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# Comparison of modified effective-medium approximation to pore-network theory for relative permeabilities

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ABSTRACT

Pore-network models have been used to derive relative-permeability and capillary-pressure relations, which are important for oil-recovery predictions and processes. Here, we show that relative-permeability and capillary-pressure relations on large scales can be obtained much faster with the effective-medium approximation. Our approach differs from previous work in that we use various shapes of non-circular pores and combinations of different shapes. We use a finite-element approach to compute the hydraulic conductivity of arbitrarily shaped prisms, which are partly filled with oil and water. Our present interest is confined to water-wet media. Striking features of the obtained constitutive relations are that the water relative permeabilities show a marked reduction below a critical water saturation—at which there is no infinite cluster of completely filled water pores—but the water relative permeabilities continue to be finite even at very low water saturations because of corner flow. The capillary pressure remains finite even at low water saturations. Primary-drainage oil relative permeabilities are non-zero at low oil saturations, which is in line with early gas breakthrough for the solution-gas drive oil-recovery mechanism. We compare the results obtained with the effective-medium approximation to the results obtained with a pore-network model consisting of a simple-cubic lattice of prisms. The comparison shows that the pore-network generated relative-permeability curves are completely dissimilar to the effective-medium approximation derived relative-permeability curves. Furthermore, below and near the percolation threshold, the pore-network results differ significantly from one realization to another and/or from one network size to another network size. The network-model results show discontinuous behavior at the percolation threshold. This implies that pore-network results are scale dependent and the pore-network sizes up to $301 \times 301 \times 301$ (the limitation determined by the available computer power) studied here are still far from a representative elementary volume (REV).

## 1. Introduction

It is known that percolation theory applied to a network of prisms can be used to improve our understanding of relative-permeability and capillary-pressure curves in porous media. For many of the theoretical details, we refer the reader to the excellent literature on percolation theory and its applications (e.g., Stauffer and Aharony, 1992; Sahimi, 1993, 1994; Heiba et al., 1984; Heiba et al., 1992; Yortsos et al., 1993; Kirkpatrick, 1973; ; Hunt and Ewing, 2009; Bedrikovetsky, 2013; Selyakov and Kadet, 2013).

Percolation theory is complementary to network models. Fenwick and Blunt (1998) used a network model to describe three-phase non-aqueous-phase-liquids (NAPL)-water-air flow in porous media. They used the spreading coefficient to determine whether NAPL films are formed between the water in the corners of the pores and the air in the center of the pores or whether lenses are formed. In this case, film flow of oil occurs, which can lead to almost zero residual oil saturation. They described both imbibition and drainage curves. Soll and Celia (1993) defined a set of rules in a network model and developed a computer code (3PSAT) to calculate three-phase capillary-pressure curves. Dong and Chatzis (1995) described the imbibition of a wetting fluid in a square prism. Kirkpatrick (1973) derived the effective-medium approach. He showed that this approximation is valid except near the percolation threshold, where it gives an incorrect limiting behavior. Levine and Cuthiell, 1986 applied the effective-medium approximation

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