RATE-DEPENDENT EQUILIBRIUM SATURATION DISTRIBUTIONS THROUGH HYSTERESIS IN TWO-PHASE FLOW IN POROUS MEDIA

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Several phenomena in two-phase flow in porous media still lack a profound physical understanding on laboratory and field scales. The standard for modeling and simulating flow processes in porous media - the extended Darcy model – contains the saturation dependent parameter-functions “capillary pressure” and “relative permeabilities” and the parameters “residual saturations”. However, research of the last decades has unequivocally shown that this approach has limitations, in particular for the prediction of fluid distribution when drainage and imbibition is involved (hysteresis), and when the flow rate varies significantly (dynamic effects). Currently, there is no e stablished general theory, which indicates how the parameter-functions have to be extended, i.e. which additional variables have to be taken into account, or by which concepts these functions have to be replaced to cope with these limitations. Most approaches focus on the incorporation of one these phenomena.

Here, we present an experiment, which illustrates how rate-dependent and hysteretic effects may be related and that rate-dependent equilibrium saturation distribution are possible without introducing explicit rate-dependent parameter-functions. This emphasizes the care that must be taken in numerical and experimental investigations of non-standard effects.

Consider a quasi-one-dimensional incompressible and homogeneous porous column aligned with gravity, which is completely saturated with an incompressible wetting fluid. The column is closed at the lateral walls and the less dense incompressible non-wetting fluid may enter from the top while the denser wetting fluid may leave the column at the bottom. In addition, the column can be closed at the top and bottom to prevent fluids from leaving it. At the beginning of the experiment the pressures at the top and the bottom of column are such that the fluids are in equilibrium.

Two distinct experimental protocols are compared. First, the wetting fluid pressure at the bottom of the column is decreased very slowly so that the column is continuously drained and the fluid distribution is always in equilibrium until a certain amount of non-wetting fluid has invaded the column. In the second protocol, a significant pressure difference is applied so that the invasion is advection dominated and the hyperbolic Buckley-Leverett theory applies. When the same amount of non-wetting fluid as in the first experiment has invaded the column, the column is closed such that the fluids redistribute due to capillary forces and gravity. This leads to a further drainage in some parts of the column while other parts are imbibed. The comparison of the results shows that the differences in the solutions are significant and should be considered when rate-dependent phenomena are studied. A particular result highlights the qualitative differences observed from the different experimental protocols, wherein the viscosity ratio of the fluids only impacts the equilibrium profile in the advection-dominated case.