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Mixed convection instability during carbon dioxide storage into deep saline aquifers

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A two-phase mixed convection and instability analysis through quality of flow is presented during carbon dioxide storage into a deep saline aquifer. Numerical simulation is conducted within the context of a two-dimensional rectangular geometry which top is in wavy shape. There, from centre point we are injecting cooler carbon dioxide with a pressure which is higher than aquifer pressure. We assume that the aquifer is a partially saturated porous medium, and that the voids of the solid skeleton are filled with water vapor and liquid water, thus we have a three-phase system. The gas phase is considered as a mixture of ideal gases composed of carbon dioxide and water vapor, which represent miscible species through diffusion. Heat transfer is accounted through conduction, convection as well as latent heat transfer.

The structure and stability of the two-phase mixed convection process can be characterized by the so-called phase change number and the subcooling number (see Ishii and Zuber [1]). Phase change number is describing the ratio of the inlet mass-flux to the condensation mass-flux. Mixture quality is given by the two numbers, i.e. phase change number and subcooling number. Identical phase change number and subcooling number represent similar quality development of the flow. In the region of non-boiling, the subcooling number is larger than the phase change number. The instability in the low quality region, where phase change number is slightly larger than subcooling number, but very near, is called Type I instability Fukuda [2]. The instability in the higher quality region is called Type II.

Theoretically, the thermo-hydro coupled processes in geological porous media are governed by the mass and energy balance laws of continuum mechanics. The governing partial differential equations are written at macroscopic level based on averaging procedures, which is suitable for understanding the microscopic behavior of porous media. The primary variables are capillary pressure, gas pressure and temperature along with a large group of empirical and constitutive relations, such as the saturation vapor pressure, heat of condensation, water saturation and diffusion coefficients etc.

The established numerical model is highly nonlinear. Governing equations are discretized in space and time, and are linearized within the context of the finite element method. In particular, a Galerkin's procedure is used for spatial discretization, and the generalized trapezoidal method is used for the time integration. A combined, monolithic and staggered scheme is used to solve the coupled system (i.e. monolithic for the multi-phase flow and staggered for the heat transport) with variable time stepping. The numerical module for non-isothermal multi-phase flow is implemented within the object-oriented finite element code OpenGeoSys (OGS) developed by the authors.

REFERENCES

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