Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 12 (13): 1396-1401, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.1396.1401

Effect of Oxides Nanoparticle Materials on the Pressure Loss and Heat Transfer of Nanofluids in Circular Pipes

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Abstract: Laminar flow and heat transfer of different nanofluids particles in water, namely Al_2O_3, CuO and TiO_2, flowing through a circular tube under constant heat flux conditions have been numerically analyzed. The investigation was performed for nanoparticles of size 100 nm. The numerical results obtained are compared with existing well-established correlations. The prediction for the Nusselt number for nanofluids agrees well with the Pak-Choi correlation. The thermophysical properties of the nanofluids are estimated by using the equations available in literature. Comparison of convective heat transfer coefficients for Al_2O_3, CuO and TiO_2 based nanofluids are presented. It is found that pressure loss increases with the particle volume concentration. However, the flow demonstrates enhancement in heat transfer which becomes better with the increase in the Reynolds number of the flow, but is accompanied with an increase in shear stress.

Key words: Nanofluid, heat transfer enhancement, oxide nanoparticles, pressure loss, heat transfer coefficient

INTRODUCTION

The idea of using combination of solids and fluids was to enhance the efficient heat transfer properties of the fluid because the fluid in general was poor in thermal properties while the metal had high thermal properties. Hence, this idea was used to enhance thermal properties, but had a bad effect on the flow properties, where the solid particles, in millimeter and micrometer size, behaved as a two-phase flow and increased the power needed to force the fluids. The preparation of nanofluids was made through suspension of nanoparticles in a base fluid (Zamzamian *et al*., 2011), which increases the thermal properties of the nanofluid and makes it behaves as a one-phase flow. The liquid-particles are compounds consisting of solid nanoparticles with sizes less than 100 nm, suspended in a liquid. In order to evaluate the heat transfer characteristics of nanofluids there must be adequate data on the thermophysical properties of such fluids (Zamzamian *et al*., 2011).

Eastman *et al*. (2001) found that there is an increase of 40% in thermal conductivity for one nanofluid composition of copper suspended in ethylene glycol at 0.3% volume concentration. Das *et al*. (2003) have reported that the suspension of alumina with a volume concentration of 1-4% in water will increase thermal conductivity until 10-25%. Li and Xuan (2000) studied experimentally the effect of volume concentration of 0.5-1.2% copper-water nanofluids on the enhancement of heat transfer coefficient was 1.05 to 1.14% in a circular tube with constant heat flux at the wall of the tube at the constant velocity inlet. Also, Xuan and Li (2003) investigated experimentally the flow and convective heat transfer of nanoparticles of Cu suspended in deionized water through straight horizontal brass pipes with constant heat flux, where the concentrations of Cu in water are in the range of 0.3-2%. The Nusselt equation was derived for the laminar and turbulent range, i.e., 800-25, 000, where in this range, the classical correlation (Dittus and Boelter, 1930) is not applicable for nanofluids. The enhancement of heat transfer compared with water based fluid for 2% concentration is 60%.

Wen and Ding (2004) built an experimental system to study the convective heat transfer enhancement at the entrance region using a nanofluid of Al_2O_3-deionized water for laminar flow and the system includes the nanofluid flowing through the copper pipe under constant heat flux at the wall for different concentrations of nanoparticles. The Nusselt equation was calculated for the nanofluids ant temperature profile along the test pipe

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and the results showed that the Reynolds number and volume concentration are the primary effects in the heat transfer coefficient. Yang *et al*. (2005) presented the experimental study to a laminar flow and heat transfer enhancement in a horizontal tube heat exchanger for nanofluid. The disc shape graphite nanoparticle with aspect ratio 0.02 was used to enhance heat transfer nevertheless the highly increase in viscosity of nanofluid. Yang *et al*. (2005) investigated a two series of nanofluids with different base fluids were used with the flow rates were of 62-507 cm^3 min^{-1}, the Reynolds number 5-110 and the fluid temperature 50-70°C. The experimental results illustrated that the heat transfer coefficient increased with the Reynolds number and the particle volume fraction, while the heat transfer coefficient of the nanofluids moderately increased compared with the base fluid and its temperature. Sundar *et al*. (2007) reported the experimental investigation to study the Peclet and Nusselt number for different volume fraction alumina-water flowing in a circular tube at constant wall temperature. The enhancement of heat transfer was found from the experiment to be much higher than the prediction of heat transfer correlations used with nanofluid properties suggested by Anoop *et al*. (2009).

An experimental rig was used to study the effect of twisted tape inserted in a circular tube on the heat transfer of nanofluids with different volume concentrations. The further enhancement in heat transfer with twisted tape was achieved when compared with a smooth tube under the same conditions by Gherasim *et al*. (2009), where the pressure drop and convective heat transfer coefficient of water-based Al_2O_3 nanofluids flowing through a uniformly-heated circular tube in the fully-developed laminar flow regime were measured. Gherasim *et al*. (2009) study the experimental results show that Darcy's equation for single-phase flow is applicable for predictions of the friction factor for nanofluids, while the convection heat transfer coefficient increases by up to 8% at a concentration of 0.3 vol% compared with that of pure water for this enhancement which could not be predicted by the Shah equation. The correlation of heat transfer in the entrance region has suggested depending on the experimental results for the flow of nanofluids in a tube with constant heat flux. The effect of size of alumina nanoparticles suspended in water on convective heat transfer in the entrance laminar region was studied. The smaller size of nanoparticles gives better enhancement in heat transfer in the developing region by Maiga *et al*. (2004) and Khoddamrezaee *et al*. (2010) examined the exergy heat transfer rate of the ethylene glycol-alumina nanofluid in the circular duct with constant wall temperature laminar flow, where the study focussed on pressure drop and turbulent convective heat transfer performance for CuO nanoparticles suspended in water. The results yielded 20% pressure drop and 25% average increase of the heat transfer coefficient, which showed good agreement predictions for the Buongiorno correlation.

Hence, the purpose of this paper is to study the effect of volume concentrations of different oxide nanofluids flowing in circular pipes with constant heat flux on heat transfer and pressure losses.

MATERIALS AND METHODS

Thermophysical properties of nanofluids: The calculation of the convective heat transfer requires knowing the transport properties for the nanofluid which is density, heat capacity, thermal conductivity and viscosity. Each property of nanofluid depends on many factors such as volume fraction, material type of nanoparticles, base fluid and temperature of the base fluid.

Density: In the absence of experimental data for nanofluid densities, a constant temperature-independent density ρ, based on volume fraction of the nanoparticles ϕ, are typically used:

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_p \quad (1)$$

where, ρ_f, ρ_p and ρ_{nf} represent densities of the base fluid, the nanoparticle and the nanofluid, respectively.

Specific heat: Similarly, in the absence of experimental data relative to nanofluids, it has been suggested by Li and Xuan (2000) that the effective specific heat C_{pnf} can be calculated using the following equation:

$$C_{pnf} = \frac{\phi\rho_p C_p + (1-\phi)\rho_f C_{nf}}{\rho_{nf}} \quad (2)$$

where, C_p and C_{nf} is specific heats of the nanoparticle and the nanofluid, respectively. This is the standard equation for nanofluid specific heat C_{nf} and the effective specific heat determined through energy balances during the experiments in this study was found to be within 1% of the calculation.

Thermal conductivity: To determine the thermal conductivity of nanofluids, the following model appears appropriate for nanofluids (Xuan and Roetzel, 2000; Akbarinia and Behzadmehr, 2007; Rezaee and Tayebi, 2010).

$$K_{nf} = \left[\frac{K_p + 2K_f - 2(K_f - K_p)\phi}{K_p + 2K_f - (K_f - K_p)\phi}\right] K_f \quad (3)$$

where, K_f, K_p and K_{nf} is thermal conductivity coefficients of the base fluid, the nanoparticle and the nanofluid, respectively. Where K_f it's a function to the temperature.

Viscosity: To calculate the effective dynamic viscosity of nanofluid can be calculated using Einstein's equation for a viscous fluid containing a dilute suspension (Ø<0.2) of rigid, small and spherical particles which is written as follows:

$$\mu_{nf} = (1 + 2.5\varphi)\mu_f \quad (4)$$

where, μ_{nf} is the viscosity of nanofluid and μ_f is the viscosity of base fluid and it's a function to the temperature. However, experimental work to establish the viscosity of nanofluids showed that the measured viscosity it is have accepted variance with the existing theoretical predictions (Drew and Passman, 1999; Wen and Ding, 2004). The equation used to predict the viscosity of Al_2O_3-water, CuO-water and TiO_2-water nanofluids, respectively.

Governing equations

Geometrical: The case set for this investigation is the three-dimensional steady state incompressible flow with forced laminar convection of nanofluids flowing inside a circular tube having a diameter of 0.01 m and a length of 2 m with the thickness of the tube being 0.001 m. The flow enters the tube with a constant temperature and a uniform velocity. The relevant governing equations used can be written as follows:

- Conservation of mass:

$$\nabla \cdot \rho_{nf} \vec{V} = 0 \quad (5)$$

- Momentum equation:

$$\nabla \cdot \left(\rho_{nf} \vec{V}\,\vec{V}\right) = -\nabla P + \nabla.\left(\mu_{nf}\, \nabla^2 \vec{V}\right) \quad (6)$$

- Energy equation:

$$\nabla \cdot \left(\rho_{nf} \vec{V} C_{Pnf} T\right) = \nabla \cdot \left(K_{nf}\, \nabla T\right) \quad (7)$$

The governing equations of the fluid flow are non-linear and coupled partial differential equations, subjected to the following boundary conditions. At the tube inlet section, uniform axial velocity V_{in} and temperature T_{in}, turbulent intensity and hydraulic diameter were specified. At the outlet section, the flow and temperature fields were assumed to be fully-developed and the flow and temperature fields were also assumed as fully-developed (x/D>10). Outflow boundary conditions were enforced for the outlet section. This boundary condition implies zero normal gradients for all flow variables except pressure. On the upper wall of the tube, the no-slip boundary condition was imposed. The wall is subjected to a uniform heat flux of 5000 W m^{-2} as shown in Fig. 1.

Numerical procedures: To solve the present problem, the CFD module in the COMSOL Multiphysics software was employed, which utilizes the governing Eq. 5-7 to generate the pressure, velocity and temperature fields. The solution was obtained based on the spatial integration of the conservation equations using the finite element method, converting the governing equations into a set of algebraic equations. The algebraic ''linear equations'', resulting from this spatial integration process, are sequentially solved throughout the physical domain considered. COMSOL solves the systems resulting from linearization, schemes using a numerical method. The residuals resulting from the integration of the governing Eq. 4-6 are considered as convergence indicators and uniform. In order to ensure the accuracy as well as the consistency of numerical results, several non-uniform grids were subjected to an extensive testing procedure for each of the cases considered.

The results obtained for the particular test case showed that, for the tube flow problem under consideration, the 757, 817 elements appears to be satisfactory to ensure the precision of numerical results as well as their independency with respect to the number of nodes used. Such a grid has 315,157 elements along the tube. The computer model has been successfully validated with correlations reported by Pak and Cho (1998) for thermally and hydraulically developing flow, showing an average error less than 2%, as reported in Fig. 2 and 3 where the local Nusselt number is calculated according to the following definition:

$$Nu(z) = \frac{h(z) \cdot D}{K_0} \quad (8)$$

where, D is the diameter of the circular duct and h(z) is defined as:

$$h(z) = \frac{q}{T(z)_w - T(z)_b} \quad (9)$$

From the previous equation, h_{avg} is calculated as:

$$h_{avg} = \frac{1}{L}\int_0^L H(z)\,dz \tag{10}$$

and the average Nusselt number becomes:

$$Nu_{avg} = \frac{h_{avg} \cdot D}{k_0} \tag{11}$$

RESULTS AND DISCUSSION

Validation of the results: The half-tube was used to reduce the calculation time as a result of a symmetry approach of modeling. The tube had a diameter of 0.01 m and a length of 1 m and the nanofluid flowed with a constant velocity and a temperature of 300 K. Constant heat flux 5000 W m^{-2} was applied to the outer wall of the tube as shown in Fig. 1. The Reynolds (Re) number varied from 100 to 1,000. The comparison of the numerical results with the theoretical data validated the numerical model for conventional fluid. The Darcy friction factor f was given by Blasius which can be derived from Eq. 7 and 8, i.e.:

$$f = 64/Re \tag{12}$$

$$\Delta p = f\left(\frac{1}{D}\right)\left(\frac{1}{2}\rho V^2\right) \tag{13}$$

Figure 2 shows the comparison of pressure drop for water in copper pipe estimated from Blasius Eq. 13 and the numerical results in the present study; a good agreement is observed with maximum deviation of 3% from the theoretical equation over the range of Reynolds numbers. The Nusselt number for fully-developed laminar flow for water and 2% Al_2O_3 nanofluid is compared with the empirical correlation given by Shah (2006) is presented in Fig. 3. The results give a good agreement with this correlation for water. The figure shows the enhancement in heat transfer for 2% Al_2O_3 nanofluid comparing to pure water. The enhancement in heat transfer as a result to the enhance in thermal conductivity of base fluid.

Effect of nanoparticle volume fraction concentration on heat transfer coefficient: Figure 4, 5 and 6 show the variation of the heat transfer coefficient for different volume concentrations for three different nanofluids at a range of x/D. It shows that the heat transfer coefficient increases with the rise of the volume concentration as well as the heat transfer coefficient decrease with an increase in x/D at the Reynolds number 700. This is due to the increase of the Prandtl number of the nanofluid and to an increase in volume concentration. Here, the results are similar to that observed by He *et al.* (2009) and Bianco *et al.* (2009).

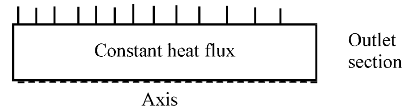

Fig. 1: Schematic representation of the test section used in the present analysis

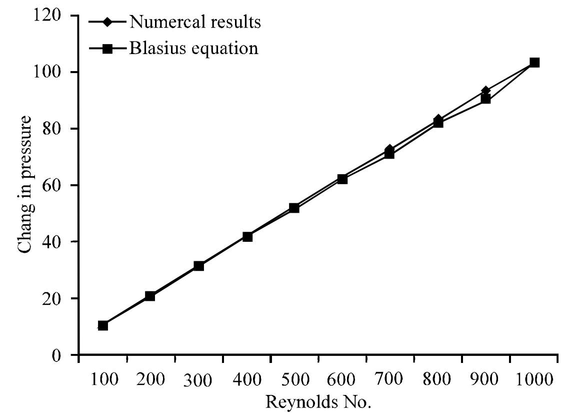

Fig. 2: The comparison of pressure drop by Blasius' equation and numerical model results for water

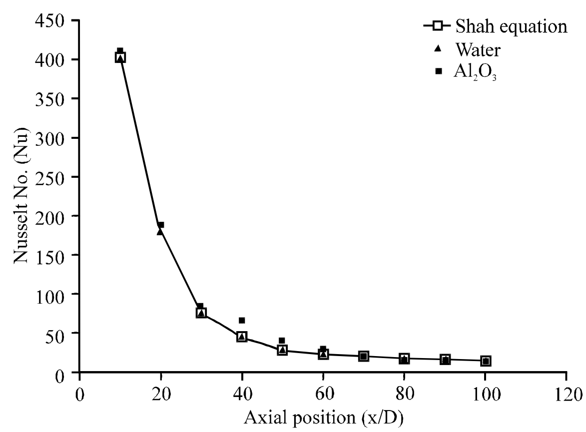

Fig. 3: Comparison of the numerical local Nusselt number with empirical Shah equation for water and 2% Al_2O_3 nanofluid under the constant heat flux at Re 1000

Material effect on heat transfer coefficient: Figure 7 shows the effect of the material types of nanoparticles where the CuO-water nanofluids has the best enhancement over the TiO_2 and Al_2O_3 nanofluids for the same volume fraction and the Reynolds number.

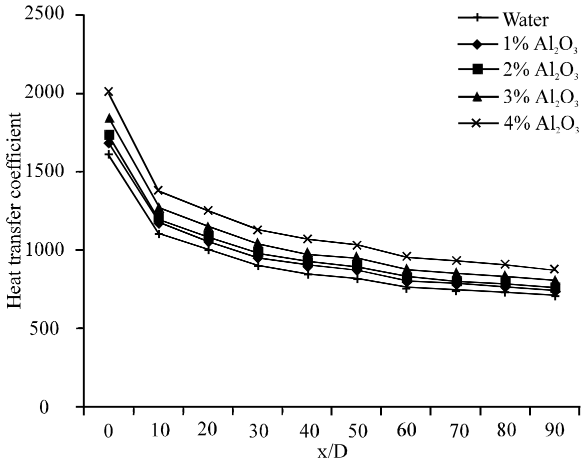

Fig. 4: The influence of the Al_2O_3 nanoparticle volume concentration on the heat transfer coefficient along the tube at Reynolds number 700

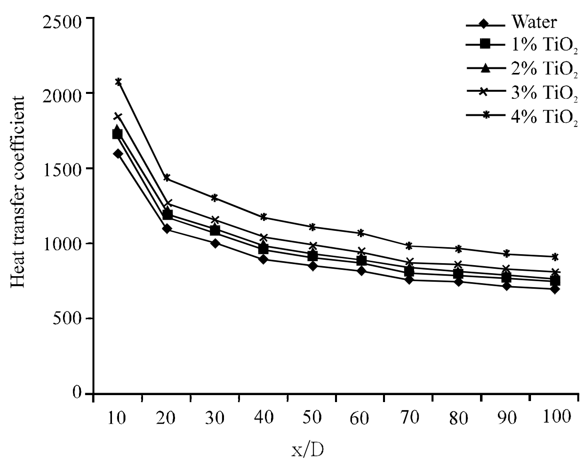

Fig. 5: The influence of the TiO_2 nanoparticle volume concentration on the heat transfer coefficient along the tube at Reynolds number 700

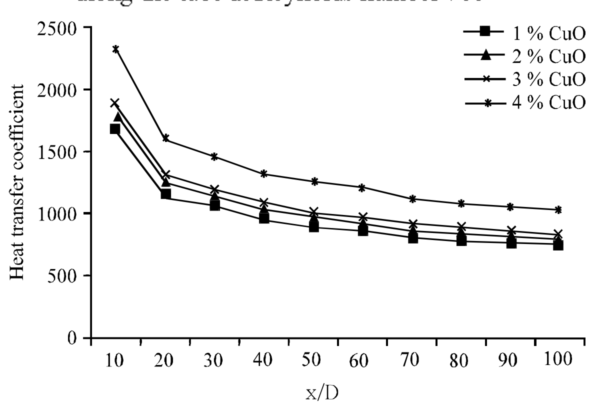

Fig. 6: The influence of the CuO nanoparticle volume concentration on the heat transfer coefficient along the tube at Reynolds number 700

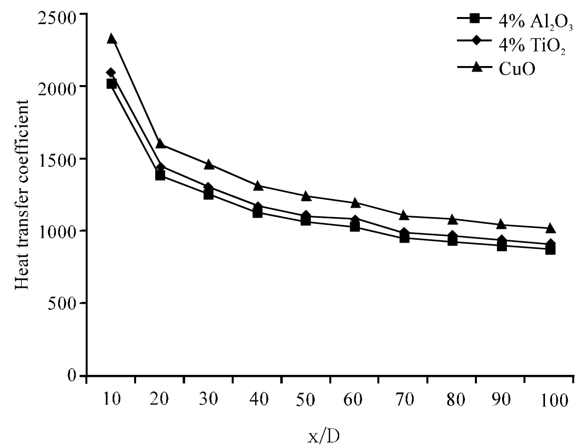

Fig. 7: The comparisons of heat transfer coefficient for Al_2O_3, TiO_2 and CuO nanofluids along the tube at Reynolds number 700

CONCLUSIONS

In this study, the hydrodynamic and thermal behaviors of water-Al_2O_3, water-CuO and water-TiO_2 nanofluids flowing inside a uniformly-heated tube were numerically investigated in stationary condition and for laminar flow for a range of Reynolds numbers from 100 to 1000 with a range of volume concentrations from 0 to 4%. The results show that both the Nusselt number and the heat transfer coefficient of nanofluids are strongly dependent on nanoparticles and increase with the increasing of the volume concentration of nanoparticles. Also for each investigated concentration value, the heat transfer enhancement is higher for the highest Reynolds number. The results illustrate that by increasing the volume concentration, the pressure losses increase. These results are in good agreement with other well-established correlations. So, these correlations could be used to predict the heat transfer behavior of these kinds of fluids.

ABBREVIATIONS

K = Thermal conductivity (W/m K)
h = Heat transfer coefficient (W/m^2 K)
p = Pressure of the tube
q = Constant heat flux at the wall of the tube
Re = Reynolds number
Nu = Average Nusselt number
C_p = Specific heat capacity
V = Velocity vector

Greek letters:

ρ = Density

μ = Dynamic viscosity
ϕ = Volume fraction

Subscripts:

nf = nanofluid
p = Nanoparticles
f = Base fluids

REFERENCES

Akbarinia, A. and A. Behzadmehr, 2007. Numerical study of laminar mixed convection of a nanofluid in horizontal curved tubes. Applied Therm. Eng., 27: 1327-1337.

Anoop, K.B., T. Sundararajan and S.K. Das, 2009. Effect of particle size on the convective heat transfer in nanofluid in the developing region. Int. J. Heat Mass Transfer, 52: 2189-2195.

Bianco, V., F. Chiacchio, O. Manca and S. Nardini, 2009. Numerical investigation of nanofluids forced convection in circular tubes. Applied Therm. Eng., 29: 3632-3642.

Das, S.K., N. Putra, P. Thiesen and W. Roetzel, 2003. Temperature dependence of thermal conductivity enhancement for nanofluids. ASME Trans. J. Heat Transfer, 125: 567-574.

Dittus, F.W. and L.M.K. Boelter, 1930. Heat Transfer for Automobile Radiators of the Tubular Type. University of California press, USA., Pages: 461.

Drew, D.A. and S.L. Passman, 1999. Theory of Multicomponent Fluids. Springer, Berlin.

Eastman, J.A., S.U.S. Choi, S. Li, W. Yu and L.J. Thompson, 2001. Anomalously increased effective thermal conductivities of ethylene glycolbased nanofluids containing copper nanoparticles. Applied Phys. Lett., 78: 718-720.

Gherasim, I., G. Roy and C. Tam, 2009. Experimental investigation of nanofluids in confined laminar radial flows. Int. J. Therm. Sci., 48: 1486-1493.

He, Y., Y. Mena, Y. Zhao, H. Lu and Y. Ding, 2009. Numerical investigation into the convective heat transfer of TiO2 nanofluids flowing through a straight tube under the laminar flow conditions. Applied Therm. Eng., 29: 1965-1972.

Khoddamrezaee, F., R. Motallebzadeh and D. Jajali Vahid, 2010. Simulation of ($EG+Al_2O_3$) nanofluid through the shell and tube heat exchanger with rectangular arrangement of tubes and constant heat flux. J. Applied Sci., 10: 500-505.

Li, Q. and Y. Xuan, 2000. Experimental Investigation of Transport Properties of Nanofluids. In: Heat Transfer Science and Technology, Wang, B. (Ed.). Higher Education Press, China, pp: 757-784.

Maiga, S.E.B., C.T. Nguyen, N. Galanis and G. Roy, 2004. Heat transfer behaviors of nanofluids in a uniformly heated tube. Superlattices Microstruct., 35: 543-557.

Pak, B.C. and Y.I. Cho, 1998. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Exp. Heat Transfer, 11: 151-170.

Rezaee, F.K. and A. Tayebi, 2010. Exergy destruction of forced convective (ethylene glycol+alumina) nanofluid through a duct with constant wall temperature in contrast to (ethylene glycol) fluid. J. Applied Sci., 10: 1279-1285.

Shah, R.K., 2006. Thermal entry length solutions for the circular tube and parallel plates. Proc. 3rd National Heat Mass Transfer Conf. Indian Inst. Technol., 1: 11-75.

Sundar, L.S., K.V. Sharma and S. Ramanathan, 2007. Experimental investigation of heat transfer enhancements with Al2O3 nanofluid and twisted tape insert in a circular tube Int. J. Nanotechnol. Appl., 1: 21-28.

Wen, D. and Y. Ding, 2004. Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions. Int. J. Heat Mass Transfer, 47: 5181-5188.

Xuan, Y. and W. Roetzel, 2000. Conceptions for heat transfer correlations of nanofluids. Int. J. Heat Mass Transfer, 43: 3701-3707.

Xuan, Y. and Q. Li, 2003. Investigation on convective heat transfer and flow features of nanofluids. J. Heat Transfer, 125: 151-155.

Yang, Y., Z.G. Zhang, E.A. Grulke, W.B. Anderson and G. Wu, 2005. Heat transfer properties of nanoparticle-in-fluid Dispersions (nanofluids) in laminar flow. Int. J. Heat Transfer, 48: 1107-1116.

Zamzamian, A., S.N. Oskouie, A. Doosthoseini, A. Joneidi and M. Pazouki, 2011. Experimental investigation of forced convective heat transfer coefficient in nanofluids of Al_2O_3/EG and CuO/EG in a double pipe and plate heat exchangers under turbulent flow. Exp. Therm. Fluid Sci., 35: 495-502.