On the development of instabilities under density-driven flow conditions in saturated porous media: physical and numerical experiments

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ABSTRACT

Density driven flow occurs frequently in nature, e.g. in geothermal reservoirs, at waste disposal sites or due to saltwater intrusions. If a dense fluid is spilled and infiltrates through the soil it eventually reaches a prevailing freshwater (groundwater) table, leading to a situation where the dense fluid overlies a less dense. Due to buoyancy, the denser fluid moves through the less dense fluid. Typically, this results in the formation of dense plume fingers which are known to have an influence on the propagation of the plume in space and time. While the dense fingers flow direction is downward, it is counterbalanced by upward flow of freshwater between the fingers. The formation of those dense fingers is commonly attributed to material heterogeneity in heterogeneous porous media. However, the formation of fingers also occurs in media that are considered homogeneous on the lab scale (porous media where all grains have the same diameter). In homogeneous sand, the formation of dense fingers can be attributed to either i) the different arrangement of grains (e.g. in tetrahedrons or hexahedrons) inducing pore-scale heterogeneity, or ii) random variations in solute concentration causing varying buoyancy effects where both i) and ii) finally result in different average flow velocities. The adequate reproduction of those two effects in numerical models however remains a challenging task.

Building on previous work we try to mimic pore-scale heterogeneity in numerical models by applying perturbations to trigger the onset of instabilities. Such artificially generated perturbations have already been utilized with success previously by Schincariol et al. 1997, Simmons et al. 1999 and Weatherill 2004. We present results from a physical sand-tank experiment as well as results from numerical simulations of it. For the physical experiment a highly dense solution of NaCl (fluid density of 1200 kg m^{-3}) is stained with 0.3 g l^{-1} Eocine and injected with a constant infiltration rate on top of a domain filled with fully saturated coarse sand. This creates a situation where the dense stained solute overlies the less dense freshwater. Aim of the physical experiment is to have a benchmark to verify variable-density flow models.

The physical experiment is then implemented as a numerical model. Different trigger methods are implemented in the numerical model and by comparison to results of the physical experiment examined for their capability to realistically reproduce nature. Results indicate that the application of an artificial perturbation is necessary to create dense plume fingers and a propagation of the plume matching the propagation in the physical experiment.

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