Interaction of temperature- and salinity-driven natural convection in homogeneous porous media

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Onset of thermal and haline convection was studied separately by Lapwood (1948) and Wooding (1956) in theoretical models using analytical methods. They established that the buoyancy force caused by difference in temperature ($\Delta T$) or concentration ($\Delta c$) can induce natural convection depending on the model properties (e.g. geometry, permeability, etc.). In the course of further numerical simulations, the thermal ($Ra_T$) and the haline Rayleigh number ($Ra_H$) proved itself useful to characterise the type, the intensity and the form of the natural convection (e.g. Diersch and Kolditz, 2002). The main purpose of our study was to examine numerically the combined effect of temperature- and salinity-driven natural convection in a two-dimensional homogeneous porous medium.

Two-dimensional finite element base model was set up in agreement with the Elder problem (Wooding, 1956) in order to verify the numerical calculation. First, it was established that (1) the critical Rayleigh numbers are mathematically equivalent in the two separated cases ($Ra_{Tcr}=Ra_{Hcr}=4\pi^2$), and (2) time-dependent thermal or haline natural convections evolve, when the Rayleigh number lies within the range of 300–600. Numerical simulations were accomplished to investigate the interaction of the temperature- and salinity-driven natural convection. Non-dimensional thermal expansion and haline concentration were increased from $\alpha\Delta T=0.01$ to 1 and from $\beta\Delta c=10^{-5}$ to $10^{-3}$, respectively, while the variation of the Darcy flux, the temperature, the concentration, the Nusselt and the Sherwood numbers was computed. The main points of this study were that (1) how the onset of the thermohaline convection is facilitated by the positive interaction of the thermal and haline effects ($Ra_{T/Hcr}$); (2) under what conditions time-dependent flow evolves in the theoretical models; (3) whether a new non-dimensional number can be defined instead of the two separated Rayleigh numbers in order to characterise the behaviour of the thermonaline convection. These simulations draw attention to the importance of understanding the physical background of thermohaline convection, for instance, at the margin of confined and unconfined carbonate systems (e.g. Buda Thermal Karst), or in the case of groundwater flow induced by water pumping/injection of deep geothermal power plants.

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References:

