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JUSTIFICATION OF REPRESENTATIVE DATA VOLUME OF POROSITY AND PERMEABILITY PROPERTIES FOR OBTAINING STATISTICALLY RELIABLE PETROPHYSICAL CONNECTIONS

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The article discusses the issues of justifying the data volume for a petrophysical description of an object based on the results of traditional laboratory measurements, as well as X-ray tomography data processing. A new approach to the calculation of porosity and permeability properties of reservoirs with the data of the X-ray tomography method by forming an array of virtual cubes is considered. The issues of required number of allocated cubes for fluid dynamics modeling are discussed. The criteria for the number of laboratory measurements and virtual cubes derived from a digital model for obtaining statistically reliable petrophysical connections are shown. Paper concludes that it is necessary to correctly compare the calculated and laboratory petrophysical connections.
***Key words*:** rock sample analysis; X-ray tomography; petrophysical connections; data volume; porosity; permeability; virtual cube

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Introduction. The first works in the field of the X-ray tomography (XRT) use for the study of rocks, including oil and gas reservoirs, date back to the 80s of the previous century [15]. Currently, this method is of increased interest among oil and gas enterprises, what is related, on the one hand, to the fact that it is non-destructive, requires a small-sized sample of any shape for investigation and, therefore, opens up prospects for research on weakly consolidated rock samples, which cannot be studied by laboratory means. On the other hand, mathematical modeling allows calculating the properties necessary for petrophysicists and developers. Of most interest is the idea of creating a «virtual rock samples storage» with the aim of using it to select methods for enhanced oil recovery.

The number of studies using XRT for measurements of rock samples from productive petroleum deposits is increasing. Today, as a rule, tomography complements the lithological description of the rock sample and is used to quantify the porosity [3, 5, 10]. The calculation of filtration characteristics (for example, gas permeability) is less common [7, 11], and the calculated capillary curves or relative phase permeability curves are found in rare cases [9]. Researchers are faced with the limitations of mathematical algorithms, large time expenditures for carrying out calculations, as well as high requirements for computing power.

There are several approaches for calculating porosity and permeability properties (PPP) (Fig.1). The first is to select a representative volume (REV – representative elementary volume) and use it in hydrodynamic modeling on the pore scale [1, 6, 8, 12-14]. The use of this approach requires significantly larger computational resources, and therefore an alternative approach was proposed with the formation of much smaller volumes (virtual cubes) [2, 4]. Reducing the virtual cube lowers the requirements for the computer, but also reduces its representativeness with respect to the original sample. Therefore, the authors of this article propose to allocate arrays of virtual cubes from a single rock sample. This approach saves computational resources and the operating time of the X-ray tube to obtain the result, as well as allows building petrophysical connections using a limited number of standard rock sample cylinders or fragments if it is destroyed.

This paper presents the justification for selecting the required number of virtual cubes to build a statistically reliable petrophysical connection using XRT data.

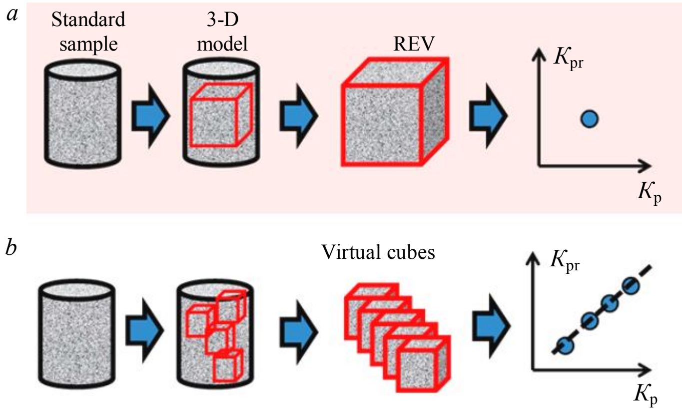

Fig.1. Approaches to the calculation of rocks' porosity and permeability properties
a – traditional approach – one value (supercomputer);
b – new approach - several values (stationary computer)

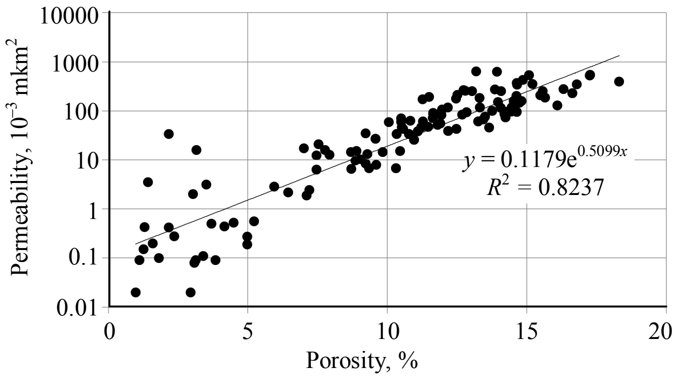

Fig.2. Dependence $K_{pr} = f(K_p)$ for deposits of the Middle Devonian Afoninsky horizon

Object and method of research. The object of the research is terrigenous deposits of the Middle Devonian Afoninsky horizon. Laboratory investigation was carried out on 150 samples, for the XRT studies two samples, represented by fine- and medium-grained sandstone, quartz-based in mineral composition (90-95 %) were used. Cavernous space is represented by pores of intergranular type and is distributed evenly.

The method of X-ray tomography is to use the penetrating ability of unidirectional X-ray radiation with the subsequent registration and construction of the X-ray image on the X-ray receivers. The result of XRT imaging and post-processing is a three-dimensional rock sample model. To evaluate the porosity and permeability properties, the cavernous space is outlined and its volumetric model is constructed. In the boundries of the proposed approach, it is meant to divide the cavernous space model of the processed sample into fragments (virtual cubes), which are used to calculate the porosity and gas permeability and build the corresponding petrophysical dependence $K_{pr} = f(K_p)$.

The number of virtual cubes keeps changing until the petrophysical dependence stops changing and in the best way reflects the dependence obtained in the laboratory on samples of 30 × 30 mm in accordance with state standard 26450.2-85 «Mining rocks. Method for determining the absolute gas permeability coefficient for stationary and non-stationary filtration». Following parameters were chosen as those controlling the dependence: dispersion, mean square deviation (MSD) and tangent of the petrophysical connection angle.

Results of the research, discussion. According to reference document (RD) 153-39.0-072-01 «Technical instructions for conducting geophysical surveys and operations with cabled instruments in oil and gas wells», in order to construct rock sample-rock sample petrophysical connections it is necessary to investigate at least 30 rock samples. In this regard, it was decided to first check this point on the laboratory dependence (Fig.2), where the sample were chosen randomly.

Fig.3 shows the variation in dispersion, mean square deviation and tangent angle depending on the chosen samples size. To correlate permeability values, it is possible to achieve stabilization of parameters with 40 rock samples, while for porosity, 80 samples are required for this. The tangent angle is a complex parameter, which takes into account the interrelationship of both parameters, and, as can be seen, stops changing when the number of studied samples is 80. Thus, for this type of reservoir, the number of samples needed to build a statistically reliable dependence of permeability on porosity is about 80, which is consistent with the rules of RD (more than 30 samples). If only 30-40 samples are taken for research, incorrect data may be obtained, so it is recommended to carry out a similar statistical analysis, which, in turn, can be seen as addition to the specified RD.

Identical procedures were carried out in the case of XRT, only in this case the dependence was built inside a single sample. The assumption that virtual cubes cut from XRT data of single rock

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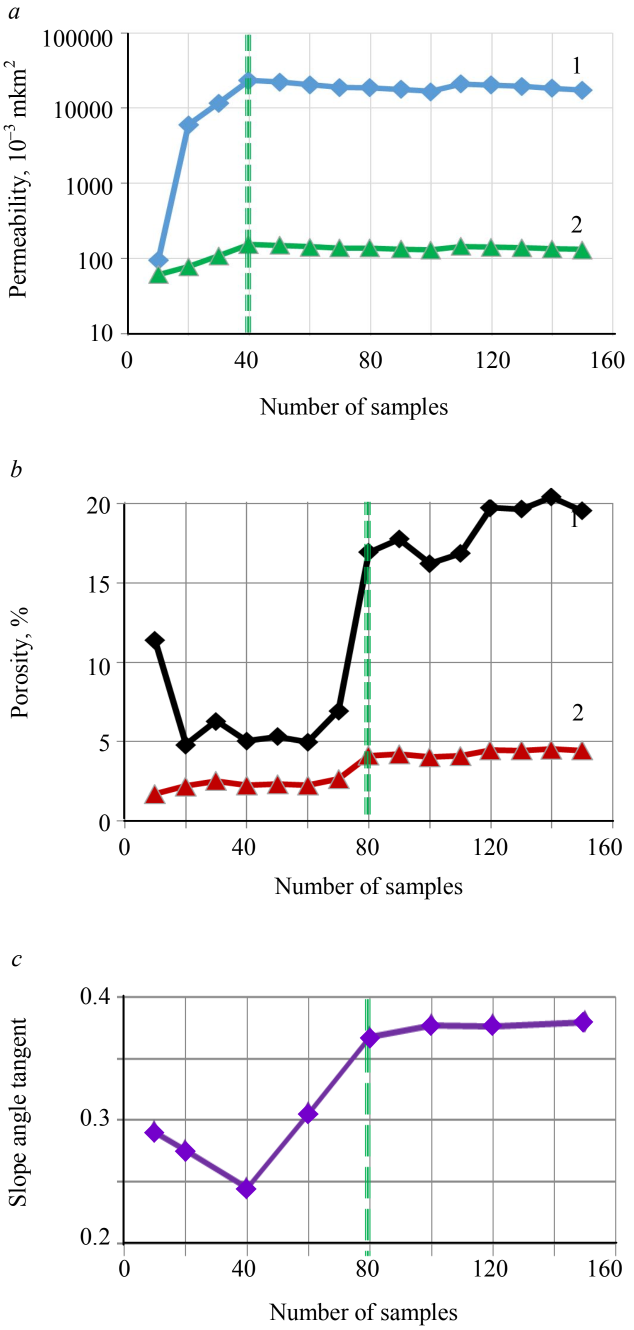

Fig.3. Dependences of dispersion and mean square deviation of permeability (*a*), porosity (*b*), angle tangent (*c*) on number of studied samples
1 – dispersion; 2 – MSD

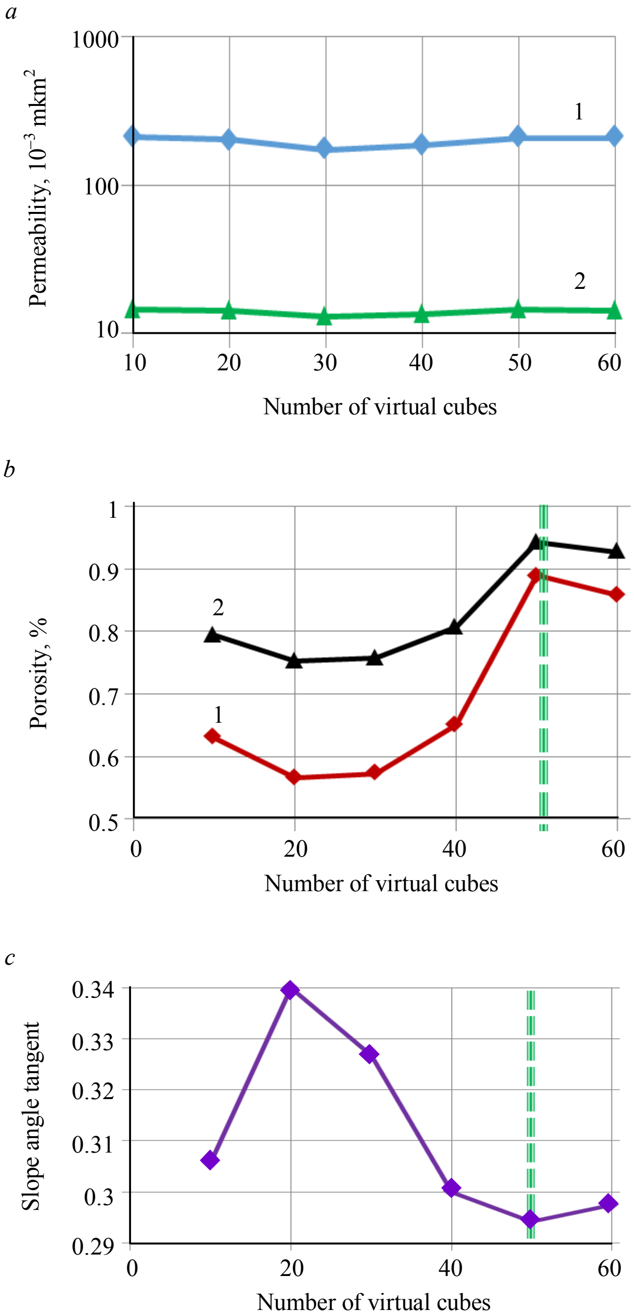

Fig.4. Dependences of dispersion and mean square deviation of permeability (*a*), porosity (*b*), angle tangent (*c*) on number of virtual cubes
1 – dispersion; 2 – MSD

sample may form a correlation link between porosity and permeability is new and has not been applied in practice before. Fig.4 shows the results for one of the studied samples.

As can be seen, in the case of permeability, the dispersion and the MSD remain almost unchanged with an increase in the number of virtual cubes. For porosity, as well as for slope angle tangent, these values are set at a constant level with 50 cubes. However, for the second sample studied, this number was 40 cubes, which suggests that the number of allocated cubes from each sample, required to build a statistically reliable connection, is individual. As a result of applying this approach, the calculated relationship between porosity and permeability was obtained, its comparison with the connection, obtained in laboratory conditions, is shown in Fig.5, a. In general, it is possible to note a good agreement of the results, however, the dependence obtained by XRT has a

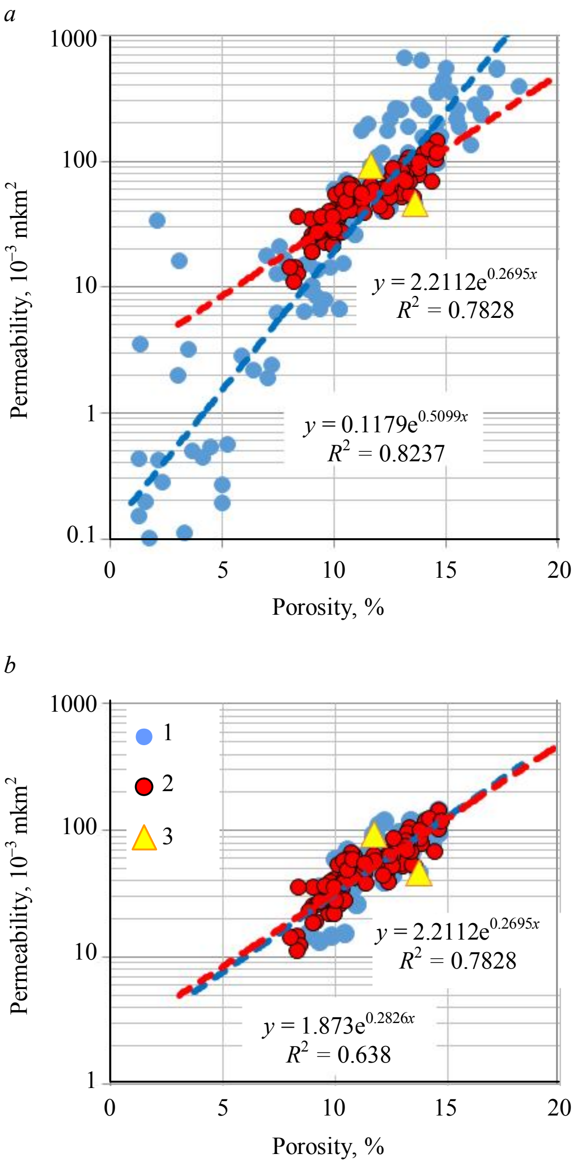

Fig.5. Comparison of the results:
a – with full range of laboratory studies
b – in the range of studies obtained by XRT
1 – laboratory; 2 – XRT; 3 – samples for XRT

slightly different slope. This can be explained by the fact that the selected samples (yellow triangles) characterize a narrow area of laboratory dependence; therefore, it is not entirely correct to compare the results for these two samples with a laboratory dependence, which has a much wider spread. In this regard, the comparison interval was limited to the area where there were calculated data of the XRT. Fig.5, b shows that this achieves complete convergence of petrophysical connections.

Conclusion

In the framework of this project, the main components of a statistical approach to determining the porosity and permeability properties of rocks according to XRT data using an array of virtual cubes are formulated:

1. The justification for the number of cubes to be cut based on the use of such statistical parameters as dispersion, mean square deviation and slope angle tangent. This approach is universal, since it can be applied to both terrigenous and carbonate samples.

2. It is shown that the proposed approach is also applicable for laboratory rock samples studies, while also helps to more reasonably justify the choice of the samples number for constructing statistically reliable links and may be seen as an addition to RD 153-39.0-072-01.

3. Reliable construction of petrophysical connections using a statistical approach based on the data of virtual cubes created on the basis of the XRT survey, is only possible within the limits of the obtained PPP values. Approximation of the calculated dependencies for fragments in the zone of the better or worse PPP can lead to errors.

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