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SIMULATION STUDY OF TURBULENT CONVECTIVE HEAT TRANSFER ENHANCEMENT IN HEATED TUBE FLOW USING TIO_2-WATER NANOFLUID

Adnan M. Hussein[1, 2], R. A. Bakar[1], K. Kadirgama[1] and K. V. Sharma[1]

[1]Faculty of Mechanical Engineering
26600 Pekan, PAHANG, University Malaysia PAHANG
[2]Al-Haweeja Institute, Foundation of Technical Educations, IRAQ
E-mail: adnanphd2012@gmail.com
Phone: +60179809114

ABSTRACT

Simulation by convenient software same as FLUENT was used to predict the friction factor and Nusselt number for forced convection heat transfer of TiO_2-water nanofluid. The range of Reynolds number is from 10000 to 100000 to be turbulent flow in a horizontal straight tube with heat flux 5000 w/m^2 around it. The volume fraction of nanoparticle was (0.25%, 0.5%, 0.75% and 1%) and diameter of particle is 27nm. The results show that the friction factor and Nusselt number are increasing with increasing of volume fraction. Results compared with the experimental data available in literature and there are good agreements.

Keywords: Nanofluid; Simulation; Convection heat transfer; Friction factor, FLUENT

INTRODUCTION

There are number of studies conducted forced convection of TiO_2-water through tube under single phase model (Heris, 2009, Yurong and Yi, 2007, Asirvatham, 2009, Gnielinski, 1976, Kim et al, 2009, Xuan and Li, 2003, Vajjha et al, 2010 and Bianco et al, 2011). Pak and Cho (1998) investigated the effect of two different metallic oxide particles, alumina (Al_2O_3) and titanium dioxide (TiO_2), with mean diameters of 13 and 27 nm, respectively, on base fluid (water) experimentally. The Reynolds and Prandtl numbers were varied in the ranges 10000-100000 and 6.5-12.3, respectively. Results showed that Darcy friction factor for the volume concentration (1-3%) was good agreement with Kay’s correlation for turbulent flow of a single-phase fluid. The Nusselt number of the dispersed fluids for fully developed turbulent flow is increased with increasing volume concentration as well as the Reynolds number. Duangthongsuk and Wongwises (2010) found the heat transfer coefficient and friction factor of the TiO_2-water nanofluids with diameters of 21 nm and volume concentrations of 0.2–2.0 vol.% flowing in a horizontal double tube counter-flow heat exchanger under turbulent flow conditions, experimentally. The results showed that the heat transfer coefficient of nanofluid is higher than that of the base liquid and increased with increasing the Reynolds number and volume concentrations. The pressure drop of nanofluids was slightly higher than the base fluid and increases with increasing the volume concentrations. A theoretical model proposed by (Sharma et al.,2010) to predict friction and heat transfer coefficients for a wide range of nanofluids containing Cu, CuO, TiO_2, SiC,

ZrO_2, and Al_2O_3 nanoparticles of different sizes, concentration and temperatures dispersed in water. The results showed deviation of experimental with theoretical data because of using to different values of properties employed. Forced convection flows of nanofluids consisting of water with TiO_2 and Al_2O_3 nanoparticles in a horizontal tube with constant wall temperature are investigated numerically by (Demir, 2011). The horizontal test section is modeled and solved using a CFD program. Palm et al.'s correlations are used to determine the nanofluid properties. Numerical results showed the heat transfer enhancement due to presence of the nanoparticles in the fluid in accordance with the results of the experimental study used for the validation process of the numerical model. A study of heat transfer enhancement of Al_2O_3 nanofluid using low volume fraction nanofluids in turbulent pipe flow with constant wall temperature was studied by (Kumar, 2011). CFD modeling of the nanofluid flow adopting the single phase approach. Nanofluid, up till a volume fraction of 1% is found to be an effective heat transfer enhancement technique. The Nusselt number (*Nu*) and friction factor predicted for the low volume fractions (i.e. 0.02%, 0.1 and 0.5%). Numerical study of turbulent forced convection flow of Al_2O_3-water nanofluid in a circular tube was subjected by (Bianco, 2011). Heat transfer enhancement increases with the particle volume concentration and Reynolds number. Comparisons with correlations present in literature are accomplished and there was a very good agreement. Experimental study of turbulent forced convection heat transfer was conducted by Sundar and Sharma (2010) the study was concluded a pipe employing twisted tape inserts with and without Al_2O_3–water nanofluid. The increasing in the heat transfer coefficient was observed both with and without pipe inserts. It then also developed generalized correlations for the estimation of Nusselt number and friction factor for pipes with and without inserts.

In this work, CFD simulation by FLUENT software will be used to predict friction factor and forced convection heat transfer Nusselt number. The study concludes turbulent forced convection for TiO_2-water nanofluid then compared with available experimental work.

MATHEMATICAL MODEL

CFD model by FLUENT software was used to solve governing equations of turbulent forced convection heat transfer in horizontal tube with constant heat flux. The description of problem under taken graphing by GAMBIT model and mesh the section test with size of (1000 x 20), 1000 with length of pipe and 20 with radius as shown in Figure 1. The governing equations (continuity, Momentum and energy) are written as: (Sharma et al., 2010)

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\rho_{nf}u\right)=0 \qquad (1)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\rho_{nf}uu\right)=-\frac{1}{r}\frac{\partial P}{\partial x}+\frac{1}{r^2}\frac{\partial}{\partial x}(\tau) \qquad (2)$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\rho uT\right)=\frac{1}{r^2}\frac{\partial}{\partial x}\left\{\frac{k_{nf}}{C_p}\frac{\partial T}{\partial x}\right\} \qquad (3)$$

Which solved iteratively using finite volume method (FVM) and SIMPLE scheme was adopted for the treatment of pressure. The Reynolds number studied in this work is high, turbulent viscous, i.e. k-ε model has been employed. In this work, converged solutions were considered for residuals lower than 10^{-6} for all the governing equations (Das et al., 2007). The results of simulation for nanofluid were compared with the theoretical data available for the conventional water. The theoretical data of water were simulated in FLUENT software too. Then comparing these data with Dittos-Boelter correlation (5) for heat transfer (*Nu*) as shown (Cimbala et al., 2005)

$$f = \frac{0.316}{Re^{0.25}} \tag{4}$$

$$Nu = \frac{h_f}{k_f} D = 0.023 Re^{0.8} Pr^{0.4} \tag{5}$$

It is observed that a grid of (1000 x 20) has good agreement with the theoretical results and hence this model is considered as the optimum grid for carrying out all the analysis.

THERMAL PROPERTIES OF NANOFLUID

The thermal properties of nanofluid are (density, heat capacity, thermal conductivity and viscosity) have been estimated by equations below (Sharma et al., 2010)

$$\rho_{nf} = \left(\frac{\phi}{100}\right)\rho_p + \left(1 - \frac{\phi}{100}\right)\rho_f \tag{6}$$

$$C_{nf} = \frac{\frac{\phi}{100}(\rho C)_p + \left(1 - \frac{\phi}{100}\right)(\rho C)_f}{\rho_{nf}} \tag{7}$$

$$k_r = \frac{k_{nf}}{k_f} = \left\{ 0.8938\left(1 + \frac{\phi}{100}\right)^{1.37}\left(1 + \frac{T_{nf}}{70}\right)^{0.2777}\left(1 + \frac{d_p}{150}\right)^{-0.0336}\left(\frac{\alpha_p}{\alpha_f}\right)^{0.01737} \right. \tag{8}$$

$$\mu_r = \frac{\mu_{nf}}{\mu_f} = C1\left(1 + \frac{\phi}{100}\right)^{11.3}\left(1 + \frac{T_{nf}}{70}\right)^{-0.038}\left(1 + \frac{d_p}{170}\right)^{-0.061} \tag{9}$$

Where: k_p (thermal conductivity) of TiO_2 = 8.4 W/m ^oC, ρ_p (density) of TiO_2 = 4175 kg/m^3, Cp_p (heat capacity) of TiO_2 = 692 J/kg K (Yurong and Yi, 2007)

BOUNDARY CONDITIONS

Volume concentration nanofluids (0.25%, 0.5%, 0.75% and 1%) at 25^{o}C were used for TiO_2-water as input fluids. For comparison purposes, water was also employed as working fluid. Simulation study has been carried out with uniform velocity profile at the inlet of the horizontal tube. Turbulent intensity (I) was specified for an initial guess of turbulent quantities (k and ε). The turbulent intensity was estimated for each case based on the formula $I = 0.16Re^{-1/8}$. Outflow boundary condition has been used at the outlet boundary. The wall of the tube was assumed to be perfectly smooth with constant wall heat flux ($5000 W/m^2$) was used at the wall boundary.

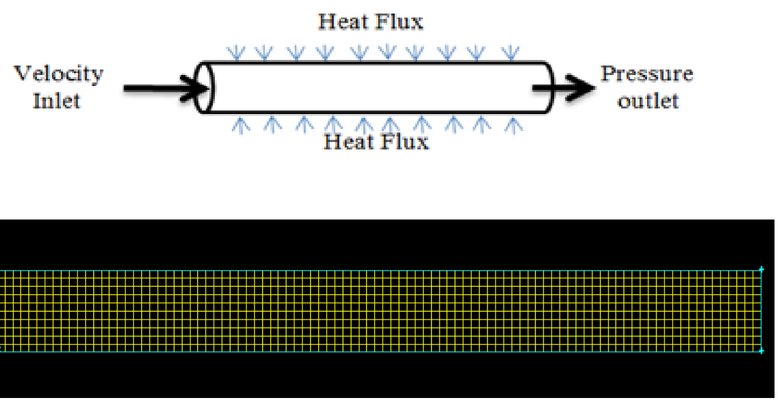

Figure 1. Mesh generated by GAMBIT.

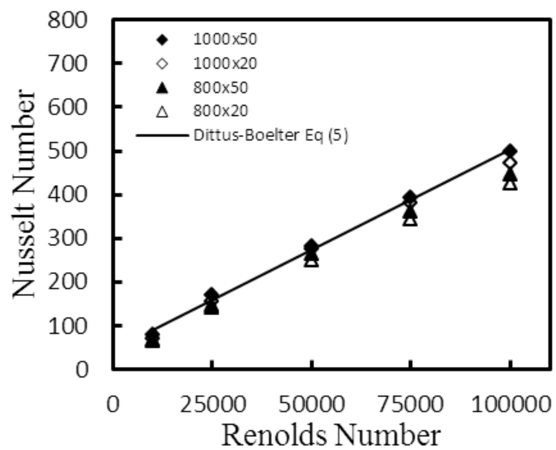

Figure 2. Optimum mesh grid size for Nusselt Number with Reynolds Number for pure water at 25 ^oC.

RESULTS AND DISCUSSION

Simulation results were made reliable by comparing them with available correlation in the literature. Nusselt number for the base fluid (pure water) in the turbulent regime was compared with that of Dittus-Boelter equation (5) as shown in Figure 2. *Nu* from simulation is in very good agreement with that of the correlation values. The effect of nanofluid volume fraction on friction factor and heat transfer enhancement is shown in Figure 3 and Figure 4 There have same behavior of friction factor from Blassius equation and simulation data which decrease when *Re* and volume fraction of nanofluid are increased as shown in Figure 3 *Nu* from Dittos-Boelter equation has same behavior of simulation data which increasing when Re and volume fraction of nanofluid are increased as shown in Figure 4 The reason of increasing of friction factor and Nu with increasing in volume fraction of nanofluid is the high thermal properties of TiO_2 which enhancement of heat transfer and hydrodynamic flow. Figures 5 and 6 show the results of CFD analysis of friction factor and Nu versus Re compared with (Pak and Cho, 1998) experimental data for TiO_2-water nanofluid with particle size is 27 nm and base temperature is 25^oC. The results show that good agreement with deviation is 4%.

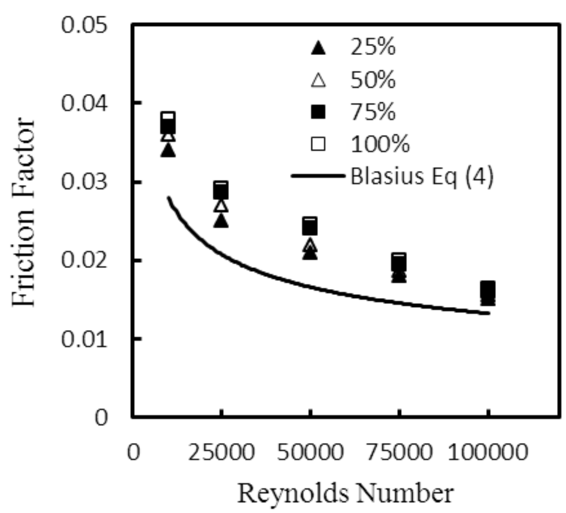

Figure 3. Effect of nanofluid volume fraction on friction factor.

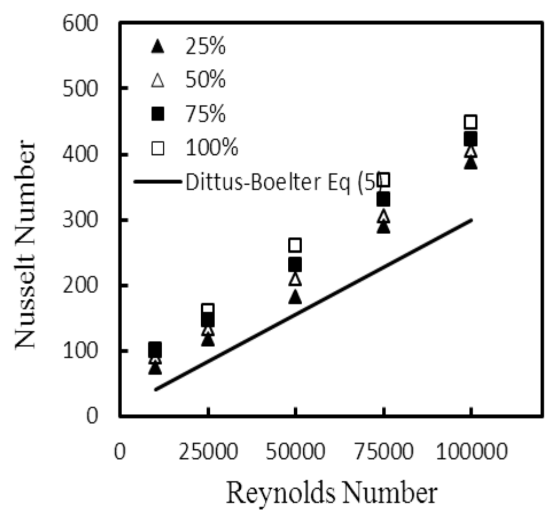

Figure 4. Effect of nanofluid volume fraction on heat transfer enhancement.

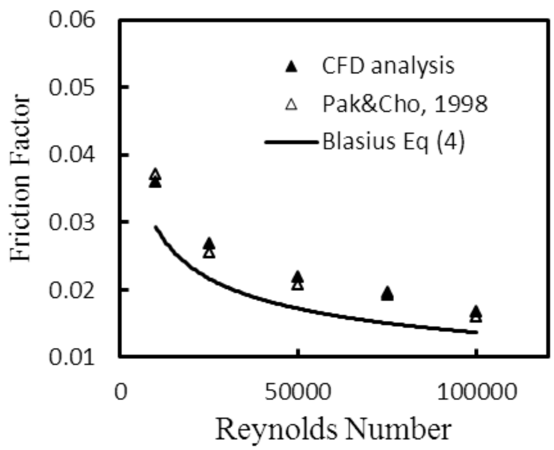

Figure 5. Comparison CFD results of friction factor with (Pak and Cho, 1998) data.

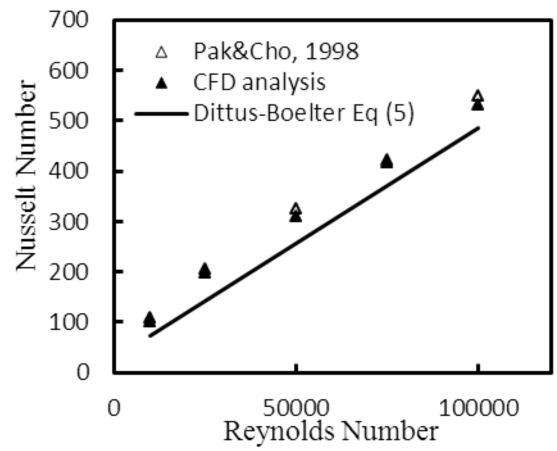

Figure 6. Comparison CFD results of *Nu* with (Pak and Cho, 1998) experimental data.

CONCLUSIONS

Friction factor and Nusselt number are increased with increasing of volume fraction. When adding solid particle on base fluid it will increase of friction factor and enhancement in heat transfer. The results of friction factor and Nusselt number from simulation showed good agreement with correlations of Blassius and Dittos Boelter equation respectively. The increasing in friction factor and *Nu* is 9.5% and 13.6% respectively. There was a good agreement with (Pak and Cho, 1998) experimental data with deviation is 4%.

NOMENCLATURES

- C - Specific heat capacity [W/ kg.^{o}C]
- D - Diameter [m]
- E - Energy [W]
- f - Friction factor
- htc - Convection heat transfer coefficient [W/m^2.^{o}C]
- k - Thermal conductivity [W/m.^{o}C]
- K_{eff} - Effective thermal conductivity [W/m.^{o}C]
- Nu - Nusselt Number [$htc\ .D/K_{eff}$]
- P - Pressure [N/m^2]
- Pr - Prandtle Number [$C.\mu/K_{eff}$]
- Re - Renolds Number [$\rho.\ u.\ D/K_{eff}$]
- u - Velocity [m/s]
- μ -Viscosity [N.s /m^2]
- ρ - Density [kg/m^3]
- τ - Shear stress [N/m^2]
- ϕ - Volume fraction

Subscripts

- f liquid phases
- p solid particle
- eff effective
- nf nanofluid

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REFERENCES

Asirvatham, L.G. 2009. Experimental Study on Forced Convective Heat Transfer with Low Volume Fraction of CuO-Water Nanofluid. Energies, 2: 97-119.

Bianco, V., Manca, O., Nardini, S. 2011. Numerical Investigation on Nanofluids Turbulent Convection Heat Transfer inside a Circular Tube. Int. J. of Thermal Sciences, 50: 341-349.

Bianco, V. 2011. Numerical Investigation on Nanofluids Turbulent Convection Heat Transfer inside a Circular Tube. Int. J. of Thermal Sciences, 50: 341-349.

Cimbala, J.M., Cengel, Y.A. 2005. Fluid Mechanics Fundamentals and Applications. 1st Edition, McGraw-Hill.

Das, S.K., Stephen, U.S., Choi, Wenhua, Y., Pradeep, T. 2007. Nanofluids Science and Technology. Wily Inc.

Demir, H. 2011. Numerical Investigation on The Single Phase Forced Convection Heat Transfer Characteristics of TiO_2 Nanofluids in a Double-Tube Counter flow Heat Exchanger. Int. Comm. in Heat and Mass Transfer, 38: 218–228.

Duangthongsuk, W., Wongwises, S. 2010. an Experimental Study on The Heat Transfer Performance and Pressure Drop of TiO_2-water nanofluids flowing under a Turbulent Flow Regime. Int. J. of Heat and Mass Transfer, 53: 334–344.

Frank, M.W. 1991. Viscous Fluid Flow. International Edition, McGraw-Hill.

Gnielinski, V. 1976. New Equations for Heat and Mass Transfer in Turbulent Pipe and Channel Flow. Int. Chemical Eng, 16: 359–368.

Heris S.Z. 2009. Convective Heat Transfer of a Cu/WATER Nanofluid Flowing through a Circular Tube. Experimental Heat Transfer, 22: 217–227.

Kim, D., Kwon, Y., Cho, Y., Li, C., Cheong, S., Hwang, Y., Lee, J., Hong, D., and Moon S. 2009. Convective Heat Transfer Characteristics of Nanofluids under Laminar and Turbulent Flow Conditions. Current Applied Physics, 9: 119-123.

Kumar, P. 2011. A CFD Study of Heat Transfer Enhancement in Pipe Flow with Al_2O_3 Nanofluid. World Academy of Science, Engineering and Technology, 57: 746-750.

Pak, B.C., Cho, Y.I. 1998. Hydrodynamic and Heat Transfer Study of Dispersed Fluids with Submicron Metallic Oxide Particles. Experimental Heat Transfer, 11: 151-171.

Sharma, K.V., Sarma, P.K., Azmi, W.H., Mamat, R., Kadirgama, K. 2010. Correlations to Predict Friction and Forced Convection Heat Transfer Coefficients of Water Based Nanofluids for Turbulent Flow in a Tube. IJMNTFTP, 3: 1-25.

Sundar L.S., Sharma, K.V. 2010. Turbulent Heat Transfer and Friction Factor of Al_2O_3 Nanofluid in Circular Tube with Twisted Tape Inserts. Inter. J. Heat and Mass Transfer, 53: 1409 – 1416.

Vajjha, R.S., Das, D.K., Kulkarni, D.P. 2010. Development of New Correlations for Convective Heat Transfer and Friction Factor in Turbulent Regime for Nanofluids. Int. J. of Heat and Mass Transfer, 53: 4607 – 4618.

Xuan, Y., Li, Q. 2003. Investigation on Convective Heat Transfer and Flow Features of Nanofluids. J. of Heat Transfer, 125: 151–155.

Yurong He, Yi J. 2007. Heat Transfer and Flow Behavior of Aqueous Suspensions of TiO_2 nanoparticles (nanofluids) Flowing upward through a Vertical Pipe. Int. J. of Heat and Mass Transfer, 50: 2272–2281.