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Three-dimensional simulation of natural convection in cubic cavity partially filled with porous media

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Abstract

The natural convection heat transfer in fluid and porous media is one of interest in several natural and industrial fields. This work focuses on natural convection in a cubic enclosure, partially filled with a central cubic porous media, heated and cooled along vertical walls by uniform temperature. The formulation of the problem is based on Darcy-Brinkman model and the density variation is taken into account by the Boussinesq approximation. The Variations of Nusselt number on the hot and cold walls are also presented to show the overall characteristics of heat transfer to the interior of the enclosure. The study found that the fluid flow and heat transfer are governed by the dimensionless thickness of the porous layer, and the thermal conductivity ratio of the solid matrix of the porous media to that of the fluid.

Keywords: Natural convection, Three-dimensional, Porous media, Cubic enclosure, Out thermal equilibrium

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1. Introduction

Fluid flow and heat transfer in saturated porous media has received a considerable attention and has been the subject of much intensive research numerically, mathematically and experimentally. This interest is due to the fact that this kind of structure is encountered in various engineering and geophysical problems, such as oceanography, geophysics, design of heat exchangers, hydrology, biology and chemical processes (see, for instance [1-2]). In particular these problems where heat transfer takes place in a confined enclosure partially filled with porous medium have many applications, such as: thermal insulation, solar collectors with a porous absorber, thermal energy storage system [3]. Numerical investigation has been made of double thermosolutal convection in a rectangular cavity filled with a porous medium saturated by an aqueous solution of sodium chloride (NaCl). The porous medium will be subject to cross gradients [4]. They show that the nonlinear variation of the density influences strongly the flow structure and the heat transfer. The structures of this flow show that the density maximum generates a complex flow structure of two contra rotating cells of unequal importance. They showed that the condition on the separating interface has a significant effect on the flow field and heat transfer in such composite enclosure. Many researchers analyzed the heat transfer in multilayer geometrical, horizontal saturated porous layer and an overlying fluid layer has been investigated using the Darcy-Brinkman flow [5]. Natural convection in vertical enclosures containing simultaneously a fluid and a porous layer was investigated [6]. The numerical results show good agreement with experiments conducted utilizing various glass beads, fluids and test-cell sizes. Recent numerical investigation has been made of three-dimensional double diffusive natural convection across a cubical enclosure partially filled by vertical porous layer saturated with fluid buoyancy driven flow by heat and species diffusion is considered in this study [7]. This paper presents a numerical three-dimensional study of natural convection in a cubic cavity partially filled in the center by a block porous media which is outside thermal equilibrium with the fluid media. Therefore, a parametric change in effect of the thickness of the porous layer and the thermal conductivity ratio on the structure of the fluid motion and the heat transfer rate are shown. Hence, the results are given in term of fluid motion and heat transfer and analyzed on the basis of dynamic fields (streamtraces and velocity), isotherms and the Nusselt number reflecting the rate of heat transfer in fluid and porous media.

Nomenclature

Cp	Heat capacity
Da	Darcy number
e	Dimensional thickness of the porous layer, (m)
g	Gravitational acceleration, $\left(m/s^2\right)$
H'	Length of the enclosure, (m)
K	Permeability of the porous medium
Nu	Average Nusselt number
P	Dimensionless pressure
Pr	Prandtl number, (υ/α)
Ra	Rayleigh number, $\left(g\beta_T H'^3 \Delta T'/\upsilon\alpha\right)$
T	Dimensionless temperature, $\left((T'-T_0)/\Delta T'\right)$
t	Dimensionless time
(u,v,w)	Dimensionless component of the velocity, $\left((u'.H'/\alpha),(v'.H'/\alpha),(w'.H'/\alpha)\right)$
(x,y,z)	Dimensionless coordinate system, $\left((x'/H'),(y'/H'),(z'/H')\right)$
Greek Symbols	
α	Thermal diffusivity, $\left(m^2 s^{-1}\right)$
β_T	Coefficient of thermal expansion, $-1/\rho_0\left(\partial\rho/\partial T'\right)_P$, $\left(K^{-1}\right)$
ρ	Volume density, (Kg/m^3)
υ	Kinematics viscosity, $\left(m^2/s\right)$
η	Dimensionless thickness of the porous layer, (e/H')
λ	Thermal conductivity