World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:9, No:2, 2015

Investigation of Enhancement of Heat Transfer in Natural Convection Utilizing of Nanofluids

S. Etaig, R. Hasan, N. Perera

***Abstract*—**This paper analyses the heat transfer performance and fluid flow using different nanofluids in a square enclosure. The energy equation and Navier-Stokes equation are solved numerically using finite volume scheme. The effect of volume fraction concentration on the enhancement of heat transfer has been studied icorporating the Brownian motion; the influence of effective thermal conductivity on the enhancement was also investigated for a range of volume fraction concentration. The velocity profile for different Rayleigh number. Water-Cu, water AL2O3 and water-TiO2 were tested.

***Keywords*—**Computational fluid Dynamics, Natural convection, Nanofluid and Thermal conductivity.

I. INTRODUCTION

THE heat transfer enhancement has been investigated intensively within the two–dimensional enclosure for last few decades; the natural convection heat transfer arises within an enclosure because of the temperature deffirence and buoyancy force, one of the limitation of enhancinhg the heat transfer of the natural convection is the intrinsicaltly low thermal conductivity of the conventional fluids. Enhancing the thermal conductivity of fluids attracted the attentions of researchers since years, an innovative technique represents in dispersing particles with diametrer less than 100x 10^{-9} m, Due to their enhanced thermo physical properties nanofluids are potential heat transfer fluids with heat transfer performance, this method was first introduced by [1] the nanofluids are now promising for their thermophysical properties to enhance the heat transfer. The investigation of the enhancement of heat transfer due to the use of nanofluids has recently attracted the attention of many researchers [2]-[5]. This new innovative class of fluids used in cooling containing ultrafine nanoparticles (1–100 nm diameter) has shown splendid behaviour during tests including increased thermal conductivity and augmented heat transfer coefficient compared to conventional fluids. Numerous studies have shown that nanofluids have superb physical properties [6], among of which is thermal conductivity has been studied most extensively but remains contentious. As a novel strategy to increase heat transfer performance of coolants by the adding nanoparticles of diameters less than 100 nm, nanofluids show superior heat transfer properties and are being considered as promising working fluids to be used for cooling hot systems such as solar collectors, electronic cooling systems, heat pipes, and nuclear reactors [7]. Putra et al [8] observed the natural convective characteristics of water based Al2O3 nanofluids, they reported that adding nanoparticles to base fluid systematically worsen the natural convective heat transfer with the increase in nanoparticle concentration. However, they did not give an acceptable reason for decrease of the natural convective heat transfer in a cavity with the increment of the volume fraction of nanoparticlesAccording to many literature [9]-[17] investigations the thermal conductivity is found to be the most affecting key role in the enhancement utilizing nanofluids, the effective thermal conductivity was modelled using theoretical and experimental models of nanofluids. Saleh et al. [18] investigated the natural convection in trapezoidal filled with nanofluids. Nasrin et al. [19] investigated the heat transfer performance in a vertical closed enclosure and it is found that the nanoparticle volume fraction play a significant role on the temperature field. Ghasemi and Aminossadati [20] carried out a numerical study and investigated on natural convection heat transfer in an inclined enclosure filled with CuO–water nanofluids. Ho et al. [21] investigated experimentallt the natural convection heat transfer of Al2O3-water based nanofluid. Ghasemi et al. [22] studied the effect of the effect of the Brownian motion in a triangular enclosure with natural convection.

The aim of the present work is to investigate the heat transfer enhancement in natural convection using in a square enclososture with different nanoparticles types and incorporating the Brownian motion using a numerical study .

II. PROBLEM DESCRIPTION

A schematic diagram of the physical domain is shown in Fig. 1. The model consists of a square enclosure with length and hight eual to L. the upper and bottom walls are thermally insulated , the left wall is heated at temperature T_H and right wall is maintained at lower temperature T_C. the enclosure is filled with water based nanofluid, the nanoparticle investigated are: Al_2O_3, Cu and TiO_2 with spherical diameter of 25 nm. The water and the nanoparticle are assumed in thermal equilibrium, Newtonian and incompressible, the flow is laminar, and the thermophysical properties are assumed temperature dependent and shown in the following section. The thermal properties of Al2O3, Cu and TiO2 particles are shown in Table I.

III. GOVERNING EQUATIONS

The governing equations are written as;
Continuity equation

S. E., R. H., and N. P. are with the Northumbria Uinversity, Newcastle Upon Tyne, UK; (e-mail: Etiag.mahmud@Northumbria.ac.uk, Reaz.Hasan@Northumbria.ac.uk, Noel.Perera@Northumbria.ac.uk).

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = 0 \tag{1}$$

Momentum equation

$$\frac{\partial(\rho \vec{v})}{\partial t} + \nabla.(\rho \vec{v})\vec{v} = -\nabla p + \nabla.(\tau) + \rho g + F \tag{2}$$

Energy equation

$$\frac{\partial(\rho E)}{\partial t} + \nabla.(\vec{v}(\rho E + P)) = \nabla.\left(k_{eff} \nabla T - \sum h_j J_j + (\tau \vec{v})\right) \tag{3}$$

The thermophysical properties of the nanofluid are expressed as

The nanofluid density

$$\rho_{nf} = (1-\phi)\rho_f + \phi \rho_s \tag{4}$$

The specific heat of the nanofluid

$$C_{pnf} = \frac{(1-\phi)(\rho C_p)_f + \phi(\rho C_p)_s}{\rho_{nf}} \tag{5}$$

The effective thermal conductivity was modelled as corcione [23]

$$\frac{K_{static}}{K_f} = 1 + 4.4 \operatorname{Re}^{0.4} \operatorname{Pr}^{0.66} \left(\frac{T}{T_{fr}}\right)^{10} \left(\frac{K_s}{K_f}\right)^{0.03} \phi^{0.66} \tag{6}$$

where k_f and k_s are the thermal conductivity of base fluid and particle respectively

$$K_{eff} = K_{static} + K_{brownian} \tag{7}$$

$$\operatorname{Re} = \frac{2\rho k_b T}{\pi \mu_f^2 d_p} \tag{8}$$

k_b=1.38066 $\times 10^{-23}$ j/k is the Boltzmann's constant; d_p is the particle diameter; Pr is the Prandtl number for base fluid and expressed as:

$$\operatorname{Pr} = \frac{\mu c_p}{k} \tag{9}$$

T_{fr} is the freezing temperature for the base fluid.

The thermal conductivity with Brownian motion was modelled as proposed by [12]

$$K_{Brownian} = 5 \times 10^4 \beta \phi \rho_f C_{pf} \sqrt{\frac{KT}{\rho_s d_s}} f(T, \phi) \tag{10}$$

K is the Boltzmann constatnt= 1.3807x10^{-23}

$$\beta = 0.0011(100\phi)^{-0.7272} \tag{11}$$

$$f(T, \phi) = (-6.04\phi + 0.4705)T + (1722.3\phi - 134.63) \tag{12}$$

The viscosity was modelled by [24] as:

$$\mu_{nfststic} = \frac{\mu_f}{\left(1 - 34..87\left(\frac{d_s}{d_f}\right)^{-0.3} \phi^{1.03}\right)} \tag{13}$$

$$\mu_{eff} = \mu_{estatic} + \mu_{Brownian} \tag{14}$$

where ds is the nanoparticle diameter, df is the equivalent diameter of the base fluid and given by:

$$d_f = 0.1\left(\frac{6M}{N\pi\rho_{f0}}\right)^{\frac{1}{3}} \tag{15}$$

where M is the molecular mass weight of the base fluid, N is the Avogadro number, ρ_{f0} is the mass density of the base fluid calculated at T=293 K

The Brownian viscosity was modelled as [25]

$$\mu_{Brownian} = 5 \times 10^4 \beta \phi \rho_f \sqrt{\frac{KT}{\rho_s d_s}} f(T, \phi) \tag{16}$$

$$h = \frac{q}{(T_H - T_C)} \tag{17}$$

Q is the heat flux,h s the heat transfer coefficient

$$Nu = \frac{h.L}{k} \tag{18}$$

$$Ra = \frac{g\beta L^3 (T_H - T_C)}{\alpha \nu} \tag{19}$$

TABLE I
NANOPARTICLE THERMAL PROPERTIES

Nanoparticle	Density Kg/m^3	Thermal conductivity w.m^{-1}.k^{-1}	Specific heat J.kg^{-1}.k^{-1}
Al2O3	3950	35	765
Cu	8933	400	385
TiO2	4250	8.93	686.2

IV. NUMERICAL SIMULATION

In the present work the energy and momentum equations are solved numerically using finite volume scheme, the Ansys work bench 14.5 package was sued, a source code written in C language was developed to introduce the thermophysical properties of the nanofluids as a user defined function. The geometry created using ANSYS WORKBENCH design modeler,the mesh created using ANSYS Mesh, a laminar model was used in the natural convection simulation using the for pressure velocity coupling, Courant number=200, under relaxation factor was chosen 1 fo density, body force and energy. Explicit relaxation factor 0.75 for momentum and pressure, body force weighted for pressure spatial discretization, the time step=0.021 s, number of time steps=17000, the transient formulation is first order implicit,the hot and cold temperature for boundary conditons are 274 k and 273 k respectively, a grid independence test was carried out and found that grid 300X300 and grid 350x350 have average Nu 4.89, so grid 300X300 was chosen,the results are shown in Table II.

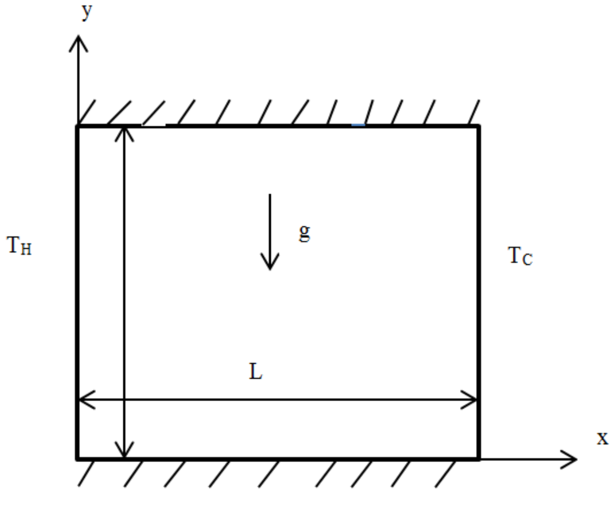

Fig. 1 Schematic diagram of the physical model

TABLE II
GRID INDEPENDENCE TEST

Grid	192X192	250X250	300X300	350X350
Nu avg	4.6533	4.7152	4.8193	4.1897

V. RESULTS AND DISCUSSION

The simulation of the average Nu for different Ran umber are shown in Fig. 1 it shows that the heat transfer rate increases with the increase of Ra which is in agreement with the literature.

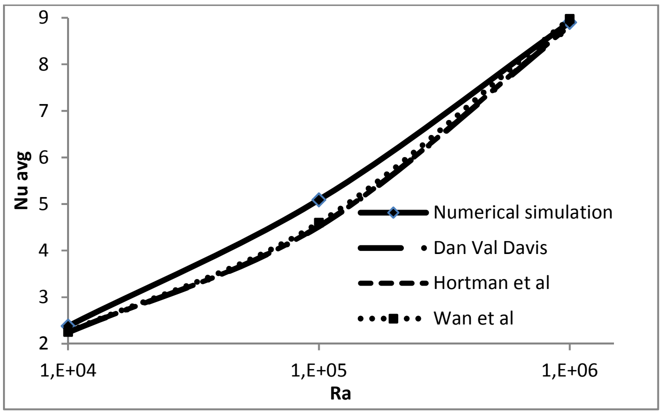

Fig. 2 Variation of Nu against Ra

The simulation also investigated the effect of the volume fraction on the heat transfer rate, as shown in Fig. 3 that the heat transfer ate deteriorated with the increase of the volume fraction which in agreement with the literature that the natural convection is weakened with the increase of the volume fraction, Figs. 4 (a), (b) show the effect of the heat transfer rate on volume fraction with Brownian motion effect for Cu-waer nanofluid and TiO2-water nanofluid, it clearly seen that the incorporating he Brownian motion enhance heat transfer rate for the three different nanoparticles.

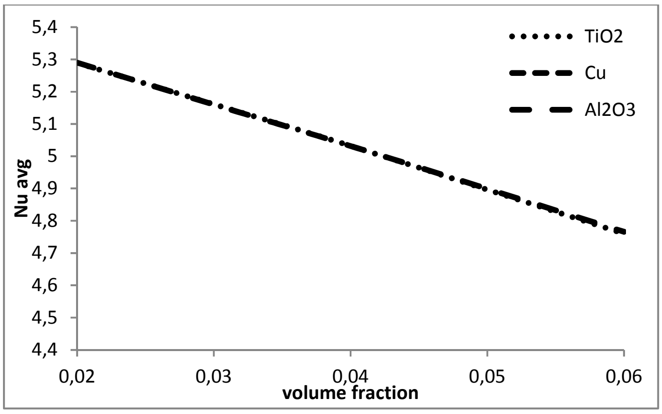

Fig. 3 Variation of Nu with volume fraction

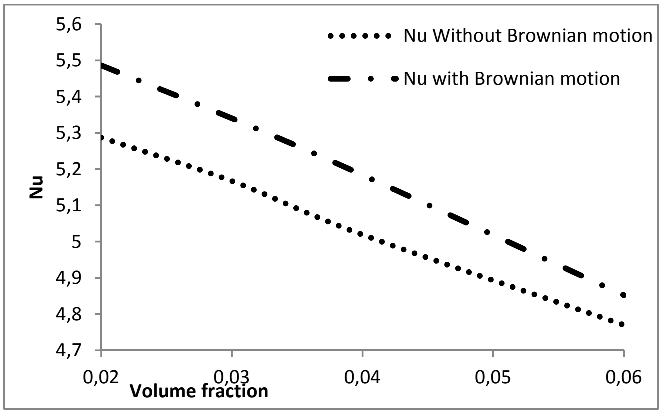

Fig. 4 (a) Cu-water effect of Nu against volume fraction

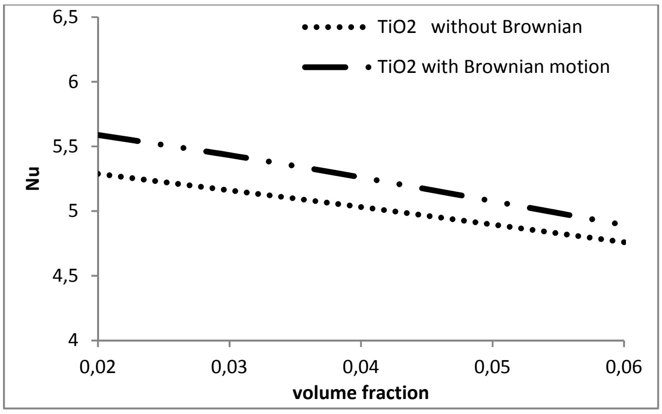

Fig. 4 (b) TiO2-water effect of Nu against volume fraction

The effect of the enhancing of the heat transfer rate with Brownian motion for Al2O3-water nanofluid, Cu-water nanofluid and TiO2-water nanofluid with increasing the Ra number is also shown in Fig. 5 it is also concluded that taking the Brownian motion will increase N with the increase of Ra.

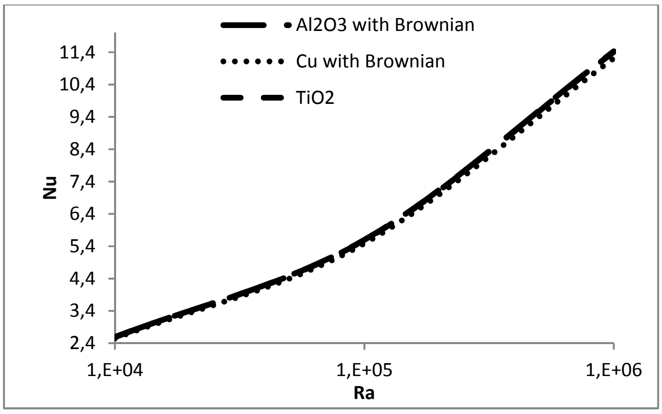

Fig. 5 Effect of Ra number on Nu number for various nanofluids

The simulations also showed the comparison between the effect of Ra on Nu with and without the Brownian motion as illustrated in Figs. 6 (a)-(c) for three different nanofluids, it is shown that the effect of Ra on Nu with and with Brownian motion have similar trends for low Ra and for Ra greater than 10^5 the effect with Brownian motion becomes greater, and this is due to the increase of the buoyant force and Corcione model failed to predict the heat transfer rate in that region.

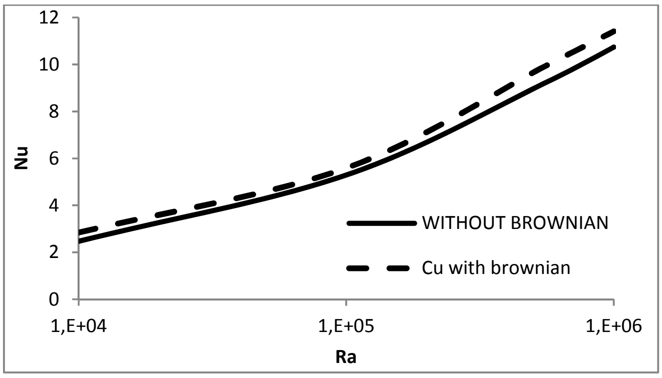

Fig. 6 (a) Effect of Ra against Nu for Cu-water with and without Brownian motion

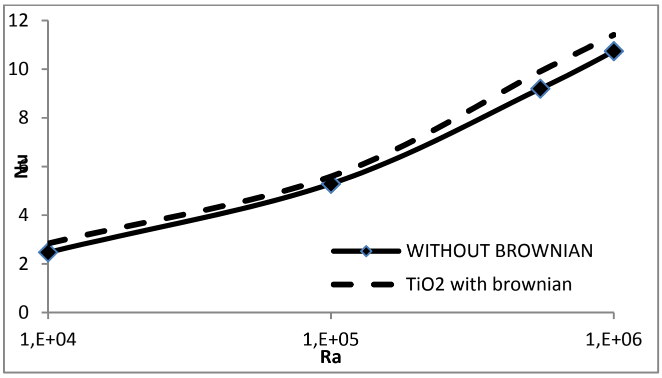

Fig. 6 (b) Effect of Ra against Nu for TiO2-water with and without Brownian motion

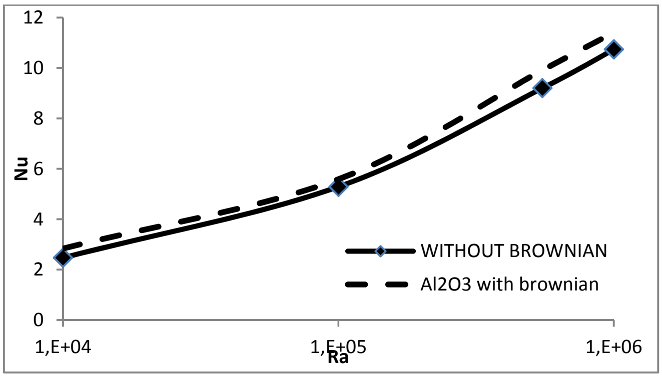

Fig. 6 (c) Effect of Ra against Nu for Al2O3-water with and without Brownian motion

The volume fraction effect on the velocity was also investigated as shown in Fig. 7 it can be read that increasing the volume fraction will decrease the maximum velocity.

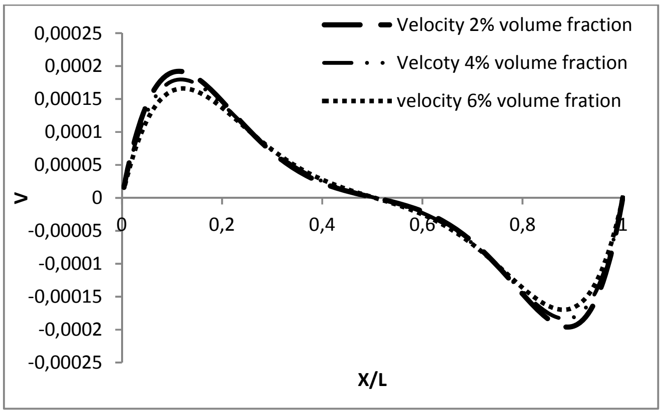

Fig. 7 Effect of the volume fraction on the velocity

The stream contour or various volume fractions are shown in Figs. 8 (a)-(d).

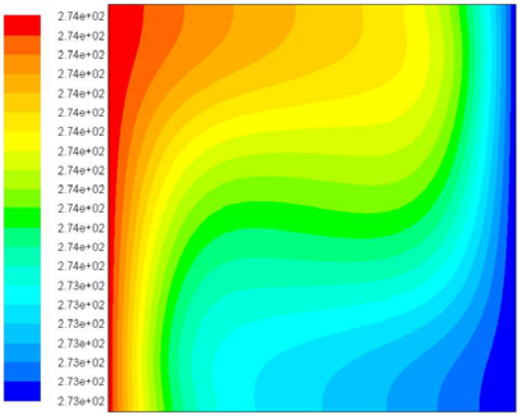

Fig. 8 (a) Temperature contour for 2% volume fraction

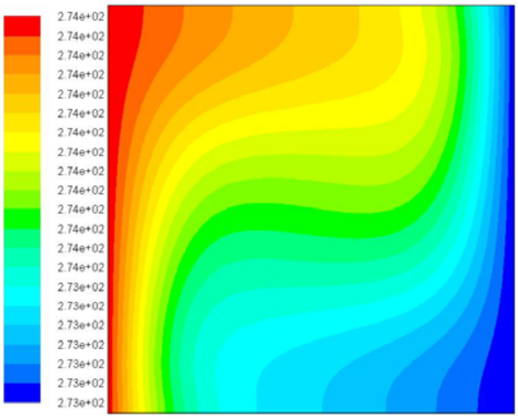

Fig. 8 (b) Temperature contour for 3% volume fraction

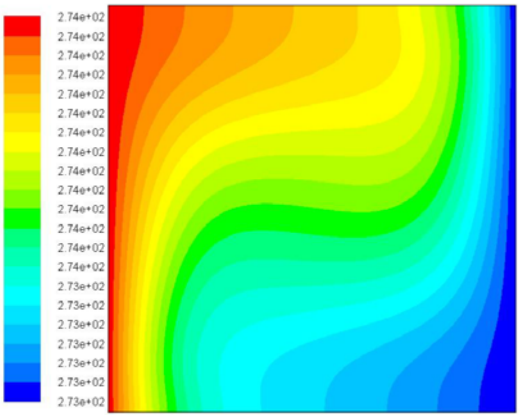

Fig. 8 (c) Temperature contour for 4% volume fraction

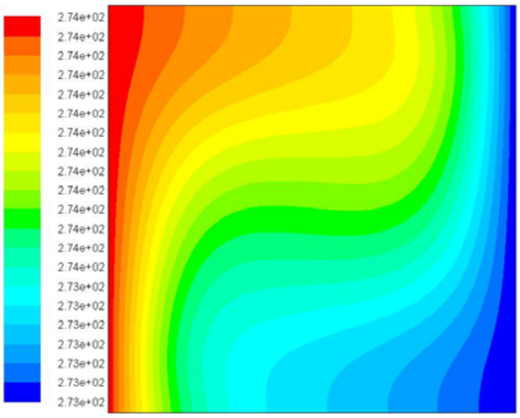

Fig. 8 (d) Temperature contour for 6% volume fraction

VI. CONCLUSION

Numerical simulation of 2D square enclosure was employed to investigate the heat transfer enhancement in natural convection incorporating the effect of the Brownian motion for various nanofluids,the effect of increase of Rayleigh number was found to increase the heat transfer enhancement, while the increase of the volume fraction deteriorated the heat transfer rate, incorporating the Brownian motion was found to have a negligible effect in the low Ra numbers and in Ra>10^5 the Nu was found greater than that without Brownian motion which could be due to the limited applicability of Corcione model.

REFERENCES

[1] Choi, S.U.S. and J.A. Eastman, *Enhancing thermal conductivity of fluids with nanoparticles*. 1995. Medium: ED; Size: 8 p.

[2] Xuan, Y. and Q. Li, *Heat transfer enhancement of nanofluids.* Int J Heat Fluid Flow, 2000. 21: p. 58 - 64.

[3] Eastman, J.A., et al., *Anomalously increased effective thermal conductivities of ethylene glycol-based nanofluids containing copper nanoparticles.* Applied Physics Letters, 2001. 78(6): p. 718-720.

[4] Keblinski, P., et al., *Mechanism of heat flow in suspension of nano-sized particle (nanofluids).* Int J Heat Mass Transf, 2002. 45(4): p. 855 - 863.

[5] Khanafer, K., K. Vafai, and M. Lightstone, *Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids.* Int J Heat Mass Transf, 2003. 46(19): p. 3639 - 3653.

[6] Wen, D. and Y. Ding, *Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions.* International Journal of Heat and Mass Transfer, 2004. 47(24): p. 5181-5188.

[7] Saidur, R., K.Y. Leong, and H.A. Mohammad, *A review on applications and challenges of nanofluids.* Renewable and Sustainable Energy Reviews, 2011. 15(3): p. 1646-1668.

[8] Putra, N., W. Roetzel, and S. Das, *Natural convection of nano-fluids.* Heat and Mass Transfer, 2003. 39(8-9): p. 775-784.

[9] Abu-Nada, E., *Effects of variable viscosity and thermal conductivity of Al2O3-water nanofluid on heat transfer enhancement in natural convection.* Int J Heat Fluid Flow, 2009. 30: p. 679 - 690.

[10] Daungthongsuk, W. and S. Wongwises, *A critical review of convective heat transfer of nanofluids.* Renewable and Sustainable Energy Reviews, 2007. 11(5): p. 797-817.

[11] Gu, B., et al., *Thermal conductivity of nanofluids containing high aspect ratio fillers.* International Journal of Heat and Mass Transfer, 2013. 64(0): p. 108-114.

[12] Koo, J. and C. Kleinstreuer, *A new thermal conductivity model for nanofluids.* Journal of Nanoparticle Research, 2004. 6(6): p. 577-588.

[13] Lee, J.-H., et al., *A Review of Thermal Conductivity Data, Mechanisms and Models for Nanofluids.* International Journal of Micro-Nano Scale Transport, 2010. 1(4): p. 269-322.

[14] Lee, S., et al., *Measuring thermal conductivity of fluids containing oxide nanoparticles.* Journal of Heat Transfer, 1999. 121: p. 280 - 289.

[15] Murshed, S.M.S., K.C. Leong, and C. Yang, *Investigations of thermal conductivity and viscosity of nanofluids.* International Journal of Thermal Sciences, 2008. 47(5): p. 560-568.

[16] Patel, H.E., et al., *Thermal conductivities of naked and monolayer protected metal nanoparticle based nanofluids: Manifestation of anomalous enhancement and chemical effects.* Applied Physics Letters, 2003. 83(14): p. 2931-2933.

[17] Syam Sundar, L., M.K. Singh, and A.C.M. Sousa, *Investigation of thermal conductivity and viscosity of Fe3O4 nanofluid for heat transfer applications.* International Communications in Heat and Mass Transfer, 2013. 44(0): p. 7-14.

[18] Saleh, H., R. Roslan, and I. Hashim, *Natural convection heat transfer in a nanofluid-filled trapezoidal enclosure.* International Journal of Heat and Mass Transfer, 2011. 54(1–3): p. 194-201.

[19] Nasrin, R., M.A. Alim, and A.J. Chamkha, *Buoyancy-driven heat transfer of water–Al2O3 nanofluid in a closed chamber: Effects of solid volume fraction, Prandtl number and aspect ratio.* International Journal of Heat and Mass Transfer, 2012. 55(25–26): p. 7355-7365.

[20] Ghasemi, B. and S.M. Aminossadati, *Natural Convection Heat Transfer in an Inclined Enclosure Filled with a Water-Cuo Nanofluid.* Numerical Heat Transfer, Part A: Applications, 2009. 55(8): p. 807-823.

[21] Ho, C.J., et al., *Natural convection heat transfer of alumina-water nanofluid in vertical square enclosures: An experimental study.* International Journal of Thermal Sciences, 2010. 49(8): p. 1345-1353.

[22] Ghasemi, B. and S.M. Aminossadati, *Brownian motion of nanoparticles in a triangular enclosure with natural convection.* International Journal of Thermal Sciences, 2010. 49(6): p. 931-940.

[23] Corcione, M., E. Habib, and A. Quintino, *A two-phase numerical study of buoyancy-driven convection of alumina–water nanofluids in differentially-heated horizontal annuli.* International Journal of Heat and Mass Transfer, 2013. 65(0): p. 327-338.

[24] Corcione, M., *Rayleigh-Bénard convection heat transfer in nanoparticle suspensions.* International Journal of Heat and Fluid Flow, 2011. 32(1): p. 65-77.

[25] Koo, J. and C. Kleinstreuer, *Laminar nanofluid flow in microheat-sinks.* International Journal of Heat and Mass Transfer, 2005. 48(13): p. 2652-2661.

Open Science Index, Mechanical and Mechatronics Engineering Vol:9, No:2, 2015 publications.waset.org/10001519.pdf