Linear Stability Analysis of Double-Diffusive Convection in Porous Media, with Application to Geological Storage of CO₂

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Received: 17 October 2008 / Accepted: 25 November 2009 / Published online: 12 December 2009 © Springer Science+Business Media B.V. 2009

Abstract Onset of double-diffusive buoyancy-driven flow resulted from vertical temperature and concentration gradients in a horizontal layer of a saturated and homogenous porous medium is investigated using amplification factor theory. After injection of CO₂ into a deep saline aquifer, the density of the brine saturated with CO₂ increases slightly. This increase in density induces natural convection. The effect of geothermal gradient is also considered in this work as a second incentive for convection and the double-diffusion convection was studied. Linear stability analysis is used to predict the inception of instabilities and initial wavelength of the convective instabilities. The analysis presented is applied to acid gas injection (as an analogue for CO₂ storage) into saline aquifers in the Alberta basin. It is found that the geothermal gradient does not have significant effect on the onset of convection for these aquifers. It is shown that the geothermal effects on the onset of natural convection are negligible as compared to the solutal effects induced by dissolution and diffusion of CO₂ in deep saline aquifers. Therefore, the linear stability analysis and the long-term numerical simulation of CO₂ sequestration into such saline aquifers may be assumed to be isothermal in terms of natural convection occurrence.

Keywords Natural convection · Double-diffusion convection · Stability analysis · CO₂ Sequestration · Saline aquifers · CO₂ Storage

List of Symbols

\( A \) Time components of the perturbed velocity amplitude function
\( a \) Dimensionless wave number
\( B \) Time components of the perturbed concentration amplitude function
\( C \) Concentration (kg/m\(^3\))
\( c \) Specific heat capacity (kJ/kg K)
Molecular diffusion (m²/s)
Derivative operator
Time components of the perturbed temperature amplitude function
Derivative
Gravitational acceleration (m/s²)
Porous layer thickness (m)
Imaginary number
Thermal conductivity (W/m K)
Permeability (m²)
Lewis number (dimensionless)
Pressure (kg/m s²)
Rayleigh number (dimensionless)
Temperature (K)
Temperature of the bottom layer (K)
Time (s)
Velocity in x-direction (m/s)
Volume (m³)
Velocity in y-direction (m/s)
Vector of Darcy velocity (m/s)
Velocity in z-direction (m/s)
Amplification factor (dimensionless)
Coordinate direction (m)
Coordinate direction (m)
Vertical coordinate direction (m)
Thermal diffusivity (m²/s)
Coefficient of density increase by concentration (m³/kg)
Coefficient of thermal expansion (K⁻¹)
Porosity (dimensionless)
Density (kg/m³)
Viscosity (kg/m s)
Density difference (kg/m³)
Matrix to fluid specific heat capacity (dimensionless)
Laplacian operator
Laplacian operator
Concentration
Dimensionless
Effective (effective Rayleigh number)
Fluid
Constant of scaling
Bulk matrix
Reference state
Solutal
Thermal
x -Direction
y -Direction
z -Direction