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Numerical investigation of Heat Transfer Enhancements in a Circular Tube with CuONanofluid and Quadrate Perforated Twisted Tape Insert

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ABSTRACT

This paper reports a numerical investigation on the heat transfer characteristics in a constant heat-fluxed tube with the existence of copper water nanofluid and twisted tape inserts using Computational Fluid Dynamics (CFD) simulation. Different concentration (2% and 4% V/V) of CuOnanofluid with two types of twisted tape; Classical twisted tape (CCT) and quadrate perforated twisted tape (QPT) with twist different twist ratio (y=2.93, 4.89) and were used for simulation. The results show that there were significant increases in heat transfer coefficient in the tube fitted with twisted tape with decreasing of twist ratio (y). The results also revealed that the QPT insert with twist ratio (y=2.93) and 4% V/V nanofluid offered further enhancement in heat transfer than those of Classical twisted tape.

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INTRODUCTION

Heat transfer augmentation techniques have been widely applied to heat exchanger applications; chemical and process industry, heat recovery, refrigeration and air conditioning systems. The augmentation is classified into three main techniques namely active, passive and compound. The active techniques require an external force such as electric field, acoustic or surface vibration. The passive technique involves additives, special surface geometries or swirl flow devices i.e.; Twisted tape inserts. 3

On the other hand, the compound techniques are made by a combination between two or more passive and/or active techniques. Up to the present, several heat transfer enhancement techniques using twisted tape have been developed (Jaisankar, S., *et al*., 2009; Kapatkar, A.V.N., *et al*., 2011; Eiamsa-ard, S., 2010; Guo, J., *et al*., 2011; Ibrahim, E.Z., 2011). Thereafter and due to advances in computer hardware and software and consequent increase in calculation speed, the CFD modeling technique was developed as a powerful and effective tool for better understanding of the complex hydrodynamics in many industrial processes. Mugam *et al* (2008) reported CFD simulations of heat transfer characteristics using different concentrations of Al_2O_3nanofluid and helical twist tape inserts with different twist ratio in a circular tube. Pathipakka & Sivashanmugam (2010) proposed CFD simulation of the heat transfer characteristics of aAl_2O_3nanofluid in a constant heat fluxed tube fitted with helical twist inserts. Different concentrations (0.5%, 1.0% , 1.5%) of Al_2O_3nanofluid in presence helical twist inserts with different twist ratios (y = 2.93, 3.91, 4.89) were used for the simulation. The results show that the helical tape insert of twist ratio 2.93 with Al_2O_3volume concentration of 1.5% offered 31% heat transfer enhancement at Reynolds number of 2039. In the present work a numerical investigation of heat transfer enhancement in a tube induced by quadrate perforated twist tape inserts with 2% and 4% volume fractions of CuOnanofluid are reported. The commercial software, Fluent 6.3.26, is chosen as the CFD tool for simulation. The result obtained by simulation elaborate that the configuration of square perforated twist tape with CuO volume concentration of 4% offered additional enhancement in heat transfer with significant increases in friction factor than those of Classical twisted tape. This study can be used as guideline for experimental work of heat transfer augmentation.

MATERIALS AND METHODS

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Physical Models:

The geometry and Grid of the Quadrate Perforated twisted tape insert (QPT) with a relative twist ratio (y=2. 93) are illustrated in Figs. 1, 2. An Aluminium tape of 0.08 cm thickness and 2.45 cm width is uniformly winding over a length of 7.5and 12.5 cm to produce twist ratios of 2.93and 4.89. The twist ratio `y' is defined as the ratio of the length of one full twist (360°) to the tape width. Quadrate cut with 1 x 0.7 cm were used to produce perforated twisted tape. Steel tube with a diameter (D) of 2.54 cm and length (L) of 180cm was used as test section and water was selected as the base fluid for nanoparticles. The thermo-physical properties of water and CuO nanoparticles are selected at 298K and assumed to be temperature independent.

Fig. 1: Quadrate perforated twisted tape insert

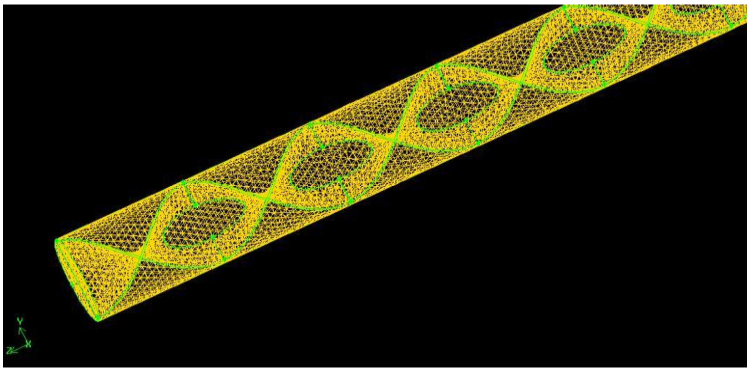

Fig. 2: Grid for (QPT) inserts

Thermophysical Properties of Nanofluids:

The thermophysical properties of nanofluids used for simulation were obtained from the equations mentioned in. Table 1 elaborated the thermophysical properties of CuO nanoparticles and water as base fluids.

Table 1: The thermophysical properties of water and CuO nanoparticles.

Properties	CuO	Water
ρ (kg/m^3)	5600	996.5
Cp (J/kg·K)	533	4181
k (W/m·K)	17.65	0.613
dp (nm)	0.29	-
μ (Ns/m^2)	-	1E−03

Modelling Parameters and Numerical Method:

Numerical values of water mass flow rate and heat flux used for simulation are given in table 2.

Table 2: Numerical values used for simulation

Mass flow rate	Heat flux (W/m^2)
(Kg/s)	
0.00384	782.9275132
0.00769	1565.855026
0.01153	2348.78254
0.01537	3131.710053
0.01922	3914.637566
0.02306	4697.565079
0.02690	5480.492592
0.03074	6263.420105
0.03459	7046.347619
0.03843	7829.275132

RESULTS 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 (582932, 665875 and 727830). 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 665875 was chosen to reduce the computational time.

Model Validation:

The computations data of the Nusselt number and friction factor were performed for plain tube to validate against data developed by Stephan correlations (Stephan, K. and P. Preußer, 1979) and demonstrated in Fig. 3. The results reasonably agreed well with the available correlations within ±8% for Nusselt number.

The Effect of Twist Ratio:

Variation of simulated Nusselt number and friction factor with Reynolds number for the tube fitted with classical twisted tape inserts are shown in Figs. 5. For the test range of Reynolds number, the Nusseltnumber in lower twist ratios are higher than those from higher ratio (y). The results elaborate that the lower twist ratio provides higher tangential contact between the swirling flow and the tube surface.

The Effect of Nanofluid Volume Fractions:

CuO nanoparticle of 2% and 4% volume fraction with different values of Reynolds number is investigated and results are illustrated in Fig 7. It is clearly noted that the Nusselt number enhanced with increases of volume fraction of nanoparticles. This means that the volume fraction increases the random movements of the particles thence enhance the thermal dispersion of the flow.

Effect of Twist Tape Configuration:

Variation of simulated Nusselt number and friction factor with Reynolds number for the tube fitted with classical and quadrate perforated twist tape with twist ratio y=2. 93 is shown in Fig. 9. It is obviously that the new configuration gives more heat transfer enhancement than the classical twist tape.

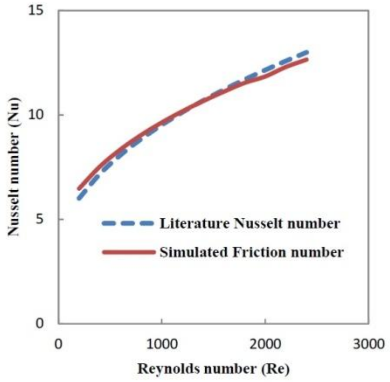

Fig. 3: Plain tube simulated Nusselt Number vs literature value

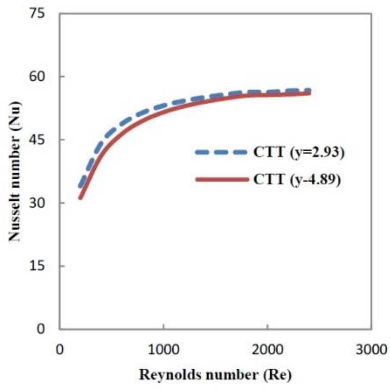

Fig. 4: The effect of twist ratio (y) on Nusselt Number

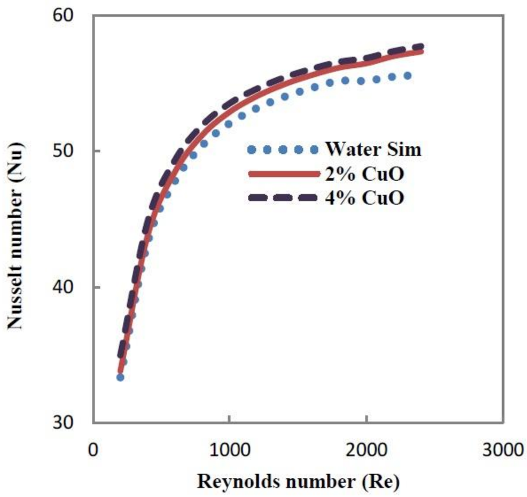

Fig. 5: The effect of CuOnanofluid volume concentration on Nusselt number for CCT of twist ratio 2.93

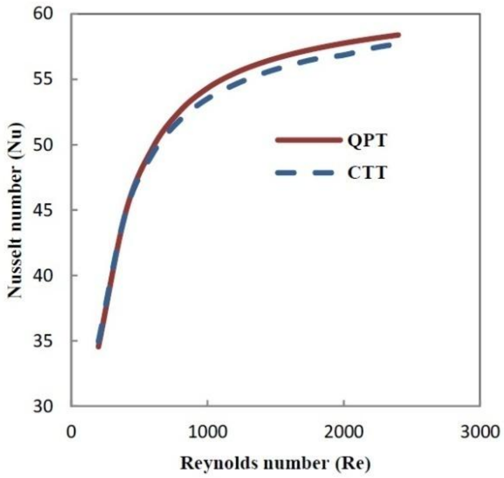

Fig. 6: The effect of twist configuration 4% CuOnanofluid on Nusselt number

Conclusion:

CFD simulation for the heat transfer augmentation in constant heat-fluxed tube fitted with classical and quadrate perforated twisted tape (SPT) with 2% and 4% volume fraction of CuOnanofluid were carried out using FLUENT version 6.2.3.26. The simulated data are matching with the literature value of plain tube for validation with maximum discrepancy of ± 8% for the Nusselt number and ±10% for friction factor. The results show that the Nusselt number increased with the increases of the nanoparticle volume fraction, Reynolds number and twist tape decreases. The results also revealed that the quadrate perforated twisted tape (QPT) with 4% CuOnanofluid offered about 17% enhancement of the Nusselt number with significant increases in friction factor than those of Classical twisted tape.

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