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Signal from geometries containing corners — analytical and random walk calculations

A. Hiorth[a], U.H. a Lad[a], J. Finjord[b] and S.M. Skjaeveland[c]

[a]IRIS — International Research Institute of Stavanger, Norway
[b]Department of Technology and Natural Sciences, University of Stavanger, Norway
[c]Department of Petroleum Technology, University of Stavanger, Norway

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A simple representation of a porous medium is the bundle-of-tubes model. Cylindrical tubes are sufficient for single-phase flow when wettability is not a topic. During the last decade, however, it has become abundantly clear that most reservoirs are mixed-wet. At pore scale where the oil phase touches the internal pore surface, the wettability may be oil-wet and the sharp corners water-wet and water filled. This type of mixed wettability is in pore network modelling literature represented by tubes having equilateral cross sections. A wettability index can be defined as the surface wetted by oil (or water) divided by the total internal surface area [1].

In NMR spectroscopy, diffusion editing can separate the oil and water signals. By interpreting the NMR signal from a porous rock by a bundle-of-equilateral-tubes, the wettability index can be obtained. To calibrate the model properly, we need to solve the Bloch–Torrey equations inside an equilateral triangular geometry and perform experiments on equilateral tubes. The analytical solution has been found (submitted to TiPM), and experiments on triangular tubes are in progress. All the analytical solutions for the equilateral triangle have been confirmed by random-walk simulations.

In this paper, we study the magnetic signal for water and oil in a single equilateral triangular pore. Moving from slightly oil-wet to water-wet makes the magnetic signal from the water in the corners more multi-exponential. This is mainly due to change in the water volume in the corners. We also compare the analytical solution for an equilateral triangle with the well-known solutions of Brownstein and Tarr [2] for plate, cylinder and sphere. For uniform initial magnetization, it is found that all the solutions qualitatively behave in the same manner. Nonuniform initial magnetization may be caused by susceptibility differences as described by Song [3] and Lisitza and Song [4]. By assuming nonuniform magnetization, for simplicity by a delta function, we can study the evolution of the magnetic signal analytically. We have considered two cases: (1) all the exited spins in the pore center and (2) close to the surface. In general, nonuniform magnetization increases the weight of the higher modes. For all combinations of pore radii (a), surface relaxation ( ) and diffusion constant (D), the lowest mode always gives the highest contribution to the magnetic signal. An important exception from this statement is when the initial magnetization is close to a corner. This initial configuration only exists for the triangle. Even for low surface relaxation, ã= a/D=1, the magnetic signal is multi-exponential, and for ã=4 the lowest mode is the least dominant one. This shows that the equilateral triangular geometry has a qualitatively different behavior from the one-dimensional geometries: plate, cylinder and sphere. And it clearly shows that, to detect higher eigenmodes caused by inhomogeneous initial magnetization, it is vital that the initial magnetization is concentrated close to the corners.

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