ijournals International Journal of Software & Hardware Research in Engineering
ISSN No: 2347-4890 Volume 2 Issue 1/ January 2014

MODELLING AND SIMULATION OF CORRUGATED PLATE HEAT EXCHANGER FOR PROCESS INDUSTRY

S.Murugapoopathi [1]; C. Senthilkumar[2]

Assistant Professor, Department of Mechanical Engineering, PSNA college of Engineering and Technology, Dindigul-624622, India.[1,2]

ABSTRACT
In this paper CFD analysis of plate heat exchanger (PHE) has been used to optimize its design and performance flow field, heat transfer rate, temperature distribution and pressure drop. PHE has a three dimensional narrow channel of herringbone pattern. Its corrugation angle, herringbone angle and pitch distances are the variables for the CFD analysis. The computational domain contains a corrugation channel and the simulations adopted the shear stress transport (SST) κ-ω model as the turbulence model. The results, thus obtained will give the optimum values for different parameters of PHE.

General Terms
Your general terms must be any term which can be used for general classification of the submitted material such as Pattern Recognition, Security, Algorithms et. al.

Keywords
PHE, CFD Analysis, Heat transfer, Optimization parameters.

1. INTRODUCTION
Plate heat exchangers PHEs are used in a variety of chemical, process, and power industries over a broad range of temperatures due to their compactness, ease of maintenance, flexibility, and favorable thermal-hydraulic characteristics. The chevron or herringbone design is the most commonly used surface pattern in PHEs. Inclination angle, corrugation shape, amplitude and wavelength, plate thickness, etc. are important design parameters for these plates. The plates are closely packed at an angle to form cross-corrugated passages that exhibit high heat transfer rates with Comparatively low pressure drops. This Corrugated plate heat exchangers (PHE) are continuously replacing conventional shell and tube exchangers, due mainly to their high thermal effectiveness, close temperature approach as well as ease of inspection and cleaning. They are widely used in the food processing industries and are also selectively used in the chemical processing industries. This type of compact heat exchanger consists of a number of plates embossed with some form of corrugated surface pattern and abutted assembly, with their corrugations forming narrow passages. The stack of plates is placed in a bolted frame with solid end plates that hold the remaining plates together. The seal between the fluid streams is achieved by means of elastomeric gaskets placed in the side grooves of the plates. The modular nature of the PHE, which allows a variation of the number of plates, and the pattern of the corrugations imprinted onto the plate are among the parameters that influence its performance.

2. MODELLING
Numerical simulation of plate heat exchangers PHEs is an important tool to better understand the fundamental mechanisms, the flow patterns, swirl flows, and their effects on the heat transfer and pressure drop. It helps in faster development of new products by simulating the effect of various design parameters. Some of the previous numerical works on PHEs assumed the computational domain either as a unit cell 1–4 or one complete channel 5–8. In the former approach, the plate is considered to be a repeating unit cell with periodic boundary conditions generally fully developed flow. However, in the latter, a channel either hot or cold formed between two consecutive plates has been considered for simulation. Further, few studies 5,6have also assumed one plate to be flat to keep the geometry simple. Uniform wall temperature or uniform heat flux at the plate in many cases both are not constant and also not known *a priori* are the typical thermal boundary conditions selected in almost all cases..

The requirement for detailed and accurate measurement of the design response parameters (e.g., temperature, pressure and velocity fields) is very difficult to achieve, because the flow passages in compact heat exchangers are complex in geometry and are of relatively small dimensions. Computational Fluid Dynamics (CFD) can be considered an effective tool for estimating the momentum and heat transfer rate in this type of heat exchangers and for evaluating their performance. However, the accuracy of the calculations depends on the choice of the most appropriate flow model for the CFD simulation. The

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most common two-equation turbulence model, based on the equations for the turbulence energy *k*, and its dissipation *e*, is the *k-e* model. In order to calculate the boundary layer, either 'wall functions' are used, overriding the calculation of k and e in the wall adjacent nodes, or integration is performed to the surface, using a 'low turbulent Reynolds (low-Re) k-e model . Menter and Esch state that in a standard k-e model, the wall shear stress and heat flux are overpredicted (especially for the lower range of the Reynolds number encountered in this kind of equipment) due to the over prediction of the turbulent length scale in the flow reattachment region, which occurs on the corrugated surfaces in these geometries. This is caused by the fact that the wall functions used by the k-e model neglect the influence of the viscous sub layer. On the other hand, the low-Re k-e model, which uses 'dumping functions' near the wall , to avoid the use of wall functions, is not considered capable of predicting the flow parameters in the complex geometry of a corrugated narrow channel. It also requires a finer mesh near the wall, is computationally expensive compared to the standard k-e model and is unstable in convergence. An alternative to the k-e model is the k-x model developed by Wilcox, which uses the turbulence frequency, x, instead of the turbulence dissipation, e. The k-x model provides analytical solutions both for the sub layer and the logarithmic region , and it does not have the problems of the k-e model that occur in the low-Re region for the e-equation. While it is more robust and does not require a very fine grid near the wall , the k-x model is sensitive to the free stream values of turbulence frequency, x, outside the boundary layer. A combination of the two models is the SST (Shear Stress Transport) model, which, by employing specific 'blending functions', activates the Wilcox model near the wall and the k-e model for the rest of the flow and, in this way, benefits from the advantages of both models. The most common two-equation turbulence model, based on the equations for the turbulence energy *k*, and its dissipation *e*, is the *k-e* model. In this project, a CFD code is employed to study the flow and thermal characteristics within the complicated passages of a PHE. The computational domain used includes two complete conduits of an existing PHE. The objective of this work is to explore the potential of a general purpose CFD code for computing detailed characteristics of the flow inside a PHE, with the intention of using the

code as a useful tool in studying the effect of various geometrical configurations of the overall performance of the PHE

3. HEAT TRANSFER CALCULATIONS

The simulations were performed for the constant wall temperature of corrugated plate. The temperature is assumed as 60˚C. A constant inlet temperature of water at 25˚C is used through the simulation. The material of corrugated plate is assumed as stainless steel. The heat transfer coefficient between plate and air can be calculated by using the following relations.

$Nu = h D / k$

Where D –Hydraulic mean diameter

$D = 4\ w\ b / (w+b)$

b- Mean spacing between the plates

$D = 4 \times 0.125 \times 0.024 / (0.125 + 0.024)$

$D = 0.0806$ m .

$Re = VD/ \nu$

$Re = 0.05 \times 0.0403 / 1.006 \times 10^{-6}$

$= 2001.414$

$Nu = 0.5\ Re^{0.5}\ Pr^{0.333}$

$Nu = 0.5 \times 2001.414^{0.5} \times 7.02^{0.333} = 83.47$

$h = 1156.65\ W / m^2\ K$

The following physical properties of water at 25 C are used

$\nu = 1.006 \times 10^{-6}\ m^2/s$

$k = 0.5978$ W/m k

$Pr = 7.02$

3.1 Major Dimensions of the Plate

Length of the plate	-440 mm
Width of the Plate	-125mm
Thickness of the plate	-3mm
Mean spacing between the plates	-24mm
Pitch Distance	- 17mm and 23mm
Corrugation Angle	-30 deg, 45deg, 55deg
Herringbone Angle	- 55 deg, 60deg, 65deg

4. MODELING AND MESHING OF GEOMETRY

The primary purpose of geometry creation is to generate a solid that defines region for fluid flow. This section describes a step by step creation of geometry and regions. Dimensions and geometry details of existing model was collected.

Modeling was done using CFX-BUILD module.

4.1 Creating B-Rep Solids

B–Rep (Boundary Representation) defines the surface enclosing a volume. B -Rep solid is created in order to create a fluid domain for analysis.

4.2 Creating regions

These regions use solids such as B – rep solid to define extent of the region. First 3D region is created which comprises of the entire solid model Then 2D region is created for defining inlet and outlet. Creation of regions facilitates to assign boundary condition for inlet, outlet and other defined regions.

4.3 Cfx -Pre Processing

4.3.1 Boundary Conditions and Domain Specifications

Inlet Boundary Conditions

Temperature = 298 K

Pressure = 1 bar

Outlet Boundary Condition

Pressure = Static pressure

Wall boundary Conditions

Wall influence on flow : No slip

Wall Roughness : Smooth wall

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Heat transfer : Adiabatic

4.3.2 Domain Specification

Domain Type : Fluid Domain
Fluid : Water
Heat transfer Model : Thermal Energy
Turbulence Model : K-Epsilon

4.5 Result Analysis

4.5.1 Effect Corrugation Angle

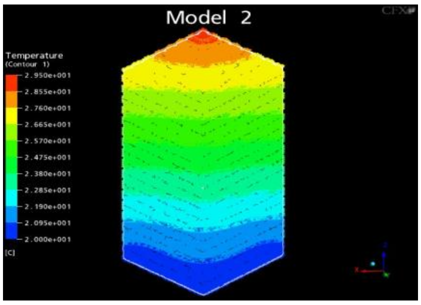

Fig 1: Corrugation Angle 30 deg

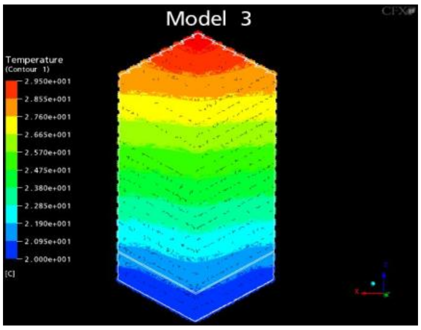

Fig 2: Corrugation Angle 45 deg

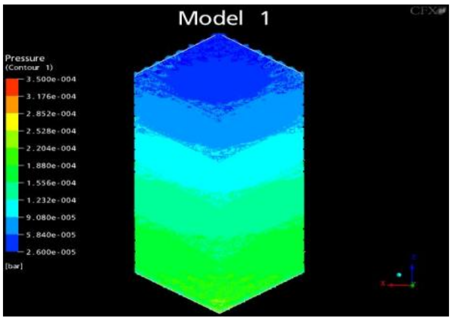

Fig 3: Corrugation Angle 55 deg

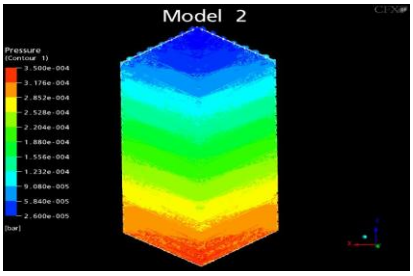

Fig 4: Corrugation Angle 30 deg

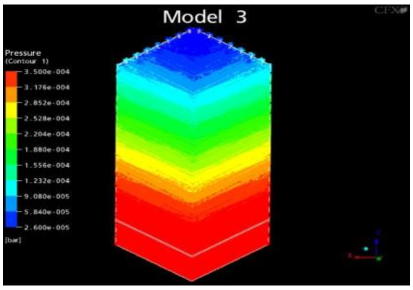

Fig 5: Corrugation Angle 45 deg

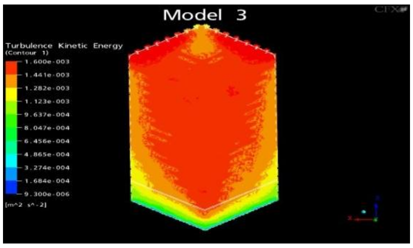

Fig 6: Corrugation Angle 55 deg

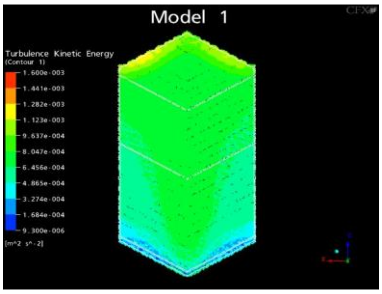

Fig 7: Corrugation Angle 30 deg

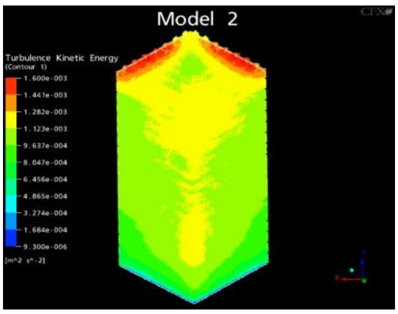

Fig 8: Corrugation Angle 55 deg

4.5.2 Effect of Herringbone Angle

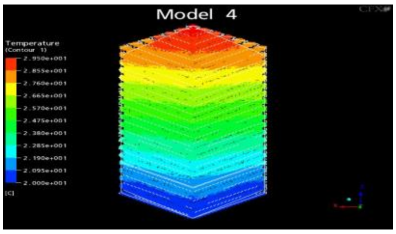

Fig 9: Herring bone angle 55deg

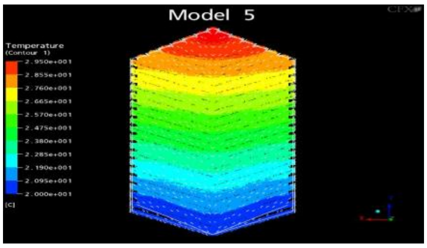

Fig 10: Herring bone angle 60deg

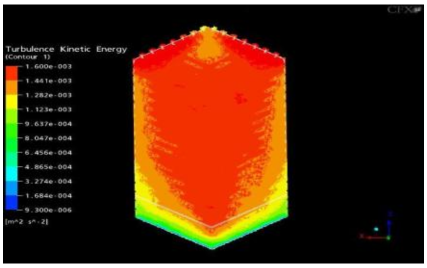

Fig 11: Herring bone angle 65 deg

4.5.3 Effect of Pitch Distance

Figure shows the temperature distribution for the corrugate plate of pitch distances of 17mm and 23mm. While comparing the two models for the same temperature range 17mm pitch model shows comparatively increased heat transfer. This is obviously lesser pitch distance makes more surface area for heat transfer.

Figure shows the pressure distribution along the length of the plate. While comparing for the same pressure range 17mm pitch model shows increased pressure at the inlet and correspondingly reduced velocity.

The results of turbulence kinetic energy for the models show that when pitch distance decreases the turbulence increases. The intensity of turbulence has been observed significantly high in the 17mm pitch model. While comparing for the same value the intensity of turbulence in this model prevails, this will consequently enhance the heat transfer rate

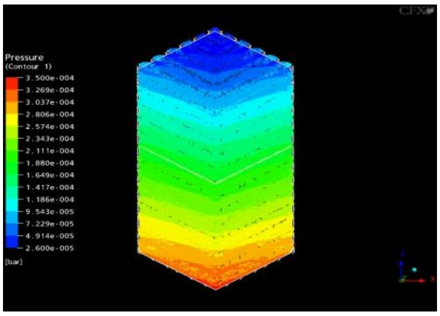

Fig 12: Pitch Distance 17 mm

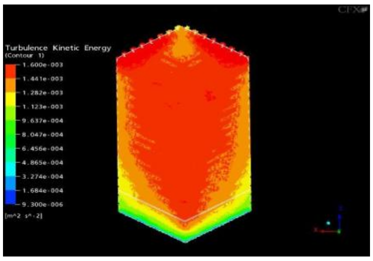

Fig 13: Pitch Distance 23mm

Figure shows the temperature variation along the corrugated plate. The temperature gradually increases from inlet to outlet. Temperature distribution shows that for the three models of corrugation angle 30, 45,55 degrees model 3(Corrugation angle 55 deg) is having comparatively higher heat transfer rate. The increased corrugation angle makes increased heat transfer area and consequently increased temperature of the fluid at outlet.

The pressure distribution in the corrugated plate shows that increased pressure at inlet and gradually decreases towards outlet. While comparing three models for the same pressure range it has been observed that model 3 is having comparatively higher pressure rise at inlet and consequently higher velocity drop which is undesirable.

The results of turbulence kinetic energy for the models show that when corrugation angle increases the turbulence increases. The intensity of turbulence has been observed significantly high in model 3.While comparing for the same value the intensity of turbulence in model 3 prevails which will consequently enhance the heat transfer rate.

5. CONCLUSION

The following points have been concluded from the analysis. When the corrugation angle increases the heat transfer rate and intensity of turbulence are increasing but significant pressure rise in the flow which will reduce the flow velocity. There is no significant variation in parameters observed for variation of herringbone angle. When the pitch distance increases the heat transfer and intensity of turbulence increases significantly and also increases the pressure at inlet.

5. ACKNOWLEDGMENTS
Our thanks to the experts who have contributed towards development of the template.

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