HEAT AND MASS TRANSFER IN COMPOSITE FLUID–POROUS LAYER: EFFECT OF PERMEABILITY

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الخلاصـة :

نُجري في هذا البحث تمثيلاً عددياً لسريان انتشارٍ ثنائيٍّ مستقر ذى بعدين في طبقةِ مائعٍ مساميةٍ مركبةٍ. ومع الأخذ بتدرج درجة الحرارة و المذاب أفقيا ودراسة أثريْ الطَّـفوٍّ فقد يزيد أو يُنقص أحدهما الأخر. لقد شـُكِّل الوسطُ المساميّ وفقًا لنموذج (دارسي-- برنكمن و فوركهيمر وخوارزمية SIMPLER) الذي يعتمد على تقريب محددة الحجوم المستخدمة لحلِّ مزدوجِ السرعة–الضغط. كما أُجريت السلاسل الممتدة للتشابه العددي في المراحل التالية ، $١٠^{٣} \le Gr \le ١٠^{٦}$ ، $١٠^{-٨} \le Da \le ١$ ، $-٢٠ \le N \le ٢٠$ و $١ \le Le \le ١٠^{٢}$ ومن الواضح أنَّ التأثير الرئيس لوجود الطبقة المسامية هو التقليل من انتقال الحرارة والكتلة عندما تقل السماحية. مع التوافق المناسب للأرقام (غراشف ولويس ونسبة الطفو). كما قمنا بتوضيح نماذج جريان متعددة الخلايا.

مفاتيح الكلمات: ثنائي الانتشار ، وسط مائع ، أوساط المسامية ، انتقال الحرارة و الكتلة ، الحجوم المحددة.

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Abstract

Numerical simulations are conducted for two-dimensional, steady state, double diffusive flow in a composite fluid–porous layer. Both the temperature and solute gradients are imposed horizontally, and the two buoyancy effects can either augment or counteract each other. The porous medium is modeled according to the Darcy–Brinkman and Forchheimer model, and the SIMPLER algorithm, based on the finite volume approach, is used to solve the pressure–velocity coupling. An extensive series of numerical simulations is conducted in the range: $10^3 \le Gr \le 10^6$, $10^{-8} \le Da \le 1$, $-20 \le N \le 20$, and $1 \le Le \le 10^2$. It is shown that the main effect of the presence of the porous layer is to reduce the heat and mass transfer when the permeability is reduced. With appropriate combination of Grashof number, Lewis number, and the buoyancy ratio, multiple cell flow patterns are illustrated.

Keywords: Double diffusion, Porous media, Heat and mass transfer, Finite volume.

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1. INTRODUCTION

Double-diffusive natural convection in a fluid saturated porous medium occurs in a wide variety of applications such as geothermal energy, fibrous insulating materials, and cryogenic systems. The combined heat and mass transfer in porous media is limited because of complexities involved in double-diffusive natural convection. Most of the previous studies on this topic use Darcy's law for solving the flow within the porous medium [1]. Natural convection of heat and mass in a square porous cavity subjected to a constant temperature and concentration has been investigated by Trevisan and Bejan [1]. These authors use the Darcy model for modeling the flow in a porous medium. The numerical study has been carried out for a range of Darcy–Rayleigh numbers, Lewis numbers, and buoyancy ratios. Our studies focus on combined thermal and solutal natural convection of a binary fluid in a closure partially filled by a porous medium and submitted to a transverse magnetic field. Such a configuration has been previously studied in the case of thermal convection by Le Breton *et al.* [2]. This study shows that the main effect of the porous medium is to reduce the upwind flow and then to decrease the convective heat transfer. Lage [3] studied the effect of the convective inertia term on Bénard convection in a porous medium, and he showed that the inertia term included in the general momentum equations has no effect on overall heat transfer. Bian *et al.* [4] considered the interaction of an external magnetic field with convection currents in a porous medium. The porous medium was modeled according to Darcy's model and it was found that with the applied magnetic field, the temperature and velocity fields are significantly modified. The aim of this paper is to analyze double diffusion natural convection flow in the presence of a porous layer and the flow is modeled using the generalized model of Darcy–Brinkman–Forchheimer. It is of interest to study the effect of a thin porous layer on the heated wall and especially on the evolution of the overall heat and mass transfer.

2. PROBLEM DEFINITION AND GOVERNING EQUATIONS

The problem considered is the two-dimensional natural convection flow in a vertical square cavity which is saturated by a binary fluid, see Figure 1. Horizontal temperature and concentration differences are considered between the vertical

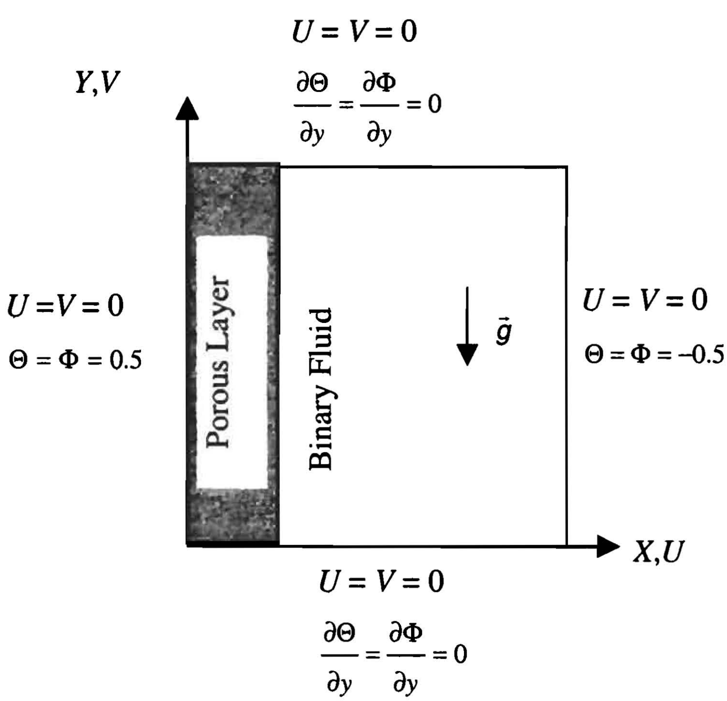


Figure 1. The physical model and coordinate system.

walls, and zero mass and heat flux are imposed at the horizontal walls. Both the velocity components are equal to zero at the boundaries and the left hand vertical wall is covered with a thin porous layer. In order to simplify the analysis, some assumptions have been made, as follows.

- The binary fluid is assumed to be Newtonian, incompressible, and to satisfy the Boussinesq approximation.
- The flow in the cavity is laminar and two-dimensional.
- The porous medium is assumed to be isotropic, homogeneous, and in thermodynamical equilibrium with the binary fluid.
- The Soret and Dufour effects are neglected.

The density variations depend on the temperature and concentration and are described by the state equation:

$$\rho = \rho_0[1-\beta_T(T-T_0)-\beta_C(C-C_0)] \ ,$$

where $\beta_T = -\frac{1}{\rho}\left[\frac{\partial \rho}{\partial T}\right]_C$ and $\beta_C = -\frac{1}{\rho}\left[\frac{\partial \rho}{\partial C}\right]_T$.

We now introduce the dimensionless parameters as follows:

$$(X,Y)=\frac{(x,y)}{H},\quad (U,V)=\frac{(u,v)}{(\alpha_p/H)(Ra\Pr)^{1/2}},\quad \tau=\frac{t}{(H^2/\alpha_p)}(Ra\Pr)^{1/2},\quad \lambda=\frac{(\rho Cp)_p}{(\rho Cp)_f},$$

$$\Theta=\frac{T-(T_1+T_2)/2}{T_1-T_2},\quad \Phi=\frac{C-(C_1+C_2)/2}{C_1-C_2},\quad P=\frac{\varepsilon^2 H^2(p+\rho_f g y)}{\rho_f\alpha_p(Ra\Pr)} \ ;$$

and the governing dimensionless equations become:

continuity equation:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \ ; \tag{1}$$

X-momentum equation:

$$\frac{1}{\varepsilon}\frac{\partial U}{\partial \tau}+(\mathbf{V}.\nabla)U=-\frac{\partial P}{\partial X}+\varepsilon\left(\frac{\Pr}{Ra}\right)^{1/2}\nabla^2 U-\frac{C_f\varepsilon^2}{\sqrt{Da}}|\mathbf{V}|U-\frac{\varepsilon^2}{Da}\left(\frac{\Pr}{Ra}\right)^{1/2}U \ ; \tag{2}$$

Y-momentum equation:

$$\frac{1}{\varepsilon}\frac{\partial V}{\partial \tau}+(\mathbf{V}.\nabla)V=-\frac{\partial P}{\partial Y}+\varepsilon\left(\frac{\Pr}{Ra}\right)^{1/2}\nabla^2 V-\frac{C_f\varepsilon^2}{\sqrt{Da}}|\mathbf{V}|V-\frac{\varepsilon^2}{Da}\left(\frac{\Pr}{Ra}\right)^{1/2}V+\varepsilon^2(\Theta+N\Phi) \ ; \tag{3}$$

energy equation:

$$\frac{1}{\lambda}\frac{\partial \Theta}{\partial \tau}+(\mathbf{V}.\nabla)\Theta=\frac{1}{(\mathrm{Ra.Pr})^{1/2}}\nabla^2\Theta \ ; \tag{4}$$

species equation:

$$\varepsilon\frac{\partial \Phi}{\partial \tau}+(\mathbf{V}.\nabla)\Phi=\frac{1}{Le.(Ra.\Pr)^{1/2}}\nabla^2\Phi \ . \tag{5}$$

The variation in space of the permeability leads to $Da \to \infty$ in the fluid region and $\varepsilon \to 1$.

The initial and boundary conditions for the dimensionless equations are as follows.

Initial condition (at $\tau = 0$)

$$\Theta = \Theta_0 = 0, \ \ \Phi = \Phi_0 = 0, \ \ U = V = 0 \ \text{for} \ 0 \le Y \le 1 \ \text{and} \ 0 \le X \le 1/A\}. \tag{6}$$

Boundary conditions:

$$\left.\begin{array}{lll} \Theta = \Phi = 0.5, & U = V = 0 \ \text{for} \ X = 0 & \text{and} \ 0 \le Y \le 1 \\ \Theta = \Phi = -0.5, & U = V = 0 \ \text{for} \ X = 1/A & \text{and} \ 0 \le Y \le 1 \\ \dfrac{\partial \Theta}{\partial Y} = \dfrac{\partial \Phi}{\partial Y} = 0, & U = V = 0 \ \text{for} \ Y = 0 & \text{and} \ 0 \le X \le 1/A \\ \dfrac{\partial \Theta}{\partial Y} = \dfrac{\partial \Phi}{\partial Y} = 0, & U = V = 0 \ \text{for} \ Y = 1 & \text{and} \ 0 \le X \le 1/A \end{array}\right\}. \tag{7}$$

3. NUMERICAL PROCEDURE

The coupled transient equations have been solved to obtain steady state solutions. When a converging result is approached, the transient terms vanish and the steady-state equations are solved. This formulation more over allows us to detect instabilities [2].

The differential equations are discretized in space with the control-volume finite difference method described by Patankar [5]. The resulting finite difference scheme has the form:

$$A_P \phi_P = A_E \phi_E + A_W \phi_W + A_N \phi_N + A_S \phi_S + b \tag{8}$$

and the expressions for the coefficients in Equation (8) may be found in reference [5]. The advection–diffusion part of the coefficients A_E, A_W, A_N, and A_S is modified for stability according to the power law scheme of [5] and b is the source term which includes the value of ϕ_P at the previous time step. The SIMPLER algorithm is adopted to solve the velocity–pressure coupling of Equations (1)–(5).and the convergence of the numerical solution was monitored locally. The max-norm was used for the velocity components U, V, temperature Θ, and concentration Φ, and the convergence criterion at each time step is as follows:

$$\text{Max}\left| \frac{(u,v,\Theta,\Phi)^{i+1} - (u,v,\Theta,\Phi)^{i}}{(u,v,\Theta,\Phi)^{i}} \right| \le 10^{-4}, \tag{9}$$

in which i and $i+1$ denote two consecutive iterations at the same time step.

The simulation are generally performed using 81×81 sinusoidal grid. It is realized that this relatively coarse grid is adequate to resolve all details of the flow structures in the cavity. The selected mesh size should only be viewed as a compromise between accuracy and computational time. The calculations were performed on a PC (700 MHZ).

The average heat and mass transfer at the walls are given in dimensionless terms by the Nusselt and Sherwood numbers defined as follows:

$$\left. Nu = \int_0^1 \left[\frac{\partial \Theta}{\partial x} \right]_{x=0} dy, \qquad Sh = \int_0^1 \left[\frac{\partial \Phi}{\partial x} \right]_{x=0} dy \right\}. \tag{10}$$

4. TEST VALIDATION

The numerical accuracy of the present study has been checked over a large number of purely thermal convection situations in a porous medium and the results obtained have been compared with the results obtained from previous studies in Tables 1 and 2 for the Darcy and combined Darcy–Brinkman representation of the porous medium flow. The validation is performed using 81×81 sinusoidal grid. It may be seen from the tables that the agreement with references [6, 7] is excellent in most cases.

5. RESULTS AND DISCUSSION

In this section, some representative results are presented in order to illustrate the effect of the various controlling parameters, such as the Darcy number, Lewis number, and the buoyancy ratio N.

5.1. Influence of the Porous Layer

The set of simulated results displayed in Figure 2 show the variation of the average Nusselt and Sherwood numbers at the active wall (left hand wall) as a function of X_p, for $Ra = 10^5$, $Da = 10^{-5}$, $Le = 10$, and $N = 1$. The analysis of the figure shows that it is not necessary to introduce a very great thickness of porous medium to obtain a significant decrease of the heat and mass transfer. For a thickness of the porous medium which is greater than 0.305, the Nusselt and Sherwood numbers decrease very slowly for an increasing thickness. This observation is in good agreement with the result reported by Le Breton *et al.* [2]. Further, it can be deduced that the role of the porous layer is actually to reduce the upward flow and the convective heat and mass transfer in the area where it is strongest. It can be also noted that the decrease of heat and mass transfer is more pronounced for very small values of the permeability. Indeed, in Figure 3 we have reported the

Table 1. Darcy Model (Pure Heat Transfer, $N = 0$).

	$\overline{Nu}$			
$Ra^* = Ra.Da$	Lauriat and Prassad [6]	Trevisian and Bejan [1]	Nithiarasu *et al.* [7]	Present Work
10	1.07		1.08	1.06
50		2.02	1.958	1.936
100	3.09	3.27	3.02	2.98
500			8.38	8.32
1000	13.41	18.38	12.514	12.49

Table 2. Darcy–Brinkman Model (Pure Heat Transfer, Pr = 1).

		$\overline{Nu}$		
Ra^*	Da	Lauriat and Prassad [6]	Nithiarasu *et al.* [7]	Present Work
10	10^{-6}	1.07	1.08	1.06
100	10^{-6}	3.06	3.00	2.98
1000	10^{-6}	13.2	12.25	12.11
10	10^{-2}	1.02	1.02	0.99
100	10^{-2}	1.7	1.71	1.68
1000	10^{-2}	4.26	4.26	4.24

streamlines, temperature, and concentration fields for $X_p = 0.2$, $Da = 10^{-8}$, $Ra = 10^5$, $Le = 10$, and $N = 1$. It can be seen from this figure that the flow is confined only in the fluid region, see Figure 3(*a*), with the porous layer having the same role as a solid wall, which is characterized by a quasi-double diffusive heat and mass transfer in which the isotherms and concentration lines are parallel to the vertical wall, Figures 3(*b*) and (*c*).

5.2. Influence of Permeability

In this section, we focus on the role of the permeability of the porous medium, which appears through the Darcy number. Figure 4 displays the average wall Nusselt and Sherwood numbers *versus* the Darcy number, where we observe three distinct zones. When the Darcy number is less than about 10^{-6} it has a relatively weak impact on the mass transfer. In this range of Darcy number, the porous medium acts almost as a solid wall and the mass transfer is quasi-diffusive. In the second zone, where the Darcy number is in the range $10^{-6} - 10^{-3}$, the Sherwood number increases rapidly with increasing Darcy number. Finally, when the Darcy number is greater than about 10^{-3} then the Sherwood number remains almost constant and the porous medium is very permeable.

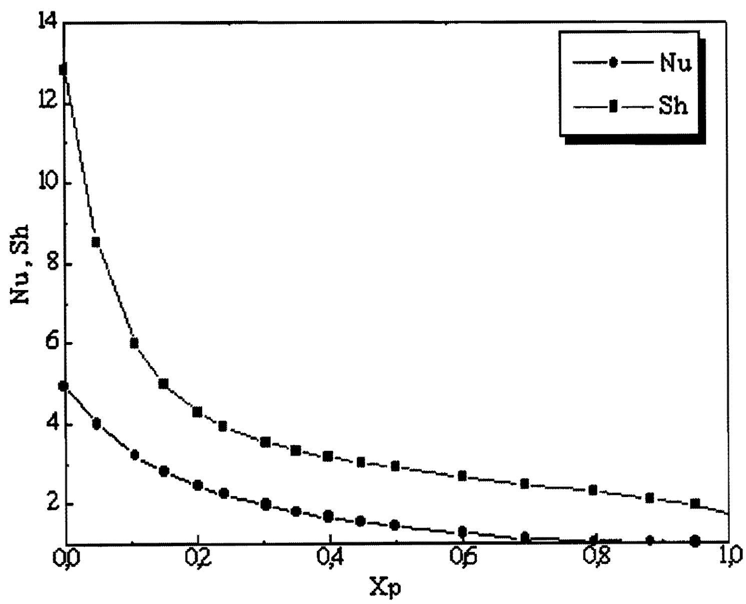
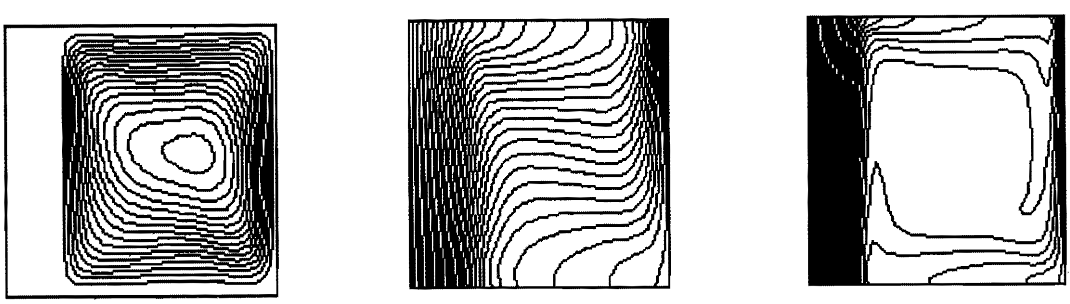


Figure 2. Effect of the porous layer thickness on the heat and mass transfer:
Ra = 10^5, Da = 10^{-5}, N = 1, Le = 10.



(*a*) Streamlines (*b*) Isotherms (*c*) Isoconcentrations

Figure 3. Streamlines, Isotherms, and Isoconcentrations:
Ra = 10^5, Da = 10^{-8}, N = 1, Le = 10, X_p=0.2.

For heat transfer, the variation of the Nusselt number has approximately the same trend as the Sherwood number in the same range of Darcy number. The main difference is that this variation is not monotonic and it exhibits a significant minimum. Therefore, an increase in the permeability leads to a better penetration of the flow in the porous layer and the enhancement of the overall heat transfer. For a better comprehension of this phenomena, we have reported in Figure 5 the vertical velocity profile at the horizontal midplane for $Ra = 10^5$, $Le = 10$, and $N = 1$. For low values of the permeability ($Da = 10^{-7}$), we can observe that there is no flow in the porous layer ($v = 0$) and the absolute maximum values of the vertical velocity take place in the fluid part. Moreover, the velocity profile is linear in the porous layer and follows Darcy's law. The interface fluid/porous behaves like a solid wall on which a bounder layer develops. This description remains valid until $Da = 10^{-4}$, which corresponds to the start of the restructuring of the flow. The growing penetration of the fluid in the porous layer with increasing Darcy number induces an increase in the maximum value of the vertical velocity near the fluid/porous interface.

In order to illustrate the influence of the permeability on flow structure, isotherms, and concentration lines, we have examined the effect of the Darcy number in the case of the full porous cavity, and the results are presented in Figure 6. For high values of the permeability ($Da = 1$), we observe that there is a better penetration of the fluid with multiple cell flow, and the behavior of the fluid is similar to that obtained by Gobin *et al.* [9] in the case of a square cavity without any porous medium. As the Darcy number increases, $Da = 10^{-7}$, the structure of the flow became monocellular and the very weak flow is then characterized by a quasi-double diffusive heat and mass transfer.

5.3. Influence of *Le* and *N*

The behavior of the mass transfer with the absolute value of buoyancy ratio N is illustrated in Figure 7. Positive and negative values of N are considered, which represent respectively cooperating and opposing thermal and solutal buoyancy effects. We can see from this figure that the overall mass transfer increases with increasing value of $|N|$ and the Lewis number. The mass transfer for $N < 1$ is less important compared for $N > 1$ and this gap decreases with increasing of buoyancy ratio N. For the heat transfer, Figure 8 displays the Nusselt number as a function of buoyancy ratio N, for different values of Lewis number. The influence of N on average heat transfer means that the convective transport of heat increases with N, for moderate Lewis number ($Le = 1$). However, this behavior holds only in a range of moderate Lewis numbers. The results displayed in Figure 8 for $Le = 10$ and 100, show that Nusselt number decreases with increasing buoyancy ratio, N. This behavior is in contradiction with the scaling law given in the literature [1] and [10], and it requires more detailed analysis.

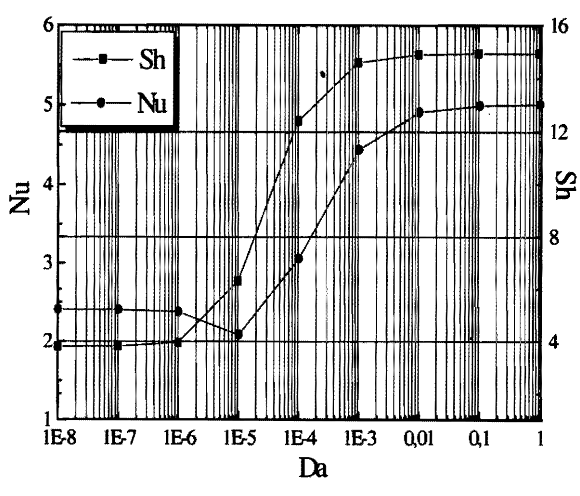


Figure 4. Effect of permeability on the heat and mass transfer: Ra=10^5, N=1, Le=10, X_p=0.2.

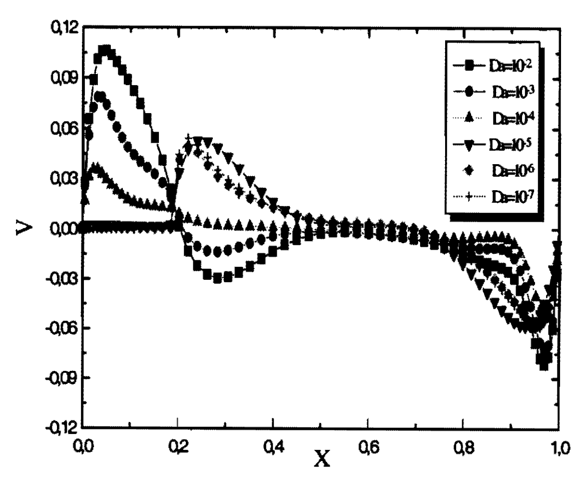


Figure 5. Vertical velocity profiles on the horizontal midplane: Ra=10^5, N=1, Le=10, X_p=0.2.

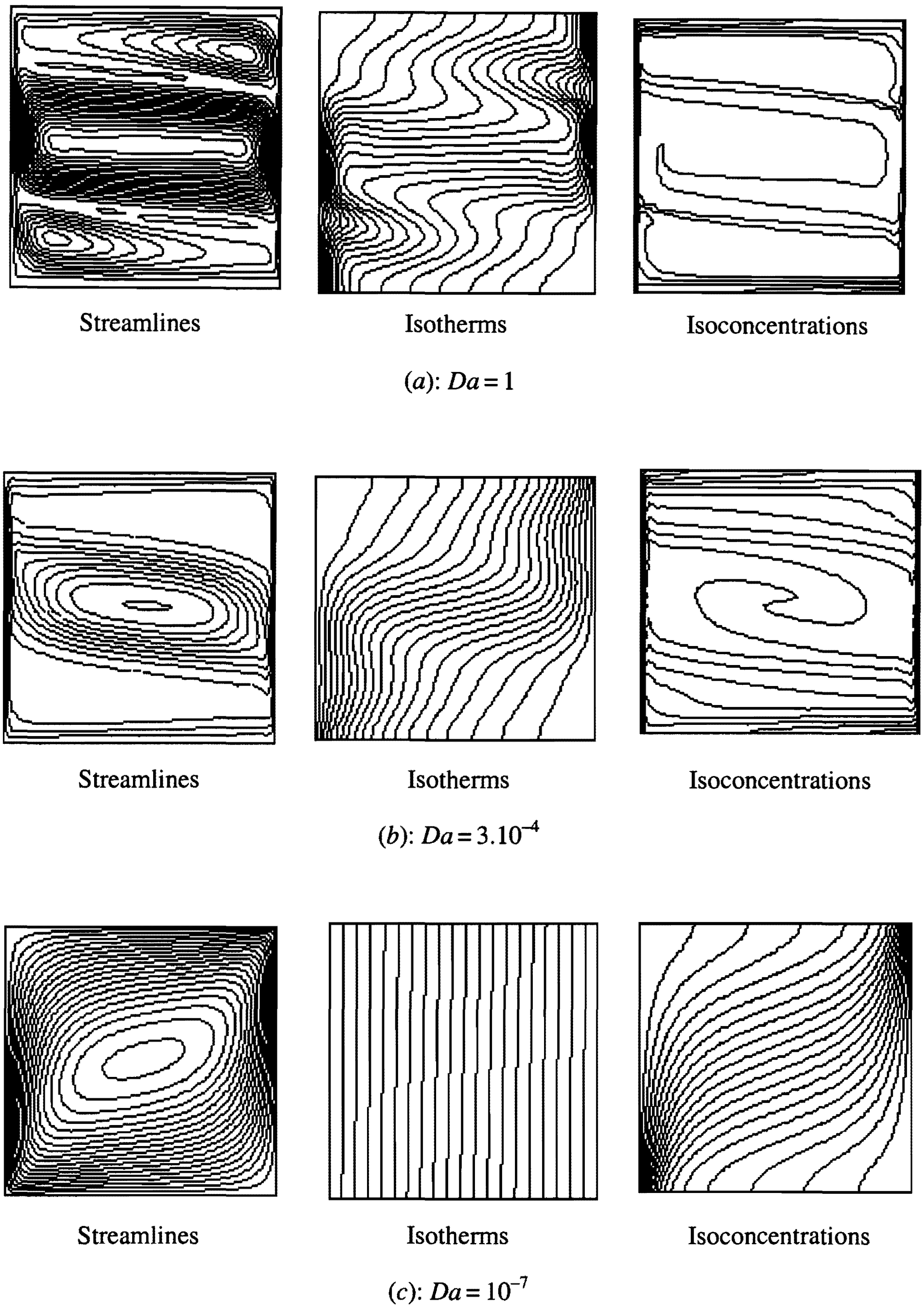


Figure 6. Streamlines, isotherms, and isoconcentrations for values of Da *being*
(a): Da = *1; (b):* Da = *3* 10^{-4}*; and (c):* Da = 10^{-7}, Ra = 10^5, N = *10*, Le = *100*, X_p = *1*/A.

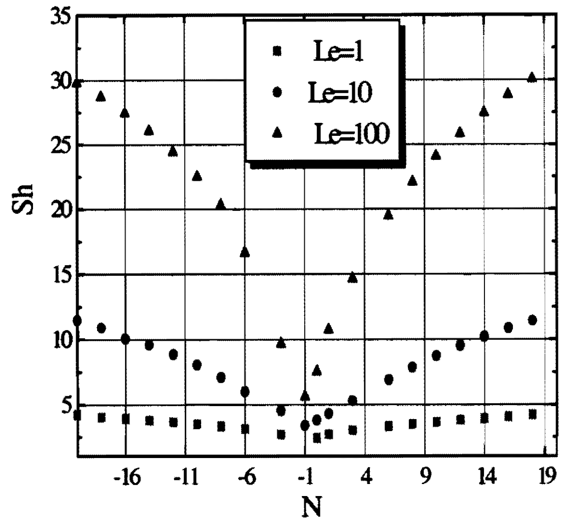


Figure 7. Effect of buoyancy ratio on mass transfer:
Ra = 10^5, Da = 10^{-5}, $X_p = 0.2$.

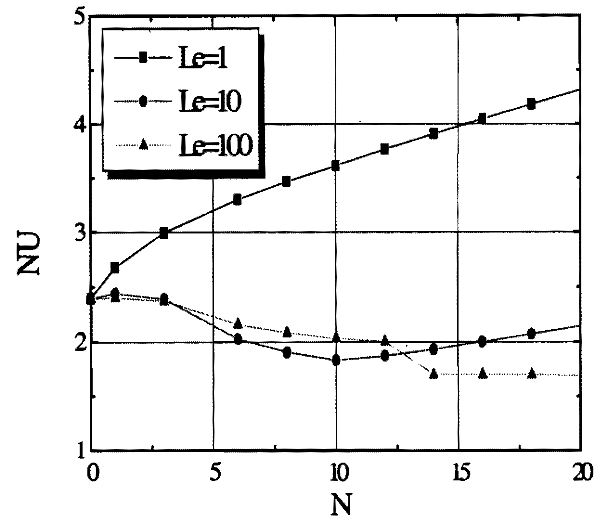


Figure 8. Effect of buoyancy ratio on heat transfer:
Ra = 10^5, Da = 10^{-5}, N = 10, $X_p = 0.2$.

6. CONCLUSION

Double-diffusive natural convection in a composite fluid–porous layer has been studied numerically and the results obtained by this model are in good agreement with the heat transfer results given in literature. The main conclusions of this study are summarized as follows.

- The role of the porous media is to reduce significantly the vertical velocities near the fluid/porous interface on which a bounder layer develops
- The heat and mass transfer, as well as the flow field, are profoundly affected by the relative magnitude of the thermal and solutal buoyancy forces.
- The overall heat and mass transfers decrease for a decreasing permeability.

The present analysis is focused on the influence of a limited number of dimensionless parameters. As an extension of this work, it is particularly relevant to take into account the effect of aspect ratio (*A*), the conductivity ratio, and to correlate the heat and mass transfer in order to use them easily.

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NOMENCLATURE

A : aspect ratio = H/L

C_P : specific heat at constant pressure

C_f : inertial coefficient

D : mass diffusivity, m^2s^{-1}

Da : Darcy number = K/H^2

$\vec{g}$: acceleration due to gravity

H : Cavity high, m

K : permeability, m^2

L : cavity width, m

Le : Lewis number = Sc/Pr

N : buoyancy ratio = Gr_S/Gr_T

$\overline{Nu}$: overall Nusselt number

P : pressure, Pa

Pr : Prandtl number = ν/α

Ra : Rayleigh number = Gr . Pr

Sc : Schmidt number = ν/D

$\overline{Sh}$: overall Sherwood number

$U(V)$: dimensionless velocity in $X(Y)$ direction

$\mathbf{V}$: velocity vector

Gr_T : thermal Grashof number = $g\beta_T \Delta T H^3/\nu^2$

Gr_S : solutal Grashof number = $g\beta_C \Delta C H^3/\nu^2$

(X, Y) : dimensionless Cartesian coordinate

Greek Symbols

α : thermal diffusivity = $k/\rho c_P$, m^2s^{-1}

β_T : isobaric coefficient of thermal expansion fluid

β_C : isobaric coefficient of solutal expansion fluid

ρ : density, $Kg.m^{-3}$

ν : kinematic viscosity, m^2s^{-1}

τ : dimensionless time

Θ : dimensionless temperature = $(T-(T_1+T_2)/2)/\Delta T$

Φ : dimensionless concentration = $(C-(C_1+C_2)/2)/\Delta C$

ΔT : temperature difference between plates = $T_1 - T_2$

ΔC : concentration difference between plates = $C_1 - C_2$

ε : porous media porosity

ψ : stream function

Subscripts

1 : heated surface

2 : cooled surface

f : fluid

p : porous media

0 : average value

Superscripts

i : time iteration

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3. COLLEGE OF ENGINEERING SCIENCES

Chemical Engineering (Ref: 320/CES)

Faculty openings for Associate & Full Professors. Specialists in Process Control, Plant Design, Numerical Methods/Simulation, & Polymerization Reaction Engineering are particularly needed.

In addition, the department invites applications for visiting professors at the rank of Full Professor.

Civil Engineering (Ref: 340/CES)

Ph.D. in Environmental Engg. with at least Associate Professor rank & background in Chemical, Physical, & Biological Treatment of Water & Wastewater. Specialization in the area of Solid & Hazardous Waste. Experience in experimental work including treatability studies & Chemical Analysis.

Electrical Engineering (Ref: 360/CES)

Faculty positions for the ranks of Assistant Professor, Associate Professor, and Full Professor. The department also invites applicants for visiting positions. Areas of interest are: 1. Communications Systems, 2. Microprocessors & Digital Systems, 3. Analog & Digital Electronics, and 4. VLSI.

Mechanical Engineering (Ref: 370/CES)

Faculty positions (Full, Associate Professor, Assistant Professor, & Lecturer) in the areas of Machine Design, Dynamics and Control, Manufacturing Processes, Materials Sciences and Thermal Sciences.

4. COLLEGE OF INDUSTRIAL MANAGEMENT

Accounting & M.I.S. (Ref: 625/CIMA)

Faculty positions in the following areas:

Accounting Major (Professorial positions). Ph.D. or DBA majors, priority will be given to candidates with strength in Accounting Information Systems, Auditing & Financial Accounting.

M.I.S. Major (Professorial positions). Ph.D. or DBA with an MIS major (or an equivalent field such as Information Systems, Information Technology, E-Commerce, Computer Science). Priority will be given to candidates with strength in Systems Analysis and design, Client Server Applications Development and Database Management.

Finance & Economics (Ref: 620/CIMF)

Openings for all Professorial ranks in Finance. Duties include: Teaching, research and professional activities in Finance and related subject areas. Teaching assignments may include undergraduate and graduate courses in Investments, Corporate Finance, Financial Institutions Management, Risk and Insurance, Real Estate Management, Investment Policy, International Finance & Security Analysis and Portfolio Management.

Management & Marketing (Ref: 615/CIMM)

Faculty positions for the ranks of Assistant Professors and above, in the field of Management, Marketing, Business Communications, and Operations Management. Faculty will teach various courses offered in our BS in Management, BS in Marketing and in our MBA program.

5. COLLEGE OF ENVIRONMENTAL DESIGN

Architecture (Ref: 460/CEDA)

Faculty positions in the following fields: 1. Computer Aided Design, 2. Architectural Design Methods, 3. Theory of Architecture, and 4. History of Architecture, and to teach graduate and undergraduate courses, developing and participating in the research activities of the Department.

Construction Engineering & Management (Ref: 470/CEDC)

Applicants should hold a Ph.D. in Construction Engineering & Management, specialized in construction engineering/methods and applications of computer in CEM. Industrial work experience is strongly desired.

6. EDUCATIONAL SERVICES (Lecturer Positions)

English Language Center (Ref: 660/ELC)

We have opportunities for well-qualified, committed and experienced teachers of English as a foreign language to start in September and January each year. Applicants should be willing to teach in a structured, intensive program to which they are encouraged to contribute ideas and materials.

Qualifications: MA in TEFL/TESL or Applied Linguistics, or a one-academic-year, full-time postgraduate diploma in TEFL/TESL from a recognized university.

Experience: Minimum two years' overseas teaching experience in EFL/ESL.

Physical Education (Ref: 265/PE)

Applications are invited for Lecturer positions.

Qualifications: Physical Education Specialists - teachers with recognized coaching experience in badminton, track & field, soccer, gymnastics, basketball, swimming, table tennis, martial arts, volleyball, fencing, and squash.

M.E. Prep. Year Program (Ref: 370/PYP)

Applications are invited at Lecturer rank in the areas of graphics (geometrical and engineering drawing), sheetmetal fabrication, automotive mechanics, woodworking, and basic electrical engineering. Any combination of these subjects would be an advantage. Applicants should have teaching and industrial experience.

Math. Orientation Program (Ref: 660/MTH)

We have opportunities for well-qualified, committed and experienced teachers of mathematics to start in September and January each year. Applicants should be willing to teach in a structured intensive program to which they are encouraged to contribute ideas and materials. They will be required to teach pre-calculus (college algebra) and calculus courses (A-level algebra, trigonometry, and calculus). M.S. degree in Math or equivalent.

Salary/Benefits: *Two-year renewable contract. Competitive salaries based on qualifications and experience. Free furnished air-conditioned on-campus housing unit with free essential utilities and maintenance. The appointment includes the following benefits according to the University's policy: air ticket to Dhahran on appointment; annual repatriation air tickets for up to four persons; assistance with local tuition fees for school-age dependent children; local transportation allowance; two months' paid summer leave; end-of-service gratuity. The KFUPM campus has a range of facilities including a medical and dental clinic, an extensive library, computing, research and teaching laboratory facilities, and a recreation center.*

To apply: Mail, fax, or e-mail cover letter and detailed résumé to:

Dean, Faculty & Personnel Affairs, KFUPM, **DEPT. No. FPA-211,** Dhahran 31261, Saudi Arabia

Fax: 966-3-860-2429 - E-Mail: faculty@kfupm.edu.sa

Please visit our web site: http://www.kfupm.edu.sa for additional information and application forms.

PLEASE QUOTE THE RELEVANT REFERENCE NUMBER IN ALL CORRESPONDENCE