Geophysical Research Abstracts
Vol. 12, EGU2010-11126-1, 2010
EGU General Assembly 2010

Percolation in two phase flow in porous media on macroscopic scales

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The standard model for multiphase flow in porous media on scales of centimeters to hectometers shows several deficiencies when compared with experiments. Fundamental parameter functions are not unique due to hysteretic and dynamic effects. Residual saturations cannot be predicted but are injected as parameters into the standard model.

A macroscopic mixture theory for immiscible two phase displacement in porous media, which takes into account the differences in percolating and nonpercolating phases, was proposed in [1] and further elaborated in succeeding works [2-6].

Quasi-stationary solutions of a limiting case, the residual decoupling approximation (RDA), are promising [6]. However, further analytical and numerical studies are required to evaluate whether the theory contributes to an improved understanding of hysteretic and dynamic effects like trapping, break up and coalescence of phases in biphasic flow in porous media on laboratory and field scales.

Numerical simulation of processes that occur when a closed porous column containing two immiscible fluids of different densities is raised from a horizontal to a vertical position in a gravitational field have been reported recently [7,8]. It was illustrated how the model inherently accounts for hysteresis because imbibition and drainage processes occur simultaneously in the medium. An additional difficulty is that the interface between the drainage and imbibition domain is moving with time. However, the motion is part of the solution and it is not required to insert knowledge about the motion beforehand.

Here, analytical and quasi-analytical solutions of a hyperbolic limit of the theory are presented. The limit resembles the Buckley-Leverett theory of the commonly applied two-phase flow theory. For the calculation of analytical solutions the finding of a fractional flow reformulation, is exploited. The results show shocks and rarefaction waves similar to the traditional theory. A gravity driven redistribution problem addresses parallel occurrence of drainage and imbibition in one medium analytically. This introduces heterogeneities even in an ex-ante homogeneous medium.

The results show that the degeneracy of states of the traditional theory is resolved within the new one. Hence, it is possible to address several deficiencies of the traditional theory when accounting for the percolation of the fluids. The results show that hysteresis in relative permeabilities is indeed mapped inherently by the new theory. It is further indicated that dynamic effects in saturations and residual saturations are contained and that the representation of irreducible fluids by constant parameters in the traditional theory is questionable.

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