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Experimental study of gas flow and relative permeability in low-porosity media using LF-NMR

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The key characteristics of complex oil and gas reservoirs include high heterogeneity in the porous space, ultra-low permeability resulting from the nanoscale dimensions of pores, and the presence of solid insoluble organic compounds in the rock. These factors complicate the application of existing physical and mathematical flow models with sufficient accuracy. This causes challenges in accurately predicting producible hydrocarbon reserves and impedes the development of unconventional formations.

To enhance the characterization of the gas flow in low-porosity and low-permeability media, a detailed study of mass transfer is essential. This involves obtaining the relative permeability for multiphase systems that is typically determined from laboratory filtration experiments using rock samples. However, assumptions made during relative permeability determination, including methodological ones, often prove invalid when describing mass transfer in low-permeability porous media, resulting in quality of the field hydrodynamic model and increase development risks.

The objective of this study is to develop an enhanced laboratory-based method for determining gas-water and oil-water relative permeability in medium- and low-permeability reservoirs using NMR relaxometry under high-pressure conditions. NMR relaxometry enables the quick and accurate determination of sample saturation in tight rocks without additional contrasting during the core flooding experiment. The study considers surface phenomena in liquid-gas, liquid-solid, liquid-liquid, and gas-solid systems, determining their impact on mass transfer during filtration in rock samples. Experimental study was conducted using pressure-pulse decay porosimetry for obtaining reservoir properties, low-field NMR relaxometry (2 MHz) on 1-inch core plugs and X-ray computed microtomography. Probes of degassed oil samples, deuterium oxide, carbon dioxide and methane were used as fluids in experimental modeling of the relative permeability.

As result, the method for determining the relative permeability in two-phase systems using NMR relaxometry was proposed. The current study also reports the results of fluid adsorption on crushed rock samples containing clays and organic matter using high-pressure NMR experiments. The analysis of results include the three-dimensional pore-network model based on experimental work. Validation of the model was conducted using values of reservoir properties (porosity, permeability, and pore size) determined by computed microtomography, as well as permeability values from the obtained relative permeability curves. In addition, sensitivity analysis of the developed pore-network model highlights the influence of pore connectivity, pore size distribution, gas phase diffusion on the absolute and relative gas permeability.

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