ENHANCEMENT OF HEAT TRANSFER COEFFICIENT MULTI-METALLIC NANOFLUID WITH ANFIS MODELING FOR THERMOPHYSICAL PROPERTIES

by

Hyder H. BALLA [a,b*], ***Shahrir ABDULLAH*** [a], ***Wan Mahmood Wan Mohd FAIZAL*** [a],
Rozli ZULKIFLI [a], ***and Kamaruzaman SOPIAN*** [a]

[a] Department of Mechanical and Material Engineering, National University of Malaysia,
Bangi, Malaysia
[b] Foundation of Technical Educations, Baghdad, Iraq

Original scientific paper
DOI:10.2298/TSCI121128139B

The Cu and Zn-water nanofluid is a suspension of the Cu and Zn nanoparticles with the size 50 nm in the water base fluid for different volume fractions to enhance its thermophysical properties. The determination and measuring the enhancement of thermophysical properties depends on many limitations. Nanoparticles were suspended in a base fluid to prepare a nanofluid. A coated transient hot wire apparatus was calibrated after the building of the all systems. The vibro-viscometer was used to measure the dynamic viscosity. The measured dynamic viscosity and thermal conductivity with all parameters affected on the measurements such as base fluids thermal conductivity, volume factions, and the temperatures of the base fluid were used as input to the artificial neural fuzzy inference system to modeling both dynamic viscosity and thermal conductivity of the nanofluids. Then, the adaptive neuro-fuzzy inference system modeling equations were used to calculate the enhancement in heat transfer coefficient using computational fluid dynamics software. The heat transfer coefficient was determined for flowing flow in a circular pipe at constant heat flux. It was found that the thermal conductivity of the nanofluid was highly affected by the volume fraction of nanoparticles. A comparison of the thermal conductivity ratio for different volume fractions was undertaken. The heat transfer coefficient of nanofluid was found to be higher than its base fluid. Comparisons of convective heat transfer coefficients for Cu and Zn nanofluids with the other correlation for the nanofluids heat transfer enhancement are presented. Moreover, the flow demonstrates anomalous enhancement in heat transfer nanofluids.

Key words: *Cu-water, Zn-water, ANFIS modeling, heat transfer enhancement, nanofluid*

Introduction

The nanofluid is a suspension of monocular metallic nanoparticles in the base fluid to enhance the heat transfer of the water properties. The experimental set-up to measure the thermal conductivity of the nanofluids was built by Choi *et al.* [1]. The enhancement of thermal conductivity for metallic and other nanoparticles suspended in the base fluid were measured by Eastman *et al.* [2]. The transient hot wire method was used to measure the thermal conductivity

---

[*] Corresponding author; e-mail: hyderballa@yahoo.com

enhancement of nanofluids. The obtained correlation was compared with Hamilton and Crosser [3] model for an effective volume fraction of nanoparticles on thermal conductivity. The procedure for preparing a nanofluid which is a suspension consisting of nanophase powders and base fluid presents by Yuan and Li [4]. Their transmission electron microscopy (TEM) photographs are given to illustrate the stability and evenness of suspension. The hot-wire apparatus was used to measure the thermal conductivity of copper nanofluids.

The modeling of the enhancement of thermal conductivity for multi-metallic (Cu/Zn) nanofluid using the adaptive neuro fuzzy inference system (ANFIS) was studies by Balla *et al.* [5]. An artificial neural network has been used to predict the thermal conductivity of a nanofluid. The model for the enhancement in thermal conductivity of a nanofluid using a diffusion neural network was proposed by Papari *et al.* [6]. The model was used to predict the thermal conductivity of MWCNTs-oil, MWCNTs-DW, MWCNTs-DE, MWCNTs-EG, SECNTs-PMMA, and SECNT-epoxy. The results were compared with other mathematical models and experimental results. The predicted thermal conductivity was in a good agreement with the literature values. The measurements of the thermal conductivity for different types of nanofluids TiO_2, c-Al_2O_3, and CuO nanoparticles suspended in a 0.5 wt% of carboxymethyl cellulose aqueous solution was presents by Hojjat *et al.* [7].

The higher enhancement in a heat transfer coefficient for the nanofluid draw the researchers to present the model and study the heat transfer coefficient of nanofluid [8-13]. They were found that the heat transfer coefficient increase with the increase in Reynolds number and volume fractions, at the same time the pressure drop along the pipe depends on the nanoparticles size suspended in the base fluid. The heat transfer coefficient highly depends on the thermophysical properties of the nanofluids [9, 10].

In this study, enhancement of heat transfer for different types of nanofluids flow in a circular pipe for different volume fraction and Reynolds number. The ANFIS was used to modeling the thermal conductivity and dynamic viscosity of the nanofluids. The CFD modeling was used to determine the heat transfer enhancement for the nanofluids in pipe.

Nanofluids preparation and properties

2.1 Preparation of the nanofluids

The preparation of nanofluids is the first step for this study. Five volume fractions were prepared (0.2, 0.4, 0.6, 0.8, and 1%) for each type of the nanofluids. The properties of nanoparticles were illustrated in tab. 1. No desperation or stabilizer was used because the fact that any addition will change the fluid properties. Figure 1 shows the TEM for the aggregation of the nanoparticles after one hour in fig. 1(a), and one day in fig. 1(b). The figure illustrate the aggregated of the nanoparticles start to appear after one day for Cu-water nanofluid. While in the sample after one day the nanoparticles independently suspended in the base fluid. The mass of the nanoparticles add to the base fluid calculated:

Table 1. The properties of Cr nanoparticles

Nanoparticles	Size [nm]	Thermal conductivity [$Wkg^{-1}K^{-1}$]	Density [kgm^{-3}]	Heat capacity [$Jkg^{-1}K^{-1}$]
Cu	50	93	7190	449
Zn	50	112	7000	383.4

$$\varphi = \frac{V_\mathrm{p}}{V_t} \tag{1}$$

The mass of the nanoparticles is:

$$m_{\mathrm{p}} = 1 \cdot 10^{-3} \varphi \rho_{\mathrm{p}} \tag{2}$$

The density of the nanofluid is determined:

$$\rho_{\mathrm{nf}} = (1-\varphi)\rho_{\mathrm{f}} + \varphi \rho_{\mathrm{p}} \tag{3}$$

While the heat capacity of the nanofluid is determined:

$$C_{\mathrm{pnf}} = \frac{\varphi \rho_{\mathrm{p}} C_{\mathrm{pp}} + (1-\varphi)\rho_{\mathrm{f}} C_{\mathrm{pf}}}{\rho_{\mathrm{nf}}} \tag{4}$$

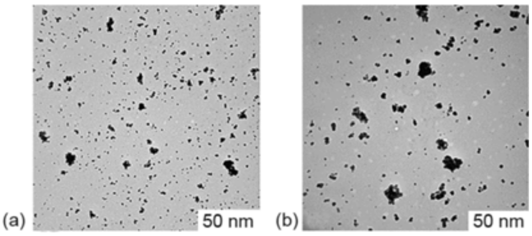

Figure 1. (a) the Cu water nanofluids with 1% at 30 °C after one hour of suspended, (b) the Cu water nanofluid 0.6% at 30 °C after one day suspended

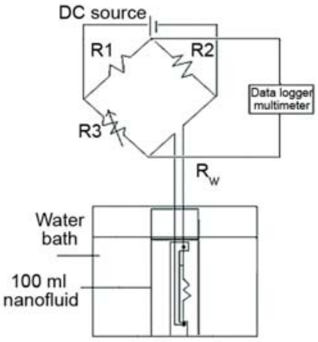

Figure 2. Schematic diagram of the coated transient hot wire set-up

Thermal conductivity measurements

The coated transient hot wire method is widely used to determine the thermal conductivity of liquids and gases. The more details for the experimental set-up were illustrated clearly by Balla *et al.* [8, 9]. Before and after analysis of the nanofluid samples, the accuracy of the probe is carefully checked using pure water and a standard sample of water of well-known thermal conductivity. The experimental thermal conductivities at temperatures from 20 °C to 60 °C for a nanofluid were determined first. An overall average deviation of 0.6% is obtained for comparing water thermal conductivity at the same temperature. Approximately 50 mm of the sample to be analyzed was sealed in a glass sample flask. Additional details of the apparatus and method are illustrated in fig. 2. While figs. 3(a) and (b) show the enhancement of thermal conductivity for the nanofluids with temperatures for different volume fractions. The figure shows the thermal conductivity ratio increase with temperatures.

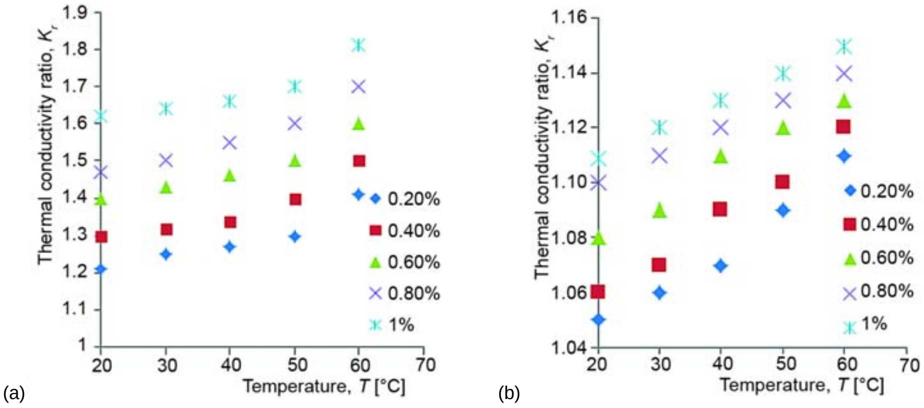

Figure 3. The change of meaasured thermal conductivity ratio with tempreatures for different volume fractions; (a) Cu-water nanofluids, (b) Zn-water nanofluids *(for color image see journal web-site)*

Dynamic viscosity measurement

The dynamic viscosity was measured using the SV-10 sine-wave vibro-viscometer at the accurate temperature for the metal Cu and Zn suspended in water. The dynamic viscosity of nanofluids were measured for different volume fractions in the range of 0.2-1 vol.% and the temperature range of 30-60 °C. The change of dynamic viscosity ratio with temperatures for different volume fraction was shown in fig. 4. The dynamic viscosity of the nanofluids decreases with increasing temperature.

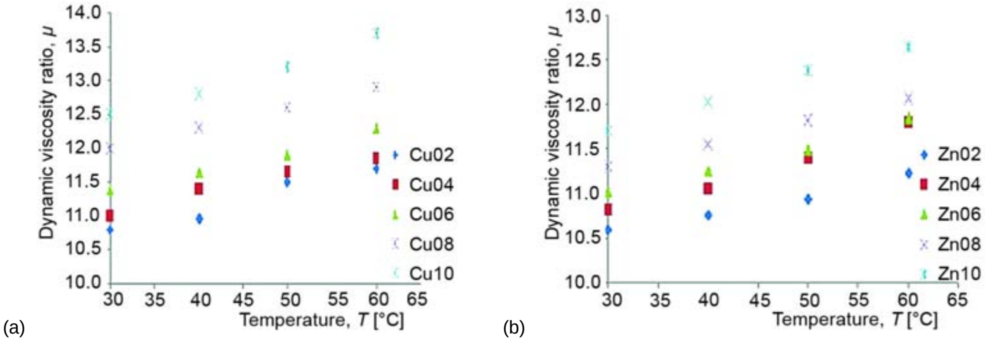

Figure 4. The change of the measured dynamic viscosity with temperatures for different volume fraction of (a) Cu nanofluids, (b) Zn nanofluids *(for color image see journal web-site)*

The ANFIS modeling

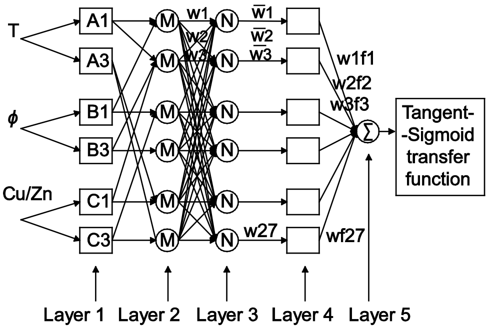

Figure 5. The structure of the ANFIS and layers

The combine of both fuzzy logic methods and the neural network to obtained the ANFIS. When these two systems are combined, they may qualitatively and quantitatively achieve a proper result that will include either fuzzy intellect or calculative abilities of a neural network. As with other fuzzy systems, the ANFIS structure is organized into two introductory and concluding parts, which are linked together by a set of rules. Five distinct layers may be recognized in the structure of an ANFIS network, which forms a multilayer network (fig. 5). The first layer in the ANFIS structure performs fuzzy formation and the second layer performs fuzzy "AND" and fuzzy rules. The third layer performs normalization of membership functions and the fourth layer is the conclusive part of fuzzy rules and the last layer calculates network outputs. Detailed information about ANFIS network structure and each layer function is given in Balla *et al.* [8].

Governing equations and solution procedure

The flow enters the tube with a constant temperature and a uniform velocity. The relevant governing equations used can be written:

$$\nabla \rho_{\text{nf}} \vec{\text{V}} = 0 \qquad (5)$$

$$\nabla(\rho_{\mathrm{nf}}\vec{\mathrm{V}}\;\vec{\mathrm{V}}) = -\nabla P + \nabla(\mu_{\mathrm{nf}}\nabla^{2}\vec{\mathrm{V}}) \tag{6}$$

$$\nabla(\rho_{\mathrm{nf}}\vec{\mathrm{V}}C_{\mathrm{pnf}}T) = \nabla(K_{\mathrm{nf}}\nabla T) \tag{7}$$

The dynamic viscosity and thermal conductivity were substitute from the fitting equations obtained from the ANFIS model. 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 2 m, and the nanofluid flowed with a constant velocity and a temperature of 300 K. Constant heat flux 1000 W/m^2 was applied to the outer wall of the tube as shown in fig. 6. The Reynolds number was varied from 100 to 2000.

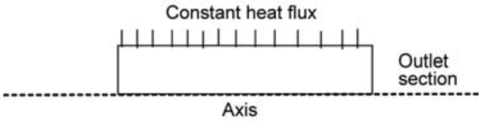

Figure 6. The schematic diagram for the cross-sectional pipe

The CFD COMSOL Multiphysics 3.5 was used to solve the present problem. The governing eqs. (5)-(7) are solved by finite elements method. This method is based on the spatial integration of the conservation equations over FEM, converting the governing equations to a set of algebraic equations. The algebraic "linear equations", resulting from this spatial integration process, are sequentially solved throughout the physical domain considered. The COMSOL solves, the systems resulting from linearization, schemes using a numerical method. The residuals resulting from the integration of the governing eqs. (5)-(7) 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. Results obtained for a particular test case showed that, for the tube flow problem under consideration, the 757817 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.

Where the local Nusselt number is calculated according to the definition:

$$\mathrm{Nu}(z) = \frac{h(z)D}{K_0} \tag{8}$$

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

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

From eq. (9), h_{avg} is calculated:

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

The average Nusselt number becomes:

$$\mathrm{Nu}_{\mathrm{avg}} = \frac{h_{\mathrm{avg}}D}{k_0} \tag{11}$$

Results and discussion

The enhancement of heat transfer coefficient of nanofluids flowing in pipe with constant heat flux at the wall in laminar flow regime was studied. As well, the measuring properties of the thermal conductivity and dynamic viscosity were studied. Moreover, the ANFIS model was used to modeling both the thermal conductivity and dynamic viscosity of nanofluids. The fitting modeling equations were used to study the heat transfer coefficient of the nanofluids.

Thermophysical properties of the nanofluid

Figures 3(a) and (b) show the measured thermal conductivity ratio change with temperatures for different volume fractions of both Cu and Zn nanofluids. The thermal conductivity ratio increase with increase of the temperature. This enhancement in the thermal conductivity ratio may be due to the increase of the energy for the metallic nanoparticles, then increase the energy will increases the Brownian motion of the nanoparticles. As well, the increase of the volume fraction will increase the thermal conductivity of the nanofluid. This increase may be due to the increase of the surface area of the metallic nanoparticles, this may be lead to, increases the nanolayer around the nanoparticles. Where the nanolayer is a base fluid layer consists around the nanoparticles with higher thermal conductivity than the same base fluid.

The dynamic viscosity change with temperatures for different volume fractions shows in figs. 4(a) and (b). The figure shows the increase of the dynamic viscosity ratio with increase of the temperatures. The nanofluid dynamic viscosity stay behaves same as the base fluid but with lower magnitude in the decreasing for the dynamic viscosity change with temperatures.

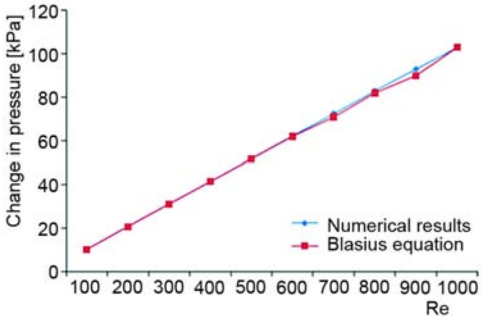

Figure 7. Validations of the pressure change of pipe numerical results with the Blasius equations

Validations of the numerical results

The computer model has been successfully validated with Blasius equation as shown in fig. 7. The figure shows the comparisons of the pressure change along the pipe with the Reynold number for water. The pressure losses obtained from the numerical results was compared with the pressure losses determined by Blasius equations:

$$f = \frac{64}{\mathrm{Re}} \tag{12}$$

$$\Delta p = f \frac{l}{D} \frac{\rho V^2}{2} \tag{13}$$

The CFD results

Figures 8(a) and (b) show the change of a heat transfer coefficients along the tube at the Reynolds number 700 and different volume fractions range for both Cu and Zn nanoparticles suspended in water. The figures show the higher heat transfer coefficient at the entering of the tube then decrease as the flow began to be fully developed. The higher enhancement of the heat transfer coefficients at the inlet of the tube may be due to the combine of the entering properties and the nanoparticles effect on the heat transfer. The heat transfer coefficients

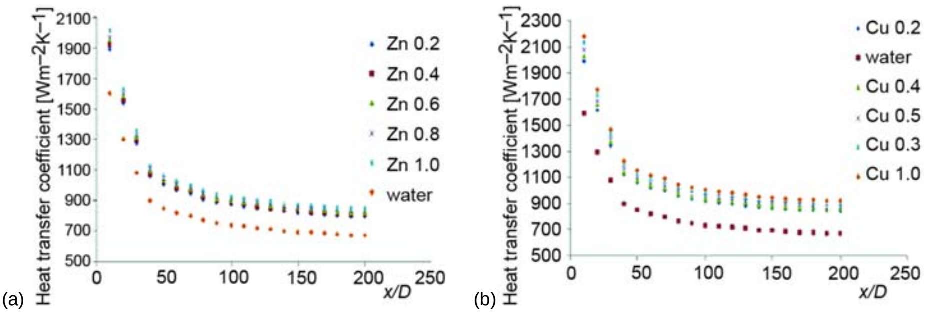

Figure 8. The change of heat transfer coefficient along *x/D* and for range of volume fraction at Reynolds number 700; (a) Zn nanofluid, (b) Cu nanofluid *(for color image see journal web-site)*

behavior is the same for water but with higher magnitude. To study the effect of the increase of the velocity on the heat transfer coefficient as well the Reynold number, figs. 9(a) and (b) show the heat transfer coefficients along the pipe with Reynold number 1500 for both the Cu and Zn suspended in water with different volume fraction. The higher heat transfer coefficient for Cu nanofluid obtained is higher than the heat transfer coefficient for Zn nanofluid. The figures show the heat transfer coefficients increases with the increase in the Reynold number.

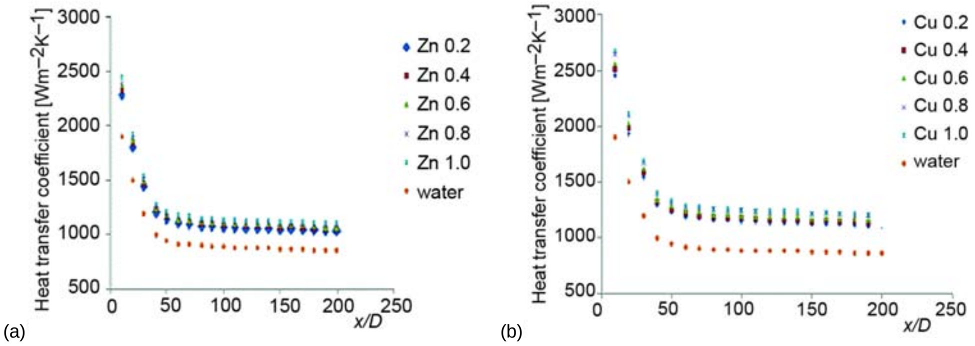

Figure 9. The change of heat transfer coefficient along *x/D* and for range of volume fraction at Reynolds number 1300; (a)Zn nanofluid, (b) Cu nanofluid *(for color image see journal web-site)*

Conclusions

The ANFIS model presents to predict both thermal conductivity and dynamic viscosity of the nanofluid. The ANFIS model has a good agreement with the experimental data. The Cu and Zn nanofluids present higher heat transfer coefficient compared with base fluid. The heat transfer coefficients determined with the thermophysical properties predict by the ANFIS model have a good agreement with the experimental measurements. The hybrid nanofluids present a good enhancement for the heat transfer coefficient with higher enhancement in the ratio for Cu is 40% while for the Zn is 20% in compare with water for volume fraction 1%.

Nomenclature

C_p – specific heat capacity
h – heat transfer coefficient, $[\mathrm{Wm^{-2}K^{-1}}]$
K – thermal conductivity, $[\mathrm{Wm^{-1}K^{-1}}]$
p – pressure of the tube
q – constant heat flux at the wall of the tube
Re – Reynolds number
T – temperature
$\vec{V}$ – velocity vector
x/D – the ratio of local position to the diameter of the pipe

Greek letters

μ – dynamic viscosity
ρ – density
ϕ – volume fraction

Subscripts

f – base fluids
nf – nanofluid
p – nanoparticles

References

[1] Choi, S. U. S., *et al*., Enhancement of Heat Transfer with Nanofluid, *Appl. Phy. Lett., 79* (2001), 14, pp. 312-314

[2] Eastman, J. A., *et al*., Anomalously Increased Effective Thermal Conductivities of Ethylene Glycol Based Nanofluids Containing Copper Nanoparticles, *Applied Physics Letter, 78* (2001), 6, pp. 718-720

[3] Hamilton, R. L., Crosser, O. K., Thermal Conductivity of Heterogeneous Two-Component Systems, *Industrial & Engineering Chemistry Fundamentals, 1* (1963), pp. 187-191

[4] Qiang, L., Investigation on Convective Heat Transfer and Flow Features of Nanofluids, *J. Heat Tran., 125* (2003), 1, pp. 151-155

[5] Balla, H. H., *et al*., Modelling and Measuring the Thermal Conductivity of Multi-Metallic Zn/Cu Nanofluid, *Research on Chemical intermediate, 39* (2012), 6, pp. 2801-2815

[6] Papari, M. M., *et al*., Modelling Thermal Conductivity Augmentation of Nanofluid Using Diffusion Neural Networks, *International Journal of Thermal Sciences, 50* (2011), 1, pp. 44-52

[7] Hojjat, M., *et al*., Thermal Conductivity of Non-Newtonian Nanofluids: Experimental Data and Modelling Using Neural Network, *International Journal of Heat and Mass Transfer, 54* (2011), 5-6, pp. 1017-1023

[8] Balla, H. H., *et al*., Effect of the Nanoparticles Materials on the Pressure Losses and Heat Transfer of Nanofluid in a Circular Pipe, *Applied Journal of Sciences, 12* (2012), 13, pp. 1396

[9] Balla, H. H., *et al*., Effect of Reynolds Number on Heat Transfer and Flow for Multi-Oxide Nanofluids Using Numerical Simulation, *Research on Chemical Intermediate, 39* (2013), 5, pp. 2197-2210

[10] Akbarinia, A., Behzadmehr, A., Numerical Study of Laminar Mixed Convection of a Nanofluid in Horizontal Curved Tubes, *Applied Thermal Engineering, 27* (2007), 8-9, pp. 1327-1337

[11] Anoop, K. B., *et al*., Effect of Particle Size on the Convective Heat Transfer in Nanofluid in the Developing Region, *International Journal of Heat and Mass Transfer, 52* (2009), 9-10, pp. 2189-2195

[12] Bianco, V., *et al*., Numerical Investigation of Nanofluids Forced Convection in Circular Tubes, *Applied Thermal Engineering, 29* (2009), 17-18, pp. 3632-3642

[13] He, Y., *et al*., Numerical Investigation into the Convective Heat Transfer of TiO_2 Nanofluids Flowing through a Straight Tube under the Laminar Flow Conditions, *Applied Thermal Engineering, 29* (2009), 10, pp. 1965-1972

Paper submitted: November 28, 2012
Paper revised: May 5, 2013
Paper accepted: September 4, 2013