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Calculation of relative permeabilities for two-phase flows in highly permeable porous media: direct calculation vs. closure problems

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Recent work shows that fluid-fluid interactions should be included in the macroscopic description of two-phase flows, at least for highly permeable porous media. Upscaling of pore-scale equations for momentum transport leads to macroscopic equations with a mobility matrix involving four relative permeability terms. Diagonal terms are standard and extra-diagonal, also called cross-terms, account for fluid-fluid interactions. Although the theoretical upscaling is known for some cases (e.g. concentric-annular flow in tube), the determination of the full matrix, either experimentally [1,2] or numerically [3,4], has proved very difficult. One approach consists in solving the closure problems derived from upscaling to compute the four relative permeabilities [5]. However, the closure problems rely on strong assumptions and miss some of the key physical ingredients of the two-phase flow problem.

Here, we show that a technique based on variations of a body force allows us to precisely calculate these four relative permeabilities. The idea is to alternatively apply a slightly different body force to each fluid to calculate coupling terms. In this model, we maintained a constant phase distribution and saturation, a condition which is not always fulfilled in the literature. We show, in a simple 2D geometry, that the results from the closure problems fail because the boundary conditions at the interface between the fluids do not allow to account for the complexity of the flow, e.g. by neglecting important viscous dissipation zone. Therefore, we propose to modify the fluid-fluid boundary conditions for velocity in the closure problem to account for these dissipation zones. We further find that the non-diagonal relative permeability terms are not negligible. This fact is in agreement with previous work for film flow in simple 2D cells with a solid obstacle.

The proposed numerical method can be used to calculate the relative permeability, including cross terms. The main advantage of the modified closure problem is that its computation time is low. This technique may be a good alternative in some cases (e.g. for low capillary number). We anticipate that the elements brought in this work on the choice of the body force variations could serve as a basis for the calculation of relative permeabilities in more complex geometries.

Time Block Preference

Time Block A (09:00-12:00 CET)

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