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Numerical and Experimental Analysis for Fluid Flow Inside Corrugated Tube Equipped with Twisted Tapes

H. Ghalyanchi Langeroudi, K. Javaherdeh*

Faculty of Mechanical Engineering, University of Guilan, Rasht, Iran

ABSTRACT: The aim of present paper is to study numerical simulation by using finite volume method for Newtonian and non-Newtonian fluid flow inside corrugated tube equipped with typical twisted tape and V-cut twisted tape at constant heat flux. For validation of this simulation, this results compared with empirical correlations of researchers. In this analysis water was as Newtonian fluid and 0.2 wt % carboxymethyle cellulse in water was as a non-Newtonian fluid, the range of Reynolds number for Newtonian and non-Newtonian fluid varied 5300 to 25700 and 2400 to 6800 respectively. In this analysis, the effects of using different turbulence models, variable heat flux and creating V-cut on Nusselt number and friction factor is investigated. The obtained results showed that standard κ -ω model of turbulence for Newtonian fluid is a proper model rather than the other models and it had good agreements between experimental data, and the average differences for Nusselt number in typical and V-cut twisted tapes were less than 15.2% and 14.4% respectively. On other hand, in identical condition for non-Newtonian fluid, using of standard κ - ε model of turbulence is a proper model rather than the other models and the average differences on Nusselt number for typical twisted tape were less than 18%..

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1- Introduction

Heat transfer can be enhanced by three main methods which are active, passive and compound methods that all of the three methods to get a smaller size, effective, and low price device [1]. The passive methods are more used compared with the active methods because the swirl inserts manufacturing process is simple and can be easily employed in an existing heat exchanger. Among the methods used in the passive method, twisted tapes as one of the passive methods have been extensively studied due to simple configuration and ease of installation. These tapes by generating swirls increases the fluid mixing of the near-wall and central regions, reducing the hydraulic diameter and elongating the flow path finally cause to increase the heat transfer rate [2-4]. The objective of this paper is to study numerical simulation for Newtonian and non-Newtonian fluid flow inside corrugated tube equipped with typical Twisted Tape (TT) and V-cut Twisted Tape (VTT) at constant heat flux. For validation of this simulation, this results compared with experimental data and empirical correlations of researchers. In this analysis water was as Newtonian fluid and 0.2 wt % CarboxyMethyle Cellulse (CMC) in water considered as a non-Newtonian fluid, the Reynolds number for Newtonian and non-Newtonian fluid varied 5300 to 25700 and 2400 to 6800 respectively. And also in this analysis the effects of using different models of turbulence, various heat flux and creating cut on Nusselt number and friction factor was investigated.

2- Methodology

2.1. Experimental analysis

In this investigation, test section are made of a corrugated copper tube with length (L), outer diameter (D_o_o), height (e) and pitch (p) of corrugation 1000 mm, 19 mm, 0.5 mm and 18 mm respectively (Fig. 1). The twisted tape inserts are made out of aluminum sheet with 1.0 mm thickness and 14 mm width (W) with twisted ratio (y=4.5), in Fig. 2 the geometries of twisted tape (TT and VTT) and the lay-out of present work are shown. In every runs of experiments for calculating Nusselt number and friction factor, it is necessary to be measured and recorded the different parameters in experiment (bulk and wall temperatures, flow rate, pressure drop).

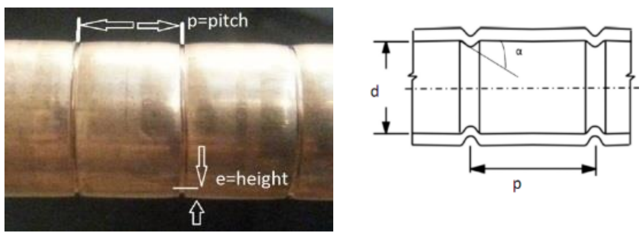

Fig. 1. Geometry of corrugated tube

*Corresponding author's email: javaherdeh@guilan.ac.ir

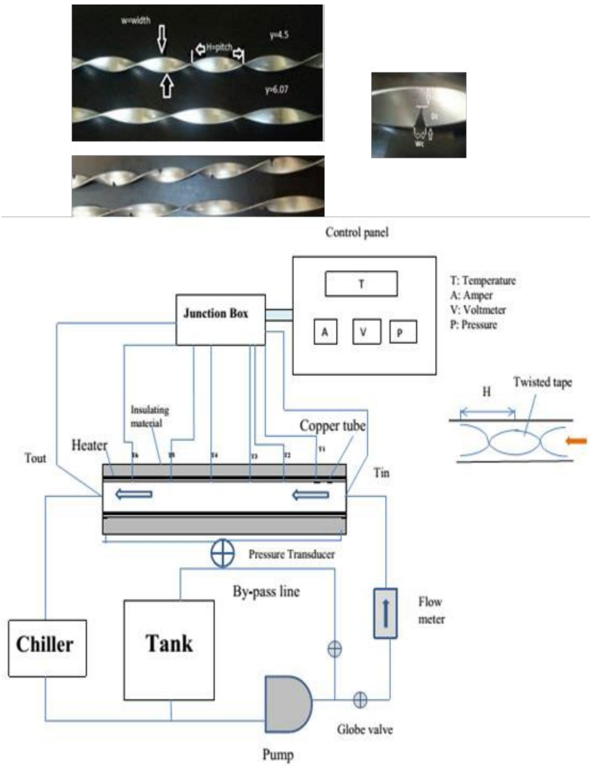

Fig. 2. A schematic of the specimen [1]

2.2. Numerical analysis

In the numerical analysis, the problem to be solved in three dimensional, turbulent flow and with steady state conditions. The constant heat flux considered in tube wall, and also the heat conduction in twisted tape and tube wall to be neglected. The finite volume approach is applied to solve the governing partial differential equations. This equations are continuity, momentum and energy equations with the below details:

a) Continuity equation:

$$\nabla . v = 0 \tag{1}$$

b) Momentum equation:

$$\frac{\partial(\rho v)}{\partial t} + \nabla.(\rho v v) = -\nabla p + \nabla.\mu(\nabla v) \tag{2}$$

c) Energy equation:

$$\rho C_p \left(\frac{\partial T}{\partial t} + \nabla . vT\right) = \nabla.(K.\nabla T) \tag{3}$$

For solving problem in turbulent flow used of three models of turbulence (a) k-ε standard (b) RNG k-ε (c) k-ω. In this experiment the constant heat flux ($q''=-k\,\partial T/\partial r$) imposed at surface of the tube wall (r=d/2) is known. In the inlet of the test section, velocity and temperature specified and at the outlet of test section a pressure-outlet condition is considered. No slip condition applied on the surfaces of the tube wall and twisted tapes. The finite volume method is used to discretize the governing partial differential equations encountered in this work. The finite method sub-divides the calculation domain into a set of control volumes where in lies the computational nodes. A second order upwind scheme is applied for convective and diffusive terms. To evaluate pressure field, the pressure-velocity coupling algorithm SIMPLE (Semi Implicit Method for Pressure Linked Equations) is selected. The turbulence intensity is kept at 5% and turbulent viscosity ratio considered 10 at inlet. Convergence criteria of 0.001 for continuity and 10^{-6} for energy are set.

3- Results and Discussion

In this investigation in order to evaluate the validity of the numerical results about the fluid flow inside corrugated tube equipped with twisted tapes, these results compared with the empirical correlation of researcher works for fluid flow inside plain tube that equipped with twisted tapes [5-7] at similar conditions. The variations of Nusselt number and friction factor respect to Reynolds number for three states of turbulence models for Newtonian and non-Newtonian fluid compared with empirical correlation equations. These numerical results showed for Newtonian fluid show that κ- ω model for turbulence is proper than the other models, the differences for Nusselt number rather than experimental results for typical and v-cut twisted tapes [8] are 15.2% and 14.4% respectively. For non-Newtonian fluid flow shows that the k-ω model for turbulence is proper than the other models, differences for Nusselt number rather than analytical results is lower 18%. For all cases, Nusselt number increased with increasing Reynolds number. This phenomenon is related to the increase of swirl-flow speed, resulting in a more efficient destruction of the thermal boundary layer. And also the Nusselt number and the friction factor in the tube equipped with VTT are higher than the tube that fitted with

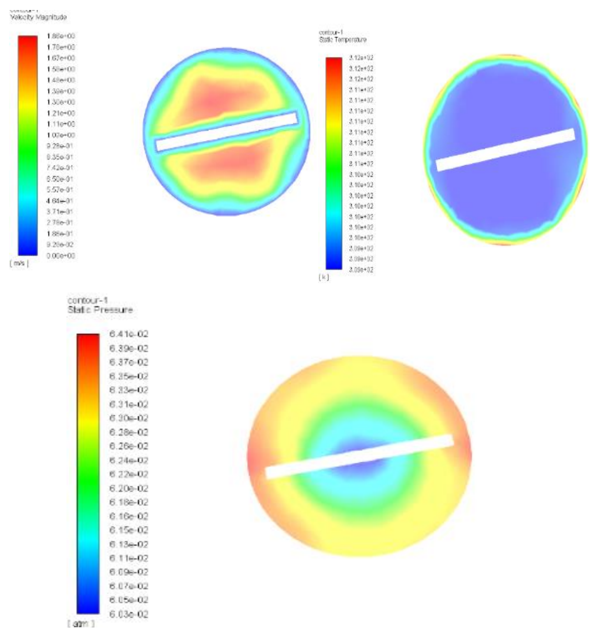

Fig. 3. Contours of Velocity, Temperature and pressure for fluid flow inside corrugated tube equipped with twisted tape in specified Reynolds number

TT. Referring to past investigations [9] typical VTT provides an additional turbulence to the fluid in the vicinity of the tube wall and vortices behind the cuts and thus leads to a higher heat transfer enhancement in comparison with the TT. On the other hand, increase in Reynolds number increases the heat transfer due to disturbance in boundary layer and causing increased convection heat transfer from wall to fluid.

In Fig. 3 shows contours of temperature, velocity and pressure for specified Reynolds number. By drawing contours for variable Reynolds number for typical and v-cut twisted tape concludes that the in identical cross-section of pipe equipped with twisted tapes reveals that by increasing Reynolds number, the variations of velocity and temperature contours inside pipe for typical and v-cut twisted tapes are insignificant, in while that the variations of pressure contours for both states are remarkable.

4- Conclusion

The main results of these paper describe to below details:

a) The numerical results obtains that k-ω standard model for Newtonian fluid and k-ω model for non-Newtonian fluid are proper models rather than used models in turbulence. And also the maximum deviations for average Nusselt number for Newtonian and non-Newtonian fluid flow are 15.2% and 18% respectively.

b) The V-cut twisted tapes provides an additional turbulence to the fluid near the tube wall and vortices behind the cuts and thus leads to a higher heat transfer enhancement in comparison with the TT, the maximum deviations for average Nusselt number for V-cut twisted tape rather than experimental data is lower 14.4%.

c) The results obtains that by varying heat flux, the variations of Nusselt number are Negligible.

d) In identical cross-section of pipe equipped with twisted tapes reveals that by increasing Reynolds number, the variations of velocity and temperature contours inside pipe for typical and V-cut twisted tapes are insignificant, in while that the variations of pressure contours for both states are remarkable.

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