**JOURNAL OF CURRENT RESEARCH IN SCIENCE (ISSN 2322-5009)**
**CODEN (USA): JCRSDJ**
**2013, Vol. 1, No. 6, pp:470-474**
**Available at [www.jcrs010.com](www.jcrs010.com)**

**ORIGINAL ARTICLE**

# ANALYSES OF STREAM LINE AND TEMPERATURE FIELD OF LID DRIVEN CAVITY WITH A HEATED BARRIER

Esmaieli A, Hashemi M, Shameli A, Shokrollahi M
*Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran*

**ABSTRACT:** In this investigation we focused on problem of combined convection fluid flow of $Al_2O_3$- water in lid driven square cavity. The cavity containing a heated obstacle subjected to nanofluid while temperature and nanoparticles concentration dependent thermal conductivity and effective viscosity inside a square cavity. The governing equations have been calculated utilizing the FVM method while the SIMPLER algorithm is used to couple velocity and pressure fields.
**KEYWORDS:** Heat Transfer, Streamline, Convection, Nanofluid.

## INTRODUCTION

Nanofluids are a suspension of nano-sized solid particles in a base fluid ethylene glycol, water or propylene glycol. The first to coin the "nanofluids" for these fluids with higher thermal properties was Choi, (1995). Existence of high thermal conductivity metallic nanoparticles in base fluid increases the thermal conductivity of such mixtures; hence conventional fluids have a rather low thermal conductivity with respect to nanofluids. So, different types of nanofluids are used to enhance the rate of heat transfer in many practical engineering applications (Choi *et al.,* (2004); Godson *et al.,* (2010) and sarkar *et al.,* (2011).
Many researchers have investigated on the thermophysical properties of nanofluids such as effective dynamic viscosity, thermal conductivity, thermal expansion coefficient and etc. (Lee *et al.,* (1999); Xie *et al.,* (2002); Patel *et al.,* (2005) and Chang *et al.,* (2005). Moreover many theoretical, numerical and experimental studies on influence of existence of nanoparticle in convective heat transfer have been reported.
The first study concerning natural convection of a nanofluid confined in a differentially heated enclosure seems to be due to Khanafer *et al.,* (2003). A comparative study of different models based on the thermophysical properties of copper-water nanofluid is developed and investigated. Their numerical results indicate that the suspended nanoparticles substantially increase the heat transfer rate at any given Grashof number. A heat transfer correlation of the average Nusselt number for various Grashof numbers and volume fraction is proposed by the authors. The same problem was considered by Jou and Tzeng, (2006). The Khanafer and coworker's model was used to investigate the convective heat transfer enhancement in rectangular enclosures filled with an $Al_2O_3$-water nanofluid. It was also reported that increasing the buoyancy parameter and volume fraction cause an increase in the average heat transfer coefficient. Natural convection heat transfer of nanofluids in a square cavity, heated isothermally from the vertical sides, has been investigated numerically by Ho *et al.,* (2008) and Santra *et al.,* (2008).
Chen *et al.,* (2007) considered Darcy–Brinkman–Forchheimer extended model to examine free convection inside a porous cavity. This model has been initially introduced by Brinkman, (1947) in order to account for the transition from Darcy flow to highly viscous flow, in the limit of high permeability. Darcy–Forchheimer model is based on the effect of inertia and viscous forces in the porous media.
This model was used by Poulikakos and Bejan, (1985) and Lauriat and Prasad, (1989) in order to investigate the natural convection in a vertical enclosure filled with a porous medium. The extended Darcy–Forchheimer model was also used to describe resistance to flow through the porous baffles by Miranda and Anand,

**Corresponding Author:** Esmaieli A, Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran. **E-mail:** abu.esmaieeli@gmail.com

(2004). Al-Amiri *et al.*, (2008) investigated the wall heat conduction effect on the natural-convection heat transfer within a two-dimensional cavity, which is filled with a fluid-saturated porous medium and their study was based on Forchheimer – Brinkman-extended Darcy model.

Several investigates on mixed convection in single or double lid-driven enclosure flow and heat transfer including different cavity geometries and configurations, different base fluids and boundary condition have been reported. Effect of existence a obstacles within the cavity is one of the interesting investigations for researchers. Recently free convection fluid flow and heat transfer investigated numerically by Mahmoodi and Mazrouei, (2012). Their work was included of Cu-water nanofluid around the adiabatic square bodies at the center of a square cavity. They illustrated that for most Rayleigh numbers the Nusselt number increases with increase in the volume fraction of the nanoparticles. They also showed that at low Rayleigh numbers by increasing the size of the adiabatic square body, the rate of heat transfer decreases and opposite is true at high Rayleigh numbers. Mixed convection of $Al_2O_3$-water nanofluid in cavity with hot moving bottom wall and cold right, left, and top walls is investigated numerically by Mahmoodi, (2011). Also in valuable study, the effect of nanofluid variable properties on mixed convection in a rectangular cavity has been analyzed by Mazrouei Sebdani *et al.*, (2012).

## MODELING AND GOVERNING EQUATIONS

Fig. 1 shows the physical model of the present study schematically. The system is considered to be unsteady, laminar, incompressible mixed convective flow and heat transfer in a two dimensional square cavity of length L filled with nanofluid.

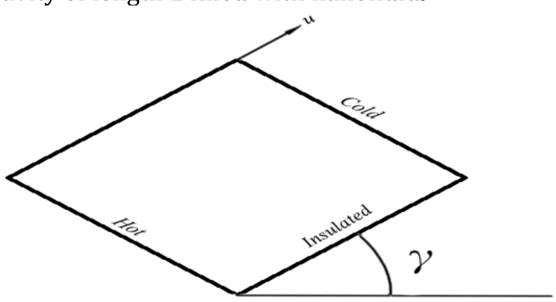


**Figure 1:** diagram of square inclined lid-driven cavity.

The cavity is filled with a suspension of $Al_2O_3$ nanoparticles in water that the nanoparticles and the base fluid are in thermal equilibrium and there is no slip between them.

The governing equations for a steady, two-dimensional laminar and incompressible flow are expressed as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial x}+\upsilon_{nf}\nabla^2 u, \quad (2)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial y}+\upsilon_{nf}\nabla^2 v+\frac{(\rho\beta)_{nf}}{\rho_{nf}}g\Delta T, \quad (3)$$

and

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\nabla^2 T. \quad (4)$$

The dimensionless parameters may be presented as

$$X=\frac{x}{L},\; Y=\frac{y}{L},\; V=\frac{v}{u_0},\; U=\frac{u}{u_0}$$
$$\Delta T=T_h-T_c,\; \theta=\frac{T-T_c}{\Delta T},\; P=\frac{p}{\rho_{nf}u_0^2}. \quad (5)$$

Hence,

$$\mathrm{Re}=\frac{\rho_f u_0 L}{\mu_f},\; Ri=\frac{Ra}{\mathrm{Pr.Re}^2},\; Ra=\frac{g\beta_f\Delta T L^3}{\upsilon_f\alpha_f},\; \mathrm{Pr}=\frac{\upsilon_f}{\alpha_f}. \quad (6)$$

The dimensionless form of the above governing equations (1) to (4) become

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \quad (7)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\upsilon_{nf}}{\upsilon_f}\frac{1}{\mathrm{Re}}.\nabla^2 U \quad (8)$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{\upsilon_{nf}}{\upsilon_f}\frac{1}{\mathrm{Re}}.\nabla^2 V+\frac{Ri}{\mathrm{Pr}}.\frac{\beta_{nf}}{\beta_f}\Delta\theta \quad (9)$$

and

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\alpha_{nf}}{\alpha_f}\nabla^2\theta \quad (10)$$

### *2.1. Thermal Diffusivity And Effective Density*

Thermal diffusivity and effective density of the nanofluid are

$$\alpha_{nf}=\frac{k_{nf}}{(\rho c_p)_{nf}} \quad (11)$$

$$\rho_{nf} = \varphi\rho_s + (1-\varphi)\rho_f \qquad (12)$$

*2.2. Heat Capacity And Thermal Expansion Coefficient*

Heat capacity and thermal expansion coefficient of the nanofluid are therefore

$$(\rho c_p)_{nf} = \varphi(\rho c_p)_s + (1-\varphi)(\rho c_p)_f \qquad (13)$$

$$(\rho\beta)_{nf} = \varphi(\rho\beta)_s + (1-\varphi)(\rho\beta)_f$$

*2.3. Viscosity*

The effective viscosity of nanofluid was calculated by:

$$\mu_{eff} = \mu_f(1+2.5\varphi)\left[1+\eta\left(\frac{d_p}{L}\right)^{-2\varepsilon}\varphi^{2/3}(\varepsilon+1)\right] \qquad (14)$$

This well-validated model is presented by Jang and coworkers. For a fluid containing a dilute suspension of small rigid spherical particles and it accounts for the slip mechanism in nanofluids. The empirical constant ε and η are -0.25 and 280 for $Al_2O_3$; respectively. It is worth mentioning that the viscosity of the base fluid (water) is considered to vary with temperature and the flowing equation is used to evaluate the viscosity of water,

$$\mu_{H_2O} = (1.2723\times T_{rc}^{5} - 8.736\times T_{rc}^{4} + 33.708\times T_{rc}^{3} - 246.6\times T_{rc}^{2} + 518.78\times T_{rc} + 1153.9)\times 10^{6} \qquad (15)$$

Where, $Trc = Log(T-273)$.

*2.4. Dimensionless Stagnant Thermal Conductivity*

The effective thermal conductivity of the nanoparticles in the liquid as stationary is calculated by the Hamilton and crosser (H-C model)(1962), which is:

$$\frac{k_{stationary}}{k_f} = \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + \varphi(k_f - k_s)} \qquad (16)$$

*2.5. Total Dimensionless Thermal Conductivity Of Nanofluids*

$$\frac{k_{nf}}{k_f} = \frac{k_{stationary}}{k_f} + \frac{k_c}{k_f} = \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + \varphi(k_f - k_s)} + c\frac{Nu_p d_f (2-D_f)D_f}{\Pr(1-D_f)^2}\frac{\left[\left(\frac{d_{max}}{d_{min}}\right)^{1-Df} - 1\right]^2}{\left(\frac{d\max}{d\min}\right)^{2-Df} - 1}\frac{1}{d_p}$$

This model was proposed by Xu and coworkers in which it has been chosen in this study to describe the thermal conductivity of nanofluids. c is an empirical constant(e.g. c = 85 for the deionized water and c = 280 for ethylene glycol) but independent of the type of nanoparticles. Nup is the Nusselt number for liquid flowing around a spherical particle and equal to two for a single particle in this work. The fluid molecular diameter df =4.5*10[-10](m) for water in present study. The fractal dimension $D_f$ is determined by:

$$Df = 2 - \frac{\ln\varphi}{\ln\left(\frac{d_{p,\min}}{d_{p,\max}}\right)}$$

Where, $d_{p,max}$ and $d_{p,min}$ are the maximum and minimum diameters of nanoparticles, respectively. Ratio of minimum to maximum nanoparticles $d_{p,min}/d_{p,max}$ is R.

$$d_{p,\max} = d_p . \frac{D_f - 1}{D_f}\left(\frac{d_{p,\min}}{d_{p,\max}}\right)^{-1}$$

$$d_{p,\min} = d_p . \frac{D_f - 1}{D_f}$$

## NUMERICAL APPROACH

Continuity, momentum and energy equations are discretized using the finite volume method and with staggered grid system. The convection terms is approximated by a blend of central difference scheme and upwind scheme (hybrid-scheme) which is conducive to a stable solution. Besides, a second-order central differencing scheme is served to the diffusion terms. The algebraic system arising from numerical discretization is computed using Tridiagonal Matrix Algorithm (TDMA) To verify grid independence, numerical procedure was examined for nine different mesh sizes, namely; 21 × 21, 31 × 31, 41 × 41, 51 × 51, 61 × 61, 71 × 71, 81 × 81, 91 × 91 and 101 × 101. Average Nu at Re=10, and φ=0.06 is attained for each grid size as shown in Fig 2.

As can be observed, 91 × 91 uniform grid size yields the required accuracy and was hence applied for all simulation exercises in this work as presented in the following section.

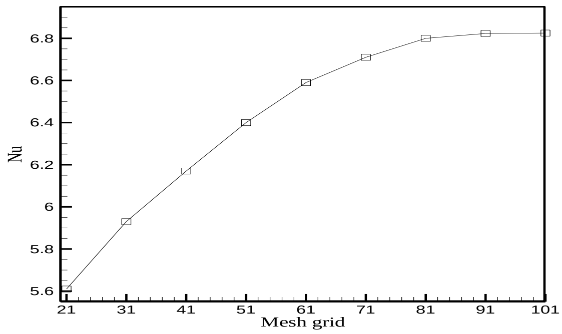


**Figure 2:** grid study

## RESULTS AND DISCUSSION

Fig. 3 exhibits streamlines and isotherms in different angles of cavity positioned in Re=100, φ=0.05 and h=0.1L. Flow pattern in horizontal position of cavity shows formation of a primary clockwise cell which has almost occupied all the cavity space. As the cavity inclination is upraised to 30º, buoyancy and shear forces lose their perfect co-directionality and a change thus happens in flow pattern in the cavity. In such state, two small vortexes are composed resulted from the force of upper section movement lid and near the lid itself while the intensity of the main cell is a little reduced.

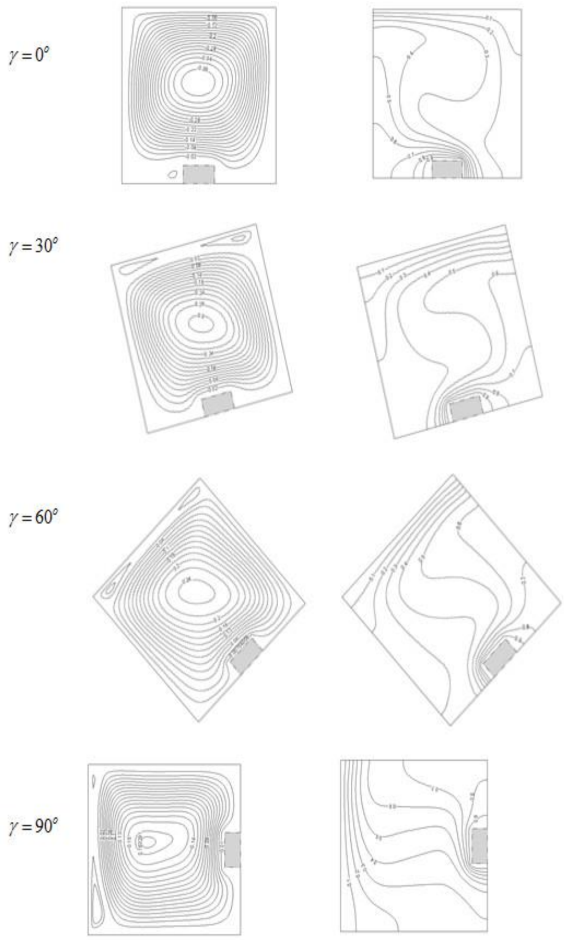


**Figure 3:** streamlines and isotherms in different angles of cavity positioned in Re=100, T=300.

As a result of the dominance of natural convection over forced convection in the Richardson range studied in this figure, the central cell resulted by buoyancy force is in all positions stronger than upper vortexes caused by shear force from upper lid. Isotherm lines show more intensity at areas close to hot walls.

## REFERENCES

Al-Amiri A, Khanafer K, Pop I. Steady-state conjugate natural convection in a fluid-saturated porous cavity. Int J Heat Mass Transfer 2008;51:4260– 4275.

Brinkman HC. On the permeability of media consisting of closely packed porous particles. Appl Sci Res 1947;1:81–86.

Chang H, Jwo CS, Lo CH, Tsung TT, Kao MJ, Lin HM. Rheology of CuO nanoparticle suspension prepared by ASNSS. Reviews on Advanced Materials Science 2005;10:128–132.

Chen XB, Yu P, Winoto SH, Low HT. Free convection in a porous wavy cavity based on the Darcy–Brinkman–Forchheimer extended model. Numer Heat Transfer A 2007;52:377–397.

Choi SUS, Zhang ZG, Keblinski P. Nanofluids, Encyclopedia of Nanoscience and Nanotechnology 2004;6:757–773.

Choi SUS. Enhancing thermal conductivity of fluids with nanoparticles, Developments and applications of non-Newtonian flow. In: Siginer DA, Wang HP (Eds.), FEDvol. 231/MDvol. 66. The American Society of Mechanical Engineers 1995;pp:99105.

Godson L, Raja B, Lal DM, Wongwises S. Enhancement of heat transfer using nanofluids-An overview. Renew Sust Energy Rev 2010;14:629–641.

Ho CJ, Chen MW, Li ZW. Numerical simulation of natural convection of nanofluid in a square enclosure: effects due to uncertainties of viscosity and thermal conductivity. Int J Heat Mass Transfer 2008;51:4506-4516.

Jou RY, Tzeng SC. Numerical research of nature convective heat transfer enhancement filled with nanofluids in rectangular enclosures. Int Comm Heat Mass Transfer 2006;33:727-736.

Khanafer K, Vafai K, Lightstone M. Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids. Int J Heat Mass Transfer 2003;46:3639-3653.

Lauriat G, Prasad V. Non-Darcian effects on natural-convection in a vertical porous enclosure. Int J Heat Mass Transfer 1989;32:2135–2148.

Lee S, Choi SUS, Li S, Eastman JA. Measuring Thermal Conductivity of Fluids Containing Oxide Nanoparticles. International Journal of Heat and Mass Transfer 1999;121:280-289.

Mahmoodi M, Mazrouei Sebdani S. Natural Convection in a Square Cavity Containing a Nanofluid and an Adiabatic Square Block at the Center. Superlattice Microst 2012;52:261-275.

Mahmoodi M. Mixed convection inside nanofluid filled rectangular enclosures with moving bottom wall. Thermal Science 2011;15(3):889-903.

Mazrouei Sebdani S, Mahmoodi M, Hashemi, SM. Effect of nanofluid variable properties on mixed convection in a square cavity. Int J Thermal Sci 2012;52:112–126.

Miranda BMD, Anand NK. Convective heat transfer in a channel with porous baffles. Numer Heat Transfer A 2004;46:425–452.

Patel HE, Pradeep T, Sundararajan T, Dasgupta A, Dasgupta N, Das SK. A micro convection model for thermal conductivity of nanofluid. Pramana-Journal of Physics 2005;65:863–869.

Poulikakos D, Bejan A. The departure from Darcy flow in natural-convection in a vertical porous layer. Phys Fluids 1985;28:3477–3484.

Santra AK, Sen S, Chakraborty N. Study of heat transfer augmentation in a differentially heated square cavity cavity using copper-water nanofluid. Int J Therm Sci 2008;47:1113-1122.

Sarkar J. A critical review on convective heat transfer correlations of nanofluids. Renew Sust Energy Rev 2011;15:3271–3277.

Xie HQ, Wang JC, Xi TG, Li Y, Ai F. Dependence of the thermal conductivity of nanoparticle–fluid mixture on the base fluid. J Mat Sci Let 2002;21:1469–1471.