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Rayleigh-Bénard convection in porous media: benchmark of FEM models

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Natural convection can significantly contribute to heat transfer in sedimentary basins. Such process can be approximated by Darcy flow through porous media where the thermal expansion of the fluid may lead to gravitational instability in the system. In this study, we numerically investigate a two-dimensional Rayleigh-Bénard experiment where thermally driven flow occurs in a fluid-saturated porous media uniformly heated from below and cooled from above. The purpose of this study is to document the behavior of different FEM models and to provide an error analysis of these simulations.

Several numerical issues arise in this problem. First of all, the velocity field describing the average fluid motion might be incorrectly computed if the pressure and temperature fields are not carefully discretized. We employ a standard FEM model with different order of shape functions and a mixed-FEM model where the pressure and the velocity fields are independently discretized with different sets of continuous/discontinuous shape functions. The temperature field and the velocity field should be approximated similarly to prevent from numerical artifacts. The advection term, accounting for the fluid flow, is explicitly treated with the method of characteristics and different time integration: the Euler's and the 4th order Runge-Kutta's scheme.

For all these simulations, we put a strong focus on the effect of the time and spatial domain discretizations (dt, dx) and document the convergence of each numerical method. In order to quantitatively compare the final results, we base our benchmark on the analytical scaling of the non-dimensional Nusselt/Rayleigh numbers. We show that even for slightly supercritical Rayleigh number, all the previously mentioned numerical issues have a prior importance for the accuracy of the simulations. Our mixed-FEM model is adequate to simulate the Rayleigh-Bénard experiment and shows a well-behaving convergence as a function of dt and dx.