Control of a displacement front in potential flow using flow-rate partition

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We consider the problem of the control of a displacement front in a porous medium, via flow-rate partition in a well. We assume that the flow is potential and that the displacement is at a unit mobility ratio. These assumptions are for mathematical convenience only and can be later relaxed. The specific question we address is how to partition the flow rate within the injection well, so that the displacement front can be steered according to pre-determined dynamics, or as is necessary. For a given front evolution as a function of time and space, we show that the flow rate in the injection well can be partitioned as a function of time within the well, so that the front evolves as desired. In particular, for a homogeneous reservoir, we derive an integral equation in an analytical form, the solution of which determines the injection rate profile as a function of time. We provide illustrative applications for various cases.

The approach is then generalized to heterogeneous reservoirs of either known or uncertain permeability heterogeneity. We show that a similar approach applies, except that the kernel in the integral equation must be determined numerically. This can be obtained by repeated calculations of the Green’s function in a heterogeneous system. We address some specific problems, e.g. of controlling the front in order to prevent channeling, or in order to by-pass a certain region in the reservoir. In addition, for uncertain heterogeneous fields, we discuss ensemble-averages of the injection profile, which lead statistically to the control of the average properties of the front.

The results find applications to the rapidly emerging field of smart wells and the optimization of displacement problems in oil reservoirs using flow rate control.