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A Variational Level Set Method for Simulation of Capillary-Controlled Displacements

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Capillary pressure and wettability are key properties in multiphase flow processes in porous rocks. CO2 storage processes in subsurface aquifers or depleted oil reservoirs represents an application where estimation of capillary entry pressure in internal formation layers or cap rock are required to evaluate the capillary seal efficiency and CO2 plume evolution.

In this work, a variational level set method is adopted to simulate capillary-controlled displacements in pore spaces from segmented rock images. In this method, each phase is represented by its own indicator function called a level set function. The total energy of the multiphase system, that is, the interfacial energy and the bulk phase energy, can be calculated based on the level set functions and the material properties. Contact angles are incorporated by applying a surface tension function at the solid boundary. The problem amounts to minimising the total energy of the system subject to certain constraints which describes the boundary conditions and prevents formation of overlapping and vacuum regions at fluid interfaces due to evolution of several level set functions. By applying the gradient projection method, a set of evolution equations are formulated, which are coupled through the Lagrange multipliers and constraints. These equations are solved by using the standard numerical schemes applied in the level set method.

For different contact angles, we simulate capillary-controlled displacements into straight tubes with pore cross-sections determined from SEM images of Bentheim sandstone. The results are compared with the entry pressures and cross-sectional arc menisci configurations computed by a previously developed 2D semi-analytical model. Finally, preliminary variational level set simulations are performed in subsets of 3D rock images of sandstone.