Gas-Water Relative Permeability: Direct Measurements and Implications for Water and Gas Production

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Abstract

Relative permeability has a significant impact on gas or oil and water production, but is one of the most complicated properties in unconventional reservoirs. Current understanding of relative permeability for unconventional reservoir rocks is very limited, mainly because of a lack of direct measurements of relative permeability for rocks with matrix permeability at sub-micron-Darcy levels. Because of the difficulties related to direct measurements, most studies on relative permeability in unconventional reservoirs are based on indirect or modeling methods. In this work, a modified gas-expansion method for shale matrix permeability measurement was adopted to measure gas relative permeability directly under the scenario of water imbibition for samples from different unconventional reservoirs. Evolution of gas permeability, along with gas porosity and fracture-matrix interaction, during the process of water redistribution (mimicking what occurs in shut-in periods in real production) were also closely measured. Results show that gas relative permeability in the matrix decreases during water redistribution because of water imbibition from fractures to matrix and water-block effect. Water-block effect is more significant at low water saturations than higher water saturations, leading to a rapid-to-gradual drop of gas relative permeability with increasing water saturation. A conceptual model on water redistribution in a fracture-matrix system and the change of gas and water relative permeability is proposed based on experimental results and observations. Influencing factors including pore size, shape, connectivity, and wettability are taken into account in this conceptual model. The combined effect of these four influencing factors determines the level of residual gas saturation, the most important parameter in defining the shape of relative permeability curves. Water relative permeability is predicted based on the conceptual model and the measured gas relative permeability using modified Brooks-Corey equations. Deduction of oil-water relative permeability is also discussed. Relative permeability contains important implications for the gas-water distribution/redistribution in a dynamic fractured system and therefore water and gas production. Hysteresis effect has important influence on relative permeability and needs to be carefully incorporated in the reservoir evaluation or production prediction based on the specific imbibition and drainage history. Systematic characterization of the relative permeability of gas or oil and water can allow a better prediction on production from specific layers or lithofacies and the whole reservoir.

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