Heat transfer enhancement of laminar flow in a circular tube using Swirl / vortex generator

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A R T I C L E I N F O

A B S T R A C T

Swirl/vortex flow generator is an important form of passive augmentation techniques consist of a variety of tube inserts, geometrically varied flow arrangements and duct geometry modifications that produce flows. Twisted-tape is one of the most important members of this form which used extensively in different type heat exchangers. This paper presents a research on heat transfer enhancement and friction factor characteristics in a circular tube using CFD simulation. Plain twisted tape inserts with twist ratios (y = 2.93, 3.91) and slant baffled twisted tape inserts with baffle angle 30° and twist ratio (y = 2.93) have been used for the simulation. The results obtained by simulation matched with the literature correlations for plain tube with the discrepancy of less than ± 8% for Nusselt number and ± 6.25% for friction factor. The results have also revealed that the heat transfer in term of the Nusselt number enhanced with increases of Reynolds number, decreases of twist ratio. Among the various twist ratios, the slant baffled twisted tape with twist ratio of y=2.93 hasoffered a maximum heat transfer enhancement with significant friction factor.

INTRODUCTION

The performance of conventional heat exchanger can be substantiallyimproved by a number of enhancement techniques. These techniques are classified broadly as passive or active techniques. The active technique requires an external power facilitate the desired flow modification such as electrostatic field, surface or liquid vibration, etc. Whereas, the passive technique doesnot require any external energy, it required fluid additives, special surface geometries r swirl flow devices i.e.; Twisted tape inserts. Numerous of experimental works on heat transfer augmentation studies using twisted tape have been reported in the literature (Ujhidy, A., *et al.*, 2003; Ibrahim, E.Z., 2011; Jaisankar, S., *et al.*, 2009; Guo, J., *et al.*, 2011; Wongcharee, K. and S. Eiamsa-ard, 2011). However, delimited literatures are available in CFD modeling of heat transfer using twist tape inserts, Pathipakka and Sivashanmugam (Pathipakka, G. and P. Sivashanmugam, 2010) proposed CFD simulation of heat transfer and friction factor characteristics of the circular tube fitted with a right-left helical twist insert with 100 mm spacer basedon experimental work. The simulated results of Nusselt number and friction factor were compared with the experimental data with good agreement. Shabanian *et al.,* (2011) conducted an experimental and CFD modeling on at transfer and friction factor characteristics in air cooled heat exchanger using butterfly twist tape insert to investigate the effect of insert configuration onthe Nusselt number, friction factor and thermal performance factor. Salman *et al* (2013) reports the application of a mathematical model of the heat transfer enhancement and friction factor characteristics of water in constant heat-fluxed tube fitted with Classical and elliptical cut twisted tape inserts using Fluent version 6.3.26. The results show that the elliptical cut twisted tape with twist ratio offered higher heat transfer rate with significant increases in friction factor. Salman *et al,m* (2013) numerically investigated the heat transfer of water in constant heat-fluxed tube fitted with Classical and V-Cut twisted tape inserts using Fluent version 6.3.26.in a uniformly heated circular tube fitted with V-cut twisted tape inserts in laminar flow using Fluent version 6.3.26. The results also reveal that the V-cut twisted tape generated a maximum heat transfer rate with significant increases in friction factor. As compared with classical twisted tape. This paper is to present numerical study on the heat transfer rate and friction factor characteristics in a round tube fitted with with slantbaffled twisted tape (SBT) insert based on an

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experimental data fromPathipakka and Sivashanmugam (2010). Liquid water was employed as the test fluid for the Reynolds number range of 200 to 2300. Moreover, the plain twisted tape insert was also conducted for comparison. The longer term objective of this paper is to reveal that the insert configuration can play an important role on heat augmentation.

MATERIALS AND METHODS

Physical models:
The geometry and Grid of the Slant baffled twisted tape insert (SBT) witha relative twist ratio (y=2. 93) is depicted in Figuers 1, 2. The material of construction of the tube and twisted tape is Steel and aluminium, respectively. Water is selected as the working fluid and the thermo-physical properties of fluid are selected at 298K and assumed to be temperature independent.

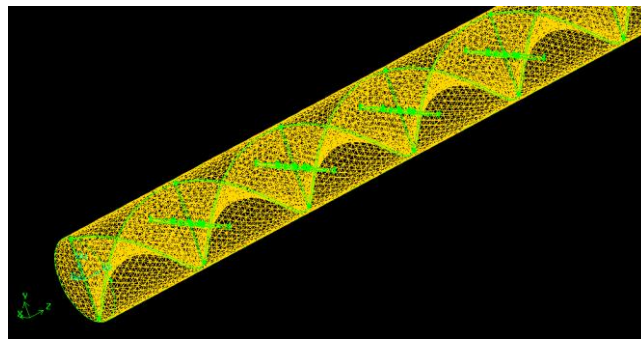**Fig. 1:** Slant baffled twisted tape insert

Fig. 2: Grid for (SBT) inserts

Modelling Parameters and Numerical method:
Experimental data mentioned in [8] with the commercial software,FLUENT 6.3.26 was chosen as the CFD tool to solve governing equations. Three dimensional steady state laminar flow through the tube fitted with baffled twisted tape inserts under constant heat flux is investigated by the following model equations.

Continuity equation for an incompressible fluid.

$$\frac{\partial p}{\partial t} + \nabla.(\rho \vec{\upsilon}) = S_m \tag{1}$$

Conservation of momentum.

$$\frac{\partial \upsilon}{\partial t} + \rho(\vec{\upsilon}.\nabla)\vec{\upsilon} = -\nabla p + \rho \overline{g} + \nabla.\tau_{ij} + \vec{F} \tag{2}$$

Conservation of energy.

$$\rho \frac{\partial}{\partial t}(\rho E) + \nabla.\{\vec{\upsilon}(\rho E + \rho)\} = \nabla.\left\{ K_{eff} \nabla T - \sum h_i \, (\vec{\tau}_{eff}.\vec{\upsilon})\right\} + S_h \tag{3}$$

RESULT AND DISCUSSION

Grid Independence Test:
A grid independence test was used to evaluate the effects of grid sizes on the simulated results; three mesh volumes for Re= 2000 were considered (692973, 775152 and 813865). It's observed that all the mesh volume has similar results of the Nusselt number with a percentage error up to 0.3%. Hence, the domain with meshed volume of 775152 was chosen to reduce the computational time.

Validation of Plain Tube Simulation Results:
      The results obtained by simulation are validated using plain tube correlations developed by Sieder and Tate (1936). The simulated data of the Nusselt number for a tube are compared with these correlations as illustrated in Figures 3 and 4. The results reasonably agreed well with the available correlations within ±8% and ± 10% for Nusselt number and friction factor respectively.
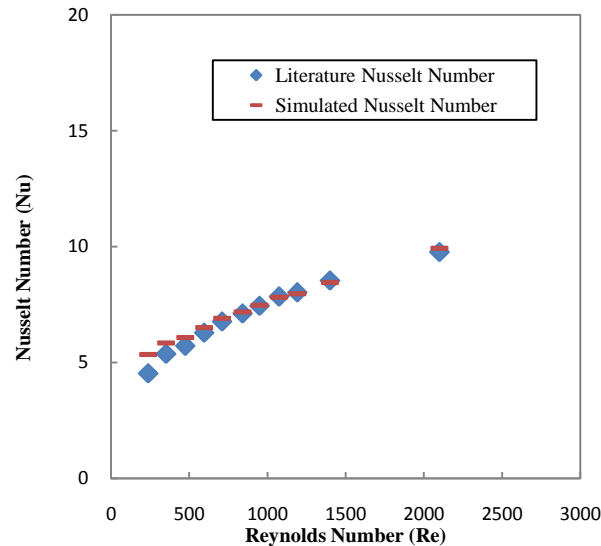

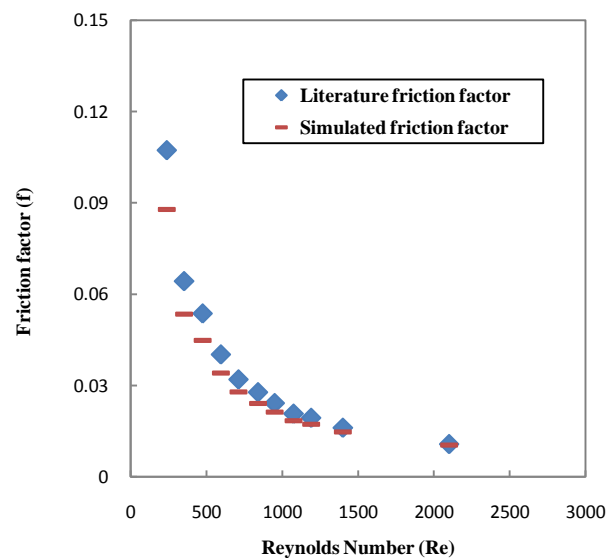**Fig. 3:** Plain tube simulated Nusselt Number vs Literature data

Fig. 4: Plain tube simulated friction factor vs Literature data

Effect of twist ratio on heat transfer and friction factor:
      Simulated data of the Nusselt numbers, friction factor and their variation with a Reynolds number of plain twisted tape inserts with twist ratio (y=2. 93 and 3.91) are shown in Figuers5 and 6.
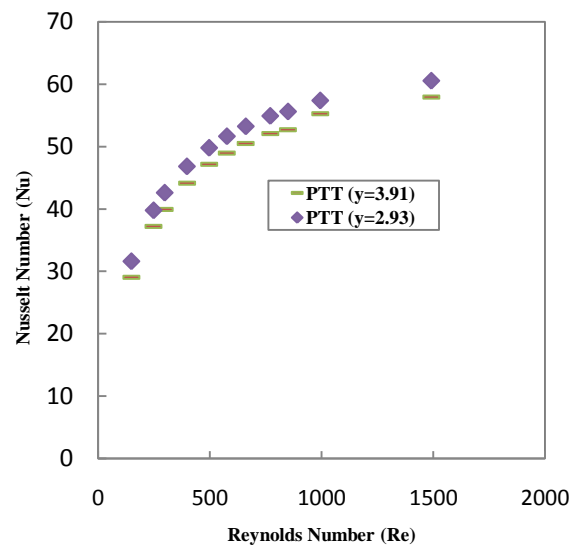
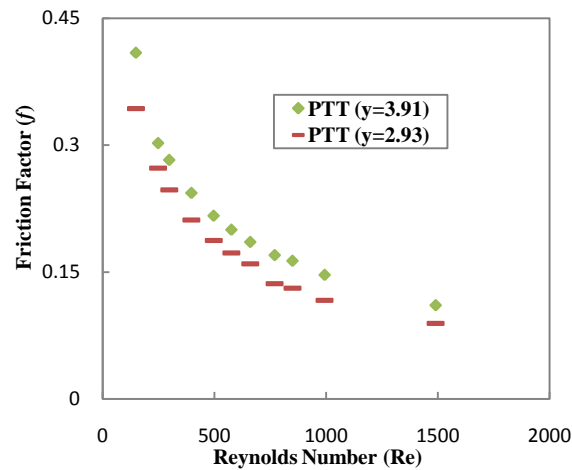**Fig. 5:** Simulated Nusselt Number for PTT with (y=2.93, 3.91)

Fig. 6: Simulated Froction Factor for PTT with (y=2.93, 3.91)

Effect of Twist Tape Configuration on Heat Transfer and Friction Factor:
Simulated data for the Nusselt numbers, friction factor and their variation with Reynolds number for Baffled twisted tape insert (BTT) with twist ratio y=2. 93 and is shown in figures 7 and 8
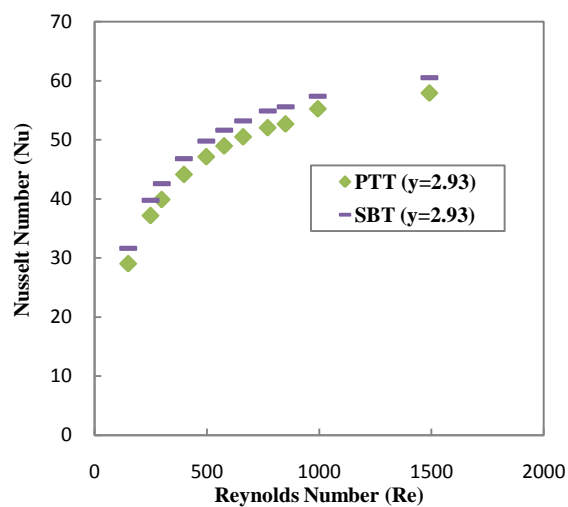

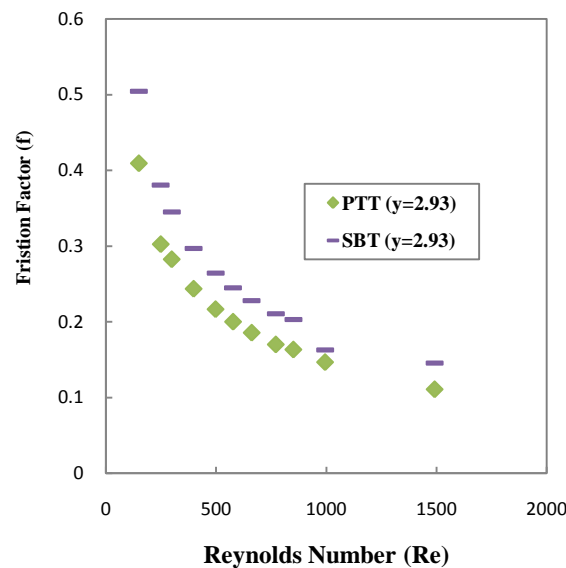**Fig. 7:** Simulated Nusselt Number for PTT and SBT

Fig. 8: Simulated Friction Factor for PTT and SBT

Conclusion:

CFD simulation for the heat transfer augmentation in a circular tube inserted by slant baffled twisted tape insert (SBT) with a twisted ratio y=2. 93 and baffle angle 30° has been simulated using FLUENT version 6.2.3.26. The data obtained by simulation are matching with the literature value for plain tube for validation with the discrepancy of less than ± 8% for the Nusselt number and ±6. 25% for friction factor. The simulated results for the tube fitted with Plain twisted tape inserts with twist ratios (y = 2.93, 3.91) was also conducted for comparison. The results show that the Slant baffled twisted tape (SBT) insert offered further enhancement in heat transfer with significant increases in friction factor than those of plain twisted tape.

ACKNOWLEDGEMENT

Nomenclature:

E   Energy component in energy equation
F   Force component in momentum equation, N
f   Fanning friction factor
g   Acceleration due to gravity, m/s2
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/m2
S_m Accumulation of mass, Kg
S_h 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/m2.

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