ISSN 0974 - 9373

Vol. 18 No.2 (2014) **Journal of International Academy of Physical Sciences** pp. 101-107

Numerical Investigation on Mixed Convection in a Cavity Filled with Nanofluids

M. Muthtamilselvan
Department of Mathematics
Bharathiar University, Coimbatore-641046, India
Email: muthtamil1@yahoo.co.in

(Received October 12, 2013)

Abstract: A numerical investigation of laminar mixed convection heat transfer in a lid-driven cavity filled with nanofluid under the influence of a magnetic field is executed. The left and right vertical walls of the cavity are insulated while the top and bottom horizontal walls are kept constant but different temperatures. The top wall is moving on its own plane at a constant speed while other walls are fixed. A uniform magnetic field is applied in the vertical direction normal to the moving wall. The governing differential equations are discretized by the control volume approach and the coupling between velocity and pressure is solved using the SIMPLE algorithm. The heat and mass transfer mechanisms and the flow characteristics inside the cavity depended strongly on the strength of the magnetic field. A comparison is also presented between the results obtained from the Maxwell and modified Maxwell models. The results show that the heat transfer is generally higher based on the modified Maxwell model.

Keywords: Nanofluid, Magnetic field, Maxwell model

Mathematics subject classification: 58D30

1. Introduction

Investigations of mixed convection of a fluid confined in a cavity with moving wall have applications in problems such as manufacturing solar collectors, optimized thermal designing of buildings, and cooling of electronic devices, and have attracted many researchers[1,2]. Wan and Kuznetsov[3] investigated numerically fluid flow in a rectangular vibrating lid-driven cavity with three different aspect ratios. They found that the sizes of the secondary eddies vary for different aspect ratios of the cavity. A major limitation against enhancing the heat transfer in such engineering systems is the inherently low thermal conductivity of the commonly used fluids, such as, air, water, and oil. In order to enhance the thermal conductivity of conventional heat transfer fluids, it has been tried to develop a new type of modern heat transfer fluid by suspending ultrafine solid particles in base fluids. In 1993, Masuda et al.[4] studied the heat transfer performance of liquids with solid nanoparticles suspension. However, the term of ”nanofluid” was first named by Choi[5] in 1995, and successively gained popularity. Because of the extensively greater thermal conductivity and heat transfer performance of the nanofluids as compared to the base fluids, they are expected to be ideally suited for practical applications.

The aforementioned literature survey reveals that although many numerical efforts have been made to investigate convection heat transfer of nanofluids in a square cavity using Maxwell model, there is a lack of exploration on the modified Maxwell model. Therefore, this paper deals with a numerical study of mixed convection in a lid-driven cavity filled with different nanofluids in the presence of magnetic field using modified Maxwell model. The present investigation can be used to cool automobile engines and welding equipment and to cool high heat-flux devices such as high power microwave tubes and high-power laser diode arrays. A nanofluid coolant could flow through tiny passages in Micro-Electro-Mechanical Systems (MEMS) to improve its efficiency. The measurement of nanofluids critical heat flux (CHF) in a forced convection loop is useful for nuclear applications.

2. Mathematical Analysis

Consider a steady-state two-dimensional square cavity filled with nanofluid of height H as shown in Fig. 1. It is assumed that the top wall is moving from left to right at a constant speed U0 and is maintained at a constant temperature θh. The bottom wall is maintained at a constant temperature θc $(\theta h > \theta c)$. The vertical sidewalls are considered to be adiabatic. A uniform magnetic field is applied in the vertical direction normal to the moving wall. The nanofluid in the enclosure is Newtonian, incompressible, and laminar. The nanoparticles are assumed to have uniform shape and size. Under the above assumptions the system of equations can be written in the following non-dimensional form

(2.1) $$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0,$$

(2.2) $$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\rho_f}{\rho_{nf}}\frac{\partial P}{\partial X} + \frac{1}{\mathrm{Re}}\frac{\mu_{eff}}{v_f\,\rho_{nf}}\nabla^2 U,$$

(2.3) $$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\rho_f}{\rho_{nf}}\frac{\partial P}{\partial Y}+\frac{1}{\text{Re}}\frac{\mu_{eff}}{v_f\rho_{nf}}\nabla^2 V+\frac{(\rho\beta)_{nf}}{\rho_{nf}\beta_f}RiT-\frac{\alpha_{nf}}{\alpha_f}\frac{Ha^2}{\text{Re}}V,$$

(2.4) $$U\frac{\partial T}{\partial X}+V\frac{\partial T}{\partial Y}=\frac{\alpha_{nf}}{\alpha_f}\frac{1}{\text{Pr.Re}}\nabla^2 T.$$

In the above equations the following non-dimensional parameters are used

$$X=\frac{x}{H},\ Y=\frac{y}{H},\ U=\frac{u}{U_0},\ V=\frac{v}{U_0},\ T=\frac{\theta-\theta_c}{\theta_h-\theta_c},$$

$$Gr=\frac{g\beta\Delta\theta H^3}{{v_f}^2},\ Ha^2=\frac{\sigma {B_0}^2H^2}{\mu},\ P=\frac{p}{\rho {U_0}^2},\ \text{Re}=\frac{U_0H}{v_f},\ \text{Pr}=\frac{v_f}{\alpha_f}.$$

The non-dimensional boundary conditions, used to solve equations (2.1) to (2.4) are as follows.

$$U=1,\ V=0,\ T=0\ (Y=1),$$

$$U=0,\ V=0,\ T=0\,(Y=0),$$

$$U=V=0,\ \frac{\partial T}{\partial X}=0\ (X=0,\ 1).$$

3. Method of Solution

The governing equations along with the boundary conditions are solved numerically employing finite volume method using staggered grid arrangement. The semi-implicit method for pressure linked equation (SIMPLE) is used to couple momentum and continuity equations as given by Patankar.

4. Results and Discussion

In this paper the mixed convection flow inside the cavity is numerically investigated using modified Maxwell model. In the present analysis, the Prandtl number and the Grashof number is assumed to be Pr = 6.2 and Gr = 100 respectively. The range of Reynolds number, Hartmann number and solid volume fraction of nanoparticles are $10\le \text{Re} \le 1000$, $0\le \text{Ha}\le 50$ and $0\le \chi \le 0.06$.

Fig. 2 show typical contour maps for the streamlines and isotherms obtained numerically for different values of Reynolds number Re (Re = 1000, 500, 100, 10) at a fixed χ = 0.06(Cu). As it is clear from the definition of Ri (Ri = Gr/Re^2), the Richardson number provides a measure of the importance of buoyancy-driven natural convection relative to the lid-driven forced convection. For high values of Re (Re = 1000, 500, forced convection dominated regime), Fig. 2(a,b), indicate that the buoyancy effect is overwhelmed by the mechanical or shear effect due to the movement of the top lid and the flow features are similar to those of a viscous flow of a non-stratified fluid in a lid-driven cavity. The streamline behavior in a two-dimensional lid-driven cavity is characterized by a primary recirculating cell occupying most of the cavity generated by the lid and two secondary eddies near the bottom wall corners with one near the right bottom corner is bigger and stronger than the one in the left bottom corner of the cavity. The isotherms are clustered heavily near the bottom surface of the cavity which indicates steep temperature gradients in the vertical direction in this region. In the remaining area of the cavity the temperature gradients are very weak and this implies that the temperature differences are very small in the interior region of the cavity due to the vigorous effects of the lid-driven circulations. Fig. 2(c) show that the moderate value of Re = 100 the buoyancy effect is of relatively comparable magnitude of the shear effect due to the sliding lid. Fig. 2(d) show that the small value of Re = 10 the isotherm plot indicate that conduction mode heat transfer dominants. The corresponding streamlines show the flow circulation is very weak and small eddies are visible in the bottom corners of the cavity. When the value of Re decreased from 1000 to 10 the bigger and stronger corner eddies becomes small and weaker one due to the effect of Richardson number.

Fig. 3(a-d) present the streamlines (on the right) and isotherms (on the left) for Re = 100 and χ = 0.06 (Cu). When Ha = 0 streamlines show the main cell occupied entire cavity and small eddies are visible near the bottom corners. When Ha is increased from 0 to 10 the corner eddies become a small bottom recirculating cell. When Ha is increased to 50 three recirculating cells formed one below one due to the increasing effect of magnetic field. For the highest value of Hartmann number, flow structure changes completely. The corresponding isotherm (Fig. 3(a-d)) plots indicate that the thermal boundary layer increases due to the increasing of effectiveness of magnetic field. The temperature gradient is distributed starting from the right corner into the cavity as illustrated in Fig. 3(a). Mostly temperature gradient is parallel to the horizontal wall it indicate that conduction heat transfer dominates entire cavity is shown in Fig. 3(b-d).

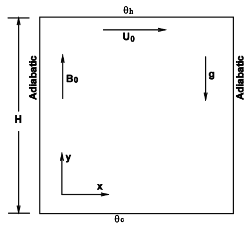


Fig.1: Flow configuration and coordinate system.

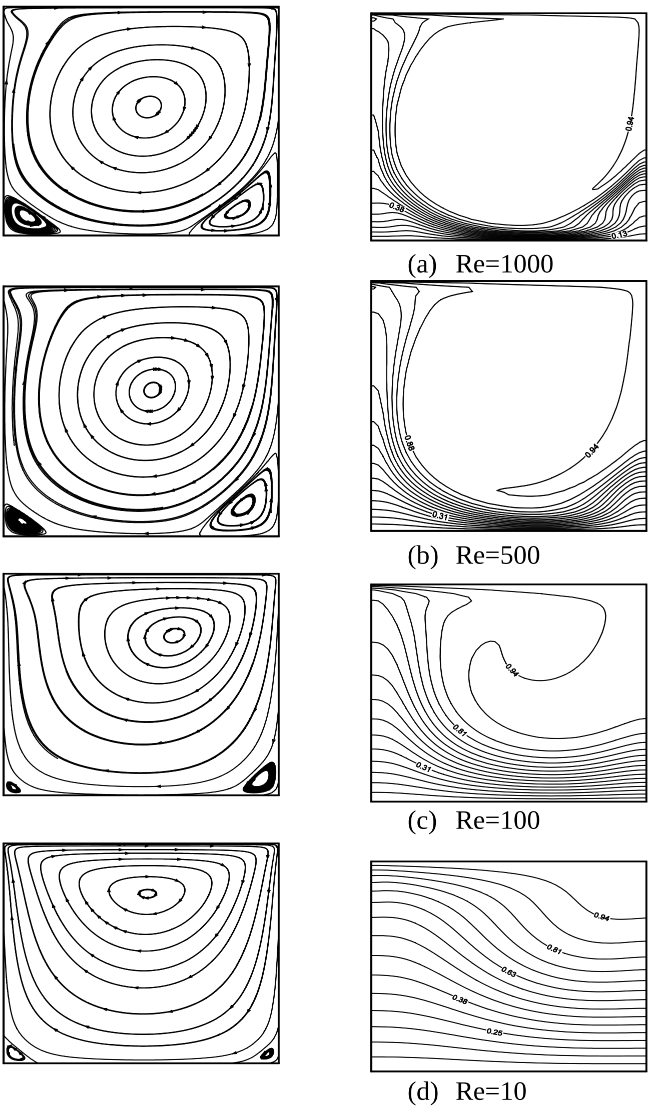
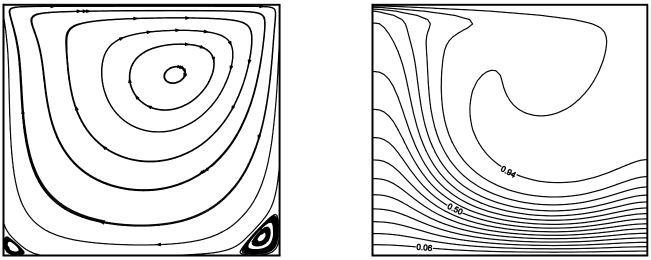
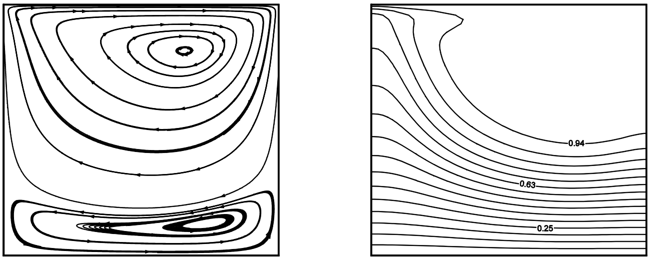


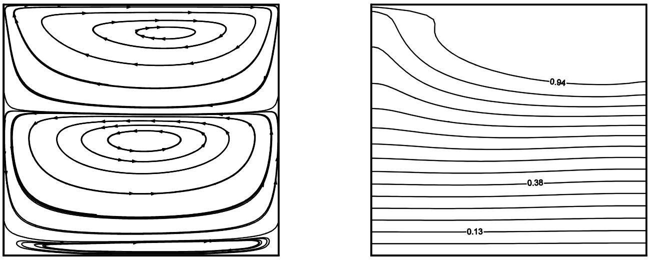
Fig. 2: Streamlines (on the left) and isotherms (on the right) for *Ha* = 0 and χ = 0.06.



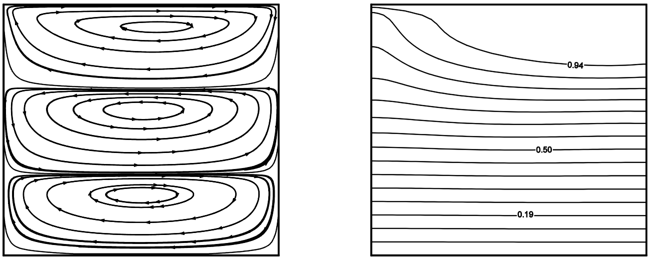
(a) Ha=0



(b) Ha=10



(c) Ha=20



(d) Ha=50

Fig.3: Streamlines (on the left) and isotherms (on the right) for *Re* = 100 and = χ 0.06.

5. Conclusions

This paper presents a numerical study of mixed convective flow and heat transfer of a five different nanofluid in a lid-driven cavity in the presence of magnetic field. Graphical results for various parametric conditions were presented and discussed. It is found that the flow and heat transfer inside the cavity are strongly dependent on the Reynolds and Hartmann numbers. The suspended nanoparticles remarkably enhance heat transfer process and the nanofluid has larger heat transfer coefficient than that of the original base liquid under the same Reynolds number. This is due to a substantial increase in effective dynamic viscosity compared to that of the base fluid and consequently a stronger convection is induced. Results indicated that the average Nusselt number increases linearly with the increase in the solid volume fraction at given Reynolds number. A comparison study between the results obtained from the Maxwell and modified Maxwell models indicate that the heat transfer rates obtained based on the modified Maxwell model are generally higher than those obtained based on the classical Maxwell model.

References

1. H. F. Oztop and I. Dagtekin, Mixed convection in two-sided lid-driven differentially heated square cavity, *International Journal of Heat and Mass Transfer*, **47** (2004) 1761-1769.

2. M. A. R. Sharif, Laminar mixed convection in shallow inclined driven cavities with hot moving lid on top and cooled from bottom, *Applied Thermal Engineering* , **27** (2007) 1036-1042.

3. Q. Wan and A.V. Kuznetsov, Investigation of the acoustic streaming in a rectangular cavity induced by the vibration of its lid, *Int. Commu. Heat Mass Transfer*, **31** (2004) 467-476.

4. H. Masuda, A. Ebata, K. Teramae and N. Hishinuma, Alteration of thermal conductivity and viscosity of liquid by dispersing ultra-fine particles (dispersion of Al2O3,SiO2 and TiO2 ultra-fine particles), *NetsuBussei (in Japanese)*, **7 (4)** (1993) 227-233.

5. S. U. S. Choi, Enhancing thermal conductivity of fluids with nanoparticles, *Proceedings of the 1995 ASME International Mechanical Engineering Congress and Exposition, ASME, New York*, (1995) 99-105.