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ONSET OF MIXED CONVECTION IN AN ADSORPTIVE POROUS MEDIUM

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Abstract. *The onset of thermal convective instability in fluid flow through a parallel-plates horizontal channel in the presence of physical adsorption has been investigated. Linear Stability Analysis (LSA) is used in a mixed-convection problem formulation within a homogeneous saturated hygroscopic porous medium. Darcy's Law is used to model the flow field, and transport equations for a dilute mixture of dry air and water are employed to describe the heat and mass flow through the channel. The bounding walls are impermeable at the top and permeable to water at the bottom; they are also subjected to different temperatures: the lower wall is heated while the upper wall is cooled. The normal modes method is applied to perform the LSA of the problem and the resulting eigenvalue composed of a system of complex-valued equations is carried out numerically by a shooting method. Results are reported for the neutral stability curves and determined the critical values for the onset of instability.*

Keywords: *Linear Stability Analysis, heat and mass transfer, porous medium physical adsorption, dispersion relation, eigenproblems*

NOMENCLATURE

c	specific heat
$\mathcal{D}$	effective gas-phase mass diffusivity
$\boldsymbol{g}$	gravity acceleration
k_e	effective thermal conductivity
H	layer thickness
i	specific enthalpy
i_{sor}	differential heat of sorption
m	mass
T	Temperature
t	time
$\boldsymbol{v}$	bed velocity (effective velocity)
$x,\ y,\ z$	spatial coordinates
Y	water vapor concentration in dry basis (kg water/kg dry air)
W	water concentration in adsorbed phase (kg water/kg adsorbent)

Greek symbols

α_e	effective thermal diffusivity
β	thermal expansion coefficient
ρ_a	density of dry air
ρ_e	effective of bulk density of dry porous medium
ρ_p	density of dry porous particle
ϵ	pertubation
ε	porosity
K_e	permeability
μ	dynamic viscosity
ϕ	relative humidity
p	pressure field

Dimensionless parameters

δ	wave number related to z-direction
γ	wave number related to x-direction
ω	angular frequency
Le	Lewis number
Ra	Darcy-Rayleigh number
Pe	Péclet number

Subscripts

a	dry air
c	critical value
l	adsorbed water
max	maximum value
p	particles
s	solid portion of (dry) particles
v	water vapor

1. INTRODUCTION

1.1 Problem formulation

Consider a three-dimensional fluid in a channel filled with a porous channel as show in Fig. 1.

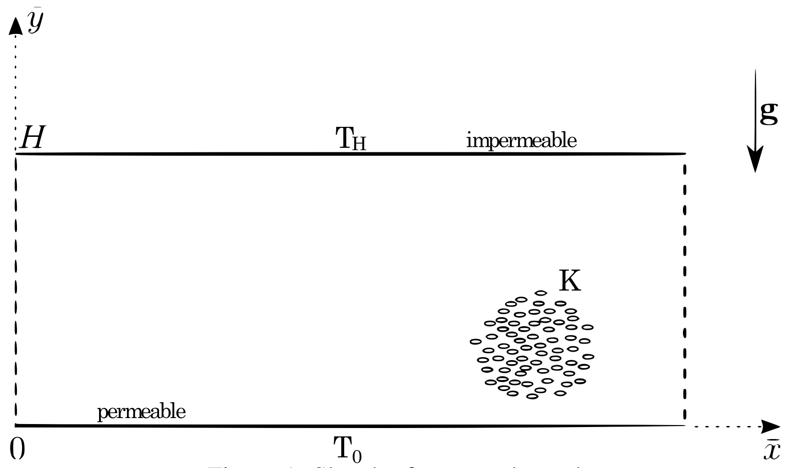


Figure 1: Sketch of porous channel

The channel is conceived as a medium filled with porous particles such that there is a bed porosity ε_b and a particle porosity ε_p, both of which remain constant. The total porosity ε is given by $(1-\varepsilon) = (1-\varepsilon_p)(1-\varepsilon_b)$. Water vapor concentration is small (dilute solution), such that a momentum conservation balance for dry air alone is employed. Flow occurs within the void space between adjacent particles, and there is local thermodynamic equilibrium between the solid phase and the fluid phase. Flow occurs within the void space between adjacent particles, and there is local thermodynamic equilibrium between the solid phase and the fluid phase.

1.2 Momentum balance for dry air

This is given by a Darcy model (1a):

$$\frac{\mu}{K_e}\boldsymbol{v} = -\nabla p + \rho_a\,\beta\,(T_H - T)\,\boldsymbol{g}, \qquad \nabla\cdot\boldsymbol{v} = 0, \tag{1a}$$

$$\varepsilon\,\rho_a\frac{\partial Y}{\partial t} + \rho_e\frac{\partial W}{\partial t} + \rho_a\,\boldsymbol{v}\cdot\nabla Y = \nabla\cdot\left(\mathcal{D}\,\rho_a\,\nabla Y\right), \tag{1b}$$

(1c)

where the first two terms on the left-hand-side represent water storage in vapor (in void spaces) and adsorbed (on adsorbent surface) forms, while the third one represents the vapor transport due to advection effects. The term on the right-hand-side represents the transport due to vapor diffusion. The water concentration is written in terms of dry-basis quanties: in gas-phase (Y) and water in the adsorbed phase (W); as a result, the densities of dry air ρ_a and bulk (dry) porous medium

$\rho_e = (1 - \varepsilon_b)\, \rho_p$ appear in the previous equation.

$$\hat{C}\, \frac{\partial T}{\partial t} \,+\, C\, \boldsymbol{v} \cdot \nabla T \,=\, \nabla \cdot (k_e\, \nabla T) \,+\, i_{sor}\, \rho_e\, \frac{\partial W}{\partial t}, \tag{1d}$$

where the last equation (1a) is the mass conservation balance for dry air. such that the mass conservation for dry air becomes unnecessary. (1b) is the mass balance for water vapor and (1c) is the energy balance for the porous medium. where the first term on the left-hand-side represent the sensible energy storage in the fluid-filled porous medium and the second the heat transport rate due to advection. The terms on the right-hand-side represent the energy transport due to heat conduction and the rate of heating due to adsorption effects, respectively.

2. NORMALIZATION

The normalization of the problem is achieved by introducing the following dimensionless variables:

$$\xi = \frac{x}{H}, \quad \eta = \frac{y}{H}, \quad \zeta = \frac{z}{H}, \quad t^* = \frac{t}{t_t}, \quad T^* = \frac{T - T_H}{T_0 - T_H}, \quad U = \frac{\alpha_e}{H} = \frac{k_e}{\rho_e\, c_s\, H}, \tag{2a}$$

$$W^* = \frac{W}{W_{\max}}, \qquad Y^* = \frac{Y}{Y_{\max}}, \quad u^* = \frac{u}{U}, \quad v^* = \frac{v}{U}, \quad w^* = \frac{w}{U}, \quad t_t = \frac{H^2}{\alpha_e}, \tag{2b}$$

where U is a diffusion-based velocity and t_t is a diffusion-based time scale. H is the spacing between plates and the value of $Y_{\max}$ can be calculated from a saturation condition at a reference temperature. The normalized boundary conditions are given by:

$$v^* = 0, \qquad T^* = 1, \qquad \frac{\partial Y^*}{\partial \eta} = m_v^*, \qquad \text{at} \qquad \eta = 0, \tag{3a}$$

$$v^* = 0, \qquad T^* = 0, \qquad \frac{\partial Y^*}{\partial \eta} = 0, \qquad \text{at} \quad \eta = 1, \tag{3b}$$

in which the dimensionless water inflow rate at the bottom plate m_v^* is defined as:

$$m_v^* = \frac{\dot{m}_v''\, H}{\rho_a\, Y_{\max}\, \mathcal{D}}. \tag{4}$$

Finally, the coefficients χ and $\hat{\chi}$ take into account variations in heat capacity due to the presence of moisture, in the fluid, and in the sorbent material, respectively:

$$\chi = 1 + c_p^*\, Y^*, \qquad \hat{\chi} = \chi\, \mathrm{C}^* + 1 + c_l^*\, W^*, \tag{5}$$

where:

$$c_p^* = \frac{c_{p,v}\, Y_{\max}}{c_{p,a}}, \qquad c_l^* = \frac{c_l\, W_{\max}}{c_s}. \tag{6}$$

The normalization of the governing equations thus yields three dimensionless momentum equations, a mass transfer equation for water vapor and an energy transfer equation:

$$\frac{\partial w^*}{\partial \eta} - \frac{\partial v^*}{\partial \zeta} = -\mathrm{Ra}\, \frac{\partial T^*}{\partial \zeta}, \qquad \frac{\partial v^*}{\partial \xi} - \frac{\partial u^*}{\partial \eta} = \mathrm{Ra}\, \frac{\partial T^*}{\partial \xi}, \qquad \frac{\partial w^*}{\partial \xi} = \frac{\partial u^*}{\partial \zeta}, \tag{7a}$$

$$\frac{\partial Y^*}{\partial t^*} + \Omega \frac{\partial W^*}{\partial t^*} + \frac{1}{\varepsilon}(u^* \frac{\partial Y^*}{\partial \xi} + v^* \frac{\partial Y^*}{\partial \eta} + w^* \frac{\partial Y^*}{\partial \zeta}) = \frac{1}{\varepsilon \mathrm{Le}}(\frac{\partial^2 Y^*}{\partial \eta^2} + \frac{\partial^2 Y^*}{\partial \xi^2} + \frac{\partial^2 Y^*}{\partial \zeta^2}), \tag{7b}$$

$$\hat{\chi}\, \frac{\partial T^*}{\partial t^*} + \chi \mathrm{C}^*\, (u^* \frac{\partial T^*}{\partial \xi} + v^* \frac{\partial T^*}{\partial \eta} + w^* \frac{\partial T^*}{\partial \zeta}) = \frac{\partial^2 T^*}{\partial \eta^2} + \frac{\partial^2 T^*}{\partial \xi^2} + \frac{\partial^2 T^*}{\partial \zeta^2} + i_{sor}^*\, \frac{\partial W^*}{\partial t^*}, \tag{7c}$$

where Ra is the Darcy-Rayleigh number, Le is the Lewis number, C^* is the thermal capacity ratio (dry solid matrix to that of dry air), i^*_{sor} is the dimensionless heat of sorption, and Ω is the ratio of the maximum water uptake in the adsorbent to that present in the gas phase of a clear channel of the same dimensions, respectively given by:

$$\mathrm{Ra} = \frac{g\,\beta\,\Delta T\,H\,K_e}{\nu\,\alpha}, \qquad \mathrm{Le} = \frac{\alpha_e}{\mathcal{D}}, \tag{8a}$$

$$\mathrm{C}^* = \frac{\varepsilon\,\rho_a\,c_{p,a}}{\rho_e\,c_s}, \qquad i^*_{sor} = \frac{i_{sor}\,W_{\max}}{c_s\,\Delta T}, \qquad \Omega = \frac{W_{\max}\,\rho_e}{\varepsilon\,Y_{\max}\,\rho_a}, \tag{8b}$$

3. LINEAR STABILITY ANALYSIS

3.1 Basic Solution

A stationary solution describing a flow in the layer can be obtained as

$$v^*_b = 0, \quad u^*_b = \mathrm{Pe}, \quad w^*_b = 0, \quad Y^*_b = m^*_v\left(1 - \frac{1}{2}\eta\right)\eta - \frac{m^*_v}{\mathrm{Pe\,Le}}\xi, \quad T^*_b = 1 - \eta. \tag{9a}$$

where the subscript b stands for base-state solution, Pe is an arbitrary real constant playing the role of the Péclet number associated with the basic flow, $r^*_M = r_M/Y_{\max}$, and $p^*_{vs} = p_{vs}/p$.

3.2 Onset of Convective Stabilities

A Linear Stability Analysis of the studied problem is now carried-out. The study of the stability of the solution is initiated by introducing small perturbations on the base-state, which can be written as:

$$u^* = u^*_b + \epsilon\,u^*_p, \qquad v^* = v^*_b + \epsilon\,v^*_p, \qquad w^* = w^*_b + \epsilon\,w^*_p, \tag{10a}$$

$$T^* = T^*_b + \epsilon\,T^*_p, \qquad Y^* = Y^*_b + \epsilon\,Y^*_p, \qquad W^* = W^*_b + \epsilon\,W^*_p, \tag{10b}$$

where ϵ is the small perturbation parameter, b represent the basic state and p is for disturbances. This perturbed solution (10) is then substituted into the governing equations (7):

$$\frac{\partial w^*_p}{\partial \eta} - \frac{\partial v^*_p}{\partial \zeta} = -\mathrm{Ra}\,\frac{\partial T^*_p}{\partial \zeta}, \qquad \frac{\partial v^*_p}{\partial \xi} - \frac{\partial u^*_p}{\partial \eta} = \mathrm{Ra}\,\frac{\partial T^*_p}{\partial \xi}, \qquad \frac{\partial w^*_p}{\partial \xi} = \frac{\partial u^*_p}{\partial \zeta}, \tag{11a}$$

$$\frac{\partial Y^*_p}{\partial t^*} + \Omega\,\frac{\partial W^*_p}{\partial t^*} - \frac{u^*_p m^*_v}{\varepsilon\,\mathrm{PeLe}} + \mathrm{Pe}\frac{\partial Y^*_p}{\varepsilon \partial \xi} + \frac{v^*_p}{\varepsilon} m^*_v\,(1-\eta) = \frac{1}{\varepsilon\,\mathrm{Le}}\left(\frac{\partial^2 Y^*_p}{\partial \eta^2} + \frac{\partial^2 Y^*_p}{\partial \xi^2} + \frac{\partial^2 Y^*_p}{\partial \zeta^2}\right) \tag{11b}$$

$$\hat{\chi}\,\frac{\partial T^*_p}{\partial t^*} + \chi\,\mathrm{C}^*\left(\mathrm{Pe}\,\frac{\partial T^*_p}{\partial \xi} + v^*_p\right) = \frac{\partial^2 T^*_p}{\partial \eta^2} + \frac{\partial^2 T^*_p}{\partial \xi^2} + \frac{\partial^2 T^*_p}{\partial \zeta^2} + i^*_{sor}\,\frac{\partial W^*_p}{\partial t^*}, \tag{11c}$$

which are then simplified using the base state solution (9) and terms with order higher than ϵ^1 are dropped. The perturbations are then expressed as normal modes and replaced into the linearized perturbed equations, the dispersion equations are obtained.

$$u^*_p \to u_n(\eta)\,\mathrm{e}^{\mathrm{i}\,(\gamma\,\xi + \delta\,\zeta - \omega\,t^*)}, \tag{12a}$$

$$v^*_p \to v_n(\eta)\,\mathrm{e}^{\mathrm{i}\,(\gamma\,\xi + \delta\,\zeta - \omega\,t^*)}, \tag{12b}$$

$$w^*_p \to w_n(\eta)\,\mathrm{e}^{\mathrm{i}\,(\gamma\,\xi + \delta\,\zeta - \omega\,t^*)}, \tag{12c}$$

$$Y^*_p \to Y_n(\eta)\,\mathrm{e}^{\mathrm{i}\,(\gamma\,\xi + \delta\,\zeta - \omega\,t^*)}, \tag{12d}$$

$$T^*_p \to T_n(\eta)\,\mathrm{e}^{\mathrm{i}\,(\gamma\,\xi + \delta\,\zeta - \omega\,t^*)}, \tag{12e}$$

$$W^*_p \to W_n(\eta)\,\mathrm{e}^{\mathrm{i}\,(\gamma\,\xi + \delta\,\zeta - \omega\,t^*)}. \tag{12f}$$

Where γ and δ are the dimensionless wave numbers related to the two directions, $\omega = \omega_r + \omega_i\,\mathrm{i}$, ω_r is the angular frequency and ω_i is the growth rate. Since the focus here is finding the onset of convective instability, that is the marginal condition, the growth rate is set to zero, i.e. $\omega_i = 0$, and ω_r is treated just as ω. Substituting the normal modes into the linearized perturbed equations, the dispersion equations are obtained:

$$w_n'(\eta) + \mathrm{i}\,\delta\,\mathrm{Ra}\,T_n(\eta) = \mathrm{i}\,\delta\,v_n(\eta), \tag{13a}$$

$$u_n'(\eta) + \mathrm{i}\,\gamma\,\mathrm{Ra}\,T_n(\eta) = \mathrm{i}\,\gamma\,v_n(\eta), \tag{13b}$$

$$\delta\,u_n(\eta) = \gamma\,w_n(\eta), \tag{13c}$$

$$\frac{m_v^*}{\varepsilon}(1-\eta)\,v_n(\eta) - \mathrm{i}\left(Y_n(\eta)\,(\omega - \gamma\,\frac{\mathrm{Pe}}{\varepsilon}) + \omega\,\Omega\,W_n(\eta)\right) = \frac{Y_n''(\eta) - (\gamma^2 + \delta^2)\,Y_n(\eta)}{\varepsilon\,\mathrm{Le}} + \frac{m_v^*\,u_n(\eta)}{\varepsilon\,\mathrm{Le}\,\mathrm{Pe}}, \tag{13d}$$

$$\chi\,\mathrm{C}^*\,v_n(\eta) + T_n'' - \mathrm{i}\,i_{sor}^*\,\omega\,W_n(\eta) = (\mathrm{i}\,\mathrm{C}^*\,\mathrm{Pe}\,\gamma\,\chi + (\gamma^2 + \delta^2 - i\,\hat{\chi}\,\omega))T_n(\eta). \tag{13e}$$

The quantity $W_n(\eta)$ can be written as a Taylor Series expansion up to order one about the base-state:

$$W_n(\eta) = \left.\frac{\partial\phi}{\partial T^*}\right|_b T_n(\eta) + \left.\frac{\partial\phi}{\partial Y^*}\right|_b Y_n(\eta), \tag{14}$$

where the derivatives of the relative humidity are calculated by

$$\frac{\partial\phi}{\partial T^*} = -\Delta T\left(\frac{\phi}{p_{vs}}\,\frac{\partial p_{vs}}{\partial T}\right), \qquad \frac{\partial\phi}{\partial Y^*} = \phi\,\frac{r_M\,Y_{\max}}{Y\,(r_M + Y)}. \tag{15}$$

Then, equations (13d, 13e) can be further simplified by solving equations (13a) (13b) and (13c) for $u_n(\eta)$, $w_n(\eta)$ and $T_n(\eta)$, such that

$$u_n(\eta) = \mathrm{i}\,\frac{\gamma\,v_n'(\eta)}{(\gamma^2 + \delta^2)}, \qquad w_n(\eta) = \mathrm{i}\,\frac{\delta\,v_n'(\eta)}{(\gamma^2 + \delta^2)}, \tag{16a}$$

$$T_n(\eta) = \frac{v_n(\eta)}{\mathrm{Ra}} - \frac{v_n''(\eta)}{\mathrm{Ra}\,(\gamma^2 + \delta^2)}. \tag{16b}$$

Then system (13) can be be rewritten in a more compact form:

$$f_v(\eta)\,v_n''(\eta) - g_v(\eta)\,v_n'(\eta) + h_v(\eta)\,v_n(\eta) = \frac{1}{\varepsilon\,\mathrm{Le}}\,Y_n''(\eta) + h_Y(\eta)\,Y_n(\eta), \tag{17a}$$

$$-j_v(\eta)\,v_n''''(\eta) + k_v(\eta)\,v_n''(\eta) + l_v(\eta)\,v_n(\eta) = l_Y(\eta)\,Y_n(\eta), \tag{17b}$$

$$j_v = \frac{1}{\mathrm{Ra}\,(\gamma^2 + \delta^2)}, \qquad f_v = \mathrm{i}\,\omega\,\Omega\,j_v \left.\frac{\partial \phi}{\partial T^*}\right|_b, \qquad g_v = \frac{i\,m_v^*\,\gamma\,\mathrm{Ra}\,j_v}{\varepsilon\,\mathrm{Le}\,\mathrm{Pe}}, \tag{18a}$$

$$h_v = \frac{m_v^*}{\varepsilon}\,(1-\eta) - f_v\,(\gamma^2 + \delta^2), \tag{18b}$$

$$h_Y = \left(-\,\mathrm{i}\gamma\,\frac{\mathrm{Pe}}{\varepsilon} + \frac{\Omega\,l_Y}{i_{sor}^*} - \frac{(\gamma^2 + \delta^2)}{\varepsilon\,\mathrm{Le}} + \mathrm{i}\,\omega\right) \tag{18c}$$

$$k_v = \frac{1}{\mathrm{Ra}} + j_v\left(\mathrm{i}\,\mathrm{Pe}\,\gamma\,\chi\,\mathrm{C}^* + \frac{i_{sor}^*\,f_v}{\Omega\,j_v} + \gamma^2 + \delta^2 - \mathrm{i}\,\hat{\chi}\,\omega\right) \tag{18d}$$

$$l_v = \left(-\,k_v + \frac{1}{\mathrm{Ra}}\right)(\gamma^2 + \delta^2) + \chi\,\mathrm{C}^*, \qquad l_Y = \mathrm{i}\,i_{sor}^*\,\omega \left.\frac{\partial \phi}{\partial Y^*}\right|_b, \tag{18e}$$

which should be solved with the following boundary conditions:

$$v_n(0) = 0, \qquad v_n(1) = 0, \tag{19a}$$

$$v_n''(0) = 0, \qquad v_n''(1) = 0, \tag{19b}$$

$$Y_n'(0) = 0, \qquad Y_n'(1) = 0. \tag{19c}$$

Such dispersion relationship allows one to determine neutral stability curves of relevant parameters. The solution of the eigenvalue problem is solved by using the numerical shooting method. Then a finding root method can be used to solve the new problem for the additional initial conditions, that must satisfy the boundary condition disregarded, which consists in reducing a boundary value problem to a family initial value problem, where this family is chosen in such a way to contain the solution of the giving boundary value problem and then solving it using a numerical method for solving differential equations with a given initial condition. The boundary conditions relative to $\eta = 1$ is ignored and new initial conditions at $\eta = 0$ is created.

$$v_n'(0) = 1, \tag{20}$$

$$v_n'''(0) = c_2^R + c_2^I\,\mathrm{i}, \tag{21}$$

$$Y_n(0) = c_3^R + c_3^I\,\mathrm{i}. \tag{22}$$

where c_2^R, c_2^I, c_3^R, c_3^I are parameters to be determined and the other condition is imposed to fix the overall scale of the eigenfunctions.

In fact, these parameters are partial derivatives of the original constants with respect to the wave numbers. Any differential eigenvalue problem is always undetermined up to a constant, which means its solution can always be normalized by one of its constants, reducing the total number of constants by one, which leads $v_n'(0)$ =1.

For given values of Péclet number Pe, a wave number k, and setting the growth rate as zero, the solution gives the values of Rayleigh number Ra, the angular frequency ω and the results of the additional condition.

4. RESULT AND DISCUSSION

The classical Darcy Bénard problem describes a porous layer heated from below and bounded by isothermal walls. Horton and Rogers (1945) were one of the first to investigate the Darcy Bénard instability. Barletta (2011), de B. Alves and Barletta (2013), and Dodgson (2013) employed different types of analysis about the onset of convective instability. The exactly same critical conditions results obtained for the onset of convective instability are given by:

$$\mathrm{Ra}_c = 4\,\pi^2 \cong 39.4784\,, \qquad \gamma_c = \pi \tag{23}$$

A simple case of this analysis implies prescribed temperatures and impermeable on both walls, by considering i_{sor}^*,

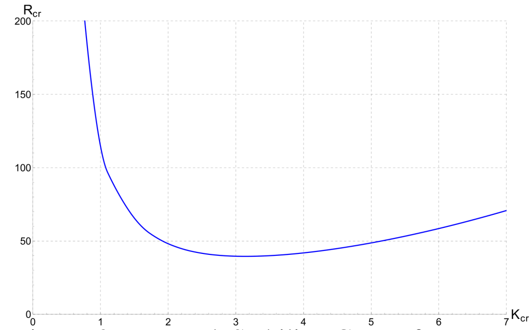


Figure 2: Neutral Stability Curve for Darcy-Bénard problem.

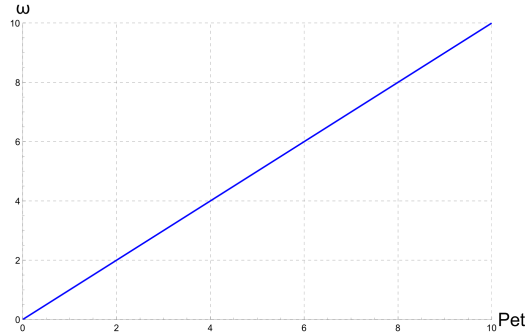


Figure 3: Different values of Pe for different values of ω.

Ω and m_v^* equal zero to change from that of the classical Darcy Bénard problem, whose convective instability has critical points (γ_c, Ra_c), since this is the lowest linear instability conditional one would reach in an experiment upon increasing the heat transferred through the boundaries.

Figure 2 shows the neutral stability curve and figure 3 shows that the value of ω changes as Pe changes for simple case of this analysis.

Table 1 shows values of the properties of the porous medium. This table also includes the values for the specific heats, thermal conductivities, as well as the mass diffusivity. Table 2 shows values of dimensionless parameters adopted to investigate the adsorption and its effects on fluid flow through an adsorbent porous media.

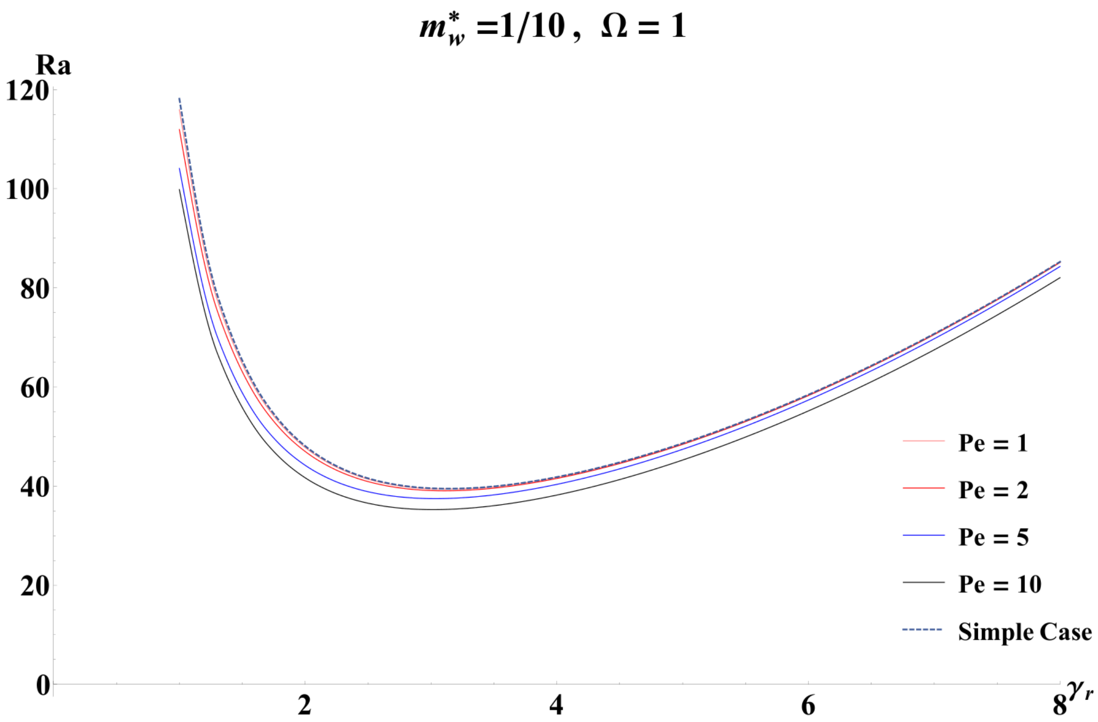
Table 1: Thermophysical properties

Property	Values	Unit	Reference
α_e	$2,3 \times 10^{-5}$	m^2/s	Calculated
c_s	920	J/kgK	(Sphaier and Worek, 2004)
c_l	4180	J/kgK	(Sphaier and Worek, 2004)
$c_{p,v}$	1872	J/kgK	(Sphaier and Worek, 2004)
$c_{p,a}$	1007	J/kgK	(Sphaier and Worek, 2004)
$\mathcal{D}$	3×10^{-5}	m^2/s	(Sphaier and Worek, 2004)
ε_b	$0,3$	—	(Sphaier and Worek, 2004)
ε_p	$0,4$	—	(Sphaier and Worek, 2004)
ε	$0,42$	—	Calculated
H	$1,0$	m	Adopted
ρ_p	1300	kg/m^3	(Sphaier and Worek, 2004)
ρ_e	910	kg/m^3	Calculated
ρ_a	1,1614	kg/m^3	(Sphaier and Worek, 2004)
W_{max}	0,4	kg/kg	Adopted
W_{max}	0,4	kg/kg	Adopted

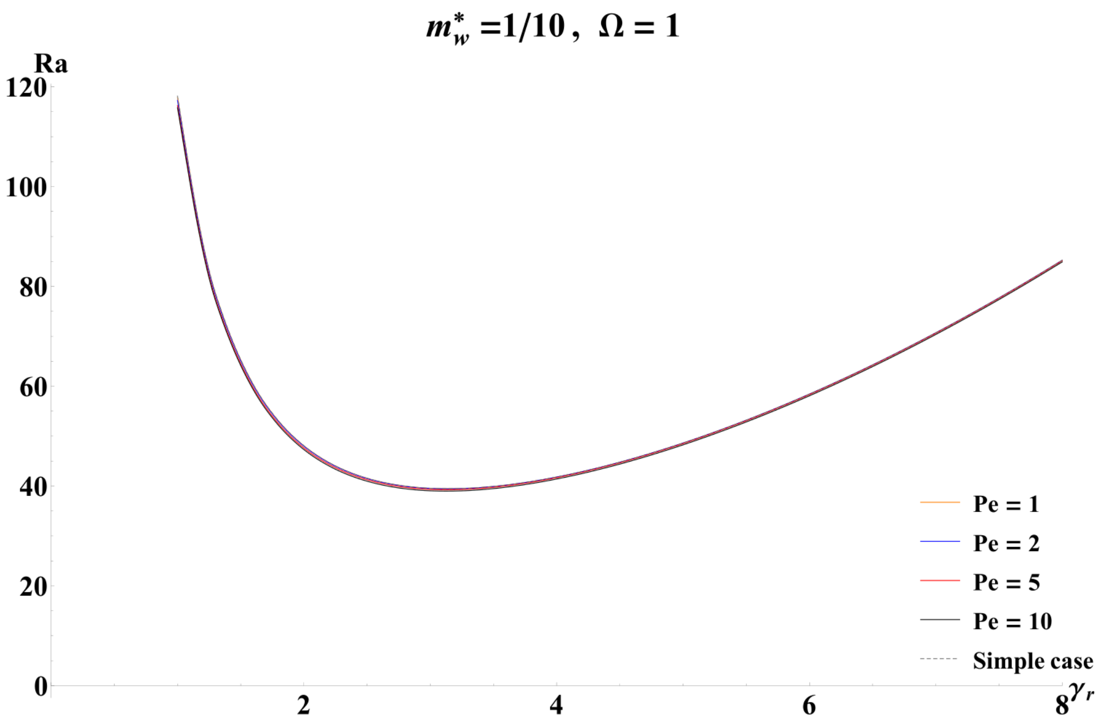
Table 2: Dimensionless parameters

Dimensionless parameters	Values
Lewis number, Le_g	0.75
Isotherm separation factor, r	0.5 - 2
χ	1.0
$\hat{\chi}$	1.0
C*	1.0
m_w^*	$0.1 - 10$
i_{sor}^*	$1 - 10$
Ω	$1 - 100$

A study of the neutral stability curves has been carried out for different values of dimensionless parameters as shows (4a, 4b 5a , 5b , 6a, 6b). These curves that are plotted in the (Ra,γ) plane.



(a) i_{sor}^*=10

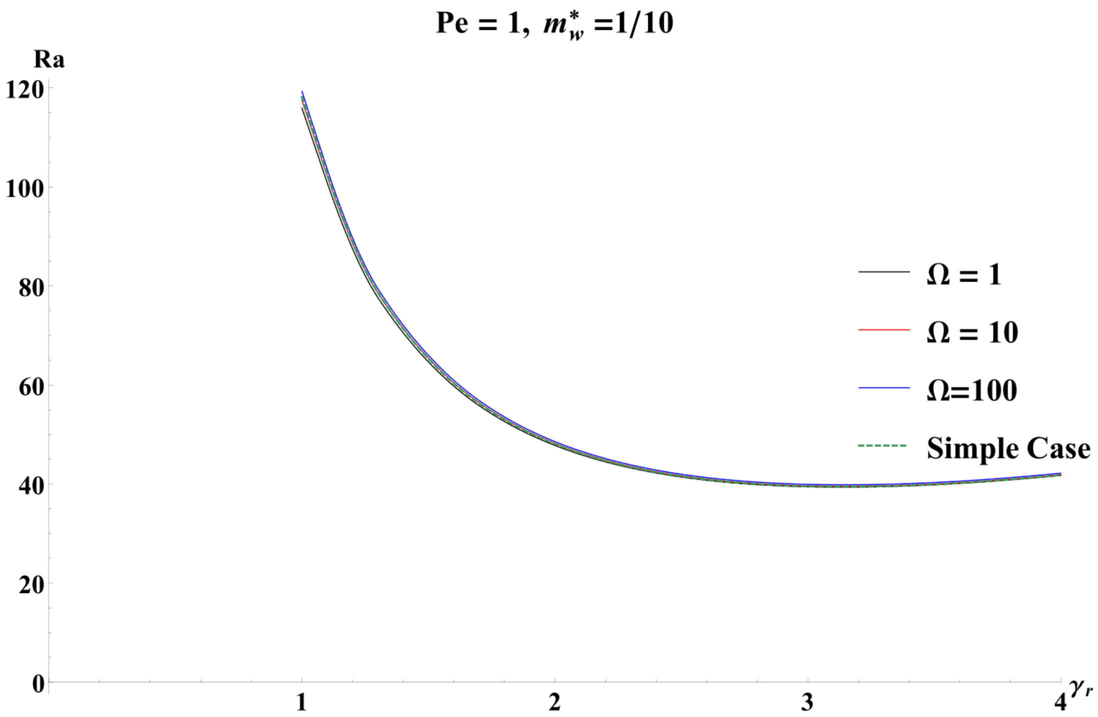


(b) i_{sor}^*=1

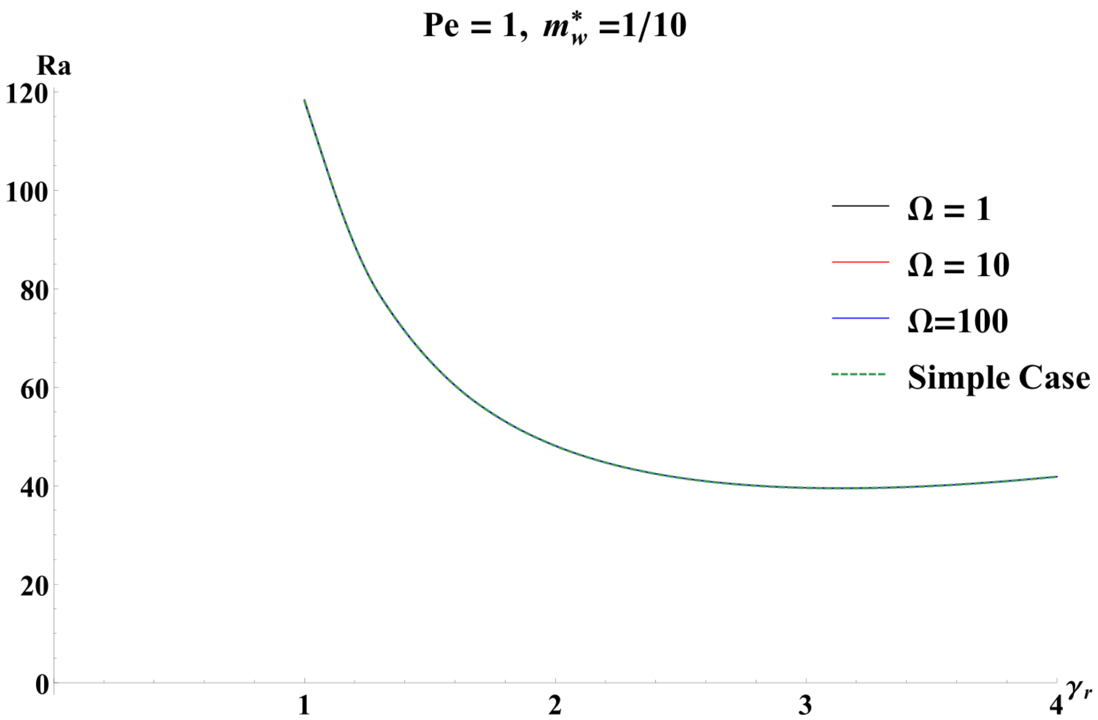
Figure 4: Neutral stability curve for different values of $Peclet$

Figure 4a shows that the system is destabilized by increasing the Peclet number and i_{sor}^*=10 either or both destabilizes the flow. Figures (5b,5a) illustrate that the ω parameter not affected the system. Figure 6a shows the system is destabilized by increasing the value of m_w^*. As can be seen from figures all of the parameters was not affected significantly.

Figures (7a, 7b) present the neutral stability curves for different positions. Although the flow profile was assumed to



(a) i^*_{sor}=10



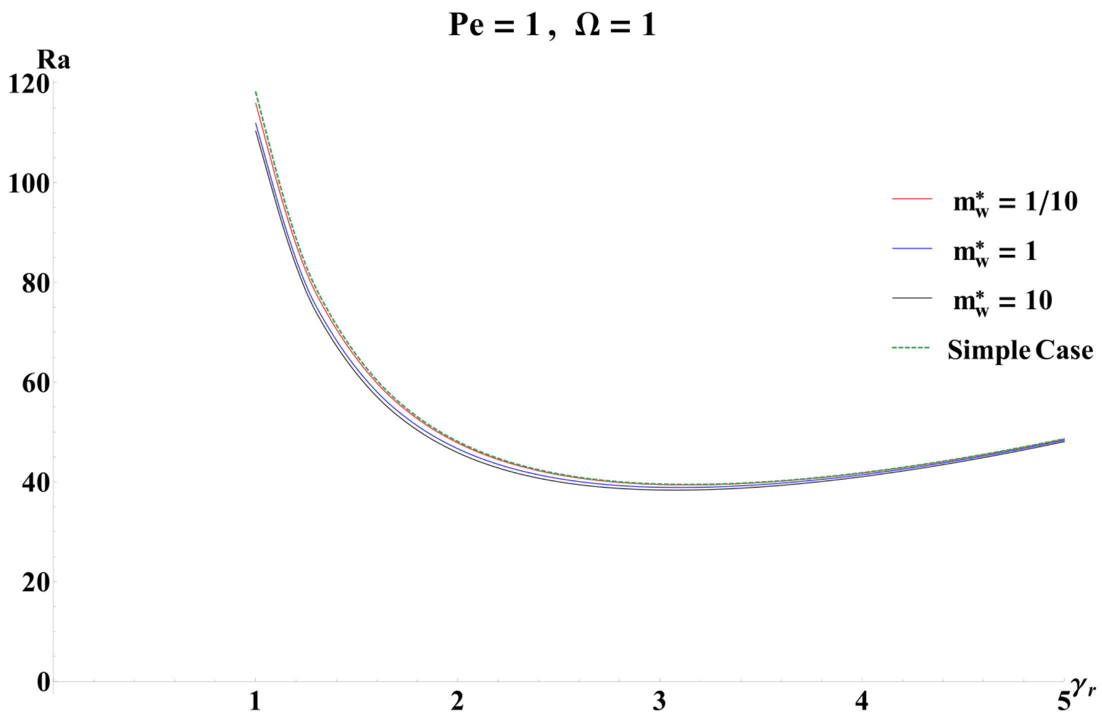
(b) i^*_{sor}=1

Figure 5: Neutral stability curve for different values of Ω

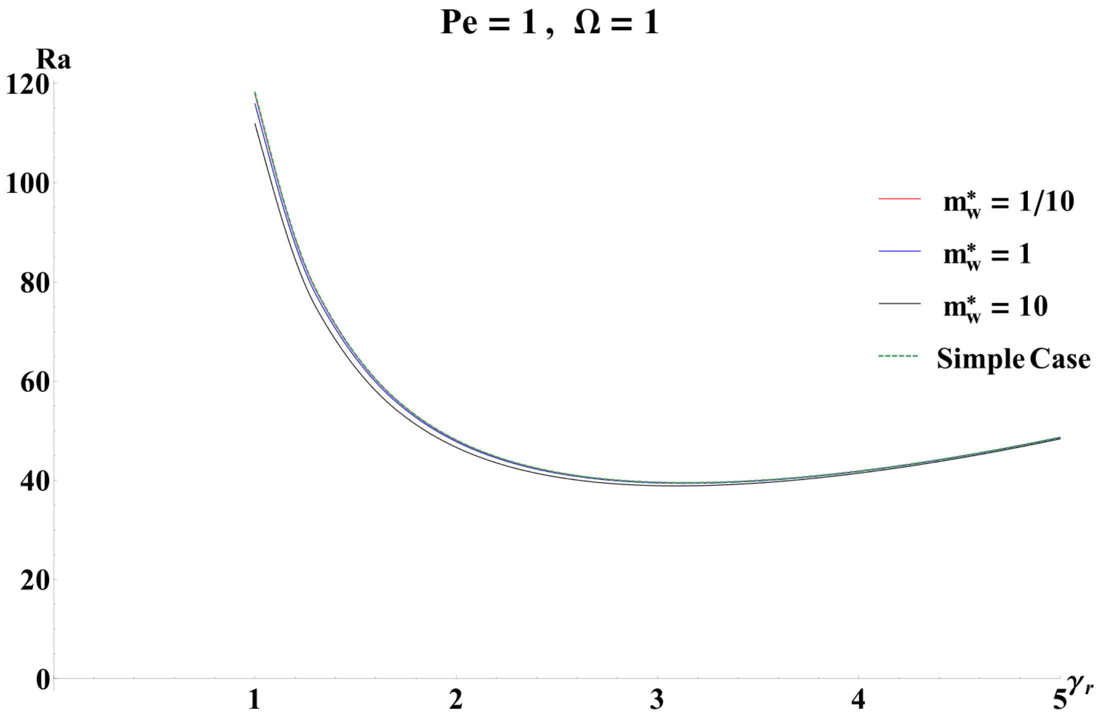
be local, the position does not affect the neutral curve shape

5. CONCLUSIONS

A linear stability analysis has been employed in the present paper to uncover the onset of convective instability in the Darcy-Benard problem with a porous medium with adsorption. The effect of the adsorption, as well as of the heating-from-below setup, has been emphasized. A basic state characterized by a uniform horizontal through flow, with a prescribed



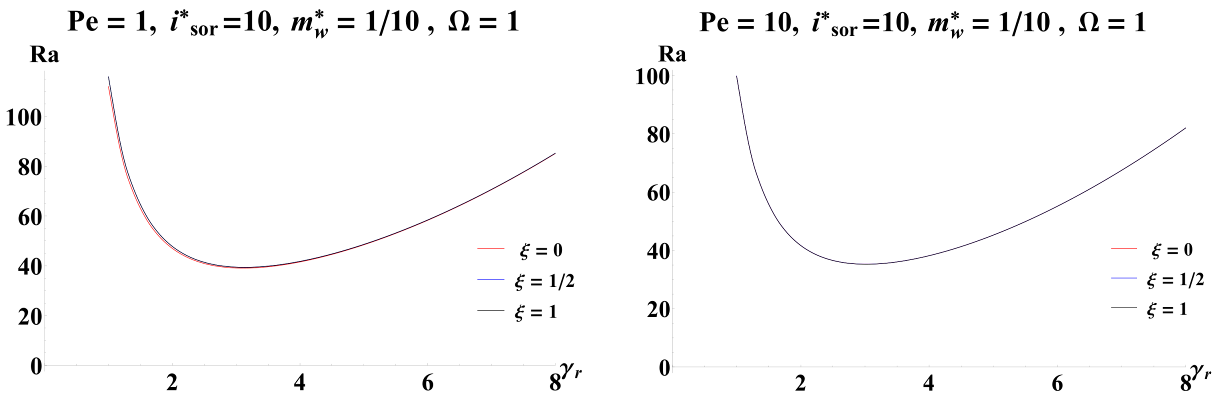
(a) i^*_{sor}=10



(b) i^*_{sor}=1

Figure 6: Neutral stability curve for different values of m^*_w

Peclet number, and by a uniform and vertical temperature gradient has been considered. The governing equations for small-amplitude disturbances of the basic state have been solved for the normal modes. The dispersion relation has been obtained also for the simple case of Darcy-Benard problem. The results was obtained from the linearized analysis by using the well established numerical algorithms built-in function NDSolve of the Mathematica software system Wolfram (2003), which allows the calculation of the critical values of Ra and γ by using the FindRoot routine (Newton and secant-type methods) for a large range of values of Pe. We finally mention that neutral stability curves display an upward concave



(a) Pe=1 (b) Pe=10

Figure 7: Neutral stability curve for different positions, i^*_{sor}=10

shape, the one typical of Darcy-Benard like instability. In the particular case of the problem by considering the adsorption parameters equals zero, we recovered the well known result $\mathrm{Ra}_c = 4\pi^2$ with $\gamma_c = \pi$. The main results of this analysis are that adsorption parameters does not affect significantly the neutral stability condition for the onset of the convective instability and the most unstable case was found by increasing Peclet number.

6. ACKNOWLEDGEMENTS

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