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Effect of aspect ratio on convection in a porous enclosure with partially active thermal walls

M. Bhuvaneswari [a], S. Sivasankaran [b], Y.J. Kim [a,*]

[a] School of Mechanical Engineering, Sungkyunkwan University, Suwon 440-746, South Korea

[b] University College, Sungkyunkwan University, Suwon 440-746, South Korea

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ABSTRACT

The aim of the present numerical investigation is to understand the effect of aspect ratio and partially thermally active zones on convective flow and heat transfer in a rectangular porous enclosure. Five different heating and cooling zones are considered along the vertical walls while the remaining portions of the sidewalls and top and bottom of the enclosure are adiabatic. The Brinkman–Forchheimer extended Darcy model is used in the study. The governing equations are solved by the finite volume method with the SIMPLE algorithm. The computations are carried out for a wide range of parameters and the results are presented graphically. The results reveal that the location of heating and cooling zones has a significant influence on the flow pattern and the corresponding heat transfer in the enclosure. The rate of heat transfer approaches to a constant value for very low values of the Darcy number. The heat transfer rate is decreased on increasing the aspect ratio.

1. Introduction

Convective flow in porous media has been of great interest due to wide applications in many engineering, agriculture, geothermal, medical and biological sciences. Examples include storage of grain, transpiration cooling, ground water pollution, food technology, radioactive waste management and certain biological materials [1–3]. Prasad and Kulacki [4] numerically studied convection heat transfer in a rectangular porous enclosure. It is observed from their results that the heat transfer rate increases on increasing the aspect ratio. Natural convection in a cavity filled with non-Darcian porous medium is numerically investigated by Beckermann et al. [5]. The flow is modeled using the Brinkman–Forchheimer-extended Darcy equations and the significance of non-Darcian effects is demonstrated. Du and Bilgen [6] studied natural convection in a cavity filled with uniform heat generating, saturated porous medium for a wide range of Rayleigh numbers and aspect ratios. Various heat transfer modes were identified in their study depending on the Rayleigh number and the aspect ratio range. Nithiarasu et al. [7] investigated natural convection in a fluid saturated non-Darcian porous medium with variable porosity. They found that the nature of porosity variation significantly affects the heat transfer and convection flow.

Das and Sahoo [8] numerically studied the effect of Darcy, Rayleigh numbers and heat generating parameter on natural convection of fluid saturated heat generating porous medium in a square cavity. They found that the peak temperature occurs at the top central part and weaker velocity prevails near the vertical walls of the enclosure due to the heat generation. Hossain and Wilson [9] numerically analyzed natural convective flow in a fluid-saturated heat generating porous medium in an enclosure. They found that increasing the porosity of the medium reduces the volume flow rate of the fluid in the dominant vortex and leads to a general reduction in heat transfer at the walls. Saeid and Pop [10] numerically investigated

* Corresponding author.
E-mail addresses: msubhuvana@yahoo.com (M. Bhuvaneswari), sd.siva@yahoo.com (S. Sivasankaran), yjkim@skku.edu (Y.J. Kim).

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Nomenclature

Ar	Aspect ratio
c_p	Specific heat
Da	Darcy number
g	Acceleration due to gravity $(\mathrm{m/s^2})$
Gr	Grashof number
H	Height of the enclosure (m)
K	Permeability of the porous medium
L	Width of the enclosure (m)
p	Effective pressure (Pa)
Pr	Prandtl number
Nu	Nusselt number
$\overline{Nu}$	Average Nusselt number
T	Dimensionless temperature
t	Dimensional time (s)
(x, y)	Dimensional co-ordinates (m)
(X, Y)	Dimensionless co-ordinates
(u, v)	Dimensional velocity components in (x, y) direction (m/s)
(U, V)	Dimensionless velocity components in (X, Y) direction

Greek letters

α	Thermal diffusivity $(\mathrm{m^2/s})$
β	Coefficient of thermal expansion (1/K)
ε	Porosity
ν	Kinematic viscosity $(\mathrm{m^2/s})$
ρ	Density $(\mathrm{kg/m^3})$
θ	Dimensional temperature (K)
σ	Specific heat ratio
τ	Dimensionless time

Subscripts

h	Hot
c	Cold

convection heat transfer of cold water around the temperature of maximum density in a two-dimensional porous cavity. The problem of natural convection flow in a porous cavity filled with water near its maximum density subjected to thermal non-equilibrium condition was numerically examined by Saeid [11]. It is found from their results that the values of the average Nusselt number are approaching unity for the very shallow cavity, where the buoyancy effects are small. Natural convection in a square porous cavity with internal heat generation by the generalized non-Darcy approach was numerically investigated by Krishna et al. [12]. They found that the anisotropic properties have significant influence on the flow behavior and heat transfer.

Most of the research works are concerned with natural convection in rectangular geometries due to either a vertically or horizontally imposed heat flux or temperature difference. However, the active walls may be subject to abrupt temperature non-uniformities due to shading or other effects in some applications like solar energy collection and cooling of electronic components. The relative position of the hot and cold wall regions has significant effects on the flow pattern and heat transfer. In order to have the results to possess these applications, it is essential to study the convective heat transfer in an enclosure with partially active thermal walls. Kuhn and Oosthuizen [13] numerically investigated convection heat transfer in a partially heated rectangular enclosure. They found that the Nusselt number increases up to a maximum and then decreases as the heated location moves from the top to the bottom. Natural convection in a square cavity with partially thermally active sidewalls for five different heating locations was numerically analyzed by Valencia and Frederick [14]. They observed that the heat transfer rate is enhanced when placing the heating location at the middle of the hot wall.

Yucel and Turkoglu [15] made a numerical study on convective flow and heat transfer in a partially heated and partially cooled cavity. They found that for a given cooler size, the mean Nusselt number decreases with increasing the heater size. On the other hand, for a given heater size, Nusselt number increases with increasing the cooler size. Saeid and Pop [16] numerically investigated the effect of discrete heating on natural convection in a porous cavity. It is shown that the location of the discrete heater has important influence on the flow and heat transfer characteristics. Natural convection heat transfer in a partially cooled and inclined rectangular porous enclosure had been investigated numerically by Oztop [17]. He found