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Simulation of (EG+Al_2O_3) Nanofluid Through the Shell and Tube Heat Exchanger with Rectangular Arrangement of Tubes and Constant Heat Flux

F. Khoddamrezaee, R. Motallebzadeh and D. Jajali Vahid
Faculty of Mechanical Engineering, Sahand Tabriz University of Technology, Tabriz, Iran

Abstract: In this study, the characteristics of (EG+AL_2O_3) nanofluid and (EG) fluid which cross a rectangular arrangement of tubes in a shell and tubes heat exchanger have been investigated. The stagnation point, separation point, heat transfer coefficient and shear stress in both of nanofluid and purefluid have been determined and compared with each other. The heat transfer and velocity simulation of two phase flow have been done by mixture model. Results show that by using of nanofluid, the stagnation and separation points of flow were postponed and the amount of heat transfer coefficient and shear stress increased but the effect of shear stress increase can be neglected in compare of unusual heat transfer rising.

Key words: Rectangular arrangements of tubes, heat exchanger, nanofluid, constant heat flux

INTRODUCTION

Using a fluid with better heat performance is an effective parameter to increase heat transfer rate in the heat exchangers. Previously to increase heat transfer in the heat exchanger, engineers used suspension of fluid and solid particle with the micron and millimeter diameter. But using this kind of particle causes sedimentation and decrease the flow rate. Pipe scrubbing and great pressure loss in the pipelines are the disadvantages of using large particles in basefluid.

The difference of density between the base fluid and the rigid particles causes sedimentation or buoyancy lift of particles. In sedimentation case, when the gravity force on the rigid particle become equivalent to the Archimedes force, the summation of two forces becomes zero and the particle move downward with the constant velocity. The particles sediment when they reach the nonmoving surface, where, the fluid velocity is also zero.

Sedimentation velocity of the particles in the fluid is calculated by Stocks low:

$$V_s = (\rho_2 - \rho_1)(2gr^2)/9\mu$$

In this relation (ρ_2-ρ_1) is the density difference between base fluid and the suspended particles. If the particles density is less than the fluid density the particles move upward with the constant velocity V_s and if the particles density is more than the fluid density they move downward and sediment. When the fluid density and particles density are near to each other the sedimentation velocity decreases. Also, decreasing in the sedimentation velocity occurs by decreasing the particles radius. Sedimentation velocity of the particles has a vise versa relation with the kinetic viscosity of the fluid. However, suspension stability increases by increasing the kinetic viscosity of the fluid. So, researchers suggest using of the particle with the nanometer size in the base fluid (especially water, oil and ethylene glycol) to decrease the sedimentation velocity. Using the particles with the nanometer size not only causes the better stability of the suspension but also causes an exaggerating increase in heat transfer performance. According to the recent studies, increasing in conduction coefficient of nanofluids is the major reason of increasing the convection heat transfer rate in nanofluids.

Xuan and Li (2003) studied experimentally the convection heat transfer and friction coefficient characters of nanofluid in both of laminar and turbulent flow. Their results show that heat transfer coefficient of the nanofluid is more than the base fluid in the same conditions. This coefficient changes with the changing the flow velocity and volumetric ratio of nano particles. Yang *et al.* (2005) studied the convection heat transfer coefficient of graphite nano particles in laminar flow in a horizontal heat exchanger experimentally. This study has considered the result of changing the Reynolds number, volume ratio, temperature and type of fluid on the heat transfer coefficient.

Lee and Choi (1996) studied force convection heat transfer in parallel channels by using a special nanofluid and found that the heat resistant decreases with the ratio

Corresponding Author: F. Khoddam Rezaee, Iran Power Development Company (IPDC), No. 3, Shahamati St., Valie Asr Ave., P.O. Box 14155-6393, Tehran, Iran Tel: +98-21-88902258 Fax: +98-21-88806886

of 0.5. Wen and Ding (2004) studied the experimental result of (Al_2O_3-water) nanofluid convection heat transfer along a copper tube with 4.5 mm diameter and 970 mm length. They find that nanofluid heat transfer coefficient increases by increasing the Reynolds number and the volumetric ratio of particles. Also, heat transfer coefficient increasing in the entrance part is more than the other. Despite of better heat transfer characters, nano particles movement causes non steady temperature and viscosity counter occur. Heris *et al*. (2006) studied laminar flow of CuO-water and (Al_2O_3-water) in a copper tube with 1 m length, 6 mm diameter and 0.5 mm thickness. The copper tube is positioned inside a stainless steel tube with internal diameter of 32 mm. To obtain constant temperature boundary condition on the copper tube, saturated vapor flows inside the stainless steel tube. The results show that heat transfer coefficient increases by increasing the particles volumetric ratio and Peclet number.

Hong *et al*. (2006) investigated the effect of the clustering of nanoparticles on the thermal conductivity of nanofluids. The results show that thermal conductivity of nanofluids is directly related to the agglomeration of nanoparticles and increases nonlinearly with increasing volume concentration. Leong *et al*. (2006) proposed a new model for predicting thermal conductivity of nanofluids by considering the effects of the interfacial layer at the solid-liquid interface. Zhang *et al*. (2007) showed that the thermal conductivity of some nanofluids indicated no anomalous enhancements.

Timofeeva *et al*. (2007) studied the thermal conductivity and viscosity of Alomina nanoparticles dispersed in water and ethylene glycol. Results showed that the measured thermal conductivity of nanofluids was less than the predicted values of the effective medium theory. He *et al*. (2007) showed that the thermal conductivity of nanofluids increases with increasing volume fraction in a nonlinear trends. Lee *et al*. (2007) showed that viscosity of nanofluids significantly decreases with increasing temperature. Murshed *et al*. (2008) investigated the thermal conductivity and viscosity of nanofluids. The results showed that the measured thermal conductivity and viscosity of nanofluids are higher than those of base fluids and increase with increasing particle volume concentration.

In this study, the velocity profile, heat transfer coefficient and shear stress of ($EG+AL_2O_3$) nanofluid through the shell and tube heat exchanger with rectangular arrangement of tubes have been considered and compared with the base fluid (EG).

MATERIALS AND METHODS

Mixture method is used to solve the governing equations. In this method nanofluid acts like a pure fluid. There is no velocity difference between fluid and the particles. The fluid and the particles have heat equilibrium. Continuity, momentum and energy equations for one phase fluid are used for the nanofluid. The effect of nano particles enters in the nanofluid physical characteristics. The distribution of the particles is assumed to be steady in the base fluid because the diameter of the particles is less than 100 nm.

Eastman *et al*. (1997) studied that, the Ethylene Glycol and Alumina nanofluids have better stability than the other nanofluids.

Governing equations: Continuity, momentum and energy are the governing equations. They are defined for solving the multi phase fluid with mixture method for two phase flow as follow:

$$\frac{\partial}{\partial t}(\rho_m) + \nabla(\rho_m V_m) = \dot{m} \quad (1)$$

$$V_m = \frac{\sum_{k=1}^{n} \alpha_k \rho_k V_k}{\rho_m} \quad (2)$$

$$\rho_m = \sum_{k=1}^{n} \alpha_k \rho_k \quad (3)$$

where, $\dot{m}$ is mass transfer rate between two phases or mass production resource. V_m and ρ_m are the mean velocity and mean density of nanofluid. n is number of phases. α is volume percentage of each phases. V_k and ρ_k are the phases velocity and density.

The momentum equation for mixture is:

$$\begin{aligned} &\frac{\delta}{\delta t}(\rho_m V_m) + \nabla(\rho_m V_m V_m) = \\ &-\nabla P + \nabla[\mu_m(\nabla V_m + \nabla V_m^T)] + \rho_m g + F + \\ &\nabla(\sum \alpha_k \rho_k V_{dr,K} V_{dr,K}) \end{aligned} \quad (4)$$

$$V_{dr,k} = V_k - V_m \quad (5)$$

In this relation F is the body force and the Einstein equation is used to estimate the viscosity of suspension.

$$\mu_m = \sum (1 + 2.5\alpha_k)\mu_{bf} \quad (6)$$

The energy equation of mixture phase is:

$$\frac{\delta}{\delta t}\sum_{K=1}^{n}\alpha_k\rho_k E_k + \nabla\sum_{k=1}^{n}\alpha_k V_k(\rho_k E_k + P) = \nabla(K_{eff} + \nabla T) + S_e \quad (7)$$

where, S_e is applied to all kind of heat sources.

$$E_k = H_k + \frac{V_k^2}{2} - \frac{p}{\rho_k}$$

For compressible flow $E_k = H$ and for incompressible flow H_k is sensible enthalpy of k phase.

For EG-Al_2O_3 nanofluid without mass resource, above equations simplified to continuity, momentum and energy equations of single phase fluid flow. The effect of nano particles enters in the physical characteristics of fluid. Therefore:

$$\mathrm{div}(\rho_{nf}.V) = 0 \quad (8)$$

$$\mathrm{div}(\rho_{nf}V.V) = -\mathrm{grad}P + \mu_{nf}\nabla^2 V \quad (9)$$

$$\mathrm{div}(\rho_{nf}V.C_{P,nf}.T) = \mathrm{div}(K_{eff}\mathrm{grad}T) \quad (10)$$

where, in the above equations:

$$\rho_{nf} = \frac{M_{nf}}{V_{nf}} = \frac{M_b + M_P}{\bar{V}_b + \bar{V}_P} = \frac{\rho_b\bar{V}_b + \rho_P\bar{V}_P}{\bar{V}_b + \bar{V}_P} = (1-\alpha)\rho_b + \alpha\rho_P \quad (11)$$

$$(\rho C_P)_{nf} = (1-\alpha)(\rho C_P)_b + \alpha(\rho C_P)_P \quad (12)$$

$$\mu_{nf} = (1 + 2.5\alpha)\mu_b \quad (13)$$

where, P indices stand for the particles characters; b stand for the base fluid characters and nf stands for nanofluid characters. C_p is the specific heat. α is volume percentage of nano particles in base fluid.

In this study, ratio of conduction coefficient of nanofluid to base fluid is calculated from experimental results of Hamilton and Crosser (1962).

$$K_{eff} = \frac{K_p + (n+1)K_b + (n-1)(K_b - K_p)\alpha}{K_p + (n-1)K_b - (K_b - K_p)\alpha}K_b \quad (14)$$

where, n ($n = 3/\psi$) is geometry coefficient.

ψ is the ratio of area between a sphere with the same volume of particle and particle real body area. It is called spherical coefficient.

Boundary conditions and geometry: To solve the Eq. 8 through 10, boundary conditions are:

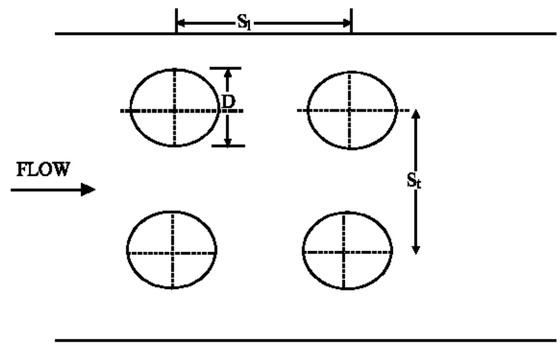

Fig. 1: Heat exchanger with rectangular arrangement of tubes schematic

Constant velocity V_0 = 1 (m sec^{-1}) and constant temperature T_0 = 273 (k) is applied to inlet.

Velocity of nanofluid on the outer wall is assumed to be zero. The heat flux through the surface of each tube is assumed to be q = 10241 (w m^{-2}). As shown in the Fig. 1 S_r = 40 cm, S_L = 40 cm and D = 20 cm. Four tubes with 20 cm diameters are positioned with the central distance of 40 cm from each other. Heat flux is q = 10241 (w m^{-2}) from the tube walls and is assumed to be constant. Nanofluid (Ethylene Glycol+Alumina) flow vertical to tubes axes. The tubes are arranged rectangular. It is assumed that the alumina particles with the diameter of 1 have a stable suspension in ethylene glycol base fluid.

Numerical methodology: To solve the Eq. 8-10 with the illustrated boundary conditions; finite volume method, non organized triangle mesh and simple algorithm is used.

Validation: It is needed to compare the results of calculations with the experimental or numerical study by the other researcher to ensure about the methodology and calculations. The results are predicated by simulation of the nanofluid (EG+Al_2O_3) with zero nano particle volume ratio is studied and compared with the (Zukauskas, 1972) experimental results. The predication must be as above because there is no other experimental or theoretical results about nanofluid flow around the tubes. Zukauskas (1987) found the relation between heat transfer ratio and Re_D, Pr, S_T/D.

$$\overline{Nu}_D = Pr^{0.36}(Pr/Pr_w)^n f(Re_D) \quad (15)$$

where, for gases n = 0 and for fluids n = 0.25.

In Eq. 15 Pr_w is Prandtl number in the wall temperature T_w. The other characters are calculated with reference to fluid temperature. The function $f(Re_D)$ is defined by Reynolds number and tubes arrangement.

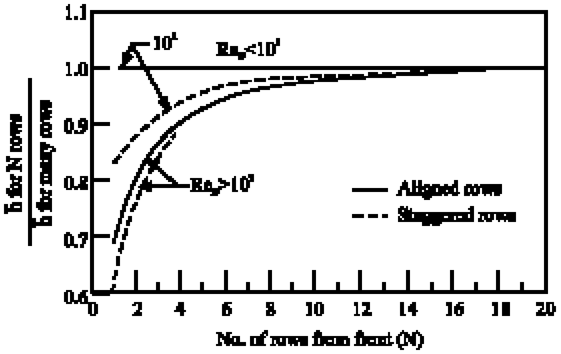

Fig. 2: Correction factor diagram of heat transfer coefficient for the different columns

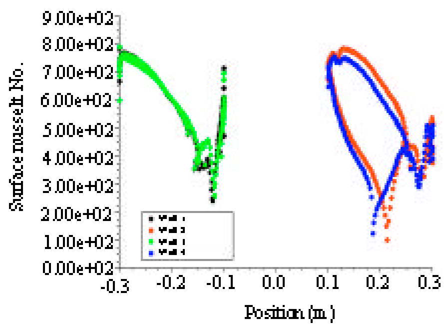

Fig. 3: Validation results diagram

$$\left.\begin{array}{l}10^{3} < Re_D < 2\times10^{5}\\ \frac{S_T}{S_L} \geq 0.7\end{array}\right\} \Rightarrow f(Re_D) = 0.27Re_D^{0.63} \qquad (16)$$

With inserting the value of S_T, S_L and D in Eq. 15 and 16:

$$\overline{Nu_D} = \frac{\bar{h}D}{K} = 1054$$

By using the correction factor from Fig. 2:

For the first row $\overline{Nu_D} = 739$ and for the second row $\overline{Nu_D} = 844$.

The simulated diagram is shown in Fig. 3. Note to the inlet velocity in relation 16 it is found that the maximum values in the diagram are consonant to the results from (Zukauskas, 1987) relations. By using the mean velocity, which is assumed to be half of the inlet velocity, the values which are calculated from Eq. 15 and 16 decreases.

RESULTS AND DISCUSSION

Velocity profile comparison: With reference to $(EG+Al_2O_3)$ velocity profile in Fig. 4, for tubes 1 and 3 the velocity becomes maximum on β = 80° and the flow separation happens on β = 100°. Therefore, by increasing in β the backward flow happens. On the other tubes column (walls 2 and 4) flow separation degree increases and reach to β = 120°. The velocity profiles shows that nanofluid has more velocity in the area between tube rows therefore, the convection heat transfer is more than the other areas.

As it is seen, nanofluids flow becomes turbulent after the separation and the backward flow has high velocity. Stagnation point is on β = 0° for the walls 1 and 3. For walls 2 and 4 the stagnation points are on β = 80°.

In Fig. 5, the velocity profile of the pure Ethylene Glycol fluid on the rectangular arrangement of tubes is shown. Note to this profile the separation point happens on β = 90° for all the walls. According to the diagram stagnation points on the walls 1 and 3 are on β = 0° and for the walls 2 and 4 are on β = 60°.

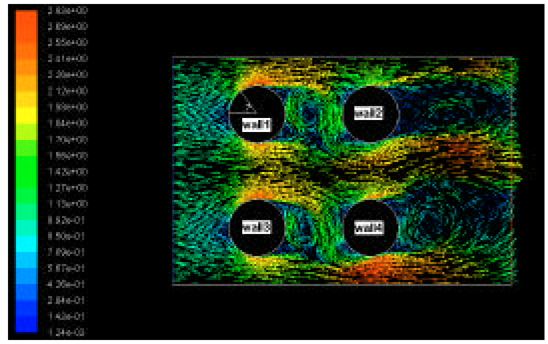

Fig. 4: Velocity counters of nanofluid in heat exchanger with rectangular arrangement

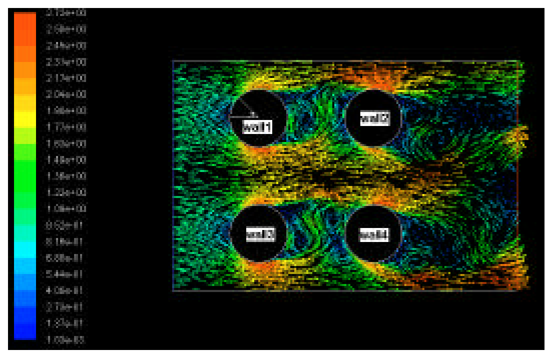

Fig. 5: Velocity counters of pure fluid in heat exchanger with rectangular arrangement

Heat transfer coefficient comparison between $(EG+Al_2O_3)$ nano fluid and (EG) pure fluid: In Fig. 6 the diagram shows that the heat transfer coefficients of walls 1 and 3 are coincided on each other for the pure fluid (EG). This

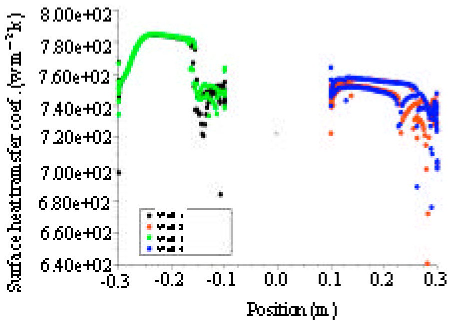

Fig. 6: Heat transfer coefficient of pure fluid in heat exchanger with rectangular arrangement

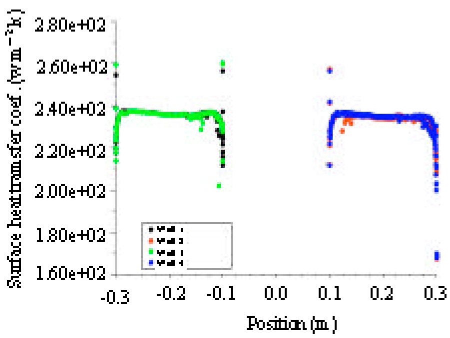

Fig. 7: Heat transfer coefficient of nanofluid in heat exchanger with rectangular arrangement

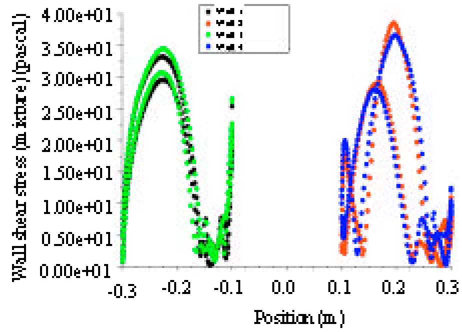

Fig. 8: Shear stress on the walls of nanofluid in heat exchanger with rectangular arrangement

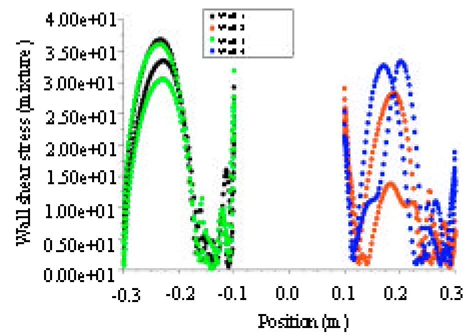

Fig. 9: Shear stress on the walls of pure fluid in heat exchanger with rectangular arrangement

matter also happens for walls 2 and 4. Heat transfer coefficient on first column of tubes (walls 1 and 3) is the same as the second column (walls 2 and 4). Therefore, by increasing the number of tubes vertically or horizontally heat flux from each tube has one value.

In Fig. 7 the diagram shows that heat transfer coefficients of walls 1 and 3 are approximately coincided on each other for nanofluid. This matter also happens for walls 2 and 4. But the heat transfer coefficient on the first column of tubes (walls 1 and 3) is different from the second column (walls 2 and 4). The maximum heat transfer coefficient happens on the first column. The value of the heat transfer coefficient on first column is 785 w m^{-2} k. The second column heat transfer coefficient is 760 w m^{-2} k. The heat transfer coefficient decreases in comparison with the first column by increasing number of the columns. This coefficient becomes constant after the flow becomes fully develop.

By using nanofluid (EG+Al_2O_3) heat transfer coefficient increases by the ratio of 3.25 on the first column and 3.16 on the second column.

Shear stress comparison between nanofluid (EG+Al_2O_3) and pure fluid (EG): Theoretical relations and experiments show that shear stress of flow increases in the tube by using nanofluid in comparison with pure fluid. Figure 8 shows the shear stress on the walls when the nanofluid (EG+Al_2O_3) is external flow on the tubes. Shear stress value on the first column of tubes is less than 35 Pa. The shear stress value on the second column is about 40 Pa.

Figure 9 shows the shear stress on the walls when the pure fluid (EG) flow on the tubes. Figure 9 shows that the shear stress on the first column is approximately the same as nanofluid. But on the second column the value of the shear stresses on the walls are 35 Pa which are different from the value on the second column when the nanofluid flows on the walls.

It can be estimated from the above that the shear stress in external flow with nanofluid increases due to the increasing in viscosity of the nanofluid in comparison with the pure fluid. The increasing ratio of shear stress is about 1.19. However, this increasing happens only on the second column and the shear stress does not have great difference between nanofluid and pure fluid on the first column.

The effect of the increasing in shear stress in comparison with the extreme increasing of heat transfer coefficient is negligible.

NOMENCLATURES

C_p	
D	m
f	
G	
g	m sec^{-2}
h	w m^{-2}.k
h_{nf}	w m^{-2}.k
k	w m^{-1}.k
k_{nf}	w m^{-1}.k
k_b	w m^{-1}.k
k_p	w m^{-1}.k
n	
Nu	
Nu_{nf}	
Pe	
Pr	
Pr_{nf}	
Q	j
r	m
Re	
Re_{nf}	
T	k
T_w	k
T_f	k
$\bar{V}_b$	m^3
$\bar{V}_p$	m^3
V_s	m sec^{-1}
Greek symbols	
α	
μ	kg m sec^{-1}
υ	m^2 sec^{-1}
ρ	kg m^{-3}
ψ	

REFERENCES

Eastman, J.A., S.U.S. Choi, S. Li, L.J. Thompson and S. Lee, 1997. Enhanced thermal conductivity through the development of nanofluids. Proc. Mat. Res. Soc. Symp., 457: 3-11.

Hamilton, R.L. and O.K. Crosser, 1962. Thermal conductivity of heterogeneous two component systems. Ind. Eng. Chem. Fundamen., 1: 187-191.

He, Y., Y. Jin, H. Chen, Y. Ding, D. Cang and H. Lu, 2007. Heat transfer and flow behavior of aqueous suspensions of TiO_2 nanoparticles (nanofluids) flowing upward through a vertical pipe. Int. J. Heat Mass Transfer, 50: 2272-2281.

Heris, S.Z., S.G. Etemad and M.N. Esfahany, 2006. Experimental investigation of oxide nanofluids laminar flow convective heat transfer. Int. Commun. Heat Mass Transfer, 33: 529-535.

Hong, K.S., T.K. Hong and H.S. Yang, 2006. Thermal conductivity of Fe nanofluids depending on the cluster size of nanoparticles. Applied Phys. Lett., Vol. 18. 10.1063/1.2166199.

Lee, S. and S.U.S. Choi, 1996. Application of metallic nanoparticle suspensions in advanced cooling systems. Proceedings of International Mechanical Engineering Congress and Exhibition, Nov. 12-22, Atlanta, USA., pp: 9-9.

Lee, J.H., K.S. Hwang, S.P. Jang, B.H. Lee, J.H. Kim, S.U.S. Choi and C.J. Choi, 2007. Effective viscosities and thermal conductivities of aqueous nanofluids containing low volume concentrations of Al_2O_3 nanoparticles. Int. J. Heat Mass Transfer, 51: 2651-2656.

Leong, K.C., C. Yang and S.M.S. Murshed, 2006. A model for the thermal conductivity of nanofluids-the effect of interfacial layer. J. Nanoparticle Res., 8: 245-254.

Murshed, S.M.S., K.C. Leong and C. Yang, 2008. Investigations of thermal conductivity and Viscosity of nanofluids. Int. J. Thermal Sci., 47: 560-568.

Timofeeva, E.V., A.N. Gavrilov, J.M. McCloskey and Y.V. Tolmachev, 2007. Thermal conductivity and particle agglomeration in alumina nanofluids: Experiment and theory. Phys. Rev. E, Vol. 76. 10.1103/PhysRevE.76.061203.

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: 5181-5181.

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.

Zhang, X., H. Gu and M. Fujii, 2007. Effective thermal conductivity and thermal diffusivity. Exp. Thermal Fluid Sci., 31: 593-599.

Zukauskas, A., 1972. Heat Transfer from Tubes in Cross Flow. In: Advances in Heat Transfer, Irvine, J.F. and J.P. Hartnett (Eds.). Academic Press Inc., New York.

Zukauskas, A., 1987. Heat transfer from tubes in crossflow. Adv. Heat Transfer, 18: 87-159.