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"Digital petrophysics" in studies of porosity properties of low-permeable reservoirs

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Abstract. The article focuses on study in the properties of low-permeable reservoirs. The object of the research is the Bazhenov formation rocks taken from a well drilled in an oilfield of the West Siberian basin. A series of experiments were carried out to determine porosity of rocks by different methods: the helium saturation, nuclear magnetic resonance (NMR), microcomputed tomography (mCT). A comparative analysis was conducted to assess the efficiency of different methods. The obtained results have shown that common methods of petrophysical surveys are insufficient for carbonate-argillaceous Low-permeable rocks, containing a great amount of hand extractable organic matter. The additional data received by the mCT method gave an opportunity to increase sufficiently the reliability of the research results. We have concluded that the most efficient method for the study of low-permeable rocks is a combined use of the NMR and the mCT.

1. Introduction

Nowadays, special attention is given to hydrocarbon accumulations belonging to the category of hard recoverable reserves located in unconventional and structurally complex reservoirs. This is particularly important for Western Siberia where the majority of large oil deposits discovered in the 1960s-80s are nearly exhausted. One of the challenges for the development of oilfields is that low-permeable reservoirs with high oil viscosity cannot be explored by conventional petrophysical methods. Therefore, it is necessary to develop innovative exploration techniques for the study of reservoir properties.

In Western Siberia, hydrocarbon accumulations belonging to the category of hard recoverable reserves mainly occur in Upper Jurassic and Lower Cretaceous reservoirs: the Tyumen, Bazhenov, and Achimovsky formations. The deposits of these formations may be of different geological structures, but they all have the same peculiarity. These reserves are considered to be hard recoverable because of the following characteristics: low reservoir porosity and permeability, lithologic variation, inhomogeneity of spatial structure, and higher formation pressure gradient of productive horizons [1]. In such conditions, the conventional methods of determining reservoir properties using core data may be ineffective. While preparing samples (extracting hydrocarbons) it is hard or impossible to recover the organic matter completely, the residues of bitumen in micro- and nanopores distorts the survey results. Therefore, it seems advisable to introduce new techniques in the petrophysical studies of unconventional reservoirs. The mCT seems to be the most promising method allowing 3D visualizing the pore space structure of a rock sample.

2. Theoretic characteristic of porosity determination methods

The main task of petrophysical studies is to determine porosity and permeability of a reservoir. Any conventional method of open porosity determination by pore space saturation with liquid or gas requires oil pre-extraction from core-samples with subsequent water drying off. After that, pore space is saturated with liquid or gas, and open porosity is calculated. In case of unconventional reservoirs (low permeability, high oil viscosity), accurate calculations are impossible as liquid organic matter cannot be completely extracted without rock destruction, which leads to the significant errors in porosity determination.

An alternative approach to the reservoir properties determination is the nuclear magnetic resonance (NMR) method, i.e. resonance absorption of electro-magnetic waves by nuclei, occurring as a result of change in their spins vectors direction. The NMR takes place in the samples placed in the strong constant magnetic field and simultaneously exposed to the perpendicularly directed alternating magnetic radio-frequency field [4].

As a rule, the NMR method is more efficient for analysis of low-permeable reservoirs than conventional techniques to determine porosity by extraction and saturation. However, it is difficult to determine porosity of argillaceous and highly pyritized rocks by this method. There are also some challenges related to correct interpretation of the combined signal in time allocation of transverse relaxation (T_2).

The disadvantages of the NMR method are described in a number of scientific works devoted to the study of reservoir properties. For example, Zubkov Yu M and Potapov A G wrote, "… the use of the term "porosity" by the NMR is not quite correct because, in fact, we do not determine the porosity of samples by a relaxometer, but the total volume content of hydrocarbons which form a part of the fluids saturating a certain sample. Drying samples with the standard technique at the temperature of 105℃ does not allow extracting hydrogen containing fluids completely, so when afterwards we saturate the samples with water or kerosene, we receive overestimated porosity values by the NMR in comparison with the weight method. The errors are especially large when we study argillaceous samples and samples containing liquid hydrocarbons as, for example, bituminous sediments of the Bazhenov formation. On the contrary, the samples containing mixed lattice constituents with swelling components possess specific properties: when molecules of hydrogen containing fluids run into the interlayer space of these clay minerals, they are so tightly held by them that the time of relaxation of hydrogen atoms becomes too short to be fixed by the NMR device. Therefore, the porosity values of these samples received by the weight method are higher than the porosity values received by the NMR method" [3].

Shumskajte M J and Glinskih V N argue that the amount and type of clay minerals influence the results of the NMR measurements; they lead to the variation of amplitude, shift of spectra, and determine decisive influence of clay bound water on the total bound fluid at remaining saturation. [2]

The most reliable data on the porosity properties of low-permeable rocks can be obtained by the microcomputed tomography (mCT) method. The principle of this method is to develop a 3D model of the internal structure of a sample using a set of X-ray photographs. The main advantages of this method are nondestructive testing, assessment of the sample quality for further investigations, complex data on physical-mechanical and structural-textural properties of rocks, and study of samples with irregular geometric forms.

The mCT method also has some disadvantages. They include limited camera resolution, difficulties in distinction of minerals similar in X-ray density as well as challenges with fluid and kerogen segmentation within the rock. Hence, it is necessary to select carefully scanning and reconstruction modes according to the rock lithotype. Due to the challenge of formalizing the requirements for measurement parameters, there are no federal standards for determination of mineral composition, porosity, and permeability by the mCT method. However, there is a number of research experiments, including correlations between the mCT data and information gathered by conventional techniques, the optical microscopy, in particular. The comparative analysis shows a high correlation degree of the obtained results [1, 4-8].

3. Experiment

The object of the research is the Bazhenov formation rocks taken from a well drilled in an oilfield in the eastern part of the West Siberian basin.

Experimental instruments include: microcomputed tomograph Skyscan 1172 (the Academic Geochemical Laboratory, Tyumen Industrial University); NMR-spectrometer Khromatek-20M made by JSC Special Design Bureau “Khromatek”; porosimeter-permeameter AP-608 made by the company “Coretestsystems”; microscope OLYMPUS BX53; X-ray diffractometer DRON-7 with mounted solid state energy-dispersive detector (Siberian Research Institute of Petroleum Industry).

The experiment consists of an assessment of the porosity determination effectiveness in studies of low permeable bituminous reservoirs. A complex analysis of two Bazhenov formation samples was conducted using X-ray phase analysis to determine mineral composition; helium saturation method, NMR, and mCT to determine porosity.

The samples of cylindrical form with the diameter of 4 mm were studied by the mCT. The scanning parameters: voltage across the tube – 100 kV; turning angle – 0.3°; the number of photographs – 5; camera resolution – 1.6 μm/pxl. The software – CTan, CTvox, Nrecon. The results of the complex analysis of the samples are presented in figure 1 and table 1.

Table 1. The porosity of the samples.

№	The nuclear magnetic resonance method	Helium method	micro-CT method
1	8.39	3.46	18.20
2	13.70	11.79	17.70

The helium saturation method shows very low porosity values that can be explained by insufficient extraction of organic matter from capillary and subcapillary porous channels. The lowest porosity values are observed in sample №1 that is composed of biomorphic clay rock (silicon content 50%, clay content 35%), enriched in organic matter.

The size analysis of equivalent-diameters of porous channels was carried out by the mCT method. The results are shown in figure 2. The pore space of sample №1 consists primarily of channels with the diameter less than 8 μm, but the maximum diameter is about 15 μm. Sample №2 is characterized by interbedding of phosphatic calcareous oil-saturated rock (with high content of P2O5 – more than 17%) and argillite enriched in organic matter. It has channels with the diameter of up to 13 μm, and the maximum diameter is about 32 μm. It allows concluding that the size of porous channels influences the extraction of organic matter from the rock. It is advisable to carry out additional experiments in order to identify sizes of porous channels with organic matter which is hard for extraction without rock destruction. These data would be very useful for updating effectiveness criteria for organic matter extraction from low-permeable rock samples.

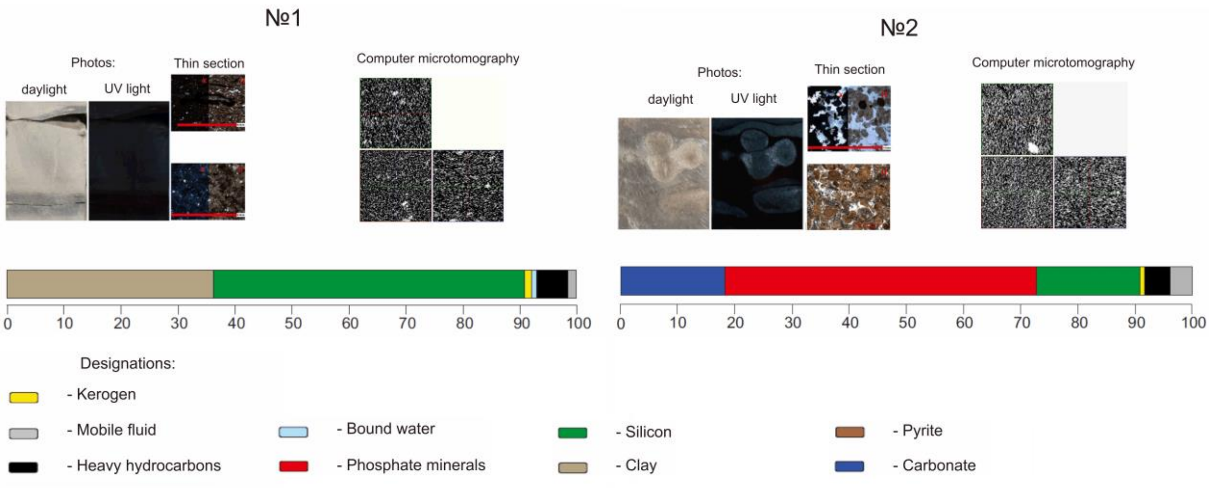

Figure 1. The results of complex analysis of two Bazhenov formation samples.

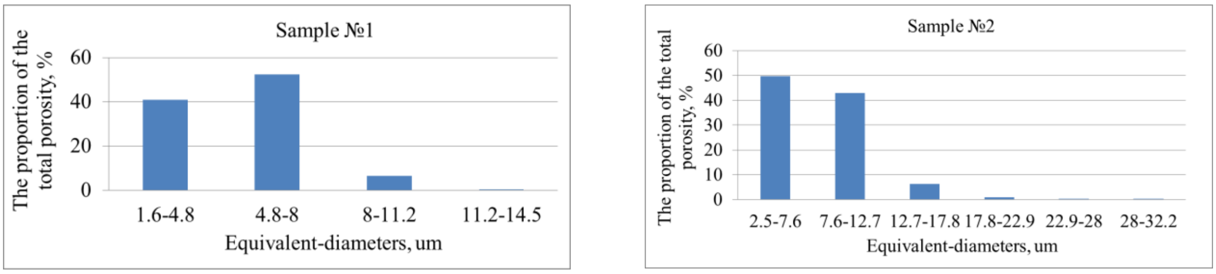

Figure 2. The distribution of equivalent-diameter by the mCT method.

4. Conclusion

The NMR method shows the results similar to those of the mCT while studying sample №2 which does not contain clay matter. While studying sample №1, where clay matter content is about 35%, the NMR method shows erroneously low results.

The mCT method shows the highest porosity values. However, it is important to note that this method determines organic matter including kerogen as a pore space. To receive accurate data it is necessary to subtract the kerogen content from the total porosity found by the mCT method. As a result, we have received the following porosity values: sample №1 – 16.2%; sample №2 – 12.7%.

Based on the comparative analysis of methods for determining porosity of reservoirs with low permeability and high content of heavy hydrocarbons the following conclusions are made:

- The NMR method is effective to determine porosity of rocks with low clay matter content.
- In this case, the method of determining porosity by helium saturation is ineffective. It is explained by the impossibility to extract petroleum from capillary and subcapillary porous channels without rock destruction. To identify the sizes of porous channels it is necessary to conduct additional research as well as to take into account the heavy oil holdup in the rock.
- The mCT method has shown the highest porosity values of rocks. It should be noted that kerogen possesses low X-ray density so the content data in the rock are required. It is necessary to subtract the kerogen content from the obtained total porosity values.
- The complex use of the NMR and mCT methods provides the most reliable data on the permeability and porosity properties of low-permeable reservoirs.

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