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ORIGINAL ARTICLE

ANALYSIS OF MIXED CONVECTION IN LID-DRIVEN ENCLOSURE SUBJECTED TO A NANOFLUID

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ABSTRACT: Investigation of mixed convection heat transfer of Al2O3-water nanofluid with variable properties inside Lid-driven cavity contain a heated square obstacle has been done numerically in this article. The governing equations are solved utilizing the finite volume method and SIMPLER algorithm. Using the developed code, the effects of solid volume fraction and Richardson number on the flow and thermal fields and heat transfer inside the cavity are investigated. In this research, four edged obstacle is placed exactly on center of low bottom wall, while diameter of nanoparticle is 47 nanometers, diameters ratio is 0.007, Grashof number is constant and supposed to be equal by 104.The results indicate that the average Nusselt number for all range of solid volume fraction increases with decrease in the Richardson number.
KEYWORDS: Mixed convection, Cavity, Nanofluid, Solid Concentration

INTRODUCTION

Accurate prediction of the flow conditions in the driven cavity is of outmost importance for a number of technological applications, such as coating and polishing processes in microelectronics, passive and active flow control using blowing/suction cavities and riblets. A major limitation against increasing the heat transfer in such engineering systems is the inherently low thermal conductivity of the commonly used fluids, such as, air, water, and oil. The idea is to insert within the fluid, metallic particles of nanometer size hope to increase the effective thermal conductivity of the mixture. In fact, the presence of the nanoparticles in the fluids increases appreciably the effective thermal conductivity of the fluid and consequently enhances the heat transfer characteristics (Choi, 1995; Chandrasekar *et al.,* 2010). The term nanofluid was then introduced by Choi, (1995) and is commonly used to characterize this type of colloidal suspension. Because the prospect of nanofluids is very promising, several studies of convective heat transfer in nanofluids have been reported in recent years.

Most of the studies considering the heat transfer performance using nanofluids in natural convection were investigated based on rectangular enclosures in the last decades (Imai *et al.,* 2013; Khanafer *et al.,* 2003; Abu-Nada and Oztop, 2009). However, little work has been carried out for mixed convection of nanofluid in cavity. Tiwari and Das, (2007) studied numerically the mixed convection in two-sided lid-driven diff erentially heated square cavity filled with nanofluid.

They showed that the additions of nanoparticles in a fluid are capable of increasing the heat transfer capacity of base fluid. As solid volume fraction increases, the effect is more pronounced. Sebdani *et al.,* (2012) numerically studied the effects of Al_2O_3/water nanofluid on mixed convection heat transfer in a square cavity with a heat source on the bottom wall and moving downward cold side walls. They prove that when the Reynolds number increases, while the Rayleigh number is keeping constant, the forced convection becomes stronger that causes the heat transfer rate to increases. When the Rayleigh number increases, while the Reynolds number is kept constant, the heat transfer rate increases. The presence of nanoparticles causes increase in heat transfer rate only at Ra = 10^3 while at Ra = 10^4 and 10^5 the rate of heat transfer decreases with increase in nanoparticles volume fraction. The main objective of this study is to investigate the effect of the training walls on the hydrodynamic structure of the flow and heat transfer rate in a rectangular cavity partially heated and filled with a nanofluid (Water/SiO_2).

SCHEMATIC DIAGRAM AND FORMULATION

A schematic diagram of the considered model is shown in Figure (1) with coordinates. It is a two-dimensional square enclosure of length L and filled with Al2O3-water nanofluid.

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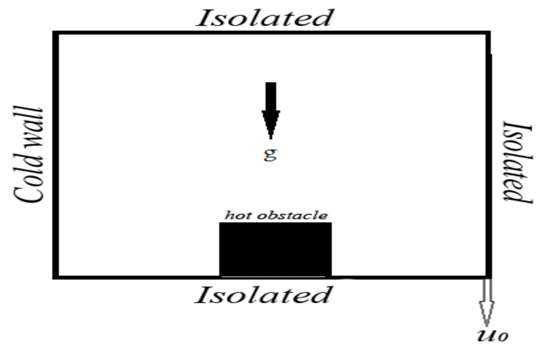

Figure 1: Schematic diagram of current study.

The thermo-physical properties of the cu-water nanofluid, presented in Table 1, are considered to be constant with the exception of its density which varies according to the Boussinesq approximation.

Table 1: Thermophysical properties of water and nanoparticles at T =25°C.

Physical properties	Fluid phase (Water)	Solid (Al_2O_3)
Cp(J/kg k)	4179	765
ρ (kg/m3)	997.1	3970
K (W m-1 K-1)	0.6	25
β×10-5 (1/K)	21.	0.85
µ×10-4(Kg/ms)	8.9	---
dp (nanometer)	---	47

The thermal conductivity and the viscosity of the nanofluid are taken into consideration as variable properties; both of them change with volume fraction and temperature of nanoparticles. Under the above assumptions, the system of governing equations is:

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

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

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

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

$$X=\frac{x}{L},\ Y=\frac{y}{L},\ V=\frac{v}{u_0},\ U=\frac{u}{u_0} \quad (5)$$

$$\Delta T=T_h-T_c,\ \theta=\frac{T-T_c}{\Delta T},\ P=\frac{p}{\rho_{nf}u_0^2}.$$

Hence,

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

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

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

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

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

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

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

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

2.2. Heat capacity and thermal expansion coefficient

Heat capacity and thermal expansion coefficient of the nanofluid are therefore

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

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

2.3. Viscosity

The effective viscosity of nanofluid was calculated by:

$$\mu_{eff}=\mu_f(1+2.5\varphi)\left[1+\eta\left(\frac{d_p}{L}\right)^{-2\varepsilon}\varphi^{2/3}(\varepsilon+1)\right] \quad (15)$$

This well-validated model is presented by Jang *et al.,* (2007) 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 Al2O3, 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,

$$\mu_{H_2o}=(1.2723\times T_{rc}^{\ 5}-8.736\times T_{rc}^{\ 4}+33.708\times T_{rc}^{\ 3}-246.6\times T_{rc}^{\ 2}+518.78\times T_{rc}+1153.9)\times 10^6 \quad (16)$$

Where, T_{rc}= *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 model (Hamilton and Crosser, 1962), which is:

$$\frac{k_{stationary}}{k_f} = \frac{k_s + 2k_f - 2\varphi(k_f - k_s)}{k_s + 2k_f + \varphi(k_f - k_s)} \qquad (17)$$

2.5. Validation

The proposed numerical scheme is validated by comparing the present code results against the numerical simulation published by Talebi *et al.*, (2010) in Figure (2). It is clear that the present code is in excellent agreement with another work reported in literature as shown in Figure (3).

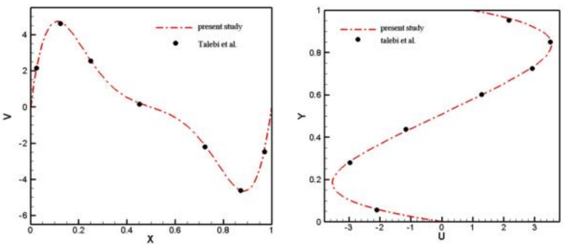

Figure 2: Comparison between current study and Talebi *et al.*, (2010) at Re=1, Ra=1.47e4, $\varphi = 0.03$

RESULT AND DISCUSSION

In this research, four edged obstacle is placed exactly on center of low bottom wall, while diameter of nanoparticle is 47 nanometers, diameters ratio is 0.007, Grashof number is constant and supposed to be equal by 104. Stream line and isotherm variations according to solid volume fraction of dispersed nanoparticle is shown in Figure (3) for Ri=100, T=300 and h=0.3L. 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.

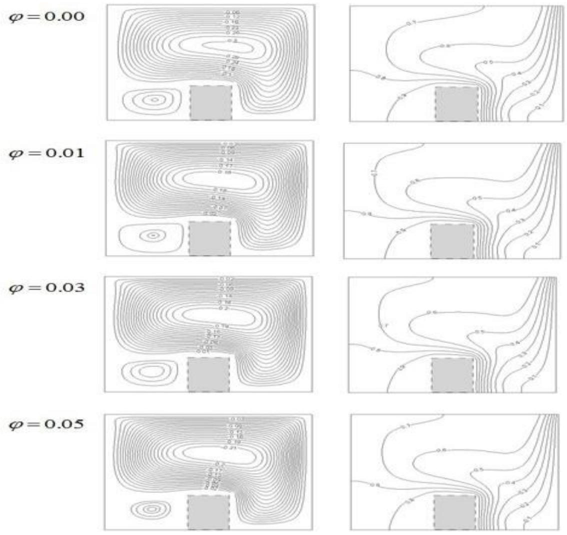

Figure 3: streamlines and temperatureline in different solid volume fraction

Average Nusselt number variation with respect to Richardson number in base fluid and nano-fluid by solid volume fraction inside cavity of T=300 and h=0.3L is shown in Figure (4). As it can be shown, Richardson number increase and buoyancy force domination on shear force, it causes decreasing of heat transfer. Another considerable item is that most increasing of Nusselt number by nano particle addition to water of solid concentration in Ri=100 happens which buoyancy force has domination on all forces. This subject shows that nano-particle use effects are mostly seen by increasing and domination of buoyancy force. In the other hand, as seen, addition of nano- particles to base fluid causes acceptable increase of Nusselt number in all studied Richardson number. In Ri=0.01by addition of nano-particle by solid volume fraction=0.05 and in Ri=100 Nusselt number is increased by 4.5%and 21.4% respectively.

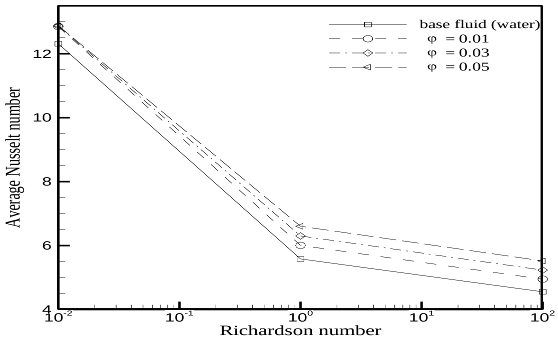

Figure 4: Nusselt number changes with respect to Richardson number

CONCLUSION

In this article, mixed convection flow and heat transfer inside an inclined cavity filled with nanofluid with two hot square bodies was numerically simulated and the results were investigated. The following items are introduced as results of this study:

1. Adding nanoparticles to the base fluid increases the Nusselt number and heat transfer in all ranges of the parameters in this study.
2. Increasing volume fraction at different values of Richardson number causes the heat transfer to increase between two bodies and the nanofluid.

REFERENCES

Abu-Nada E, Oztop HF. Effects of inclination angle on natural convection in enclosures filled with Cu–water nanofluid. Int J Heat Fluid Flow 2009;30:669–678.

Chandrasekar M, Suresh S, Chandra Bose A. Experimental investigations and theoretical determination of thermal conductivity and viscosity of Al2O3/water nanofluid. Exp Therm Fluid Sci 2010;34:210–216.

Choi US. Enhancing thermal conductivity of fluids with nanoparticles. ASME Fluids Eng Div 1995;231:99–105.

Hamilton RL, Crosser OK. Thermal conductivity of heterogeneous two component systems. Indus Eng Chem Fund 1962;1:187–191.

Jang SP, Lee JH, Hwang KS, Choi SUS. Particle concentration and tube size dependence of viscosities of Al2O3-water nanofluids flowing through micro- and minitubes. Appl Phys Lett 2007;91:24-31.

Jmai R, Beya BB, Lili T. Heat transfer and fluid flow of nanofluid-filled enclosure with two partially heated side walls and different nanoparticles. Super lattices and Microstructures 2013;53:130–154.

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

Sebdani SM, Mahmoodi M, Hashemi SM. Effect of nanofluid variable properties on mixed convection in a square cavity. Int J Therm Sciences 2012;52:112-126.

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

Tiwari RK, Das MK. Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids. Int J Heat Mass Transf 2007;50:2002–2018.