Numerical study of turbulent flow and heat transfer of a nano fluid in a circular tube with twisted tape insert

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Abstract

Nano fluids have higher thermal conductivities compared to fluids and increase the heat transfer coefficient. In addition, twisted tapes have also shown to increase the heat transfer coefficient with a relatively small pressure loss penalty. This numerical study is conducted in order to gain an understanding of behavior of the thermal and nano fluid flow in turbulent flow regime in the tube with twisted tape insert. Convective heat transfer coefficient and friction factor of nano fluid for flow in a tube with twisted tape insert is determined numerically and validated. Effects of the various volume concentration of nano fluid on heat transfer enhancement (Nu) and friction factor (f) are numerically investigated for twisted tapes at different twist ratios. This analysis indicates the heat transfer coefficient and friction factor of nano fluid in a tube with twisted tape is higher compared to flow of water in a tube with twisted tape.

Key words: Numerical study, Twisted Tape, Nano Fluid, Heat Transfer, Friction factor

1. Introduction

In general, the working fluid such as water, oil and ethylene glycol is used for various industrial fields, power generation and air conditioner. Those fluids with low thermal conductivity suppress development of compact and higher performance heat exchangers. Fluid including nano particles is referred to as nanofluid, which is a term proposed by Choi [1995]. The term nanofluid refers to a two phase mixture with its continuous phase being generally a liquid and dispersed phase constituted of nanoparticles. Many researchers (Kim et al (2009), Fotukian et al (2010), Chen et al (2008), Torii (2010)) investigated the characteristics of nanofluids concerning thermal behavior. They showed higher thermal conductivity and heat transfer coefficient enhancement compared with base fluids. This paper studied also twisted tapes. Twisted tape swirl generators are utilized as passive heat transfer enhancement devices which work without any external power source. Twisted tapes have been applied in several systems such as shell and tube heat exchanger, solar water heater, boiler and chemical engineering process. The tapes have gained rising attention due to their advantages of steady performance, simple configuration and ease of installation. The investigation on heat transfer and flow friction in tubes fitted with various tape geometries have been conducted by many researches (Chang et al (2007), Thianpong et al (2009), Eiamsa-ard et al (2009), Yadav et al (2009), Yildiz et al (1998), Sharma et al (2009), Sundar et al (2010)) for base fluids and nano fluids. In all of them reported increase the heat transfer with a relatively small pressure. Numerical study of heat transfer coefficient and friction factor for nanofluid flow in a tube with twisted tape inserts is not available in the last studies. This numerical study is conducted in order to gain an understanding of behavior of the thermal and Al_2O_3 nano fluid flow in turbulent flow regime in the tube with twisted tape insert. This study including the effects of the ϕ (volume concentration), d_p (nano particles diameter) and twist ratio (H/W) on heat transfer (Nu) and friction factor (f) are examined under constant wall heat flux using Al_2O_3 nanofluid and water as the testing fluid

Data and Material

in the calculation, the density of Al_2O_3 and water is taken as 3970 kg/m^{3}and 998 kg/m^{3}and that f specific that of Al_2O_3 and water as 880 J/kg K and 4178 J/kg K respectively.

2. Research Methodology

The mathematical modeling involves the prediction of flow and heat transfer behaviors, the available finite difference procedures for swirling flows and boundary layer are employed to solve the governing partial equations. The major assumptions are: (1) the flow through the twisted tape is turbulent and incompressible; (2) the flow is in steady state; (3) the convection is force; (4) the properties of the fluid and nanofluid are temperature independent; (5) Newton's convective law is applicable to nanofluid in the nanofluid range tested.

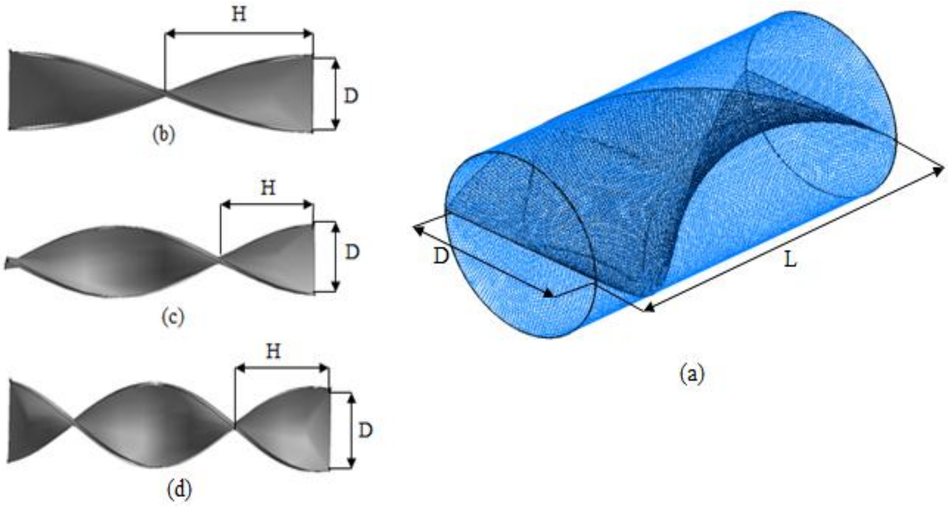


Fig.1: (a) tube with twist tape.
(b) H/D = 41.67 (c) H/D = 27.78 (d) H/D = 20.83

H/W: twist ratio W = D
D: diameter of pipe and width of twist tape (twist tape fitted in pipe)
L: length of pipe and length of twist tape

The numerical study is conducted in the Reynolds number range of 10000-20000 with tapes of different twist ratios (H/D = 41.67, H/D = 27.78 and H/D = 20.83) for water and nanofluids with different volume concentration ($\phi = .01, \phi = .03, \phi = .05$) and different nanoparticles diameter. ($d_p = 20\times10^{-9}$, $d_p = 47\times10^{-9}$ and $d_p = 60\times10^{-9}$) under constant wall heat flux (q = 11789.255 W/m^2).

2.1. Governing equations

The governing equations used to describe the fluid flow and heat transfer in round tubes with twisted tape inserts are established. The continuity, momentum and energy equations for steady state, constant density and three dimensional can be written:

Continuity equation:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

Momentum equation:

$$\frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}[\mu(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_k}{\partial x_k})] + \frac{\partial}{\partial x_j}(-\rho\overline{u'_i u'_j}) \tag{2}$$

Energy equation:

$$\frac{\partial}{\partial x_i}[u_i(\rho E + p)] = \frac{\partial}{\partial x_j}(k_{eff}\frac{\partial T}{\partial x_j}) \tag{4}$$

$$E = h - \frac{P}{\rho} + \frac{u^2}{2} \tag{5}$$

$$-\rho\overline{u'_i u'_j} = \mu_t(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}) - \frac{2}{3}(\rho k + \mu_t\frac{\partial u_k}{\partial x_k})\delta_{ij} \tag{6}$$

E: total energy (J) ρ: density (kg/m^3) P: static pressure (pa) h : enthalpy (J)

k_{eff} : Effective thermal conductivity (W/m-k)

2.2. Solution procedure

In the present numerical solution, the turbulence model and energy are discretized using the Second order. Upwind and for continuity and volume friction using the first order. Upwind. The turbulence intensity is kept at 10% at the inlet.

4. Results and Analysis

Tow parameters of interest for the present work are: (1) friction factor and (2) Nusselt number. The friction factor, f is computed from pressure drop ΔP across the length of the tube (L) using following equation:

$$f = \frac{\Delta P / L}{\frac{1}{2}\rho u^2 D} \tag{6}$$

ΔP : Pressure drop (pa) Re: Reynolds number

The Nusselt number is defined as:

$$Nu = \frac{hD}{k} \tag{7}$$

h : convective heat transfer coefficient (W/m^2-k) Nu : nusselt number

The values of friction factor and Nusselt number for water estimated with Eq. 6 and Eq.7 is for (H/D = 41.67) compared with the values obtained from Sundar et al (2010) and found to be good agreement as shown in Figs. 2~3.

Figs. 4~5 shows the comparison friction factor and Nusselt number of water and nanofluid for different volume concentration (ϕ =.01,ϕ =.03,ϕ =.05 and $d_p = 47\times10^{-9}$) in a tube and with tape insets for (H/D = 41.67).

Figs. 6~7 shows the comparison friction factor and Nusselt number of nanofluid for different nanoparticles diameter ($d_p = 20\times10^{-9}$, $d_p = 47\times10^{-9}$ and $d_p = 60\times10^{-9}$and ϕ =.01) in a tube and with tape insets for (H/D = 41.67).

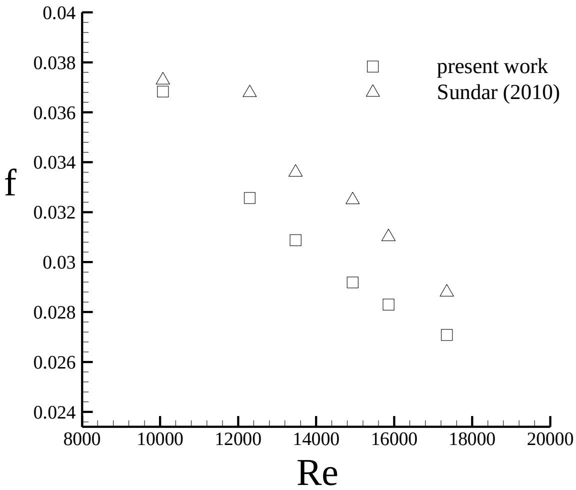


Fig.1: Comparison of friction factor of water in a tube and with tape inserts.

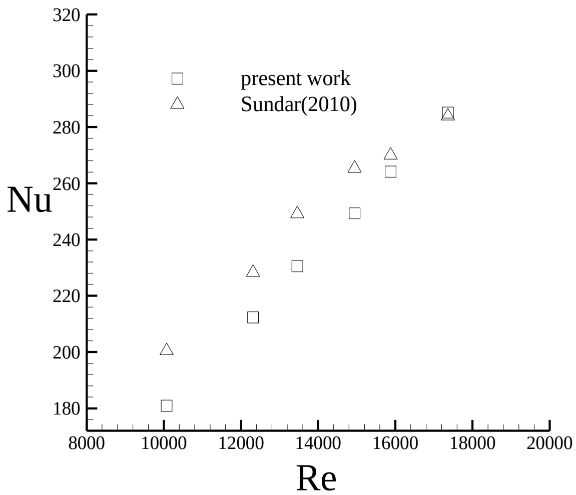
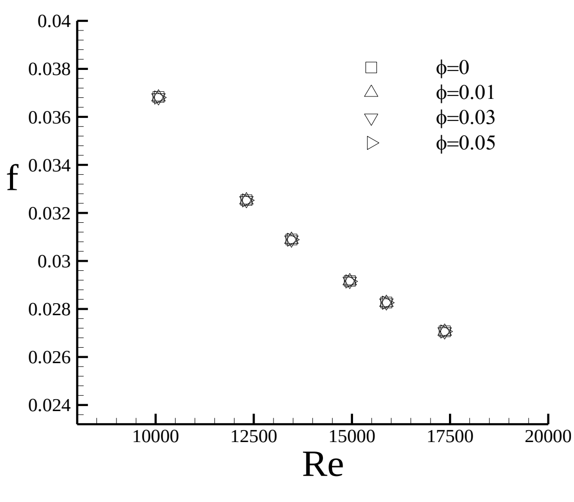


Fig.1: Comparison of Nusselt number of water in a tube and with tape inserts.



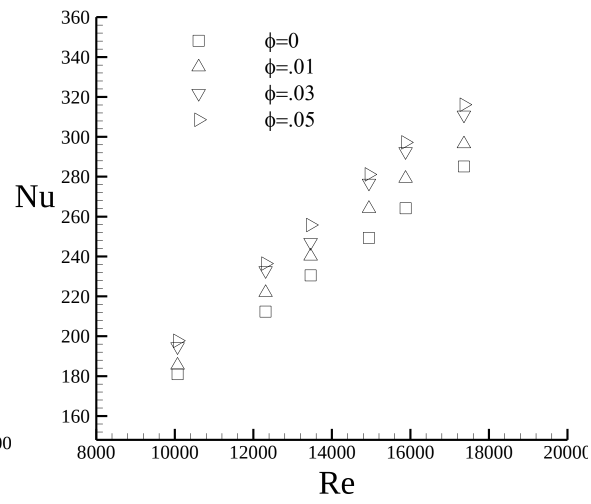


Fig. 4: Comparison friction factor and of water and nanofluid for different volume concentration.

Fig. 5: Comparison Nusselt number and of water and nanofluid for different volume concentration.

The values of friction factor and Nusselt number for nanofluid estimated with Eq. 6 and Eq.7. Figs. 8~9 shows the comparison friction factor and Nusselt number of nanofluid (ϕ =.01 and d_p = 47×10^{-9}) in a tube and with tape insets for different twist ratio (H/D = 41.67, H/D = 27.78 and H/D = 20.83).

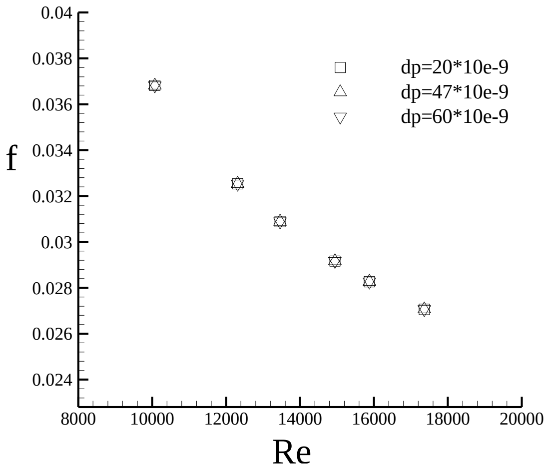


Fig. 6: comparison friction factor and of nanofluid for different nanoparticles diameter.

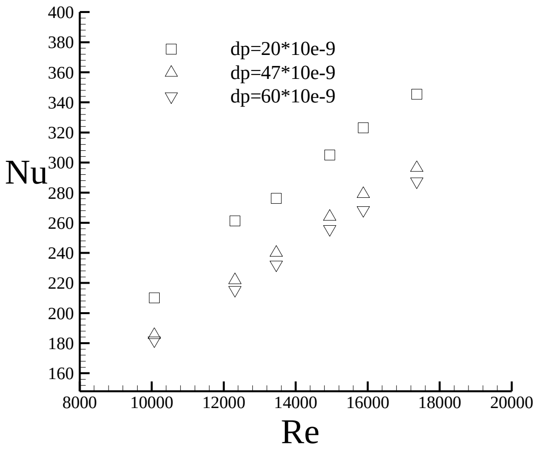


Fig. 7: comparison Nusselt number and of nanofluid for different nanoparticles diameter.

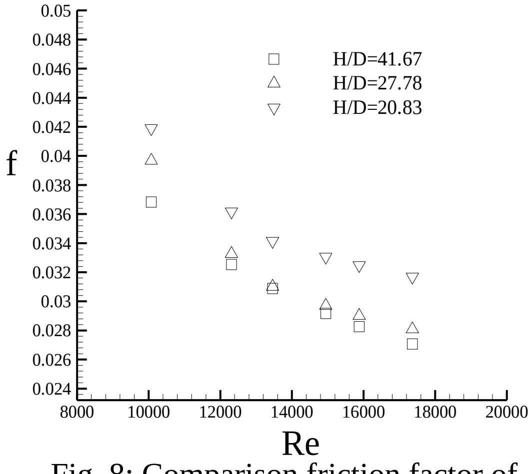


Fig. 8: Comparison friction factor of nanofluid in a tube and with tape insets for different twist ratio.

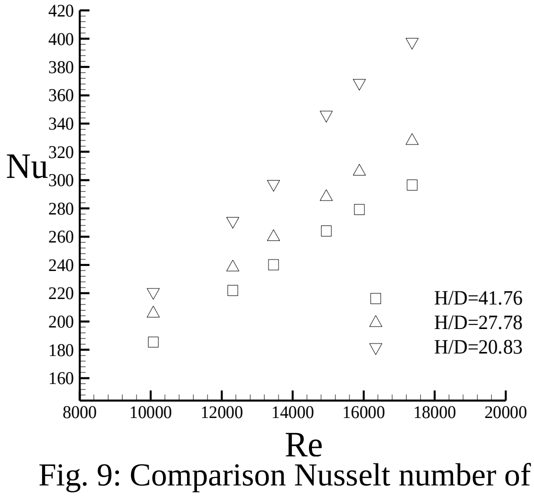


Fig. 9: Comparison Nusselt number of nanofluid in a tube and with tape insets for different twist ratio.

5. Conclusions

1. With increase in nanoparticles diameter and volume concentration of nanofluid we see increase in heat transfer coefficient but there is no significant increase in friction factor.

2. With decrease in twist ratio we see increase in heat transfer coefficient and friction factor but the rate of increase in heat transfer coefficient is higher than increase in friction factor.
3. heat transfer coefficient increase with increase in Reynolds number and friction factor decrease with increase in Reynolds number.

References

Chang, Shyy. Woei. & Tsun, Lirng. Yang. & Liou, Jin. Shuen. (2007) Heat transfer and pressure drop in tube with broken twisted tape inert. *Experimental Thermal and Fluid Science.* NO. 32, pp. 489–501.

Chen, H. & Wang, W. & He, Y. & Ding, Y. & Zhang, Y. & Tan, C. & Lapkin, A. A. & Bavykin, D. V. (2008). *Power Technol*. 11 (2) 151.

Choi, S. U. S. (1995) ASME FED 99.

Eiamsa-ard, Smith. & Thianpong, Chinaruk. & Eiamsa-ard, Petpices. & Promvonge, Pongjet. (2009). Convective heat transfer in a circular tube with short-length twisted tape insert, *International Communications in Heat and Mass Transfer*. NO. 36, pp. 365–371.

Fotukian, S. M. & Nasr Esfahany, M. (2010). Experimental investigation of turbulent convective heat transfer of dilute γ-Al2O3/water nanofluid inside a circular tube. *International Journal of Heat and Fluid Flow*. NO. 31, pp. 606–612.

Kim, Doohyun. & Kwon, Younghwan. & Cho, Yonghyeon. & Li, Chengguo. & Cheong, Seongir. & Hwang, Yujin. & Lee, Jaekeun. & Hong, Daeseung. & Moon, Seongyong. (2009). Convective heat transfer characteristics of nanofluids under laminar and turbulent flow conditions. *Current Applied Physics.* , NO. 9, pp. e119–e123.

Sharma, K.V. & Sundar, L. Syam. & Sarma, P. K. (2009). Estimation of heat transfer coefficient and friction factor in the transition flow with low volume concentration of Al_2O_3 nanofluid flowing in a circular tube and with twisted tape insert. *International Communications in Heat and Mass Transfer*, NO. 36, pp. 503–507.

Sundar, L. Syam. & Sharma, K.V. (2010). Turbulent heat transfer and friction factor of Al_2O_3 Nanofluid in circular tube with twisted tape inserts. *International Journal of Heat and Mass Transfer*, NO. 53, pp. 1409–1416.

Thianpong, Chinaruk. & Eiamsa-ard, Petpices. & Wongcharee, Khwanchit. & Eiamsa-ard, Smith. (2009). Compound heat transfer enhancement of a dimpled tube with a twisted tape swirl generator. *International Communications in Heat and Mass Transfer*, NO. 36, pp. 698–704.

Torii, Shuichi. (2010). Turbulent Heat Transfer Behavior of Nanofluid in a Circular Tube Heated under Constant Heat Flux. *Hindawi Publishing Corporation Advances in Mechanical Engineering*. Article ID. 917612, 7 pages.

Yadav, Anil. Singh. (2009). Effect of Half Length Twisted-Tape Turbulators on Heat Transfer and Pressure Drop Characteristics inside a Double Pipe U-Bend Heat Exchanger. *Jordan Journal of Mechanical and Industrial Engineering*. NO. 1(4), pp. 17-22.

Yildiz, Gengiz. & Bicer, Yasar. & Pehlivan, Dursun. (1998). Effect of Twisted Strips on Heat Transfer Pressure Drop In Heat Exchangers. *Energy Converse*. Mgmt vol. 39 , NO. 3/4, pp. 331-336.