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Multiscale Calculation of Two-phase Flow in Digital Core Analysis

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Digital core analysis has become an additional tool to physical experimental analysis for multiphase flow experiments. Digital core analysis is fast and can give more insight into the details inside a rock. In digital core analysis different imaging technologies with different resolutions are employed to identify pores and textures scaled from millimeters to nanometers in a heterogeneous rock, such as a carbonate rock. In each resolution the field of view of 3D image volume is up to a few thousand pixel in one direction. Utilizing a highly efficient pore scale simulator and a powerful computer, the size of 3D rock volume that can be practically handled in a multiphase flow simulation is about one thousand pixels in each direction. To compute the multiphase flow properties in a heterogeneous rock with pores scaled from millimeters to nanometers several image resolutions have to be combined. One approach is to compute multiphase flow properties in different scales independently and then upscale them to the whole rock sample. The dynamic flow exchanges in different scales are ignored. Especially the flow path and the wettability changes provided by under-resolved finer scales are ignored. It is also hard to handle the effects of overlapped pores in two images of neighboring scales in the same region in the upscaling.
We developed a scale-coupled multiscale model to calculate two-phase flow distributions for certain capillary pressure (Pc) in the porous plate experiment. The two-phase distributions then can be used to calculate the relative permeability (Kr) and the saturation factor (n) for capillary dominated flow. In the multiscale model, a rock sample in a certain scale is geometrically represented by pores, solids and Darcy regions that have under-resolved pores. Two phase flow in the resolved pore space is directly simulated using a lattice-Boltzmann model (LBM). The two phase flow properties in a Darcy region are given by a prescribed map function. The map function can be obtained in a finer scale simulation or theoretically modeling. The map function gives the two-phase flow properties in a Darcy region based on the flow phases and pressure distributions surrounding the Darcy region. In the meantime the boundary conditions on surface of a Darcy region of LBM simulation in resolved pores depend on two phase properties in the Darcy region. The flow distributions in pore and Darcy regions, and the boundary conditions for different scales dynamically change with applied capillary pressure. The scale coupled calculation starts from the finest scale. The calculated two phase flow properties, such as Pc, Kr and n, in a finer scale serves as map functions of Darcy regions in the coarser scale calculation. The calculation ends in the coarsest scale, usually the plug or core scale. The scale coupled multiscale model of two-phase flow has been tested in different heterogeneous rock samples and two-phase flow properties in different scale levels will be reported.

References

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Primary author: Dr NIE, Xiaobo (Ingrain, A Halliburton Service)

Co-author: Dr TOELKE, Jonas (Ingrain, A Halliburton Service)

Presenter: Dr NIE, Xiaobo (Ingrain, A Halliburton Service)

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