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Numerical Investigation of a Tube in Tube Helical Coil Heat Exchanger using ANSYS Software

Umesh Baboo, Dr. Satyendra Singh, Himanshu Singh, Amit Singh Bisht

Abstract— The advancement of compact type heat exchanger raises the demands of applications of Tube in Tube Helical Coil heat exchangers. Tube in Tube Helical Coil heat exchanger is one of the most widely used heat exchangers in industrial applications as it enables guaranteed advantages, like compact size, higher rate of heat transfer, effective performance at high pressure and temperature difference and lower cost. A very few experimental and numerical analysis has been accomplished for Tube in Tube Helical Coil heat exchangers. Hence, in this work the effects of flow rate and flow and flow direction on heat transfer characteristics are numerically investigated with the help of “ANSYS Software” for tube in tube helical coiled heat exchanger. Due to the complex design of tube in tube helical coil type heat exchanger, the first step is to design the Tube in Tube Helical Coil heat exchanger in Solid Works software for present study. Results indicate that, an increment of the hot or cold water flow rate and hot or cold water inlet temperature increases heat flux. The amount of heat flux in case of parallel flow is less than that of the counter flow.

Index Terms— TTHC heat exchanger, Ansys fluent, heat flux, Nusselt number, dean number, flow rate, flow direction.

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1 INTRODUCTION AND LITERATURE REVIEW

THE aim of manufacturing a heat exchanger is to get an efficient way of heat transfer from one fluid to another fluid, by direct contact or indirect contact. The modes of heat transfer are: conduction, convection and radiation. In a heat exchanger the heat transfer through radiation is negligible as it is not taken into account in comparison to conduction and convection. Conduction occur when the heat flow from the high temperature fluid to the surrounding solid wall. The conductive heat transfer rate can be maximized in two ways; by selecting a minimum thickness of wall or by employing highly conductive material. But in the performance of a heat exchanger, convection is plays the major role. Forced convection transfers the heat from one moving fluid to another fluid through the wall of the tube or shell in a heat exchanger. The hotter fluid rejects heat to the cooler fluid as it flows along or across the heat exchanger.

Sadighi D. H. et al. [1] presents the method which has been employed to fabricate a TTHC heat exchanger for the study. The results showed that exergy loss increases on increasing hot or cold water flow rates, hot water inlet temperature and coil diameter. The results also showed that the effects of flow, thermodynamic and geometrical parameters on exergetic characteristics (exergy loss, dimensionless exergy loss and second law efficiency). Eiamsa-ard S. and Promvonge P. [2] has been carried out experimental study on helical tape inserts in a double pipe heat exchanger to investigate enhancement in heat transfer and they found that concentric double pipe heat exchanger improves the heat transfer rate using various types of helical tapes. Naphon P. [3] experimentally investigated the heat transfer characteristics depend directly upon the hot and cold water mass flow rates in case of coil-wire insert in a tube. Kumar V. et al. [4] numerically investigated the effect of different flow rates of hot as well as cold fluid tube in a tube-in-tube helically coiled (TTHC) heat exchanger. They found in their experiments that for a constant flow rate in the annulus region overall heat transfer coefficient increases on increasing the inner-coiled tube flow rate. New correlations have been suggested for pressure drop and heat transfer rate in the outer tube of TTHC. Kharat R. et al. [5] proposed the new correlations for heat transfer coefficient in case of flow between concentric helical coils and compare with existing correlations. It has been carried out numerically using CFD fluent. Farzaneh-Gord M. et al. [6] optimizes the geometry and flow conditions for tube-in-tube helical heat exchangers with laminar as well as turbulent flow. The optimization technique used is entropy generation minimization approach. For the same objective, they theoretically optimize the geometry and mathematically developed and modeled the various geometrical problems to investigate. Sadighi D. H. et al. [7] continued their work on tube-in-tube helically coiled heat exchanger and introduce turbulator in heat exchanger to investigate thermal-frictional behavior and find the fabrication method. Results showed that, use of turbulator for outer tube (hot water side) increases the air side Nusselt number. As described above, a very few CFD analysis has been carried out for TTHC heat exchangers. Thus, the effects of flow rate and flow direction on flow characteristics (Nusselt number and heat flux) are studied for tube in tube helically coiled heat exchangers in the present work.

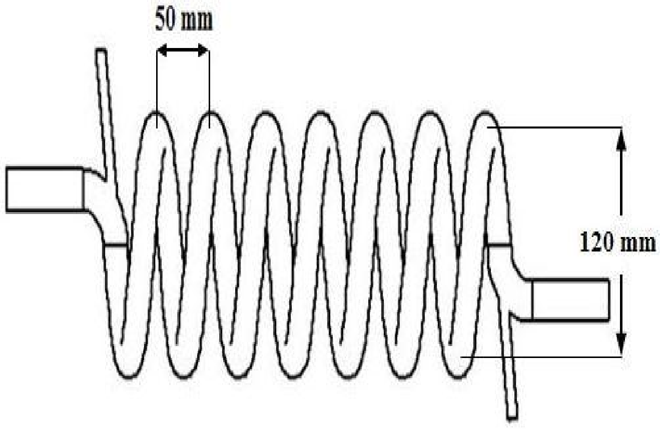

Fig.1. Tube-in-tube helical Coil heat exchanger

2 NOMENCLATURE

Symbol	Quantity (Unit)
Q	Heat transfer rate (W)
Q	Heat flux (W/m^2)
ṁ	Mass flow rate (LPM)
Ρ	Density of water (kg/m^3)
G	Gravitational acceleration (m/s^2)
Nu	Nusselt number
De	Dean number
Re	Reynolds number
C_1	Constant used in k- model
C_2	Constant used in k- model
C	Constant used in standard k –ε model
J	Colburn factor
Greek Symbols	
Δψ	Availability
K	Turbulent kinetic energy (J)
μ	Dynamic viscosity (kg/m-s)
μ_l, μ_t	Laminar, turbulent viscosity(kg/m-s)
Μ	Kinematic viscosity (N-s)
Suffix	
H	Hot
C	Cold
Abbreviations	
TTHC	Tube in tube helical coil heat exchanger
CFD	Computational fluid dynamics
LPM	Liter per Minute

Table 1 Tube geometry

Tube	Turn	D (mm)	d_i (mm)	d_o (mm)	P (mm)
Inner Tube	7	60-240	6	9	30-140
Outer Tube	7	60-240	20	22	30-140

3 MATHEMATICAL MODELING OF TTHC HEAT EXCHANGER

In the present study, numerical analysis through "ANSYS fluent 16.0" was carried out to investigate the heat transfer characteristics for a tube in tube helical coiled heat exchanger by varying the various input parameters like hot and cold water flow rates and flow direction to determine the fluid flow pattern in TTHC heat exchanger.

In earlier step, thermodynamic parameters (inlet temperatures) and geometrical parameters keep constant and the effects of hot fluid stream side and cold fluid steam side flow rates are investigated. For this purpose, each hot side flow rate (1, 2, 3, 4 and 5 LPM) is numerically experimented with three different cold side flow rates (1, 2 and 3 LPM). It should be notice that, due to high pressure drop through the coiled tube, there is a limitation at cold side flow rate. It should not more than around 4 LPM to coil side of test section. In the next step, the effects of hot fluid stream side are investigated keeping all other parameters constant rather than this time the flow become parallel flow. Different conditions taken into consideration in this study are given in Table 2.

4 GOVERNING EQUATIONS

Conservation of mass is given by continuity Equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \qquad (1)$$

And for constant density,

$$\frac{\partial \rho}{\partial t} = 0 \qquad (2)$$

The Navier-Stokes equations follow Newton's 2nd law. The body and the surface forces are acting on the finite

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- Umesh Baboo M. Tech. Scholar, Department of Mechanical Engineering, B.T.K.I.T, Dwarahat, Uttarakhand, India, PH-+919634444022. E-mail: shakyaumesh2020@gmail.com
- Dr. Satyendra Singh Associate Professor, Department of Mechanical Engineering, B.T.K.I.T, Dwarahat, Uttarakhand, India. E-mail: ssinghiitd@rediffmail.com
- Himanshu Singh M. Tech. Scholar, Department of Mechanical Engineering, B.T.K.I.T, Dwarahat, Uttarakhand, India.
- Amit Singh Bisht M. Tech. Scholar, Department of Mechanical Engineering, B.T.K.I.T, Dwarahat, Uttarakhand, India.

element. In CFD Software, the momentum equation is given by

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial x}\right) = -\rho g - \frac{\partial p}{\partial x} + \mu\frac{\partial^2 y}{\partial x^2} \qquad (3)$$

The energy equation is given as,

$$\rho C_p\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = k\frac{\partial^2 T}{\partial y^2} \qquad (4)$$

Table 2 Comprehensive information of tested conditions

-		**Flow Parameters**			**Thermodynamic Parameters**			**Geometric Parameters**	
		Flow Rate (Inner Tube)	**Flow Rate (Outer Tube)**	**Flow Direction**	**T_c , inlet**	**T_h , Inlet**	**Fluid Type**	**Coil Diameter (mm)**	**Coil Pitch (mm)**
Effect of Flow Characteristics	**Effect of inner tube flow rate**	1-5	1	Counter	15	40	Water	120	50
		1-5	2	Counter	15	40	Water	120	50
		1-5	3	Counter	15	40	Water	120	50
	Effect of Outer tube flow rate	1	1-5	Counter	15	40	Water	120	50
		2	1-5	Counter	15	40	Water	120	50
		3	1-5	Counter	15	40	Water	120	50
	Effect of flow Direction	1	1	Parallel	15	40	Water	120	50
		2	1	Parallel	15	40	Water	120	50
		3	1	Parallel	15	40	Water	120	50
		4	1	Parallel	15	40	Water	120	50
		5	1	Parallel	15	40	Water	120	50

The time constant for turbulence may be determined by the turbulent kinetic energy and dissipation rate of turbulent kinetic energy by following equation,

$$\tau = \frac{k}{\varepsilon} \qquad (5)$$

In such cases, using mixture properties and mixture velocities is needed to capture vital features of the turbulent flow model. The K- ε equations describing the model are as follows:

$$\frac{\partial(\rho_m k)}{\partial t} + \nabla.\ (\rho_m \vartheta_m k) = \nabla.\left(\frac{\mu_{t,k}}{\sigma_k}\nabla k\right) + G_{k,m} - \rho_{m\varepsilon} \qquad (6)$$

And,

$$\frac{\partial(\rho_m \varepsilon)}{\partial t} + \nabla.\ (\rho_m \vartheta_m \varepsilon) = \nabla.\left(\frac{\mu_{t,m}}{\sigma_\varepsilon}\nabla \varepsilon\right) + \frac{\varepsilon}{k}\left(C_{1\varepsilon}G_{k,m} - C2\varepsilon\rho m\varepsilon \right. \qquad (7)$$

ANSYS Fluent 16.0 comprises of the following there steps that includes pre-processing, solver and Post processing. Pre-processing defines the geometry, element type, real constants, and material properties while the solver defines the type of analysis and setting boundary conditions. Post processing part reviews the results using graphical displays and tabular listings and verify against analytical solutions.

5 RESULT AND DISCUSSION

5.1 Effect of flow rate and flow direction on heat flux

As shown in fig. 1, heat flux increased with the increase of hot water (inner tube) or cold water (outer tube) flow rate. Indeed, the rate of heat transfer increased due to the increment of hot water flow rate and also increases with the increase of cold water flow rate (outer tube).

The minimum and maximum values of slope are obtained at 1 LPM and 3 LPM respectively.

The amount of heat flux in case of parallel flow is less than that of the counter flow as shown in figure 2. However the counter flow pattern can obtain more amount of heat transfer rate as compare to parallel flow pattern.

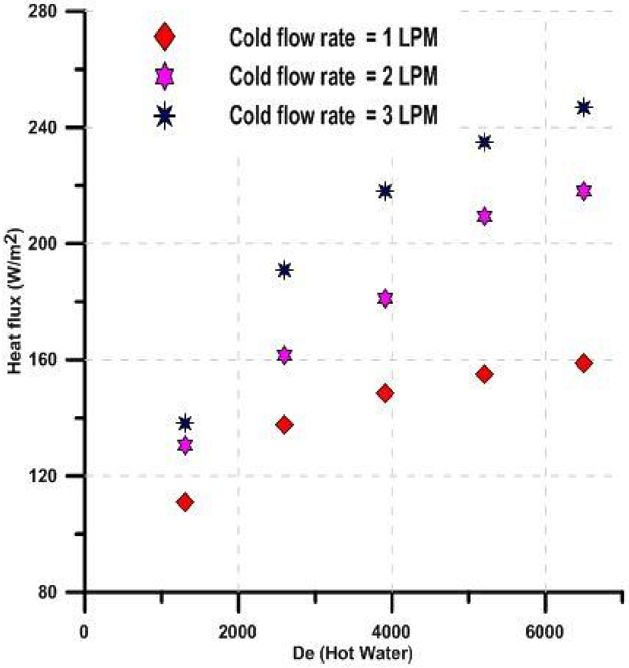

Fig. 1 Effect of water flow rate on heat flux

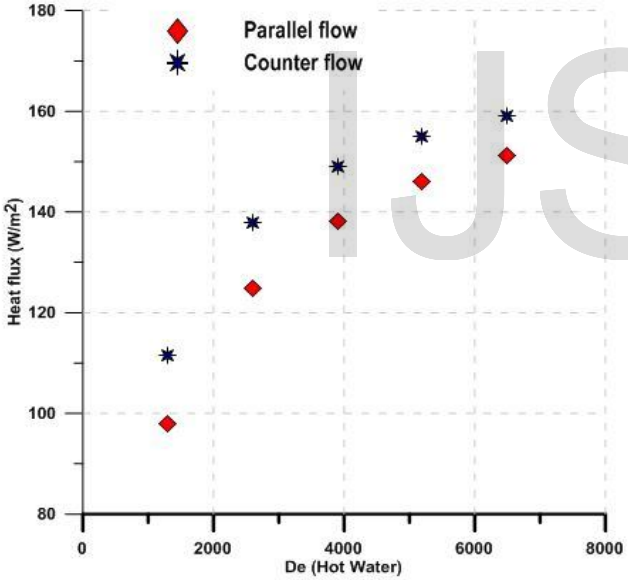

Fig. 2 Effect of flow direction on heat flux

5.2 The effect of hot and cold water flow rate and flow direction on nusselt number

As shown in Figure 3, Nusselt number increased with the increase of hot water (inner tube) or cold water (outer tube) flow rate. On increasing the cold water flow rate the effect of hot water flow rate is severer. The Nusselt number in case of parallel flow is less than that of the counter flow as seen in figure 4.

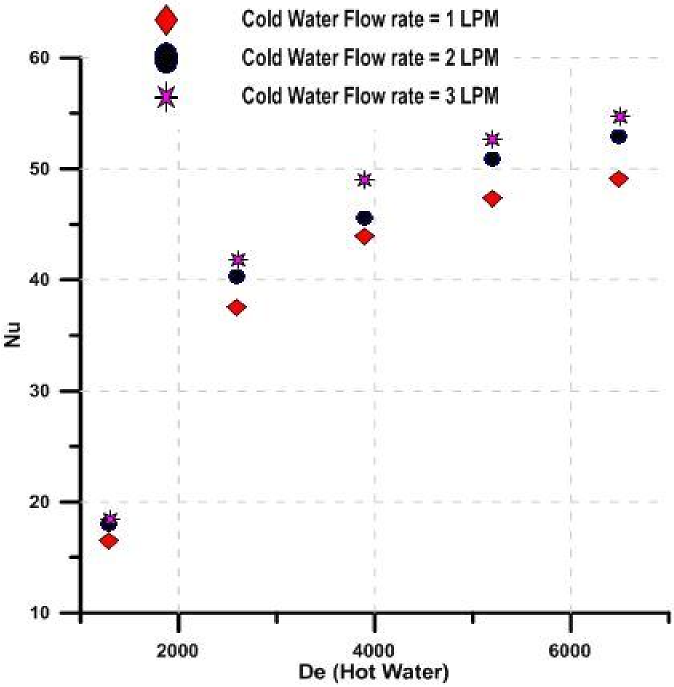

Fig. 3 Effect of flow rate Nusselt number

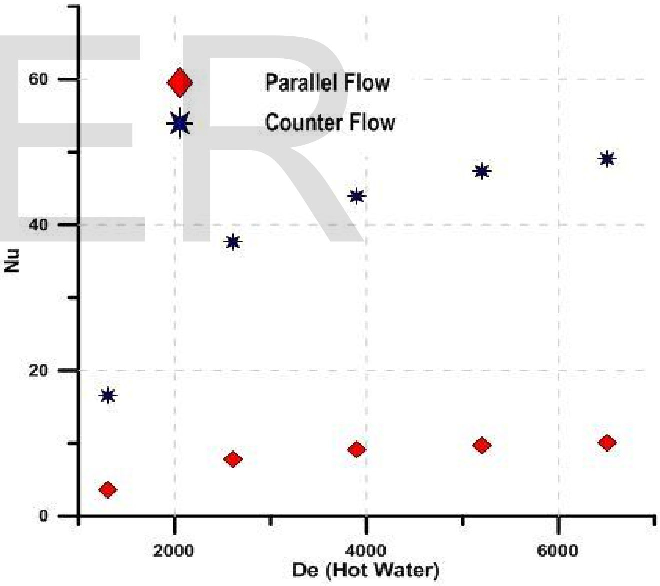

Fig. 4 Effect of flow direction Nusselt number

5.3 Residual and contour

Residual sum can be plotted using an XY co-ordinate system. The abscissa of the XY co-ordinate system corresponds to the number of iterations and the ordinate corresponds to the log-scaled residual values. For the present analysis, the solution is converged after completing 287 iterations and the corresponding residual graph is shown in fig. 5.

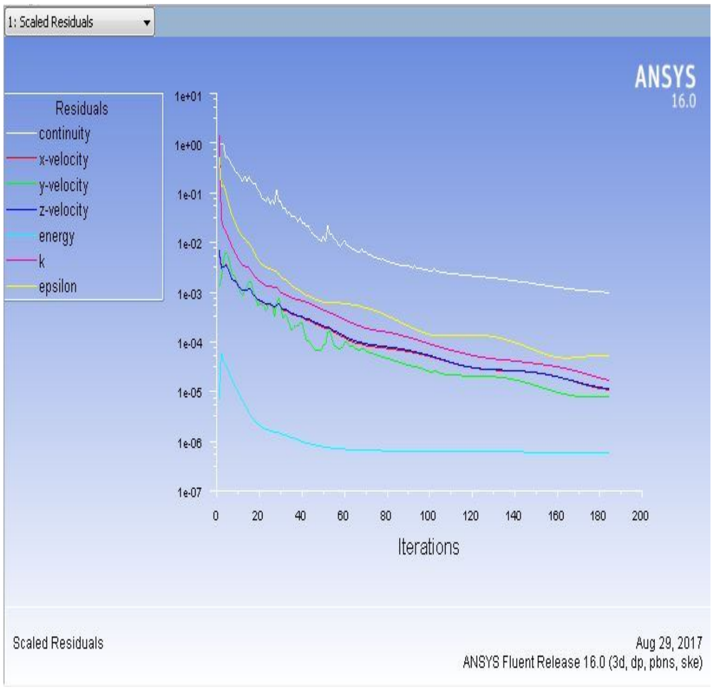

Fig. 5 Residual graph

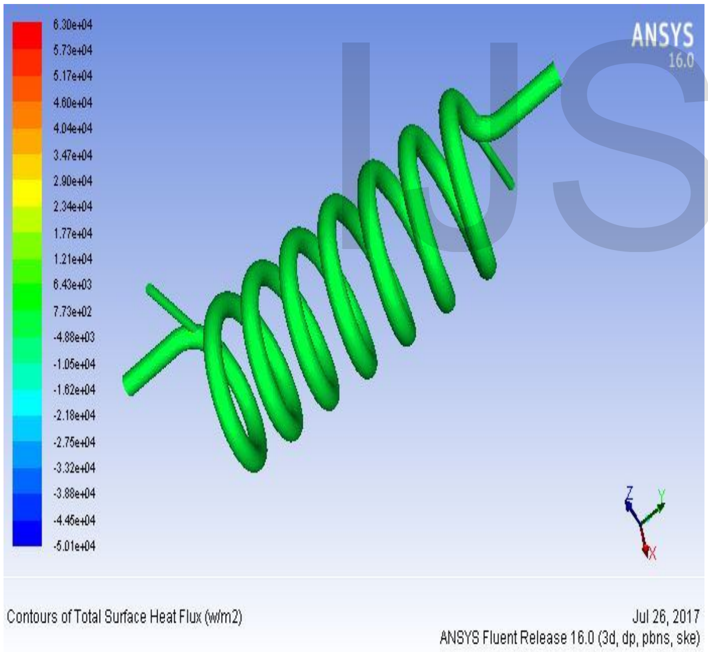

Fig. 6 Contours of total surface heat flux for parallel flow

6 CONCLUSION

Indeed, the rate of heat transfer increased due to the increment of hot water flow rate and also increases with the increase of cold water flow rate (outer tube). The minimum and maximum values of slope are obtained at 1 LPM and 3 LPM respectively. The counter flow pattern can obtain more amount of heat transfer rate as compare to parallel flow pattern. As far as, the effect of hot and cold water flow rates on Nusselt number (Nu) is considered, Nusselt number increases with the increase of hot or cold water flow rates. The results of flow direction are considerable. The Nusselt number in case of parallel flow is less than that of the counter flow.

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