Geophysical Research Abstracts
Vol. 15, EGU2013-3114-3, 2013
EGU General Assembly 2013

Evaluation of the Oberbeck-Boussinesq Approximation for the numerical simulation of variable-density flow and solute transport in porous media

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Subsurface water systems are endangered due to salt water intrusion in coastal aquifers, leachate infiltration from waste disposal sites and salt transport in agricultural sites. This leads to the situation where more dense fluid overlies a less dense fluid creating a density gradient. Under certain conditions this density gradient produces instabilities in form dense plume fingers that move downwards. This free convection increases solute transport over large distances and shorter times. In cases where a significantly larger density gradient exists, the effect of free convection on transport is non-negligible. The assumption of a constant density distribution in space and time is no longer valid. Therefore variable-density flow must be considered.

The flow equation and the transport equation govern the numerical modeling of variable-density flow and solute transport. Computer simulation programs mathematically describe variable-density flow using the Oberbeck-Boussinesq Approximation (OBA). Three levels of simplifications can de considered, which are denoted by OB1, OB2 and OB3. OB1 is the usually applied simplification where variable density is taken into account in the hydraulic potential. In OB2 variable density is considered in the flow equation and in OB3 variable density is additionally considered in the transport equation.

Using the results from a laboratory-scale experiment of variable-density flow and solute transport (Simmons et al., Transp. Porous Medium, 2002) it is investigated which level of mathematical accuracy is required to represent the physical experiment the most accurate. Differences between the physical and mathematical model are evaluated using qualitative indicators (e.g. mass fluxes, Nusselt number). Results show that OB1 is required for small density gradients and OB3 is required for large density gradients.