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ORIGINAL ARTICLE

Stability analysis of Electro-thermo convection of binary fluid with chemical reaction in a horizontal porous layer

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Weakly non-linear stability analysis

Abstract In the present article, we illustrate the onset of electro-thermo convection of a binary fluid in a horizontal porous layer subject to fixed temperatures and chemical equilibrium on the bounding surfaces. The state of convection is considered, when the solubility of dissolved components depends on temperature. We use linear stability analysis to investigate how the vertical electric field and dissolution or precipitation of the component affects the onset of convection. Darcy-Brinkman's law and Boussinesq approximation are employed with the equation of state taken to be linear with respect to temperature and concentration. We present a comparative study for four different bonding surfaces in linear case and weakly non-linear study in free-free (F/F) case for different controlling parameters. From the linear stability analysis, we find that the larger value of AC electric Rayleigh number (R_{ea}) and Damköler number enhance (χ) the onset of convection whereas the larger value of inverse Darcy number delay (Da^{-1}) the onset of convection. The stability criteria for different bounding surfaces are given as $F/R > R/R > R/F > F/F$ (where F represents free and R stands for rigid bounding surfaces). The effect of parameters is qualitatively same for all surfaces but differs quantitatively. We are getting same kind of results for limiting cases such as pure electro convection, pure double diffusive electro-convection and pure thermal double diffusive convection. From weakly non-linear stability analysis, we show heat and mass transfer effect for unsteady and steady cases for same parameters. With increasing value of R_{ea} and χ, enhance the unsteady and steady convection whereas reverse is obtained with increasing Da^{-1}. We also draw streamlines, isotherms and isohalines in unsteady case for different times $(0.001, 0.03, 0.06, 0.1)$ as well as in steady case for different Rayleigh number (at critical Rayleigh number and more than critical). These plots represent state of conduction and convection.

1. Introduction

Onset of convection due to combined effect of a vertical electric field and a thermal gradient concurrently applied to

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Nomenclature

Latin symbols

a wave number
A_1 amplitude of streamline perturbation
d height of the fluid layer
Da Darcy number, $\frac{\kappa_{Tz}}{d^2}$
$\overrightarrow{E}$ electric field
$\overrightarrow{f_e}$ electric origin
$\overrightarrow{g}$ acceleration due to gravity
H rate of heat transport per unit area
J rate of mass transport per unit area
k lumped effective reaction
K_x, K_y, K_z characteristic permeability tensor in the x, y and z directions, $K^{-1} = K_x^{-1}ii + K_y^{-1}jj + K_z^{-1}kk$
Le Lewis number, $\frac{\kappa_T}{\kappa_S}$
Nu Nusselt number
P pressure
Pr Prandtl number, $\frac{\phi v}{\kappa_T}$
$\overrightarrow{q}$ velocity, (u, v, w)
R_T Darcy-Rayleigh number, $\frac{\beta_T g \Delta T d^3}{\phi v \kappa_T}$
R_S solute Darcy-Rayleigh number, $\frac{\beta_S g \Delta T d^3}{\phi v \kappa_T}$
R_{ea} AC electric Rayleigh numbers, $\frac{E_0^2 \gamma^2 \epsilon_0 d^2 (\Delta T)^2}{\phi \rho_0 \kappa_T v}$
S solute concentration
ΔS solute difference across the porous layer
Sh Sherwood number
T temperature
ΔT temperature difference across the porous layer
t time
V electric potential
x, y, z space co-ordinates

Greek symbols

β_S coefficient of solute expansion
β_T coefficient of thermal expansion
η $\frac{\Delta S}{\Delta T}$
χ Damköhler number, $\frac{\kappa d^2}{\phi \kappa_T}$
Λ ratio of viscosities, $(\frac{\tilde{\mu}}{\mu})$
λ normalized porosity parameter, $\frac{\phi(\rho c)_f}{(\rho c)_m}$
κ_T thermal diffusivity tensor, $\kappa_{Tx}ii + \kappa_{Ty}jj + \kappa_{Tz}kk$
γ thermal expansion coefficient of dielectric constant
ϵ dielectric constant
κ_S solute diffusivity
μ dynamic viscosity
ϕ porosity
v kinematic viscosity, $\left(\frac{\mu}{\rho_0}\right)$
$\tilde{v}$ effective viscosity, $\left(\frac{\tilde{\mu}}{\rho_0}\right)$
σ growth rate
ρ fluid density
ρ_0 reference fluid density
ρ_e charge density
ω frequency
ψ stream function
$(\rho c)_f$ volumetric heat capacity, $(\rho c)_m = (1-\epsilon)(\rho c)_s + \epsilon(\rho c)_f$, where
f, s, m properties of fluid, solid and porous matrix respectively

Other symbols

∇_1^2 $\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$

Subscripts

b basic state
l lower
u upper
0 reference

Superscripts

/ perturbed quantity
$*$ dimensionless quantity
c critical
f finite amplitude
st stationary

horizontal dielectric fluid layer guides complex physical interactions in the flow and has received much attention in recent years [1–4]. The research in this field considered reasonable interest due to the application of combined effects (such as potential technology [5–9]) that generates electro-thermo-convective instabilities in fluids that could be a promising way to increase the heat transfer by means of electrical forces. This kind of instability problem is called electro-thermo-convection (ETC).

Assuming the variation in dielectric constant as a linear function of temperature, initially a study has been performed on electro-hydrodynamic convection by Roberts [10]. An excellent review on the natural convection problem under alternating current (AC) or direct current (DC) electric field has been given by Jones [11] and Saville [12]. Problem related to ETC in a layer of porous medium under the influence of electric field attracted interest because of its application in drying process [13,14]. Moreno et al. [15] have investigated transport-related effects of imposing AC currents over two-phase flows, oil and water, in porous rocks. Some interesting and important literatures indicating the work related ETC in porous layers are [16–19].

An obvious question arises that what will happen if we consider binary electric fluid in place of electric fluid? It is matter of investigation that whether chemical reaction will take place or not?

As a consequence of above questions it is important to introduce the applications and literature survey for convection in binary fluid and reaction convection. Natural convection due to simultaneous diffusion of thermal as well as solutal in porous medium appears in many geothermal as well as industrial applications. In some geothermal situations [20], the amount of solute dissolved in fluid changes with changing temperature, pressure and the local rock chemistry. The solute may be in dissolved form or precipitated onto the porous matrix. Thermal convection extensively affects the exchange of dissolved species with the porous medium. It may be affected with the change in amount of minerals dissolved in fluid.

Double diffusive convection in porous layer was initialized by Nield [21] using linear stability analysis considering the lim-

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