

Relative permeability of hydrate-bearing sediments from percolation theory and critical path analysis: theoretical and experimental results

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Relative permeabilities to water and gas are important parameters for accurate modeling of the formation of methane hydrate deposits and production of methane from hydrate reservoirs. Experimental measurements of gas and water permeability in the presence of hydrate are difficult to obtain. The few datasets that do exist suggest that relative permeability obeys a power law relationship with water or gas saturation with exponents ranging from around 2 to greater than 10. Critical path analysis and percolation theory provide a framework for interpreting the saturation-dependence of relative permeability based on percolation thresholds and the breadth of pore size distributions, which may be determined easily from 3-D images or gas adsorption-desorption hysteresis. We show that the exponent of the permeability-saturation relationship for relative permeability to water is related to the breadth of the pore size distribution, with broader pore size distributions corresponding to larger exponents. Relative permeability to water in well-sorted sediments with narrow pore size distributions, such as Berea sandstone or Toyoura sand, follows percolation scaling with an exponent of 2. On the other hand, pore-size distributions determined from argon adsorption measurements we performed on clays from the Nankai Trough suggest that relative permeability to water in fine-grained intervals may be characterized by exponents as large as 10 as determined from critical path analysis. We also show that relative permeability to the gas phase follows percolation scaling with a quadratic dependence on gas saturation, but the threshold gas saturation for percolation changes with hydrate saturation, which is an important consideration in systems in which both hydrate and gas are present, such as during production from a hydrate reservoir. Our work shows how measurements of pore size distributions from 3-D imaging or gas adsorption may be used to determine relative permeabilities.