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CFD analysis of Heat transfer and friction factor characteristics ina circular tubefitted with Parabolic-cut twisted tape inserts

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Abstract: This paper reports the Computational Fluid Dynamics (CFD) modellingstudy on heattransferand friction factor of aconstant heat-fluxed tube equipped with Parabolic-cut twisted tape inserts in the laminar flow regime using a commercial CFD package(FLUENT-6.3.26). Two geometry parameters of the Parabolic-cut twisted tape have been considered in this study,a twist ratio and cut depth. The simulation has been carried out for twist tapeswith twist ratio (y=2.93, 3.91and 4.89) andcut depth(w =0.5, 1 and 1.5 cm). The CFD predicted resultsmatched with the literature correlations for plain tube for validation, with the discrepancy of lessthan ±8%for Nusselt number and ±6.5 % for friction factor.The results have also revealed that the Nusselt number and the frictionfactor in the tube with Parabolic-cut twisted tape (PCT) increase with decreasing twist ratios (y) andcut depth (w).

Key word: Heat transfer augmentation, Friction factor, Parabolic-cut twisted tape,Fluent, CFD simulation.

INTRODUCTION

The augmentation techniques of heat transfer are widely applied to improving the performance of heat exchangersin chemical industries and air conditioning systemsto reduce the size and costs of the heatexchangers, these techniques are classified as active and passive techniques. The active techniques require external forces, e.g. electric field, surface vibration or Jet impingement. The passive techniques require special surface geometries or swirl/vortex flow devices.Many of experimental works on heat transfer augmentation using twisted tape as swirl/vortex flow deviceshave beenreported in the literature(Saha, Gaitonde *et al*. 1990; Manglik 1993; Naumov 1994; Wang 2002; Ujhidy 2003; Jaisankar, Radhakrishnan *et al*. 2009; Guo, Fan *et al*. 2011; Ibrahim 2011; Wongcharee and Eiamsa-ard 2011).Whereas, fewliteraturesare available in CFD modeling of heat transfer using twist tape inserts(Sivashanmugam 2008) reported the modeling of heat transfer augmentation in a circular tube fitted with helical twist insert in a laminar and turbulent flow using CFD.

(Mugam 2009)conducted CFD simulations of heat transfer characteristics of Al_2O_3nanofluid in a circular tube fitted with helical twist inserts under constant heat flux using Fluent version 6.3.26.Different concentrations of Al2O3 nanoparticles(0.5%, 1.0% , 1.5%) and twist tape inserts with different twist ratio (y = 2.93, 3.91, 4.89)have been used for the simulation. The predicted results obtained by simulation compared with the literature value of water for plain tube helical tape inserts. (Pathipakka and Sivashanmugam 2010)proposed CFD simulation of heat transfer and friction factor behavior for the circular tube fitted with right-left helical twist insert with 100 mm spacer. The simulated Nusselt number and friction factor are compared with the experimental data with good agreement. (Shabanian, Rahimi *et al*. 2011) have carried out an experimental and CFD modeling on heat transfer and friction factor characteristics in air cooled heat exchanger using butterfly twist tape insert. They found that the insert configuration has a main effect on the new number, friction factor and thermal performance factor,the maximum thermal performance factor was obtained by the butterfly insert with an inclined angle of 90°. The results verified using CFD simulation with good agreements between the predicted and measured values of Nu number and friction factor values.

In the present study, a new configuration of twist tape inserts is reportedflowusing CFD simulation, to predict the Nusselt number and friction factor in laminar flow regimes based on experimental data mentioned in (Pathipakka and Sivashanmugam 2010). This study can be used as guideline for experimental works.

Physical model:

The geometry of the Parabolic-cut twisted tape (PCT) insert is illustrated in Fig. 1. Twist tape of thickness (t) of 0.08 cm and width (W) of 2.545 cm with relative twisted ratios (y = 2.93, 3.91 and 4) fits in a tube with a diameter (D) of 2.54 cm and length (L) of 180cm. Different cut depth (w = 0.5, 1 and 1.5 cm) is used for each twisted tape. Steel and aluminium are selected as the material of construction of the tube and twisted tape, respectively. Water is selected as the working fluid and the thermophysical properties assumed to be

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temperature independent. The thermo-physical properties of water and materials used for simulation are shown in Table 1. The Reynolds number (Re), Nusselt number (Nu) and the friction factor (f) are defined by the following equations:

$$\mathrm{Re} = \frac{\rho u D}{\mu} \quad (1)$$

$$Nu = \frac{hD}{k} \quad (2)$$

$$f = \frac{16}{\mathrm{Re}} \quad (3)$$

Where ρ is the density, u is velocity, μ is dynamic viscosity and k is the thermal conductivity of the fluid. *h*is the heat transfer coefficient and *D*is the inner diameter of the tube.

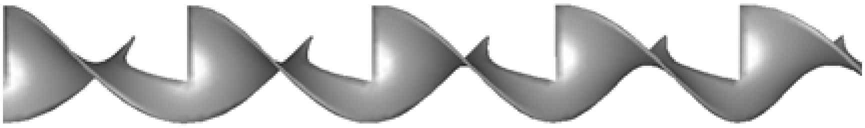

Fig. 1: Parabolic-cut twisted insert

Table 1: Thermo-physical properties of materials at 298 K

Materials	Density (Kg/m^3)	Specific heat (J/kg K)	Thermal conductivity (W/m K)	Viscosity (Pa s)
Water	998.2	4182	0.6	0.001003
Steel	8030	502.48	16.27	-
Aluminium	2719	871	202.4	-

Numerical Simulations:

Three dimensional steady state laminar flow under constant heat-fluxed tube, fitted with twist tape inserts are particularized by the following model equations:

3.2.1 Continuity equation for an incompressible fluid.

$$\frac{\partial p}{\partial t} + \nabla.(\rho \vec{v}) = S_m \quad (4)$$

3.2.2. Conservation of momentum.

$$\rho \frac{\partial v}{\partial t} + \rho(\vec{v}.\nabla)\vec{v} = -\nabla p + \rho \bar{g} + \nabla.\tau_{ij} + \vec{F} \quad (5)$$

3.2.3. Conservation of energy.

$$\frac{\partial}{\partial t}(\rho E) + \nabla.\{\vec{v}(\rho E + \rho)\} = \nabla.\{K_{eff} \nabla T - \sum_j h_j (\vec{\tau}_{eff} .\vec{v})\} + S_h \quad (6)$$

Geometry And Grid Arrangement:

The geometry and the gird were generated using GAMBIT the pre-processing module of the FLUENT code.The geometry and the grid for both the plain tube and Parabolic-cut twisted tape are created inGAMBIT and imported into FLUENT. The geometry consists of a cylindrical tube of diameter 25.54cmand length of 180cm. Figure 2 shows the grid for theplain tube configuration using a quadrilateral face mesh over the volume of the cylinder.

Different types of meshing twisted tapes are available to mesh the volume but tetrahedral/hybrid and T Grid type elements is the best mesh for irregular shapes. The grid generated in the tube fitted with PCT inserts is shown in Figure 3. Boundary conditions for the geometry are defined for inlet, outlet, wall of twist tape andcylinderwall,the continuum volume of fluid is defined as water.The mesh file was exported to FLUENTsuccessfully.

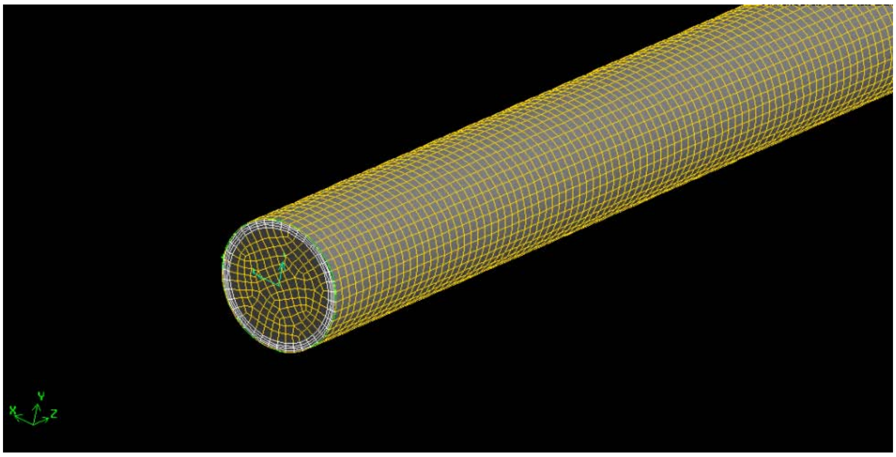

Fig. 2: Grid for the plain tube

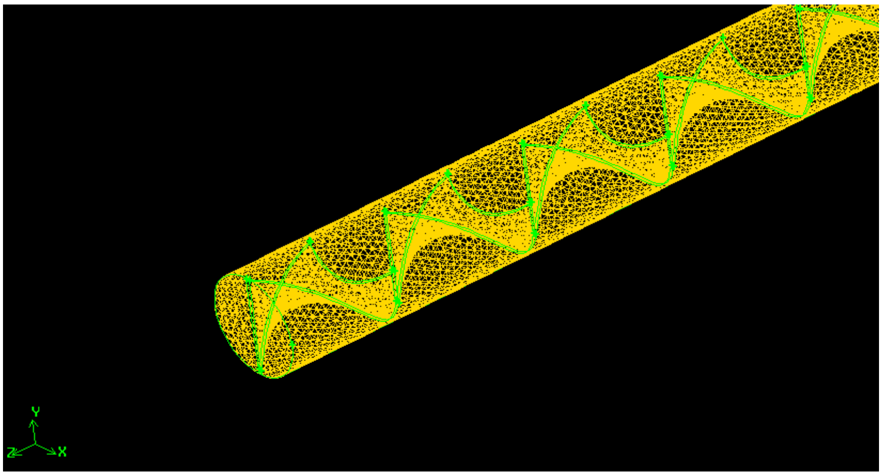

Fig. 3: Grid for the plain tube with Parabolic-cut twisted tape (PCT) insert

Modeling Parameters:

Numerical values of experimental data mentioned in (Pathipakka and Sivashanmugam 2010)were used in a number of the simulations are given in Table2.

Table 2: Numerical values of the parameters used for simulations.

Flow rate (kg/sec)	0.003	0.005	0.006	0.008	0.01	0.116	0.0133	0.015	0.0166	0.02	0.03
Heat flux (w/m^2)	240.03	340.77	459.15	563.38	749.85	1001.57	1363.26	1512.68	1893.56	2130.05	2445.25

Numerical Method:

The commercial CFD packageof Fluent 6.3.26softwarewas chosen as the CFD tool to solve the above-mentioned governing equations companied withboundary conditions. Solution sequential algorithm (segregated solver algorithm) has been used with settings; implicit formulation, steady(time-independent) calculation, viscous laminar model and energy equation. SIMPLE as the pressure-velocity coupling method and first - Order Upwind scheme for energy and momentum equations as well as default values for under-relaxation factors and convergence criterion.

RESULTS AND DISCUSSION

Validation Of Plain Tube Simulation Results:

The simulated data of Nusselt number and friction factor for plain tube are being compared with the correlations developed by (Tate 1936)for validation. Thepredicted are demonstrated in Figures4 and 5, apparently, present results reasonably agree well with the available correlations within ±8% for Nusseltnumber and±6.25% for friction factor respectively.

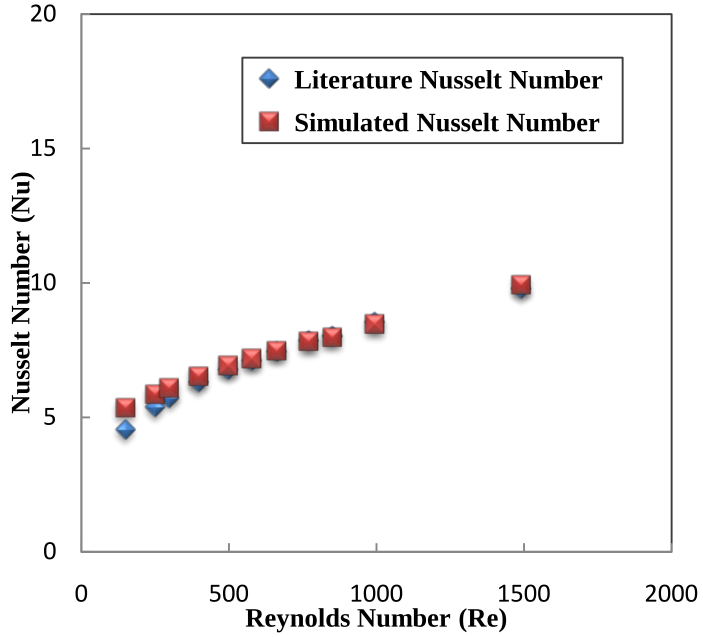

Fig. 4: Plain tube simulated Nusselt Number vs Literature data

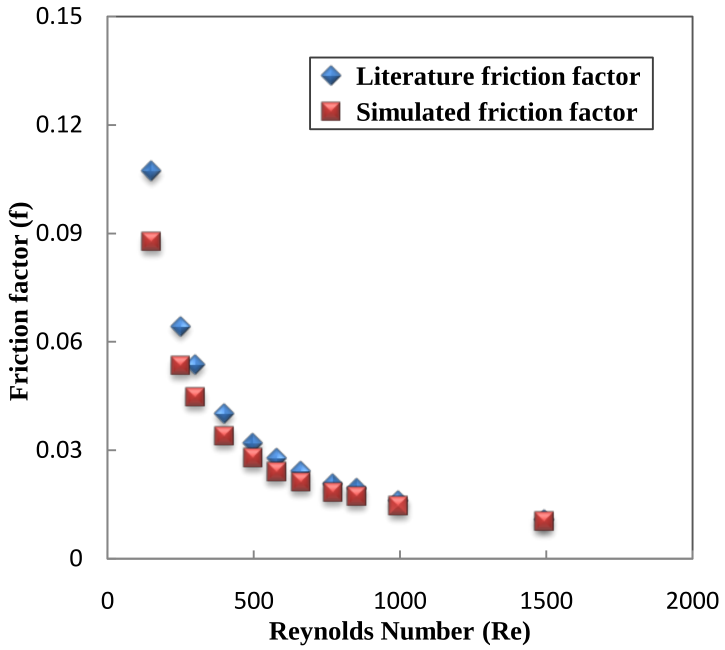

Fig. 5: Plain tube simulated friction Factor vs literature data

Effect Of Twist Ratio On Heat Transfer And Friction Factor:

The simulated data of the Nusselt number and friction factor and their variation with a Reynolds numberofpublic-cut twisted tape inserts with twist ratio (y=2.93, 3.91and 4.89) and cut depth (w =0.5 cm) is shown in Figuers 6 and 7.Figure 6indicate that the Nusselt number increases with Reynolds number and the heat transfer rate is higher for the twist tape set than the plain tube, because of strong swirl flow in thetwist tape. It is found that the heat transfer rate at the twist ratio (y=2.93) is higher than those from higher ratio (y= 3.91 and

4.89), thismean that the turbulent intensity and the flowlength obtained from the lower twist ratio are higher than those at higher ratios (y). Figure 7shows the variation of friction factor with a Reynolds number for different twist ratios (y=2. 93, 3.91and 4.89). The friction factor obtained from the tube withtwisted tape insert is significantly higher than the plain tube. Moreover, the use of smallertwist ratio leads to higher tangentialcontact between the swirling flow and the tube surface. Therefore, the twisted tape with twist ratio (y= 2.93) has a maximum friction factor.

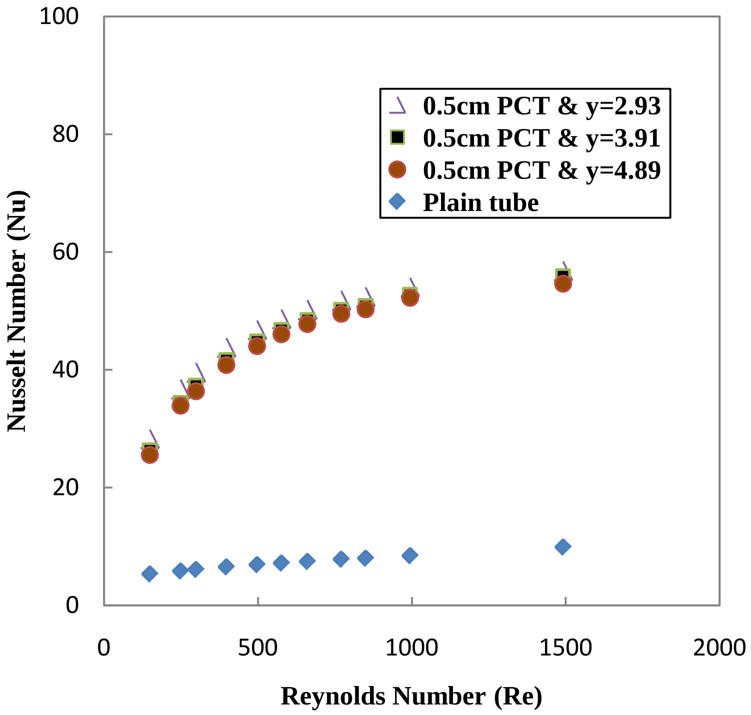

Fig. 6: Simulated Nusselt Number for Plain tube and Parabolic-cut twisted tape with cut depth (w=0. 5cm)and a different twist ratio (y).

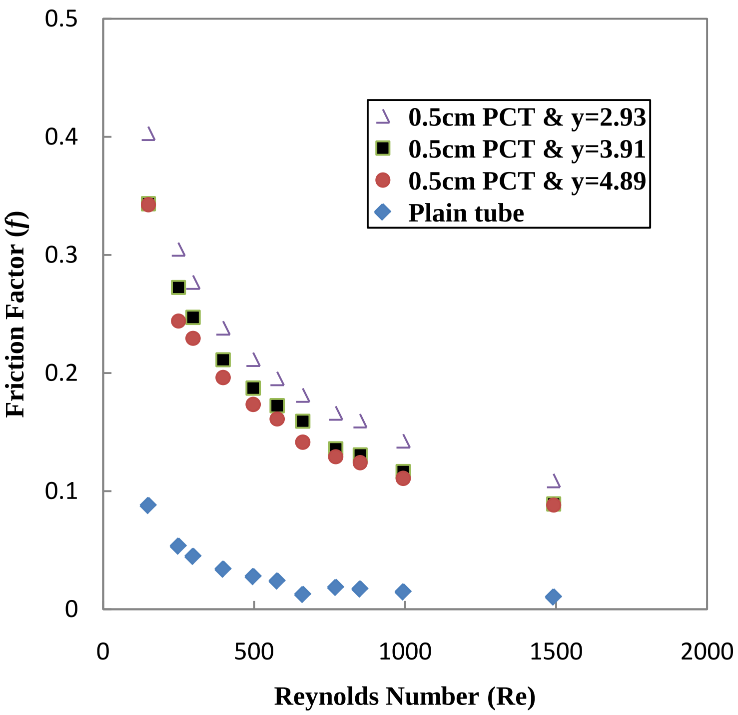

Fig. 7: Simulated Nusseltfriction factor for Plain tube and Parabolic-cut twisted tape with cut depth (w=0. 5cm)and a different twist ratio (y)

Effect Of Cut Depth On Heat Transfer And Friction Factor:

The Nusselt number and friction factor and their variation with a Reynolds numberof PCTinserts with twist ratio y=2. 93and cut depth (w =0. 5, 1 and 1.5 cm) is shown in figures 8 and 9. Fora given Reynolds number, Nusselt number and friction factor are increased with decreasing cut depth, this is mainly due to the combined effects of common swirling flow by the twisted tape and turbulence generated by the alternative cuts along the edge of the twisted tape which leads to the destruction of the thermal boundary layer and creating better flow mixing between the fluids at the core and heating wall surface.

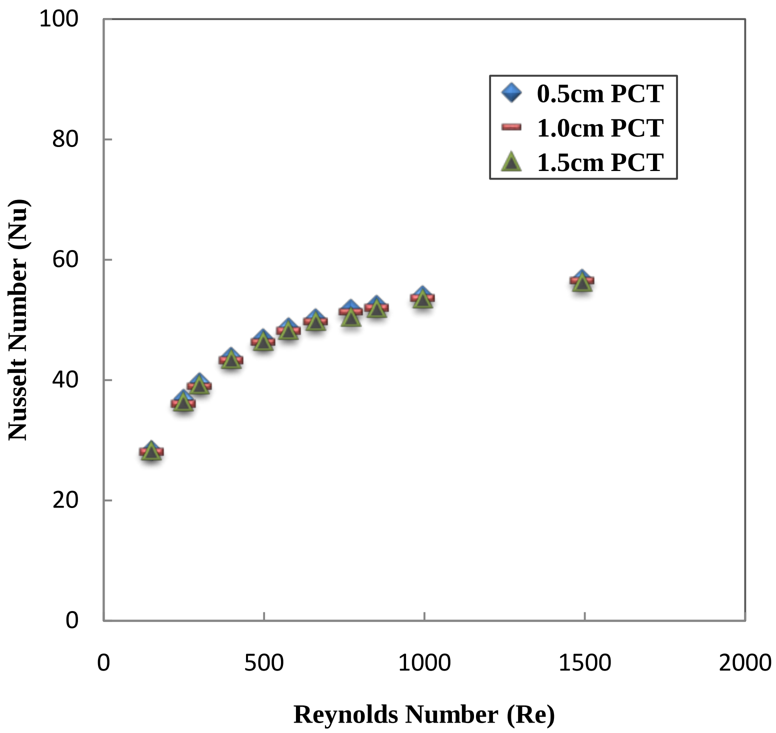

Fig. 8: Simulated Nusselt Number for Parabolic-cut twisted tape with y=2.93and different cut depth(w).

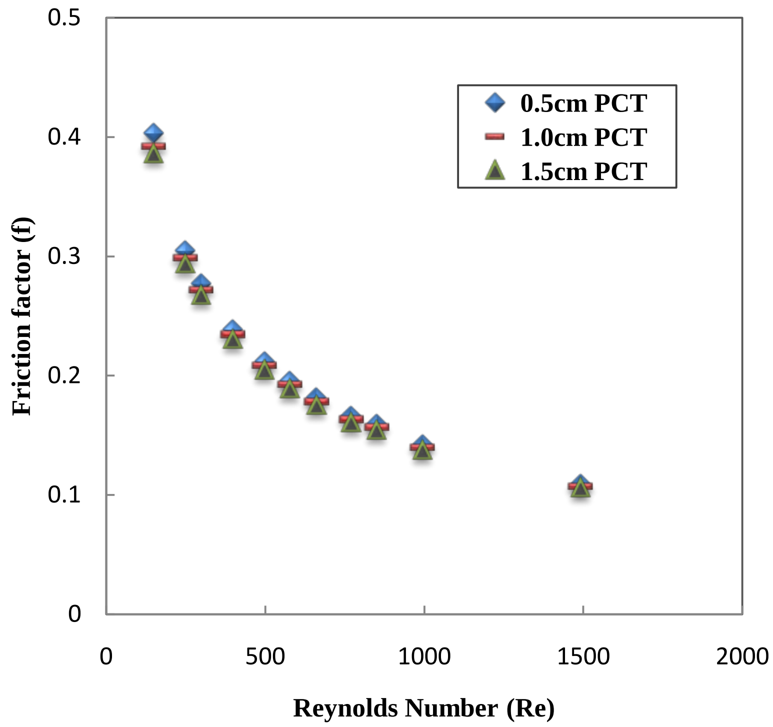

Fig. 9: Simulated friction factor for Parabolic-cut twisted tape with y=2.93and different cut depth (w).

Velocity Field:

Vector of velocity predicted forthe Quadrant-cut twisted tape inserts with twist ratio(y=2.93) and cut depth(w =0.5, 1 and 1.5 cm) are depictedin figure10 As seen in the figure, longitudinalvortices are generated around tapes. Theselongitudinal vortices play a critical role of disturbing the boundarylayer and uniform the temperature in the core flow. Itis clearly seen that thesetwisted tapesinduce similar swirling flow.

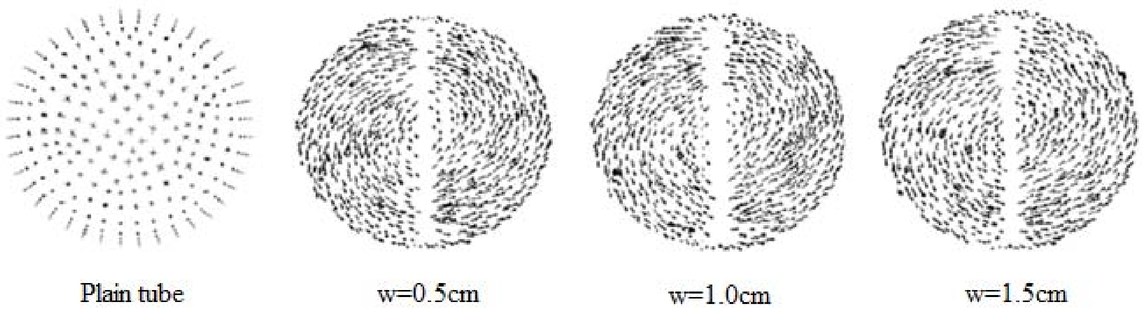

Fig. 10: The velocity vector of plain tube and tube fitted with (PCT) anddifferentcut depth

Temperature field:

Figure13show thetemperature field of V-cuttwisted tape and Quadrant-cut twisted tape insertswith twisted ratio(y=2.93) and cut depth (w =0.5, 1 and 1.5 cm), these kind of twisted tapes provide better temperature distribution than the plain tube.

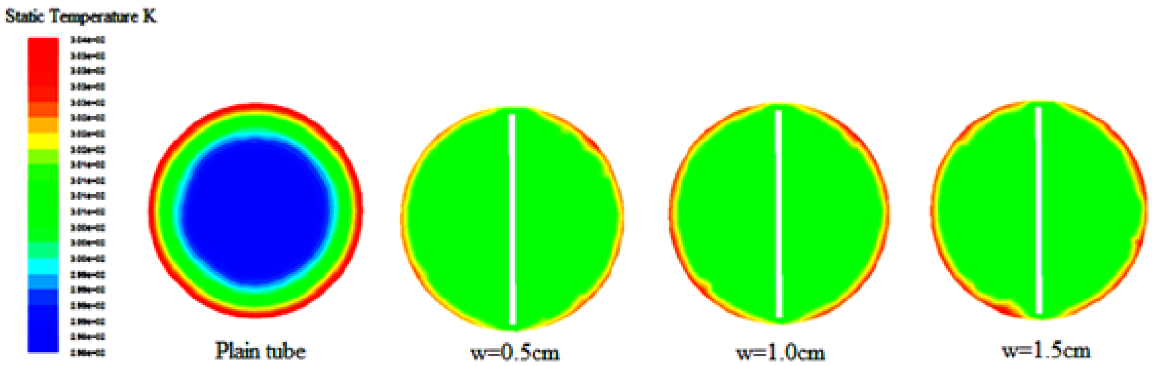

Fig. 13: The temperaturefield of plain tube and tube fitted with (PCT) with different cut depth

Conclusion:

In the present study CFD simulation for the heat transfer augmentation in a circular tube inserted by Parabolic-cut twisted tape insertswith a twisted ratio (y=2. 93. 3.91 and 4.89) and cut depth (w =0.5, 1 and 1.5 cm)in laminar flow conditions has been simulated using fluent version 6.23.26. The data obtained by simulation match with the literature value for plain tube with a maximum discrepancyof ± 8%, ± 6.5% for Nusselt number and friction factor, respectively.The data obtained by simulation shows that theParabolic -cut twisted tape with twist ratio (y=2.93) and cut depth (w=0.5cm) offered a high heat transfer rate and frictionfactor compared to the plain tube and other twisted tape.In addition, the influence of the cut depth (w=0.5cm)was moredominant than those of (w =1 and 1.5 cm) for all the Reynolds number.

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Nomenclature:

E Energy component in energy equation
F Force component in momentum equation, N
F Fanning friction factor
g Acceleration due to gravity, m/s^2
k_{eff} Thermal conductivity in Energy equation, W/m K

m mass flow rate of fluid, kg/s
Re Reynolds number based on internal diameter of the tube, dimensionless
Nu Nusselt number, dimensionless
p Pressure component in momentum equation, N/m^2
Sm Accumulation of mass, Kg
Sh Accumulation of Energy, J
T Temperature.°C.
v Velocity component in momentum equation, m/s
y Twist ratio (Length of one twist (360°)/ diameter of the twist), dimensionless

Greek Symbols:
ρ Density component in governing equations
$\vec{\tau}$_eff Stress component in momentum equation, N/m^2.

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