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Numerical Prediction of Forced Convective Heat Transfer and Friction Factor of Turbulent Nanofluid Flow through Straight Channels

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Abstract – *A numerical analysis has been implemented applying on turbulent forced convection flow of water inside a horizontal circular channel with a constant heatflux applied to the wall. Nusselt number and friction factor have been tested for Reynolds number, Re= 5000to 20000. Results present that the heat transfer rate increases as the Reynolds number increase. On the other hand, the friction factor increase when the Reynolds number decrease. Finally, results of the average Nusselt number and frictional factor for pure fluid (water) have been verified and validated with experimental results as well as with available correlations where a logical good agreement has been fulfilled.*

Keywords: turbulent, nanofluid, Nusselt number, friction factor

1.0 INTRODUCTION

Generally classical heat transfer fluids such as water, ethylene glycol and engine oil have relatively poor thermal conductivities compared to solid particles [1]. Previously, improvement of heat transfer was achieved in various ways such as those depending on modifying the fluid flow by changing the geometry, making some changes in boundary conditions and adding small micro particles to the base fluids [2]. However, enhancement of base fluid thermal properties by dispersing micrometer-sized particles in fluid resulted in drawbacks such as block out and deposition [3, 4]. So, to overcome these disadvantages and to meet the requirements of modern efficient heat transfer equipment, nanofluids were created. The notion of nanofluids are novel generation of heat transfer fluids formed by mixing metallic or non-metallic nanoparticles with size is less than 100 nm with base fluids[5]. Many studies have shown that the nanofluids have significantly higher thermal properties compared to conventional fluids and proved that the nanofluids have a considerable influence on heat transfer augmentation [6].

In order to employ the nanofluid in heat transfer processes, many investigations on its characteristics of heat transfer and flow are required. Pak and Cho [7] conducted turbulent flow of two different nanofluids inside circular channel under uniform heat flux experimentally. In their investigation, Al_2O_3 and TiO_2 were suspended in water and their results exhibited that with increasing the volume fraction of nanoparticles and the Reynolds

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number, the nusselt number increased. turbulent and laminar flow of Cu-water nanofluid through straight channel which subjected to a constant heat flux was investigated experimentally by Li and Xuan [4].their results showed that the performance of heat transfer was significantly improved by adding nanoparticles to the base fluid (water). Sundar et al. [8] investigated experimentally the convective heat transfer with turbulent Fe_3O_4Nanofluid inside a circular tube. It is found that addition of magnetic nanoparticle in the base fluid enhanced the heat transfer rate significantly compared to the other types of nanofluids. Fotukian and Nasr Esfahany [9] studied turbulent flow of dilute Al_2O_3/water nanofluid in circular channel in terms of the convective heat transfer. Their results showed that considerable enhancements of the heat transfer of the base fluid as small quantities of nanoparticles were added. Sajadi and Kazemi [10] studied experimentally the effect of adding titanium dioxide particles into the base fluid under turbulent condition in a circular pipe on heat transfer behaviour. They found that the heat transfer coefficient increased with volume fraction of TiO_2. Nguyen et al. [11] conducted experimentally the behaviour of heat transfer characteristics of Al_2O_3/water nanofluids for an electronic application as a cooling system. They observed the heat transfer coefficient with a certain particle volume concentration remarkably increased compared to the base fluid.

Qiang and Yimin [12] studied experimentally the effect of both turbulent and laminar Cu–water nanofluid flow inside a circular tube on the performance of heat transfer. They found that the heat transfer rate increased due to addition of nanoparticles in the base fluid. Kim et al. [13], also, investigated experimentally the influence of Al_2O_3–water nanofluid on performance of heat transfer flowing inside a circular tube for both laminar and turbulent flow regime. Their results showed that by adding specific volume fraction of nanoparticles, heat transfer rate increased clearly compared to the base fluid for both laminar and turbulent flow, respectively. Maiga et al. [14], on the other hand, investigated numerically the effect of dispersing several fractions of Al_2O_3 nanoparticles numerically in base fluid on heat transfer enhancement, this study conducted inside circular channel and under fully turbulent flow regime. Their results exhibited that the heat transfer rate improved noticeably with the increase of nanoparticle volume fraction. Also, Kumar [15] analysed numerically the influence of Al_2O_3–water nanofluid under both laminar and turbulent flow regime on heat transfer rate. His results showed that in turbulent flow case, heat transfer rate remarkably improved compared tothat in the laminar flow regime. Numerical investigation of turbulent flow heat transfer of CuO, TiO_2 and Al_2O_3/water nanofluids in square duct under constant heat flux has been reported by Rostamani et al. [16]. Their results showed that the heat transfer rate increase with nanoparticle concentration and the influence of CuO to enhance heat transfer rate is higher compared to TiO_2 andAl_2O_3.

The purpose of this study is to design numerical prediction of turbulent nanofluid flow in straight channel to achieve certain objective. Firstly, to investigate the effect of using Fe_3O_4/water nanofluid with different range of volume fractions on heat transfer and friction factor. Secondly, to examine the influence of changing the shape of the geometry on heat transfer and friction factor.

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2.0 METHODOLOGY

2.1 Statement of the problem

In this paper, the geometry contains 3D circular channel with length and hydraulic diameter are 1.7 m and 0.014 m, respectively as shown in Figure 1. A constant heat flux (13381W/m^2) is applied to the all channel walls. *Fe3O4* nanoparticles with 36 nm size suspended in distilled water will be employed as a heat transfer fluid. The volume fraction of nanofluid is ranging from 0.1 to 0.6 % and Reynolds numbers are ranging from 5000 to 20000 [8]. In this study, the boundary conditions are assumed steady state, single phase, incompressible and Newtonian turbulent fluid flow, constant thermophysical properties of nano fluids, wall thickness and heat conduction in the axial direction are neglected.

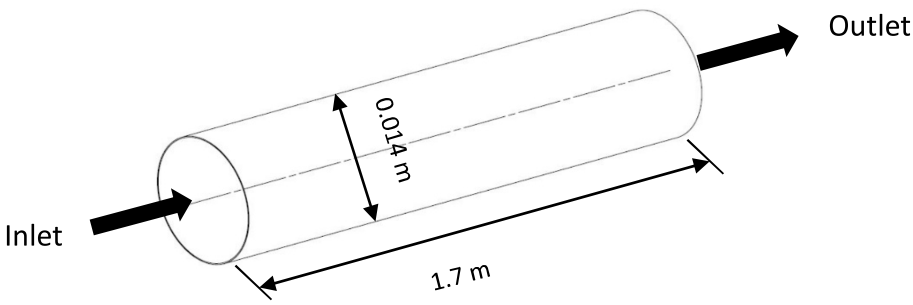

Figure 1: Schematic diagram of the geometry.

2.2 Thermophysical Properties of Nanofluid

The effective thermophysical properties of nanofluid are calculated by employing the following correlations [17]:

$$\rho_{nf}=(1-\varphi)\rho_{water}+\varphi\rho_{fe3o4} \tag{1}$$

$$C_{nf}=(1-\varphi)C_{water}+\varphi C_{fe3o4} \tag{2}$$

where ρ_{nf} and C_{nf} are density and specific heat of nanofluid, respectively.

On the other hand, the effective thermal conductivity is given by [18]:

$$k_{nf}=k_{water}\left\{\frac{k_{fe3o4}+2k_{water}-2\varphi(k_{water}-k_{fe3o4})}{k_{fe3o4}+2k_{water}+2k_{fe3o4}(k_{water}-k_{fe3o4})}\right\} \tag{3}$$

and the effective viscosity of nanofluid is defined as follows [19]:

$$\mu_{nf}=\mu_{water}\left(\frac{1}{(1+\varphi)^{0.25}}\right) \quad (4)$$

2.3 Governing Equations

Fe3O4nanofluid was accounted as incompressible, Newtonian, steady state and the effect of viscous heating was negligible. The Reynolds Average Navier-Stokes flow governing equations in the Cartesian co-ordinates are represented as below [20]:

Continuity equation:

$$\nabla.\left(\rho_{nf}.V_m\right)=0 \quad (5)$$

Momentum equations

$$\nabla.\left(\rho_{nf}.V_m.V_M\right)-\nabla P+\nabla.\left(\mu_{nf}.\nabla V_m\right) \quad (6)$$

Energy equation

$$\nabla.\left(\rho_{nf}.C.V_m.T\right)=\nabla.\left(k_{nf}.\nabla T\right) \quad (7)$$

In the current numerical investigation, near wall standard k-ε model is employed. Standard k-ε signifies two further correlations which are turbulent kinetic energy (k) and dissipation rate (ε).

Turbulent kinetic energy (k) and rate of dissipation (ε) can be represented by the equations below:

$$div(\rho\bar{V}k)=div\left\{\frac{(\mu+\mu_t)}{\sigma_k grad k}\right\}+G_k-\rho\mathcal{E} \quad (8)$$

$$div(\rho\bar{V}\mathcal{E})=div\left\{\left(\mu+\left(\frac{\mu_t}{\sigma_{\mathcal{E}}}\right)\right)grad\mathcal{E}\right\}C_{1\mathcal{E}}\left(\frac{\mathcal{E}}{k}\right)G_k+C_{2\mathcal{E}}\rho\left(\frac{\mathcal{E}^2}{k}\right) \quad (9)$$

where G_k indicates to generation rate of turbulent kinetic energy resulted from gradient of mean velocity, σ_k and $\sigma_{\mathcal{E}}$ represent the effective Prandtl numbers for turbulent kinetic energy and rate of dissipation, respectively. $C_{1\mathcal{E}}$ and $C_{2\mathcal{E}}$ are constants and μ_t represents the eddy viscosity and it can be calculated by:

$$\mu_t=\frac{\left(\rho C_\mu k^2\right)}{\mathcal{E}} \quad (10)$$

$C_\mu$is a constant and its value is 0.09

In equations (8) and (9); $C_{1\mathcal{E}}=1.44;\ C_{2\mathcal{E}}=1.92;\ \sigma_k=1$ and $\sigma_{\mathcal{E}}=1.3.$

Further information is available in Launder and Spalding [21].

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2.4 Numerical Approach

This problem was solved by computational fluid dynamics (CFD) code Fluent. Control volume approach was employed in order to discretise the governing equations and convert them into set of algebraic equations. Terms such as convection and diffusion and also other quantities resulted from the governing equations were discretised by second order upwind scheme. Semi Implicit Method for Pressure Linked Equations [SIMPLE] was used to couple pressure and velocity. Gauss–Seidel linear equation associated with an algebraic multigrid approach was employed to solve the systems resulted from discretization scheme. For all the simulations achieved in the current investigation, convergence criteria for the solutions are accounted as the residuals become less than 10^{-6}.

2.5 Grid independent test

In order to obtain the best numerical solution in terms of accuracy and saving computation time, grid independent test was carried out for the physical model. In this present analysis, the grid optimization has been experienced for four different number of elements for pure water which are498472, 786440, 1361840 and1892289 as shown in figure 2. The results of Nusselt number computed for all four mesh systems were suitable and the differences were negligible. Therefore, any number of elements for the four cases can be employed, but in thiscase, mesh with number of element 1361840has been employed as the best in terms of the accuracy.

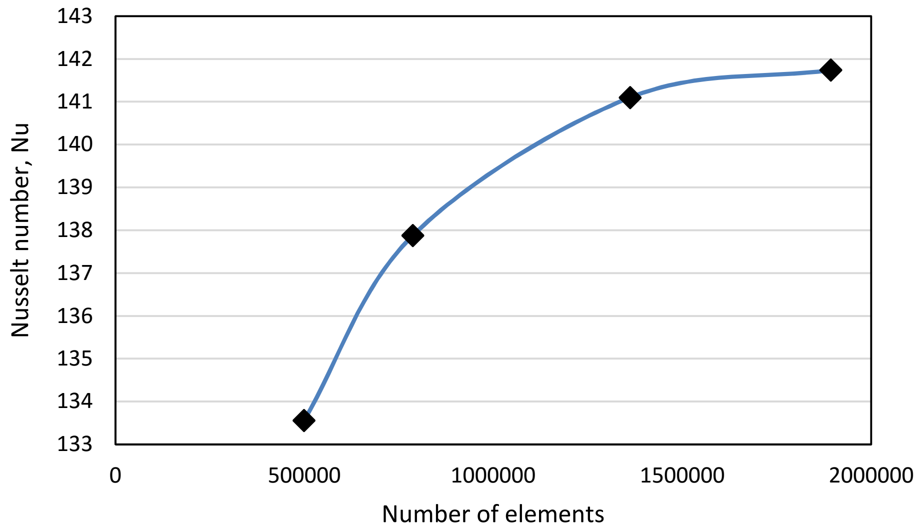

Figure 2: Grid independency test.

3.0 RESULTS AND DISCUSSION

In order to validate and verify the present computational model, the simulation results for turbulent conventional fluid flow (pure water) in circular channel were compared with experimental and numerical data from literature in terms of Nusselt number and friction factor for Reynolds number ranging from 5000 to 20000.

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3.1 Nusselt Number

In this problem, the Nusselt number for the fully developed turbulent flow for water were calculated from the following equation [8]:

$$\overline{Nu}=\frac{\bar{h}.D}{k} \tag{11}$$

where $\bar{h}$, D and k are average convective heat transfer coefficient, tube diameter, thermal conductivity of the fluid, respectively.

$$\bar{h}=\frac{q''}{T_W\text{-}T_b} \tag{12}$$

where q'', T_W and T_b are heat flux, average wall temperature and temperature of the bulk, respectively.

The numerical Nusselt number compared with the experimental data of Sundar [8] and the correlation of Notter and Rouse for single phase fluid [22] which is presented as equation (13).

$$Nu=5+0.015Re^{0.856}Pr^{0.347} \tag{13}$$

From figure 3, It can be noticed that there is a very good agreement between the current study results of Nusselt number and both the experimental data of Sundar and the correlation of Notter and Rouse indicating that the reliability of the values from the simulation. On the other hand, it is seen that as the Reynolds number increase the Nusselt number increase which in turn lead to increase the enhancement of heat transfer.

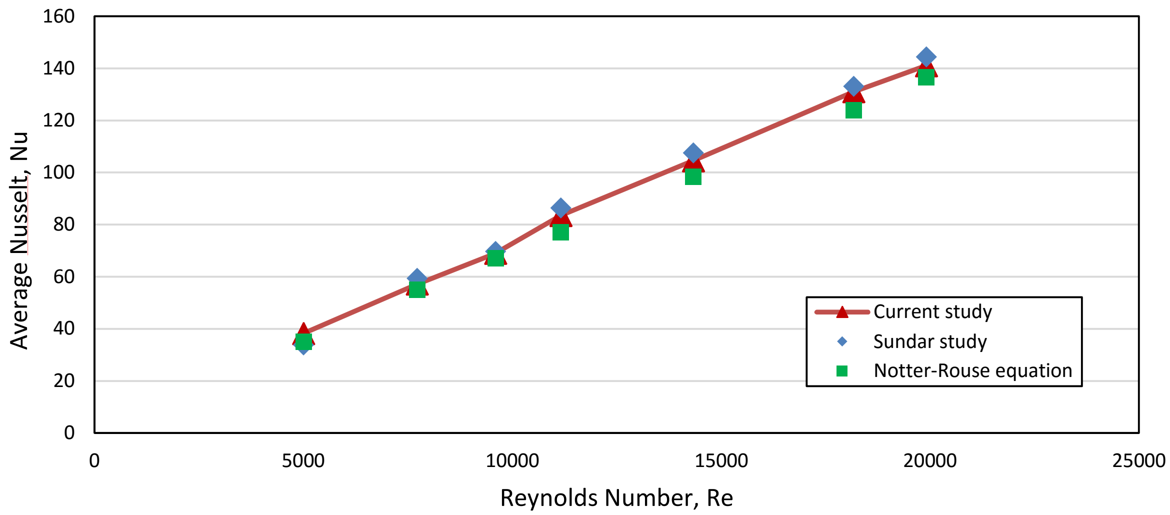

Figure 3: Comparison of the current study with experimental data of Sundar and the correlation of Notter and Rouse for pure water.

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3.2 Friction factor

In order to demonstrate the validity of simulation work, the numerical results of friction factor for water were calculated and compared with the experimental data of sundar [8] and the Darcy friction correlation given by Blasius which is presented as Equation (14) from White [23].

$$f=4C_f=4\left(0.0791Re^{-\frac{1}{4}}\right) \tag{14}$$

As it is seen in Figure 4, a very good agreement between the numerical predictions and both the experimental data of Sundar and Blasius correlation are observed over the range of the Reynolds number studied.

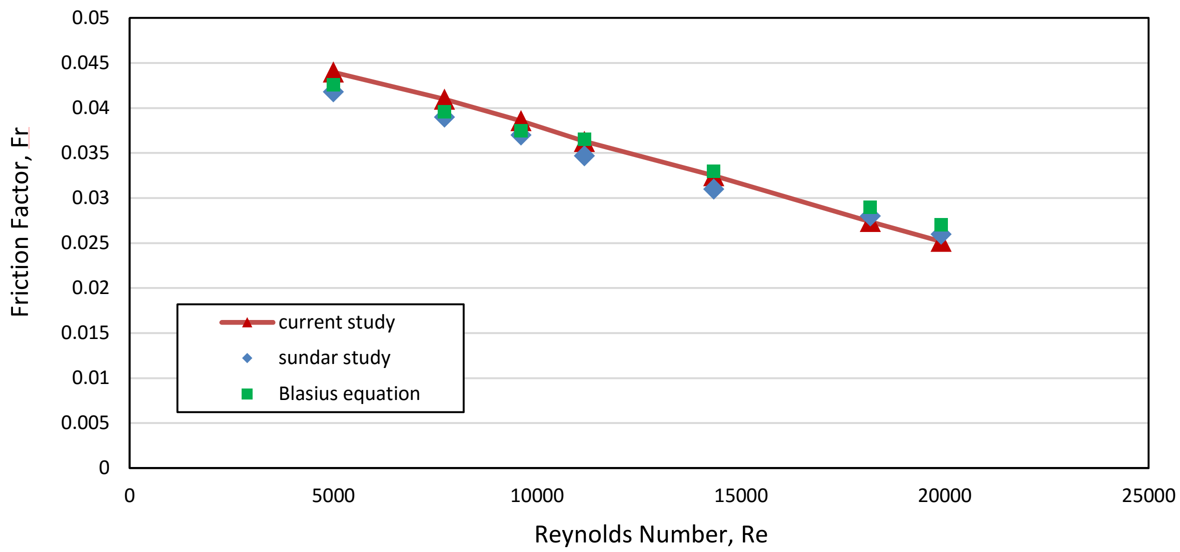

Figure 4: Comparison of current study with the experimental study of Sundar and Darcy friction factor by Blasius correlation.

4.0 FUTURE WORK

Since the current study has been validated and verified in terms of Nusselt number and friction factor, for that it is reliable and it can be extended to include the following investigations:

1. Applying Fe_3O_4 nanofluid with different range of volume fractions rather than water due to its exceptional magnetic, electronic and optical properties as well as its higher thermal conductivity [24] in order to compare the enhancement of heat transfer and friction factor for both cases.

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2. The effect of employing different cross sectional geometries (circular, rectangular and square) on enhancing heat transfer and friction factor.

5.0 CONCLUSION

In this paper, a numerical study of turbulent flow of water through horizontal circular pipe has been implemented and the computational results in terms of average Nusselt number and friction factor have been validated with data from literature by using computational fluid dynamics tools.

The results obtained from this study exhibited that:

1. A very good agreement with the results from the literature in terms of Nusselt number and friction factor.
2. As the Reynolds number increased, the Nusselt number increased which in turn resulted in improving the heat transfer.
3. The friction factor decreased with increasing the Reynolds number.

So, this study is reliable and could be employed to predict the heat transfer behaviour and friction factor of Fe_3O_4/water nanofluids with different volume fractions and different cross sectional geometries.

REFERENCES

[1] M.M. Keshavarz, M. Hejazian, Modeling of turbulent forced convective heat transfer and friction factor in a tube for Fe_3O_4 magnetic nanofluid with computational fluid dynamics, International Communications in Heat and Mass Transfer 39 (2012) 1293-1296.

[2] M. Corcione, M. Cianfrini, A. Quintino, Heat transfer of nanofluids in turbulent pipe flow, International Journal of Thermal Sciences 56 (2012) 58-69.

[3] C.C. Tang, S. Tiwari, M.W. Cox, Viscosity and Friction Factor of Aluminum Oxide–Water Nanofluid Flow in Circular Tubes, Journal of Nanotechnology in Engineering and Medicine (2013) 021004.

[4] Q. Li, Y. Xuan, Convective heat transfer and flow characteristics of Cu-water nanofluid, Science in China Series E: Technological Science, 45 (2002) 408-416

[5] A.M. Hussein, K.V. Sharma, R.A. Bakar, K. Kadirgama, The effect of cross sectional area of tube on friction factor and heat transfer nanofluid turbulent flow, International Communications in Heat and Mass Transfer 47 (2013) 49-55.

[6] Y. Xuan, Q. Li, Investigation on convective heat transfer and flow features of nanofluids, Journal of Heat transfer 125 (2003) 151-155.

[7] B.C. Pak, Y.I. Cho, Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles, Experimental Heat Transfer an International Journal 11 (1998) 151-170.

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences
ISSN (online): 2289-7879 | Vol. 8, No. 1. Pages 1-10, 2015

[8] L.S. Sundar, M.T. Naik, K.V. Sharma, M.K. Singh, T.C.S. Reddy, Experimental investigation of forced convection heat transfer and friction factor in a tube with Fe_3O_4 magnetic nanofluid, Experimental Thermal and Fluid Science 37 (2012) 65-71.

[9] S.M. Fotukian, M.N. Esfahany, Experimental investigation of turbulent convective heat transfer of dilute γ-Al_2O_3/water nanofluid inside a circular tube, International Journal of Heat and Fluid Flow 31 (2010) 606-612.

[10] A.R. Sajadi, M.H. Kazemi, Investigation of turbulent convective heat transfer and pressure drop of TiO_2/water nanofluid in circular tube, International Communications in Heat and Mass Transfer 38 (2011) 1474-1478.

[11] C.T. Nguyen, G. Roy, C. Gauthier, N. Galanis, Heat transfer enhancement using Al_2O_3–water nanofluid for an electronic liquid cooling system, Applied Thermal Engineering 27 (2007) 1501-1506.

[12] L. Qiang, L.X.Yimin, Convective heat transfer and flow characteristics of Cu-water nanofluid, Science in China (Series E) 45 (2002) 408-416.

[13] D. Kim, Y. Kwon, Y. Cho, C. Li, S. Cheong, Y. Hwang, S. Moon, Convective heat transfer characteristics of nanofluids under laminar and turbulent flow conditions, Current Applied Physics 9 (2009) 119-123.

[14] S.E.B. Maïga, C.T. Nguyen, N. Galanis, G. Roy, Heat transfer behaviors of nanofluids in a uniformly heated tube, Superlattices and Microstructures 35 (2004) 543-557.

[15] P. Kumar, A CFD study of heat transfer enhancement in pipe flow with Al_2O_3 nanofluid, World Academy of Science, Engineering and Technology 57 (2011) 746-750.

[16] M. Rostamani, S.F. Hosseinizadeh, M. Gorji, J.M. Khodadadi, J. M. (2010). Numerical study of turbulent forced convection flow of nanofluids in a long horizontal duct considering variable properties, International Communications in Heat and Mass Transfer 37 (2010) 1426-1431.

[17] S. Kakaç, A. Pramuanjaroenkij, Review of convective heat transfer enhancement with nanofluids, International Journal of Heat and Mass Transfer 52 (2009) 3187-3196.

[18] E.J. Wasp, J.P. Kenny, R.L. Gandhi, Solid--liquid flow: slurry pipeline transportation.[Pumps, valves, mechanical equipment, economics], Ser. Bulk Material Handling (United States) 1 (4) (1977).

[19] H.C. Brinkman, The viscosity of concentrated suspensions and solutions, The Journal of Chemical Physics 20 (1952) 571-571.

[20] M.K. Moraveji, M. Darabi, S.M.H. Haddad, R. Davarnejad, Modeling of convective heat transfer of a nanofluid in the developing region of tube flow with computational fluid dynamics, International Communications in Heat and Mass Transfer 38 (2011) 1291-1295.

[21] B.E. Launder, D.B. Spalding, Mathematical models of turbulence, Academic Press, London/New York, 1972.

[22] R.H. Notter, C.A. Sleicher, A solution to the turbulent Graetz problem—III Fully developed and entry region heat transfer rates, Chemical Engineering Science 27 (1972) 2073-2093.

[23] F.M. White, I. Corfield, Viscous fluid flow (Vol. 3), New York: McGraw-Hill, 1991.

[24] J.A. Lopez, F. González, F.A. Bonilla, G. Zambrano, M.E. Gómez, Synthesis and characterization of Fe_3O_4 magnetic nanofluid, Revista Latinoamericana de Metalurgia y Materiales (2010) 60-66.