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The importance of inertial effects and Haines jumps in pore scale modelling of drainage displacement for geological CO_2 sequestration

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We investigate pore scale drainage associated with immiscible displacement of brine by CO_2 in a porous medium, using state-of-the-art multi-GPU lattice Boltzmann (LB) simulations. Our goal is to better understand the pore scale processes involved in the geological sequestration of CO_2. Correctly resolving the pore scale dynamics of multiphase flow in permeable media is of paramount importance for upscaling to reservoir scale displacement processes and the design of efficient CO_2 storage operations. Our current investigations are based on previous work on pore-filling events in single junction micro-models [1] and capillary filling mechanisms including Haines jump dynamics [2,3]. According to the seminal work by Lenormand *et al.* [3], immiscible displacement can be characterised by only two dimensionless numbers, namely the capillary number Ca and the viscosity ratio M, which quantify the ratio of the relevant forces, i.e. the viscous and capillary forces. The above description is thought to be valid in the limit of low Reynolds numbers $Re \to 0$. However, our current investigations reveal that inertial effects cannot be neglected in the range of typical Capillary numbers (Ca) associated with multiphase flow in permeable media ($Ca < 10^{-3}$), and accessible to numerical pore scale modeling ($Ca > 10^{-6}$). We observe that, even as Ca and Re decrease, inertial effects are still important over a transient amount of time during abrupt jump events (Haines jumps), when the non-wetting phase passes from a narrow restriction to a wider pore body. Therefore, the description based on the phase diagram of Lenormand *et al.* [4] may not be sufficient. We include inertial effects by introducing the Ohnesorge number, defined as $Oh^2 = Ca/Re$. We show that this dimensionless number is essential to restrict the parameter selection process, as it is fixed for a given system and independent of the flow rate. We show that the Ohnesorge number reflects the true thermophysical properties of the system under investigation. Considering that the Ohnesorge number is typically in the range of $10^{-3} - 10^{-2}$ for a system of brine-CO_2 at the pore scale, it becomes clear that the usual approach in numerical simulations of keeping both Ca and Re low, without respecting the ratio of the two, is fundamentally wrong. Given that inertial effects cannot be neglected in this range of dimensionless numbers, a full Navier-Stokes solver should be used instead of just a Stokes solver, and the value of the ratio Ca/Re should be matched. This approach will resolve the pore scale fluid dynamics correctly. Our results demonstrate that the displacement sequence as well as the fluid distribution in the porous rock can be affected significantly by the choice of the simulation parameters.

References

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