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Evaluation of the void space structure and flow channels in low-permeability reservoir rocks

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In recent years, the share of unconventional reserves in global oil production has been growing that leads to the development of efficient methods in exploration and development of tight reservoirs. The key features of low-porosity and low-permeability reservoirs are the high heterogeneity of the void space, the ultra-low rock permeability due to the nanoscale pores, and the presence of clays or solid insoluble organic compounds.
At the present stage of the experimental petrophysics, there is no standardized set of laboratory-based techniques for assessing the porosity, permeability and water saturation of such rocks. Thin layering, lenticularity, unpredictable changes in lithological characteristics (for example, heterogeneous clay distribution and carbonatization), reservoir properties and oil saturation of tight rocks create uncertainty in the petrophysical model, which, in turn, does not enable the accurate assessment of producible oil volumes.
Study of the composition (mineral, elemental and fractional) and structure of the void space can help to reduce this uncertainty in further modeling. The microstructure of the rock is determined by the geometry of the fluid flow channels, the size of these channels and their distribution. In other words, the characteristics of the reservoir properties of the tight rocks are always related to the parameters of the void space structure. Understanding of the void space structure can be obtained from theoretical calculations of various pore-pore connection models and from experimental works using direct and indirect laboratory methods. In this work, to examine and visualize the structure of the void space of low-permeability rocks, a set of modern techniques and equipment including gas porosimetry, computed microtomography (microCT), mercury porosimetry (MICP), nuclear magnetic resonance (NMR) and low-temperature adsorption / BET was used. Reservoir properties were determined for the rock collection of 45 core plugs and duplicate core samples. Additional tests include the X-ray diffraction analysis for determining the mineral composition and petrographic analysis of thin sections.
Results include the comparison of reservoir properties (porosity, permeability and pore size) determined by different techniques and discussion on advantages and limitations of each method for target low-permeability sandstone reservoir. The structure of the void space was characterized by pore size and pore throat distributions:the pore throats varies from 0.001 to 0.3 μm, the sizes of the pores ranged from 0.01 to 10 μm. The porosity of rock the collection varied from 6 to 14%, gas permeability did not exceed 0.2 mD. The contribution of the clay components and heavy hydrocarbons to the total porosity of samples in some intervals was demonstrated by results of NMR, microCT and MICP. Pore size distributions for the same samples by different methods were plotted jointly to illustrate the limitations of MICP, NMR thin section analysis and microCT at two resolutions. In conclusion, it is demonstrated how the reservoir properties and the void space (pores and pore throats) should be analyzed based on the results of both routine (gas porosimetry, liquid saturation, centrifuging, thin sections) and high-precision methods (NMR, microCT, low-temperature adsorption, etc.).

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