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Linear Stability Analysis on Rotationally Modulated Reactive DDC in Anisotropic Porous Media

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ABSTRACT

In this paper the rotational influence on double diffusive reactive convection in anisotropic porous layer saturated with a binary mixture is analyzed using linear stability theory. The Darcy model with the Coriolis term is employed to study the influence of rotation, chemical reaction, and anisotropy on system stability. The effects of Taylor number, reaction rate, solute Rayleigh number, Lewis number, anisotropy parameters, and normalized porosity are examined. Rotation is found to be stabilizing, while chemical reactions can either stabilize or destabilize the system. Anisotropy significantly affects the stability criterion. Stationary and oscillatory convection are illustrated graphically.

Keywords: Rotation, Chemical reaction, Porous layer, Anisotropy & Double Diffusive Convection

INTRODUCTION

Double diffusive convection (DDC) in porous media has been motivated by its wide range of applications, from the solidification of binary mixtures to the heat transfer in geothermal reservoirs. It has implications for many geological processes, such as crustal heat and solute transport, metamorphism, the diagenetic evolution of sedimentary basins and ore genesis. Besides its importance in the hydrogeological context, double diffusive convection in porous media has wide variety of geotechnical applications, among them contaminant transport in saturated soil, underground disposal of nuclear wastes, liquid re-injection, the migration of moisture in fibrous insulation, and electro-chemical and drying processes. The problem of double diffusive convection in porous medium has been extensively investigated and the growing volume of work devoted to this area is well documented by Nield and Bejan (2006), Ingham and Pop (1998, 2005), Vafai (2000, 2005) and Vadasz (2008).

The study of DDC in a rotating porous media is motivated both theoretically and by its practical applications in engineering. Some of the important areas of applications in engineering include the food and chemical process, solidification and centrifugal casting of metals, rotating machinery, petroleum industry, biomechanics and geophysical problems. There are only few studies available on DDC in a porous medium in the presence of rotation. Chakrabarti and Gupta (1981) have analyzed the nonlinear thermohaline convection in a rotating porous medium. The effect of rotation on linear and nonlinear double diffusive convection in a sparsely packed porous medium was studied by Rudraiah et al. (1986). The Lyapunov direct method is applied to study the nonlinear conditional stability problem of a rotating doubly diffusive convection in a sparsely packed porous layer by Guo and Kaloni (1995). The nonlinear stability of the conduction–diffusion solution of a fluid mixture heated and salted from below and saturating a porous medium in the presence of rotation is studied by Lombardo and Mulone (2002) using Lyapunov direct method.

Thermal convection is considered to be an important and in many practical cases a major mechanism for the transport and deposition of salts and other chemicals in sedimentary basins. A variety of chemical reactions can occur as fluid, carrying various dissolved species, moves through a permeable matrix. The nature of the resulting dissolution or precipitation depends on the reaction kinetics and the influence of temperature, pressure, and other factors on them has been studied by Phillips (2009). The effect of chemical reactions on convective motion is not fully known and has received relatively little attention. The first study on the effect of chemical reaction on the onset of convection in a porous medium was due to Steinberg and Brand (1983, 1984). Their analysis is restricted to the regime where the chemical reaction was sufficiently fast that the solutal diffusion could be neglected. Gatica et al. (1989) and Viljoen et al. (1990) investigated the effect of exothermic-reaction on the stability of the porous system. Their study is limited to the case where the thermal and solutal diffusivities are equal so that overdamped oscillations are not possible. Malashetty and Gaikwad (2003) performed linear stability analysis for chemically driven instabilities in binary liquid mixtures with fast chemical reaction. They found analytical expressions for the onset of stationary and oscillatory instabilities. Recently, Pritchard and Richardson (2007) made an exhaustive study of the effect of temperature dependent solubility on the onset of thermosolutal convection in an isotropic porous medium. A linear stability analysis was used to investigate how the dissolution or precipitation of concentration affects the onset of convection and selection of an unstable wavenumber. The analysis was further extended using a Galerkin method to predict the structure of the initial bifurcation, and they compared analytical results with numerical integration of the full nonlinear equations. More recently, Malashetty and Biradar (2011) have investigated the onset of double diffusive reaction-convection in an anisotropic porous layer.

Due to the structure of a porous material there can be a pronounced anisotropy in properties such as permeability or thermal diffusivity. Anisotropy is generally a consequence of preferential orientation or asymmetric geometry of porous matrix or fibers encountered in numerous systems in industry and nature. In geological processes such as sedimentation, compaction, frost action and the reorientation of the solid matrix are responsible for the creation of an anisotropic porous medium. Anisotropy is particularly important in a geological context, since sedimentary rocks generally have a layered structure; the permeability in the vertical direction is often much less than in the horizontal direction. Anisotropy can also be a characteristic of artificial porous materials like pelletting used in chemical engineering process and fiber material used in insulating purpose. The review of research on convective flow through anisotropic porous media has been well documented by McKibbin (1985) and Storesletten et al. (1998, 2004). The effect of anisotropy in mechanical and thermal properties on thermohaline convection in a porous layer has been analyzed by Tyvand (1980). The onset of double diffusive convection in an anisotropic porous medium with additional constraints like rotation and cross diffusion effects including weak nonlinear theory has been studied by Malashetty and co-workers (2008-2011). The study on convection in anisotropic porous media saturated with binary fluid is very sparse.

The DDC thought to occur in certain casting and crystal growth operations. It is demonstrated that the dynamics occurring in the mushy layer are critical to the quality of the final product and suppression of convection is an important factor. The rotation is being used as a means to suppress convection. The earlier studies have modeled the mushy layer as isotropic porous medium. Realistically, the permeability and thermal diffusivity are anisotropic. In view of these, it is of interest to gain a general understanding of the manner in which rotation affects the hydrodynamic stability of a double diffusive anisotropic porous layer. Therefore, in the present paper, we study the effect of rotation on the onset of double diffusive reaction-convection in an anisotropic porous medium. The main aim of this study is to analyze the linear stability of a rotating reactive binary mixture in a horizontal porous layer with anisotropic permeability and thermal diffusivity. Our objective is to study how the onset criterion for stationary and oscillatory convection is affected by the Taylor number, chemical reaction parameter and anisotropy parameters.

Mathematical Formulations:

We consider an infinite horizontal reactive fluid-saturated anisotropic porous layer confined between the planes z = 0 and z = d, with the vertically downward gravity force $\mathbf{g}$ acting on it. The temperatures T_l and T_u with $T_l > T_u$ and solute concentrations S_l and S_u with $S_l > S_u$ are imposed at the bottom and top boundaries, respectively. The boundaries are impermeable, and we assume chemical equilibrium at the boundaries. A Cartesian frame of reference is chosen with the origin in the lower boundary and the z-axis vertically upwards. The porous layer rotates uniformly about the z-axis with a constant angular velocity

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$\mathbf{\Omega}=(0,0,\Omega)$. The Darcy model is employed for the momentum equation. The transport of heat and solute is described by the advection-diffusion equations Philips (2009) .The Boussinesq approximation, which states that the variation in density is negligible everywhere in the conservations except in the buoyancy term, is assumed to hold. With these assumptions the governing equations are

$$\nabla\cdot\mathbf{q}=0\,, \tag{1}$$

$$\nabla p+2\mathbf{\Omega}\times\mathbf{q}+\mu\mathbf{K}\cdot\mathbf{q}-\rho\mathbf{g}=0\,, \tag{2}$$

$$(\rho c)_m\frac{\partial T}{\partial t}+(\rho c)_f(\mathbf{q}\cdot\nabla)T=(\rho c)_m\nabla\cdot(\boldsymbol{\kappa}_\mathbf{T}\cdot\nabla T)\,, \tag{3}$$

$$\varepsilon\frac{\partial S}{\partial t}+(\mathbf{q}\cdot\nabla)S=\varepsilon\kappa_S\nabla^2S+k\left(S_{eq}(T)-S\right), \tag{4}$$

$$\rho=\rho_0\left[1-\beta_T(T-T_0)+\beta_S(S-S_0)\right]\ , \tag{5}$$

where $\mathbf{q}=(u,v,w)$ is the velocity, p the pressure, T the temperature, S the concentration, ε represents the porosity, $\mathbf{\Omega}=(0,0,\Omega)$ angular velocity of rotation, $\mathbf{K}=K_x^{-1}\mathbf{ii}+K_y^{-1}\mathbf{jj}+K_z^{-1}\mathbf{kk}$ is the inverse of the anisotropic permeability tensor and $\boldsymbol{\kappa}_\mathbf{T}=\kappa_{Tx}\mathbf{ii}+\kappa_{Ty}\mathbf{jj}+\kappa_{Tz}\mathbf{kk}$ is the anisotropic thermal diffusion tensor. We restrict consideration to horizontal isotropy in mechanical and thermal properties of the porous medium, i.e., $K_x=K_y$ and $\kappa_{Tx}=\kappa_{Ty}$. The permeability and thermal diffusivity tensors of the porous medium are assumed to have principal axes aligned with the coordinate system. Further, κ_S is the solute diffusivity and k is a lumped effective reaction rate, and $S_{eq}(T)$ is the equilibrium concentration of the solute at a given temperature. The quantities β_T and β_S are the thermal volume expansion coefficient and density coefficient for salinity, respectively, and both are positive. The volumetric heat capacity of the fluid is denoted by $(\rho c)_f$ and that of the saturated medium as a whole by $(\rho c)_m=(1-\varepsilon)(\rho c)_s+\varepsilon(\rho c)_f$, where the subscripts f, s and m denote the properties of the fluid, solid, and porous matrix, respectively. Following Pritchard and Richardson (2007), and Jupp and Woods (2003), it is assumed that the equilibrium solute concentration is a linear function of temperature so that $S_{eq}(T)=S_0+\phi(T-T_0)$. Further, if chemical equilibrium at the boundaries is assumed, then $\phi=\frac{S_l-S_u}{T_l-T_u}=\frac{\Delta S}{\Delta T}$. The coefficient ϕ in general may be positive or negative. Obviously, if ϕ > 0, the solubility increases with temperature, while if ϕ < 0, the solubility decreases with temperature. It should be noted that, only the case ϕ > 0 is considered in the present paper.

The boundary conditions are that at the upper boundary, $T=T_u$, $S=S_u$ and at the lower boundary $T=T_l$, $S=S_l$, and the vertical component of velocity vanishes at both the boundaries. The basic state of the fluid is assumed to be quiescent. We then find the temperature and solute distribution in the basic state as

$$T_b(z)=-\frac{\Delta T}{d}z+T_l \text{ and } S_b(z)=-\frac{\Delta S}{d}z+S_l \tag{6}$$

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The initial distribution of solute is $S_b = S_{eq}\left(T_b\right)$ and since S_{eq} is linear in T, we allow the existence of a steady basic state in which the solute is everywhere in chemical equilibrium with the solid matrix and therefore the vertical flux of solute is constant in space. We study the stability of this basic state using the method of small perturbations. Now, we superpose infinitesimal perturbations on this basic state in the form

$$\mathbf{q} = \mathbf{q}_b + \mathbf{q}', T = T_b(z) + T', S = S_b(z) + S', p = p_b(z) + p', \rho = \rho_b(z) + \rho', \tag{7}$$

where the prime indicates perturbations. Substituting Eq. (7) into Eqs. (1) - (5), and using the basic state solutions, we get the linearized equations governing the perturbations in the form

$$\nabla.\mathbf{q}' = 0, \tag{8}$$

$$\nabla p' + 2\mathbf{\Omega}\times\mathbf{q}' + \mu\mathbf{K}\cdot\mathbf{q}' + \rho_0\left(\beta_T T' - \beta_S S'\right)\mathbf{g} = 0, \tag{9}$$

$$\left(\rho c\right)_m \frac{\partial T'}{\partial t} + \left(\rho c\right)_f \left(\left(\mathbf{q}'\cdot\nabla\right)T' - w'\frac{\Delta T}{d}\right) = \left(\rho c\right)_m \nabla\cdot\left(\boldsymbol{\kappa}_{\mathbf{T}}\cdot\nabla T'\right), \tag{10}$$

$$\varepsilon\frac{\partial S'}{\partial t} + \left(\mathbf{q}'\cdot\nabla\right)S' - \left(w'\frac{\Delta S}{d}\right) = \varepsilon\kappa_S\nabla^2 S' + k\left(S_{eq}\left(T'\right) - S'\right). \tag{11}$$

By operating curl twice on Eq. (9), we eliminate p' from it and then render the resulting equation and the Eqs. (8)- (11) dimensionless by setting

$$\begin{gathered}\left(x', y', z'\right) = \left(x^*, y^*, z^*\right)d,\ t' = t^*\left(d^2/\kappa_{Tz}\right),\ \left(u', v', w'\right) = \left(\varepsilon\kappa_{Tz}/d\right)\left(u^*, v^*, w^*\right),\\ T = \left(\Delta T\right)T^*, S = \left(\Delta S\right)S^*\end{gathered} \tag{12}$$

to obtain non-dimensional equations as (on dropping the asterisks for simplicity)

$$\left(\nabla_1^2 + \frac{1}{\xi}\frac{\partial^2}{\partial z^2} + Ta\frac{\partial^2}{\partial z^2}\right)w - Ra_T\nabla_1^2 T + Ra_S\nabla_1^2 S = 0, \tag{13}$$

$$\frac{\partial T}{\partial t} + \lambda\left(\mathbf{q}\cdot\nabla\right)T - \lambda w = \eta\nabla_1^2 T + \frac{\partial^2 T}{\partial z^2}, \tag{14}$$

$$\frac{\partial S}{\partial t} + \left(\mathbf{q}\cdot\nabla\right)S - w = \frac{1}{Le}\nabla^2 S + \chi\left(T - S\right), \tag{15}$$

where $Ra_T = \rho_0\beta_T g\Delta T d K_z/\mu\varepsilon\kappa_{Tz}$, the Darcy-Rayleigh number, $Ra_S = \rho_0\beta_S g\Delta S d K_z/\mu\varepsilon\kappa_{Tz}$, the solute Rayleigh number, both defined in terms of the vertical permeability K_z, vertical thermal diffusivity κ_{Tz}, and the porosity ε, $Ta = \left(\frac{2\Omega K_z}{\mu}\right)^2$, the Darcy Taylor number, $Le = \kappa_{Tz}/\kappa_S$, the Lewis number, $\chi = kd^2/\varepsilon\kappa_{Tz}$, Damkohler number that measures the rate of reaction, $\xi = K_x/K_z$, the mechanical anisotropy parameter, $\eta = \kappa_{Tx}/\kappa_{Tz}$, the thermal anisotropy parameter, and $\lambda = \varepsilon\frac{\left(\rho c\right)_f}{\left(\rho c\right)_m}$, the normalized porosity parameter. The

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Lewis number Le is known to be much greater than unity, and the dimensionless reaction rate measured by the Damkohler number $\chi \geq 0$.

The boundary conditions for the dimensionless perturbation quantities are given by

$$w = \frac{\partial^2 w}{\partial z^2} = T = S = 0, \text{ at } z = 0, 1. \tag{16}$$

Linear Stability Analysis:

In this section, we predict the thresholds of both marginal and oscillatory convections using linear theory. The eigenvalue problem defined by Eqs. (13)- (15) subject to the boundary conditions (16) is solved using the time-dependent periodic disturbances in a horizontal plane. Assuming that the amplitudes of the perturbations are very small, we write

$$\begin{pmatrix} w \\ T \\ S \end{pmatrix} = \begin{pmatrix} W(z) \\ \Theta(z) \\ \Phi(z) \end{pmatrix} exp\left[i(lx + my) + \sigma t \right], \tag{17}$$

where l, m are horizontal wavenumbers and σ is the growth rate. Infinitesimal perturbations of the rest state may either damp or grow depending on the value of the parameter σ. Substituting Eq. (17) into the linearized version of Eqs. (13) - (15) we obtain

$$\left[\left(\frac{D^2}{\xi} - a^2\right) + Ta\, D^2 \right] W(z) + Ra_T a^2 \Theta - Ra_S a^2 \Phi = 0, \tag{18}$$

$$\left[\sigma - \left(D^2 - \eta a^2 \right) \right] \Theta - \lambda W = 0, \tag{19}$$

$$\left[\sigma - \frac{1}{Le}\left(D^2 - a^2 \right) + \chi \right] \Phi - \chi \Theta - W = 0, \tag{20}$$

where $D = d/dz$ and $a^2 = l^2 + m^2$.

We assume the solutions of Eqs. (18) - (20) satisfying the boundary conditions (16) in the form

$$\begin{pmatrix} W(z) \\ \Theta(z) \\ \Phi(z) \end{pmatrix} = \begin{pmatrix} W_0 \\ \Theta_0 \\ \Phi_0 \end{pmatrix} \text{Sin}\, n\pi z, \; (n = 1, 2, 3, ...). \tag{21}$$

The most unstable mode corresponds to $n = 1$ (fundamental mode). Therefore, substituting Eq. (21) with $n = 1$ into Eqs. (18) - (20), we obtain an expression for thermal Rayleigh number in the form

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$$Ra_T = \frac{\left(\delta_1^2 + \pi^2 Ta\right)\left(\sigma + \delta_2^2\right)}{\lambda a^2} + \frac{Ra_S}{\lambda}\left(\frac{\sigma + \delta_2^2 + \lambda\chi}{\sigma + \delta^2 Le^{-1} + \chi}\right). \quad (22)$$

where, $\delta^2 = \pi^2 + a^2$, $\delta_1^2 = \pi^2\xi^{-1} + a^2$ and $\delta_2^2 = \pi^2 + \eta a^2$. The growth rate σ is in general a complex quantity such that $\sigma = \sigma_r + i\sigma$. The system with $\mathrm{Re}(\sigma) < 0$ is always stable, while for $\mathrm{Re}(\sigma) > 0$, it will become unstable. For neutral stability, we have $\mathrm{Re}(\sigma) = 0$.

Stationary Convection:

For the validity of principle of exchange of stabilities (i.e., steady case), we have $\sigma = 0$ (i.e., $\sigma_r = \sigma_i = 0$) at the margin of stability. Then the Rayleigh number at which marginally stable steady mode exists becomes

$$Ra_T^{St} = \frac{\left(\delta_1^2 + \pi^2 Ta\right)\left(\delta_2^2\right)}{\lambda a^2} + \frac{Ra_S}{\lambda}\left(\frac{\delta_2^2 + \lambda\chi}{\delta^2 Le^{-1} + \chi}\right) \quad (23)$$

The minimum value of the Rayleigh number Ra_T^{St} occurs at the critical wavenumber $a = a_c^{St}$ where $a_c^{St} = \sqrt{r}$ satisfies a polynomial equation

$$a_0 r^4 + a_1 r^3 + a_2 r^2 + a_3 r + a_4 = 0, \quad (24)$$

In the absence of rotation, Eq. (23) reduces to

$$Ra_T^{St} = \frac{\left(\delta_1^2\right)\left(\delta_2^2\right)}{\lambda a^2} + \frac{Ra_S}{\lambda}\left(\frac{\delta_2^2 + \lambda\chi}{\delta^2 Le^{-1} + \chi}\right), \quad (25)$$

given by Malashatty and Biradar (2011). In the absence of a chemical reaction parameter (i.e., $\chi = 0$), and, Further $(\lambda = 1)$, Eq. (23) reduces to

$$Ra_T^{St} = \frac{\left(\delta_1^2 + \pi^2 Ta\right)\left(\delta_2^2\right)}{a^2} + \left(\frac{\delta_2^2 Ra_S}{\delta^2 Le^{-1}}\right). \quad (26)$$

This is exactly the one given by Malashatty and Heera (2008). Further in absence of both rotation and chemical reaction parameter Eq. (23) reduces to

$$Ra_T^{St} = \frac{1}{a^2}\left(a^2 + \frac{\pi^2}{\xi}\right)\left(\eta a^2 + \pi^2\right) + \left(\frac{\eta a^2 + \pi^2}{a^2 + \pi^2}\right) Le\, Ra_S. \quad (27)$$

This is the result obtained by Malashetty and Swamy (2010) for the onset of stationary double diffusive convection in an anisotropic porous layer. Further, for an isotropic porous media, that is when $\xi = \eta = 1$, Eq. (27) reduces to the classical result Nield and Bejan (2006)

$$Ra_T^{St} = \frac{1}{a^2}\left(a^2 + \pi^2\right)^2 + Le\, Ra_S, \quad (28)$$

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with critical values $Ra_{T,c}^{St} = 4\pi^2 + Le\, Ra_S$ and $a_c^{St} = \pi$. In the case of single component convection in an anisotropic porous medium, $Ra_S = 0$; the expression for stationary Rayleigh number given by Eq. (27) reduces to

$$Ra_T^{St} = \frac{1}{a^2}\left(a^2 + \frac{\pi^2}{\xi}\right)\left(\eta a^2 + \pi^2\right), \tag{29}$$

which is the one obtained by Storesletten (1998) for the case of a single component fluid saturated anisotropic porous layer (pure thermal convection). Further, for an isotropic porous medium, $\xi = \eta = 1$, the above Eq. (29) reduces to the classical result

$$Ra_T^{St} = \frac{1}{a^2}\left(a^2 + \pi^2\right)^2, \tag{30}$$

with critical values $Ra_{T,c}^{St} = 4\pi^2$ and $a_c^{St} = \pi$ obtained by Horton and Rogers (1945), and Lapwood (1948)

Oscillatory Convection:

We now set $\sigma = i\,\sigma$, in Eq. (22) and clear the complex quantities from the denominator, to obtain

$$Ra_T = \Delta_1 + i\,\sigma\,\Delta_2, \tag{31}$$

where,

$$\Delta_1 = \frac{\left(\delta_1^2 + \pi^2 Ta\right)\left(\delta_2^2\right)}{\lambda\, a^2} + \frac{Ra_S}{\lambda}\left(\frac{\sigma^2 + \left(\lambda\,\chi + \delta_2^2\right)\left(\delta^2 Le^{-1} + \chi\right)}{\sigma^2 + \left(\delta^2 Le^{-1} + \chi\right)^2}\right)$$

$$\Delta_2 = \frac{\left(\delta_1^2 + \pi^2 Ta\right)}{\lambda\, a^2} + \frac{Ra_S}{\lambda}\left(\frac{\chi\left(1-\lambda\right) + \delta^2 Le^{-1} - \delta_2^2}{\sigma^2 + \left(\delta^2 Le^{-1} + \chi\right)^2}\right).$$

Since Ra_T is a physical quantity, it must be real. Hence, from Eq. (31) it follows that either $\sigma_i = 0$ (steady onset) or $\Delta_2 = 0$ ($\sigma_i \neq 0$, oscillatory onset).

For oscillatory onset $\Delta_2 = 0$ ($\sigma_i \neq 0$) and this gives a expression for the frequency of oscillation in the form

$$\sigma^2 = \frac{a^2 Ra_S}{\left(\delta_1^2 + \pi^2 Ta\right)}\left(\delta_2^2 - \delta^2 Le^{-1} - \chi\left(1-\lambda\right)\right) - \left(\delta^2 Le^{-1} + \chi\right)^2. \tag{32}$$

Now Eq. (31) with $\Delta_2 = 0$, gives

$$Ra_T^{Osc} = \frac{\left(\delta_1^2 + \pi^2 Ta\right)\left(\delta_2^2\right)}{\lambda\, a^2} + \frac{Ra_S}{\lambda}\left(\frac{\sigma^2 + \left(\lambda\,\chi + \delta_2^2\right)\left(\delta^2 Le^{-1} + \chi\right)}{\sigma^2 + \left(\delta^2 Le^{-1} + \chi\right)^2}\right). \tag{33}$$

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The analytical expression for oscillatory Rayleigh number given by Eq. (33) is minimized with respect to the wavenumber numerically, after substituting for $\sigma^2(>0)$ from Eq. (32), for various values of the physical parameters in order to know their effects on the onset of oscillatory convection.

RESULTS AND DISCUSSIONS

The effect of rotation on the onset of double diffusive reaction-convection in an anisotropic porous layer which is heated and salted from below is investigated analytically using linear theory. In this theory, the expressions for the stationary and oscillatory Rayleigh number and for frequency of oscillation are obtained analytically.

The neutral stability curves in the $Ra_T - a$ plane for various parameter values are as shown in Figs.1-7. From these figures it is clear that the neutral curves are connected in a topological sense. This connectedness allows the linear stability criteria to be expressed in terms of the critical Rayleigh number, Ra_{Tc} below which the system is stable and unstable above.

The effect of Taylor number Ta on the marginal stability curves for the fixed values of mechanical anisotropy parameter, thermal anisotropy parameter, Damkohler number, solute Rayleigh number, Lewis number and normalized porosity parameter, is depicted in Fig. 1. We observe from this figure that the minimum of Rayleigh number for both stationary and oscillatory states increases with the Taylor number, indicating that the effect of rotation is to enhance the stability of the system in both stationary and overstable modes.

Fig.2 shows the neutral stability curves for different values of the mechanical anisotropy parameter and for fixed values of other governing parameters. We observe from this figure that the convection sets in as an oscillatory mode prior to the stationary convection. The effect of the mechanical anisotropic parameter ξ can be interpreted as follows.

One, when $\xi > 1$, keeping vertical permeability K_z constant, increasing horizontal permeability K_x decreases the minimum of the Rayleigh number for both stationary and oscillatory modes indicating that the effect is destabilizing. Larger horizontal permeability augments horizontal motion and the conduction solution is thus destabilized. Two, when $\xi < 1$, keeping vertical permeability K_z constant and decreasing horizontal permeability K_x increases the minimum of the Rayleigh number for stationary and oscillatory modes indicating that the effect is stabilizing. Further, we find that the minimum of Rayleigh number shifts towards the smaller values of the wavenumber with increasing mechanical anisotropy parameter. This indicates that the cell width increases with increasing mechanical anisotropy parameter.

Fig. 3 displays the effect of the thermal anisotropy parameter η on the neutral stability curves for fixed values of the other parameters. It is interesting to note that the effect of the thermal anisotropy parameter is opposite to that of the mechanical anisotropy parameter. Again similar to the mechanical anisotropy parameter, the effect of thermal anisotropy parameter can be interpreted as follows: Keeping vertical thermal diffusivity constant, larger values of the horizontal thermal diffusivity correspond to stabilization of the basic state and the onset of convection at a larger Rayleigh number. This can be explained by the fact that, as η increases, a heated fluid parcel loses more heat in the horizontal directions and hence lessens its buoyancy force. Therefore, the base state smaller horizontal permeability inhibits horizontal motion and then becomes more stable. Further, we find that the minimum of the Rayleigh number shifts towards the smaller values of the wavenumber with increasing thermal anisotropy parameter. This indicates that the cell width increases with increasing thermal anisotropy parameter.

The neutral stability curves for different values of the Damkohler number and for fixed values of the other parameters is shown in Fig. 4. We observe from this figure that an increase in the value of χ increases the minimum of the oscillatory Rayleigh number. This indicates that chemical reaction parameter stabilizes the

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system in the case of oscillatory mode. This may occur because when the reaction rate is fast enough, the solute concentration of a displaced fluid particle can be changed by chemical reaction to equilibrate quickly with that of the surrounding fluid, thus reducing and eventually eliminating the energy source for the onset of oscillatory instability. As a result, the instability caused by heating from below will onset into steady convection. On the other hand, increasing the chemical reaction parameter decreases the minimum of the stationary Rayleigh number, indicating that the chemical reaction parameter destabilizes the system in case of stationary mode. Thus, the Damkohler number has a contrasting effect on stationary and oscillatory modes. Furthermore, we can observe from this figure that the effect of the chemical reaction parameter is more pronounced on the stationary mode than on the oscillatory mode. It is interesting to note that the range of horizontal wave number for which the oscillatory convection is possible decreases with increasing Damkohler number. It is also worth mentioning here that the critical wavenumber for stationary convection decreases with increasing chemical reaction parameter while that for oscillatory convection increases.

Fig. 5 depicts the effect of solute Rayleigh number Ra_S on the neutral stability curves for stationary and oscillatory modes. We find that the effect of increasing Ra_S is to increase the critical value of the Rayleigh number for stationary and oscillatory modes and the corresponding wavenumber. Thus the solute Rayleigh number Ra_S has a stabilizing effect on a rotating double diffusive reaction-convection anisotropic porous medium.

In Fig. 6 the marginal stability curves for different values of Lewis number Le are drawn. It is found that with the increase of Le the critical values of Rayleigh number and the corresponding wavenumber for the oscillatory mode decrease while those for stationary mode increase. Therefore, the effect of Le is to advance the onset of oscillatory convection where as its effect is to inhibit the stationary onset.

The effect of normalized porosity parameter λ is depicted in the Fig.7. We observe that an increase in λ decreases the minimum of the Rayleigh number for stationary as well for oscillatory mode, indicating that, the effect of increasing λ is to advance the onset of convection.

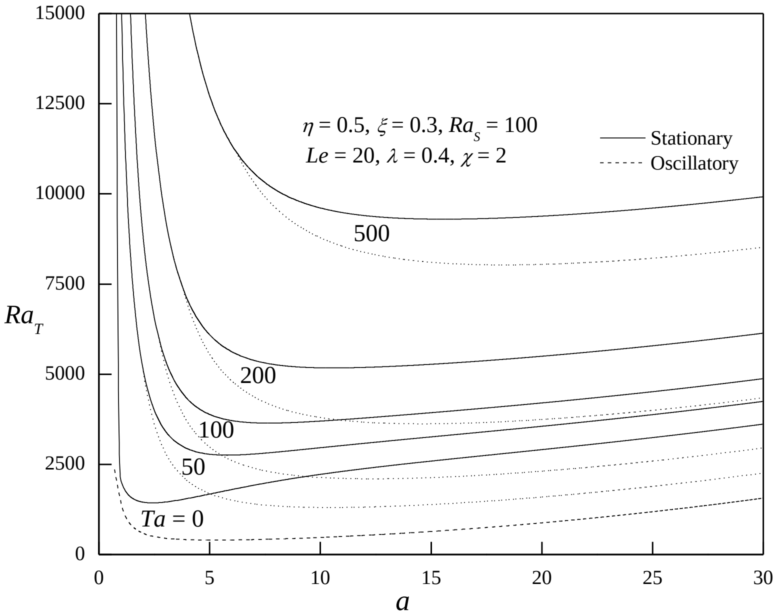

Fig. 1. Neutral stability curves for differents values of Taylor number Ta.

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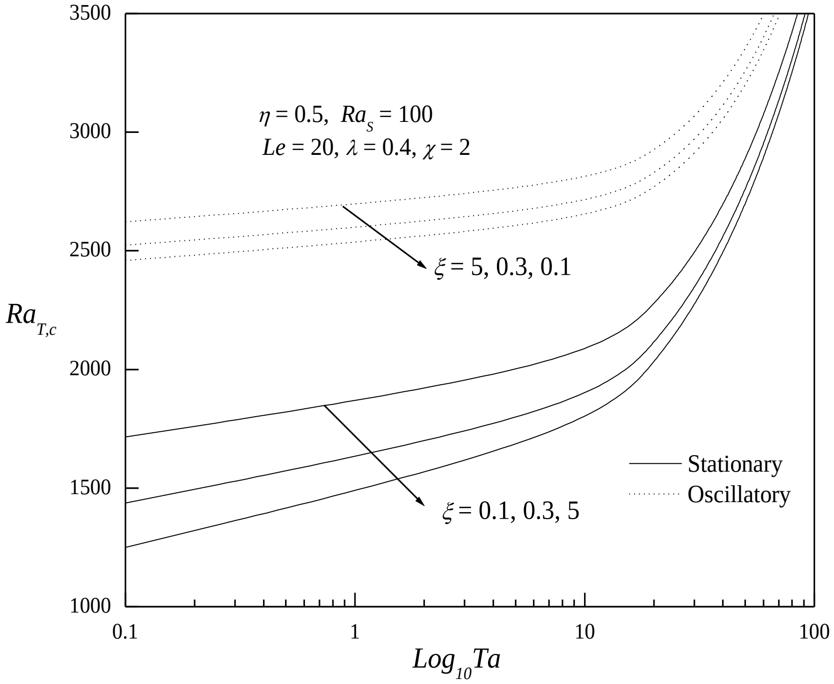

Fig . 2 . Variation of critical Rayleigh with Taylor number Ta for different values of mechanical anisotrpoy parameter ξ.

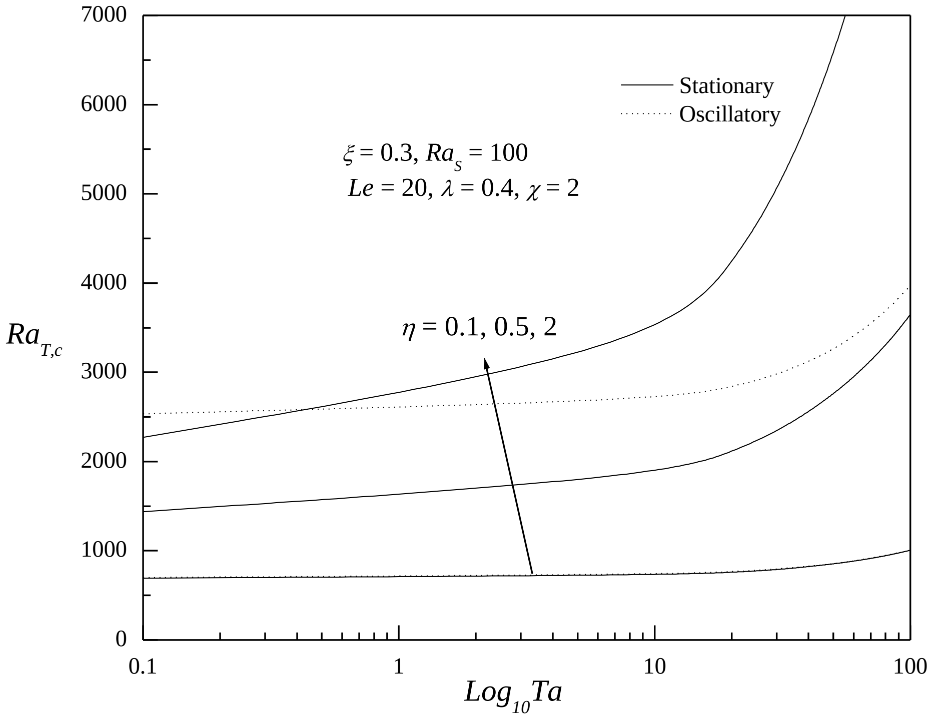

Fig . 3 . Variation of critical Rayleigh with Taylor number Ta for different values of thermal anisotrpoy parameter η.

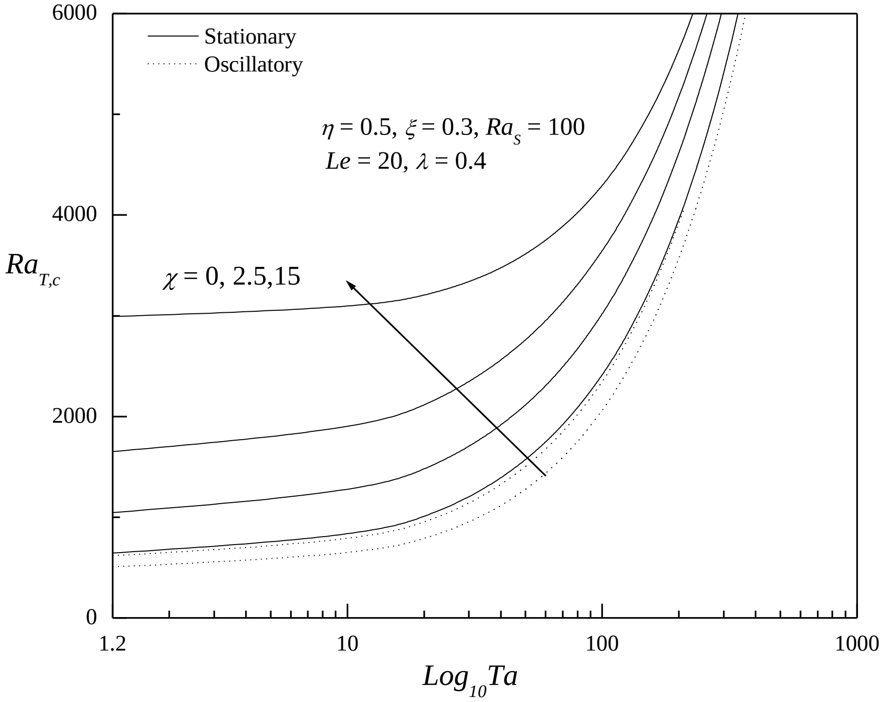

Fig . 4 . Variation of critical Rayleigh with Taylor number Ta for different values of Damkholer number χ.

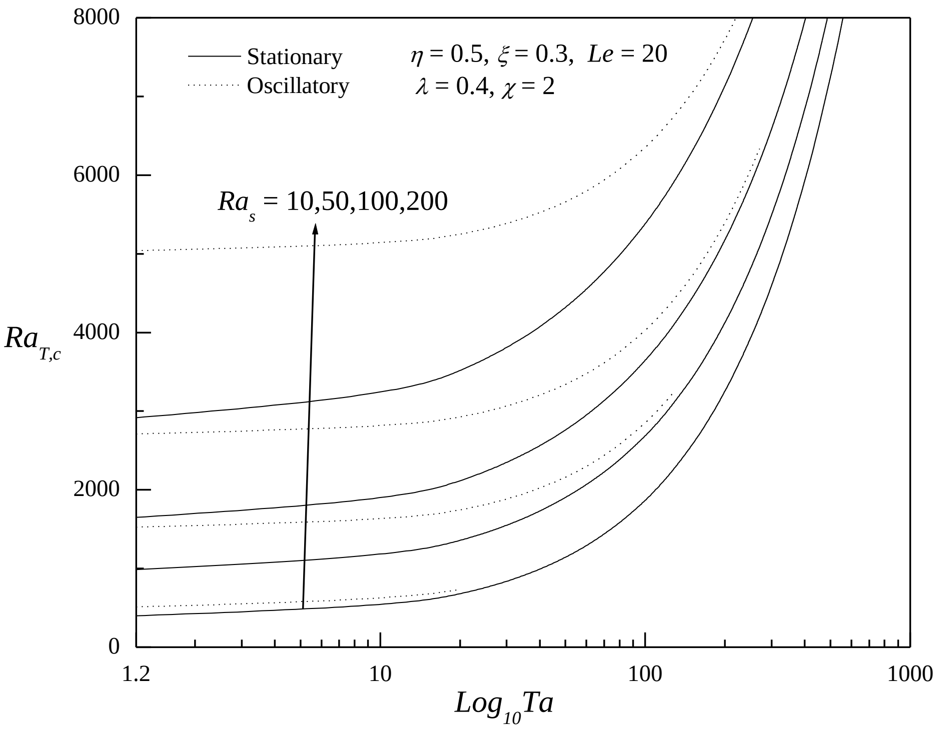

Fig . 5 . Variation of critical Rayleigh with Taylor number Ta for different values of solute Rayleigh number Ra_S.

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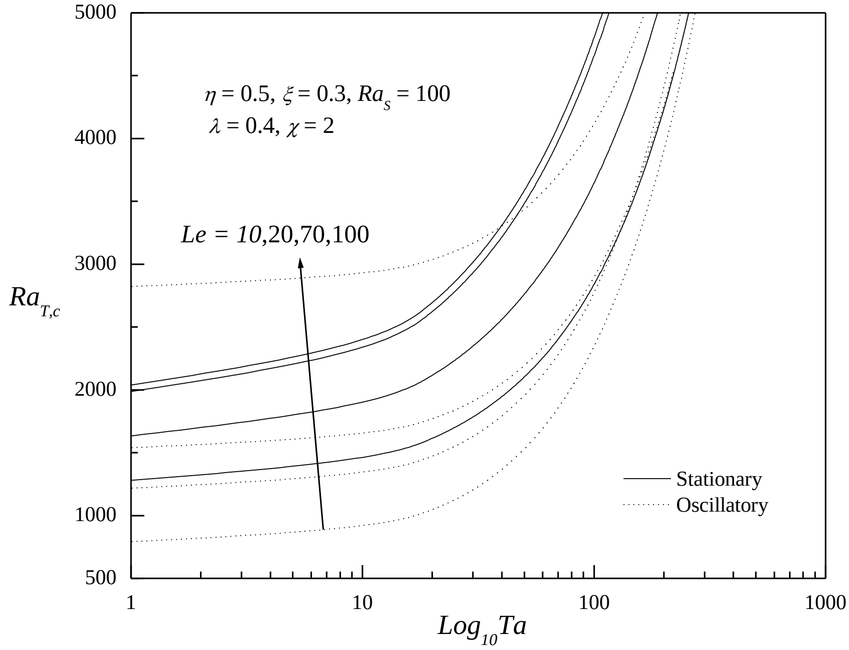

Fig . 6 . Variation of critical Rayleigh with Taylor number *Ta* for different values of Lewis number *Le*.

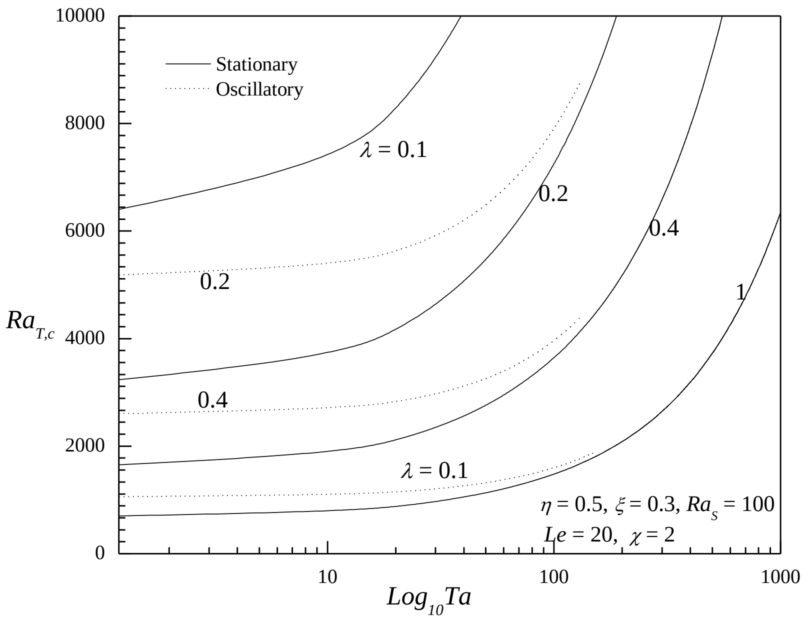

Fig . 7 . Variation of critical Rayleigh with Taylor number *Ta* for different values of normalized porosity parameter λ.

CONCLUSIONS

The onset of rotating double diffusive reaction-convection in an anisotropic horizontal porous layer saturated with binary mixture, which is heated and salted from below, is investigated analytically using linear theory.

The usual normal mode technique is used to solve the linear problem. Here the thresholds of both stationary and oscillatory convection are derived as functions of Taylor number, mechanical anisotropy parameter, thermal anisotropy parameter, Damkohler number, Lewis number, solute Rayleigh number, and normalized porosity parameter.

The Taylor number Ta has a stabilizing effect on the system. When the horizontal permeability is high ($\xi > 1$), the system is more unstable. When the horizontal component of thermal diffusivity is dominant ($\eta > 1$), the system becomes more stable; while the vertical component of thermal diffusivity is dominant ($\eta < 1$), the system becomes more unstable. The effect of increasing the Damkohler number χ is to advance the onset of stationary convection and delay the onset of oscillatory convection. The effect of solute Rayleigh number is to delay stationary and oscillatory convection. It is found that the effect of increasing Lewis number is to delay the onset of stationary convection and advance the onset of oscillatory convection. The critical Rayleigh numbers for stationary and oscillatory modes are increasing functions of Taylor number. Increasing the normalized porosity parameter advances stationary and oscillatory convection.

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