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Review

Mixed convection in a double lid-driven sinusoidally heated porous cavity

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ABSTRACT

In this paper, we have numerically simulated two dimensional (2D) mixed convection flow in a sinusoidally heated porous cavity whose two vertical walls (lids) are in motion. The left vertical wall of the square cavity is maintained at constant cold temperature and the right wall of the cavity is sinusoidally heated, while upper and bottom walls are adiabatic. Three cases are considered depending on the direction of moving walls. We have used streamfunction–vorticity ($\psi - \zeta$) formulation of Brinkmann-extended Darcy model to simulate the momentum transfer in the porous medium. The streamfunction–vorticity and the energy equations are all solved as a coupled system of equations for the five field variables consisting of streamfunction, vorticity, two velocities and temperature using compact scheme on nonuniform grids presented in Pandit et al. (2007). The numerical results are analyzed over a range of the key parameters e.g. Richardson number *Ri*, Darcy number *Da*, Grashof number *Gr*, amplitude of the temperature variation and phase deviations. A parametric study is conducted for all cases.

Contents

1. Introduction

Over the past few decades, several researchers studied convection in enclosures with various thermal boundary conditions.

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Nomenclature

Be	Bejan number
Da	Darcy number
Gr	Grashof number
g	acceleration due to gravity (ms^2)
K	permeability of the porous medium (m^2)
k	effective thermal conductivity of the porous medium (W/m K)
L	length of the side of a square cavity (m)
Nu	local Nusselt number
p'	dimensional pressure (N/m^2)
p	dimensionless pressure
V_0	dimensional velocity of the moving walls (m/s)
Pr	Prandtl number
Re	Reynolds number
t'	dimensional time (s)
t	dimensionless time
T'	dimensional temperature (K)
T	dimensionless temperature
T_0	bulk temperature (K)
T_h	temperature of hot bottom wall (K)
T_c	temperature of cold vertical wall (K)
u', v'	dimensional velocities in x', y' directions respectively (m/s)
u, v	dimensionless velocities in x, y directions respectively
x', y'	dimensional Cartesian coordinates (m)
x, y	dimensionless Cartesian coordinates
τ	irreversibility distribution ratio
ν	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
μ	dynamic viscosity (kg/m s)
α	thermal diffusivity (m^2/s)
β	thermal expansion coefficient (1/K)
ψ	stream function
ζ	vorticity
ξ	horizontal coordinate in a unit square in computational plane
η	vertical coordinate in a unit square in computational plane

Subscripts

i, j	cell faces
c	cold
h	hot

Superscript

n	time level

These studies are classified into two categories named as natural convection and mixed convection. Among the natural convection studies, the heated walls have been subjected to non-uniform temperature distribution due to shading or other effects in various fields such as cooling of electronic components, nuclear reactor systems and solar energy collections. Abourida et al. [1] investigated natural convection in a square cavity with its horizontal walls subjected to different heating modes. Saeid [2] studied numerically the natural convection in a porous cavity with sinusoidal temperature variation in the bottom wall. He concluded that the heat transfer increased on increasing the length of the heat source or the amplitude of the temperature variation. Saeid and Mohamad [3] investigated the natural convection in a porous cavity with non-uniform hot wall temperature and uniform cold wall temperature. They found that the average Nusselt number sinusoidally changed on increasing the wave number. Basak et al. [4,5] studied the natural convection flow in a porous cavity when the bottom wall is heated uniformly and non-uniformly. They also observed that the average Nusselt number showed overall lower heat transfer rate for the non-uniform heating case. Very recently, Sheremet and pop [6] studied natural convection in wavy porous cavity with sinusoidal temperature distributions on both side walls.

On the other hand, there has been considerable interest in recent years to study the fluid flow and heat transfer in a rectangular or square cavity driven by buoyancy and shear. Combination of buoyancy forces due to temperature gradient and forced convection due to shear results in a mixed convection heat transfer, which is a complex phenomenon due to interaction of these forces. The work of Torrance et al. [7] can be dated as the beginning of mixed convection in enclosures. They studied different aspect ratios of the cavity and revealed a marked influence of buoyancy for aspect ratios when Grashof number was varied over the range of values $Gr = 0, \pm 10^4, \pm 10^6$. In the recent past, many studies have reported on mixed convection in a single lid-driven cavity. Recently, Oztop and Dagtekin [8] analyzed mixed convection flow in a square cavity, where the side walls moving in same and opposite directions. They concluded that when Richardson number $Ri < 1$, the influence of moving walls on the heat transfer is same when they move in opposite direction regardless the direction of walls. For the case of opposing buoyancy and shear forces and for $Ri > 1$, the heat transfer is some what better due to formation of secondary cells on the walls. Following their work, Tiwari and Das [9], Chamkha and Abu-Nada [10], and Nasrin et al. [11] used nanofluids to enhance heat transfer for mixed convection in lid-driven cavity. Their results depict that the Richardson number plays a significant role on the heat transfer characterization. In all of these studies, both the side walls are considered in motion whereas Ismael et al. [12] have studied on heat transfer in a cavity with the consideration of both the upper and lower moving walls with partial slip. They have reported that there are critical values for the partial slip parameter at which the convection is declined. Furthermore, the importance of studying cavities with moving walls is that its main application are devices with piston moving in cylindrical containers [13].

Very recently, mixed convection in a lid-driven cavity filled with porous medium has received considerable importance due to its wide applications in various field of engineering and geophysical system, such as dynamics of lakes [14], solar ponds [15], electronic equipment cooling [16], heating and drying process [17], float glass production [18]. In this context, we refer [19–23] and the references therein. Kuhlmann et al. [24], Blohm and Kuhlmann [25], Iwatsu et al. [26] accomplished a significant contribution in this area. Khanafer and Chamka [27] studied on mixed-convection flow in a lid-driven cavity filled with a fluid saturated porous medium. They used Brinkmann-extended Darcy equation of motion. In [28], Basak et al. analyzed the influence of various wall thermal boundary conditions on mixed convection in a square cavity filled with porous medium. Sivakumar et al. [29] numerically investigated the effect of heating location and size on mixed convection in a lid-driven cavity. Sivasankaran et al. [30] also studied the mixed convection in a lid-driven square cavity with non-uniform heating on both side walls. They found that heat transfer rate is increased on increasing the amplitude ratio. Very recently, mixed convection flow and heat transfer in a square lid-driven cavity filled with fluid saturated porous medium with sinusoidal