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Research Paper

VALIDATION OF PLATE HEAT EXCHANGER DESIGN USING CFD

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Heat exchanger is an essential device used in complex engineering systems related to heat transfer processes in many industrial applications. Plate Heat Exchanger (PHE) is an important part of a condensing or evaporating system. Among many of factors which should concentrate on, the heat transfer and pressure drop is most important part during sizing and rating the performance of PHE. Due to the complex corrugated surface design flow is highly turbulent. This makes design of plate heat exchanger using empirical correlations to deviate from actual. Sometimes flow medium cannot distribute uniformly which affects the performance of plate heat exchanger. The optimization problem is formulated as the minimization of the heat transfer area, subject to constraints on the number of channels, pressure drop, flow velocity and thermal effectiveness, as well as the exchanger thermal and hydraulic model. Nowadays PHE widely use in different industries such as chemical, food and pharmaceutical process and refrigeration (ZhenHua *et al.*, 2008). However in present work PHE applied in the dairy milk pasteurizer plant model. Milk is pasteurized for killing the bacteria and preserving milk for long time. Present thesis emphasizes the CFD application to design optimization of pasteurizer plant. Thesis covers validation of CFD results with test and analytical results. Temperature distribution, flow combination and comparison of material thermal conductivity is studied. This thesis considers full assembly analysis of pasteurizer unit.

Keywords: Plate heat exchanger, Pressure drop, Temperature distribution, Parallel flow, Counter flow

INTRODUCTION

The natural laws of physics always allow the driving energy in a system to flow until equilibrium is reached. Heat leaves the warmer body or the hottest fluid, as long as there is a temperature difference, and will be transferred to the cold medium.

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Figure 1: Structure of a Typical Gasket PHE with Chevron Plates

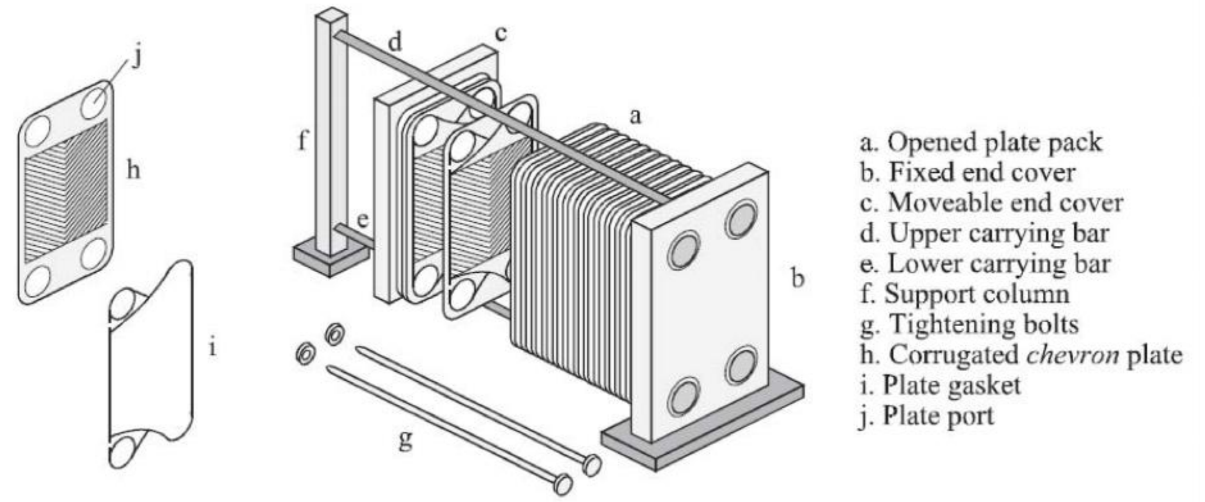
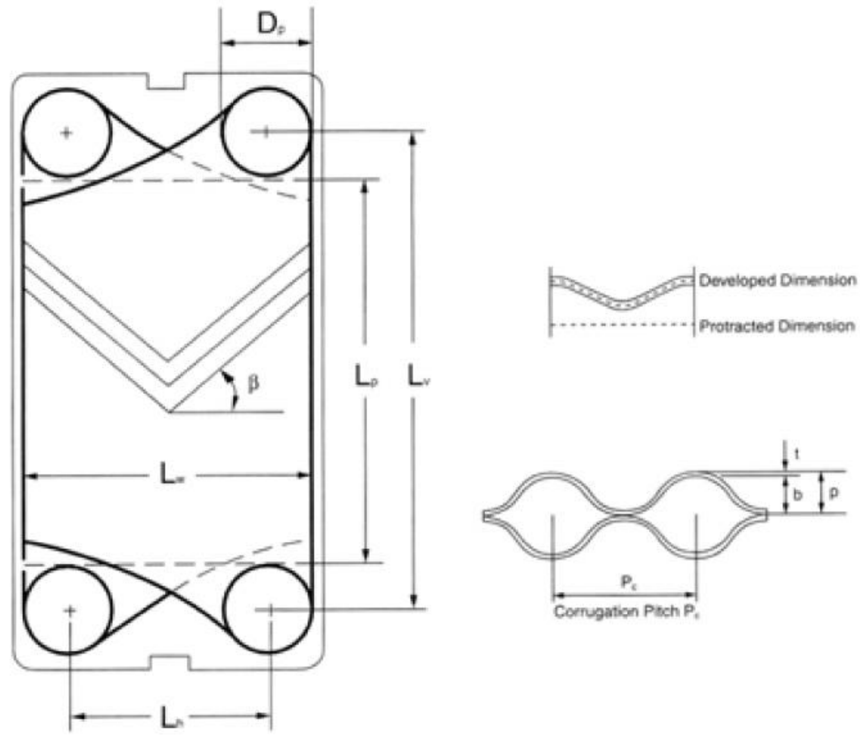


Figure 2: Dimension of Chevron Plate and Cross Section



A heat exchanger follows this principle in its Endeavour to reach equalization. With a plate type heat exchanger, the heat penetrates the surface, which separates the hot medium from the cold one very easily. It is therefore possible to heat or cool fluids or gases which have minimal energy levels.

The theory of heat transfer from one media to another, or from one fluid to another is determined by several basic rules.

- Heat will always be transferred from a hot medium to a cold medium.
- There must always be a temperature difference between the media.

The heat lost by the hot medium is equal to the amount of heat gained by the cold medium, except for losses to the surroundings.

In this thesis a new approach is introduced to validate the CFD results with experimental and analytical results. Study model is the assembly of milk pasteurizer model. Pasteurizer is used to heat the milk by using hot medium as water or steam and cool the milk at –4 °C by using brine solution.

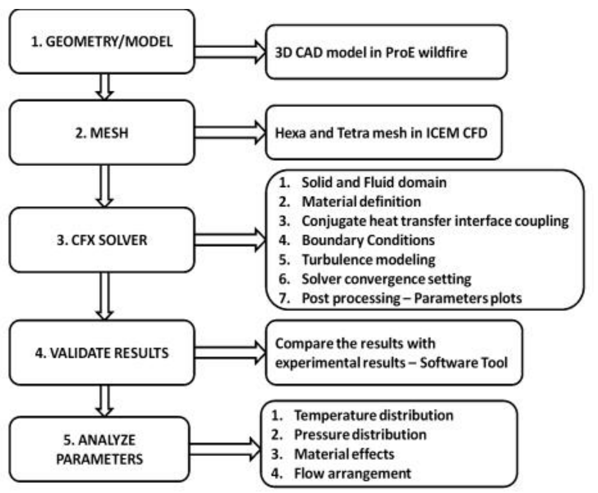
In this thesis 3D model is generated in CAD software and this assembly is analyzed for different parameters. First proper connections and boundary connections set to capture conjugate heat transfer. This setting is very critical to create connections for fluid and cold medium. Hence CFX is used as solver. Literature review highlights that no assembly analysis has been carried for plate heat exchangers due to conjugate heat transfer interface coupling was major difficulty.

Hence this thesis has major importance on plate heat exchanger study using CFD as entire assembly analysis is carried out in CFX tool by setting conjugate interface coupling easily.

This thesis also analyzes different parameters and their significance in heat transfer. Parameters considered are Temperature distribution, Pressure drop, Material properties, flow and temperature difference.

This thesis also studies temperature distribution in parallel and counter flow combination. Also the results validate the empirical correlations used to calculate overall heat transfer coefficient in NTU method. This thesis has major impact in analyzing plate heat exchanger assembly using CFD and correcting the co-relations for analytical calculations. Empirical correlations are suggested for standard specimen hence some correction factors needed to use them for specific design of plate heat exchanger. However this requires lot of precession and may be the beyond the scope of this thesis. This thesis is for validating CFD as alternate tool for prototype or preliminary design. Hence this prevents over design or under design in preliminary sizing or selection. This thesis emphases on the use of CFD to replace prototype testing. This saves cost and lead time for every project which almost 10% of every project. Also this ensures optimized

Figure 3: CAD 3D Model



and error proof design which saves 5% of the manufacturing cost. Hence short lead time and accuracy in expected results can lead to customer satisfaction and trust.

WORKING METHODOLOGY

3D Model is generated using ProEwildfire CAD software. In present thesis assembly is considered for analysis. In reference literature only single plates are considered for analysis. Initially 4 plates assembly used to realize settings for conjugate interface coupling and boundary conditions. Later in CFX solver mesh is duplicated to match required number of plates. Model is shown as in Figure 3.

Mesh Generation

Mesh is generated using ANSYS ICEM CFD tool. Meshing approach involved hexa meshing which results in structured meshing. Tetra mesh approach tried but problem in handling large number of elements. Hardware unable to process such big model. Hence strategy was shifted to hexa mesh. This creates less number of elements. The mesh nearby to walls was fine meshed to capture thermal and velocity boundary layer effects.

Solver

Ansys CFX tool is used as solver. CFX solver has many capabilities like mesh can be duplicated for many instances and connected by interface coupling. Also to simulate conjugate solid fluid domain we have special interface treatment options. In first case 4 plates have been meshed in ICEMCFD. Same mesh is repeated and coupled using interface connection to ensure effect of number of plates. There involved number of options to ensure realistic boundary conditions.

Solver Settings Involve: Defining domains as fluid and solid domains. Creating interface coupling of these domains. Defining material properties for each domain. To capture turbulence K-e model is selected. Solver QUICK scheme is considered. Power law with zero degrees equation is considered. Inlet and out boundary conditions are set based on iterations.

Table 1: CFX Solver Settings

Descritization Scheme	Quick
Pressure Velocity Coupling	Simple
Turbulence Model	K-E
Boundary Layer Capture Scheme	Power Law
Convergence Criteria	E-4
Convergence Iterations	1000
Viscous Effects	On

The Flow Model is Based on the Following Assumptions

- The fluid is Newtonian.
- The Boussinesq approximation is invoked for the fluid properties to relate density changes to temperature changes, there by coupling the temperature field to the flow field.
- Influence of external environment not considered.

Conjugate Heat Transfer and Fluid Flow Boundary Conditions

Following are the boundary condition considered confirmed after several iterations.

- Hot and Cold fluid inlet: Mass flow rate of fluid.
- Hot and Cold fluid outlet: Average static pressure.

- Thermal initialization for conjugate heat transfer.
- Solid fluid interaction for conjugate heat transfer.

Analysis for Validation of Methodology

For first case 4 plates are considered to validate the results with practical and analytical calculations. With reference to practical results developed excel sheet to calculate effective area required to ensure desired heat transfer. Excel sheet is based on analytical empirical relations. This thesis emphasizes validation of CFD results with analytical and practical results. Below are the parameters for analysis.

Table 2: CFD Input Parameters

	Hot Fluid Properties	Cold Fluid Properties
Fluid Medium	Water	Milk
Density Kg/m^3	1000	890
Viscosity (m^2/s)	1.87E-04	1.40E-04
Specific Heat (J/kgk)	4210	3900
Thermal Conductivity (W/m.K)	0.5	0.56
Flow kg/s	1.6667	1.3889
Inlet Temperature (°K)	370	283

Table 3: CFD Results at Outlet

Parameters	Hot Fluid	Cold Fluid
Outlet Temperature in °K	326	326

Table 4: Comparison Outlet Temperature (°K) of Hot Fluid

Test	Theoretical	CFD	Theoretical Error %	CFD Error %
325	331	326	–11.5385	–1.923

Table 5: Comparison Outlet Temperature (°K) of Cold Fluid

Test	Theoretical	CFD	Theoretical Error %	CFD Error %
325	328	326	–5.769	–1.923

RESULTS AND DISCUSSION

The analysis is carried out as per different phases discussed below,

Figure 4 is plotted for temperature distribution along plate heat exchanger assembly. From figure it can be seen that

Figure 4: Temperature Distribution Across Heat Exchanger

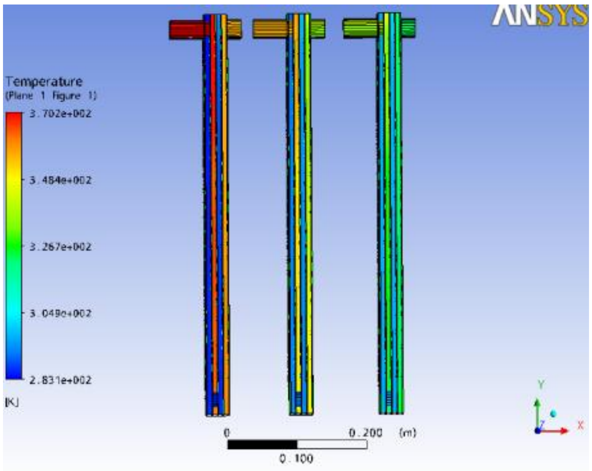


Figure 5: Temperature Distribution Across Single Plate

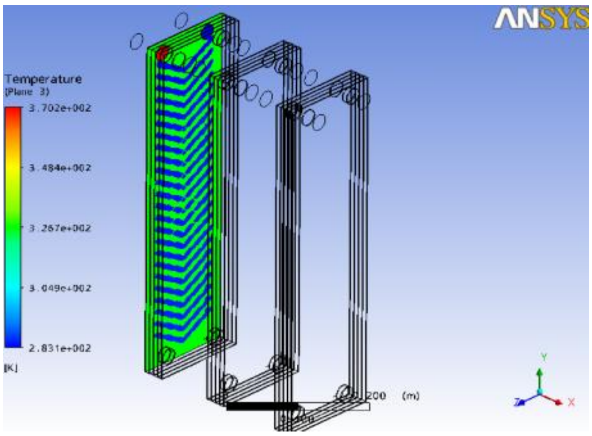


Figure 6: Temperature Distribution Across PHE (Isomeric View)

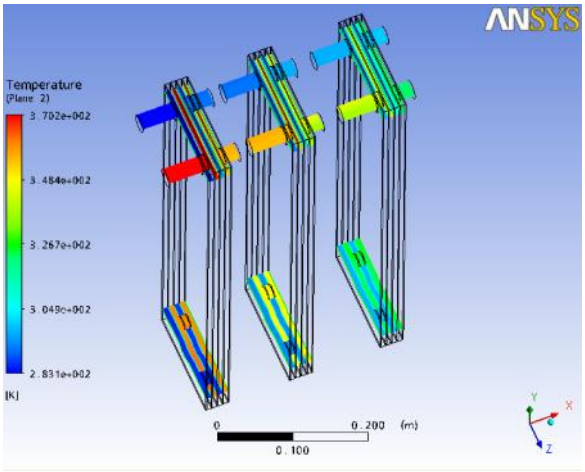
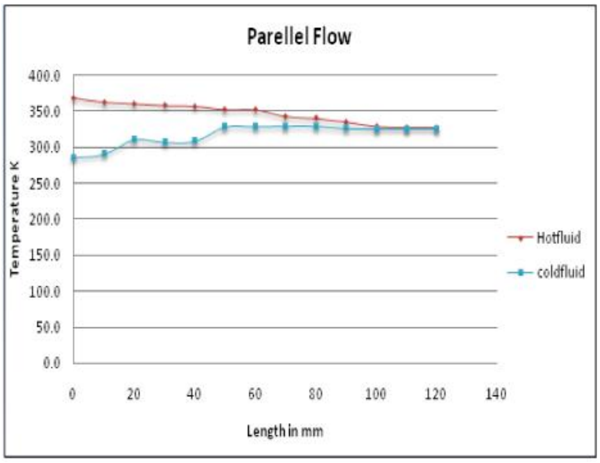


Figure 7: Parallel Flow Temperature Approach Along the PHE



temperature approach becomes narrow from left to right. This validates the nature of temperature approach in real model.

Figure 8 is plotted for temperature distribution along plate heat exchanger assembly. From figure it can be seen that temperature approach remains nearly parallel in Plate heat exchanger assembly. This validates the nature of temperature approach in real model.

Figure 8: Counter Flow Temperature Approach Along the PHE

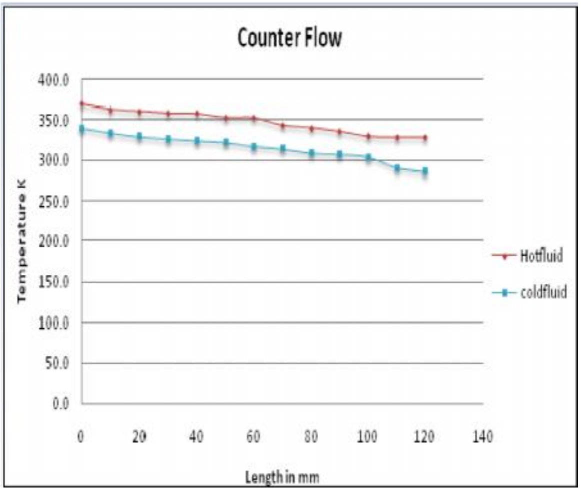
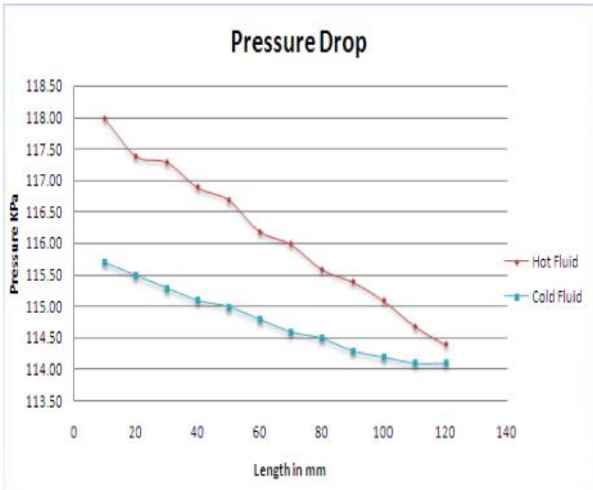


Figure 9 shows using CFD Pressure drop along plate heat exchanger can be calculated effectively. Hence design can be optimized for proper pump selection.

Material properties affect heat transfer rate and effective area requirement. In this thesis 3 materials are selected and temperature contours are plotted to show thermal conductivity influences heat transfer rate and size.

Figure 9: Pressure Drop Along the PHE



From Figures 10, 11 and 12 temperature approach in copper is better than aluminum and temperature approach in aluminum is better than steel. Temperature distribution contour plots reveal that higher thermal conductivity enhances reduced effective area requirement.

Figure 10: Temperature Distribution in Copper Plates

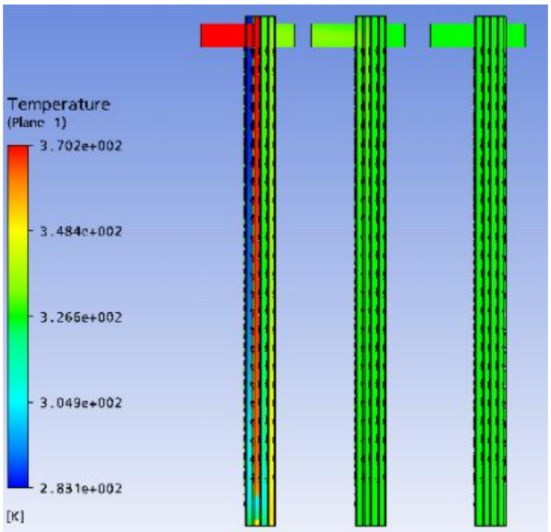


Figure 11: Temperature Distribution in Aluminum Plates

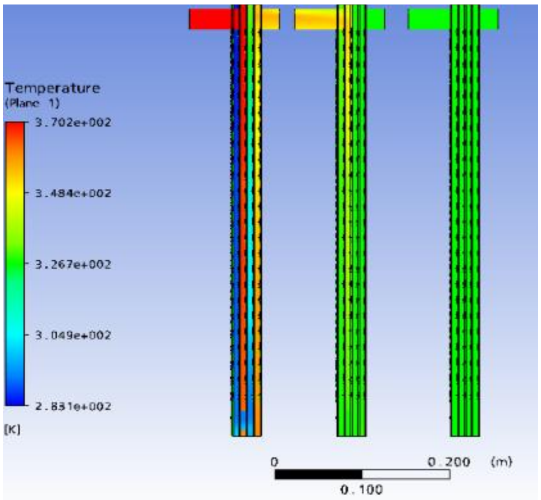
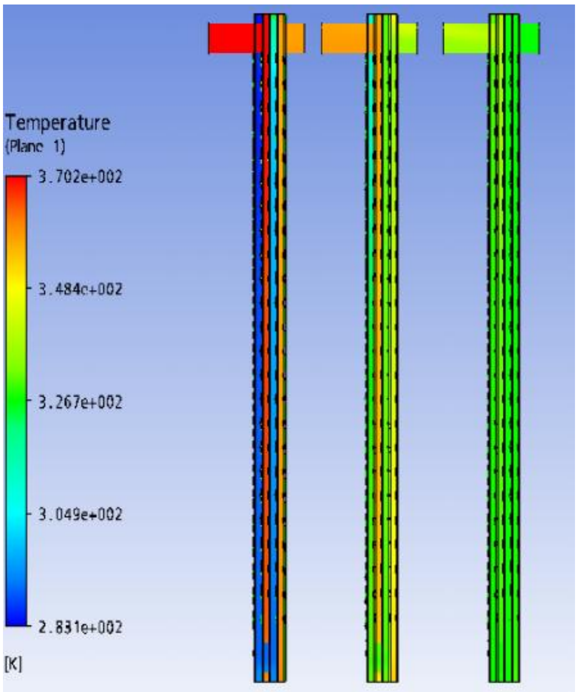


Figure 12: Temperature Distribution in Steel Plates



CONCLUSION

It can be seen from results that CFD results are quite convincing with practical and analytical results. Hence CFD can be a tool for future to ensure effective design of plate heat exchangers. As in process industry every day operating parameters change with different processes, it is difficult to design without higher reliability factor or oversize design. Hence CFD can ensure cost effective and optimum design. Many times over Size pumps cost energy loss hence by predicting accurate pressure drop energy can be saved. Using CFD one can visualize all parameters at any section of plate heat exchanger. Earlier it was only access at inlet and outlet conditions measured and then parameters varied to get actual result.

With CFD we can simulate different parameters like flow, temperature, material properties, viscosity effects and effect of number of passes easily. It is difficult to do these changes practically as operating parameters and liquid changes as per client requirement. In Figures 5 and 6 it can be seen that counter flow is more effective than parallel flow plate heat exchanger.

From Figure 9t can be seen that pressure drop calculated is in sink with test results.

It is seen from Figures 10, 11 and 12 that copper has better thermal performance than aluminum and steel. Hence thermal conductivity of material enhances heat transfer rate and saves material.

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APPENDIX

Nomenclature		
b	:	Mean mass channel gap [m]
D	:	Port diameter [m]
f	:	Friction factor
h	:	Convective heat transfer coefficient [W/m²·k]
k	:	Thermal conductivity [W/m·k]
t	:	Plate thickness [m]
L	:	Horizontal port distance [m]
Lh	:	Projected plate distance [m]
Lv	:	Vertical port distance [m]
Lp	:	Plate width inside gasket [m]
mw^2	:	Maldistribution parameter
n	:	Number of channel
Pc	:	Corrugation pitch [m]
		Greek Symbols
	:	Chevron angle [degree]
¸*c*	:	Channel friction coefficient
		Greek Symbols
c	:	Cold fluid
h	:	Hot fluid