International Communications in Heat and Mass Transfer 57 (2014) 183–192

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Numerical computation of double-diffusive natural convective flow within an elliptic-shape enclosure☆

A. Bouras [a,b], M. Djezzar [b], H. Naji [c,d,*], C. Ghernoug [b]

[a] M'sila University, B.P. 166 Ichbelia, M'sila, Algeria
[b] Laboratory of Energetic Physics, Faculty of Exact Sciences, University Constantine 1, Ain El-Bey Road, Constantine, Algeria
[c] Civil Engineering & Geo-Environment Laboratory (LGCgE-EA 4515), Lille University, Northern France, 59000 Lille, France
[d] Artois University, Faculty of Applied Sciences, Technoparc Futura, F-62400 Bethune, France

ARTICLE INFO

Available online 8 August 2014

Keywords:
Double-diffusive
Natural convection flow
Elliptic enclosure
Heat and mass transfer
Numerical simulation

ABSTRACT

This paper deals with numerical investigation of double-diffusive natural convective flow in an annular space between confocal elliptic cylinders filled with a Newtonian fluid. Uniform temperatures and concentrations are imposed along walls of the enclosure so as to induce aiding thermal and mass buoyancy forces within the fluid. Equations of concentration, energy and momentum are formulated using the dimensionless form of transport equations in elliptic coordinates for laminar two-dimensional incompressible flow which is expressed in terms of stream function, vorticity, temperature and concentration. Laminar regime is considered under steady state condition. The coupled differential equations are discretized by the finite volume method (FVM) and are solved via an in house-built computer code. Beforehand, this last has been validated through reliable results available elsewhere. The present study considered the effects of pertinent parameters on fluid flow, heat and mass transfer: the Rayleigh number up to 5.10^5. Throughout the study, the Prandtl number has been varied from 0.3 to 1. The relevant results are presented in terms of isotherms, streamlines and iso-concentrations. In addition, the heat and mass transfer rate in the annulus is translated in terms of the average Nusselt and Sherwood numbers along the enclosure's sides. Based on the obtained results, it is concluded that, in the context of double diffusive natural convective flows in elliptic-shape annuli, the potential of the proposed approach is demonstrated.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Double diffusive natural convection is the process that occurs when the flow is generated by buoyancy due to simultaneous temperature and concentration gradients. Such flows exhibit complex structures that interact with mass and heat transport mechanisms prevailing there, and of which a depth understanding is increasingly sought. They can be found in a wide range of applications such as drying, electrochemistry, the coating process, the float glass manufacture, melting and solidification processes, the storage of fuel in casks, the mixture and storage of liquefied gases in canisters with double-hull, the transport of contaminants in saturated soils, the transport in chemical engineering equipments, the desalination of sea water, and geophysics. The reader in search of fundamental work on this subject may consult Turner [1], Schmitt [2] and Viskanta et al. [3]. Studies conducted on double diffusion natural convection have been motivated by many engineering applications that they imply, and continue to be an important issue. To be concise, it is worth stating that these flows are ubiquitous in nature.

The quest for deeper understanding (experimentally and/or numerically) of the double diffusion in a rectangular enclosures has been ongoing for a long time and gave rise to fruitful research. It is worth noting that most studies interested in the double diffusion convection have focused either on rectangular, circular or lid-driven cavities with the presence of obstacles embedded inside. For these enclosures, attention was paid to relevant parameters such as the enclosure aspect ratio, the angle of inclination, the boundary conditions, and the buoyancy parameter. The greater part of these studies is two-dimensional and is essentially numerical in nature. Beyond the purely diffusive solution, most authors find at steady state either unicellular structure or multi-cellular structures, depending on controlling parameters. Lee and Hyun [4] and Hyun and Lee [5] have reported on numerical solutions for double diffusion convection in a rectangular enclosure with cooperating and opposing temperature and concentration gradients. Ghachem et al. [6] performed a numerical analysis of double diffusive natural convection and entropy generation in a three-dimensional solar dryer in order to assess effects of the buoyancy ratio for opposed temperature and concentration gradients, with a particular interest to the three-dimensional aspects and entropy generation. Teamah et al. [7] studied numerically a double

☆ Communicated by W.J. Minkowycz.

* Corresponding author at: Civil Engineering & Geo-Environment Laboratory (LGCgE-EA 4515), Lille University, Northern France, 59000 Lille, France.
E-mail address: hassane.naji@univ-artois.fr (H. Naji).

http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.08.002
0735-1933/© 2014 Elsevier Ltd. All rights reserved.

Nomenclature

A_1, A_2	major axes of the inner and outer elliptic cylinders, [m]
B_1, B_2	minor axes of the inner and outer elliptic cylinders, [m]
C	concentration, [kg m^{-3}]
C_h, C_l	high and low concentration at wall enclosure, [kg m^{-3}]
ΔC	concentration difference, [kg m^{-3}]
C_p	specific heat at constant pressure, [J kg^{-1} K^{-1}]
D	mass diffusivity, [m^2 s^{-1}]
D_h	arbitrarily selected focal distance, [m]
e_1, e_2	eccentricities of ellipses
$\vec{g}$	unit vector in the direction of the gravitation, [ms^{-2}]
h	metric coefficient, [m]
H	dimensionless metric coefficient, [−]
Le	Lewis number, [−]
N	buoyancy ratio, [−]
Nu	local Nusselt number, []
Nu_a	average Nusselt number, [−]
p	pressure, [N/m^2]
Pr	Prandtl number, []
Ra	Rayleigh number, [−]
Sh	local Sherwood number, []
Sh_a	average Sherwood number, [−]
T	local temperature, [K]
T_0	reference temperature, [K]
T_c, T_h	cold and hot wall temperature, [K]
ΔT	temperature difference, [K]
t	time, [s]
$\vec{V}$	velocity vector in Cartesian coordinates, [ms^{-2}]
V_η, V_θ	velocities components in elliptical coordinates, [ms^{-1}]
x, y	Cartesian coordinates, [m]

Greek symbols

α	thermal diffusivity, [m^2 s^{-1}]
$\beta_{C\ (T)}$	mass (thermal) expansion coefficient, [m^3 kg^{-1}] ([K^{-1}])
$\nabla.$	divergence operator
∇^2	laplacian operator
η, θ, z	elliptic coordinates, [m]
φ	inclination angle, [°]
λ	thermal conductivity of the fluid, [W m^{-1} K^{-1}]
ν	kinematic viscosity, [m^2 s^{-1}]
ρ	local fluid density, [kg m^{-3}]
ρ_0	characteristic density at reference temperature, [kg m^{-3}]
ψ	stream function, [m^2 s^{-1}]
ω	vorticity, [s^{-1}]

Subscripts/superscripts

a	average
c, h, (l, h)	cold, hot, (concentration: low, high)
i	inner
o	outer
η	according coordinate η
$+$	dimensionless quantity
θ	according coordinate θ
0	reference state

diffusion natural convective flow in an inclined rectangular enclosure in the presence of magnetic field and heat source. The authors concluded that 1) the inclination angle affects the buoyancy forces, and 2) the magnetic field reduces the heat transfer and fluid circulation due to the retardation effect of the electromagnetic body force. Also, Teamah and El Maghlany [8] carried out numerically a double diffusion natural convective flow in a rectangular enclosure with insulated moving lid. Chen et al. [9] performed double-diffusive convection in vertical annulus with opposing temperature and concentration gradients up to $Ra = 10^7$. They investigated the influences of various key parameters such as the ratio of buoyancy forces, the aspect ratio, and the radius ratio. Papanicolaou and Belessiotis [10] numerically computed the double diffusion natural convection in an asymmetrical trapezoidal enclosure with vertical temperature and concentration gradients. Chen et al. [11] investigated turbulent double-diffusive convection using LES-based lattice Boltzmann model with Ra up to 10^{11} and $0.1 \leq N \leq 2$. They found that the power-law relationship among the Nusselt (Nu), the ratio of buoyancy forces (N) and the Rayleigh number (Ra) still exists in turbulent regime. Rather recently, Moufekkir et al. [12] have achieved on a numerical study of coupled double diffusive convection and radiation in a tilted and differentially heated square enclosure filled with binary fluid (semitransparent and gray medium), using a hybrid approach of multiple relaxation time lattice Boltzmann and finite difference method (MRT-LBM-FDM). Nikbakhti and Rahimi [13] analyzed numerically the flow, heat and mass transfer for air filled in a rectangular cavity with partially thermal active walls. Kuznetsov and Sheremet [14] numerically studied the transient thermosolutal in a three-dimensional enclosure having finite thickness walls filled with air and submitted to temperature and concentration gradients. Note that in 3D point of view, some works has been performed on a double diffusion natural convective flow inside enclosures. For instance, one can mention the following Refs. [15–18], to cite a few.

The problem of double-diffusive convective flows with moving surfaces belongs to the class of lid-driven problems. These situations have relevance in several industrial processes such as drying technology. Sheu and Tsai [19] undertook a detailed numerical study on three-dimensional lid-cavity. Al-Amir et al. [20] have investigated steady mixed convection in a square lid-driven cavity under the combined buoyancy effects of thermal and mass diffusion. They observed that the heat transfer and mass transfer are enhanced for low Richardson numbers. Mohamed and El-Maghlany [8] numerically studied the double-diffusive mixed convective flow in rectangular enclosure with insulating moving lid in the presence of horizontal temperature and concentration gradients. Recently, Maiti [21] has conducted a numerical study of combined heat and mass transfer in a lid-driven square cavity subjected to a vertically parallel temperature and concentration gradients. He showed that the operational parameters, namely Re, Gr_t, and Gr_c have profound effects on the flow's structure, and heat and mass transfer fields.

Through an in depth literature survey, one can state unequivocally that all published studies on double diffusive convection have been restricted to either rectangular, circular or lid-driven cavities with the presence of obstacles embedded inside. Moreover, up to date, studies on double-diffusive convective flows in elliptic shape-annulus are very sparse. Additionally, such a geometry is easily adaptable to become either circular tubes when the axis ratio approaches unity, or flat plate when the axial ratio approaches zero. All this motivates this paper to perform the current research. With this motivation, the prime aim of the present work is to numerically investigate effects of Rayleigh number within the range of 10^2–10^6 on heat and mass transfer prevailing in the cavity, and to elucidate the interaction mechanisms of thermal and compositional buoyancy. Beforehand, it is worth describing scarce references in our possession that concern this topic. Al-Amiri et al. [22] have been carried out a numerical simulation for double diffusive convection heat transfer in a cylindrical horizontally-originated annulus. In this work, they were interested in the effects of amplitude and frequency of the heated inner cylinder on the average Nusselt. Simitev [23] conducted double-diffusive convection in a rotating cylindrical annulus with conical caps. Al-Amiri and Khanafer [24] studied numerically double-diffusive mixed convection within a rotating two-dimensional, horizontal annulus. They predicted the average Nusselt and Sherwood

Download English Version:

https://daneshyari.com/en/article/653173

Download Persian Version:

https://daneshyari.com/article/653173

Daneshyari.com