Applied Mathematics and Computation 273 (2016) 178–189

Contents lists available at ScienceDirect

Applied Mathematics and Computation

journal homepage: www.elsevier.com/locate/amc

Inclination effects of magnetic field direction in 3D double-diffusive natural convection

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A R T I C L E   I N F O

Keywords:
Double diffusive convection
Inclined magnetic field
3D cubic cavities
Spiral flow

A B S T R A C T

In this paper a numerical study which treats the effect of the magnetic field inclination on 3D double diffusive convection in a cubic cavity filled with a binary mixture is presented. The two vertical walls are maintained at different temperatures and concentrations. A particular interest is reserved to determine the effect of the magnetic field inclination on the flow structure and heat and mass transfer. The problem is formalized based on the vector potential vorticity procedure in its three-dimensional configuration and discretized based on the finite volume method. The results are given for $Ra = 105$, $Pr = 1$ and $Le = 2$. This paper presents respectively the inclination effects of the magnetic field direction on the three-dimensional flow structure and on heat and mass transfer. The main results show that the increase of the inclination of the magnetic field direction damped the flow. A critical angle, which depending on Hartmann number, caused big change on the flow structure and accented the three dimensional aspect in the cavity.

1. Introduction

Convective flows with simultaneous heat and mass transfer is generally referred either to the thermosolutale convection or double diffusion. The classical problem of natural double diffusive convection in cubic enclosures has many engineering applications such as the cooling systems of electronic components, nuclear reactor systems, food storage industry, solar energy collector and thermo-protection systems and also the geophysical fluid mechanics. In some practical cases such as the crystal growth in fluids and the metal casting the natural double diffusive convection is under the influence of a magnetic field. The physics governing the applications mentioned above is well understood and interesting experimental, numerical and analytical results have been published for the development of the velocity, temperature and concentration fields.

The study in a two-fluid mixture in rectangular enclosure has drawn a great deal of research [1,2,17]). Ece and Buyuk [7] examined the steady and laminar natural convection flow in the presence of a magnetic field in an inclined rectangular cavity which is heated and cooled on adjacent walls. They found that the magnetic field suppressed the convective flow and the heat transfer rate. They also showed that the orientation and the aspect ratio of the enclosure and the strength and direction of the magnetic

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http://dx.doi.org/10.1016/j.amc.2015.09.043
0096-3003/

Nomenclature

$\vec{B}$	magnetic field $(= \vec{B}'/B_0)$
C	dimensionless concentration $(= (C' - C'_l)/(C'_h - C'_l))$
C'_h	high species concentration
C'_l	low species concentration
D	species diffusivity
$\vec{e}_B$	direction of magnetic field
g	acceleration of gravity
Ha	Hartmann number
$\vec{J}$	Dimensionless current density $(= \vec{J}'/(\sigma \nu_0 B_0^2))$
L	cavity side
Le	Lewis number
N	buoyancy ratio
$\vec{n}$	unit vector normal to the control volume surface
T	dimensionless temperature $(= (T' - T'_c)/(T'_h - T'_c))$
t	dimensionless time $(= t'.\alpha/L^2)$
T'_h	hot wall temperature
T'_c	cold wall temperature
$\vec{u}$	dimensionless velocity $(= \vec{u}.L/\alpha)$

Greek symbols

α	angle of inclination of magnetic field direction
a_{th}	thermal diffusivity
β_T	coefficient of thermal expansion
β_C	coefficient of compositional expansion
Φ	dimensionless electric potential
μ	dynamic viscosity
υ	kinematic viscosity
σ_e	electrical conductivity
$\vec{\omega}$	dimensionless vorticity $(= \vec{\omega}'.\alpha/L^2)$
$\vec{\psi}$	dimensionless stream function $(= \vec{\psi}/\alpha)$

Superscripts

‘	dimensional variable

field had significant effects on the flow structure. Sivasankaran and Ho [27] numerically studied the effects of temperature dependent properties on the natural convection of water in a cavity under the influence of a magnetic field. They showed that the heat transfer rate is influenced by the direction of the external magnetic field and decreases with an increase of the magnetic field. Kahveci and Oztuna [11] numerically simulated the natural-convection flow in a laterally heated partitioned enclosure and concluded that the magnetic field and its direction affect the heat transfer performance of the enclosure. Sathiyamoorthy and Chamkha [25] used different thermal boundary conditions to examine the steady laminar two-dimensional natural convection in the presence of inclined magnetic field in a square enclosure filled with a liquid gallium. They found that the heat transfer decreases with the increase of the magnetic field. Besides the vertical and horizontal magnetics fields affect the heat transfer differently.

The double diffusive natural convection carried out in a two dimensional cavity filled with a binary fluid and subjected to horizontal temperature and concentration gradients with cooperating volume forces has been researched by Gobin and Bennacer [9]. They show that for high Lewis number, the thermal transfer goes down as the buoyancy ratio increase.

The analytical and numerical study of double-diffusive natural convection in a rectangular enclosure filled with non-Newtonian fluid is carried out by Makayssi et al. [14]. Indeed, in the case of a shallow cavity, the authors proposed an analytical solution based on the approximation of parallel flow. This analytical solution has a good agreement with the numerical solution. Recently, Nithyadevi and Yang [15] treat the case of a partially heated enclosure with Soret and Dufour coefficients around the density maximum.

The effect of the various parameters (thermal Rayleigh number, center of the heating location, density inversion parameter, Buoyancy ratio number, Schmidt number, and Soret and Dufour coefficients) on the flow pattern and heat and mass transfer has been depicted. More recently, an extension of a compressible flow model to double-diffusive convection of binary mixtures of ideal gas enclosed in a cavity is presented by Sun et al. [28].

The coupling of transient double diffusive convection with radiation is investigated numerically in a square cavity filled with a mixture of N_2 and CO_2 by Ibrahim and Lemonnier [10]. Their numerical results show that gas radiation modifies the structure