Development of a software based System for Design of Cryogenic Plate-Fin Heat Exchanger.

Submitted By

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14MCEI20

NIRMA
UNIVERSITY
INSTITUTE OF TECHNOLOGY
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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

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Development of a software based System for Design of Cryogenic Plate-Fin Heat Exchanger.

Major Project

Submitted in partial fulfillment of the requirements

for the degree of

Master of Technology in Computer Science and Engineering(INS)

Submitted By

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MAY 2016

Certificate

This is to certify, that the Major Project entitled **“Development of a software based System for Design of Cryogenic Plate-Fin Heat Exchanger**” submitted by **Puthussery Swathy J. (14MCEI20)**, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Computer Science and Engineering(INS)** of Nirma University, Ahmadabad is the record of work carried out by her under my supervision and guidance. In my opinion, the submitted work has reached a level required for being accepted for examination. The results embodied in this major project, to the best of my knowledge, haven’t been submitted to any other university or institution for award of any degree or diploma.

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Statement of Originality

This is to certify that

I, **Puthussery Swathy J.**, Roll. No.**14MCEI20**, a student of Master of Technology in Information and Network Security (CSE), Nirma University, Ahmedabad , hereby declare that the Major Project Report entitled "**Development of a software based System for Design of Cryogenic Plate-Fin Heat Exchanger**" has been carried out by me under the guidance of Mr. A.K.Sahu and Mr. Haresh Dave, Indian Plasma Research(IPR), Bhatt, Gandhinagar and Prof. Priyanka Sharma, Department of Computer Science and Engineering, Nirma University, Ahmedabad.This Project has been submitted in the partial fulfillment of the requirements for the award of degree Master of Technology (M.Tech.) in **Computer Science and Engineering-Information and Network Security**, Nirma University, Ahmedabad during the year 2015- 2016.
I have not submitted this work in full or part to any other University or Institution for the award of any other degree.

Signature of Student
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Place:

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Abstract

Effectiveness of heat exchangers is one of the important parameters which decide the efficiency of helium refrigerator/liquefiers. To achieve high effectiveness, it is necessary to use plate-fin heat exchangers, which provides very high heat transfer surface area per unit volume of heat exchangers. Such heat exchangers also have benefit of low pressure drop of fluid flowing through it. These cryogenic heat exchangers will be placed within a vacuum chamber having vacuum of about 10-5 mbar and hence compact heat exchangers are preferred to reduce the size and cost of the vacuum chamber. As per the chosen thermodynamic configuration of indigenous HRL, it will have 8 heat exchangers.The design methodologies for the plate-fin heat exchangers have been already developed at IPR and accordingly different database for fluid and material properties are available at IPR. Different design codes have been developed for design and optimization of these different heat exchangers. These codes are developed using excel sheets. It is required to make one code which will be user friendly for design of these different plate-fin heat exchangers. Development of such one code with GUI is the work of this project. It needs to understand the design of these plate-fin heat exchangers, how the performance of the heat exchangers can be worked out and how optimization of different parameters can be done. It needs to understand the heat transfer phenomena in the plate-fin heat exchangers.

Abbreviations

HE	Heat Exchanger
PFHE	Plate Fin Heat Exchanger
LMTD	Log Mean Temperature Difference.
LP	Low Pressure.
HP	High Pressure.
HRL	Helium Refrigeration And Liquefaction
HNL	Hot Number of Layers
CNL	Cold Number of Layers
OFHC	Oxygen Free High Conductivity

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Nomenclature

The next list describes several symbols that will be later used within the body of the document

Greek Symbols

ϵ	Effectiveness(%)	
η	Efficiency(%)	
λ	Longitudinal conduction	$W/m-K$
μ	Dynamic viscosity	$\mu Pa-s$
ρ	Density	kg/m^3
τ	Shear Stress	N/m^2
θ	Deflection Angle	
v	Velocity	m/s

List of Symbols

ΔP	Pressure Drop	bar
ΔP_{fr}	Frictional Pressure Drop	$Pascal$
ΔP_{gap}	Pressure Drop in gaps	$Pascal$
ΔP_{gr}	Gravitational Pressure Drop	$Pascal$
A_x	Free Flow Area	m^2
B	Banking Factor	
b	Sum of Height and thickness of fin	m
C_p	Specific heat	$J/kg-K$
D_h	Hydraulic Diameter	m^2
G	Mass Velocity	$kg/s-m^2$
H	Stack Height	m
h	Heat transfer coefficient	W/m^2K

i	Ineffectiveness	
k	Thermal conductivity of materials	$W/m-K$
L	Flow length of serrated fins	m
L	Length	m
l	Flow length of serrated fins	m
l	length of segment	m
m_c	Mass flow rate of hot stream	kg/s
m_h	Mass flow rate of hot stream	kg/s
N	Number of layers	
n	Fin Density	
P_r	Prandalt Number	
s	Spacing	
S_{eff}	Surface area per parting sheet area	
t	Thickness of Fin	m
T_b	Edge bar thickness	m
T_c	Cap sheet thickness	m
T_p	Plate sheet thickness	m
V	Volume of the Block	m^3
W	Width	m

Chapter 1

Introduction

1.1 Institute for Plasma Research

Institute for Plasma Research (IPR) is the place where efforts are being made in one of the most challenging necessary tasks of this century; “controlling nuclear fusion”. The idea is that the energy can be obtained by fusing nuclei of light elements to produce heavier elements; which have been a process that occurs in the Sun where the fusion of Hydrogen is the principle source of its energy. But the real change is to create this form of energy on earth by recreating the conditions of the Sun in the laboratory.[1] Since last forty years, the pursuit of this goal has been a worldwide effort. Located towards the outskirts of Ahmedabad, the Institute for Plasma Research is a recent entrant in this endeavor and is the prime expression of India’s commitment to this futuristic energy source.

The Institute has a broad charter of objectives to carry out experimental and theoretical research in plasma sciences with emphasis on the physics of magnetically confined plasma’s and certain aspects of nonlinear phenomena. The institute also has a mandate to stimulate plasma research and development activities in the universities and the industrial sector. This institute in its experimental activity has embarked on an ambitious project of building the first Indian Steady State Superconducting (SST-1) Tokamak. The Helium Refrigerator/Liquefiers (HRL) of 1.3 kW capacity for the Steady State Superconducting Tokamak (SST-1) is successfully operating independently along with integrated flow control and distribution system. [1]

1.2 Problem Definition

Different design codes have been developed for design and optimization of these different heat exchangers. These codes are developed using excel sheets. It is required to make one code which will be user friendly for designing and optimizing different counter-flow plate-fin heat exchangers required for helium plant. Development of one such code with GUI is the work of this project.

1.3 Scope

The scope of this project is to create solution which will reduce down the complexity of excel sheet giving a time saving and an easier option to carry out complex calculations. To develop a tool which is efficient and less time-consuming than the present method being done.

1.4 Reasons for new software development

It is difficult to perform analysis and optimization of 2-stream plate fin heat exchangers manually due to various permutations and combinations. Hence pressure drop and heat transfer analysis for given heat duty between hot helium and cold helium layers is done by making program in excel sheet and in C++ to get optimum size of plate n heat exchangers. Optimization of design can be done by plotting graphs and this can be validated with existing plant and through Aspen tech software.

So there arose a need to develop a GUI which reduces down the complexity of performing various calculation while calculating the various stages of heat exchangers. At the same time the software needs to be user friendly meeting all the requirements.

The present software just gives us the glimpse of the final calculations. No other results of the procedure can be obtained hence this software gives us a chance to look into the values of each step.

All the current software are costly and there's need to renew the license every year hence the development of this project is cost effective.

1.5 Project Definition

The objectives for the project are as follows:

- Study the heat exchangers requirements for indigenous development of HRL.
- Study the heat exchangers literature for design of plate-fin and other types.
- Study the property variation of helium fluid in the low temperature zone.
- Study the codes developed earlier for different heat exchangers designs.
- Develop a code which can do design and optimization for different counter-flow plate-fin heat exchangers required for helium plant.
- Develop the GUI facility to make the code user friendly.
- Include sufficient database for better design and optimization.

1.6 Summary

The thesis have been arranged into five chapters. Chapter 1 gives an insight into the definition of project along with its the scope and objectives. the problem definition has been described and discussed in detail.

Chapter 2 is the literature review part of the thesis. It describes in detail description about the heat exchangers and fluid mechanics. It also gives a general introduction to cryogenics refrigeration and liquefaction processes. Plate fin heat exchangers has been described in detail along with its application. Various software have been discussed in details used for designing the heat exchangers.

Chapter 3 entails the proposed architecture of the system, its design, its methodology and proposed model of the system.

Chapter 4 illustrates the results of the software being prepared as the part of the project along with its screen shot and description of the results.

Chapter 5 presents the concluding remarks and the recommendation for future work. And finally the references are presented which have been used for the work being carried out.

Chapter 2

Literature Survey

2.1 Introduction

The chapter includes an description of various types of heat exchangers being used for the applications of cryogenics and their designing method. This chapter also gives us an insight into the fluid mechanics property at lower temperature of liquid Helium.

Heat exchanger are of many types but in the present project the HE used is Plate fin Heat Exchanger hence a detailed survey has been carried out regarding these heat exchangers.

2.2 Cryogenics

Cryogenic is the science and technology associated with generation of low temperature below 120K.[2] The literal meaning of cryogenics is production of icy cold or low temperature. A logical dividing line has chosen by the workers at National Bureau of Standards at Boulder, Colorado for the field of cryogenics is below 123 K. There is a basic difference between Cryogenics and Refrigeration. Cryogenics is working below 120K and Refrigeration is working above 120K but below ambient. The gases, commonly known as cryogens are Nitrogen, Hydrogen, Helium, and Oxygen.[9]

2.3 Helium refrigeration and liquefaction plant(HRL)

Large-scale helium refrigeration/liquefaction plants are used for cooling superconducting magnets. The liquefaction process is achieved by using a modified Claude-cycle. The liquefaction process of existing HRL for tokamak is within the cold box.[9]

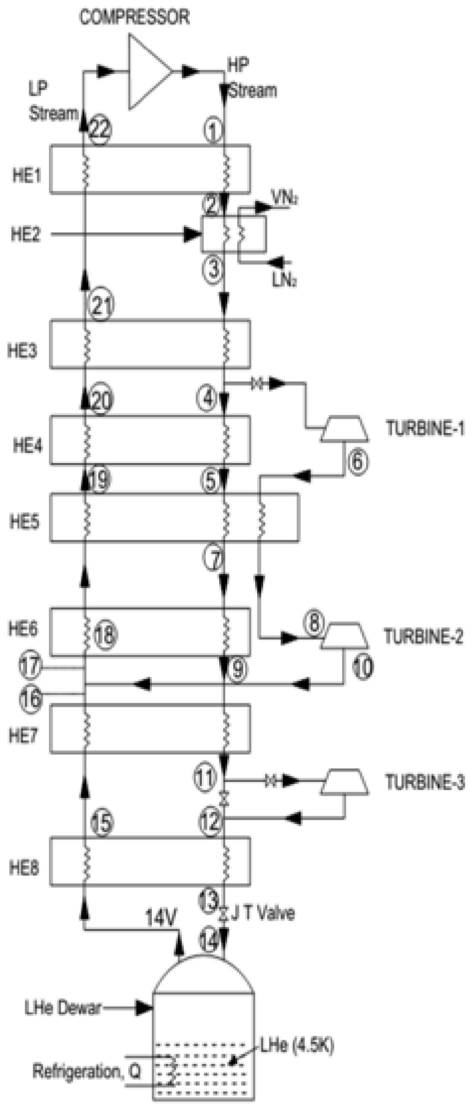


Figure 2.1: Schematic diagram of Helium Refrigeration and Liquefaction plant

2.3.1 Requirement of PFHE in helium refrigeration and liquefaction plant

Liquid helium is required for superconducting magnets used for magnetic confinement of plasma. One of the most critical components of helium refrigerator/liquifier plant is heat exchanger working at cryogenic temperature. A heat exchanger consists of heat exchanging elements such as a core or a matrix containing the heat transfer surface and fluid distribution elements such as headers, manifolds, tanks, inlet and outlet nozzles or pipes, or seals.

The primary function of heat exchangers is the conservation of cold that is allowance of the thermal energy from the incoming compressed gas by transferring energy to the low pressure cold return gas. HE are being used in the applications of cryogenic field which requires higher effectiveness in order to conserve the produced refrigerating effect.[1]

The necessity to use PFHE is for the achievement of higher effectiveness as it produces higher surface area for HE per unit volume (area to volume ratio greater than 700 m2 /m3) of heat exchanger.[23]

2.3.2 Introduction to Plate Fin Heat Exchangers

PFHE- Plate Fin Heat Exchanger is a type of HE which has a better metal surface and a result improved heat surface area. Fins are defined as the surface of metal which is being interfaced between both the fluids and are characterized by higher fin effectiveness, lower cost, higher compactness and a lower fin weight. PFHE contains parting sheets and corrugated fins which are a pile of alternate sheets and are brazed as a block. Fins make a channel between the parting sheet plates which are used by the fluids flowing between to exchange heat. Hence the parting plate acts as the primary HE surface and the fins acts as the secondary heat transfer surface. The figure below gives us an exploded view of two layers of PFHE and these layers are arranged together to form a heat exchanger in a monolithic block.[22]

2.3.3 Requirement of Plate Fin Heat Exchanger(PFHE) in HRL

The primary function of the heat exchangers is to conserve cold that is, allow the thermal energy from the compressed incoming gas by transferring energy to the low pressure cold return gas. Heat exchangers used in cryogenic applications required to have high effectiveness to conserve the refrigerating effect produced.[1] For some cases, HE with effectiveness less than 90 percent can be a reason for failure of helium plant to produce liquid helium.

To achieve such high effectiveness, it is necessary to use plate fin heat exchangers, which provides very high surface area for heat exchange per unit volume (area to volume ratio greater than 700 m2 /m3) of heat exchangers. Such heat exchangers also have benefit of low pressure drop of fluid flowing through it, reduced space, weight, support structure and footprint, energy requirement and cost, as well as improved process design, plant

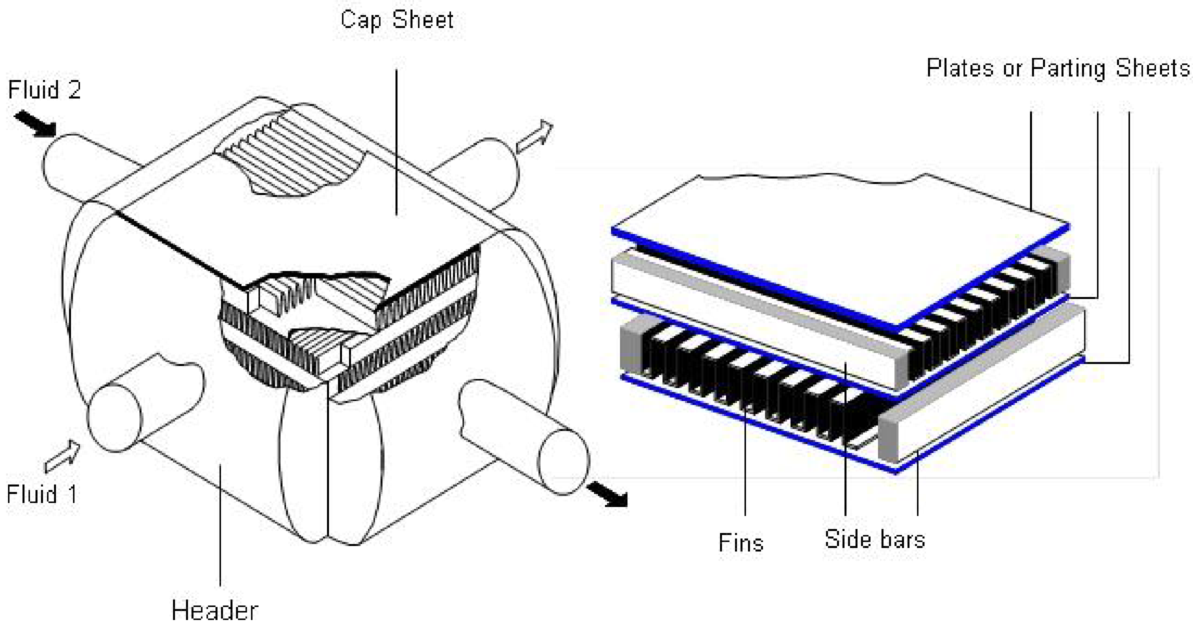


Figure 2.2: PFHE assembly and details [4]

layout and processing conditions compared to all other type of heat exchangers.

Advantages of PFHE

Varying advantages of PFHE over the other heat exchangers are as follows:[22]

- Compactness of PHFE: these exchangers have larger heat transfer surface area per unit volume.
- Effectiveness: More than 95 percent thermal effectiveness can be obtained with these exchangers.
- Temperature Control: They can operate with smaller temperature difference.Local overheating and possibility of stagnant zones can also be reduced by the form of the flow passage.
- Flexibility: Changes can be made by utilising different fluids and conditions that can be modified to adapt to varying design specification.
- Counter-Flow: True counter flow operation is possible in plate fin heat exchanger.

2.3.4 Applications of PFHE

PFHE have been applied in various number of industries which are being used in numerous applications. Mainly being used in the field of cryogenics for cryogenic separation, liquefaction of air, production of petrochemicals and large refrigeration systems. These application covers a large variety of HE scenarios such as

- Separation of air
- Aero-Space
- Air conditioners
- Fuel cells
- Oil and gas processing
- Helium and Hydrogen liquefiers
- Heat Recovery plants
- Automobile radiators
- Process Heat Exchangers
- Ethylene and propylene production plants.
- Process Heat Exchangers

2.4 Flow Arrangement

A PFHE can have flow arrangement wherein the flow can be in parallel or perpendicular direction to on another. When the flow directions are parallel, the streams may flow in the same or in opposite sense as a PFHE can have more than one streams.[22] Basically a PFHE can have three primary arrangements of flow:

- Parallel Flow
- Cross-Flow
- Counter Flow

Thermo-dynamically, counter flow arrangement is the best as it provides highest heat recovery, whereas parallel flow gives the lowest.

2.4.1 Cross Flow

The cross-flow arrangements have the fluids flowing in direction normal to each other hence thermodynamically the cross-flow HE has effectiveness between the parallel and counter-flow arrangement.Only two streams are handled in such flow hence there is no need of distributors.These flow arrangements are typically being applied in automobile radiators and also in aircraft HE.

2.4.2 Counter Flow

In this type of heat exchangers both the fluids flow in opposite direction but they are parallel to each other. Thermally the most effective arrangement is provided by the counter- flow HE as it recovers heat or cold from the process streams. And such an arrangement is more thermodynamically finer to all other flow arrangement and one of the most proficient arrangement as it produces the highest change in temperature in each fluid compared to any other fluid arrangement for the given overall thermal conductance(UA), fluid inlet temperature and flow rates of the fluid. [5]

2.5 Fluid Properties

As the temperature function and flow velocity is varied the heat transfer coefficient (h) varies. Even the local coefficient of heat transfer gets altered with change in the fluid properties. As the length varies due to boundary layer development, the heat transfer coefficient also changes.[22]

Chowdhury and Sarangi ha examined the different effects of fluid properties on the performance of cryogenic HE.[16]. A method has been delineated to incorporate the influence these effects on 2 stream HE performance and a review has been made on this topic is done by Shah.[23] Paenbarger has incorporated the longitudinal conduction of heat effect and the variation of temperature with fluid properties [24] in his computationally intensive numeric model.

Barron [1] stated that the major typical feature of cryogenic process is that all constants become variables. The main effect is given by changes in the specific heat capacity for single-phase flow. This is accompanied by large variations in the heat transfer coefficient, as well as density and viscosity in the case of two-phase ow. For the analysis of high temperature heat exchanger, Kays and London [6] suggested the use of physical properties evaluated at a mean temperature. But this approach is not useful for cryogenic process.

Thermal conductivity of Helium gas:

This is a function of temperature as pressure variation is small compared to the variation of thermal conductivity with pressure variation. [26]

$$K_g = (1.011 * 10^{-2}) + (2.397 * 10^{-9}) * T_{avg}^{0.7220} \tag{2.1}$$

Dynamic Viscosity of Helium gas:

$$\mu = \frac{-(1.855 * 10^{-5}) + (3.258 * 10^{-8})T_{avg} + (4.637 * 10^{-6}) \log T_{avg} + (3.799 * 10^{-5})(T_{avg})^{0.5}}{35.0} \tag{2.2}$$

Specific Heat of Helium gas:

$$\rho = \frac{PM}{RT} \tag{2.3}$$

where,

M = 4.003 gm/mol

R = 8.34 J / molK

2.6 Selection of Materials

At average range of temperature the property of different materials like Aluminium, Copper and Stainless Steel is obtained from the ASM handbook [23,24]. Plate Fin Heat Exchanger is developed using different materials.Generally PFHE's consists of an alloy of Stainless steel or aluminum or copper.But at present Aluminium is being preferred over other materials in cryogenics field as it has lower density, higher thermal conductivity and higher strength at lower temperature. Aluminium maintains excellent strength and ductility at temperature as low as 4.3K. For PFHE manufacturers, its lower weight and higher thermal conductivity compared to other materials make it first choice. The thermal conductivity for materials vary with respect to temperature and is explained by Marquardt and Radebaugh [25].

Usually the fins and the side bars are joined to the parting sheet, using salt brazing technology or by the vacuum brazing technique. In aluminum exchangers the brazing material is made of an aluminum alloy which is of lower melting point and in exchangers made of stainless steel is made of a nickel based alloy.

2.7 Different types of Fins

There are various types of extended surfaces like the plain rectangular, plain trapezoidal, pin fins, serrated fins, louvered fins, perforated fins etc. The offset strip fin geometry and plain rectangular fin geometry are integrated in present work.

2.7.1 Plain Fins

One of the most commonly used of all types of fins in compact heat exchangers are plain fins. The surfaces of plain fins are categorized by uninterrupted passages of flow. Manufacturing of triangular arrangement of straight fins is at high speeds and so its cost is lesser. But they are structurally weaker than the other fin types and hence they have lower heat transfer compared to the rectangular fins mainly in laminar flow. Applications requiring lower pressure drop where plain fins can be used. [9] Due to increased area density, the heat transfer is improved with plain fins rather than rise in the heat transfer coefficient.

2.7.2 Serrated Fins

To elevate the performance of PFHE, the most widely used fin geometry are serrated fins which consists of an interrupted surface. These interrupted surface can be visualized as a set of plain fins which are cut perpendicular at a regular distance to the direction of the flow. Here each segment is serrated by half the fin space laterally. Such interruption in the surface improves the heat transfer because of two different mechanisms.

It actually prevents the continuous growth of the thermal boundary layer by regularly interrupting it firstly. Then the layer of thinner boundary lowers thermal resistance compared to the continuous fin types. Such fins are used lesser in applications having high Reynold's number

2.8 Introduction to various Software

2.8.1 Aspen MUSE

The MUSE program provides you with a facility for analyzing the performance of multi-stream plate-fin heat exchangers, or performing a "first shot" design. The Aspen MUSE calculation has four calculation modes, sometimes referred to by the names of four separate, earlier programs, which were incorporated into Aspen MUSE. These are:

1. Stream-by-stream (common-wall-temperature) simulations [MUSE]
2. Layer-by-layer simulations [MULE]
3. Cross-flow exchanger simulations [MUSC]
4. Design calculations [PFIN]

Stream-by-stream (common-wall-temperature) simulations [MUSE]

The MUSE engine can perform simulation calculations to predict the performance of plate-fin heat exchangers with multiple streams.You must specify the exchangers geometry,and the stream inlet conditions(flow rate, pressure, temperature). MUSE calculates the outlet conditions and heat load of each stream. Calculations are performed at a series of points along the exchangers length, with full allowance being made for variation of stream properties and temperature differences.

MUSE is for plate-fin exchangers with axial flow. It can handle streams with multi-pass cross flow in a large number of constant width passes, which approximate to axial flow.

Aspen MULE

The MULE program is for simulation of a plate fin heat exchangers on a layer by layer basis.It must be supplied with a layer pattern. It will predict temperature profiles through the layer pattern, which can be used to assess how good the layer pattern is.MULE often needs many more iterations than MUSE to achieve convergence, particularly for layer patterns which fail to give uniform temperatures among the various layers.

A key feature of MULE output is information on how metal temperatures vary through the various layers at particular points along the exchangers.MULE offers a representative layer calculation, using the common wall temperature assumptions.MULE does not provide the thermosyphon options.

Aspen PFIN

PFIN can design a plate-fin heat exchangers with multiple streams. It is only necessary to specify the stream inlet and outlet conditions, and stream properties. The program will perform a ‘first shot’ thermal design of the exchangers. It selects appropriate fin types, and determines the number of layers of each stream, and the overall size of the unit. Distributors, nozzles and headers are also designed in outline. PFIN is intended for use by those who wish to explore various options for using plate fin exchangers at an early stage in a process design. There is no need to specify any geometric data when running PFIN.

Aspen MUSC

MUSC is for simulation of the performance of cross flow heat exchangers. These can be either simple single-pass units, or multi-pass units with cross-counter flow. There is a restriction that in any pass, all the cross flow streams must go in one direction, and all the axial flow streams in one direction. MUSC uses the common wall temperature assumption, but as a cross flow program, it determines the variation of stream and metal temperatures both along the exchangers length, and across the exchangers.

2.8.2 Aspen plate fin exchangers software

[21] One of the most recent thermal design software for designing, simulating and rating of a multi stream PFHE is ASPEN plate fin exchanger software which is latest of its kind. These exchangers are important to portable operations of many processing applications. Aspen plate fin exchanger software is one of the core element of Aspen Techs Aspen One process engineering applications. This software takes into consideration the varying losses occurring in the exchangers which include heat losses, header maldistribution flow , longitudinal conduction of heat, header’s pressure loss and many more. This software is a versatile tool for designing PFHE and has been accepted by many industries and institutes.

Features are given as follows:

- Research based correlations
- the calculation includes designing, simulating stream by stream, layer by layer or checking.
- Distributor heat transfer and calculations of pressure drop.
- Offers improved precision and flexibility.
- With complexity of exchangers inlet and outlet, Co-current and counter-current flow.
- Allows designing new HE or simulate the performance of existing exchangers.
- Single phase and two phase calculations .
- Calculations of pressure drop of exchangers, distributors, headers and nozzles.
- Multiple exchangers in series/parallel.
- Helps in designing new HE or simulate the performance of existing exchangers
- Enables us to investigate with different operating scenarios the process alternatives, providing the potential for significant capital savings.

2.9 Diagrammatic representation of PFHE

The schematic diagram of PFHE is as shown in the figure below which shows the entry and exit point of the Helium.The diagram shows a face -on view of the exchanger, showing the size and location of headers, and a side on view showing the depth. Depth information requires fin heights and number of layers to be available. Thermal zone is defined as the effective length is the region of the exchanger where heat transfer is assumed to occur. It is equal to the total length, less a distributor region at each end of the exchanger

For each distributor, it is necessary to identify the distributor type, and the side of the exchanger on which the associated header is located.There are different exit and entry point for the headers and the distributors as shown in the figure below. In diagrams of

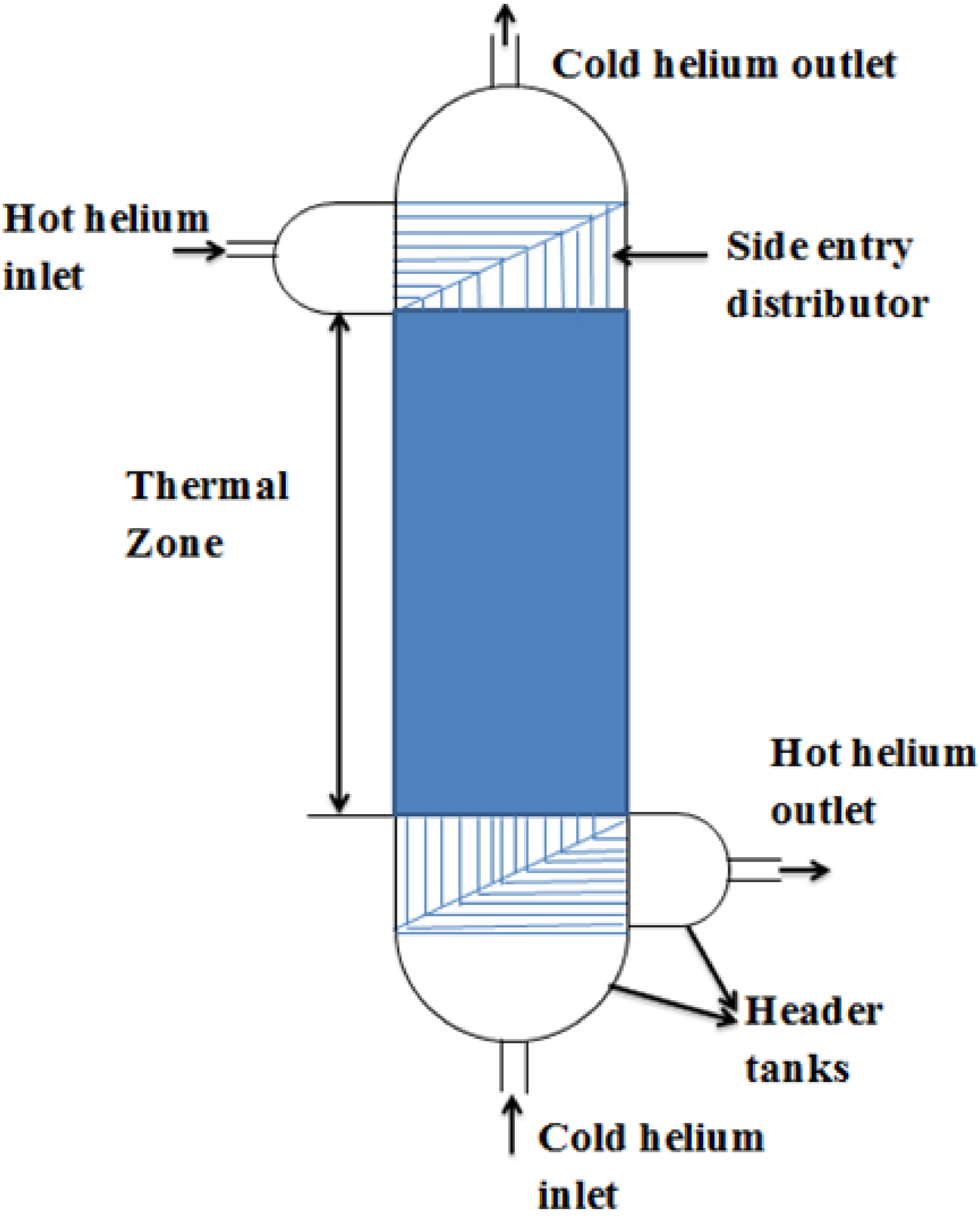


Figure 2.3: schematic diagram of PFHE

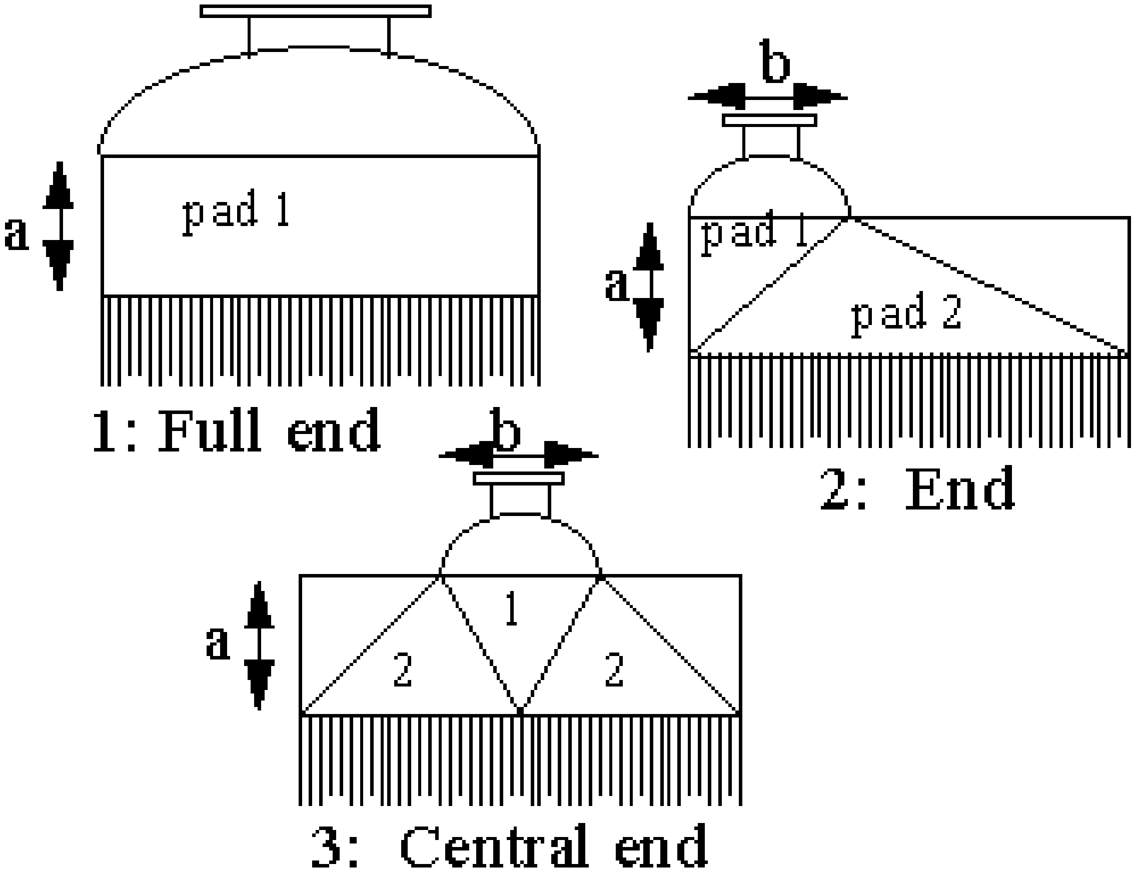


Figure 2.4: End Entry/Exit Headers and Distributors

distributors, headers on the left hand side, at the top of the exchanger are shown. But the equivalent distributors with headers on the right hand side, and/or at the bottom of the exchanger are also possible.It is also necessary to specify either one or two lengths associated with the distributor, dimensions a and b. In all cases dimension a represents the axial length of the distributor, and dimension b is its other key dimension.

The type of inlet and outlet distributor type are, full end, diagonal, end side, central, mitered and indirect. The location of the header can be in left or right side, or in the center, or twin header location or it could be unset.

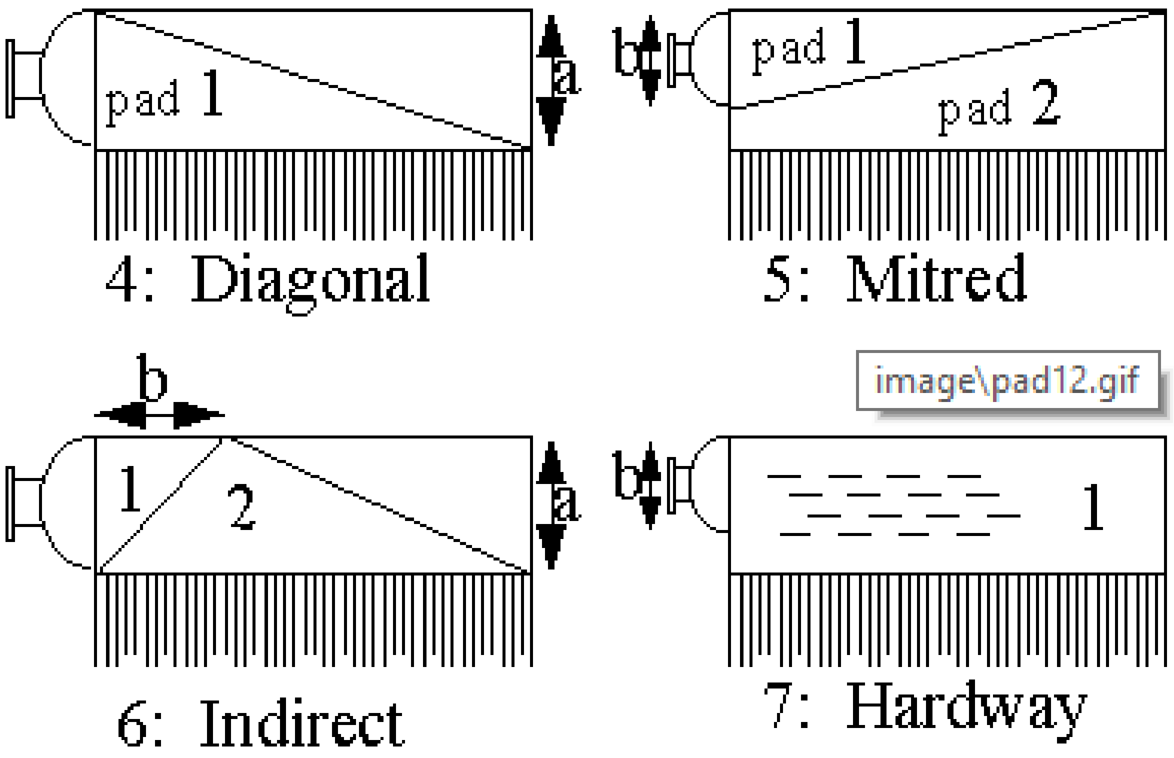


Figure 2.5: Side Entry/Exit Headers and Distributors

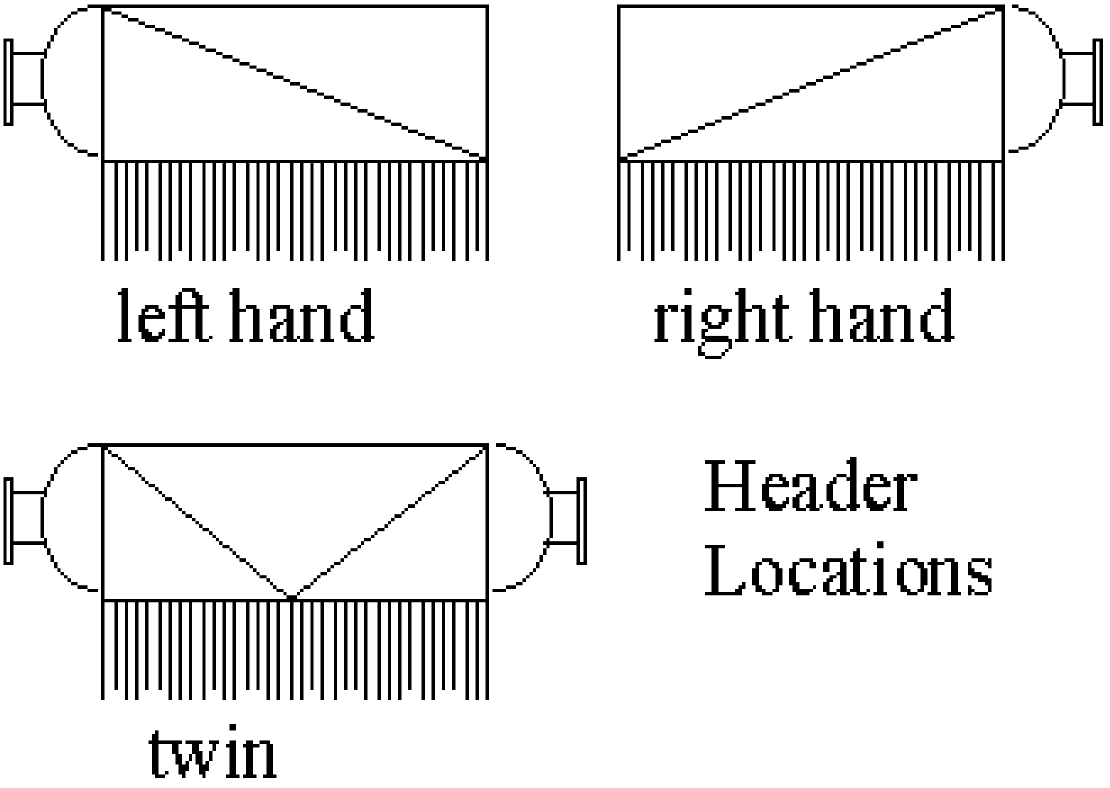


Figure 2.6: Location of the Headers

2.10 Technology Review

This project is developed in .Net Technology using SQL Server Management Studio 2008 as back end.The project is made using the platform Microsoft Visual Studio 2010 and front end C sharp. It does also maintain the database using SQL Express (in-built) as back end. The software includes the much functionality. It required lots of information to be stored. All the information stored in it should be stored in particular manner.
What is .NET? – It is simply Microsoft's vision of "software as a service". The .NET vision can be split into several different areas:[20]

- .NET Framework: the framework is an environment in which you can build, create and deploy your application and web services. It includes three major building blocks the common language run time for execution of application in any language, a set of framework classes and ASP.Net.
- .NET Products: All of the Microsoft's major products from windows to visual studio and office are being integrated into the vision and they will all offer services that will allow greater integration between products relaying on XML as a language to describe the data and SOAP as a protocol for transmission of data among products.
- .NET Services: this is for the third party developers to create corporate services on the .NET framework.

The .NET platform provides fully managed, protected and feature rich application execution environment, simplified development and deployment and seamless integration with a wide variety of languages.

2.11 Summary

This chapter gives us an insight into various types of heat exchangers their functionalities, survey on the findings and gives us prerequisite knowledge on the facts and figures required to carry out this project.

Chapter 3

Implementation Methodology

The chapter includes a detailed study of development of the project for designing and optimizing the thermal zone of cross flow heat exchangers. The flow of the whole system has been described in detail alongwith its methodology. Implementation of the project has been explained in a systematic approach.It includes the design calculation for obtaining the length of the HE, volume of the block, height of the HE, pressure drop analysis, axial conduction calculations, segmentation and optimization.

3.1 System Architecture

The system follows an entire sequence of steps which indicates the phases of heat exchangers. An individual window is prepared for each phase collecting the requirements and performing the calculations for each step.

As shown in the figure above the user is able to interact with the GUI of the software.

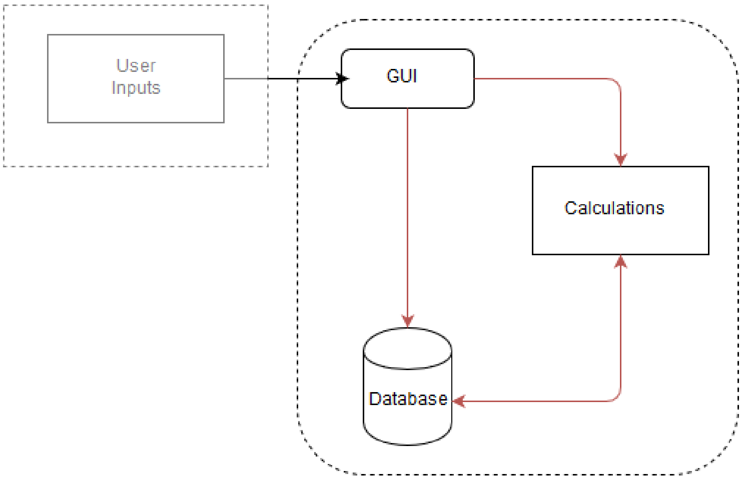


Figure 3.1: System Architecture

the GUI interacts with the database of the system as it stores the values entered by the user and at the same time with the calculation part wherein the user defined values are being used. The calculation also gets stored into the database at the same time displayed onto the GUI so that the user can get an insight into the results.

3.2 Design

The system is basically divided into two phases namely sizing and rating.The sizing part deals with the user entering most of the parameters and all other parameters being calculated. The rating part deals with the part where the we get lesser number of values from the user which is different to that of the sizing phase and define the remaining profiles. The design overview of the system:

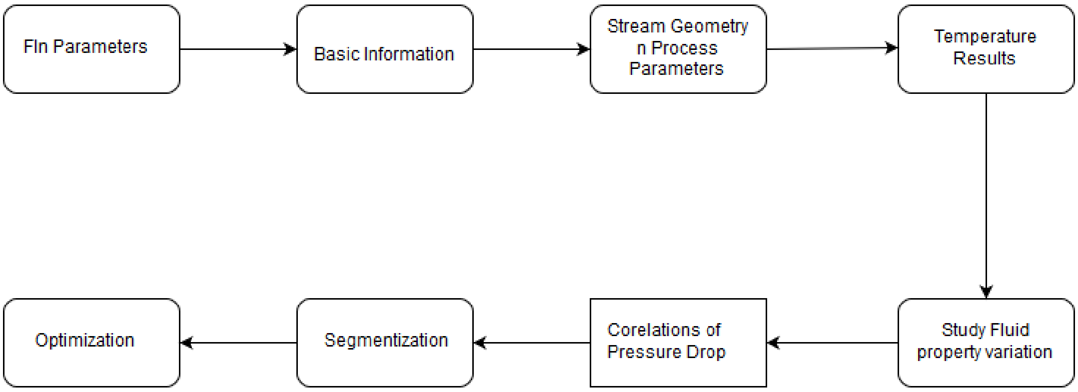


Figure 3.2: Block diagram

- Fin parameters is chosen and optimized according to the various available dimensions. Selection of the fins whether serrated or plain is required to be selected.
- Selection of material which includes Aluminium(AL-3003) and Copper(OFHC). Basic information includes the calculation of Tensile Stress, Shear Stress, parting sheet thickness, cap sheet thickness and thermal conductivity.
- Stream geometry and process parameters involve various user defined values.The dimensions are assumed according to our required dimensions and should be able to withstand operating pressure. Number of layers for each side need to be assumed.
- Temperature profiles is another important phase of HE.Here users enter three different temperature values and rest are calculated alongwith average temperature

and temperature difference.

- Properties on each fluid side are calculated from the Van Sciver. By taking average mean temperature the properties are to be found for both hot helium and cold helium stream.
- In this temperature zone, there is large non-linear property variations in the helium fluid which will be accounted and design procedures are followed for each segment and graph is being generated as per the values of each segment.
- All the set parameter need to be optimized as per the pressure drop criteria and as per the iteration, graph is generated for the varying Δ P and stack height.

3.3 Process Flow

The analysis and optimization is a difficult task for 2-stream plate fin heat exchanger manually due to the presence of a number of permutations and combinations. Hence pressure drop and heat transfer analysis for given heat between hot helium and cold helium layers is done by making programs with complex calculations in excel sheet and in C++ to get optimum size of plate fin heat exchanger. Aspen Tech software is available for the Optimization of design by plotting graph.

The project work is to design a software which would enable the exclusion of excel sheet use and exclude the requirement of C++ programming each time a new parameter need to be validated.

3.3.1 Methodology

The project flows into two section namely sizing and rating. Sizing part involves the user defining various parameters and then calculating various results and finally determining the length, height, width, pressure drop and axial conduction calculations. Rating part involves assumptions of different parameters based on the few user defined values. In this part the values defined by the users are comparatively less as compared to sizing but the

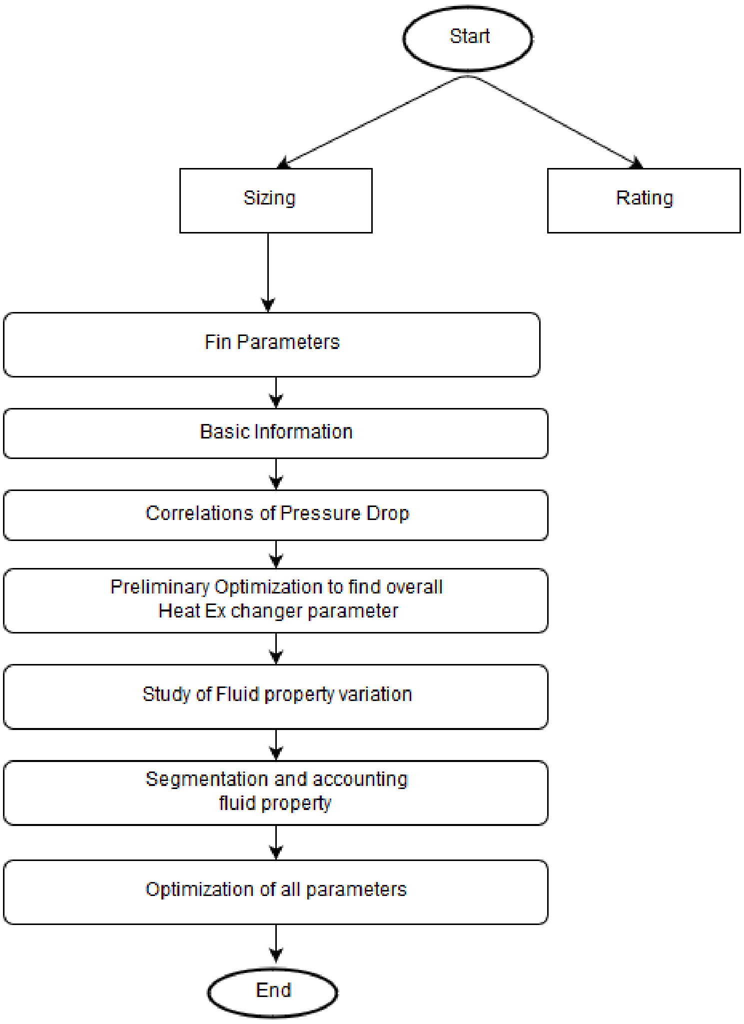


Figure 3.3: Procedure of the Design

calculations remain almost same.

Step 1 **Selection of fin parameters:**

The fin parameters includes values which need to be entered by the user which describes the structuring if the fins like fin serration length (l), fin height(h), fin density (n) and fin thickness(t). From these user defined values we calculate the fin pitch (s) and plate spacing (b).

Fin Pitch(s):

$$s = (1/n) - t \tag{3.1}$$

Plate Spacing (b):

$$b = h + t \tag{3.2}$$

Step 2 **Stream Geometry and Process parameters:**

It includes the parameters which are all user defined and is required in the further calculations.

Step 3 **Assumptions of dimensions:**

The dimensions are assumed according to our required dimensions and should be able to withstand operating pressure. Hence, Length (in the direction of flow to be kept in vertical direction) and Width and Height not to exceed 1 m x 0.5 m x 0.5 m.

Step 4 **Basic Information:**

Material Selection and accordingly its property is calculated.Plate fin heat exchangers can be made in a variety of materials. Aluminium is mainly preferred in the field of cryogenics, as it has higher conductivity, strength at lower temperature profiles and lower cost. Aluminium maintains excellent strength and ductility to temperatures as low as 4.3 K. Other than aluminum, copper(OFHC) is given as an option.[25]

Thermal Conductivity of Aluminium (Km):

$$\begin{aligned}\log K = a + (b * \log(T_{avg})) + (c * \log(T_{avg})^2) + (d * \log(T_{avg})^3) + (e * \log(T_{avg})^4) + (f * \log(T_{avg})^5) \\ +(g * \log(T_{avg})^6) + (h * \log(T_{avg})^7) + (i * \log(T_{avg})^8)\end{aligned} \tag{3.3}$$

where,

a=0.63736, b=-1.1437, c=7.4624, d=-12.691, e=11.9165,

f=-6.1872, g=0.63939,h=-0.1727 and i=0.

Thermal Conductivity of Copper (Km):

$$\log K = \frac{a + (c * \log(T_{avg})^0.5) + (e * \log(T_{avg})) + (g * \log(T_{avg})^1.5) + (i * \log(T_{avg})^2)}{(1 + b * \log(T_{avg})^0.5) + (d * \log(T_{avg})) + (f * \log(T_{avg})^1.5) + (h * \log(T_{avg})^2)} \tag{3.4}$$

where,

a=1.8743, b=-0.41538, c=-0.6018, d=0.13294, e=0.26426,

f=-0.0219, g=-0.051276, h=0.0014871, i=0.003723.

Step 5 **Tensile Stress and Shear Stress**

Based on the UTS(Ultimate Tensile Stress) we are able to calculate the tensile stress and Shear stress with following equation.

$$TensileStress(T) = \frac{UTS}{4} \tag{3.5}$$

$$ShearStress(Ts) = \frac{TensileStress}{2} \tag{3.6}$$

Step 6 **Free Flow Area and Frontal Area**

Calculation of free flow area or the frontal area is carried out by taking into account the width required (Weff) and taking into account the edge bar minimum thickness (Tb) that is required to sustain the operating pressure, which are given by following formulas,

Effective width:

$$W_{eff} = W - (2 * Tb) \tag{3.7}$$

Free flow area:

$$A_x = W_{eff} * (b - t)(1 - nt) \tag{3.8}$$

Step 7 **Fin geometry**

Fin geometry is chosen and optimized according to the various available dimensions

.Here two types of fin geometries Plain rectangular fin and Offset strip fin are taken

- Plain rectangular fins- The plain fin used can be assumed as rectangular. However, in reality the rectangular geometry of fins don't have sharp edges but rather rounded ones.[6]

  Hydraulic diameter (Dh) is calculated by:

$$D_h = \frac{2 * (b - t) * (1 - nt)}{1 - nt + (n * (b - t))} \tag{3.9}$$

- Offset strip fins- Typically, many offset strip fins are arrayed in the flow direction. Their surface geometry is described by the flow n length l, height h, transverse spacing s, and thickness t.

  Hydraulic diameter (Dh) is calculated by:

$$D_h = \frac{4shl}{2 * (sl + hl + ht) + st} \tag{3.10}$$

Step 8 **Fanning friction factor (f), Colburn factor (j) and Convective Heat Transfer Coefficient (h) analysis.**

For the determination of convection heat transfer coefficient (h), some dimensionless numbers will be introduced. The Reynolds number (Re) is interpreted as a flow characteristic proportional to the ratio of ow momentum rate to viscous force for a specified geometry. Re is also called as flow modulus and defined for internal flow as :

$$Re = \frac{GD_h}{\mu_h} \tag{3.11}$$

$$G = \frac{m}{A_x} \tag{3.12}$$

Manglik bergles correlations, 120 < Re < 10^4

For colbourn factor [15],

$$j = 0.6522 * (Re)^{-0.5403} * (\frac{s}{h})^{-0.1541} * (\frac{t}{l})^{0.1499} * (\frac{t}{s})^{-0.0678} * [x]^{0.1} \tag{3.13}$$

where,

$$x = 1 + 5.269 * 10^{-5} * (Re)^{1.34} * (\frac{s}{h})^{0.504} * (\frac{t}{l})^{0.546} * (\frac{t}{s})^{-1.055} \tag{3.14}$$

For fanning friction factor,

$$f = 9.6243 * (Re)^{-0.7422} * (\frac{s}{h})^{-0.1856} * (\frac{t}{l})^{0.3053} * (\frac{t}{s})^{-0.2659} * [x]^{0.1} \tag{3.15}$$

where,

$$x = 1 + 7.669 * 10^{-8} * (Re)^{4.429} * (\frac{s}{h})^{0.92} * (\frac{t}{l})^{3.767} * (\frac{t}{s})^{0.236} \tag{3.16}$$

Step 9 **Thermo Physical properties of the Fluid**

Calculations of the properties of each fluid is with the help of Van Sciver. By taking average mean temperature the properties are to be found for both hot helium and cold helium stream.

Step 10 **Effectiveness**

Effectiveness measures the thermal performance of HE.Further it is defined as the ratio of the actual heat transfer rate to the thermodynamically limited heat transfer rate. [8]

$$\epsilon = \frac{Actual\ heat\ transfer}{Maximum\ possible\ heat\ transfer} \tag{3.17}$$

$$\epsilon = \frac{C_h(T_{hi} - T_{ho})}{C_{min}(T_{hi} - T_{ci})} = \frac{C_c(T_{co} - T_{ci})}{C_{min}(T_{hi} - T_{ci})} \tag{3.18}$$

NTU, the number of transfer units, nominate the non dimensional heat transfer size of the HE. It calculates the rate of heat transfer being carried out.

$$NTU = \frac{UA}{C_{min}} \tag{3.19}$$

Step 11 **Fin efficiency (η f)**

In plate fin heat exchangers, the surface area can be increased using fins and thereby it increases the total heat transfer rate. Efficiency of a fin is:

$$\eta f = \frac{tanh(x)}{x} \tag{3.20}$$

$$x = h\sqrt{(\frac{hB}{2tk})} \tag{3.21}$$

where,

k= Thermal Conductivity of material

B= Banking Factor

Usually, the average value used is 2.25 but in our case, double banking stacking pattern is used. Hence, Banking factor for hot stream is taken as 1, whereas for cold stream it is taken as 4.

Step 12 **Overall Effective Heat transfer Surface Area per Parting Sheet Surface Area**

Considering Serrated fin, for a given stream is given by Manglik and Bergles,

For hot stream,

$$S_{eff} = W_{eff} * ((sl + \eta hl) + (0.5 * ht) + (0.25 * ts)) * (\frac{n}{l}) \tag{3.22}$$

For cold stream,

$$S_{eff} = W_{eff} * ((sl + 2 * \eta hl) + ht + (0.5 * ts)) * (\frac{n}{l}) \tag{3.23}$$

Step 13 **Overall thermal resistance**

The following process is followed when heat is being transferred from the hot to cold fluid at steady state:

- Convection towards the hot fluid wall
- Conduction through the wall.
- Subsequently convection from the wall towards the cold fluid.

The total thermal resistance includes the thermal convection resistances of both sides, the wall resistance and fouling resistances of both sides.

$$R_1 = (\frac{1}{h * S_{eff}})_c + (\frac{1}{h * S_{eff}})_h + (\frac{t_p + T_c}{k}) \tag{3.24}$$

$$\frac{1}{R_(total)} = \frac{N_c}{R_1} \tag{3.25}$$

$$UA = \frac{1}{R_total} \tag{3.26}$$

Step 14 **Actual block height**

Its given by the equation

$$H = (N * b) + (2 * Tc) + ((N - 1) * Tc) \tag{3.27}$$

Here,

$$N * b = (N_h * b_h) + (N_c * b_h) \tag{3.28}$$

Step 15 **Log mean temperature difference**

It is found out for counter-flow process, since counter-flow process provides for maximum heat transfer hence log mean temperature difference (LMTD) is given as,

$$\Delta T = \frac{(T_{hi} - T_{co}) - (T_{ho} - T_{ci})}{\ln \frac{(T_{hi} - T_{co})}{(T_{ho} - T_{ci})}} \tag{3.29}$$

Step 16 **Heat transfer analysis**

Under steady state conditions, if the fluids do not undergo a phase change and have constant specific heats and there is negligible heat transfer between the exchanger and its surroundings, for hot and cold fluids, heat transfer rate may be expressed as below :

For Hot fluid:

$$Q_h = m_h \bullet C_h \bullet (T_{hi} - T_{ho}) \tag{3.30}$$

For cold fluid:

$$Q_h = m_h \bullet C_h \bullet (T_{co} - T_{ci}) \tag{3.31}$$

Here,

h = Hot fluid,

c= Cold fluid.

To establish an appropriate mean value of the temperature difference between the hot and cold fluids such that the total heat transfer rate Q between the fluids can be determined from the following equation:

$$Q = UA\Delta T \tag{3.32}$$

Step 17 **Length of the Block**

Length of the block:

$$L = \frac{Q}{UA * LMTD} \tag{3.33}$$

Step 18 **Pressure drop analysis**

Total pressure loss for He stream(Plain Fins) is given as,

$$\Delta P_{total} = \Delta P_{frictional} + \Delta P_{gravitational} \tag{3.34}$$

P_{fr} is single-phase fanning friction loss is given by,

$$\Delta P_{fr} = \frac{4fLG^2}{2D_h\rho} \tag{3.35}$$

$P_g r$ is gravitational loss,

$$\Delta P_{gr} = \rho g \Delta H \tag{3.36}$$

Total pressure loss for He stream (Serrated fins) is given by,

$$\Delta P_{total} = \Delta P_{frictional} + \Delta P_{gravitational} + \Delta P_{gap} \tag{3.37}$$

P_{fr} is single-phase fanning friction loss, and is given as, fictional loss is given by,

$$\Delta P_{fr} = \frac{4fLG^2}{2D_h\rho} \tag{3.38}$$

P_gr is gravitational loss,

$$\Delta P_{gr} = \rho g \Delta H \tag{3.39}$$

P_{gap} is gap loss,

$$\Delta P_{gap} = 2 * \epsilon * (1 - \epsilon) * \frac{G^2}{2\rho} \tag{3.40}$$

where,

$$\epsilon = (1 - \frac{t}{b}) * (1 - nt) \tag{3.41}$$

For Serrated Fins number of gaps is defined by,

$$N_{gap} = \frac{L}{l} \tag{3.42}$$

where,

$$\Delta P_{gap(total)} = \Delta P_{gap} * N_{gap} \tag{3.43}$$

Step 19 **Segmentation**

In this temperature zone, there is large non-linear property variations in the helium fluid which will be accounted in this design work.Effect of fluid property variations have been accounted by making no. of small segments based on temperature range. Design procedures are to be followed for each segment.

Step 20 **Mechanical stresses**

Mechanical aspect is taken into consideration by following method:

Edge bar minimum thickness,

$$T_b = h * (\frac{(1.25 * P)}{\sigma_b})^0.5 \tag{3.44}$$

Fin minimum thickness,

$$t = \frac{P}{\eta_f * \sigma_f} \tag{3.45}$$

Where,

h= gap between sheets

σ_b= allowable tensile stress for bar material

P= relevant stream design pressure

η_f = fin density

Parting sheet and cap sheet minimum thickness,

Simple tensile stress is given by,

$$t_1 = (\frac{h}{2}) * (\frac{P}{\sigma_s}) \tag{3.46}$$

Flexural stress,

$$t_2 = \frac{P}{2 * \sigma_s * \eta_f} \tag{3.47}$$

Shear stress,

$$t_3 = \frac{P}{2 * \tau_s * \eta_f} \tag{3.48}$$

Where,

τ_s =allowable shear stress for sheet material at design temperature.

Step 21 **Axial Heat Conduction**

The design of high-effectiveness heat exchangers for cryogenic applications requires consideration of axial heat conduction in flow direction, through exchanger core and fluids. The ineffectiveness obtained due to longitudinal conduction of heat was expressed by Kays and London which was in terms of longitudinal conduction of heat parameter[18], is defined as below,

$$\lambda = \frac{K_w * A_w}{L * C_{min}} = \frac{\delta * \epsilon}{\epsilon} \tag{3.49}$$

Thus, expression for ineffectiveness without axial conduction is given as,:[20]

$$i = 1 - \epsilon = \frac{1}{1 + Ntu} \tag{3.50}$$

$$\alpha = \lambda * NTU * C_r \tag{3.51}$$

$$C_r = \frac{C_{min}}{C_{max}} \tag{3.52}$$

$$r1 = (1 - (\frac{C_{min}}{C_{max}})) * (1 + (\lambda * NTU * (\frac{C_{min}}{C_{max}}))) \tag{3.53}$$

Step 22 **Optimization**

The main aim of the optimization states to attain with minimum possible size the pressure drop required. Here optimization is done on the basis of pressure drop analysis. The total pressure drop value is compared with the user defined value and iteration is carried out until it reaches the optimum value.

Number of iterations determine the graph of total pressure drop versus stack height. The graph is plotted on the basis of the number of iterations performed.

3.4 Proposed Model

In this section, a brief description of the working environment, the assumptions and the actual working of the project has been explained.

3.4.1 System Algorithm

The proposed algorithm is a step wise description of the definition of the software.This shows the basic procedure in which the program flows making it easier to understand.

Algorithm

Inputs:

Fin parameters, Basic information, Stream geometry, Process parameters, temperature profiles and inlet & outlet condition.

Output:

Results calculating Length, Height and Volume
Temperature Results
Output Fluid Properties
Optimization values and their graphs
Segmentation values and their graphs
Diagrammatic representation of HE
Pressure Drop Calculation
Axial Conduction Results

Steps:

1. Initialize Calculation mode.
2. Initialize number of streams.
3. Initialize fluid composition.
4. Initialize fin parameters.
5. Initialize geometry parameters.
6. Calculate temperature profiles:
   I. Outlet Temperature
   II. Energy Balance
7. Calculate the property of equation
   i. For Hot Fluid
   ii. For Cold Fluid
8. Calculate Effectiveness.
9. Calculate Length, Height and Volume
   a. Assume initial temperature T, L
10. Calculate Pressure Drop
    i. For Hot Fluid
    ii. For Cold Fluid
11. Segmentation of the obtained Length.
    i. Calculate temperature profiles.
    ii. Calculate the length of each segment.
    iii. Calculate ΔP value for hot and cold fluid.
    iv. Generate graph for each of the segments.
12. Optimization on the basis of ΔP calculation

```
Get $\Delta P_{user}$
Do
{
        $\Delta P_{calculated}$
        If($\Delta P_{user} < \Delta P_{calculated}$)
        {
    }
    Else
    {
        No of layers =  no of layers + 1
    }

}while($\Delta P_{user} >= \Delta P_{calculated}$)
```

13. Generate graph for the number of iterations carried out.

3.5 Summary

The above chapter discussed in detail the architecture of the developing system, its proposed model and algorithm along with its designs and the methodology being followed. The diagrams displayed in this chapter shows the various aspects of the system being prepared giving an insight into the project.

Chapter 4

Results and Discussions

- All sample codes in this chapter are run under following specifications:

  Platform : Visual Studio 2010

  Front End : C sharp

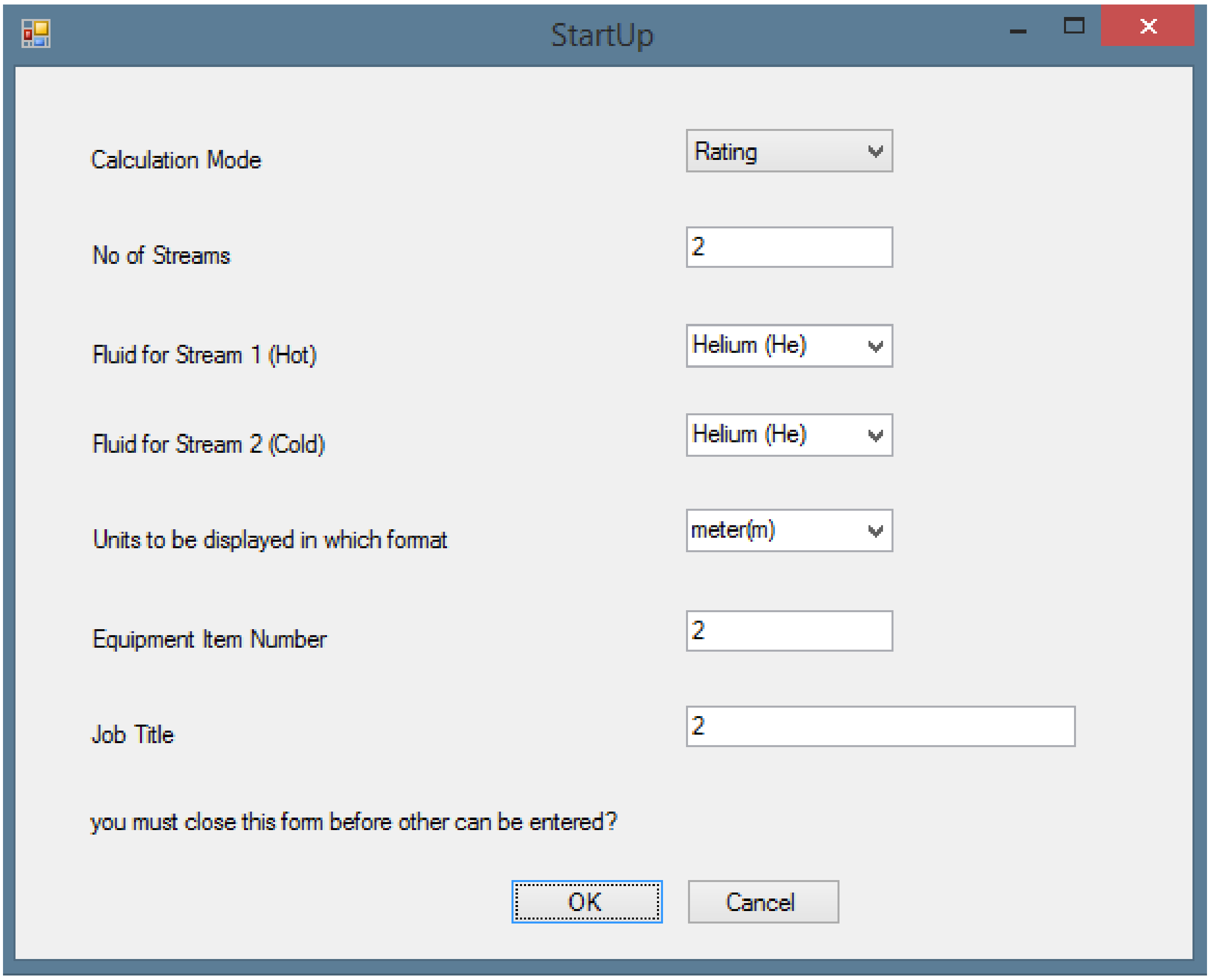
  Back End : SQLExpress
  (in-built)

4.1 Windows displaying various parameters

The following windows shows the value entered by the user as well as the calculated values for varying results. Here it includes the screen shots of these windows and a detailed description of each window.

- **Window 1: Startup**
  - The below screen shows the first phase of HE design which includes the basic information for the design development.
  - Wherein the calculation mode has varying options which gives us to proceed in different designing techniques namely sizing and rating .
  - There is also a selection criteria where you define the fluid for stream 1 and stream 2 so that further properties can be calculated.

- There is an option asking the user to enter the format of the units in which the user wants to enter the values.

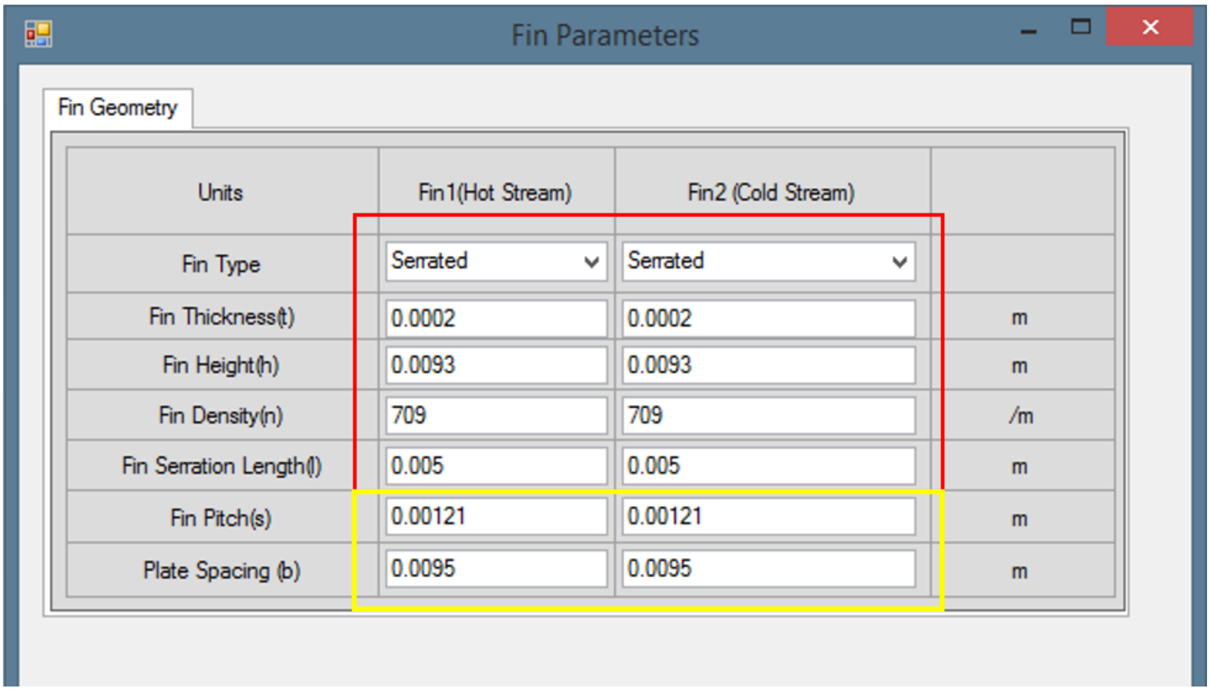


Calculation Mode	Rating
No of Streams	2
Fluid for Stream 1 (Hot)	Helium (He)
Fluid for Stream 2 (Cold)	Helium (He)
Units to be displayed in which format	meter(m)
Equipment Item Number	2
Job Title	2

you must close this form before other can be entered?

Figure 4.1: Startup Window

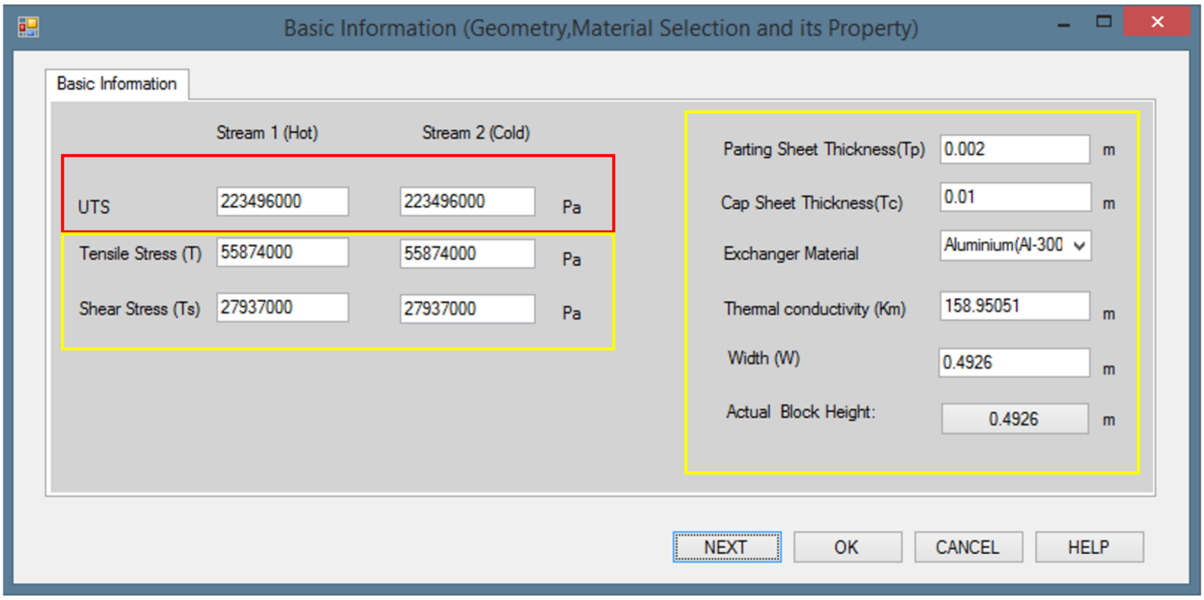
- **Window 2: Fin Parameters**
  - The below screen shows the fin parameters required for various calculations further in the program
  - The user defined parameters are shown in red box in the screen shot which includes fin type, fin thickness(t), fin height(h), fin density(n) and fin serration length(l).
  - The values shown in yellow box indicates the calculated output which are fin pitch(s) and plate spacing(b).



Units	Fin1(Hot Stream)	Fin2 (Cold Stream)	
Fin Type	Serrated	Serrated	
Fin Thickness(t)	0.0002	0.0002	m
Fin Height(h)	0.0093	0.0093	m
Fin Density(n)	709	709	/m
Fin Serration Length(l)	0.005	0.005	m
Fin Pitch(s)	0.00121	0.00121	m
Plate Spacing (b)	0.0095	0.0095	m

Figure 4.2: Fin Parameters Window

- **Window 3: Basic Information Window**
  - The below screen shows the basic information for the design of HE.
  - The user defined parameters are shown in red box which includes UTS and the selection of exchanger material.
  - The values shown in yellow box indicates the calculated output which are Tensile Stress(T), Shear Stress(Ts), Parting Sheet Thickness(Tp), Cap Sheet Thickness(Tc), Thermal conducivity(Km), Width and Actual block height.



	Stream 1 (Hot)	Stream 2 (Cold)	
UTS	223496000	223496000	Pa
Tensile Stress (T)	55874000	55874000	Pa
Shear Stress (Ts)	27937000	27937000	Pa

Parting Sheet Thickness(Tp) 0.002 m

Cap Sheet Thickness(Tc) 0.01 m

Exchanger Material Aluminium(Al-300

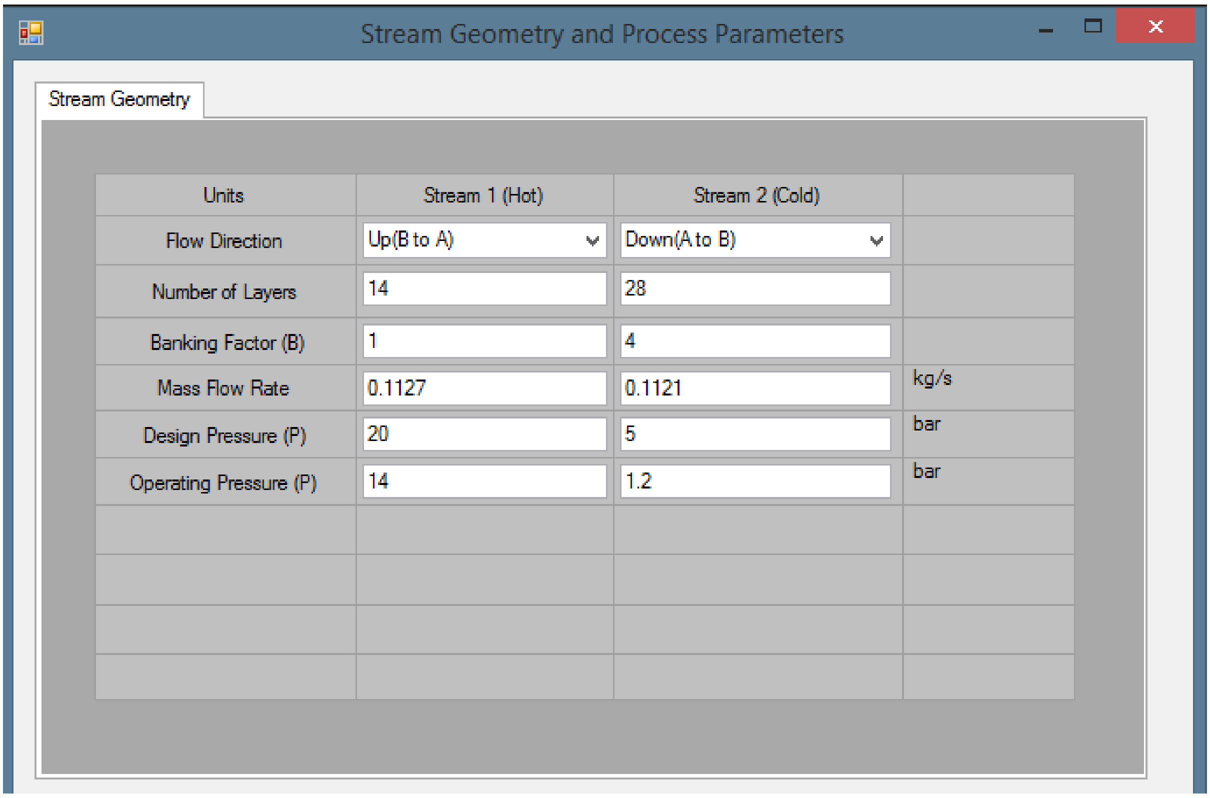
Thermal conductivity (Km) 158.95051 m

Width (W) 0.4926 m

Actual Block Height: 0.4926 m

Figure 4.3: Basic Information Window

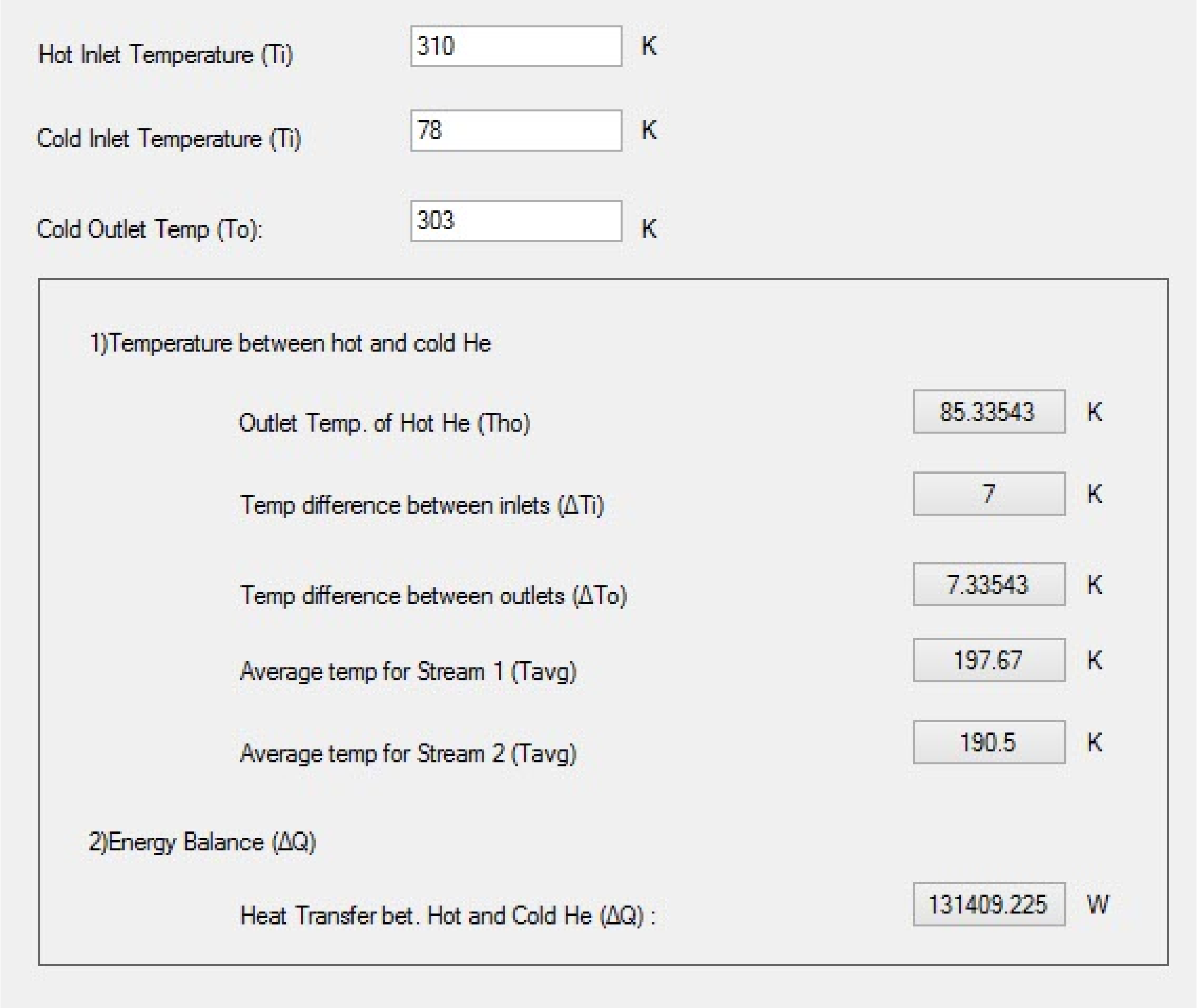
- **Window 4: Stream Geometry and Process Parameters**
  - The below screen shot acquires the value related to stream geometry and process parameters from the user.
  - The user defined parameters includes the number of layers, the mass flow rate, operating pressure, design pressure, banking factor and the flow direction.



Units	Stream 1 (Hot)	Stream 2 (Cold)	
Flow Direction	Up(B to A)	Down(A to B)	
Number of Layers	14	28	
Banking Factor (B)	1	4	
Mass Flow Rate	0.1127	0.1121	kg/s
Design Pressure (P)	20	5	bar
Operating Pressure (P)	14	1.2	bar

Figure 4.4: Stream Geometry and Process Parameters Window

- **Window 5: Temperature Results and Property Data**
  - The below screen shot user defines three temperature value namely the hot inlet temperature(Ti), cold inlet temperature(Tci) and the cold outlet temperature(Tco).
  - Based on the values entered by the user the following parameters get calculated outlet temperature(Tho), temperature difference between inlet and outlet and the average temperature for both streams alongwith the energy balance value.



Hot Inlet Temperature (Ti) 310 K

Cold Inlet Temperature (Ti) 78 K

Cold Outlet Temp (To): 303 K

1)Temperature between hot and cold He

Outlet Temp. of Hot He (Tho) 85.33543 K

Temp difference between inlets (ΔTi) 7 K

Temp difference between outlets (ΔTo) 7.33543 K

Average temp for Stream 1 (Tavg) 197.67 K

Average temp for Stream 2 (Tavg) 190.5 K

2)Energy Balance (ΔQ)

Heat Transfer bet. Hot and Cold He (ΔQ) : 131409.225 W

Figure 4.5: Temperature Results Window

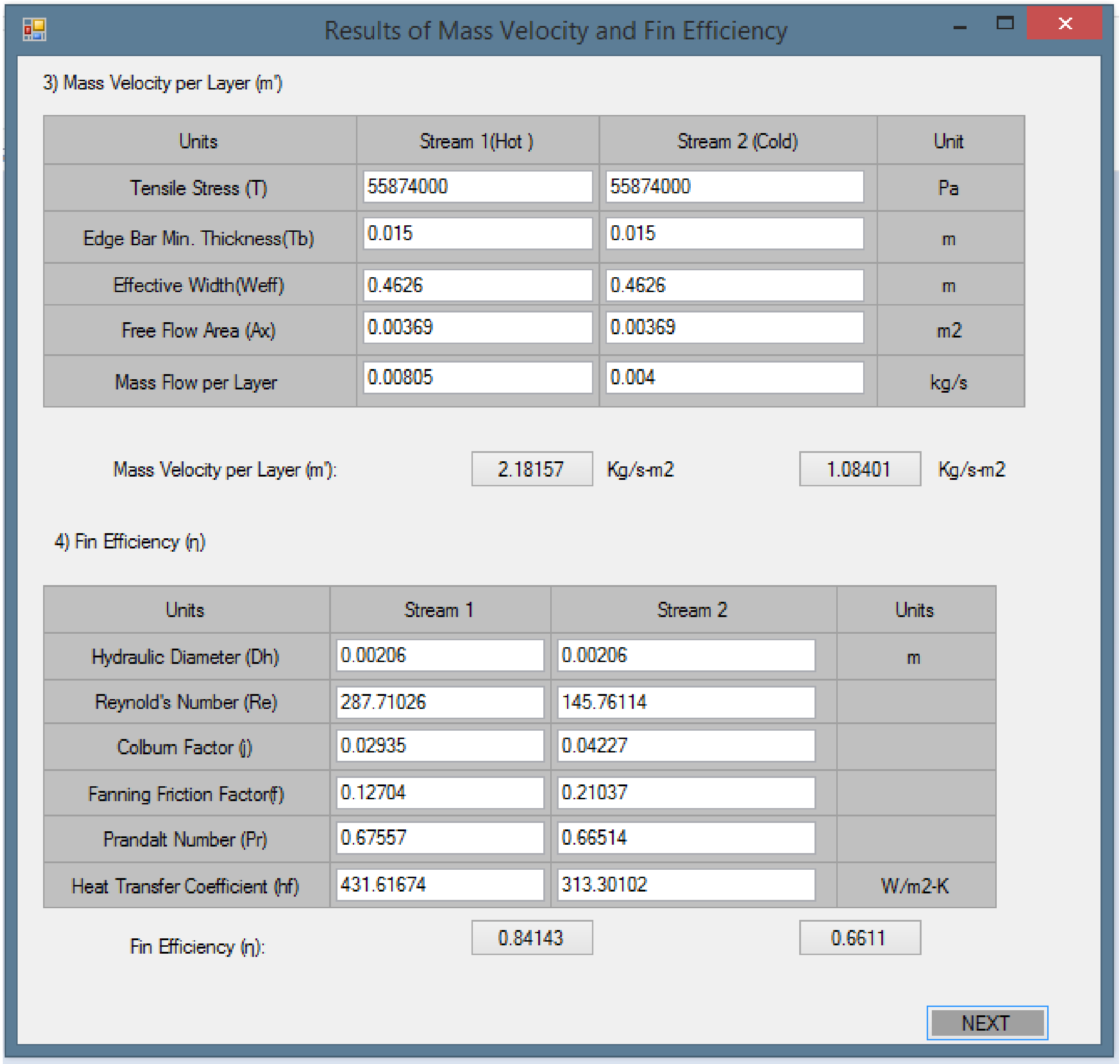
  - Along with the fluid properties like thermal conductivity(Km), Specific Heat, Dynamic Viscosity and Density for each selected fluid by the user for both the streams.

Property Calculation:

	Stream 1 (Hot)	Stream 2 (Cold)	
Select Fluid	Helium (He)	Helium (He)	
Thermal Conductivity (k)	0.12	0.12	W/ m K
Specific Heat (Cp)	5.19	5.21	KJ/Kg K
Dynamic Viscosity (µ)	15.62	15.32	Pa s
Density (ρ)	3.37	0.3	kg/m3

Figure 4.6: Property Data Window

- **Window 6: Results of Mass Velocity and Fin Efficiency**
  - The window displays the calculated result from the user defined values.
  - For the calculation of mass velocity per layer the results required are also displayed namely the Tensile Stress, Edge bar thickness, Effective width, Free flow area and mass flow per layer
  - For the calculation of fin efficiency the results calculated are Hydraulic Diameter, Reynold's number, Colburn factor, Fanning friction factor, Prandalt number and heat transfer coefficient.



3) Mass Velocity per Layer (m')

Units	Stream 1(Hot)	Stream 2 (Cold)	Unit
Tensile Stress (T)	55874000	55874000	Pa
Edge Bar Min. Thickness(Tb)	0.015	0.015	m
Effective Width(Weff)	0.4626	0.4626	m
Free Flow Area (Ax)	0.00369	0.00369	m2
Mass Flow per Layer	0.00805	0.004	kg/s

Mass Velocity per Layer (m'): 2.18157 Kg/s-m2 1.08401 Kg/s-m2

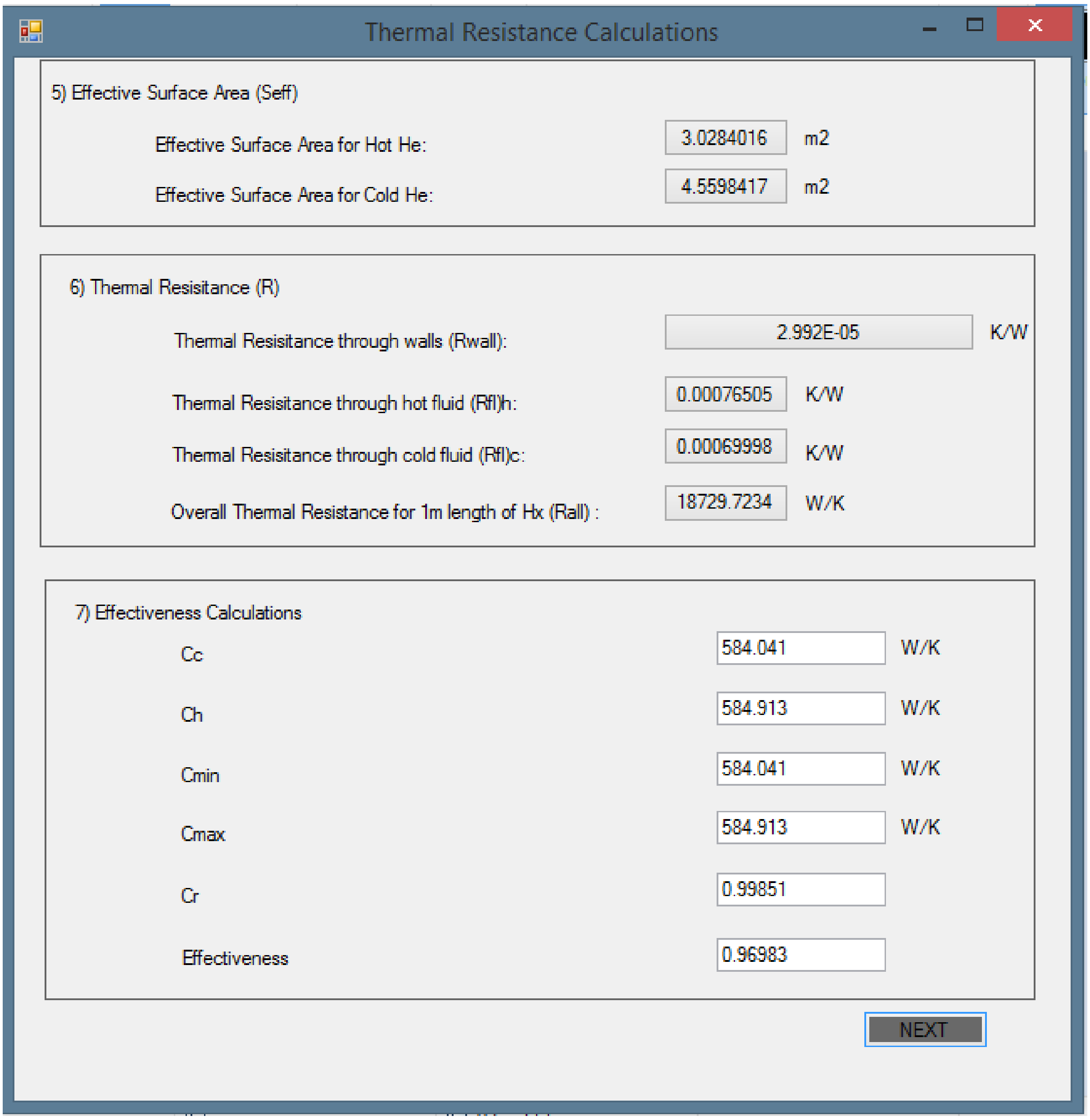
4) Fin Efficiency (η)

Units	Stream 1	Stream 2	Units
Hydraulic Diameter (Dh)	0.00206	0.00206	m
Reynold's Number (Re)	287.71026	145.76114	
Colburn Factor (j)	0.02935	0.04227	
Fanning Friction Factor(f)	0.12704	0.21037	
Prandalt Number (Pr)	0.67557	0.66514	
Heat Transfer Coefficient (hf)	431.61674	313.30102	W/m2-K

Fin Efficiency (η): 0.84143 0.6611

Figure 4.7: Results of Mass Velocity and Fin Efficiency Window

- **Window 7: Results of Thermal Resistance**
  - The window displays the calculated result of Effective Surface Area(Seff), Thermal Resistance(R) and Effectiveness calculations.
  - Effective Surface Area for both the cold and hot streams has been calculated and displayed.
  - For the calculation of thermal resistance the thermal resistance through the walls, thermal resistance through the hot and cold fluid and then the overall resistance have been calculated.



5) Effective Surface Area (Seff)

Effective Surface Area for Hot He: 3.0284016 m2

Effective Surface Area for Cold He: 4.5598417 m2

6) Thermal Resisitance (R)

Thermal Resisitance through walls (Rwall): 2.992E-05 K/W

Thermal Resisitance through hot fluid (Rfl)h: 0.00076505 K/W

Thermal Resisitance through cold fluid (Rfl)c: 0.00069998 K/W

Overall Thermal Resistance for 1m length of Hx (Rall) : 18729.7234 W/K

7) Effectiveness Calculations

Cc 584.041 W/K

Ch 584.913 W/K

Cmin 584.041 W/K

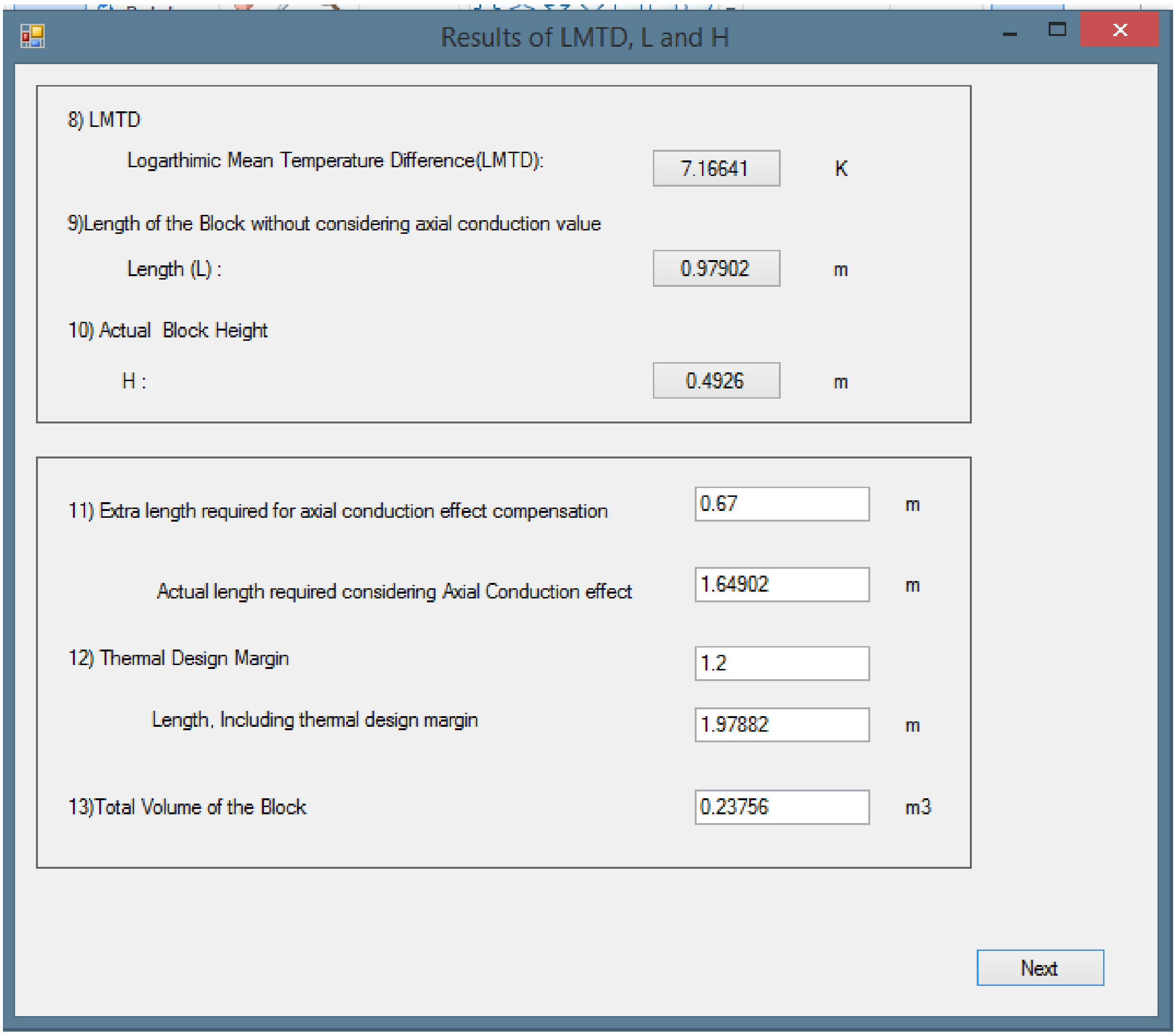
Cmax 584.913 W/K

Cr 0.99851

Effectiveness 0.96983

Figure 4.8: Results of Thermal Resistance Window

- **Window 8: Results of L, LMTD, and H**
  - The window displays the calculated result of length of the thermal zone, LMTD and the height of the block.



8) LMTD

Logarthimic Mean Temperature Difference(LMTD): 7.16641 K

9)Length of the Block without considering axial conduction value

Length (L) : 0.97902 m

10) Actual Block Height

H : 0.4926 m

11) Extra length required for axial conduction effect compensation 0.67 m

Actual length required considering Axial Conduction effect 1.64902 m

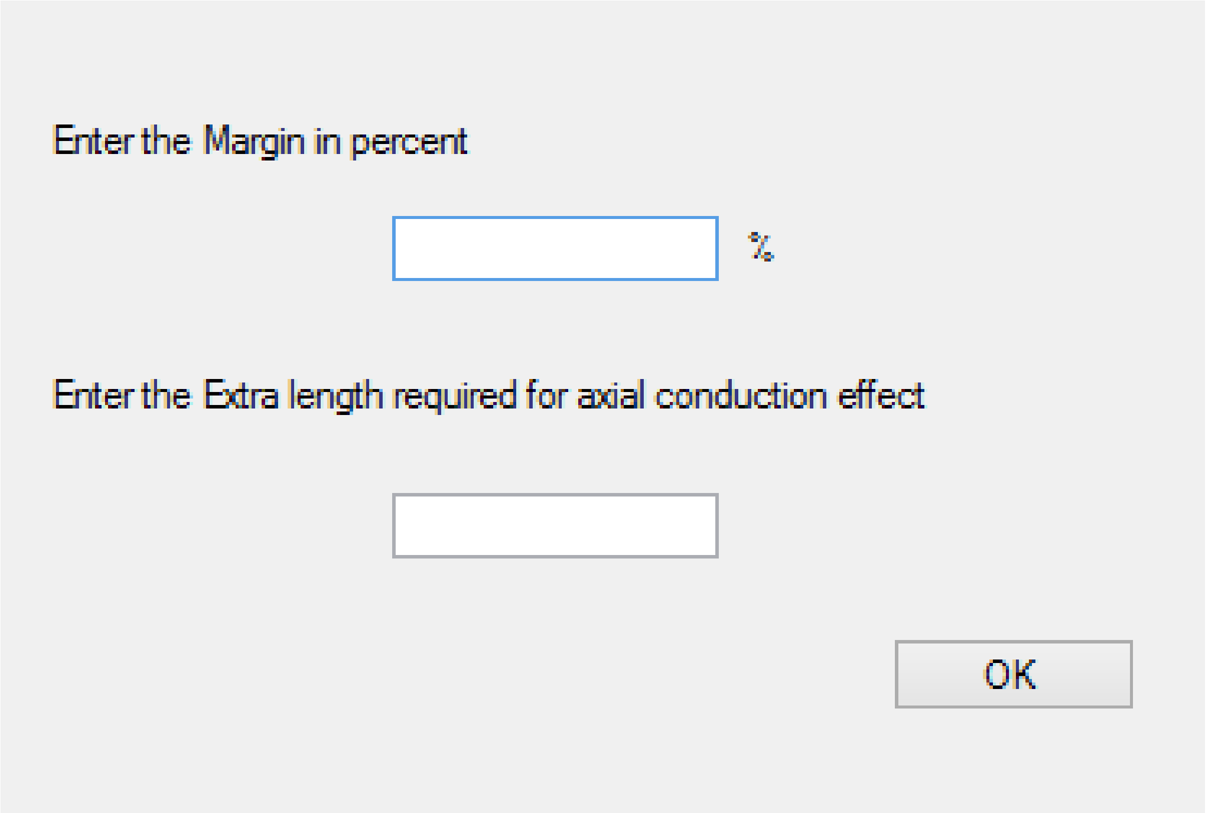
12) Thermal Design Margin 1.2

Length, Including thermal design margin 1.97882 m

13)Total Volume of the Block 0.23756 m3

Figure 4.9: Results of L, LMTD, and H Window

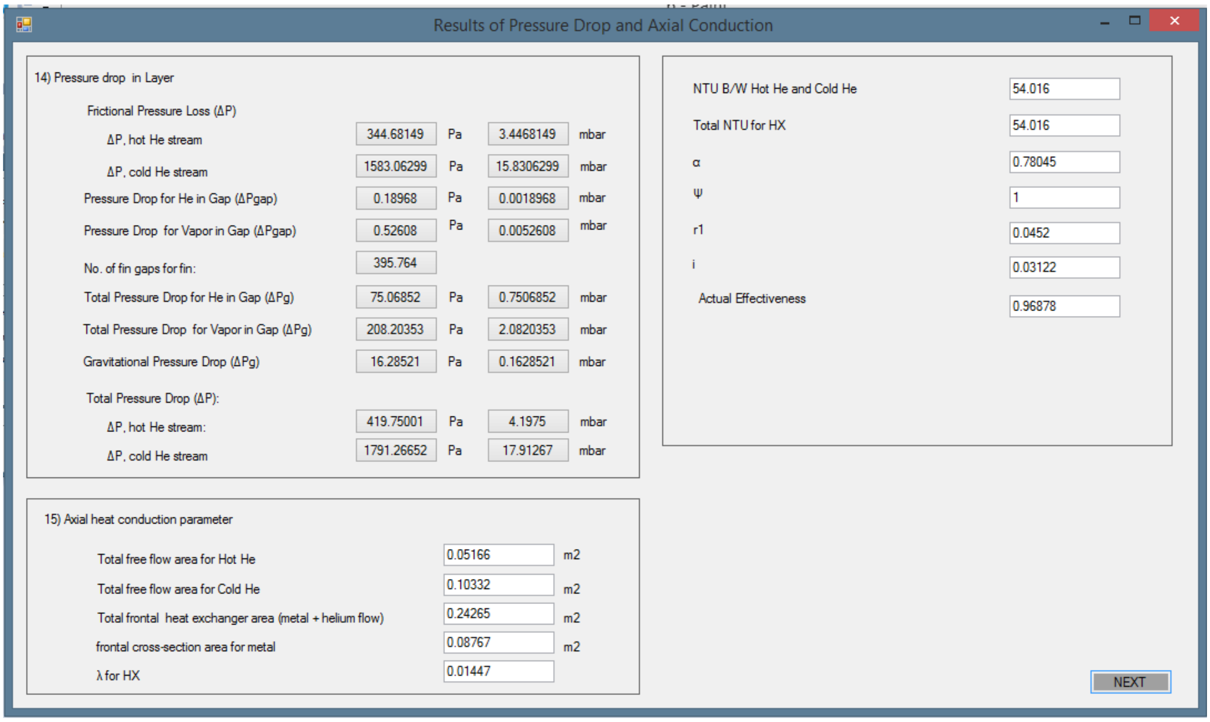
  - Along with which there is a user defined window which gets the value the thermal design margin and the extra length for axial conduction effect.


Enter the Margin in percent

Enter the Extra length required for axial conduction effect

Figure 4.10: User Defined Window

- **Window 9: Results of Pressure Drop**
  - The window displays the calculated result of Total Pressure Drop, Axial Heat Conduction parameter and Effectiveness.
  - Total Pressure drop calculation includes frictional pressure drop, pressure drop in gap for Helium and vapour, total pressure drop, gravitational pressure drop and number of fin gaps.
  - Axial conduction parameters calculation includes total free flow area, total frontal HE area, frontal cross-sectional area and then the lambda value for HE.



14) Pressure drop in Layer

Frictional Pressure Loss (ΔP)				
ΔP, hot He stream	344.68149	Pa	3.4468149	mbar
ΔP, cold He stream	1583.06299	Pa	15.8306299	mbar
Pressure Drop for He in Gap (ΔPgap)	0.18968	Pa	0.0018968	mbar
Pressure Drop for Vapor in Gap (ΔPgap)	0.52608	Pa	0.0052608	mbar
No. of fin gaps for fin:	395.764			
Total Pressure Drop for He in Gap (ΔPg)	75.06852	Pa	0.7506852	mbar
Total Pressure Drop for Vapor in Gap (ΔPg)	208.20353	Pa	2.0820353	mbar
Gravitational Pressure Drop (ΔPg)	16.28521	Pa	0.1628521	mbar
Total Pressure Drop (ΔP):				
ΔP, hot He stream:	419.75001	Pa	4.1975	mbar
ΔP, cold He stream	1791.26652	Pa	17.91267	mbar

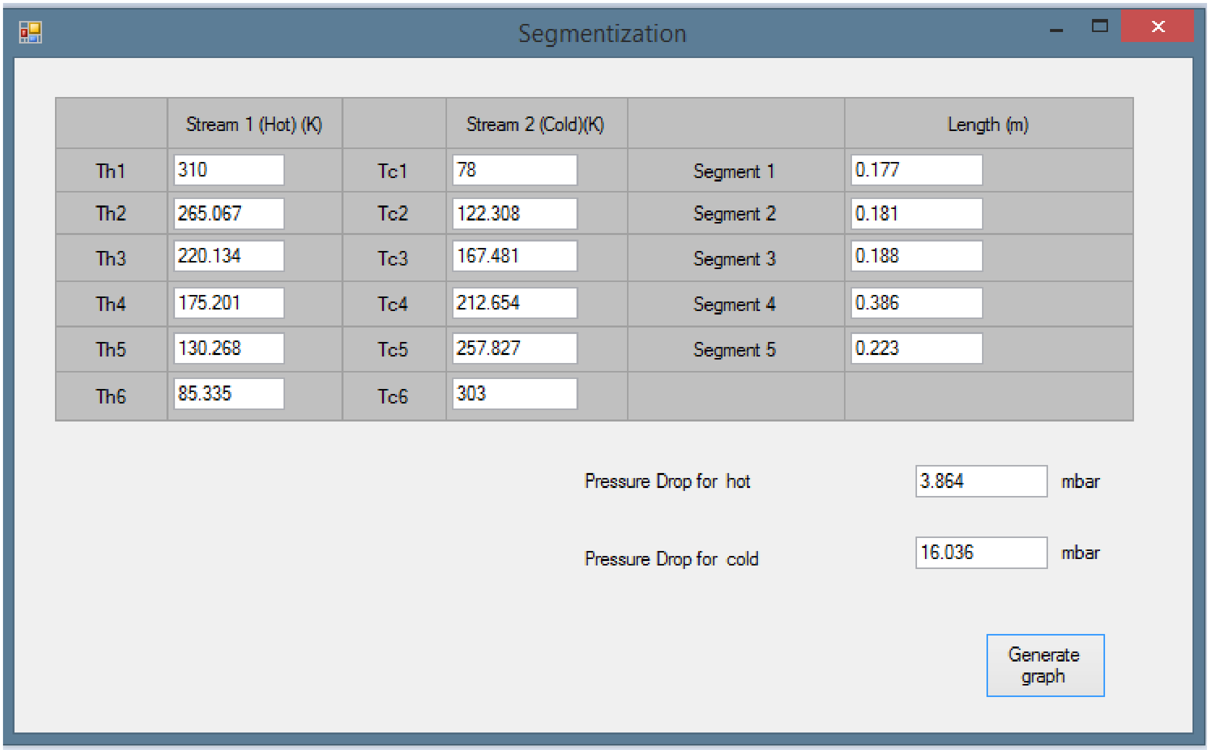
15) Axial heat conduction parameter

Total free flow area for Hot He	0.05166	m2
Total free flow area for Cold He	0.10332	m2
Total frontal heat exchanger area (metal + helium flow)	0.24265	m2
frontal cross-section area for metal	0.08767	m2
λ for HX	0.01447	

NTU B/W Hot He and Cold He	54.016
Total NTU for HX	54.016
α	0.78045
ψ	1
r1	0.0452
i	0.03122
Actual Effectiveness	0.96878

Figure 4.11: Results of Pressure Drop Window

- **Window 10: Segmentation**
  - The window calculates the segments and displays the inlet and outlet temperature for each segments alongwith its calculated length and the overall pressure drop after segmentation.



	Stream 1 (Hot) (K)		Stream 2 (Cold)(K)		Length (m)
Th1	310	Tc1	78	Segment 1	0.177
Th2	265.067	Tc2	122.308	Segment 2	0.181
Th3	220.134	Tc3	167.481	Segment 3	0.188
Th4	175.201	Tc4	212.654	Segment 4	0.386
Th5	130.268	Tc5	257.827	Segment 5	0.223
Th6	85.335	Tc6	303		

Pressure Drop for hot 3.864 mbar

Pressure Drop for cold 16.036 mbar

Figure 4.12: Segmentation Window

  - From the calculated values of temperature range and length a graph is plotted each for the hot and cold stream.

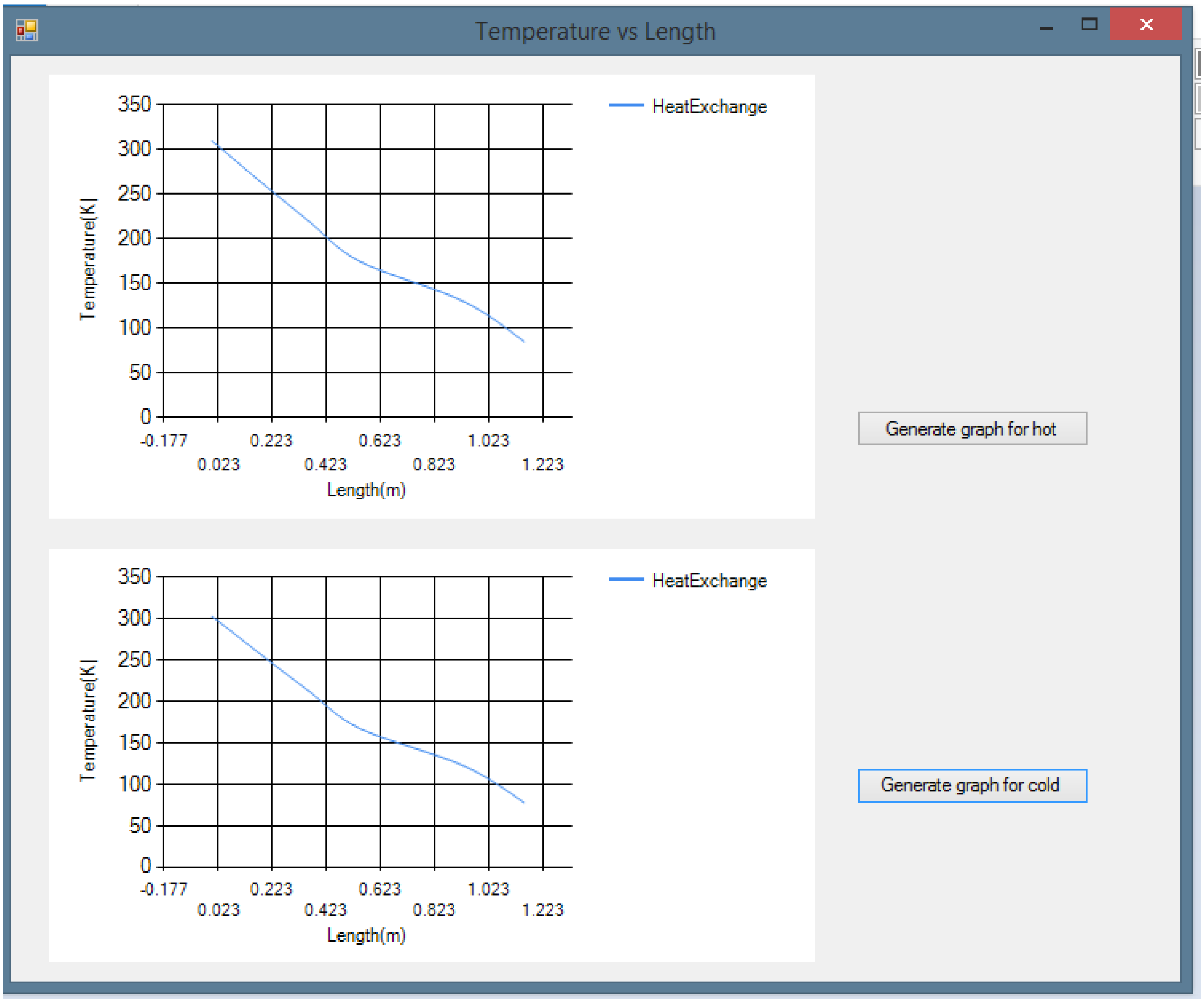
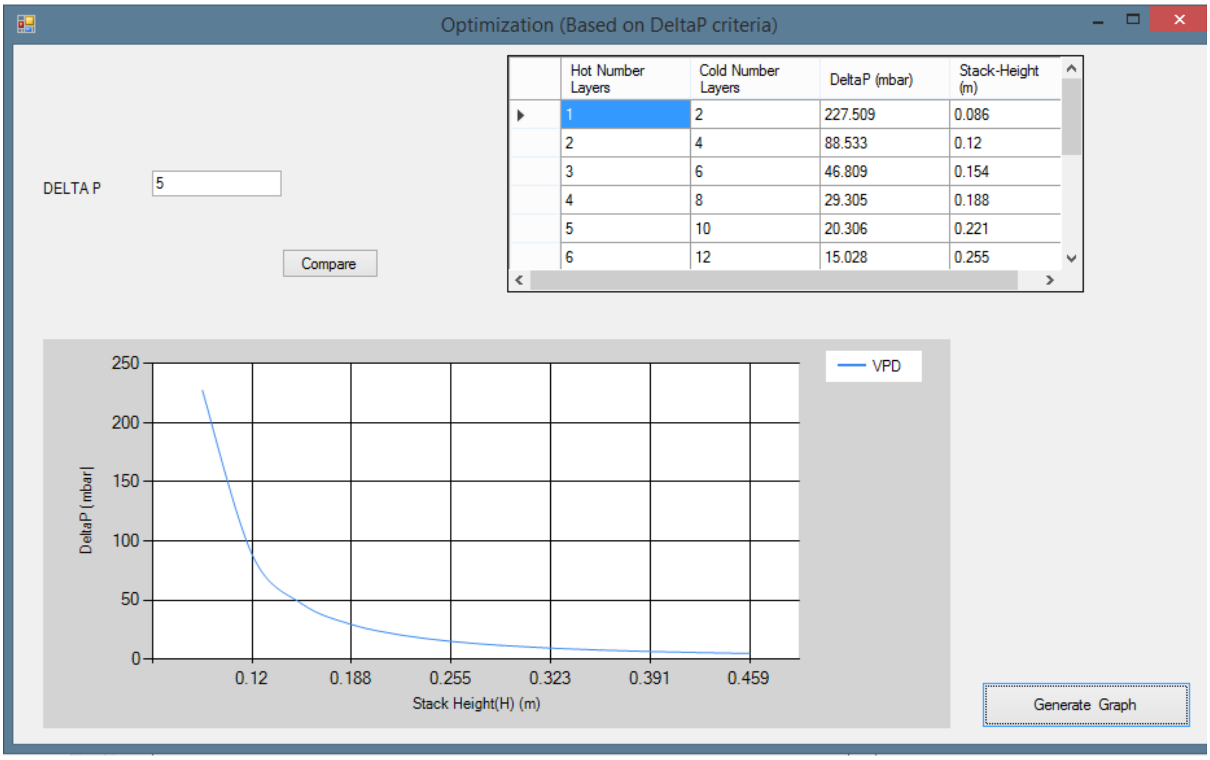


Figure 4.13: Temperature versus Length Window

- **Window 11: Optimization**
  - The window takes the δP value from the users and then starting with a pre-defined values of layers it increases the number of layers with each iteration comparing the δP of each iteration with the user defined value.
  - Thereafter from the values calculated in each iteration is used to plot a δP versus Stack Height graph.



DELTA P 5

Hot Number Layers	Cold Number Layers	DeltaP (mbar)	Stack-Height (m)
1	2	227.509	0.086
2	4	88.533	0.12
3	6	46.809	0.154
4	8	29.305	0.188
5	10	20.306	0.221
6	12	15.028	0.255

Figure 4.14: Optimization Window

4.2 Summary

The chapter gives a detailed pictorial representation of the project. Most of the windows have been explained alongwith its functionalities. This chapter includes an overview of the developed software in detail and gives us an insight towards the feel and look of the software

Chapter 5

Conclusion and Future Work

5.1 Conclusion

In the present study the software alongwith the GUI for calculating the parameters of the thermal zone of the 2-stream counter-flow Plate Fin Heat Exchanger has been carried out.It can be concluded from the present work that:

- The project is divided into two parts namely rating and sizing wherein the sizing part calculates all the parametrs based on the values being entered by the users and the rating part involves calculation of all the parameters with minimal input from the users.
- A detailed study on Heat Exchangers requirement for indigenous development of HRL alongwith heat exchangers literature for design of plate-fin.
- A extensive study has been carried out on the various excel sheets and the formulas being applied in various calculations of developing the design of Heat Exchanger.
- Each and every result calculated in the excel sheet has been displayed systematically and in an user friendly manner.
- Segmentation has been done on the basis of length and its temperature range. Each parameter for the individual segments have been calculated and the graph of temperature versus length is being displayed showing the variation.
- Optimization is being carried out on the basis of pressure criteria with changing number of layers until the value optimize with the user entered value. A graph is

being generated with the changing pressure value and stack height.

5.2 Future Work

The following work is proposed:

- Further the software can be upgraded for various flows like cross-counter flow, parallel flow and others
- The software has been developed for a single fluid Helium(He) wherein other fluids can be added and their properties can be varied as per the selected fluids for different parameters.
- The materials for which the calculations has been carried out is for Aluminium(Al 3003) and Copper(OFHC) wherein other materials can be taken into consideration.
- Optimization can be carried out on other factors other than the pressure criteria and made more effective

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