CFD analysis of heat transfer and friction factor characteristics in a circular tube fitted with horizontal baffles twisted tape inserts

Sami D Salman 1, 2, a, Abdul Amir H Kadhum 1, Mohd S Takriff 1 and Abu Bakar Mohamad 1
1 Department of Chemical and Process Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Bangi, Selangor 43600, Malaysia.
2 Biochemical Engineering Department, Al-khwarizmi College of Engineering, University of Baghdad, Baghdad 47024, Iraq
E-Mail: a sami.albayati@gmail.com

Abstract. Swirl/vortex flow generator is an important form of passive augmentation techniques. Twisted-tape is one of the most important members of this form which is used extensively in different type heat exchangers. This paper reports the effect of twisted tape inserts on heat transfer and friction factor characteristics in circular tube under constant heat flux and laminar flow conditions using CFD simulation. Plain twisted tape inserts with twist ratios (γ = 2.93, 3.91) and baffled twisted tape inserts with twist ratio (γ = 2.93) have been used for the simulation using Fluent version 6.3.26. 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 and baffle insert. Among the various twist ratios, the twisted tape with twist ratio of γ=2.93 and baffle is offered a maximum heat transfer enhancement.

1. Introduction
Heat transfer augmentation techniques can be classified to active and passive technique. The active technique requires an external power facilitate the desired flow modification such as electrostatic field, surface or liquid vibration, etc. The passive technique does not require any external energy, it required fluid additives, special surface geometries or swirl flow devices i.e.; Twisted tape inserts. A great deal of experimental works on heat transfer augmentation studies using twisted tape have been reported in the literature [1-5] Whereas, limited literatures are available in CFD modeling of heat transfer using twisted tape inserts, Sivashanmugam et al [6] presented CFD modeling of heat transfer augmentation in a circular tube fitted with helical twist inserts as swirl generator. Mugam et al [7] reported CFD simulations of heat transfer characteristics using different concentrations of Al2O3 nanofluid and helical twist tape inserts with different twist ratio in a circular tube. Pathipakka and Sivashanmugam [8] proposed CFD simulation of heat transfer and friction factor characteristics of the circular tube fitted with a right-left helical twist insert.
with 00 mm spacer based on experimental work. The simulated results of Nusselt number and friction factor were compared with the experimental data with good agreement.

Shabanian et al [9] conducted an experimental and CFD modeling on heat transfer and friction factor characteristics in air cooled heat exchanger using butterfly twist tape insert to investigate the effect of insert configuration on the Nusselt number, friction factor and thermal performance factor. The objective in this paper is to demonstrate the heat transfer and friction factor simulation for the circular tube fitted with Baffled twisted tape (BTT) insert with twist ratio (y=2.93) depend on experimental data from [8]. The longer term objective of this research is to reveal that the insert configuration can play an important role on heat augmentation. This study can be used as guideline for experimental works.

2. Materials and methods

2.1. Physical models
The geometry and Grid of the Baffled twisted tape insert (BTT) with a relative twist ratio (y=2.93) is depicted in figure1 and 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.
2.2. Modelling Parameters and Numerical method

Experimental data mentioned in [8] with the commercial software, Fluent 6.3.26 was chosen as 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.

2.2.1 Continuity equation for an incompressible fluid

\[ \frac{\partial p}{\partial t} + \nabla \cdot (\rho \vec{v}) = S_m \] (1)

2.2.2 Conservation of momentum

\[ \frac{\partial \vec{v}}{\partial t} + \rho(\vec{v} \cdot \nabla) \vec{v} = -\nabla p + \rho \vec{g} + \nabla \tau_g + \vec{F} \] (2)

2.2.3 Conservation of energy

\[ \rho \frac{\partial}{\partial t} (\rho E) + \nabla \cdot \{ \vec{v} (\rho E + \rho E) \} = \nabla \cdot \{ K_{\text{eff}} \nabla T - \sum h_i (\vec{r}_{\text{eff}} \cdot \vec{v}) \} + S_h \] (3)

3. Results and discussion

3.1. Validation of plain tube simulation results

The results obtained by simulation for plain tube are validated using correlations developed by (Tate 1936). The simulated data of the Nusselt number for a tube are compared with these correlations as demonstrated in figure 3 and 4.

![Figure 3. Plain tube simulated Nusselt Number vs Literature data.](image-url)
3.2. 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 figure 5 and 6.
3.3. 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 figure 7 and 8.

**Figure 6.** Simulated Friction Factor for PTT with \( y = 2.93, 3.91 \).

**Figure 7.** Simulated Nusselt Number for PTT and BTT.
4. Conclusion
CFD simulation for the heat transfer augmentation in a circular tube inserted by Baffled twisted tape insert (BTT) with a twisted ratio ($y=2.93$ & $3.91$) and baffle length (2 cm) 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 data obtained by simulation show that the Baffled twisted tape insert (BTT) offered a higher rate of heat transfer at the same Reynolds number.

Acknowledgement
The authors would like to thank University Kebangsaan Malaysia and MOSTI of Grant research (FRGS/1/2013/TK07/UKM/01/1) for financial support.

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$^2$
- $S_m$: 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

$\rho$ Density component in governing equations

$\tau_{\text{eff}}$ Stress component in momentum equation, N/m².

References

[1] Ujhidy A, Nemeth J and Szepvolgyi J 2003 Fluid flow in tubes with helical elements Chemical Engineering and Processing 42 1-7

[2] Ibrahim E Z 2011 Augmentation of laminar flow and heat transfer in flat tubes by means of helical screw-tape inserts Energy Conversion and Management 52 1 250-57

[3] Jaisankar S, Radhakrishnan T K and Sheeba K N 2009 Experimental studies on heat transfer and friction factor characteristics of thermosyphon solar water heater system fitted with spacer at the trailing edge of twisted tapes Applied Thermal Engineering 29 5–6 1224-31

[4] Jian Guo, Aiwu Fan, Xiaoyu Zhang, Wei Liu 2011 Numerical study on heat transfer and friction factor characteristics of laminar flow in a circular tube fitted with center cleared twisted tape International Journal of Thermal Sciences 1-8

[5] Wongcharree K and Eiamsa-ard S 2011 Friction and heat transfer characteristics of laminar swirl flow through the round tubes inserted with alternate clockwise and counter-clockwise twisted-tapes International Communications in Heat and Mass Transfer 38 3 348-52

[6] Sivashanmugam P, Nagarajan P K and Suresh S 2008 Experimental studies on heat transfer and friction factor characteristics in turbulent flow through a circular tube fitted with right left helical screw-tape inserts Chemical Engineering Communication 195 8 977-87

[7] Nagrajam P K and Mugam P 2008 CFD Simulation of heat transfer augmentation in circular tube filled with right-left helical inserts with space International journal of chemical engineering research 6 1 1-11

[8] Pathipakka G and Sivashanmugam P 2010 Heat transfer behavior of nanofluids in a uniformly heated circular tube fitted with helical inserts in laminar flow Superlattices and Microstructures 47 2 349-60

[9] Shabanian S R, Rahimi M, Shahhosseini M and Alsairafi A A 2011 CFD and experimental studies on heat transfer enhancement in an air cooler equipped with different tube inserts International Communications in Heat and Mass Transfer 38 3 383-90

[10] Sieder E N and Tate G E 1936 Heat transfer and pressure drop of liquids in tubes. Industrial and Engineering Chemistry 28 12 1429-35.