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INFLUENCE OF VIBRATION ON SORET-DRIVEN CONVECTION IN POROUS MEDIA

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Two-dimensional thermosolutal natural convection with Soret effect under the simultaneous action of vibrational and gravitational accelerations is investigated. We consider a porous cavity saturated by a binary mixture and adopt the time-averaging formulation. For an infinite horizontal layer, a stability analysis is performed from which the threshold of stability is determined. Numerical simulations, using a pseudo-spectral Chebyshev collocation method, are performed to describe the convective motion. The problem is investigated for different aspect ratios with various directions of vibration. It is concluded that, for both the stationary and the Hopf bifurcation, the vertical vibration has a stabilizing effect while the horizontal vibration has a destabilizing effect on the onset of convection.

INTRODUCTION

The effect of mechanical vibration on the stability threshold of thermal systems has attracted the attention of researchers in recent years. In thermovibrational convection, the energy of mechanical vibration in the presence of a temperature gradient can be used to control the onset of convective motion. This type of convective motion, in which the buoyancy force may be thought of as time-dependent, has been the subject of intense studies in fluid media [1–4], and with less intensity in porous media [5–9]. As with any other new branch of fluid mechanics, the progress in thermovibrational problems is a direct response to industrial applications. For example, Apollo 14 experimental results showed that spacecraft vibrations might cause an appreciable amount of heat transfer [10]. These results were in contradiction with the common belief that natural convection could not exist in space. Further research showed later that a spacecraft in orbit is subject to many disturbing influences of human as well as operational origin. These influences result in the

NOMENCLATURE

a^*	effective thermal diffusivity, m^2/s	$\tilde{R}$	acceleration ratio
A	aspect ratio	Ra	Rayleigh number
b	amplitude of vibration	R_v	vibrational Rayleigh number
c	perturbation of concentration	T	temperature, K
C_i	initial mass fraction	**V**	velocity, m/s
C	mass fraction	**W**	solenoidal vector
D^*	mass diffusion coefficient	α	angle of vibration
D_T	thermodiffusion coefficient	β_C	coefficient of mass expansion
Da	Darcy number	β_T	coefficient of thermal expansion
e	direction of vibration	ϵ	porosity
G	gravitational acceleration, m/s^2	ϵ^*	normalized porosity
H	height, m	θ	perturbation of temperature
J	unit vector in y direction	ν	kinematic viscosity, m^2/s
$\mathbf{J}_m$	mass flux ($= \nabla C - \nabla T$)	σ	volumic heat capacity ratio
k	wave number	$\dot{\psi}$	separation ratio
K	permeability, m^2	ϕ	stream function perturbation
L	length of the cavity	$\bar{\omega}$	dimensional frequency
Le	Lewis number ($= a^*/D^*$)		
n	unit vector normal to the boundary	**Subscripts**	
P	pressure, N/m^2	c	critical
Pr*	Prandtl number ($= \nu/a^*$)	co	oscillatory critical
R	vibrational parameter	cs	stationary critical

production of residual accelerations which are usually referred to as "g-jitters." It was suggested that g-jitters may be represented by a unidirectional harmonic oscillation having small amplitude [11].

Our objective is to study the effect of vibrational mechanism on coupled dissipative phenomena, namely, the Soret-driven convective motion in a porous medium saturated by a binary mixture. Under the Soret effect, the temperature gradient can produce mass flux [12]. This problem in the context of vibration in fluid media was studied in an infinite horizontal layer [13, 14]. The limiting case of high-frequency and small-amplitude vibration was studied, which enabled the time-averaged method to be used. The authors found that vibration could drastically change the stable zones in the stability diagram. Generally, vertical vibration (parallel to the temperature gradient) increases the stability of the conductive mode. Smorodin et al. [15] studied the same problem under finite frequency. They also showed that, in synchronous mode, vibration has a stabilizing effect.

For existing thermovibrational studies in porous media saturated by a pure fluid, we can mention the works of Zen'kovskaya [5] and Zen'kovskaya and Rogovenko [7] in an infinite layer heated from below or above, Khallouf et al. [6] in a rectangular cavity heated differentially, and Bardan and Mojtabi [8] in a rectangular cavity heated from below. Also, Jounet and Bardan [9] consider the thermohaline problem in a rectangular cavity. Finally, Sovran et al. [16] considered the effect of vibration on the onset of Soret-driven convection in a rectangular cavity.

In this work we study the thermoconvective motion in an infinite horizontal layer and confined cavity filled with a porous medium saturated by a binary mixture. The effect of direction of vibration on the stability threshold is investigated. Stationary as well as Hopf bifurcations are studied, and convective structures

under the combined effects of vibration and gravitational accelerations are examined.

PROBLEM DESCRIPTION

We consider a rectangular cavity filled with a porous medium saturated by a binary mixture, Figure 1. The aspect ratio is defined as $A = L/H$, where H is the height and L is the length of the cavity. The boundaries of the cavity are rigid and impermeable; the horizontal ones can be heated from below or above, while the lateral ones are thermally insulated and impermeable. The governing equations are written in a reference frame linked to the cavity. As vibration has high frequency and small amplitude, the time-averaged formulation is adopted [17]. According to this method, each field is subdivided into two parts. The first part varies slowly with time, while the second part varies quickly with time. By replacing these transformations in the governing system of equations and averaging over the vibration period, we find two coupled systems of equations. One governs the system with slow evolution and the other governs rapid evolution with respect to time. By making some assumptions, we may find the oscillatory fields exactly. By replacing these in the system with slow evolution we find the time-averaged system. Under the Boussinesq approximation the dimensionless governing equations for the mean flow averaged over the vibration period can be written as

$$\nabla \cdot \mathbf{V} = 0$$

$$B\frac{\partial \mathbf{V}}{\partial t} + \mathbf{V} = -\nabla P + \mathrm{Ra}(T + \psi C)\mathbf{j} + R_v(\mathbf{W}_T + \psi \mathbf{W}_c) \cdot \nabla\left(T + \frac{\psi}{\varepsilon^*}C\right)(\cos\alpha\mathbf{i} + \sin\alpha\mathbf{j})$$

$$\frac{\partial T}{\partial t} + \mathbf{V} \cdot \nabla T = \Delta T \tag{1}$$

$$\varepsilon^8 \frac{\partial C}{\partial t} + \mathbf{V} \cdot \nabla C = \frac{1}{\mathrm{Le}}(\Delta C - \Delta T)$$

$$\nabla \cdot \mathbf{W}_T = 0 \qquad \nabla \cdot \mathbf{W}_c = 0$$

$$T\mathbf{e} = \mathbf{W}_T + \nabla \xi_T \qquad C\mathbf{e} = \mathbf{W}_c + \nabla \xi_c$$

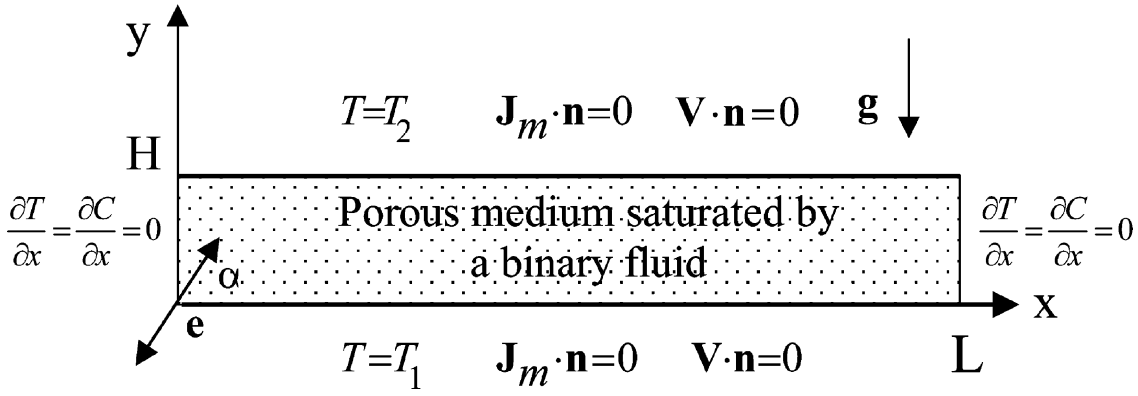

Figure 1. Geometry and coordinate system.

where $\mathbf{V}$, T, C are the velocity, temperature, and mass fraction fields, and $\mathbf{W}_T$ and $\mathbf{W}_c$ are solenoidal vectors corresponding to the temperature and concentration, respectively.

The corresponding boundary conditions are

$$\begin{aligned} &\mathbf{W}_T \cdot \mathbf{n} = \mathbf{W}_c \cdot \mathbf{n} = 0 \\ &y = 0: \qquad T = 1, \quad \mathbf{J_m} \cdot \mathbf{n} = 0 \\ &y = 1: \qquad T = 0, \quad \mathbf{J_m} \cdot \mathbf{n} = 0 \\ &x = 0, A: \qquad \frac{\partial T}{\partial x} = \frac{\partial C}{\partial x} = 0 \end{aligned} \tag{2}$$

System (1) depends on eight parameters: the thermal Rayleigh number $\mathrm{Ra} = Kg\beta\,\Delta T\,H/\nu a^*$, the vibrational Rayleigh number $R_v = (\widetilde{R}^2\mathrm{Ra}^2 B)/2(B^2\omega^2 + 1) = R^2\mathrm{Ra}^2$ ($\widetilde{R} = b\bar{\omega}^2/g$), the separation factor $\psi = -C_i(1 - C_i)(\beta_c/\beta_T)D_T/D^*$, the normalized porosity $\varepsilon^8(\varepsilon^8 = \varepsilon/\sigma)$, the Lewis number Le ($\mathrm{Le} = a^*/D^*$, in which a^* is the effective thermal diffusivity and D^* is the effective mass diffusivity), the coefficient of the unsteady Darcy term in the momentum equation $B = \mathrm{Da}/(\sigma\varepsilon\mathrm{Pr}^*)$ (in porous media $B \approx 10^{-5}$ and Da represents the Darcy number $\mathrm{Da} = K/H^2$), and finally α is the direction of vibration with respect to the heated boundary.

SOLUTION METHOD

In order to solve the system (1) with the corresponding boundary conditions (2), the projection diffusion algorithm is used [18]. The linear (viscous) terms are treated implicitly using a second-order Euler backward scheme, while a second-order semiexplicit Adams-Bashforth scheme is employed to estimate the nonlinear (advective) terms. We apply this method to an advection-diffusion equation such as (Γ is a general coefficient)

$$\frac{\partial f}{\partial t} + (\mathbf{u} \cdot \nabla f) = \Gamma \nabla^2 f \tag{3}$$

which can be discretized as

$$\frac{\frac{3}{2}f^{n+1} - 2f^n + \frac{1}{2}f^{n-1}}{\Delta t} = \Gamma\nabla^2 f^{n+1} - [2(\mathbf{u} \cdot \nabla f)^n - (\mathbf{u} \cdot \nabla f)^{n-1}] \tag{4}$$

Equation (4) may be written in the form of the following Helmholtz equation:

$$(\nabla^2 - h)f^{n+1} = s \tag{5}$$

A high-accuracy spectral method, namely, the Chebyshev collocation method with the Gauss-Lobatto zeros as collocation points, is used in the spatial discretization of the operators. The successive diagonalization method is applied to the inverse of these operators.

RESULTS

Linear Stability Analysis

For the direction of vibration parallel to the temperature gradient ($\alpha = \pi/2$), there exists a mechanical equilibrium (for both an infinite horizontal layer and a confined cavity), which is characterized by

$$\mathbf{V}_0 = 0 \qquad T_0 = 1 - y \qquad C_0 = \text{cst} - y \qquad \mathbf{W}_{T0} = 0 \qquad \mathbf{W}_{C0} = 0 \tag{6}$$

However, for other directions of vibration, we may obtain quasi-equilibrium solution only for the infinite horizontal layer. This is characterized by

$$\begin{aligned} &\mathbf{V}_0 = 0 \qquad T_0 = 1 - y \qquad C_0 = c_1 - y \qquad \mathrm{W}_{T0_x} = c_2 - y\cos\alpha \qquad \mathrm{W}_{T0_y} = 0 \\ &\mathrm{W}_{C0_x} = c_3 - y\cos\alpha \qquad \mathrm{W}_{C0_y} = 0 \end{aligned} \tag{7}$$

It should be noted that, for a confined cavity, there is no equilibrium solution under the horizontal vibration.

Infinite Horizontal Porous Layer

In order to investigate the stability of the conductive solution, we perturb the fields around the equilibrium state. Then, after linearization, we develop the disturbances in the form of normal modes. We introduce the stream function perturbation ϕ, the temperature perturbation θ, and the mass fraction perturbation c. Also, we designate the stream function perturbations ϕ_θ and ϕ_c for corresponding solenoidal fields $\mathbf{W}_T$ and $\mathbf{W}_c$. In order to facilitate our study, we use the transformations $\eta = c - \theta$ and $\phi_\eta = \phi_c - \phi_\theta$. We may write:

$$\phi = \sum_{i=1}^{N} a_i \sin(i\pi z)\exp(\sigma t + Ikx) \qquad \theta = \sum_{i=1}^{N} b_i \sin(i\pi z)\exp(\sigma t + Ikx)$$

$$\eta = \sum_{i=0}^{N-1} c_i \cos(i\pi z)\exp(\sigma t + Ikx) \qquad \phi_\theta = \sum_{i=1}^{N} d_i \sin(i\pi z)\exp(\sigma t + Ikx)$$

$$\phi_\eta = \sum_{i=1}^{N} g_i \sin(i\pi z)\exp(\sigma t + Ikx)$$

in which k is the wave number in the infinite horizontal direction $\mathrm{O_x}$ and $I^2 = -1$.

The corresponding linear stability problem is solved using the Galerkin method.

Vertical vibration. For different sets of parameters $0 < R_v < 100$, $2 < \mathrm{Le} < 100$, $\psi = -0.2$, and $\epsilon^* = 0.5$, 0.7, the numerical simulations are carried out. The results of linear stability analysis for $\mathrm{Le} = 2$ and $\epsilon^* = 0.5$ are presented in Table 1. It should be noted that, in the range of Lewis numbers studied, the results are qualitatively the same. As can be observed from Table 1, we may distinguish two

Table 1. Effect of vibrations on the Hopf bifurcation (Le = 2, $\psi = -0.2$, and $\epsilon^* = 0.5$)

R_v	Ra_{cs}	k_{cs}	Ra_{co}	k_{co}	ω_0
0	153.19	4.75	95.43	2.59	10.78
10	157.53	4.73	97.78	2.56	10.75
50	173.63	4.65	107.1	2.41	10.50
100	193.60	4.54	117.8	2.26	10.26

types of bifurcations: stationary and Hopf bifurcations. For the stationary bifurcation, we assume that the principle of the exchange of stability is valid (i.e., $\sigma \in \mathcal{R}$). From this the marginal state is determined ($\sigma = 0$). For the Hopf bifurcation ($\sigma = \sigma_r + I\omega_0$), the marginal state corresponds to $\sigma_r = 0$. It should be added that the Hopf bifurcation is present only for negative separation factors and, for the layer heated from below, it forms before the stationary bifurcation ($Ra_{co} < Ra_{cs}$). The effects of vibration on the Hopf bifurcation for $\psi = -0.2$, $\epsilon^* = 0.5$, and Le = 2 are represented in Table 1. We can conclude from Table 1 that vibration has a stabilizing effect: it increases the critical value of thermal Rayleigh number for the onset of convection. This is true for both the stationary and the Hopf bifurcation. It should be mentioned that vibration reduces the critical wave number (k_c, k_{co}) and the Hopf frequency (ω_0).

Horizontal vibration. The stability domain for different vibrational parameters in the (Ra, ψ) stability diagram is presented in Figure 2. This diagram is characterized by stationary and oscillatory bifurcations. For $\psi > 0$ the bifurcation

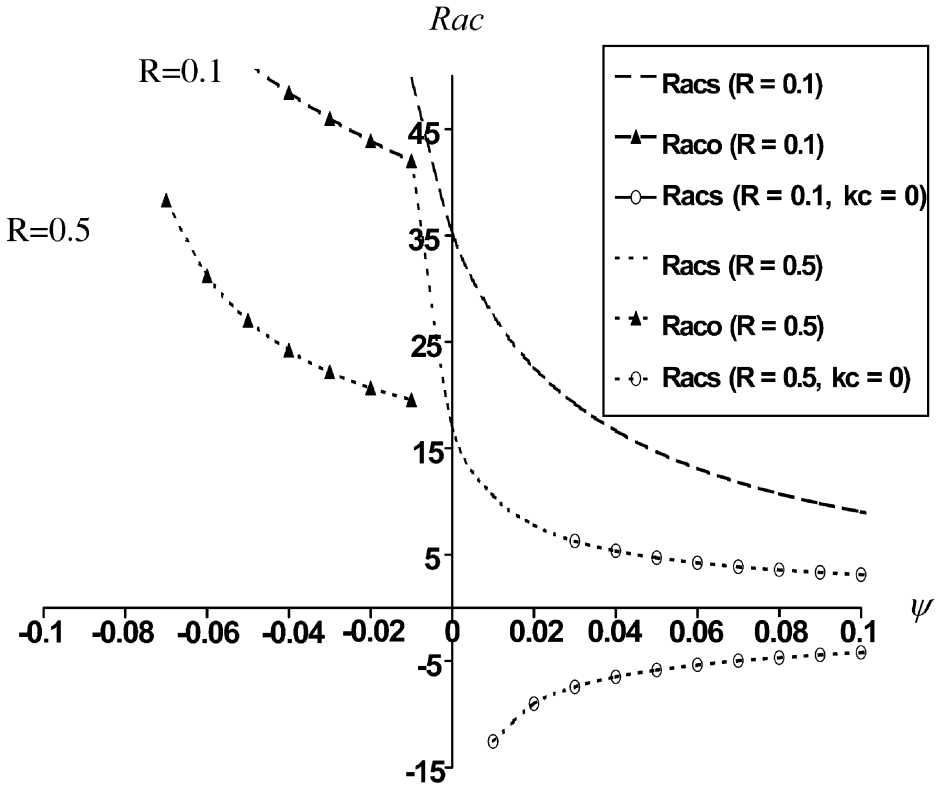

Figure 2. Stability diagram for stationary and oscillatory convection for Le = 10, $\epsilon^8 = 0.5$ and $B = 10^{-6}$.

is always of the stationary type, while for $\psi < 0$ we may obtain oscillatory or stationary bifurcations. The computations are performed for $\varepsilon^8 = 0.5$, $B = 10^{-6}$ (usual values used in porous media), and $\mathrm{Le} = 10$. The results show that horizontal vibration has a destabilizing effect on both stationary and Hopf bifurcations. One of the interesting features of Figure 2 is that we may obtain long-wave-mode instability in the regions where under static gravity conditions are infinitely/linearly stable. The existence of these regions is due to a vibrational mechanism. A regular perturbation method with the wave number as small parameter is used to study the behavior of the long-wave mode. The stability boundary can be obtained from following relation ($\alpha = 0$):

$$\mathrm{Ra}_{cs}\psi + R_v(1+\psi)\frac{\psi}{\varepsilon^*} = \frac{12}{\mathrm{Le}} \qquad (R_v = R^2\,\mathrm{Ra}_{cs}^2) \tag{8}$$

Numerical Simulation

The numerical simulations for a confined cavity are performed for vertical and horizontal vibration. The calculations are made for different aspect ratios $A = 1$ and $A = 10$. The $27 * 27$ collocation points are used for $A = 1$ while $63 * 27$ collocation points are used for $A = 10$.

Vertical vibration. The aim of this section is to provide a qualitative picture of the flow and thermal fields to complete the results of our stability analysis. In order to study the effect of vibration on the convective pattern, we set $\mathrm{Le} = 2$, $\psi = 0.4$, $A = 1$, and $\mathrm{Ra} = 30$ and change the value of the vibrational Rayleigh number R_v. The calculations are performed for $\epsilon^* = 0.5$ and 0.7 and are presented in Tables 2 and 3.

These values are chosen according to the results of the stability analysis. We conclude from Tables 2 and 3 that, for the selected values of Le, ϵ^*, ψ, A, and Ra, vibration reduces the Nusselt number and we may obtain a conductive solution. In addition, we find that for the combination of R_v, ψ, and ϵ^* we have the interesting relation $R_{vc}(1 + \psi/\varepsilon^*) = \mathrm{cst}$. For the case under study this constant is 31.5.

In order to demonstrate the effect of vibration on convective structure under different aspect ratios, we also consider convection under gravitational acceleration: $A = 10$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.4$, $\mathrm{Ra}_{cs} = 13$, and $\mathrm{R}_v = 0$. Figure 3 shows

Table 2. Effect of mechanical vibration on Nu for $A = 1$, $\alpha = \pi/2$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.4$, and $\mathrm{Ra} = 30$

R_v	Nu
5	1.204
10	1.1483
15	1.0789
16	1.0604
17	1.0359
17.5	1.0124
17.53	1.0084

Table 3. Effect of mechanical vibration on Nu for $A = 1$, $\alpha = \pi/2$, $\mathrm{Le} = 2$, $\epsilon^* = 0.7$, $\psi = 0.4$, and $\mathrm{Ra} = 30$

R_v	Nu
5	1.2057
10	1.1528
15	1.0942
16	1.0604
19	1.0329
19.7	1.0156
20.2	1.0034

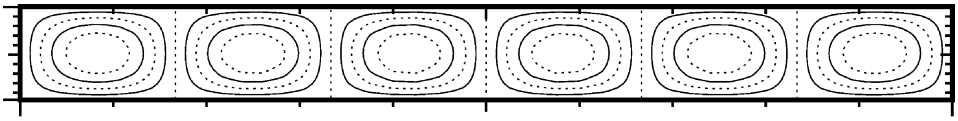

Figure 3. Onset of stationary convection for $A = 10$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.4$, $R_v = 0$, and $\mathrm{Ra}_{cs} = 13$.

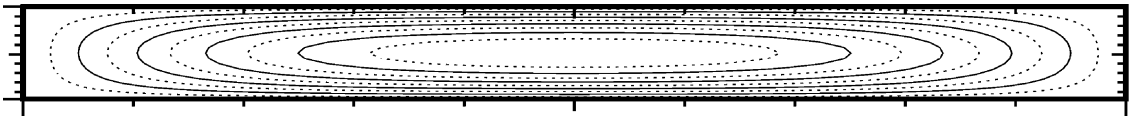

Figure 4. Effect of vertical vibration on the onset of convection for $A = 10$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.4$, $R_v = 20$, and $\mathrm{Ra}_{cs} = 15.7$.

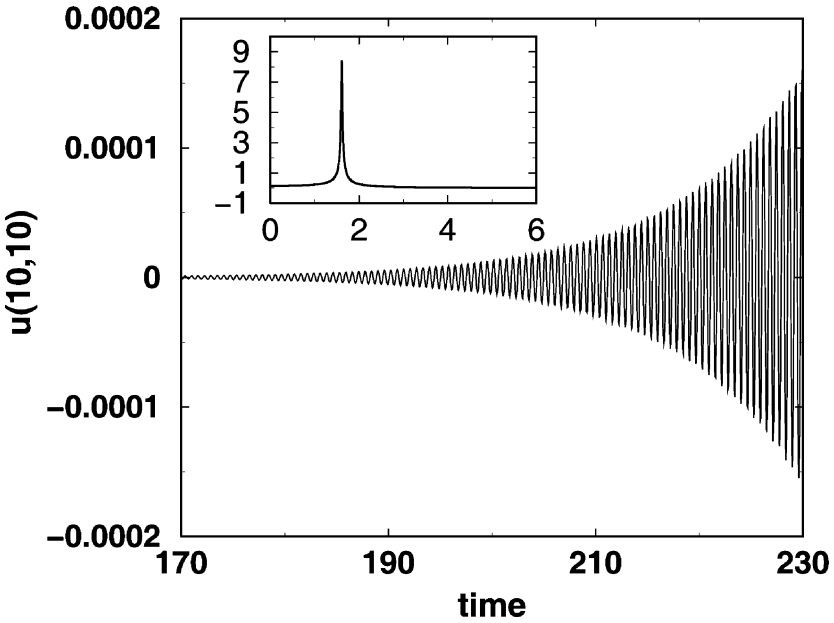

Figure 5. Onset of oscillatory convection for $A = 10$, $\psi = -0.2$, $\epsilon^* = 0.5$, $R_v = 100$, $\mathrm{Ra}_{co} = 118.5$, and $\omega_0 = 10.08$.

the streamlines corresponding to this case, which are characterized by six convective rolls. The numerical result of the onset of convection is in good agreement with the result obtained from the linear stability analysis of an infinite horizontal layer heated from below ($Racs = 12.95$, $kc = 1.94$). It should be emphasized that, based on our numerical simulations, we conclude that $A = 10$ provides a good representation of an infinite layer. Figure 4 represents the effect of vertical vibration. It is clear that vibration changes the convective structure dramatically. The results are in good agreement with the linear stability analysis ($\mathrm{Ra}_{cs} = 15.04$, $k_{cs} = 0.01$).

The result of the Hopf bifurcation for the temporal evolution of velocity for $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $R_v = 100$, $\psi = -0.2$ is presented in Figure 5. As mentioned earlier, the Hopf bifurcation appears for the negative separation factors. The numerical result shows that the critical values corresponding to the Hopf bifurcation are $\mathrm{Ra}_{co} = 118.57$, $k_{co} = 2.2$, and $\omega_0 = 10.08$. These are in good agreement with stability analysis results ($\mathrm{Ra}_{co} = 117.83$, $k_{co} = 2.26$, $\omega_0 = 10.25$).

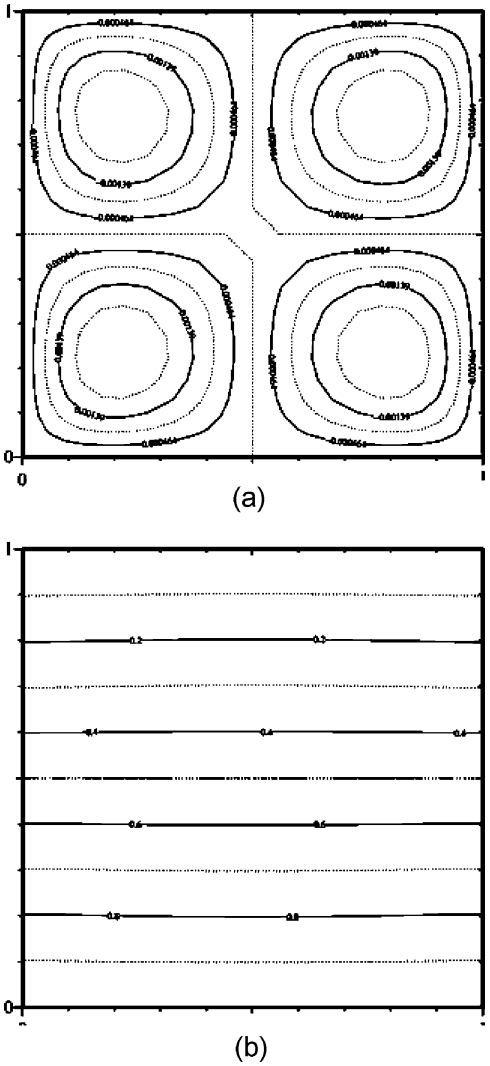

Figure 6. (*a*) Stream functions for $A = 1$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 6$, and $R = 0.3$. (*b*) Isotherms for $A = 1$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 6$, and $R = 0.3$.

Horizontal vibration. For the case of horizontal vibration, we first set $A = 1$, $\mathrm{Ra} = 6$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, and $\mathrm{R} = 0.3$. The value of Ra is set to such a value that only the vibrational mechanism is in action. Figures 6*a* and 6*b* show the corresponding fluid flow structure and temperature distribution; the stream functions are characterized by symmetrical four-vortex rolls. This structure is a typical example of an imperfect bifurcation, as was observed earlier in convection under microgravity conditions [19]. The sum of stream functions is zero in this case. If we further increase the thermal Rayleigh number to $\mathrm{Ra} = 13.15$, the gravitational acceleration will be in action, too (this value is chosen according to linear stability analysis results: for $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $R = 0.3$, the critical Rayleigh number $\mathrm{Ra}_{cs} \approx 14$). The intensity of convective motion will be accordingly increased and the sum of stream functions at all points in the domain is a good criterion for the intensity of convective motion. This case is shown in Figures 7*a* and 7*b*. As can be seen from the figures, we obtain a symmetry breaking structure. This is explained by coalescence of the two

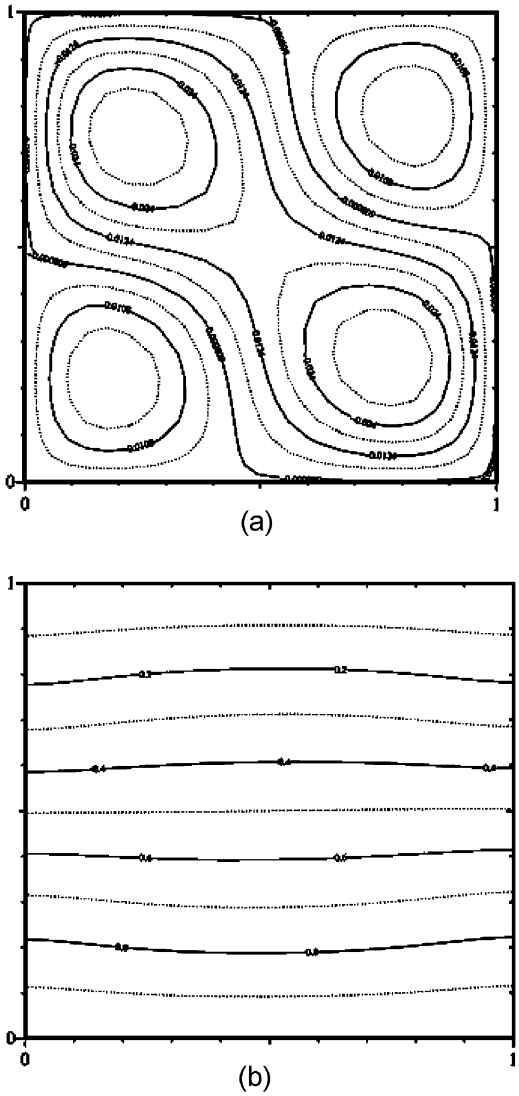

Figure 7. (*a*) Stream functions for $A = 1$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 13.15$, and $R = 0.3$. (*b*) Isotherms for $A = 1$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 13.15$, and $R = 0.3$.

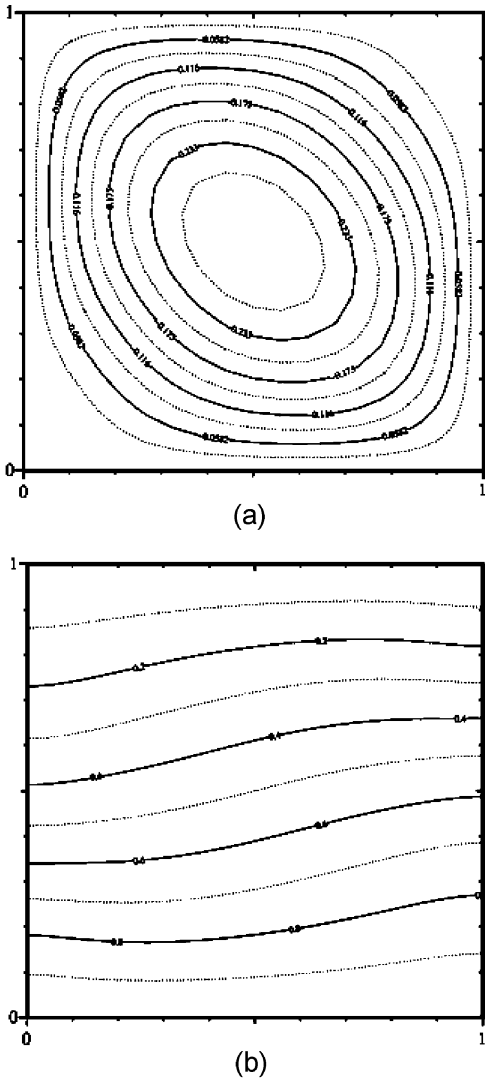

Figure 8. (*a*) Stream functions for $A = 1$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 15$, and $R = 0.3$. (*b*) Isotherms for $A = 1$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 15$, and $R = 0.3$.

rolls with the same sign in the diagonal direction and the existence of two separate off-diagonal rolls with weaker intensity. If we increase the thermal Rayleigh number further, to $\mathrm{Ra} = 15$, we find a single convective roll, which means that the gravitational effect is more important than the vibrational effect, Figures 8*a* and 8*b*.

For $A = 10$, the case corresponding to $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $R = 0.1$, and $\mathrm{Ra} = 15$ is considered. The typical four-vortex structure is presented in Figure 9. Further increase in Ra will cause a multicellular convective regime, Figure 10.

CONCLUSIONS

Two-dimensional thermosolutal convection under mechanical vibration has been studied analytically and numerically. The vibration is in the limiting range of high frequency and small amplitude. The influence of the direction of vibration for different aspect ratios of the cavity is studied and the corresponding fluid flow

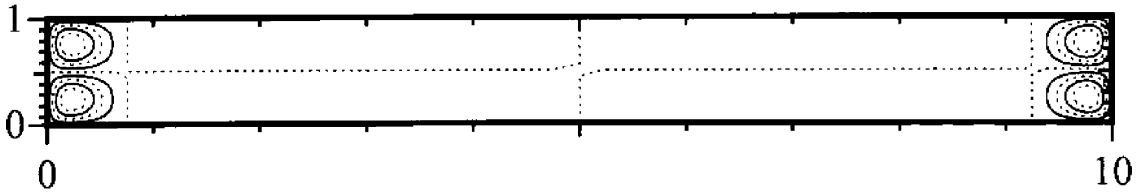

Figure 9. Stream functions for $A = 10$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 15$, and $R = 0.1$.

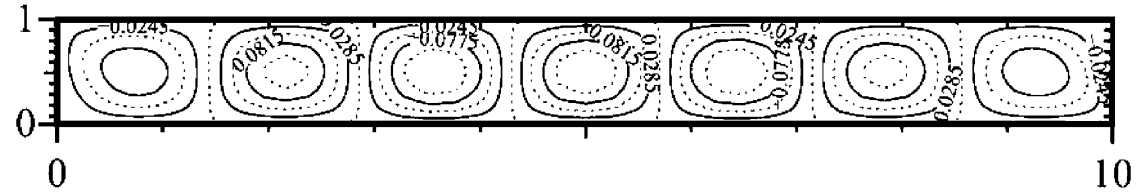

Figure 10. Stream functions for $A = 10$, $\mathrm{Le} = 2$, $\epsilon^* = 0.5$, $\psi = 0.2$, $\mathrm{Ra} = 17$, and $R = 0.1$.

structures are obtained. The geometries considered are an infinite horizontal layer and a confined cavity. Linear stability analyses of equilibrium and quasi-equilibrium states are performed for the infinite horizontal layer. It is found that when the direction of vibration is considered parallel to the temperature gradient, vibration has a stabilizing effect for both the stationary and the Hopf bifurcation. The action of vibration reduces the number of convective rolls and the Hopf frequency. However, when the direction of vibration is perpendicular to the temperature gradient, vibration has a destabilizing effect. New instability regions appear in the bifurcation diagram (Ra–ψ) in which the preferred pattern is the monocellular convective roll. Numerical simulations using a spectral method are performed which corroborate the results of the stability analysis. It is shown that the vertical vibration can reduce the number of convective rolls. The effect of vibration on the Nusselt number is also investigated, and the importance of the group $[R_{vc}(1 + \psi/\epsilon^*)]$ is emphasized. For the cases in which mechanical equilibrium is impossible, the fluid flow structures are sought. For a fixed value of vibrational Rayleigh number, we increase the Rayleigh number from a value much less than the critical value corresponding to the onset of convection in an infinite layer. We observe first a symmetrical four-vortex structure, then a diagonal dominant symmetry breaking structure, and finally a monocellular structure. These results are similar to the results obtained in a cavity filled with pure fluid under the action of vibration in weightlessness. The interesting result of this study is that, by appropriate use of parasite acceleration in a microgravity environment, we may obtain significant enhancement in heat and mass transfer rates. The scientific interest of this study lies not only in the thermomechanical aspect of the results, but also in the possibilities of potential applications as well.

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