Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2016.1154711

57 (2016) 23217–23224
October

Numerical study of double-diffusive convection developed within horizontal partially porous enclosure

Noureddine Hadidi[a,*], Rachid Bennacer[b], Yacine Ould-amer[c]

[a]*Department of Process Engineering and Environment, University Dr. Yahia Farès of MEDEA, Neighborhood Ain D'Hab MEDEA 26000, Algeria, Tel. +213 025 78 58 31; email: hadd71@yahoo.fr*
[b]*Department of Civil Engineering, LMT-ENS Cachan, 61 av. du President Wilson, F-94235 Cachan Cedex, France, email: Rachid.Bennacer@ens-cachan.fr*
[c]*Department of Energy, USTHB, FGMGP, LTPMP, B.P. 32 El Alia Bab Ezzouar, 16111 Alger, Algeria, email: youldamer@usthb.dz*

Received 22 May 2015; Accepted 11 February 2016

ABSTRACT

The present work deals the heat and mass transfer generated in horizontal partially porous enclosure. The vertical walls are subjected to of uniform conditions of temperature and concentration whereas the horizontal walls are assumed to be adiabatic and impermeable. The set of equations describing the double diffusive convection are solved numerically using the numerical control volume approach. The numerical results are presented and analyzed in terms of streamlines, isotherms, isoconcentrations lines and for the average Nusselt and Sherwood numbers.

Keywords: Double diffusive; Porous media; Partially porous enclosure; Numerical study

1. Introduction

Heat and mass transfer by natural convection in fluid and porous media is relevant to a wide range of industrial processes or environmental situations, such as soil pollution, thermal insulation, grain storage, dispersion of chemical contaminations through water saturated soil, fuel cells, drying and dehydration operations in chemical and food processing plants, thermal energy storage system, storage of nuclear waste, diffusion of the chemical elements in reactive porous beds (coal gasification), material and separation processes, storage of agricultural products, storage of nuclear waste, solar collectors with a porous absorber, chemical processes [1–5]. For this purpose, many very intense research activities over the past decades, has been done on modeling the phenomenon of double diffusive convection in a composite cavity. A very detailed summary of the work done in the past is presented in the book of Nield and Bejan [6]. Recently Most studies on steady or unsteady double diffusive natural convection induced in an in cavity filled with porous medium saturated by a fluid consider a single layer of porous medium, lid-driven enclosure and in composite with various boundary conditions. Among these studies, we can mention the numerical investigations by using finite-difference technique in lid-driven square cavity, in two-sided

*Corresponding author.

Presented at EuroMed 2015: Desalination for Clean Water and Energy Palermo, Italy, 10–14 May 2015. Organized by the European Desalination Society.

lid-driven inclined porous enclosure with presence or not heat generation, the purpose of these studies is to examine the effects of the thermal radiation and internal heat generation on natural or mixed convection flow, the numerical results are presented in terms of velocity and temperature at the mid-horizontal plane of the cavity, local Nusselt number and average, streamlines and isotherms for various values of governing physical parameters, treat by [7–9]. Other research by Mahapatra et al., studied and analyzed numerically the influence of thermal radiation alone or combined with heat generation on natural convection, non-Darcian natural convection in a square cavity filled with uniform porosity or Darcy–Forchheimer porous medium, as well as the study of heat generation effect in an inclined enclosure under the influence of magnetic field on unsteady two-dimensional laminar natural convection flow, the results show that the flow characteristics and the convection inside the tilted enclosure depend strongly upon the strength, direction of the magnetic field and the inclination of the enclosure presented by [10–13]. Also the effects of Buoyancy ratio on steady or unsteady double-diffusive natural convection with uniform or non-uniform boundary conditions in a porous cavity or in a lid-driven cavity and in an inclined rectangular lid-driven with different magnetic field analyzed by [14–16]. More Recently numerical and analytical studies of double-diffusive convection in bi-layered and inclined porous enclosure and for three dimensional in cubical enclosure partially filled by vertical porous layer, the numerical results are presented and analyzed in terms of streamlines, isotherms, isoconcentrations lines and average Nusselt and Sherwood numbers. A scale analysis is used to characterize the effect of the permeability ratio on the heat and mass transfer in case two dimensional [17–19]. The main focus of the present investigation is to study numerically a double-diffusive natural convective in a confined enclosure partially filled with a porous medium and this study focused on the effect of porosity and different Darcy modified (Ra_m) numbers, Lewis number and Buoyancy ratio (N) on streamlines and heat and mass transfer. The analysis of many previous studies, we showed that most of them deal double-diffusive convection in porous media are undertaken using one layer of porous medium, while in practice, porous media are often as several layers forming the structure, and they are generally designated as multilayer in nature. As practical application, it can refer to ground water exposed to the contamination, or moisture migration in grain storage systems. The numerical procedure used to solve the full governing equations is then discussed. The results are presented in terms of streamlines, isotherms, and isoconcentrations lines and are mainly analyzed in terms of the average heat and mass transfers at the walls of the enclosure.

2. Mathematical model

The considered physical problem in the present work is shown in Fig. 1. The cavity contains two porous layers arranged horizontally. It is considered infinitely long, square cross-section. In this case a two-dimensional and laminar convection thermosolutal established in the porous walls. The density is considered constant except in terms of thrust (Boussinesq hypothesis). A local thermodynamic equilibrium occurs between the fluid and the porous medium. The model considered is the Darcy–Brinkman. The governing equations written in dimensionless form are written mathematically as follows:

$$\frac{\partial U_i}{\partial X} + \frac{\partial V_i}{\partial Y} = 0 \tag{1}$$

$$\frac{1}{\varepsilon_i^2}\left[U_i\frac{\partial U_i}{\partial X} + V_i\frac{\partial U_i}{\partial Y}\right] = -\frac{\partial P_i}{\partial X} - \frac{Pr}{Da_i}U_i + R_v\,Pr\left(\frac{\partial^2 U_i}{\partial X^2} + \frac{\partial^2 U_i}{\partial Y^2}\right) \tag{2}$$

$$\frac{1}{\varepsilon_i^2}\left[U_i\frac{\partial V_i}{\partial X} + V_i\frac{\partial V_i}{\partial Y}\right] = -\frac{\partial P_i}{\partial Y} - \frac{Pr}{Da_i}U_i + R_v\,Pr\left(\frac{\partial^2 V_i}{\partial X^2} + \frac{\partial^2 V_i}{\partial Y^2}\right) + Ra\,Pr[\theta_i + NS_i] \tag{3}$$

$$U_i\frac{\partial \theta_i}{\partial X} + V_i\frac{\partial \theta_i}{\partial Y} = R_c\left(\frac{\partial^2 \theta_i}{\partial X^2} + \frac{\partial^2 \theta_i}{\partial Y^2}\right) \tag{4}$$

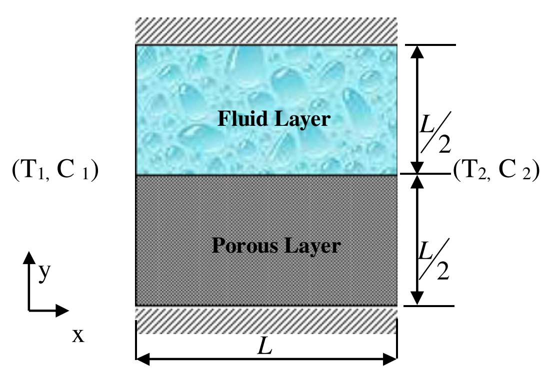

Fig. 1. Physical model and coordinates system.

$$U_i \frac{\partial S_i}{\partial X} + V_i \frac{\partial S_i}{\partial Y} = \frac{1}{Le}\left(\frac{\partial^2 S_i}{\partial X^2} + \frac{\partial^2 S_i}{\partial Y^2}\right) \quad (5)$$

The index i denotes the porous layer, it takes the values 1 or 2. The parameters appearing in these equations are defined in the nomenclature. The dimensionless boundary conditions for the problem can be written mathematically form by:

$$\text{For } Y = 0 \quad 0 \le X \le 1 \quad U_i = V_i = 0 \quad \left.\frac{\partial \theta_i}{\partial Y}\right| = 0 \quad \left.\frac{\partial S_i}{\partial Y}\right| = 0 \quad (6)$$

$$\text{For } Y = 1 \quad 0 \le X \le 1 \quad U_i = V_i = 0 \quad \left.\frac{\partial \theta_i}{\partial Y}\right| = 0 \left.\frac{\partial S_i}{\partial Y}\right| = 0 \quad (7)$$

$$\text{For } X = 0 \quad 0 \le Y \le 1 \quad U_i = V_i = 0 \quad \theta_i = -0.5 \quad S_i = -0.5 \quad (8)$$

$$\text{For } X = 1 \quad 0 \le Y \le 1 \quad U_i = V_i = 0 \quad \theta_i = 0.5 \quad S_i = 0.5 \quad (9)$$

At side of the boundary conditions, one associates also the conditions of continuity the interfaces. The setting in no dimensional from of the governing equations gave rise to a group of dimensionless parameters, namely, the Darcy number (*Da*) of porous layer, the Rayleigh number (Ra) and the Prandtl number (Pr).

3. Numerical procedure

The set of differential equations governing free convection in the porous cavity is transformed into a system of algebraic equations with the use of the control volume approach. The SIMPLER algorithm is used for the calculation of the flow field and temperature. The system of algebraic equations is solved iteratively by means of the Thomas algorithm. Under-relaxation factors are introduced to avoid the divergence of the strongly non-linear system. A staggered grid of 82 × 82 nodes was selected on the basis of a grid sensitivity study presented in Table 1. Convergence is controlled in terms of the relative error for the variables$U$, V, P, θ and S and the mass residual on each control volume. The convergence criterion is: $\left|\frac{\Phi_{ij}^{n+1} - \Phi_{ij}^{n}}{\Phi_{ij}^{n}}\right| < 10^{-5}$ and |mass residual| $< 10^{-6}$ with Φ corresponding to U, V, P, S or θ, and n and $n+1$ indicating two consecutive iterations. The discontinuity between the two porous layers is handled with the use of the harmonic mean formulation suggested by Patankar [20]. The present code was validated by comparing the results obtained with our code with studies presented in literature. Good agreement was observed, i.e. see for instance Tables 2 and 3.

Table 1
Grid sensitivity for $Ra_m = 7 \times 10^3$, $Da = 10^{-5}$, $Pr = 7$, $N = 1$, $Le = 100$

Grid	22 × 22	42 × 42	62 × 62	82 × 82	122 × 122
Nu	10.85	9.79	9.66	9.60	9.55
% Error	–	10.83	1.34	0.62	0.5
Sh	36.14	64.92	66.46	62.90	63.13
% Error	–	44.33	2.32	5.67	0.37

4. Results and discussion

Numerical simulations cover a wide range of parameters in the case of a bi-layered porous cavity porous, each layer is considered homogeneous and isotropic. For the numerical simulation of this study, we consider an aqueous solution as a fluid saturating the porous layer ($Pr = 7$). Porosity, conductivity ratio, Lewis number and the buoyancy ratio (N) are respectively set to 0.5 (first layer of porous medium), 1 (second layer of fluid), 1, 100 and 3. We placed in the domain cooperating buoyancy forces ($N > 0$).

The study of the effect of parameters variation, cited above, on the heat and mass transfer is analyzed. The results presented here cover the following ranges: the permeability ratio *Da* varied from 10^{-4} to 10^4, the modified Rayleigh number ($Ra_m = Ra \times Da_1$) is ranging from 1 to 10^3, the buoyancy force N varied from 0 to 15, Lewis number varied from 1 to 100. First, we have analyzed the effect of permeability ratio on the transfers independently of other parameters. Next, we have studied the effects on the heat and mass transfers, of the modified Rayleigh number (Ra_m), the buoyancy ratio (N) and the Lewis number. The numerical simulation results are represented as curves and include the shape of the streamlines, isotherms and isoconcentrations lines. The heat and mass transfer are translated in to the average numbers of Nusselt and Sherwood.

The flow structures, isotherms and isoconcentrations lines are presented in Figs. 2–4. For a situation presenting a low value of permeability of first layer, *Da* equal to 10^{-6} a significant resistance to the flow in the porous layer is noted. This behavior is due to the low permeability of the first layer. For this purpose, the fluid circulation in second layer (fluid) is more favorable and the thermosolutal convection is more

Table 2
Comparison of Nusselt and Sherwood for $N = 0$, $Da = 10^{-7}$, and $Pr = 0.71$

	Ra_m	100	200	400	1,000	2,000	
Bennacer et al. [21]	*Nu*	3.11	4.96	7.77	13.48	19.89	$Le = 10$
	Sh	13.24	19.83	29.36	48.20	69.08	
Goyeau et al. [22]	*Nu*	3.11	4.96	7.77	13.47	19.90	
	Sh	13.25	19.86	28.41	48.32	69.29	
Bourich et al. [23]	*Nu*	3.11	4.96	–	13.76	–	
	Sh	13.27	20.02	–	47.4	–	
Akbal and Baytas [24]	*Nu*	3.05	4.85	7.59	13.16	19.48	
	Sh	12.93	19.42	28.9	48.21	70.45	
Present code	*Nu*	3.11	4.96	7.77	13.49	19.91	
	Sh	13.32	19.98	29.55	48.28	68.48	

Table 3
Comparison of Nusselt number in the case of regime Darcy–Brinkman for $Pr = 0.71$ and $N = 0$

	Da	10^{-8}	10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}
Bennacer et al. [21]	$Ra_m = 500$	8.80	8.68	8.37	7.30	5.38	3.26
Lauriat and Prasad [25]		8.84	8.72	8.41	7.35	5.42	3.30
Present code		8.94	8.85	8.42	7.30	5.38	3.26
Bennacer et al. [21]	$Ra_m = 10^3$	13.48	–	12.26	–	–	4.18
Lauriat and Prasad [25]		13.41	–	12.42	–	–	4.26
Present code		13.51	–	12.41	–	–	4.18

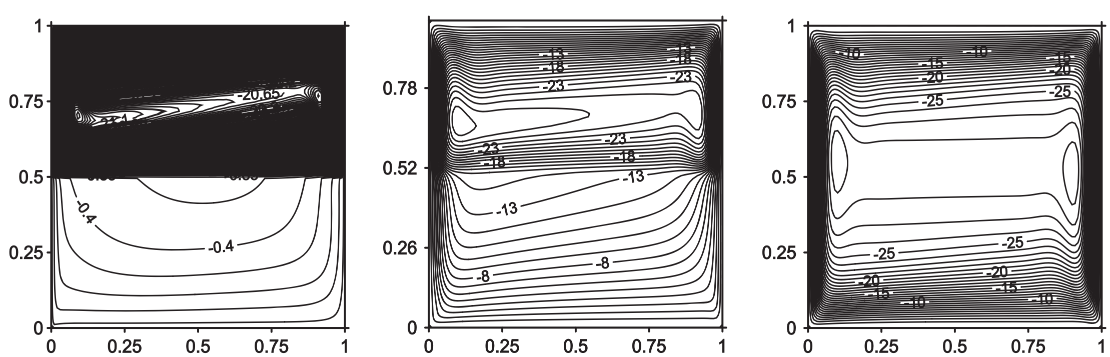

Fig. 2. Streamlines representation for various values of $Da = (10^{-6}, 10^{-4}$, and $10^{-2})$ and for $Ra = 7 \times 10^6$.

pronounced in this second layer. Indeed, the isotherms are distorted and an intensive temperature gradient takes place in the second layer whereas the isoconcentrations lines are distorted in both layers with formation of a solutal boundary layer on the vertical walls because the Lewis number is high ($Le = 100$). The isotherms in the first layer are parallel to the vertical walls, indicating that the heat transfer tends to a diffusive situation. The flow is more accelerated in porous layer with higher permeability ($Da = 10^{-4}$), the isotherms are distorted and take place for the entire cavity, the thermal boundary layer tends to be formed, located respectively on the lower and upper parts of the lateral walls. Passing for high permeability *Da* equal to 10^{-2}, the structure of streamlines very affected are elliptical extended and rotary cell fills entirely the cavity, the hydrodynamic boundary layer takes place on the walls. The isotherms are distorted and take place for the entire cavity, the thermal boundary layer tends to be formed, located on the lateral walls.

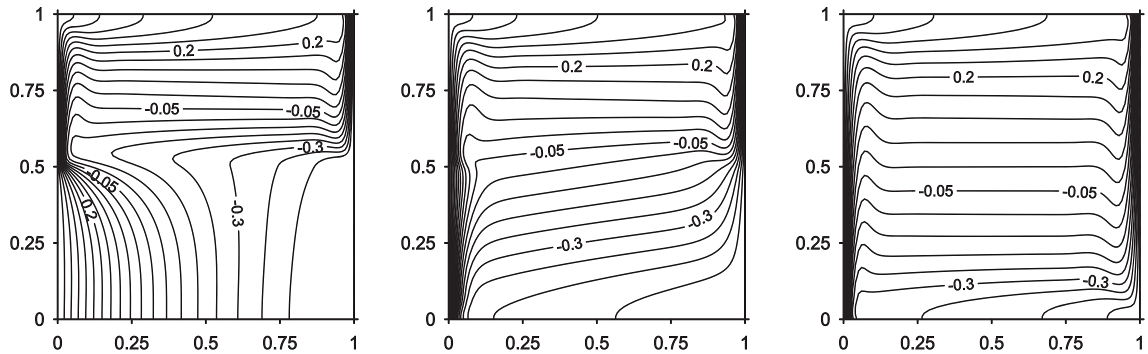

Fig. 3. Isotherms representation for various values of $Da = (10^{-6}, 10^{-4}$, and $10^{-2})$ and for $Ra = 7 \times 10^6$.

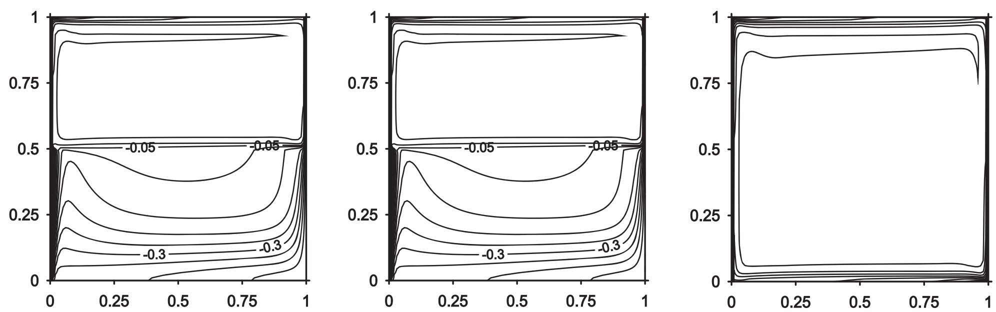

Fig. 4. Isoconcentrations representation for various values of $Da = (10^{-6}, 10^{-4}$, and $10^{-2})$ and for $Ra = 7 \times 10^6$.

Indeed, the thermosolutal convection is well pronounced in two layers. The isoconcentrations lines are, also distorted and take place the entire cavity with a significant tightening on the vertical walls of the cavity. A solutal boundary layer takes place on the lateral walls because the Lewis number is high. We note the tendency to the situation of non-dependence of the flow structures, of isotherms and isoconcentrations lines with the permeability high values of *Da*.

Fig. 5(a) and (b) illustrate the evolution of heat and mass transfer means according of *Da* for two values of *Ra* 7×10^6 and 10^4. These transfers are quantified in terms of Nusselt and Sherwood means. The above results show the existence of three regimes for the evolution of the heat and mass transfer with the permeability (*Da*). Thus, we have a diffusive regime for low values of *Da*, an intermediate regime for intermediate values of *Da* in which both *Nu* and *Sh* increase

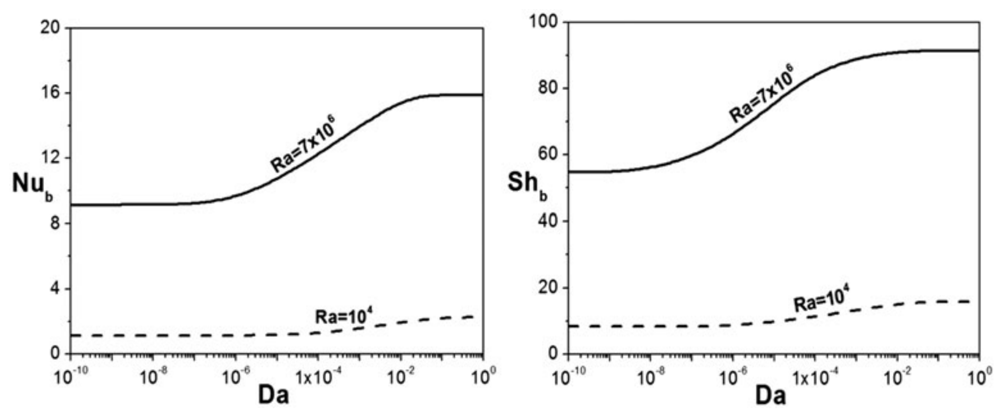

Fig. 5. Effect of Rayleigh number on transfers for $N = 3$, $Le = 100$, $Da = (10^{-10}–1)$.

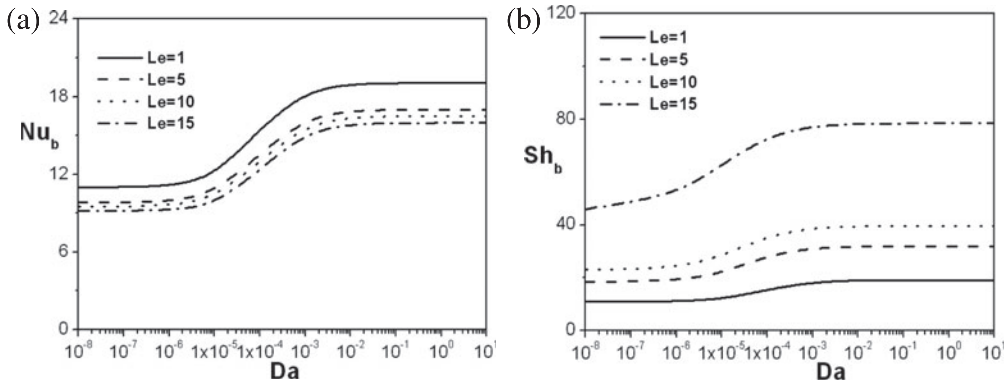

Fig. 6. Effect of Lewis number on transfers for $Ra = 7 \times 10^6$, $N = 1$: (a) heat transfer and (b) mass transfer.

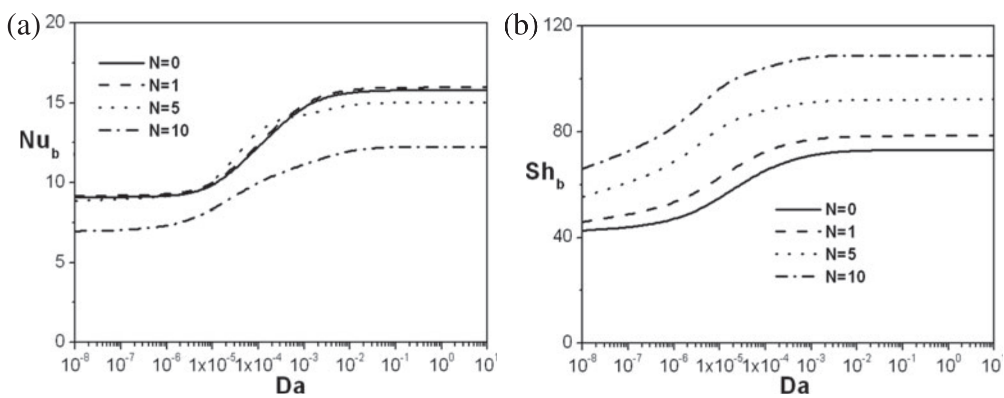

Fig. 7. Effect of buoyancy ratio on transfers for $Ra = 7 \times 10^6$ and $Le = 100$: (a) heat transfer and (b) mass transfer.

with increasing *Da* and a convective regime for high values of *Da* where *Nu* and *Sh* reach a maximum and are found to be independent of the permeability. The transition between the two regimes convective is made for a connecting value noted Da^{Cr}.

In this section, the effect of Lewis number on the transfer has been processed. Variations of Nusselt and Sherwood means according of *Da* for different values of (*Le*) are shown in Fig. 6(a) and (b). Since we are in the case of the thermosolutal convection origin heat and solutal the same size ($N = 1$), the mass transfer significantly increases with (*Le*) for the *Da* is fixed, which is not the case for the average Nusselt number.

Fig. 7(a) and (b) show the influence of buoyancy ratio (*N*) for Rayleigh number $Ra = 7 \times 10^6$ and for high value of Lewis number ($Le = 100$), it is clear that mass transfer (Sh_b) increases with increasing *N* due to the increase of the volume solutal force (high value of *Le*), by against the values of the Nusselt number (Nu_b) decreases with increasing *N* this decrease, is due to reduced of the volume thermal force resulting from the $Le = 100$. For a fixed value of *N*, there are three regimes, namely, a diffusive regime for low values of *Da*, a transition regime where mean Nusselt and Sherwood numbers *Nu* and *Sh* increase with an increase of *Da* and an asymptotic regime where *Nu* and *Sh* become independent of *Da*.

5. Conclusion

The results presented in this paper show the main trends of double diffusive, natural convection in a saturated porous layer and an overlying fluid layer in an enclosure is analyzed numerically. The analysis of the numerical results presented in this study clearly shows the dependence of the average heat transfer and mass transfer on the double diffusive parameters such as; the permeability of porous medium (*Da*), the buoyancy ratio (*N*), Rayleigh number (*Ra*) and Lewis number (*Le*). The presence of the porous layer has a strong effects on the heat and mass transfer and the modification of the flow structure, these effects depends essentially on permeability of porous layer and of the parameters related to the double diffusive natural convection characteristics, previously cited.

Nomenclature

a	—	thermal diffusivity of porous medium (m^2/s)
C	—	dimensional solute concentration (kg/m^3)
D	—	mass diffusivity (m^2/s)
Da_i	—	Darcy number of layer i, $Da_i = K_i/L^2$
g	—	gravitational acceleration (m/s^2)
k_i	—	thermal conductivity of porous layer i (W/m℃)
K_i	—	permeability of layer i (m^2)
L	—	width of porous cavity (m)
Le	—	Lewis number, $Le = a_{eff_i}/D_{eff_i}$
Nu_b		average Nusselt number, $Nu_b = \int_0^1 \left[\frac{\partial\theta}{\partial X}\right]_{X=0} dY$
N	—	Buoyancy ratio, $N = \beta_C \Delta C/(\beta_T \Delta T)$
P	—	dimensionless pressure, $P = pL^2/(\rho_f a^2/\varepsilon^2)$
Pr	—	Prandtl number, $P_r = v_f/a_{eff_i}$
Ra	—	Rayleigh number, $Ra = g\beta_T L^3 \Delta T/v_f a_{eff_1}$
R_c	—	conductivity ratio, $R_c = k_{eff_i}/k_{eff_1}$
R_v	—	relative viscosity, $R_v = \mu_{eff_i}/\mu_f$
Sh_b	—	average Sherwood number, $Sh_b = \int_0^1 \left[\frac{\partial S}{\partial X}\right]_{X=0} dY$
		dimensionless concentration,
S	—	$S = (C - C_1 + C_2)/2)/(C_1 - C_2)$
u	—	velocity component in x direction (m/s)
U	—	dimensionless velocity component in x direction, $U = uL/a$
V	—	dimensionless velocity component in y direction, $U = vL/a$
v	—	velocity component in y direction (m/s)
x	—	horizontal coordinate (m)
X	—	dimensionless horizontal coordinate, $X = x/L$
y	—	vertical coordinate (m)
Y	—	dimensionless vertical coordinate, $Y = y/L$

Greek symbols

β_s	—	coefficient of volumetric solutal expansion (m^3/kg)
β_T	—	coefficient of volumetric thermal expansion (K^{-1})
ρ	—	density of the fluid (kg/m^3)
μ_{eff}	—	apparent dynamic viscosity for Brinkman's model (kg/m/S)
v	—	Kinematics viscosity (m^2/s)
ε	—	porosity
θ	—	dimensionless temperature, $\theta = (T - (T_1 + T_2)/2)/(T_1 - T_2)$
ΔT	—	difference de température, $\Delta T = T_1 - T_2$ (℃)
Δc	—	concentration difference, $\Delta c = c_1 - c_2$

Subscripts

b	—	average
eff	—	effective
f	—	fluid
i	—	layer

References

[1] C. Béghein, F. Haghighat, F. Allard, Numerical study of double-diffusive natural convection in a square cavity, Int. J. Heat Mass Transfer 35 (1992) 833–846.

[2] A.C. Baytas, A.F. Baytas, D.B. Ingham, I. Pop, Double diffusive natural convection in an enclosure filled with a step type porous layer: Non-Darcy flow, Int. J. Therm. Sci. 48 (2009) 665–673.

[3] M. Hasan, A.S. Mujumdar, Simultaneous mass and heat transfer under mixed convection along a vertical cone, Int. J. Energy Res. 9 (1985) 129–140.

[4] A.M. Al-Amiri, K.M. Khanafer, I. Pop, Numerical simulation of combined thermal and mass transport in a square lid-driven cavity, Int. J. Therm. Sci. 46 (2007) 662–671.

[5] L.B. Younis, A.A. Mohamad, A.K. Mojtabi, Double diffusion natural convection in open lid enclosure filled with binary fluids, Int. J. Therm. Sci. 46 (2007) 112–117.

[6] D.A. Nield, A. Bejan , Convection in Porous Media, third ed., Springer-Verlag, New York, NY, 2006.

[7] T.R. Mahapatra, D. Pal, S. Mandal, Natural convection in a lid-driven square cavity filled with Darcy–Forchheimer porous medium in the presence of thermal radiation, Int. J. Nonlinear Sci. 11(3) (2011) 366–379.

[8] S. Mandal, T.R. Mahapatra, D. Pal, Natural convection in a two-sided lid-driven inclined porous enclosure with sinusoidal thermal boundary condition, Int. J. Mech. Eng. Technol. 3(3) (2012) 187–202.

[9] T.R. Mahapatra, D. Pal, S. Mandal, Mixed convection in a lid driven square cavity filled with porous medium in presence of thermal radiation and non-uniform heating, Int. J. Appl. Math. Mech. 9(13) (2013) 23–51.

[10] T.R. Mahapatra, D. Pal, S. Mandal, Influence of thermal radiation on non-Darcian natural convection in a square cavity filled with fluid saturated porous medium of uniform porosity, Non-linear Anal.: Model. Control 17(2) (2012) 223–237.

[11] T.R. Mahapatra, S. Mandal, D. Pal, Heat generation effects in an inclined enclosure under the influence of magnetic field, ARPN J. Sci. Technol. 2(6) (2012) 556–561.

[12] T.R. Mahapatra, D. Pal, S. Mandal, Combined effects of thermal radiation and heat generation on natural convection in a square cavity filled with Darcy–Forchheimer porous medium, Int. J. Appl. Math. Comput. 4 (4) (2012) 359–368.

[13] T.R. Mahapatra, D. Pal, S. Mondal, Mixed convection flow in an inclined enclosure under magnetic field with thermal radiation and heat generation, Int. Commun. Heat Mass Transfer 41 (2013) 47–56.

[14] T.R. Mahapatra, D. Pal, S. Mondal, Effects of buoyancy ratio on double-diffusive natural convection in a lid-driven cavity, Int. J. Heat Mass Transfer 57 (2013) 771–785.

[15] S. Mondal, P. Sibanda, Effects of buoyancy ratio on unsteady double-diffusive natural convection in a cavity filled with porous medium with non-uniform boundary conditions, Int. J. Heat Mass Transfer 85 (2015) 401–413.

[16] S. Mondal, P. Sibanda, Unsteady double diffusive convection in an inclined rectangular lid-driven enclosure with different magnetic field angles and non-uniform

boundary conditions, Int. J. Heat Mass Transfer 90 (2015) 900–910.
[17] N. Hadidi, Y. Ould-Amer, R. Bennacer, Bi-layered and inclined porous collector: Optimum heat and mass transfer, Energy 51 (2013) 422–430.
[18] N. Hadidi, R. Bennacer, Y. Ould-amer, Two-dimensional thermosolutal natural convective heat and mass, transfer in a bi-layered and inclined porous enclosure, Energy 93 (2015) 2582–2592.
[19] N. Hadidi, R. Bennacer, Three-dimensional double diffusive natural convection across a cubical enclosure partially filled by vertical porous layer, Int. J. Therm. Sci. 101 (2016) 143–157.
[20] S. Patankar, Numerical Heat Transfer and Fluid Flow, Hemisphere, New York, NY, 1980.
[21] R. Bennacer, A. Tobbal, H. Beji, Convection naturelle thermosolutale dans une cavité poreuse anisotrope: Formulation de Darcy–Brinkman (Thermosolutal natural convection in anisotropy porous cavity: Formulation of Darcy–Brinkman), Rev. Energ. Ren. 5 (2002) 1–21.
[22] B. Goyeau, J.P. Songbe, D. Gobin, Numerical study of double-diffusive natural convection in a porous cavity using the Darcy–Brinkman formulation, Int. J. Heat Mass Transfer 39 (1996) 1363–1378.
[23] M. Bourich, M. Hasnaoui, A. Amahmid, Double-diffusive natural convection in a porous enclosure partially heated from below and differentially salted, Int. J. Heat Fluid Flow 25 (2004) 1034–1046.
[24] S. Akbal, F. Baytaş, Effects of non-uniform porosity on double diffusive natural convection in a porous cavity with partially permeable wall, Int. J. Therm. Sci. 47 (2008) 875–885.
[25] G. Lauriat, V. Prasad, Natural convection in a vertical porous cavity: A numerical study for Brinkman-extended Darcy formulation, J. Heat Transfer 109 (1987) 688–696.