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A New Upscaling Method of Relative Permeability Curves for Reservoir Simulation

Kefei Wang and John E. Killough, SPE, Halliburton Digital and Consulting Service; Kamy Sepehrnoori, SPE, University of Texas at Austin

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Abstract

Relative permeability is one of the most important factors in numerical reservoir simulation. Although the relative permeability curves may be available on a very fine level of detail, their direct use to estimate the amount of uncertainty, which requires thousands of reservoir simulation runs, is generally not practical because of the excessive computer time and memory that would be required. Despite the extensive research that has been performed in the past few decades, effective upscaling to reduce computation times in highly heterogeneous reservoir still remains a challenging procedure.

In this paper, we demonstrate how conventional upscaling approaches may lead to large errors. To overcome the inaccuracy, we investigated and developed a new relative permeability upscaling technique for the coarse scale modeling for heterogeneous reservoirs. In our new method, single-phase upscaling was applied at the beginning to set up the base case for optimization. The regression runs were conducted by non-linear optimization. The decision variables in a standard Corey and logistic form were used to check the errors between the coarse and fine models. After the procedure converged, a new relative permeability curve for the coarse model was generated. The match for the breakthrough time and post-breakthrough performance was very accurate using the new relative permeability curves. Predictability with the new curves also appeared to be substantially improved; the newly generated relative permeability curves can be used over periods beyond that of the original match.

The new method was verified by using three-phase, 3D, and highly heterogeneous reservoir models. These verifications were performed on large models approaching one million cells with black oil and composition fluids with waterflooding and water-alternating-gas (WAG) recovery processes.

The ultimate goal of the work has been to use the upscaled models with modified relative permeabilities to investigate how uncertainty is affected by upscaling. The fine scale results indicate that more reasonable results can be obtained for estimating the effect of uncertainty with the new upscaling technique as compared to conventional methods, with computation time orders of magnitude faster than previously available.

Instruction

In numerical reservoir simulation, relative permeability curves are extremely important for reservoir evaluations because of their ability to predict fluid production during reservoir exploitation. The most reliable source of relative permeability data comes from laboratory measurements performed on cores obtained from the reservoir of interest. These curves are determined in special core analysis laboratories through a sequence of standard measurements and calculations generally performed using some adaptations of frontal advance theory. For the measurements to be meaningful, considerable care and effort must be taken to ensure that in-situ reservoir wettability is preserved during coring, surface handling, and storage and measurement operations. If a significant rock property variation is identified in a reservoir, it can be subdivided into different rock types. Because flow properties are a function of pore geometry, each lithological unit usually has a special relative permeability characteristic. Relative permeability data are not always available for each rock type, and there is little reason to believe that a single, average relative permeability curve will be representative of behavior of each layer or the whole reservoir. For this reason, various approaches have been proposed in reservoir simulation studies within the last couple of decades.

The pseudo-relative permeability curves were first introduced to the petroleum industry by Coats (1967). He developed an analytical method to calculate pseudo-relative permeability curves based on the assumption of gravity-capillary equilibrium in the vertical direction or vertical equilibrium (VE). The VE concept assumes that, as depletion proceeds, gravity and capillary forces will be in equilibrium vertically in every grid block in the reservoir model. This condition, in which the potential of