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Research Article

Computational Fluid Dynamics & Heat Transfer Analysis of Heat Exchanger with Inserts

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Abstract

In heat exchangers, enhancement of heat transfer is achieved by increasing the convection heat transfer coefficient or by increasing the convection surface area. One of the method to increase the convection coefficient within a heat exchanger is by introduces inserts within the pipes/tubes. In the present work, introduction of inserts of different materials and cuts have been investigated computationally. Effect of introduction of inserts of different cuts (square, circular and triangular) inside the inner tube of single unit on heat transfer and friction factor for heating of water for Reynolds number range 500-3000 was studied. Three different materials of the inserts Galvanized Iron (GI), Aluminium (Al) and Copper (Cu) are used and the results reveals square cuts copper inserts performs better among the selection. The variation between computational and experimental Nusselt Number was observed to be 19-28% which is attributed due to simplicity of model and assumptions.

Keywords:*Heat Exchanger, Inserts, CFD, Nusselt Number, Reynolds Number*

1. Introduction

The development of high performance thermal systems has stimulated interest in methods to improve heat transfer. In heat exchangers, enhancement of heat transfer is achieved by increasing the convection heat transfer coefficient or by increasing the convection surface area. One of the method to increase the convection coefficient within a heat exchanger is by introduces inserts within the pipes/tubes. In the present work, introduction of inserts of different materials and cuts have been investigated experimentally and computationally. Effect of introduction of inserts of different cuts (square, circular and triangular) inside the inner tube of single unit on heat transfer and friction factor for heating of water for Reynolds number range 500-3000 was studied. Three different materials of the inserts Galvanised Iron (GI), Aluminium (Al) and Copper (Cu) are used and the results reveals square cuts Copper inserts performs better among the selection.

For the purpose of validating the experimental set-up and procedure, initial test runs were carried out in the experimental set-up for evaluating the friction factor variation with Reynolds number and compared the result with literature (PaisarnNaphon, 2006). The computational fluid dynamics and heat transfer analysis for the heat exchanger was done for different materials of inserts using SOLIDWORKS flow simulation.

2. Governing Equations

Flow Simulation solves the Navier-Stokes equations, which are formulations of mass, momentum and energy conservation laws for fluid flows. The equations are supplemented by fluid state equations defining the nature of the fluid, and by empirical dependencies of fluid density, viscosity and thermal conductivity on temperature. A particular problem is finally specified by the definition of its geometry, boundary and initial conditions.

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u_i}{\partial x_i} = 0 \qquad (1.1)$$

Momentum equations:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}\left(\rho u_j u_i - \tau_{ji}\right) + \frac{\partial P}{\partial x_i} = S_i \qquad (1.2)$$

Viscous stress tensor:

$$\tau_{ii} = -\frac{2}{3}\mu D + 2\mu \frac{\partial u_i}{\partial x_i} \qquad (1.3)$$

$$\tau_{ij} = \mu \frac{\partial u_i}{\partial x_j} \qquad (1.4)$$

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Energy equation:

$$\frac{\partial(\rho h)}{\partial t}+\frac{\partial(\rho u_i h)}{\partial x_i}=-\frac{\partial p}{\partial t}+\frac{\partial}{\partial x_i}\left[\frac{k}{c_p}\frac{\partial h}{\partial x_i}-\dot{q}_i^R\right] \quad (1.5)$$

$$\frac{\partial}{\partial t}(\rho\phi)+\frac{\partial}{\partial x_j}\left(\rho u_j\phi-\frac{\Gamma_\phi}{\sigma_\phi}\frac{\partial\phi}{\partial x_j}\right)=S_\phi$$

The generalized governing equations for variable ϕ:

$$\frac{\partial(\rho\varphi)}{\partial t}+\frac{\partial(\rho u\varphi)}{\partial x}+\frac{\partial(\rho v\varphi)}{\partial y}+\frac{\partial(\rho w\varphi)}{\partial z} \quad (1.6)$$

$$=\frac{\partial}{\partial x}\left[\Gamma\frac{\partial\varphi}{\partial x}\right]+\frac{\partial}{\partial y}\left[\Gamma\frac{\partial\varphi}{\partial y}\right]+\frac{\partial}{\partial z}\left[\Gamma\frac{\partial\varphi}{\partial z}\right]+S_\varphi \quad (1.7)$$

Where Γ is diffusion coefficient
σ is Schmidt/Prandtl number,
and S is a general source term
For continuity, $\phi = 1$, $\Gamma = 0$, $S=0$
For momentum, $\phi = \{u, v, w\}$, $\Gamma = f(\mu)$
For energy, $\phi = e$ (or h), $\Gamma = k/c_p$, S=radiation

Computational Model

The computational model for the inner pipe is made in CAD software with the following dimensions:

Inner pipe ID = 19 mm

Inner pipe OD=23 mm

Length of pipe = 400 mm

Length of inserted tape= 400 mm

Width of inserted tape= 12 mm

Hole Diameter = 5 mm

Thickness of insert= 18 Gauge (1.214 mm)

Figure 1 shows the different position of insert in the inner pipe. Figure 2 shows the different profiles of cuts on the inserts.

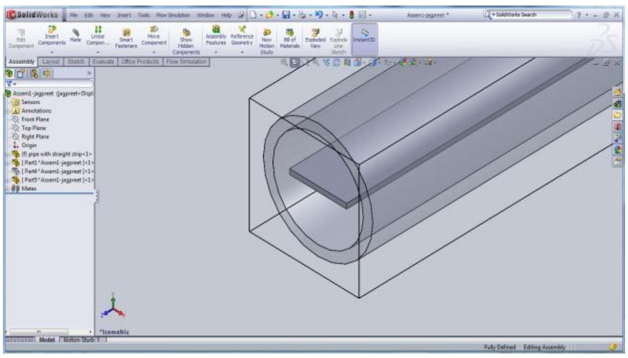

Fig.1: Position of insert in the inner pipe of heat exchanger

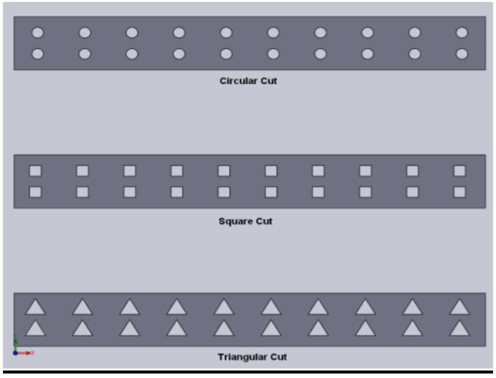

Fig.2: Different profiles/cuts on the inserts

Mesh Generation

In SolidWorks Flow Simulation, mesh contains basic cells of three different types: fluid cells, partial cells and solid cells.In the present work, the model is meshed number of times, Table 1 shows the number of cells for the various cases. It has been observed that there is more deviation between Case 1 and Case 2, while for Cases 3 to 6 the deviation decreases. The percentage variation of temperature for inlet and outlet plenum for Cases 4, 5 and 6 was less than 1%. Thus the grid system of Case 4 is adopted for the CFD analysis to have optimum solution.

Table 1: Simulated Fluid/Solid/Partial Cells with corresponding CPU time

Case	Fluid Cells	Solid Cells	Partial Cells	CPU Time
1	7560	17566	20071	0:88:30
2	8687	24076	36520	0:54:54
3	22812	49586	58338	1:49:22
4	36812	53736	73493	2:32:16
5	58448	78615	111851	3:53:29
6	85260	96084	130998	4:16:31

3. Validation of Results

For the purpose of validating the experimental set-up and

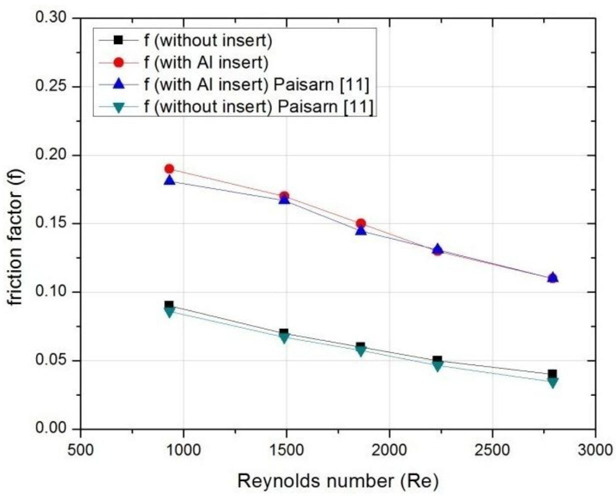

Fig.3 Validation of Experimental setup

procedure, initial test runs were carried out in the experimental set-up for evaluating the friction factor variation with Reynolds number and compared the result with literature (PaisarnNaphon, 2006).

As can be seen from the above figure 3, the present results obtained for the setup arrangement show good agreement with the results of literature(PaisarnNaphon, 2006) at all Reynolds numbers, though a little deviation is observed for the comparison with the experimental results of literature (PaisarnNaphon, 2006) at higher Reynolds numbers. The close agreement shown in the above figure confirms that the experimental procedure(Jagpreet Singh, *et al*, 2014) and the present concept for computing the Nusselt number in the computational study are in accordance with the establishedprocedure available in the literature.

4. Results and Discussion

Simulations were conducted to evaluate the thermo hydraulic performance of pipe fitted with/without inserts and then evaluating the performance of the heat exchanger with different cuts of insert.

Figure 4a shows the cut section temperature contour at the inlet section of the tube with Al as insert. Fig. 4a is the partial view of the whole pipe and temperature variation was observed throughout the length and radius. Fig.4b shows the flow trajectories at the inner pipe. The computational Nusselt number and Friction factor is calculated during the simulation by inserting the formulae in the goals.

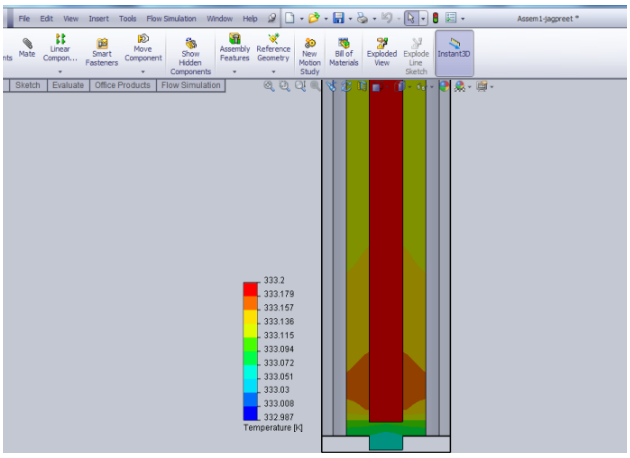

Fig.4a Cut section (partial view) Temperature contour at inlet section

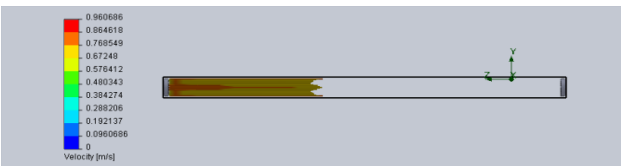

Fig.4b Flow Trajectories at inlet section (partial view)

4.1 Nusselt number variation

Figure 5 shows the variation of Nusselt number with Reynolds number for plain tube and inserted tape having GI, Al and Cu inserts. The Nusselt number with Cu insert is higher followed by Al insert and plain tube. The inserts (Fig.1) causes the flow to be spiral along the tube length and cause turbulence in the entire flow field that leads to higher heat transfer rate, the higher thermal conductivity of Cu as compare to Al and least for GI leads for higher heat transfer rate. Figure 6 shows the effect of different insertion of different cuts on the Nusselt number.

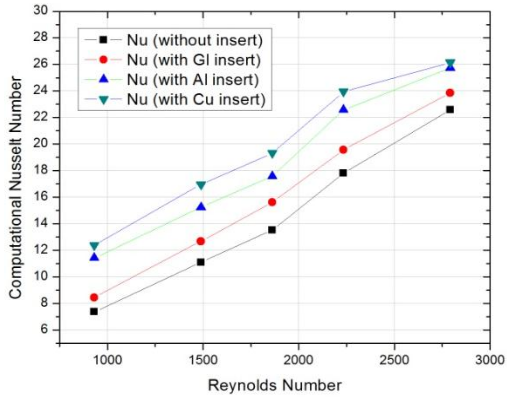

Fig.5 ComputationalNusselt number vs. Reynolds number

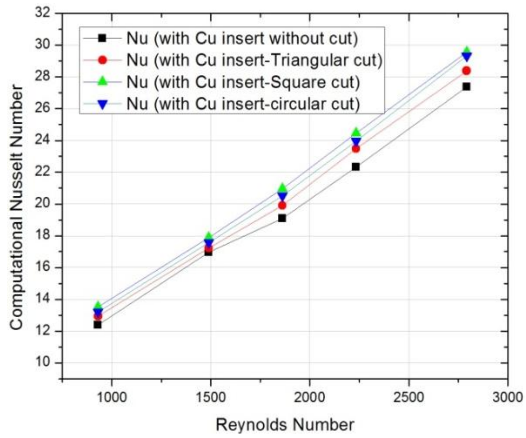

Fig.6 Computational Nusselt number vs. Reynolds number for different cuts

4.2 Friction factor results

The variation of friction factor with Reynolds number is shown in Figure 7 and 8.

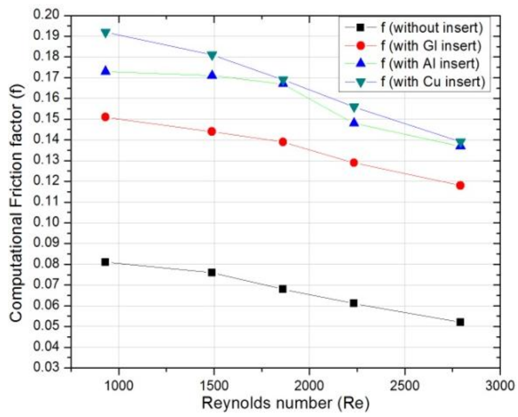

Fig.7 Computational Friction factor vs. Reynolds number

The variation clearly denotes the flow to be laminar and the friction factor is decreasing with increase in Reynolds number.

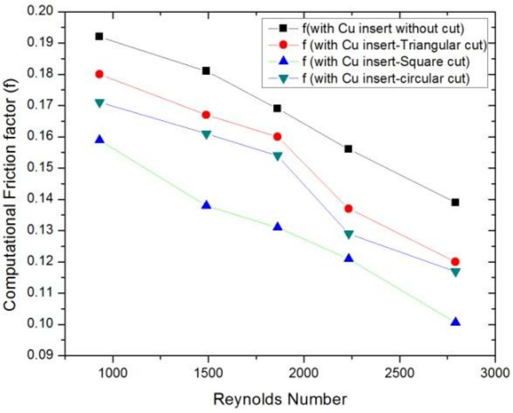

Fig. 8: Computational Friction factor vs. Reynolds number for different cuts

The friction factor for twisted tape is higher than the plain tube. The measured friction factor is in good agreement with the estimated values. A gradual slope change in the friction factor with Reynolds number is attributed to the temperature dependence of fluid viscosity and the increasing contraction and expansion pressure losses at the inlet and outlet, respectively.

Conclusion

- The Nusselt Number was observed for the Cu insert with square cut. This indicates that for a given constant heat input, the average Nusselt number becomes higher for pipe having Cu insert with square cut followed by that with circular cut and triangular cut
- The minimum friction factor was observed for the Cu insert with square cut followed by circular cut and then triangular cut; this may be attributed due to less pressure drop.
- The maximum inlet and outlet minimum temperature difference is obtained in the pipe having Cu insert. This indicates that for a given constant heat input, the average Nusselt number becomes higher for pipe having Cu as insert followed by that for Al and without insert.
- There is a gradual change in the pressure drop variation with Reynolds number. This is attributed to the temperature dependence of fluid viscosity, and the increasing contraction and expansion pressure losses at the inlet and outlet of the pipe, respectively.

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