JOURNAL OF CURRENT RESEARCH IN SCIENCE (ISSN 2322-5009)
CODEN (USA): JCRSDJ
2013, Vol. 1, No. 6, pp:465-469
Available at www.jcrs010.com

ORIGINAL ARTICLE

NUMERICAL STUDY OF THE EFFECT OF CONCENTRATION ON FLUID FLOW AND ISOTHERM LINES IN AN ENCLOSURE FILLED WITH TWO-PHASE LIQUID

Hashemi M, Amiri R, Shameli A, Shamaghdari R
Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran

ABSTRACT: This study focus on mixed convection heat transfer inside enclosure subjected to a nanofluid and having rectangular obstacle. Effects of important variable such as solid volume fraction on flow of inside of cavity and Thermal performance also Interactions among buoyancy and shear forces is investigated in this study.
KEYWORDS: Heat Transfer, Rectangular Obstacle, Enclosure, Buoyancy Force.

INTRODUCTION

Mixed convection heat transfer is one of the most important matters in many industrial applications such as electronic device cooling, heat exchangers, nuclear reactors and so on. Hence many researchers have investigated the properties ofmixed convection in a wide range of situations (Kaluri and Basak, 2010; Khadiri *et al.*, 2010; Basak *et al.*, 2009; Koca, 2008; Senthil *et al.*, 2008; Vishnuvardhanarao and Das, 2008). Aydin, (1999) performed a numerical simulation to investigate laminar combined convection in a shear and buoyancy-driven cavity. He considered two set of thermal boundary condition in order to study the interaction of the forced convection induced by the moving wall with natural convection induced by the buoyancy force, in two situations of the aiding and opposing buoyancy mechanisms. Leong *et al.*, (2005) analyzed mixed convection in an open cavity in a horizontal channel with various aspect ratios of the cavity. They found that the Reynolds number and Grashof number have significant role in control of the flow field in the cavity.

The thermal performance of lid-driven enclosures has been a subject of interest for many years due to their ever increasing applications in lubrication technologies, electronic cooling, food processing and nuclear reactors. Studies on lid-driven enclosures with horizontal, vertical and oscillating sliding walls have mainly been concerned with fluids having a relatively low thermal performance. This, in turn, limits the enhancement of heat transfer in the enclosure. With the growing demand for efficient cooling systems, particularly in the electronics industry, more effective coolants are required to maintain the temperature of electronic components below safe limits.

Ho *et al.*, (2008) studied natural convection of nanofluid in a square enclosure numerically to identify the effects due to uncertainties in effective dynamic viscosity and thermal conductivity. Zhang *et al.*, (2009) studied effects of Brownian and thermophoretic diffusions of nanoparticles on nonequilibrium heat conduction in a nanofluid layer with periodic heat flux. They showed that the Brownian and thermophoretic diffusions only affect the nanoparticle temperature, but their effect on the heat transfer enhancement is negligible. Talebi *et al.*, (2010) investigated the mixed convection flows in a square lid-driven cavity utilizing nanofluid which found that at the fixed Reynolds number, the solid concentration affects the flowpattern and thermal behavior particularly for a higher Rayleigh number. Shahi *et al.*, (2010) studied the mixed convective cooling in a square cavity ventilated and partially heated from the below utilizing nanofluid which results indicated that increase in solid concentration leads to increase in the average Nusselt number at the heat source surface and decrease in the average bulk temperature. Oztop and Dagtekin, (2004) investigated themixed convection in two-sided lid-driven differentially heated square cavity which was performed for three different cases characterized by the direction of movement of vertical walls. Tiwari and Das, (2007) have performed same study as of Oztop and Dagtekin, (2004).

Abu-Nada and Chamkha, (2010) conducted a numerical investigation on mixed convection in an inclined square enclosure filled with Al2O3-water nanofluid. The governing equations

---

Corresponding Author: Hashemi M, Department of Mechanical Engineering, Najafabad Branch, Islamic Azad University, Isfahan, Iran. **E-mail:** M.hashemi13681@gmail.com

written in terms of stream function-vorticity formulation were solved using the finite volume method. They observed significant enhancement in the heat transfer inside the cavity due to the presence of the nanoparticles.

In another study in the same year, Abu-Nada *et al.*, (2010) investigated the effects of variable properties of Al2O3-water and CuO-water nanofluids on the natural convection heat transfer in rectangular enclosures. They observed that at high Rayleigh numbers the viscosity model had a higher impact on the average Nusselt number than the thermal conductivity model. Results of a numerical study on mixed convection in a lid-driven nanofluid filled square cavity with cold side and top wall and a constant heat flux heater on the bottom wall and moving lid were reported by Mansuor *et al.*, (2010). The effects of Reynolds number, type of nanofluids, size and location of the heater and the volume fraction of the nanoparticles were considered in their study. Their results showed that the rate of heat transfer increased with increase in the length of the heater, Reynolds number and the nanoparticles volume fraction. The problem of mixed convection in a vented, partially heated from below square cavity was investigated numerically by Shahi *et al.*, (2010). The cavity had an inlet and outlet in lower corner of left wall and upper corner of right wall, respectively, and a constant heat flux heater on the middle of the bottom wall. They considered effects of Richardson number and nanoparticles concentration and found that increase in solid concentration led to increase in the average Nusselt number of the heat source. Effects of inlet and outlet location on mixed convection of nanofluid in a square cavity were investigated by Mahmoudi *et al.*, (2010). They considered four different combination of inlet and outlet location and found that the flow pattern and temperature distribution inside the cavity were dependent to outlet and inlet location.

Muthtamilselvan *et al.*, (2010) numerically studied the mixed convection in a lid-driven enclosure filled with copper–water nanofluids for various aspect ratios. It was found that both the aspect ratio and solid volume fraction affect the fluid flow and heat transfer in the enclosure. Talebi *et al.*, (2010) numerically have investigated the flow pattern and temperature fields in a lid-driven cavity utilizing copper–water nanofluid. They showed at a given Reynolds number and Rayleigh number, solid concentration has a positive effect on heat transfer enhancement. A numerical investigation of mixed convection flows through a copper–water nanofluid in a square cavity with inlet and outlet ports has been executed recently by Shahi *et al.*, (2010). They investigated the effect of presence of nanoparticles on the hydrodynamic and thermal characteristics of flow at various Richardson numbers. But the effect of the location of inlet and outlet opening has not been considered in their literature. These investigations have already been done for a mixed convection flow in the enclosures filled by pure fluid (Saha *et al.*, 2008; Saha *et al.*, 2006), but the investigation of the nanoparticle presence effect has not been carried out yet.

GOVERNING EQUATIONS AND MODELING

A schematic geometry of the two-sided lid driven enclosure considered in the present study is shown in Fig.1. The top, right and bottom walls of the enclosure are insulated and left wall is kept at low temperature, T_c, The height and the width of the cavity are noted L. The length of the cavity perpendicular to its plane is assumed to be long enough; hence the problem is considered two dimensional.

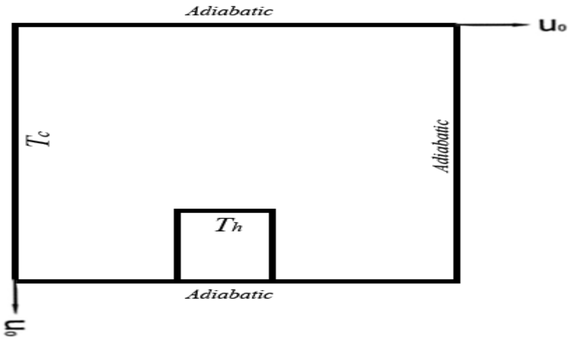

Figure 1: Schematic diagram of two-sided lid-driven cavity.

The nanofluid is assumed Newtonian and the flow is considered laminar and incompressible. It is idealized that the base fluid and nanoparticles are in thermal equilibrium and there is no slip between them. Except for the density the thermophysical properties of the nanofluid are taken to be constant.

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

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

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

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

And

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

The dimensionless parameters may be presented as

$$X = \frac{x}{L},\ Y = \frac{y}{L},\ V = \frac{v}{U_0},\ U = \frac{u}{U_0} \qquad (5)$$

$$\Delta T = T_h - T_c,\ \theta = \frac{T - T_c}{\Delta T},\ P = \frac{p}{\rho_{nf} U_0^2}.$$

Hence,

$$\mathrm{Re} = \frac{\rho_f U_0 L}{\mu_f},\ Ri = \frac{Ra}{\mathrm{Pr}.\mathrm{Re}^2}, \qquad (6)$$

$$Ra = \frac{g \mathrm{B}_f \Delta T L^3}{\upsilon_f \alpha_f},\ \mathrm{Pr} = \frac{\upsilon_f}{\alpha_f}.$$

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

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

$$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \frac{\upsilon_{nf}}{\upsilon_f}\frac{1}{\mathrm{Re}}.\nabla^2 U + \frac{Ri}{\mathrm{Pr}}.\frac{\beta_{nf}}{\beta_f}\Delta\theta Sin(\gamma) \qquad (8)$$

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

And

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

Thermal diffusivity and effective density of the nanofluid are:

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

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

Heat capacity and thermal expansion fficient of the nanofluid are therefore:

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

$$(\rho\beta)_{nf} = \varphi(\rho\beta)_s + (1-\varphi)(\rho\beta)_f \qquad (14)$$

The effective viscosity of nanofluid was proposed by Brinkman (1952). as below: (15)

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}}$$

The effective thermal conductivity of the nanofluid is calculated by the Maxwell model (1904) which is:

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

The Nusselt number can be calculated as:

$$Nu = \frac{hL}{k_f} \qquad (17)$$

Where the heat transfer coefficient h is defined as: (18)

$$\mathrm{h} = \frac{\mathrm{q_w}}{\mathrm{T_h} - \mathrm{T_c}}$$

NUMERICAL SOLUTION

The governing equations have been discretized by a control volume approach and the uniform boundary fitted grid which is finer near the wall is used. The first-order upwind and central differencing scheme were used, respectively, to approximate the convective and diffusion terms in the differential equation. The velocity-pressure coupled equation is solved in the collocated grid by using a modified SIMPLE algorithm with a one correction pressure step. In order to determine a proper grid for the numerical simulation, a square cavity filled with pure water at Ri=100 is chosen. Nine different uniform grids, namely, 21 ×21, 31×31, 41×41, 51×51, 61×61, 71×71, 81×81, 91×91 and 101×101 are employed for the numerical simulation. Average Nusselt number of the hot wall is obtained for each grid size as shown in fig 2. Obtained results show that a uniform 81×81 grid is sufficiently fine for the numerical calculation.

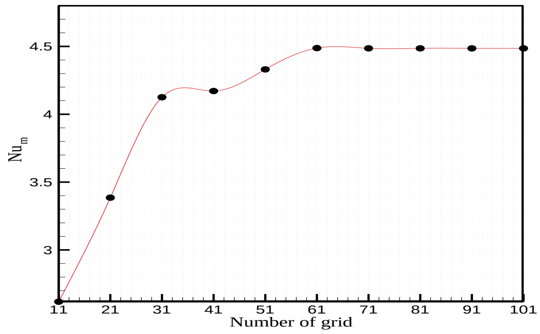

Figure 2: grid independent test

RESULTS AND DISCUSSION

This study focus on mixed convection heat transfer inside enclosure subjected to a nanofluid and having rectangular obstacle. Effects of important variable such as solid volume fraction on flow of inside of cavity and Thermal performance also Interactions among buoyancy and shear forces is investigated in this study. It should be note that rectangular obstacle is placed exactly on center of low bottom wall.

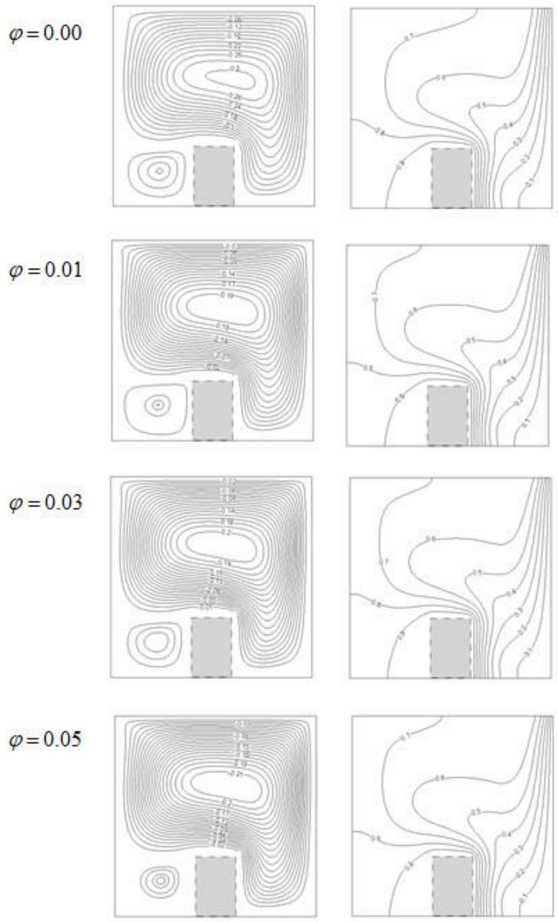

Figure 3: Streamlines and isotherms in different solid volume fraction of nanoparticle at Ri=100.

Stream line and isotherm variations according to solid volume fraction of dispersed nanoparticle are shown in figure 3 for Richardson number of 100. Thermal and stream contours for base fluid and nanoparticle by to solid volume fraction of 0.01, 0.03 and 0.05 is plotted and will be studied. Formed stream in cavity is caused by two shear forces created by top lid wall and buoyancy force created by temperature difference in cavity. Flow pattern in all studied situations shows creation of a strong big clockwise cell by elliptical core which occupies approximately most areas. A small cell also is placed in distance between left wall and obstacle. By adding nanoparticles to base fluid and increasing solid volume fraction, primary cell will be strengthen and stream line will become more closely. By increasing velocity and strength of primary cell which cause more flow of steam on hot obstacle and also by increasing thermal conductivity, it is expected that thermal conductivity to increase by increasing of solid volume fraction. Temperature field is also showing isothermal contour accumulation nearby obstacle walls. By increasing solid volume fraction, little of isothermal contour accumulation which shows severe temperature gradient in these areas, is decreased.

REFERENCES

Abu-Nada E, Chamkha AJ. Mixed convection flow in a lid driven square enclosure filled with a nanofluid. Eur J Mechanic B/Fluids 2010;29:472-482.

Abu-Nada E, Masoud Z, Oztop HF, Compo A. Effect of nanofluid variable properties on natural convection in enclosures. Int J Thermal Sci 2010;49:479-491.

Aydin O. Aiding and opposing mechanisms of mixed convection in a shear- and buoyancy-driven cavity. International Communications Heat Mass Transfer 1999;26:1019–1028.

Basak T, Roy S, Sharma PK, Pop I. Analysis of mixed convection flows within a square cavity with uniform and non-uniform heating of bottom wall. International Journal of Thermal Sciences 2009;48:891–912.

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. International Journal of Heat and Mass Transfer 2008;51:4506–4516.

Kaluri RS, Basak T. Entropy generation minimization versus thermal mixing due to natural convection in differentially and discreetly heated square cavities. Numerical Heat transfer A Applications 2010;58:475–504.

Khadiri A, Amahmid A, Hasnaoui M, Rtibi A. Soret effect on double-diffusive convection in a square porous cavity heated and salted from below. Numerical Heat Transfer A Applications 2010;57:848–868.

Koca A. Numerical analysis of conjugate heat transfer in a partially open square cavity with a vertical heat source. International Communications Heat Mass transfer 2008;35:1385–1395.

Leong JC, Brown NM, Lai FC. Mixed convection from an open cavity in a horizontal channel. International Communications Heat Mass Transfer 2005;32:583–592.

Mahmoudi AH, Shahi M, Talebi F. Effect of inlet and outlet location on the mixed convective cooling inside the ventilated cavity subjected to an external nanofluid. Int Commun Heat Mass Transfer 2010;37:1158-1173.

Mansour MA, Mohamed RA, Abd-Elaziz MM, Ahmed SE. Numerical simulation of mixed convection flows in a square lid-driven cavity partially heated from below using nanofluid. Int Commun Heat Mass Transfer 2010;37:1504-1512.

Muthtamilselvan M, Kandaswamy P, Lee J. Heat transfer enhancement of copper–water nanofluids in a lid-driven enclosure. Commun Nonlinear Sci Numer Simul 2010;15:1501–1510.

Oztop HF, Dagtekin I. Mixed convection in two-sided lid-driven differentially heated square cavity. International Journal of Heat and Mass Transfer 2004;47:1761–1769.

Saha S, Mamun AH, Hossain MZ, Islam AK. Mixed convection in an enclosure with different inlet and exit configurations. J Appl Fluid Mech 2008;1(1):78–93.

Saha S, Saha G, Ali M, Islam Q. Combined free and forced convection inside a two-dimensional multiple ventilated rectangular enclosure. ARPN Journal of Engineering and Appl Sci 2006;2:23–35.

Senthil Kumar D, Murugesan K, Thomas HR. Numerical simulation of double diffusive mixed convection in a lid-driven square cavity using velocity–vorticity formulation. Numerical Heat Transfer A Applications 2008;54:837–865.

Shahi M, Mahmoudi AH, Talebi F. Numerical study of mixed convective cooling in a square cavity ventilated and partially heated from the below utilizing nanofluid. Int Commun Heat Mass Transfer 2010;37:201–213.

Talebi F, Mahmoudi AH, Shahi M. Numerical study of mixed convection flows in a square lid-driven cavity utilizing nanofluid. Int Commun Heat Mass Transfer 2010;37:79–90. 583

Tiwari RK, Kumar M. heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids. International Journal of Heat and Mass Transfer 2007;50:2002–2018.

Vishnuvardhanarao E, Das MK. Laminar mixed convection in a parallel twosided lid-driven differentially heated square cavity filled with a fluid-saturated porous medium. Numerical Heat Transfer A Applications 2008:53:88–110.

Zhang Y, Li L, Ma HB, Yang M. Effects of Brownian and thermophoretic diffusions of nanoparticles on nonequilibrium heat conduction in a nanofluidlayer with periodic heat flux. Numerical Heat Transfer Part A: Applications 2009;56:325–341.