NUMERICAL SIMULATION OF ENHANCEMENT OF HEAT TRANSFER IN A TUBE WITH AND WITHOUT ROD HELICAL TAPE SWIRL GENERATORS

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ABSTRACT

The heat transfer augmentation techniques are widely utilized in many applications in the heating process to enable reduction in weight and size or increase the performance of heat exchangers. These techniques are classified as active and passive techniques. The active technique required external power such as surface vibration and electric or acoustic fields, whereas the passive techniques required fluid additives, special surface geometries, or swirl/vortex flow devices, that is, twisted tape inserts. Computational heat transfer flow modeling is one of the great challenges in the classical sciences. As with most problems in engineering, the interest in the heat transfer augmentation is increasing due to its extreme importance in various industrial applications. CFD modeling for the heat transfer augmentation in a circular tube fitted with and without rod helical tape inserts in turbulent flow conditions has been explained in this paper using ANSYS Fluent version 14.0. Numerical simulation analyses will be carried out to study thermal–hydraulic characteristics of air flow inside a circular tube with different tube inserts. The flow rate of the tube is considered in a range of Reynolds number between 2300 and 8800. The swirling flow devices consisting of: the full-length helical tape with or without a centered-rod of a concentric tube heat exchanger. Finally results will be compared to available experimental and analytical calculations. The data obtained by simulation are matching with the literature value for a plain tube with the discrepancy of less than plus or minus 5% for Nusselt number and for the friction factor. Enhanced heat transfer with decreasing twist ratio has been observed. Heat flux is more uniform all along the tube and decreases uniformly towards the center

Keywords: CFD, Heat Transfer, Helical Insert.
I. INTRODUCTION

Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger’s performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process.

The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to development & use of many techniques termed as Heat transfer augmentation. These techniques are also referred as Heat transfer Enhancement or Intensification. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate & pressure drop has to be done. Apart from this, issues like long term performance & detailed economic analysis of heat exchanger has to be studied. To achieve high heat transfer rate in an existing or new heat exchanger while taking care of the increased pumping power, several techniques have been proposed in recent years and are discussed in the following sections.

Nowadays, twisted-tape inserts have widely been applied for enhancing the convective heat transfer in various industries, due to their effectiveness, low cost and easy setting up. Energy and material saving consideration, as well as economical, have led to the efforts to produce more efficient heat-exchanger equipment. Therefore, if the thermal energy is conserved, the economical handling of thermal energy through heat-exchanger will be possible.

S.K.Saha A.Dutta, [1]: experimentally studied the flow of servotherm oil in acrylic circular tube fitted with insulated stainless steel twisted tape insert. They studied the effect of varying length and varying pitch twisted tape with different twist ratios on heat transfer rate and friction factor.

Watcharin Noothong et al. [3]: their aim to investigate the efficiency enhancement and to study the heat transfer and friction factor characteristics of heat exchanger. In the experimental study, concentric double tube Plexiglas material heat exchanger was used. Cold water as an annulus and hot air as an inner fluid used as a medium. Paisarn Naphon, [4]: in his experimental study he used hot and chilled water in horizontal copper double tube heat exchanger fitted with aluminum twisted tape inside. He studied effects of relevant parameters on heat transfer and pressure drop. Smith Eiamsa-ard et al., [5]: their aim was to analyze heat transfer and flow friction characteristics in a copper tube double pipe counter flow heat exchanger, containing the stainless steel helical screw-tape with or without core-rod inside. Hot and chilled water used for experimentation. Ashis K. Mazumder and Sujoy K. Saha, [6]: performs the experimental study in a square and rectangular acrylic ducts fitted with full and short length twisted tape. It was concluded that regularly spaced full length twisted tape performs better as compared to short length tape.

II. MATHEMATICAL MODELS OF FLUENT

All the fluids investigated in this research are Newtonian. This means that there exists a linear relationship between the shear stress, \( \sigma_{ij} \), and the rate of shear (the velocity gradient). In CFX, this is expressed as follows:

\[
\sigma_{ij} = -p\delta_{ij} + \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \dot{\varepsilon}_{ij}
\]
In FLUENT, these laws are expressed in the following form:

**Law of Conservation of Mass**: Fluid mass is always conserved.

\[
\frac{\partial p}{\partial t} + \frac{\partial}{\partial x_j} (\rho u_j) = 0 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots 2
\]

**Newton’s 2nd Law**: The sum of the forces on a fluid particle is equal to the rate of change of momentum.

\[
\frac{\partial}{\partial t} (\rho u_i) + \frac{\partial}{\partial x_j} (\rho u_i u_j) = \frac{\partial}{\partial x_j} \left[ -p \delta_{ij} + \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + B_i \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3
\]

**First Law of Thermodynamics**: The rate of head added to a system plus the rate of work done on a fluid particle equals the total rate of change in energy.

\[
\frac{\partial}{\partial t} (\rho H e) + \frac{\partial}{\partial x_j} (\rho u_j H e) - \frac{\partial}{\partial x_j} \left( \lambda \frac{\partial T}{\partial x_j} \right) = \frac{\partial \rho}{\partial t} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots 4
\]

The fluid behaviour can be characterised in terms of the fluid properties velocity vector \( \mathbf{u} \) (with components \( u, v, \) and \( w \) in the \( x, y, \) and \( z \) directions), pressure \( p \), density \( \rho \), viscosity \( \mu \), thermal conductivity \( \lambda \), and temperature \( T \). The changes in these fluid properties can occur over space and time. \( H \) is the total enthalpy, given in terms of the static (thermodynamic) enthalpy, \( h \):

**III. GEOMETRIC MODEL**

The arrangement of the CFD model of a concentric tube heat exchanger was set up and the details of test section are depicted in Figs. 1 and 2. The double pipe heat exchanger consisted of two concentric tubes; the inner tube for hot air flow and the outer tube for water flow. The diameters of the inner and outer tubes were 19 and 40mm, respectively. The tubes were 2000mm long and 1mm thick. Copper and steel tubes were employed for the inner and outer tubes, respectively.

The outer tube surface was wrapped with insulation to minimize heat loss to surroundings. Fig.4 represented the helical tape insert used in this test. In the experiments, the geometric conditions of the helical tape inserted were kept constant. The helical tape was made of stainless steel and has the geometric dimensions of \( W = 17 \text{mm} \) \((0.95D)\), \( d = 5 \text{mm} \) \((0.26D)\), \( P = 18 \text{mm} \) \((0.95D)\), \( t = 1 \text{mm} \) \((0.05D)\). The helical tape insert and the twisted-tape insert generate the swirling flow in the circular tube and both of them possess the different characteristics of flow. For the helical tape, the swirling flow goes in single way direction (a screw motion), while the twisted-tape shows the swirling flow in two ways direction simultaneously. Because of lower pressure drop, twisted tape insert is, in general, more popular than the helical tape despite higher heat transfer rate. However, at low values of Reynolds number the pressure drops for using both tapes are not much different. In a solar water heater system, helical tape insert can be well applied due to low Reynolds number in the system. This helical tape can help to promote higher heat transfer exchange rate than the use of twisted-tape because of shorter pitch length which leads to stronger swirling flow and long residence time.
Fig. 1: Geometry under investigation: (a) Full-length helical tape with a rod; (b) Full-length helical tape without a rod.

Fig. 2: A concentric tube heat exchanger fitted with a helical tape and definition of geometric parameters of the helical tape.

Geometric Model is created in ANSYS Design modeller which is shown in Fig. 3. and 4.
IV. CFD MESHING

Two different types of grid cells can be found in this model: tetrahedral with prism boundary layer grid in the cylinder outer region and structured grid in helical region. Structured grid consists of ordered boundary layer quadrilateral cells, which gives considerable computational advantages. Especially complex shapes are difficult to model with a structured grid. Therefore an unstructured grid with triangular cells is used at the cylinder outer region.

The following four zones can be detected in Fig5 will be treated separately in this paragraph:

1. Boundary layer near the tube body
2. Helix with structured grid
V. RESULTS AND DISCUSSIONS

A. Smooth tube Results

Prior to the simulations using with the twisted tape, the Nusselt number and the friction factor in a plain tube were calculated. The CFD data were, and then compared with the results given by the well-known correlations under a similar condition, in order to evaluate the validity of the plain tube.

![Pressure contours smooth tube velocity Re=2300](image)

**Fig.6:** Pressure contours smooth tube velocity Re=2300

Fig.6 shows the Pressure contours smooth tube velocity 2m/s. In these contours shows helical tube pressure drop 21Pa.
Fig. 7: Temperature contours smooth tube Re=2300

Fig. 7: Temperature contours smooth tube with velocity 2m/s. In this contour shows the hot water temperature drop from 353K to 321.2 also cold water temperature increased from 300K to 301.77.
Fig. 8: Velocity contours smooth tube velocity Re=2300

Fig. 8 shows the Velocity contours smooth tube velocity Re=2300, it shows the higher velocity in tube region due to air.
Fig.9: Comparisons of CFD and experimental data and empirical correlations of the plain tube for Nu

Fig. 9 shows comparison between the present experimental and analytical work. In the figures, the present work agrees well with the available correlations with ±10% in comparison Dittus–Boelter for the friction factor

B. Helical Tube Insert without Rod

The twisted tube causes more turbulence intensity in the flow, because its sharp corner edge can produce more turbulence than the smooth surface, but, it causes more recirculation region inside the groove. So, it prevents good mixing of the fluid. Thus, it results in less increase of heat transfer compare with plain tubes

Fig.10: Pressure contours Helical insert without rod Re=2300
C. Helical Tube Insert with Rod

Fig. 11: Temperature contours Helical insert without rod Re=2300

Fig. 12: Temperature contours Helical insert with rod Re=2300

Fig. 12 Temperature contours Helical Tape pitch length 18mm Re=2300. In this contour shows the hot water temperature drop from 353K to 316.5.
Fig. 13 shows the effect of using the full-length helical tape with or without a centered-rod in a circular tube on heat transfer characteristic is shown in Fig. 9. It is found that the tube fitted with the tape gives higher heat transfer rate than the plain tube. The mean Nusselt number increased at about 165% when compared with those from correlations of Dittus–Boelter. It can be attributed that the use of full-length helical tape insert can cause the swirl and pressure gradient in the radial direction. The boundary layer along the tube wall would be thinner with the increase of radial swirl and pressure resulting in more heat flow through the fluid. Furthermore, the swirl enhances the flow turbulence, which led to even better convection heat transfer. Thus, the higher Reynolds numbers the greater Nusselt number.

In comparison between the full-length helical tape with and without a centered-rod, it can be seen that the tape with rod yields higher heat transfer rate than that without rod. This can be attributed to a flow mixing behavior between two streams from using the tape without rod: swirling flow around the tape and the axial flow along the tape core. This mixing gives rise to swirling flow weaker than that from using the tape with rod which has a swirling flow only. In general, the average heat transfer rate for employing the tape with rod is found to be 5–10% better than that for the tape without rod. The corresponding increase in mean Nusselt numbers in the heat exchanger is about 145% to 165% with and without rod, respectively.
**Fig.14:** Comparisons between the pressure drop and Reynolds number for the tube with full-length helical tape inserts

**Pressure drop:** The relationship between the pressure drop and Reynolds number for using the full-length helical tape with and without a centered-rod in a concentric tube heat exchanger is presented in Fig. 5.38. In the figure, it is worth noting that pressure drop from the full-length helical tape insert decreases at low Reynolds numbers due to weak swirling flow but increases substantially at higher values of Reynolds number. It can be seen that the trend of pressure losses is similar for both the axial flow (plain tube) and the swirl flow (helical tape inserts).

The pressure loss for the tube with the tape is substantially higher than that for the plain tube because of a higher surface area and the dissipation of dynamic pressure of the fluid at high viscosity loss near the tube wall. Moreover, the pressure loss had high possibility to occur by the interaction of the pressure forces with inertial forces in the boundary layer. Also, the flow velocity is larger since the motion is not in an axial direction.

It is obvious that the use of helical tape with rod gives higher pressure drop than that of the helical tape without a rod due to larger contact surface areas. Besides, the presence of helical tape with rod reduces flow areas, resulting in a high speed rotating flow. This leads to the substantial pressure loss action of the fluid (hot air) between the rod surface and the inner tube wall higher than the case of the tape without rod. From the results of the tape without rod, pressure loss could be reduced around 30% in comparison with the full-length helical tape with rod. As compromise the use of the tape without rod for Reynolds number less than 4000 is appropriate as Nusselt number values remain nearly the same especially.
VI. CONCLUSION

CFD analysis has been conducted to investigate heat transfer enhancement by means of helical tape inserts in a double pipe heat exchanger using cold water and hot air as the test fluids. From the experimental results, it can be concluded as follows: It is found that enhancing heat transfer with passive method using different types of helical tape construction in the inner tube of a concentric double pipe heat exchanger can improve the heat transfer rate efficiently.

The maximum mean Nusselt number may be increased by 160% for the full-length helical tape with centered-rod, 150% for the full-length helical tape without rod and 145% for the regularly-spaced helical tape, s = 0.5, in comparison with the plain tube. The increase in heat transfer and pressure drop can be explained by the swirling flow as a result of the secondary flows of the fluid. Visualization streamlines show the flow pattern of the flow through the helical tape in the tube. It was observed that there are strong swirling flows in the tube fitted with the helical tape while the axial flow and the weak swirling flow were seen in the free-spacing in the case of the regularly spaced helical tape without a rod.

REFERENCES

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