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Simulation of Flow and Heat Transfer in Tube with Twisted Tape Consisting of Alternate Axis

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Abstract. Numerical prediction of a three-dimensional flow in the tube fitted with a twisted tape consisting of alternate axis is presented. A finite volume method was used for the computation and the QUICK scheme was introduced to investigate numerical diffusion. The computations are conducted for the swirl flows induced by two types of twisted tapes: (1) typical twisted tape and (2) twisted tape with alternate axis. Results of the flow structure, velocity vector, temperature field in the tube with *TA/TT* are reported. The numerical results indicate that the use of *TA* leads to more uniform fluid/temperature distribution than that of the *TT*.

Keywords : Twisted tape with alternate-axis (*TA*), Simulation, Heat transfer, Fluid friction

1. Introduction

Computational technology advancement has extended solution methods for the complicated mathematical equations by numerical analysis, especially CFD (Computational Fluid Dynamics). In predicting both internal and external flows, the CFD solution variables place emphasis on predicting the true characteristics of flows in real interaction. CFD has been applied for analysis of the heat transfer enhancement in several types of heat exchangers with twisted tapes inserts. Guo *et al.* [1] studied the heat transfer and thermal performance factor in tube with a center-cleared twisted tape. They found that the thermal performance of the tube with center-cleared twisted tape was enhanced up to 20% as compared with that of tube with the typical twisted tape (*TT*). Wang *et al.* [2] conducted the computational fluid dynamics (CFD) modeling to predict the configuration optimization of regularly spaced short-length twisted tape in a round tube. It was observed that the tape with larger rotated angle yielded a higher heat transfer value and a greater flow resistance, whereas the one with smaller twist ratio resulted in better heat transfer performance. Cui *et al.* [3] carried out numerical simulation of the heat transfer characteristics and the pressure drop of air flow in a circular tube with an edgefold-twisted tape insert. It was reported that the Nusselt number and friction factor in the tube with edgefold-twisted tape were higher than those in the tube with *TT* up to 9.2 % and 74%, respectively. Eiamsa-ard *et al.* [4] numerically analyzed the swirling flow in the tube induced by loose-fit twisted tape insertion with different clearance ratios. The mean flow patterns in a tube with loose-fit twisted tapes in terms of contour plots of velocity, pathline, pressure, temperature and turbulent kinetics energy were also described and compared with those in the tube fitted with tight-fit twisted tapes. Rahimi *et al.* [5] predicted the friction factor, Nusselt number and thermal-hydraulic performance of a tube equipped with the classic and three modified twisted tape inserts with CFD. Among the tapes of interest, the jagged insert yielded the highest Nusselt number and thermal perform factor which were higher than those given *TT* by around 31% and 22%, respectively.

The main objective of the present work is to predict the flow structure (pathline and velocity vector) and heat transfer (fluid temperature along the tube and in each crossection) behaviors in a tube with twisted tape with alternate-axis (*TA*).

2. Governing Equation

The mathematical modeling involves the prediction of flow and heat transfer behaviors. The available finite difference procedures for swirling flows and boundary layer were employed to solve the governing partial equations. Some simplifying assumptions were applied for conventional flow equations and energy equations to model the heat transfer process in tube with twisted tape. The major assumptions are; (1) the flow through the *TT/TA* is laminar and incompressible, (2) steady state flow, (3) natural convection and thermal radiation are neglected and (4) the thermo-physical properties of the fluid are temperature independent. Based on above approximations, the governing differential equations used to describe the fluid flow and heat transfer in round tubes with *TT/TA* inserts are established. In the present study, the periodic flow was consideration at axial distance in tube between 0 to 12D (Fig. 1). The continuity, momentum and energy equations for the three dimensional models are employed. For steady state, constant density flows, the time-averaged incompressible Navier-Stokes equations in the Cartesian tensor notation can be written in the following form:

Continuity equation:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial x_i}\left[u_i(\rho E + p)\right] = \frac{\partial}{\partial x_j}\left(k_{eff}\frac{\partial T}{\partial x_j}\right), \quad E = h - \frac{p}{\rho} + \frac{u^2}{2} \tag{3}$$

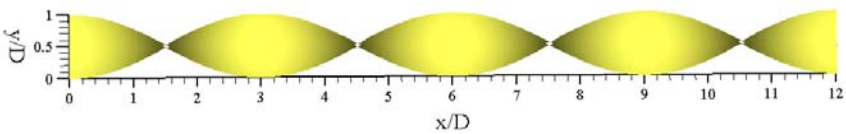
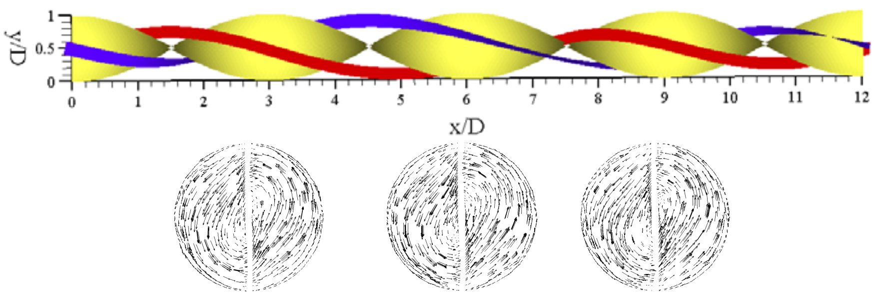
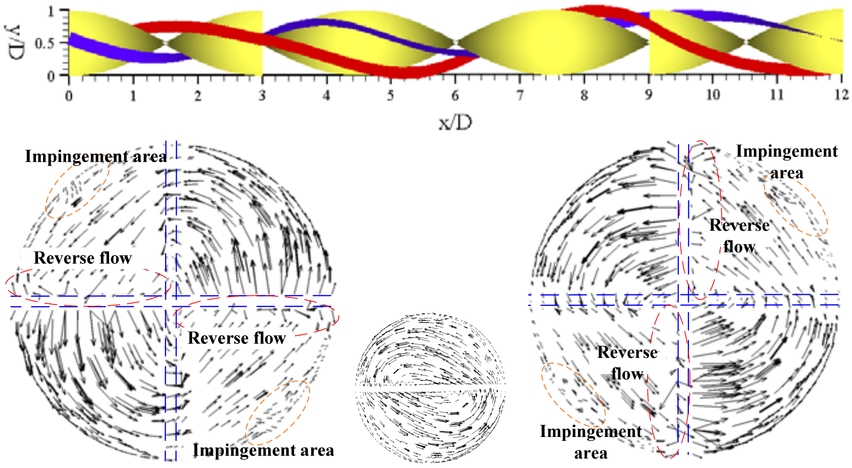


Fig. 1 Twisted tape geometry

In the present numerical solution, the time-independent incompressible Navier-Stokes equations and the various turbulence models were discretized using the finite volume technique. QUICK (Quadratic upstream interpolation for convective kinetics differencing scheme) and central differencing flow numerical schemes were applied for convective and diffusive terms, respectively. To evaluate the pressure field, the pressure-velocity coupling algorithm SIMPLE (Semi Implicit Method for Pressure-Linked Equations) was selected. Impermeable boundary condition has been implemented over the tube wall. The turbulence intensity was kept constant at 10% at the inlet, unless other-wise stated. The computation was performed until the difference between normalized residual of the algebraic equation and the prescribed value fell below a convergence criterion (10^{-6}).



(a) *TT*



x/D = 3 x/D = 6 x/D = 9

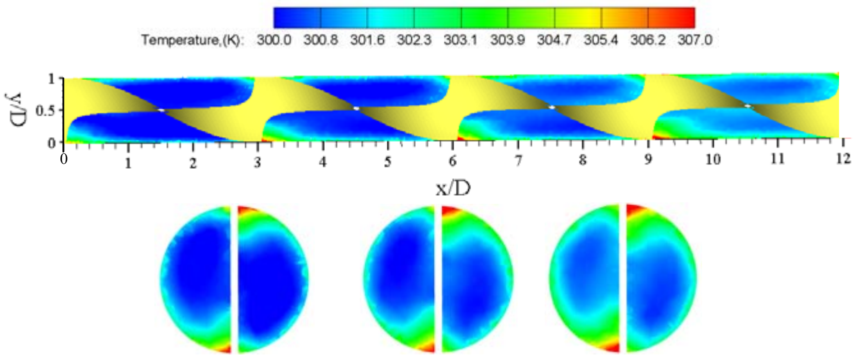
(b) *TA*

Fig. 2 Pathline and velocity vector in a tube with twisted tape

3. Simulation Results

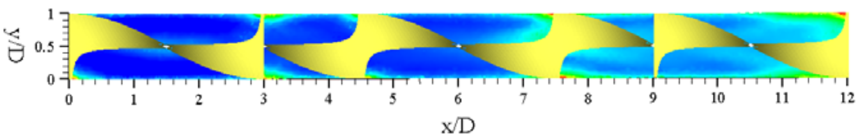
Figure 2(a-b) presents the two pathlines through the tape. In case of *TT* (Fig. 2a), it is observed that the blue pathline is consistently located in opposite side of twisted tape with respect to the red one throughout the tube. On the other hand, in case of *TA,* the blue pathline is merged with the red one at the first alternate point (at x/D = 3). The combined pathline is subsequently splited at the second alternate point (x/D = 9), behind this point the red pathline was brought to the position of the blue one and vice versa, as compared to those at the start point (x/D = 0). The unordinary behavior of the swirl flow induced by *TA* can lead to strong flow flucation and better fluid mixing (reverse flow and jet impingement) than the common swirl flow generated by *TT*.

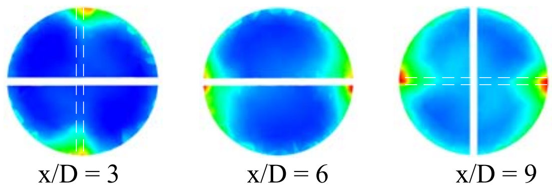
Figure 3(a-b) presents contour plot of fluid temperature in the tubes with *TT* and *TA*. the fluid temperature contour surrounded each twisted tape is presented yellow color (the tape is assumed as insulator). In general low fluid temperature is found at the core and entrance while the high fluid temperature is observed near the tube wall. The contour plot of crosssection temperature reveals that the core temperature in the tube with *TA* is lower than that in the tube with *TT*, at the same axial distance. The reduction of bulk fluid temperature for *TA* and *TT* cases become obvious at x/D > 7 for *TA* and x/D > 9 for *TT*, respectively. In addition, the temperature distribution with *TA* is considerably more uniform than that with *TT*. All results mentioned above reflect that *TA* gives superior fluid mixing to *TT*.



x/D = 3 x/D = 6 x/D = 9

(a) *TT*

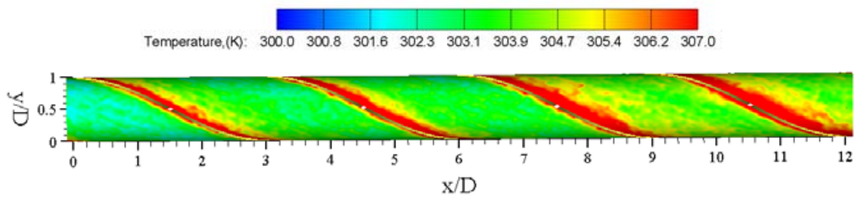




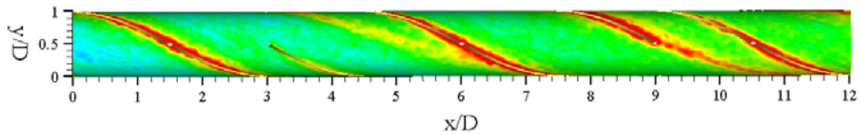
(b) *TA*

Fig. 3 Contour plot of fluid temperature at *Re* ≈ 500

Wall temperature of both tubes with *TT/TA* is demonstrated in Fig. 4(a-b). the high wall temperature (red color) is found at the edge of the tape due to high heat transfer conductivity. The colar bar thickness of of *TA* is smaller than that of *TT* due to the better fluid mixing which consequently results in more efficient distruction of thermal boundary layer near the edge of tape.



(a) *TT*



(b)) *TA*

Fig. 4 Wall temperature around inner tube with twisted tape at *Re* ≈ 500

4. Summaries

In the present work, the flow structure (pathline/vector-plot) and the temperature field in the round tube with *TA/TT* inserts. It is found that *TA* induces better fluid mixing. This consequently leads to more uniform fluid temperature distribution and more efficient heat transfer through the tube wall.

5. Acknowledgement

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