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Numerical study of double diffusive natural convective heat and mass transfer in an inclined rectangular cavity filled with porous medium ☆

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ABSTRACT

Two-dimensional double-diffusive natural convective heat and mass transfer in an inclined rectangular porous medium has been investigated numerically. Two opposing walls of the cavity are maintained at fixed but different temperatures and concentrations; while the other two walls are adiabatic. The generalized model with the Boussinesq approximation is used to solve the governing equations. The flow is driven by a combined buoyancy effect due to both temperature and concentration variations. A finite volume approach has been used to solve the non-dimensional governing equations and the pressure velocity coupling is treated via the SIMPLER algorithm. The results are presented in streamline, isothermal, iso-concentration, Nusselt and Sherwood contours for different values of the non-dimensional governing parameters. A wide range of non-dimensional parameters have been used including, aspect ratio ($2 \leq A \leq 5$), angle of inclination of the cavity ($0 \leq \phi \leq 85$), Lewis number ($0.1 \leq Le \leq 10$), and the buoyancy ratio ($-5 \leq N \leq 5$).

1. Introduction

The phenomenon of combined heat and mass transfer in a porous medium is usually referred to as double diffusion. The reason for the scarcity of work on the subject may be related to its complexity and to the lack of a general theory. In the last decade, the academic and applied interest from a number of researchers has resulted in a certain number of mainly theoretical investigations by Mojtabi and Charrier-Mojtabi [1]. An overview of the current state of the art of double diffusion in saturated porous media has been recently presented by Nield and Bejan [2], and Ingham and Pop [3,4].

The use of non-Darcian models has only been introduced recently for the solution of double diffusion (Nithiarasu et al. [5,6]). For opposing but comparable buoyant forces due to temperature and concentration, and for certain configurations, the flow can be unsteady, Nishimura et al. [7] and Weaver and Viskanta [8]. Although these oscillations have been noticed even during some experiments (Weaver and Viskanta [8]), available numerical solutions were not able to predict the particular behaviour. Such findings highlight the need for an algorithm based on the time dependent solution of the flow, and the generalized model is probably suitable for the scope envisaged. Important contributions were also made by Nithiarasu et al. [9] regarding steady double-diffusion natural convection in an enclosure filled with saturated porous media. A generalized equation was obtained and Galerkin's finite element method coupled with the Eulerian velocity correction was used. The results showed that for the high Rayleigh and Darcy numbers, the effect of flow, heat, and mass transfer become significant.

The effect of natural convection, using a constant heat flux on two opposing walls in a thin inclined porous layer was investigated both analytically and numerically by Vasseur et al. [10]. The results showed that for the tall cavity ($1 << A$), the maximum heat transfer occurs when the inclined angle varies between 90° and 180°. Also, the maximum heat transfer occurs at the smaller values of the angle when the Rayleigh number increases. Later, similar theoretical and numerical methods have been used by Sen et al. [11]. They extended the Vasseur et al. [10] analyses to cover flows which displayed unicellular convective motions only. These authors studied the multiplicity of solutions for horizontal and vertically inclined cavities. The results have been presented for Rayleigh numbers $Ra \leq 500$ with small angles. The same cases were also studied by Báez and Nicolás [12] and Caltagirone and Bories [13]. In a different study, natural convective motions in a tilted rectangular porous material have been studied numerically by Moya et al. [14] using Darcy's law and the Boussinesq approximation. The results showed that; when the aspect ratio exceeded unity, single or multiple cell convection can take place with different tilt angles, while for a square cavity, one cell convection can take place, regardless of the tilt angle.

Natural convective heat and mass transfer in an inclined porous layer was also studied experimentally by Inaba et al. [15]. Therein, two opposing walls of the tall rectangular cavity were thermally insulated, while the other walls were kept at different temperatures. Four correlative equations of heat transfer were presented for small

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