The Use of Modelling Acoustic Properties to Study the Porosity of Carbonate Rocks on Core Samples

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Abstract

The aim of this work is to quantify the pore space features of carbonate rocks according to petrophysical studies (using the pore aspect ratio - PAR) and to classify the pore space of carbonates according to the results of microscopic studies. The integration of laboratory measurements of 97 carbonate samples and petrographic analysis of 10 samples allowed the acoustic signature of pore types to be quantified. Three rock groups have been identified, which differ in a number of lithological, petrophysical, and acoustic properties. The main criterion for separation was the pore aspect ratio, which does not depend on porosity and velocity, but on the shape of the pore space.

Keywords: Carbonate rock, petrophysical study, acoustic property, elastic property, rock physics model, pore aspect ratio, laboratory measurement

Introduction

The study of reservoir properties of sedimentary deposits is very relevant both to the engineering practice of developing hydrocarbon deposits, and to the fundamental understanding of sedimentary basins [1]. Reservoir property studies are of particular importance to the rational development of mineral resources in the Republic of Tatarstan (Russia), where up to 38% of recoverable oil reserves are concentrated in carbonate rocks [2].

The aim of this work is to quantify the pore space features of carbonate rocks according to petrophysical studies (using the pore aspect ratio – PAR) and to classify the pore space of carbonates according to the results of microscopic studies.

In this paper, attention is focused on a comprehensive study of the pore space features of carbonate rocks. The use of acoustic properties for studying porosity on core samples is described in sufficient detail in the works of Fournier *et al*., [1], [3], [4]. The results of these studies show that in carbonate rocks, the dispersion of acoustic properties exists and is due to the shape of the pore space [3] and the presence of micro porosity (pore size less than 30 microns), which is not determined by optical-mineralogical studies. [5].

One of the main problems of the study of pore space of carbonate rocks is a wide variety of pore types. In this regard, the pore space should be classified taking into account the structural features of rocks and their petrophysical properties [6]. A detailed classification of porosity was proposed by Choquette and Prey in 1970 [7]. It is based on the genesis of pore space and is not related to the petrophysical properties of rocks. A more modern classification of the pore space of carbonate rocks, which takes into account petrophysical properties, was proposed by Jerry Lucia [5]. Using the results of laboratory studies of porosity, permeability and capillary properties, as well as the description of the rock matrix, Lucia divided the pore space into two main types: interparticle and vuggy porosity. Vuggy porosity, in turn, is divided into two classes depending on the interconnectedness of the pores: 1) separate-vug pores: isolated pores connected only by interparticle pores; 2) touching-vug pores: interconnected pores connected by means of channels and voids. This raises the second problem considered in this paper: the correct classification of carbonate rocks, to take into account both structural and textural features and petrophysical elastic properties. In order to improve the quality and accuracy of typing the pore space, the PAR (pore aspect ratio) is introduced, which allows the pores to be quantitatively divided into different types, taking into account the physical properties of the whole rock.

Methodology

Core samples were taken from three wells located on the southern slope of the South Tatar Arch. The samples are confined to Lower Carboniferous rocks (82 samples) and the Upper Devonian rocks (15 samples).

The whole complex of laboratory studies included:

1. Sample preparation (drilling of cylindrical samples with a diameter of 30 mm on the "BUR MT-131" machine).
2. Extraction of cylindrical core samples.

To separate cylindrical core samples from the oil and bitumen contained in them, the Soxhlet apparatus was used. An alcohol-benzene mixture was used as a solvent. The extraction was considered to be complete when a reagent of transparent colour, containing no hydrocarbons, left the sample.

3. Determination of porosity.

The porosity was measured using the gas-volumetric method based on the Boyle-Mariotte law: gas volumes and pressure are changed in the system, and particle volume and porosity are calculated from the obtained data. The porosity parameters were measured on the "Plast-215.

4. Determination of the mineral composition of the studied samples on an X-ray diffractometer.

X-ray fluorescence analysis (XRF) is one of the modern spectroscopic methods for studying substances. The objective of the method is to study the elemental composition of the samples.

The X-ray powder diffraction method is based on the collection and subsequent analysis of the spectrum arising from the irradiation of the test material with x-ray radiation. X-ray fluorescence analysis was performed on an "S8 Tiger" wave dispersive X-ray fluorescence spectrometer (Bruker, Germany). The specified equipment allows the elemental composition of solid, powder and liquid samples in the range from B to U in a vacuum or helium atmosphere, to be determined.

1. Study of the acoustic properties of core samples in model reservoir conditions.

Ultrasonic measurements were conducted using the "PIK-UZ-UEP" equipment ("Geologika"). The system consists of two ultrasonic heads, a signal source and an oscilloscope.

Velocities were calculated from the sample length and the measured one-way transit time of the waves along the sample axis. Velocities were measured under hydrostatic (reservoir) conditions, at confining pressure 20 MPa.

A more detailed study of the pore space involved analysing the acoustic properties compared to rock physics models. A quantitative measure of the pore shape in rock physics [4], [9] is the pore aspect ratio (α) (PAR). Using the assumption of an ellipsoidal pore shape, the PAR parameter is the ratio of the short radius of the ellipse to its long radius, and varies in the range from 0 (cracks) to 1 (pores of a spherical shape). It is important that the PAR parameter is a simplified (model) method for describing the shape of pores, which relates the petrophysical properties of the rock and its structural and textural features. Rock physics methods evaluate the pore aspect ratio (α) with known data on the mineral composition of rocks, porosity, and longitudinal and shear wave velocities. Using a limited collection of core samples for modelling, it is possible to quantitatively describe the relationship between acoustic velocity and rock porosity depending on the shape of the pore space.

Based on the results of laboratory studies, the values of porosity, mineralogical composition, and ultrasonic velocities were determined. Next, from every ninth sample (total 10), thin sections were made for optical microscopic studies. The criterion for choosing the “control” samples was their acoustic properties (the 10 selected samples cover the entire range of P and S wave velocities). The lithological description of the thin sections allows us to classify the available samples not only by their physical parameters, but also by their texture, and the pore features.

Results

The results of the petrophysical studies were used in modelling the theory of effective media. Rock physics modelling used the Power Log software product, in the Rock Physics Module (CGG Geosoftware). For modelling, we used the differential effective medium (DEM) theory [9], [10]. The differential effective medium (DEM) theory models two-phase composites by incrementally adding inclusions of one phase to the matrix phase. Moreover, the pores must be of a certain shape, which is described using the PAR parameter. The pore aspect ratio was quantified; it ranged from 0.012 to 0.2. The results of petrophysical studies and modelling of rock physics are presented in fig. 1. The results of comprehensive studies (petrophysical and lithological-petrographic) are presented in table 1.

Based on the results of the generalization of petrophysical and petrographic data, three rock groups were identified:

- Group 1. Rocks with fracturing, cracks are almost completely filled with calcite. PAR is less than 0.07. Mudstone. Indicated by blue circles on the graph (Fig. 1).
- Group 2. Samples are dominated by microporosity and interparticle porosity. Pore aspect ratio is from 0.07 to 0.12. Samples are presented by wackestone. Red rhombs (Fig. 1).
- Group 3. Macro and mesopores of intraparticle pore type predominate in the samples. Pore aspect ratio is generally in a range from 0.12 to 0.2. According to the results of studying thin sections of the “control” samples, this group is packstone. Green squares (Fig. 1).

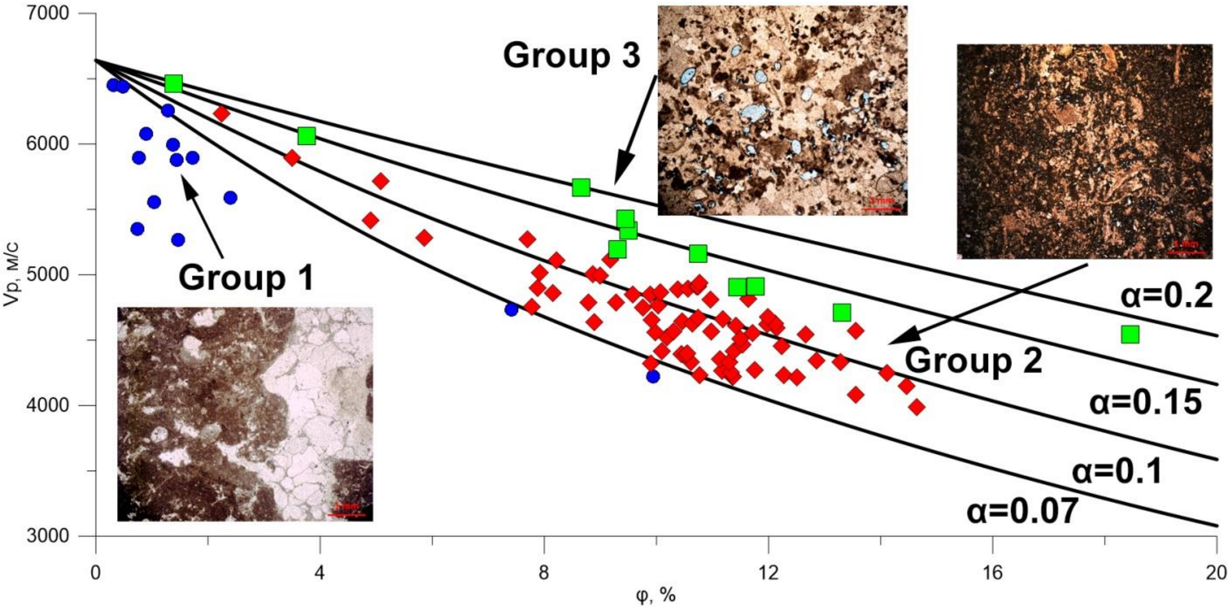

Fig. 1. Porosity versus P-wave velocity for all samples

Table 1. Results of petrophysical studies and petrographic description of thin sections

Lithofacies type	α	φ, %	Vp, m/s	Group
mudstone	0.011	0.74	5347	1
crinoidal wackestone	0.078	10.44	4393	2
crinoidal wackestone	0.082	7.88	4902	2
mudstone- wackestone	0.09	9.28	4786	2
crinoidal wackestone-packstone	0.093	11.49	4512	2
crinoidal-peloidal wackestone- packstone	0.103	10.07	4865	2
crinoidal-peloidal wackestone	0.109	10.56	4895	2
crinoidal wackestone	0.12	11.64	4816	3
peloidal-crinoidal wackestone	0.123	9.31	5196	3
packstone	0.13	3.76	6062	3

Discussion

As can be seen from Figure 1, the acoustic properties of carbonate rocks have a high degree of dispersion. Therefore, it is impossible to very accurately predict the porosity of the sample from the velocities of S and P waves. So, for example, if the P-wave velocity is 5200 m/s, the porosity varies from 1 to 10%. Conversely, if the porosity is 10%, the P-wave velocity values range from 4250 to 5500 m/s. This is primarily due to the complex structure of the pore space in the rock. It leads to a need for new tools in the analysis of elastic and reservoir properties of carbonates. In this case, such a tool is a rock physics modelling.

Verification of modelling, which is carried out using lithological research, is also necessary. The results of studying thin sections of “control” samples confirm the correct separation of the pore space of carbonates according to their physical properties and further rock physics modelling.

Conclusions

As a result of this work, 97 core samples were investigated. Porosity varies from 0.73 to 18.45%. The P-wave velocity varies from 3987 to 6462 m/s, S-waves: from 1889 to 3347 m/s.

An analysis of laboratory experiments showed that the elastic parameters of the samples are highly dispersed. Therefore, the rock physics was modelled to quantify the shape of the pore space using the PAR parameter (pore aspect ratio). This parameter ranges from 0.012 to 0.2.

Also, a “control” group consisting of 10 core samples was identified. Thin sections were made from this group, and optical microscopic studies were performed. This group consists of the following lithogenetic types: Mudstone, with a fracture, almost completely filled with calcite; wackestone, with a predominance of microporosity and interparticle porosity; packstone, with the presence of macro- and mesopores and moldic porosity.

Three rock groups have been identified, which differ in a number of lithological, petrophysical, and acoustic properties. The main criterion for separation was the pore aspect ratio, which does not depend on porosity and velocity, but on the shape of the pore space. One of the methods of rock physics modelling was tested – it was the differential effective medium theory. This method can be used to reduce uncertainty in the field of dependence of porosity and elastic properties, not only in the framework of laboratory studies, but also at the scale of the well, using logging data supported by petrophysical and petrographic laboratory studies.

Modelling results are a reliable basis for both seismic inversion and geomechanical modelling, for establishment of a reliable relationship between dynamic and static elastic parameters.

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