Double-diffusive natural convection in a partially porous square enclosure ; effect of the inclination

O. Rahli, K. Bouhadef *
Laboratoire LTPMP, Faculté de Génie Mécanique et Génie des Procédés, USTHB, Alger - Algérie
e-mail : khedbouh@yahoo .fr

I - Introduction :

Double–diffusion occurs in a wide range of scientific fields, such as oceanography, astrophysic, geology, biology and chemical processes ; so, the authors interest more and more for the heat and mass transfer developed in enclosures or cavities.

About these case of fluid flows generated by combined temperature and concentration gradients, the studies of double-diffusive natural convection have centred chiefly their analyses on the limit cases of dominating thermal buoyancy force or concentration buoyancy force. The considered spaces are enclosures comprising a fluid only **[1-2]** or completly occupred by porous medium **[3-5]**.

The studies on double-diffusive natural convection in cavities containing simultaneously a fluid and porous medium are limited at case of horizontal temperature and concentration gradients **[6-7]**.

In this study, we consider the problem of steady, laminar, two-dimensional double-diffusive, natural convection inside an inclined square enclosure filled with air and divided by a saturated porous medium. Imposed Conditions of temperature and concentration are on the left and right sides and at the bottom of porous region.
This kind of flow and heatand mass transfer problems find application in many engineering technological areas such as geothermal reservoirs, petroleum extraction, chemical catalytic reactors, prevention of water pollution, nuclear reactor, underground diffusion of nuclear wastes and other contaminants, and porous material regenerative heat exchangers.

The aim of the numerical work presented in this paper, is to shed light on an entirely new class of flows in this kind of cavities. We analyze the thermal and solutal exchanges generated in the case of co-operating thermal and concentration buoyancy effects.

We also interest to the influence of different thermophysical and geometrical parameters on heat and mass transfer, and on the regime of flow wich occurs.

* Correspondence
e-mail : khedbouh@yahoo .fr

II- Mathematical model :

We consider a steady laminar two-dimensional double-diffusive natural convection inside an inclined square cavity divided by a porous medium. The temperature T_1 and T_2 and concentration C_1 and C_2 are uniformly and respectively imposed on the two opposing walls(left and right), while the bottom of porous region is submited at temperature T_1 and concentration C_1. The other walls are assumed adiabatic and impermeable to mass transfer. The schematic of the system under consideration is shown in **figure1**.

The fluid is assumed to be incompressible, newtonian. The viscous dissipation is assumed to be negligible. The Boussinesq approximation with compositional buoyancy forces is used for the body force terms in the momentum equations.

The governing equations for the problem under consideration are based on the conservation laws of mass, momentum, energy and species.

The Darcy-Brinkman model is used to describe the flow in the porous medium and to take in account the Darcien and macroscopic viscosity effects. The energy and mass equations are also transformed and averaged to consider the porous nature of the matrix.

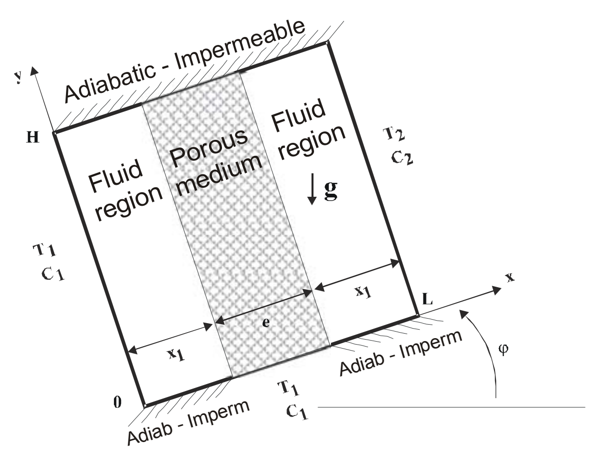

Figure 1 : Physical model

III- Numerical method :

The governing dimensionless equations are discretized using the control volume formulation developed by Patankar **[8]**. The power law scheme was used to calculate both the heat and mass fluxes across the boundaries of each control volume.

The algebraic equations obtained are solved using a numerical algorithm based on an iterative line-by-line method (TDMA) and relaxation parameters. The process was repeated until convergence.

Variying the grid fineness from 20x20 to 120x120, it became clear that the 60x60 mesh is adequate. The grid used is not uniform in the x direction with more meshes near the walls and interfaces (fluid/porous medium). In the y direction, a uniform grid was considered.

IV- Results :

In this section, numerical results for the streamlines, temperatures and concentrations for various of Lewis numbers Le, Darcy numbers Da, buoyancy ratio N and enclosure inclination angle φ, will be reported. In addition, representative results for the average Nusselt number Nu_m and the average Sherwood number Sh_m at various conditions will be presented and discussed.
In all of these results, the Prandtl number Pr is considered at the value of air (Pr = 0.71) ; the Rayleigh numbers Ra is fixed at 10^5, the aspect ratio(A) and the conductivity ratio (R_k) were fixed at value of 1. The other parameters are chosed in a range as follow :

$$10^{-6} \leq Da \leq 1 \text{ , } -10 \leq N \leq +10 \text{ , } 0.01 \leq Le \leq 5,$$
$$0° \leq \varphi \leq 90°$$

The porosity and thickness of porous medium are respectively fixed at value of ε=0.6 , E =0.33

For exemple, we can observe the effect of the buoyancy ratio on the heat and mass transfer, for various Darcy numbers (**figure 2-a &2-b**) ; and the effect of enclosure inclination angle on the average Nusselt and Sherwood numbers, for several values of Lewis number (**figure 3-a &3-b**).

Figure 2-a & 2-b show that the average Nusselt and Sherwood numbers increse with augmentation of the buoyancy ratio and the permeability.

At N =-1 and R_k = ε = Le =1, the energy equation and the concentration balance are identical, so, the temperature and the concentration dimensionless fields will be similar ($Nu_m = Sh_m$).

* Correspondence
e-mail : khedbouh@yahoo .fr

The particular value of the buoyancy ratio N= -1 gives a minimum of heat and mass transfer ; this configuration is agrees with filtration and thermal isolation processes.

Figure 3-a present the average Nusselt number versus the enclosure inclination angle variation for same Lewis numbers.

We show that the thermal exchange begin by an important value at φ = 0° and decreases until a minimum value when the inclination angle is near 30°. After this value the Nusselt number increases continuously until an, other maximal value for φ = 90°.

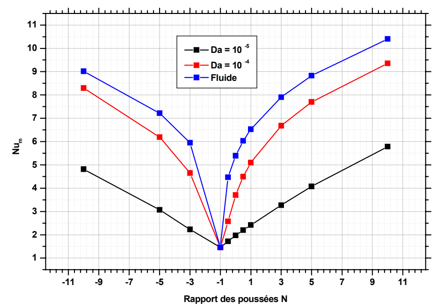

Figure 2-a: Average Nusselt number fonction of buoyancy ratio N, for Ra = 10^{+5}, Le =1, φ = 0, ε = 1, E = 0.33

For mass transfer, **figure 3-b** shows that the average Sherwood number evolution is qualitatively the same than for the heat transfer. So, we find that the mass exchange is maximum at φ =0° and minimal near 30° ; this observation is available for any value of Lewis number.
On the contrary of the thermal exchange, the mass transfer is more important when the value of Lewis number is high.

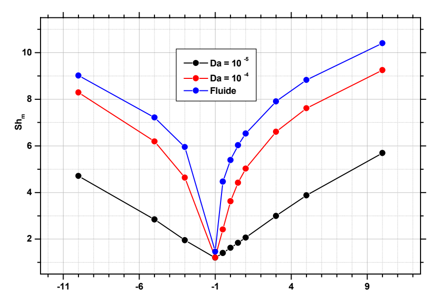

Figure 2-b: Average Sherwood number fonction of

buoyancy ratio N, for Ra = 10^{+5}, Le =1, φ = 0, ε = 1, E = 0.33

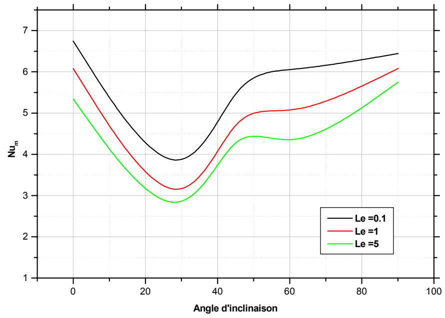

Figure 3-a : Average Nusselt number fonction of enclosure inclination agle, for Da = 10^{-3}, Ra = 10^{+5} , ε = 0.6, N =1, E=0.33

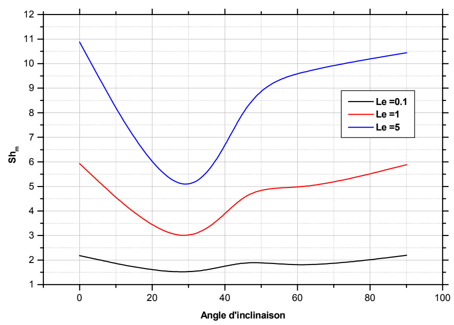

Figure 3-b : Average Sherwood number fonction of enclosure inclination agle, for Da = 10^{-3}, Ra = 10^{+5} , ε = 0.6, N =1, E=0.33

V- Conclusion :

The problem of double-diffusive flow inside an inclined square cavity wich is divided by a porous medium was studied numerically. The numerical finite volume method was employed to resolve the governing equations wich describe the problem.

Graphical results for various parametric conditions were presented and discussed. It was found that the heat and mass transfer mechanisms and the flow evolution inside the enclosure depend strongly on the dimensionless characteristic parameters (Lewis number Le, Darcy number Da, buoyancy ration N and enclosure inclination angle φ).

* Correspondence
e-mail : khedbouh@yahoo .fr

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