity\ rate\ of\ regenerator$
$NTU = Number\ of\ transfer\ unit$
Shell and tube heat exchanger
$$\varepsilon = 2\left[1 + C_r + (1 + C_r^2)^{1/2}\right]^{-1} \times \left[\frac{1 + exp\{-(NTU)(1 + C_r^2)^{1/2}\}}{1 - exp\{-(NTU)(1 + C_r^2)^{1/2}\}}\right]^{-1} \qquad (37)$$
where
$C_r = heat\ capacity\ rate\ of\ regenerator$
$NTU = Number\ of\ transfer\ unit$

CHAPTER 4

RESULT AND DISCUSSION

4.1 Tool Layout

In order to obtain the outcome of the tool, data is keyed in by the user. There are two types of data needed to be key-in by user namely:

i. Thermal properties

	A	B	C	D	E	F	G	H	I	J
1	THERMAL PROPERTIES									
2										
3		Properties				Hot (Air)		Cold(Water)		
4		Temperature, T(K)		Inlet		309		279		
5				Outlet		293		286		
6		Mass Flow Rate (kg/s)				1.6650		10.3968		
7		Heat Capacity, C_p (kJ/kg.K)				1.0050		4.1800		
8		Thermal Conductivity, k (W/m.K)				0.0263		0.2820		
9		Density, ρ (kg/m³)				1.1426		1000		
10		Viscosity		Dynamic, μ (kg/m.s)		0.00001889		0.00148052		
11				Kinematic, ν (m²/s)		0.0000159		0.00000148		
12		Inlet Pressure (kPa)				4000		4000		
13		Prandtl Number, Pr				0.7218		21.94530		
14										

Figure 4.1: Elements in Thermal properties section.

In the first work part of the tool, the White colored columns are filled based on the case study stated in C 3 S 3.1.1. These are the thermal Properties of the flowing fluids inside the heat exchanger. This data are then used in the next section as to calculate the thermal performance of the heat exchanger. The Grey colored columns indicate the values that are calculated by the tool based on the value keyed in earlier. These goes the same for all the other section of the tool.

ii. Physical properties

PHYSICAL PROPERTIES OF HEX

Properties	Hot Side	Cold Side
Fin Surface Configuration	1/8 - 20.06(D)	1/8 - 16.00 (D)
Fin per inch	20.06	16
Fin per meter	729.5822	581.92
No. of stack	200	201
Long (m)	4	
Wide (m)	4	
High of Surface (m)	0.00647	

(a)

Geometrical Characteristic

Properties	Value
Thickness of separtion plates (m)	0.000152
Splitter plate (m)	0.000127
Length of fin passage (m)	1.5
Exchanger height (m)	2.655422

Surface Geometry of Plate Fin Surface	Hot Side	Cold Site
Heat transfer surface density, β	2290	1804
S_f / S	0.843	0.845
Fin tip diameter of a disk, d_e	0.00149	0.00186
Distance between 2 plates, b	0.00511	0.00648
Fin thickness, δ	0.000102	0.000152

Properties		Hot Side	Cold Side
Overall	Frontal Area, Af (m^2)	10.621688	
	Volume,V (m^3)	42.486752	
α_h (m^2/m^3)		1127.229154	881.2956811
Total surface, S_h (m^2)		47892.30551	37443.39104
Flow are to the frontal area, σ_h (m^2)		0.41989286	0.409802492
Flow areas, A_h (m^2)		4.459970951	4.352794208

(b)

Figure 4.2: (a) and (b) Physical properties for Plate fin heat exchanger. The non-highlighted columns are the one need to be filled by user.

Referring to Figure 4.2 which is the physical properties of the heat exchanger, the data are obtained from the standard geometries issued by TEMA E-exchanger (referrer Appendix 1). The data keyed in for this section include the length, width, number of fin per inch (if applicable) and other. Different heat exchanger required different information that is needed to be provided by user. With the availability of the data, the key properties that are used to calculate the performance are then calculated.

These key data are basically the overall area which is important as it indicate the contact surface area between the two flowing fluids. Again, the column highlighted in grey are the calculated data using data keyed in by user in the white color column.

Table 4.1: The physical properties for each heat exchanger.

Heat Exchanger	Physical Properties
Plate fin	• Length and width • Fin geometry which can be obtain by referring standard surface geometry of fin (Refer Appendix I)
Finned tube	• Length and width • Height will be the same as for plate fin heat exchanger • Fin and tube geometry which can be obtain by referring standard surface geometry of fin (Refer Appendix I)
Shell and tube	• Length and width • Diameter of tube and shell • Other properties can be obtain by selecting the data from a standard source such as TEMA E-exchanger

Once the thermal and physical properties had been keyed in by user, performances of the heat exchanger are then calculated. Below are the third sections of tool which portray the performance of plate fin heat exchanger.

PERFORMANCE OF HEX

1. Heat Transfer Coefficient

Properties	Hot Side (Air)	Cold Side (Water)
mass flow rate / flow areas, G_h	3.733	23.885
Prandtl Number, Pr	0.7218	21.945
$Pr^{2/3}$	0.8047	7.838
Reynolds Number, Re	294.467	30.007
Heat Transfer Coefficient, h_h	46.625	10233.774

(a)

2. Pressure Drop

Specific Volume, v	Hot Side(Air)	Cold Side(Water)
v_1	22.1708	0.02001825
v_2	26.2784	0.0205205
vm	24.2246	0.020269375
v_m/v_1	1.0926	1.012544803
v_2/v_1	1.1853	1.025089606
ϕ_1	1.1637	1.952061918
ϕ_2	0.3706	0.050179211
ϕ_3	9386.4165	7839.056538
ϕ_4	0.5852	0.883690711
Δp	1478.3917	895.3935103

(b)

3. Efficiency

Porperties		Hot Side	Cold Side
w		0.0014	0.0017
Cover plate hight, s		0.0006	0.0008
Fin	m_f	65.8239	798.8585
	$b.m_f$	0.3364	5.1766
	tanh $b.m_f$	0.3242	0.9999
	Unit fin length, $Y_{o,f}$	1.4167	25.6210
Splitter Plate	m_s	58.9905	873.9565
	$s.m_s$	0.0374	0.6845
	tanh $s.m_s$	0.0374	0.5944
	Unit fin length, $Y_{o,s}$	1.1178	16.5600
Fin Efficiency, η_{fh}		1.9891	0.3447
Overal Passage Efficiency, η_{oh}		1.8338	0.4463
Total heat transfer area, $A_{f,h}$ (m^2)		1.0622	
C_{min} (W/K)		43.4586	
Heat transfer coefficient, h_a		46.6251	
Heat Transfer Coefficient, h_w		10233.7740	
Overall Heat transfer Coefficent	$1/U_o$ (m^2K/W)	0.0120	
	U_o (W/m^2K)	83.5690	
Number of heat transfer unit, NTU		20.4251	
Heat exchanger effectiveness,ε		0.6177	

(c)

Figure 4.3: The performance of plate fin heat exchanger. (a) heat transfer coefficient, (b) pressure drop, (c)effectiveness of heat transfer.

4.2 Performance of Heat exchanger

4.2.1. Heat Transfer Coefficient

In the next stage, the results are showed in graph as this is to make it easier to compare the performances of all three types of heat exchanger.

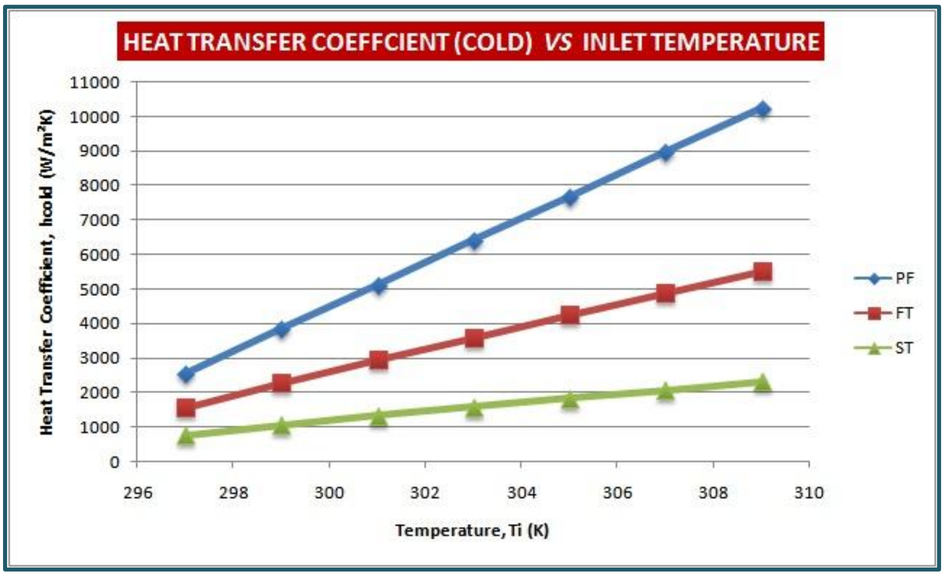


Figure 4.4: Heat transfer coefficient for cold side against inlet temperature of air.

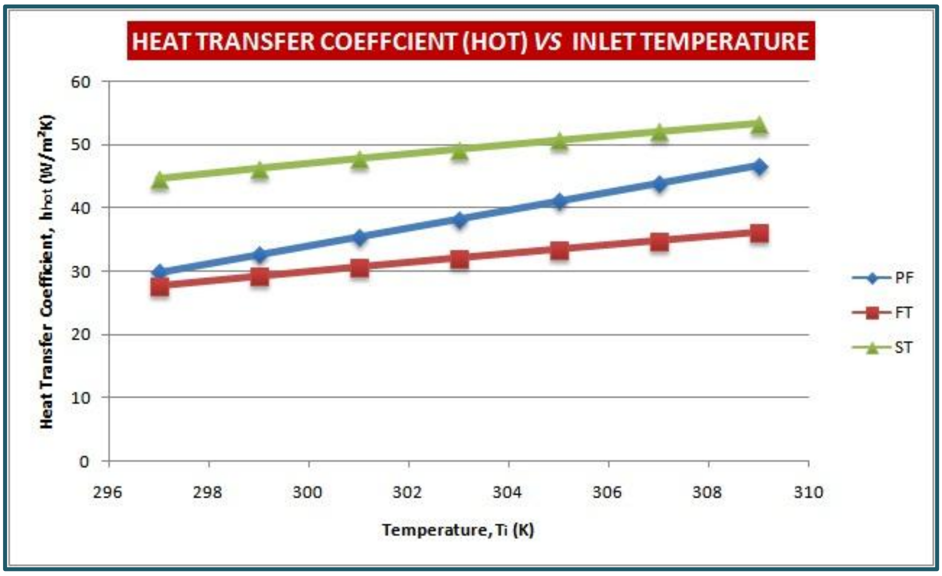


Figure 4.5: Heat transfer coefficient for hot side against inlet temperature of air.

The heat transfer coefficient for both cold and hot side show linear increment for all three types of heat exchanger. In the cold side where the chilled water flow, finned tube heat exchanger show the most of heat transfer coefficient at every temperature. On the other hand, in the hot air side, shell and tube heat exchanger show the highest value at each temperature.

There are several factors affecting the heat transfer coefficient in heat exchanger such as [19]:

i. *Temperature Difference between the two fluids.* The greater the temperature different, the greater the heat transfer rate.
ii. *Fluid flow rate.* As the flow rate increase, the heat transfer rate will also increase.
iii. *The nature of the heat conducting materials.* This factor is 'built-in' in the design of the Exchanger and choice of materials. Some material has higher conductivity compare to other type of material.
iv. *Surface area.* For larger surface area of the conducting interfaces, it will provide greater heat transfer rate. The number and the length of tube will also affect heat transfer, as will the outside diameter and metal thickness of the tubes.

4.2.2. Heat Transfer Coefficient

For pressure drop against inlet temperature, all type heat exchanger also show increment in value. At both side, shell and tube heat exchanger show the highest value represent by the green line. Since the value of pressure drop are much higher compare to the other two heat exchangers, the pressure drop for shell and tube heat exchanger are plotted with reference to the second Y-axis (on the right). For a shell and tube heat exchangers are usually design for a bigger size to cater the pressure and to ensure the pressure drop, hence in a smaller scale, large pressure drop will occur as proven in the above graph.

For heat exchanger, the pressure drop is considered as a sum of two major elements namely [2]:

i. Pressure drop associated with the core or matrix.
ii. Pressure drop associated with fluid distribution devices such as inlet/outlet headers, manifolds, tanks, nozzles, ducting and other.

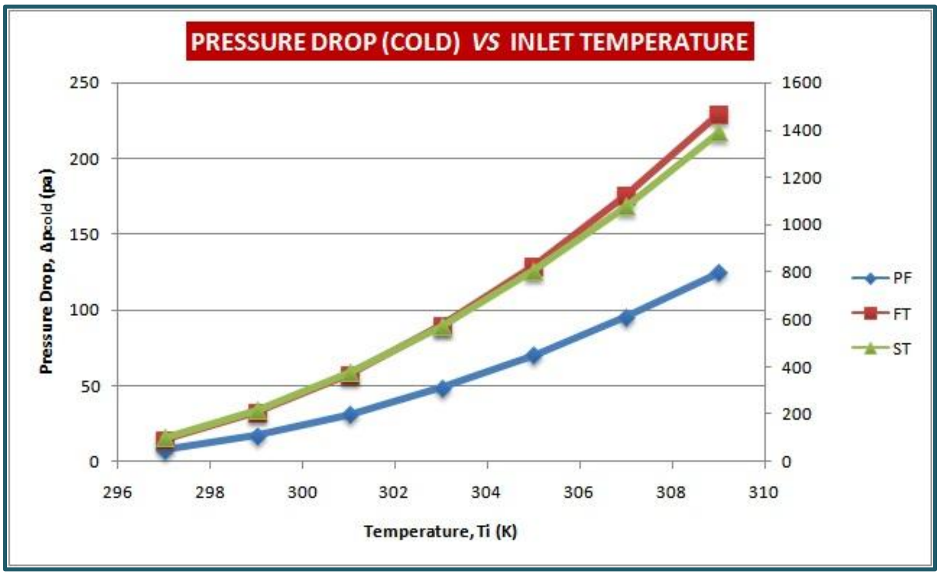


Figure 4.6: Pressure drop for cold side against inlet temperature of air.

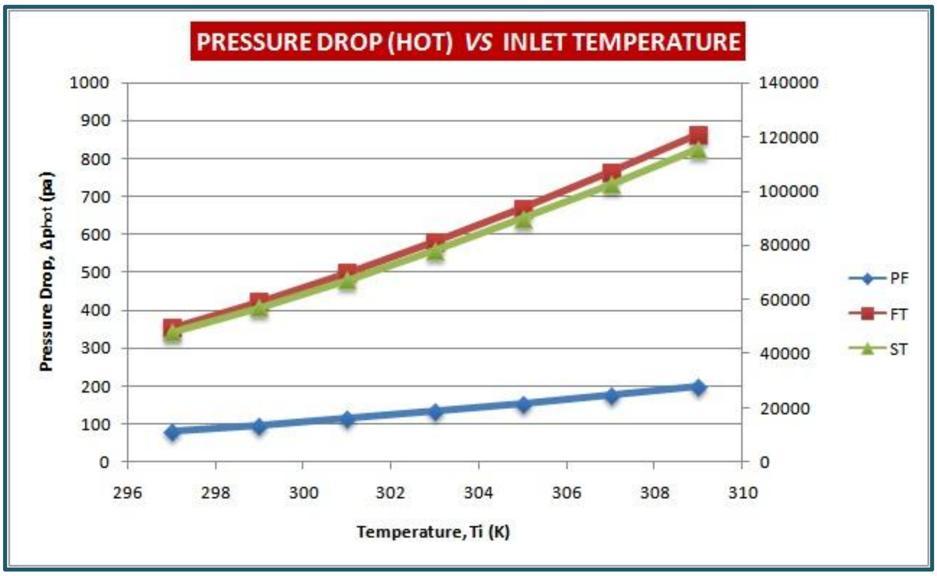


Figure 4.7: Pressure drop for hot side against inlet temperature of air.

The purpose of the heat exchanger is to transfer thermal energy from one fluid to the other and for this purpose, it requires pressure difference (and fluid pumping power) to force the fluid flow over the heat transfer surface in the heat exchanger. Hence, ideally most of the pressure drop available should be utilized in the core and a small fraction in the manifolds, headers, or other flow distribution devices. However, this ideal situation may not be the case in plate heat exchangers and other heat exchangers in which the pressure drop associated with manifolds, headers, nozzles, and so on, may not be a small fraction of the total available pressure drop.

If the manifold and header pressure drops are small, the core pressure drop dominates. The core pressure drop is determined separately on each fluid side. It consists of one or more of the following contributions, depending on the exchanger construction [2]:

i. Frictional losses associated with fluid flow over the heat transfer surface (this usually consists of skin friction plus form drag)
ii. Momentum effect (pressure drop or rise due to the fluid density changes in the core)
iii. Pressure drop associated with sudden contraction and expansion at the core inlet and outlet, and
iv. Gravity effect due to the change in elevation between the inlet and outlet of the exchanger. The gravity effect is generally negligible for gases.

In calculating the pressure drop, several assumptions were made. Those assumptions are [2]:

i. Flow is steady and isothermal, and fluid properties are independent of time.
ii. Fluid density is dependent on the local temperature only or is treated as a constant (inlet and exit densities are separately constant).
iii. The pressure at a point in the fluid is independent of direction. If a shear stress is present, the pressure is defined as the average of normal stresses at the point.
iv. Body forces are caused only by gravity (i.e., magnetic, electrical, and other fields do not contribute to the body forces).
v. If the flow is not irrational, the Bernoulli equation is valid only along a streamline.
vi. There are no energy sinks or sources along a streamline; flow stream mechanical energy dissipation is idealized as zero.
vii. The friction factor is considered as constant with passage flow length.

Apart from all the stated factors and assumptions, there are more elements contributes to the pressure drop. However, the factors are too complex and need a specific study structure to be able to fully understand the concept of the pressure drop.

4.2.3. Effectiveness

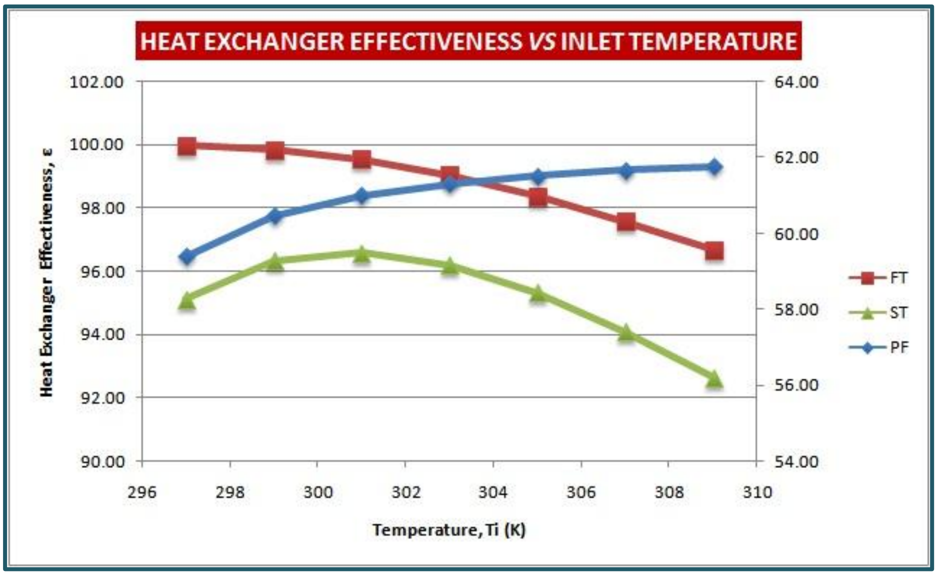


Figure 4.8: Effectiveness of heat exchanger against inlet temperature of air.

The effectiveness' for finned tube heat exchanger and shell and tube heat exchanger show significant decrement when the inlet temperature increases. In contrast, the effectiveness for plate fin heat exchanger improved with inlet temperature. Even though the value is small compare to the other two types of heat exchanger, the effectiveness can be expected to show improvement if the inlet temperature of air increase more than 310℃.

For the purpose of this tool, effectiveness-NTU method is used to calculate the effectiveness of the heat exchanger. Compare to LMTD method which involves more iterative procedure, effectiveness-NTU method is more applicable for the tool.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The development of the tool is needed as it will assist user in selecting the most suitable heat exchanger. The tool developed also able to demonstrate the possible behavior of the heat exchanger so that any alteration in the dimension can be done to avoid any mistake in fabricating the heat exchanger.

With the availability of the tool, user can easily compare the performance of three types of heat exchanger in one graph. The information gain can be used as to make decision on which is the suitable heat exchanger to be apply to the system.

However due to limitation of time, there are still a lot of room for improvement in developing the tool. With more time available in the future, this tool could be one of the important equipment in designing heat exchanger.

With the success in developing this tool, the author hope that it will welcome other to do more research and develop a more complete tool that will add more value to the tool.

5.2 Recommendations

In selecting and designing heat exchanger, the specification of the system structure, size and performance are very important. The performance of the heat exchanger must be consistent with the life cycle design system. Life cycle designs assume considerations organized in the following stage [2]:

i. Problem formulation (including interaction with a consumer)
ii. Concept development (selection of workable designs, preliminary design)
iii. Detailed exchanger design (design calculations and other pertinent considerations)
iv. Manufacturing
v. Utilization considerations (operation, phase-out, disposal)

The tool developed cover only until the third point which is the detailed exchanger design. Hence, in the future, the tool should cover more aspect for only in the designing stage, the tool also should be able to inspire user to utilize other consideration.

Currently, the tool only manages to provide user with the performance of heat exchanger in terms of heat transfer coefficient, pressure drop and effectiveness of the heat exchanger. Further study should be done so that the tool constructed can provide more outcomes. Those outcomes include the possible plan in increasing the performance of the heat exchanger, the life span of the heat exchanger and other.

Due to time constrain, the aim of this project are only focusing on the second part of the flow chart in Figure 5.1 which is the heat exchanger design computer programs. For further development of the tool, optimization package should be included in the tool. The outcome of the tool should not only focus on the performance of the heat exchanger.

The optimization package which will provide valuable information to user as user should not only focusing on the performance of the heat exchanger but, user also should have future plan regarding the implementation of heat exchanger to their system. The tool also can be integrated with a monitoring tool so that user can use data from previous designed heat exchanger to study the behavior and performance of the heat exchanger. The data are then can be use to compare with the current design of the heat exchanger.

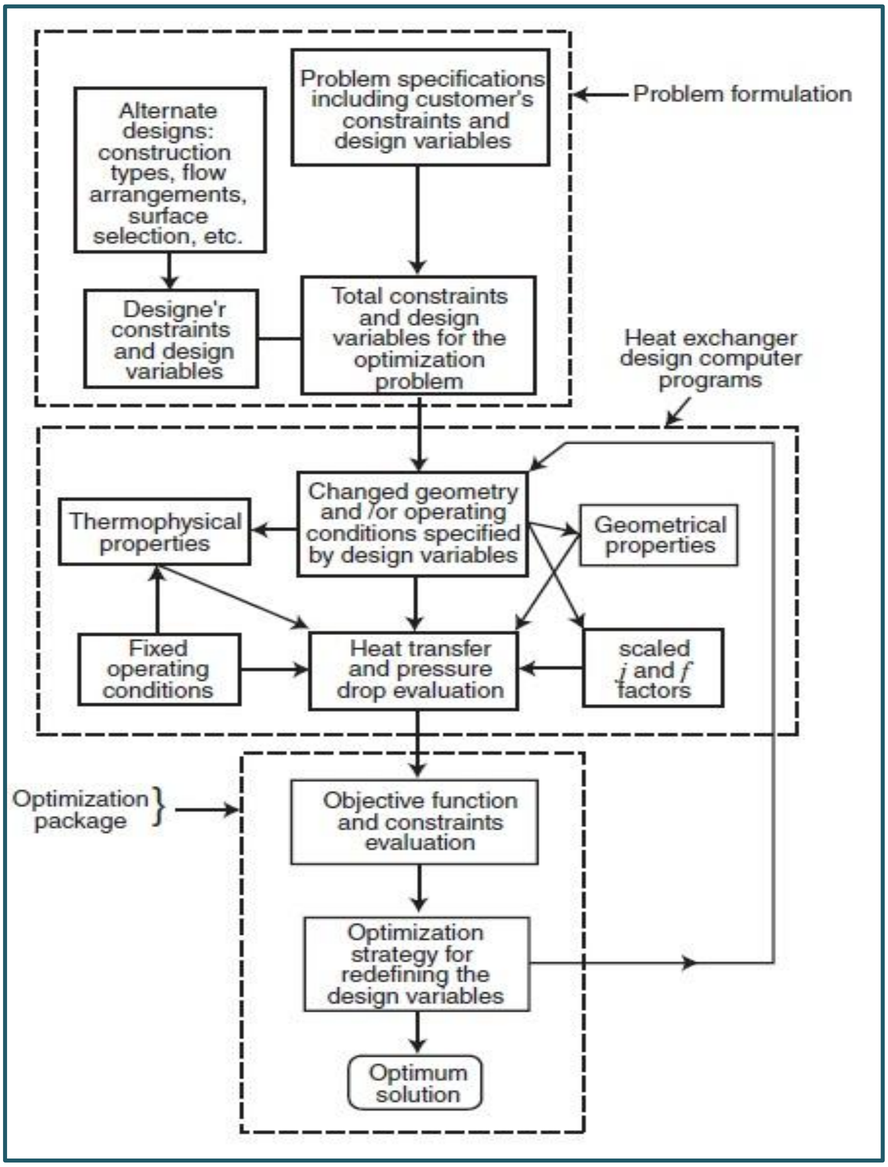


Figure 5.1: Methodology for heat exchanger optimization [2]

Last but not least, the tool can also constructed with better interface as to make it more user friendly. The constructed tool can be use as the “engine” of the future tool where user will not to rely on Microsoft Excel as to understand the performance of the heat exchanger. The tool can be develop using its own platform as it will make it easier for user to use the tool.

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Appendix I [20]

Standard Surface Geometry for Fin

Multi-tube double-pipe units – dimensions

Shell							Standard			High pressure		
	Thickness											
Nom. dia.(in)	Stan-dard	High press.	Actual o.d.	No. tubes	No. fins	Tube o.d.	Tube thk.	Fin height	Surface (m^2/m)	Tube thk.	Fin height	Surface (m^2/m)
4	6.02	8.56	114.3	7	0	19.02	2.11	0	0.84	2.11	0	0.84
4	6.02	8.56	114.3	7	0	22.2	2.11	0	0.98	2.11	0	0.98
4	6.02	8.56	114.3	7	0	25.4	3.4	0	1.12	–	–	–
4	6.02	8.56	114.3	7	16	19.02	2.11	5.33	3.23	2.11	5.33	3.23
4	6.02	8.56	114.3	7	20	22.2	2.11	5.33	3.97	–	–	–
6	7.11	–	168.3	19	16	19.02	2.11	5.33	8.76	–	–	–
6	7.11	–	168.3	14	16	19.02	2.11	5.33	6.46	–	–	–
6	7.11	–	168.3	7	20	25.4	2.77	12.7	8.23	–	–	–
8	8.18	–	219.1	19	16	19.02	2.11	8.64	12.78	–	–	–
8	8.18	–	219.1	19	20	22.2	2.11	7.11	13.46	–	–	–
8	8.18	–	219.1	19	20	25.4	2.77	5.33	11.14	–	–	–
8	8.18	12.7	219.1	19	16	19.02	2.11	7.11	10.92	2.11	7.11	10.92
8	8.18	–	219.1	19	20	22.2	2.11	5.33	10.76	–	–	–

Notes:
(1) Shell thickness = schedule 40 (standard), schedule 80 (high pressure).
(2) Surface specified for two legs.
(3) All dimensions in mm except where stated.
Courtesy: Filtration and Transfer Ltd.

Multi-tube double-pipe units – dimensions

Shell							Standard			High pressure		
	Thickness											
Nom. dia.(in)	Stan-dard	High press.	Actual o.d.	No. tubes	No. fins	Tube o.d.	Tube thk.	Fin height	Surface (m^2/m)	Tube thk.	Fin height	Surface (m^2/m)
4	6.02	8.56	114.3	7	0	19.02	2.11	0	0.84	2.11	0	0.84
4	6.02	8.56	114.3	7	0	22.2	2.11	0	0.98	2.11	0	0.98
4	6.02	8.56	114.3	7	0	25.4	3.4	0	1.12	–	–	–
4	6.02	8.56	114.3	7	16	19.02	2.11	5.33	3.23	2.11	5.33	3.23
4	6.02	8.56	114.3	7	20	22.2	2.11	5.33	3.97	–	–	–
6	7.11	–	168.3	19	16	19.02	2.11	5.33	8.76	–	–	–
6	7.11	–	168.3	14	16	19.02	2.11	5.33	6.46	–	–	–
6	7.11	–	168.3	7	20	25.4	2.77	12.7	8.23	–	–	–
8	8.18	–	219.1	19	16	19.02	2.11	8.64	12.78	–	–	–
8	8.18	–	219.1	19	20	22.2	2.11	7.11	13.46	–	–	–
8	8.18	–	219.1	19	20	25.4	2.77	5.33	11.14	–	–	–
8	8.18	12.7	219.1	19	16	19.02	2.11	7.11	10.92	2.11	7.11	10.92
8	8.18	–	219.1	19	20	22.2	2.11	5.33	10.76	–	–	–

Notes:
(1) Shell thickness = schedule 40 (standard), schedule 80 (high pressure).
(2) Surface specified for two legs.
(3) All dimensions in mm except where stated.
Courtesy: Filtration and Transfer Ltd.

Appendix II

Tool layout for Finned tube heat exchanger

PHYSICAL PROPERTIES OF HEX

Finned Tube Properties			
Surface Temperature (K)			6.00000
Width, w (m)			0.50000
Height, h (m)			1.00000
Length, l (m)			0.40000
Diameter (m)		Outer, Do	0.07500
		Inner, Di	0.06750
Radius (m)		Outer, ro	0.03750
		Inner, ri	0.03375
Wall Thickness (m)			0.00750
Pitch (m)	Transverse, Xt		0.15000
	Longitudinal, Xl		0.15000
Area (m²)	Frontal		0.40000
	Inner Pipe		0.00358
	Primary, Ap		4.31266
	Free flow, A		4.31435
Δr			0.00913
Thermal Conductivity, k			52.00000
Number of Rows, Nr			3.00000
Number of Tubes per Row, Nt			6.00000
Total Number of Rows, N			18.00000

Fin Properties		
Spacing, fs (m)		0.00875
Height, fh (m)		0.00163
Thickness, ft (m)		0.00005
Fins Number		52
Fin pitch (fin/m)		157
Total Num, Nf		34
η		0.92
Area (m²)	Pipe (Outer)	0.0942
	Fin	0.0017
	Unfinned	0.002062

PERFORMANCE OF HEX

1. Heat Transfer Coefficient

Properties	Hot Side (Air)	Cold Side (Water)
Mean Velocity	3.643	2.905
Reynolds Number, Re	17183.9961	147231.688
Prandtl Number, Pr	0.7218	21.9453
Nusselt Number, Nu	102.8970	1467.650
Stanton Number, St	0.002818119	
Heat Transfer Coefficient, hh	36.083	5518.364

2. Pressure Drop

Properties	Hot Side (Air)	Cold Side (Water)
Friction Factor	0.38	0.016581805
Roughness, ε	0.0000015	
Roughness Ratio	45000	
Friction Coefficient	0.009170	
Pressure Drop	8.6435	229.3472

3. Efficiency

Porperties		Value
Heat Transfer, Q	Pipe (Outer)	102.0210
	Fin	1.6824
	Unfinned	2.0532
	Total	127.0104
Overall fin effectiveness		0.8032
Total heat transfer area, $A_{f,h}$ (m^2)		10.6200
C_{min} (W/K)		43.4586
C_r		0.0385
Heat transfer coefficient, h_a		36.0825
Heat Transfer Coefficient, h_w		5518.3640
Fin surface efficiency, η_f		1.0000
Surface area desnsity, α (1/m)	Tube, α_t	0.8929
	Fin, α_f	0.0084
Overall Heat transfer Coefficent	1/Uo (m^2K/W)	0.0277
	Uo (W/m^2K)	36.0792
Number of heat transfer unit, NTU		3.5818
Heat exchanger effectiveness,ε		0.9667

Appendix III

Tool layout for shell and tube heat exchanger

PHYSICAL PROPERTIES OF HEX

Shell Side Properties		
Diameter, D_r (m)		0.336
Number of Baffles, N_b		14
Baffle Spacing (m)	Central, $L_{b,c}$	0.279
	Inlet, $L_{b,i}$	0.318
	Outlet, $L_{b,o}$	
Baffle cut, l_c (m)		0.0867
Number of sealing strip pairs, N_{ss}		1
Num. of Effective tube row, $N_{r,cc}$		9
Num. of effective tube rows crossed in one window zone, Nr,cw		3.868
Width of bypass lane, w_p (m)		0.019
Shell to baffle clearance, δ_{sb} (m)		0.002946

Tube Side Properties		
Total Number of Tubes, N_t		102
Diameter (m)	Outer, D_o	0.019
	Inner, D_i	0.0166
	Outer Limit, D_{otl}	0.321
Tube Length, L (m)		0.5
Tube pitch (m)	Transverse, X_t	0.0354
	Longitudinal, X_l	0.0177
Tube pitch, p_t (m)		0.025
Tube Bundle layout		45°
Wall Thickness, δ_w		0.012
Number of tube passes, n_p (m)		2
Number of pass partitions, N_p		2
Tube to baffle clearance, δ_{tb}		0.000794
Number of tube per pass, $N_{t,p}$		51
Flow area per pass, $A_{o,t}$ (m²)		0.01104

Geometrical Characteristics

	Properties		Value
Window Section	Angle, θ_b (rad)		2.1313
	Baffle cut angle, θ_{ctl}	(rad)	2.0045
		(degree)	114.8490
	Gross window area, $A_{fr,w}$ (m²)		0.01812
	Fraction of total tubes, F_w		0.1625
	Num. of tube, $N_{t,w}$		16.5715
	Area occupied by tube, $A_{fr,t}$ (m²)		0.004698
	Net flow area, $A_{o,w}$ (m²)		0.01343
	Hydraulic diameter, $D_{h,w}$ (m²)		0.03986
	Num. of effective tube rows, $N_{r,cw}$ (m²)		3.1503
Crossflow section	Fraction of total tubes, F_c		0.6751
	Num. of tube rows, $N_{r,cc}$		9
	Crossflow area, $A_{o,cr}$ (m²)		0.0327
	Number of Baffles, N_b		1
Bypass & Leakage Flow Area	Area for flow bypass, $A_{o,bp}$ (m²)		0.0095
	Fraction, F_{bp}		0.2897
	Tube to baffle leakage, $A_{o,tb}$ (m²)		0.0020
	Shell to baffle leakage, $A_{o,sb}$ (m²)		0.0010

PERFORMANCE OF HEX

1. Heat Transfer Coefficient

Properties		Shell Side
Mass Velocity, G_s (kg/m²s)		50.844
Reynolds Number, Re		51140.3754
Prandtl Number, Pr		0.7218
Nusselt Number, Nu (W/m²K)		70.7258
h_{id} (W/m²K)		97.899
r_s		0.337
r_{lm}		0.0932
r_b		0.2897
C		1.250
N^+_{ss}		0.111
n		0.600
L^+_i		1.140
L^+_o		
Correction Factor	Baffle cut & spacing, J_c	1.036
	Tube to shell leakage, J_l	0.870
	Baffle to shell leakage, J_b	0.611
	Unequal baffle spacing, J_s	0.989
Heat transfer coefficient actual, h_s		53.290 W/m²K

Properties	Tube Side
Reynolds Number, Re	10561.2846
Prandtl Number, Pr	21.94530
Nusselt number, Nu (W/m²K)	136.6851
Heat Transfer Coefficient, h_t (W/m²K)	2322.0001

2. Pressure Drop

Properties		Shell Side
b		0.163416126
Ideal friction factor, f_{id}		0.020112164
p		0.5995
Correction Factor	ζ_b	0.6552
	ζ_l	0.6514
	ζ_s	1.5803
Mass velocity, G_w (kg/m²s)		79.4061
Pressure Drop	Δpb,id (pa)	836.0387
	Δp_{cr} (pa)	4639.072011
	Δp_w (pa)	108730.2368
	Δp_{i-o} (pa)	2325.1158
	$\Delta p_{s,total}$ (pa)	115694.42

Properties	Tube Side
f	0.0072
K_e	0.4000
K_c	0.3000
σ	0.3394
Total pressure drop, $\Delta p_{t,total}$ (pa)	1391.946799

3. Efficiency

Properties		Value
Total tube outside heat transfer area, $A_{t,o}$ (m^2)		3.0442
C_{min} (W/K)		43.4586
C_r		0.0381
Heat transfer coefficient, h_s		53.2898
Heat Transfer Coefficient, h_t		2322.0001
Fouling Factor (m^2K/W)	Gas side, $\check{R}_g$	0.0004
	Water side, $\check{R}_w$	0.0002
Overall Heat transfer Coefficent	$1/U_o$ (m^2K/W)	0.0244
	U_o (W/m^2K)	41.0067
Number of heat transfer unit, NTU		2.8725
Heat exchanger effectiveness, ε		0.9265