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PROBABILISTIC EVALUATION OF THE PERMEABILITY OF THE ROCKS OF THE ELEMENTARY CELL OF A GEOLOGICAL MODEL

P. N. Strakhov, A. A. Markelova*

Peoples' Friendship University of Russia named after Patrice Lumumba, Moscow, Russia

A B S T R A C T

The article proposes a new method for calculating the permeability of a geological model cell using probabilistic methods. It is proposed as an alternative to the generally accepted method, which is based on the use of empirical dependencies between porosity and permeability based on the results of laboratory core tests. The proposed method allows us to calculate the dependences of the probabilities of exceeding certain permeability values on porosity. These are of interest for studying the geological structure of oil and gas facilities in the process of their modeling. In this work, the boundary values of filtration properties corresponding to the boundaries of reservoir classes in the classification proposed by A. A. Khanin in 1969 were used. The article discusses the problems arising from the integration of different-scale levels. One of their solutions can be obtained by using the Monte Carlo method. In particular, its use helped to simulate the reservoir properties of rocks in a virtual cell of a geological model based on analyses of the results of previous studies of core samples in laboratory conditions. The approximation of the probabilities of exceeding the corresponding values of permeability from porosity allows us to calculate histograms of this parameter for each cell of the model. To do this, it is necessary to determine the differences in the probability functions that are used for neighboring permeability thresholds. In turn, this makes it possible to perform a differentiable assessment of hydrocarbon reserves for the corresponding reservoir classes in terms of permeability. The article discusses a methodology that allows you to perform all calculations in an automated mode. The text of the article provides the necessary description of the program for calculating the probabilities of exceeding the permeability thresholds, as well as a schematic diagram reflecting the main provisions of its work. The article substantiates the expediency of not using porosity thresholds for reservoir identification. Instead, permeability histograms are calculated for each cell. This methodological scheme makes it possible to calculate reserves associated with rocks of various permeability classes in an automatic mode.

Keywords: bottomhole formation zone; asphalt-resin-paraffin deposits; nitrite composition; surfactants; enhanced oil recovery.

Date submitted: 21.06.2023 **Date accepted:** 21.05.2024

Introduction

One of the most acute problems that arises when constructing three-dimensional geological and hydrodynamic models is the assessment of the filtration properties of elementary cells [1-2]. The modern method of estimating the permeability of deposit models is extremely difficult to call correct. It is based on empirical formulas describing the dependences of permeability on porosity, which are obtained as a result of processing core study materials in laboratory conditions. The main negative quality of this approach lies in the existence of significant deviations of the measured permeability data from the calculated ones by a very large amount. Moreover, there is a certain pattern of decreasing the frequency of occurrence of points on the chart as they move away from the trend. The range of deviations does not rarely reach the order of values. Then the filtration properties of the model are determined as a result of recalculation according to the obtained porosity cube formula. When using empirical dependencies determined by the core, differences in the scale of research are ignored (the volume of an average statistical cell is about 1000 cubic meters). The proposed technique allows minimizing the errors in estimating the permeability of cells of geological models, since an estimate of the spread of values is given, which is very important when carrying out hydrodynamic modeling and creating projects for the development of hydrocarbon deposits.

In addition, in this case, it becomes possible to improve the correctness of the allocation of collector cells. Currently, there are 2 widely used ways to achieve this goal. The first is the interpolation in the inter–well space of lithology indicators (collector - non-collector), which are determined based on the interpretation of field and geophysical data. The cutoff is taken based on the average value of this parameter. At the same time, the porosity cube is often practically ignored.

The second method provides for the assignment to collectors of cells whose average porosity is greater than the boundary value, which is justified by the materials of

**E-mail:* markelova-aa@rudn.ru

http://dx.doi.org/10.5510/OGP20240200966

petrophysical studies. As a result, some rocks that have a porosity less than the conditioned value, but at the same time form a drainage system, are not taken into account. In addition, rather high-capacity deposits fall into the category of collectors, but their permeability does not allow creating a filtering system.

It is proposed to take into account not the entire volume of the cell, but only a part of it, which is determined by a formula estimating the dependence of the probability of overcoming the boundary value of permeability on porosity. As a result, when calculating oil and gas reserves, the calculations take into account the mathematical expectation of reservoir volumes (the product of the cell volume by the probability of attributing rocks with a given porosity). For large porosity values, the probability will be 1, and for rocks with very small porosity, 0.

The purpose of the research

Development of an original approach for a more detailed assessment of the filtration properties of the model, which involves the use of probabilistic methods. This will increase the information content of geological and hydrodynamic models. It should be noted that the use of statistical methods makes it possible to identify geological heterogeneities of the studied objects [3, 4]. The proposed methodology will allow for a more reasonable application of methods of influence on productive deposits, taking into account a detailed understanding of the distribution of filtration characteristics of the formation. In addition, the proposed method of describing the nature of changes in the filtration properties of the rocks of the model will have a positive effect on the calculation of changes in reservoir pressure. This is especially important for the design and actual development of oil and gas deposits with hard-to-recover reserves, since in this case the impact on productive deposits will be optimized [5, 6]. It also becomes possible to calculate hydrocarbon reserves associated with rocks of each class separately, which will have a positive impact on the accuracy of estimating the value of oil and gas reserves. Since it largely depends on the flow rates, the value of which is determined by the permeability of the rocks. Information on the share content of various classes of reservoirs can significantly affect the economic assessment both upwards and downwards.

Methodology for the probabilistic assessment of the permeability of terrigenous rocks

When carrying out the work, we proceeded from the fact that the relationship between the possibility of forming a filtering system in the sample and porosity has a probabilistic character [7, 8]. In particular, among the core collection of the Lower Cretaceous section of the West Siberian oil and gas province, represented by terrigenous rocks, there are samples with a small capacity (6-7 %), which have a permeability greater than the standard values, and vice versa, almost impermeable differences are recorded, the porosity of which is 10-15 % [9]. Thus, if a certain critical value of porosity is accepted, according to which a cut-off is made in the model when identifying reservoirs, it turns out that a part of permeable rocks will be excluded from the reservoir, and also deposits that do not have drainage systems will be attributed to filtering differences. In turn, this will lead to an incorrect prediction of the nature of the movement of fluids in the reservoir, which will negatively affect the effectiveness of the impact on the reservoir.

At the beginning of the work, an analysis was made of the results of studying the porosity and permeability of rocks, performed in laboratory conditions. The obtained data were grouped according to their capacitive properties. The interval of change in porosity was 1%. Groups with porosity from 1% to 2%, from 2% to 3%, from 3% to 4%, from 4% to 5%, etc. are formed. Thus, the entire collection of specimens was characterized.

Then, for each group created on the basis of capacitance, the proportions of samples are determined, the permeability of which, respectively, exceeds $0.1\cdot10^{-15}$; 10^{-15}; $10\cdot10^{-15}$; $100\cdot10^{-15}$; $500\cdot10^{-15}$; $1000\cdot10^{-15}$ m Darcy [10]. Thus, the frequency of occurrence of collectors of 1-6, 1-5, 1-4, 1-3, 1-2 and 1 classes is calculated [11] . Then, for each sample determined by permeability, the dependence between the frequency of exceeding the corresponding standard value of filtration properties on porosity was approximated (formula 1). As a rule, there is good agreement between measured and calculated values (correlation coefficient is 0.91 – 0.98).

$$P_{\kappa}^{sample} = 1 - exp\left[-\exp\left(A_1 \times K_p^{sample} - B_1\right)\right] \qquad (1)$$

where P_{κ}^{sample} – is the probability of assigning a sample of the corresponding capacitive group to collectors, d. units; K_p^{sample} – the average porosity of the samples of the capacitive group, d. units; A_1, B_1 – coefficients of proportionality.

The obtained empirical dependencies have a clearly expressed asymptotics in the region of small and large values. At minimum values of porosity, the possibility of exceeding the permeability of the corresponding standard value practically tends to zero, and at very high values of capacitance properties, the analyzed function tends to unity. Also, which looks quite natural, the higher the standard value of permeability is taken, the less is the probability of the existence of this class of reservoirs for the analyzed capacitive group.

In principle, formula 1 can be used when constructing the model. However, it should be borne in mind that it is unlikely that there is no variability in the reservoir properties of rocks in the cell [12]. Their underestimation has a negative impact on the reliability of the geological model. 8-10 million samples can be safely placed in a model cell. For obvious reasons, it is impossible to determine their filtration and capacitance properties, therefore, they should be modeled in the current situation [12, 13]. During the construction of the cell model, it is recommended to use the Monte Carlo method [12]. It is assumed that the unit cell of the geological model consists of a very large sample of virtual rocks having sizes commensurate with the sample, which are studied in the laboratory. Then, each conditional rock is assigned a porosity value using a random number generator. At the same time, certain conditions are met:

1. The average porosity value of a conditional sample collection is identical to the capacitance parameter of the corresponding unit cell.
2. For the sampling of virtual cell samples, the normal nature of the porosity distribution was assumed. It should be noted that in certain situations, under certain geological conditions, which are justified by specific factual data, modernization of this function is allowed.

3. The spread of values of the capacitive properties of the corresponding set of conditional samples, as a rule, does not exceed half of the average porosity determined for the corresponding cell.

At the next stage, for each virtual sample of the corresponding sample, the probability values of exceeding a certain conditioned permeability value were calculated according to formula 1. The geometric mean values of the functions under consideration were calculated. Then, for each cell of the geological model, empirical dependences of the probability of exceeding the required critical values of capacitive properties on porosity were determined, which are approximated by formula 2 (fig. 1). The correlation coefficients of the comparison of the initial and calculated

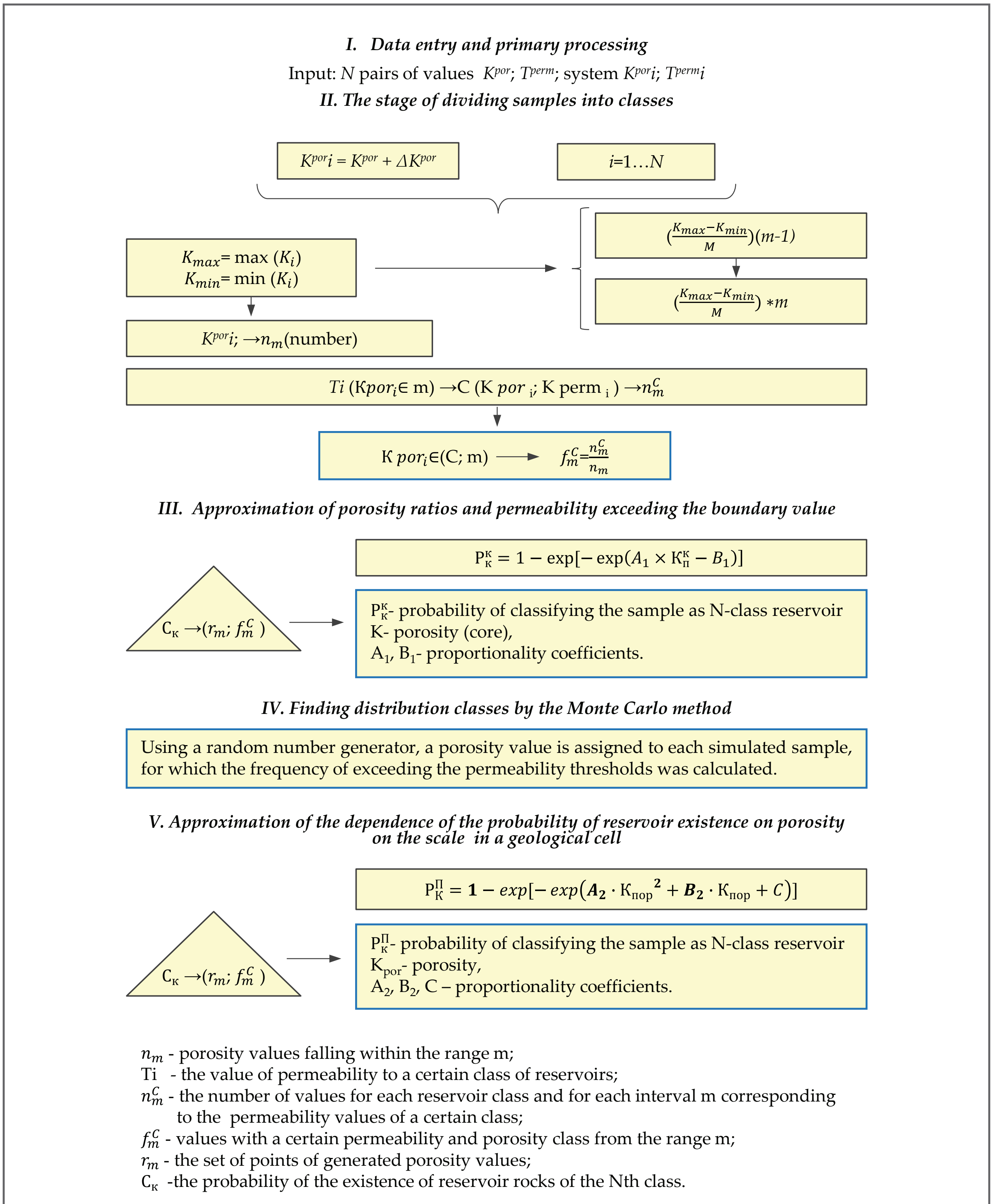

Fig. 1. Principal block diagram of the program for determining the dependence of the probability of the existence of reservoirs of a certain class on porosity

values are quite large, as a rule, they fall into the range 0.995-0.999.

$$P_K^{cell} = 1 - \exp\left[-\exp\left(A_2 \cdot K_{por\_cell}{}^2 + B_2 \cdot K_{por\_cell} + C\right)\right] \quad (2)$$

where P_K^{cell} – probability of existence of a cell permeability not less than a certain critical value, d. units; K_{por_cell} – cell porosity, units; A_2, B_2, C – coefficients of proportionality.

As a result, we have the opportunity to recalculate the porosity cube of the geological model, which is calculated during interpolation of the results of interpretation of field and geophysical data and in order to determine the probability of exceeding the corresponding boundary values of permeability, which allows us to determine the frequency of occurrence of each class of reservoirs (formula 3). It should be noted that when constructing a porosity cube, it is also recommended to use materials from the dynamic analysis of the wave field [10].

$$P^N_{K\,por\_cell_i} = P^{1-N}_{K\,por\_cell_i} - P^{1-(N-1)}_{K\,por\_cell_i} \quad (3)$$

where $P^N_{K\,por\_cell_i}$ – frequency of occurrence (probability of existence) of the N-th class collector in the i-th cell, d. units; $P^{1-N}_{K\,por\_cell_i}$ – frequency of occurrence (probability of existence) of collectors of 1-N classes in the i-th cell, d. units; $P^{1-(N-1)}_{K\,por\_cell_i}$ – frequency of occurrence (probability of existence) of collectors of 1-(N-1) classes in the i-th cell, d.

Automation of the process of constructing permeability histograms of geological model cells

The theoretical provisions presented in the article were implemented in a software product that allows you to automate the necessary calculations (fig. 1). Conventionally, they can be divided into 5 stages. Initially, the analysis and input of primary information was carried out, which is the results of determining the reservoir properties of core samples. At the next stage, the samples were divided into the corresponding classes according to the capacitive characteristic in accordance with the principles described above. Also, the proportion of rocks in the group with a permeability greater than the corresponding threshold value ($0.1 \cdot 10^{-15}$; 10^{-15}; $10 \cdot 10^{-15}$; $100 \cdot 10^{-15}$; $500 \cdot 10^{-15}$; $1000 \cdot 10^{-15}$ m Darcy). Next, approximations of the dependence for each set of classes are carried out (formula 1). At the fourth stage, the calculations were transferred to the cell scale level, using the Monte Carlo method. Thus, each cell was represented as a collection of a very large number of rocks that are comparable in size to core samples. The principles of formation of capacitive properties of virtual rocks were discussed earlier in this article. Then the probability of exceeding the corresponding conditional value for each cell of the model is determined. In conclusion, the desired empirical dependencies were calculated (formula 2). These calculations were tested in the study of the reservoir of the Lower Cretaceous section of Western Siberia (fig. 2). The obtained functions allow for each cell of the porosity cube using formula 3 to calculate the permeability histogram (fig. 3) [14-17].

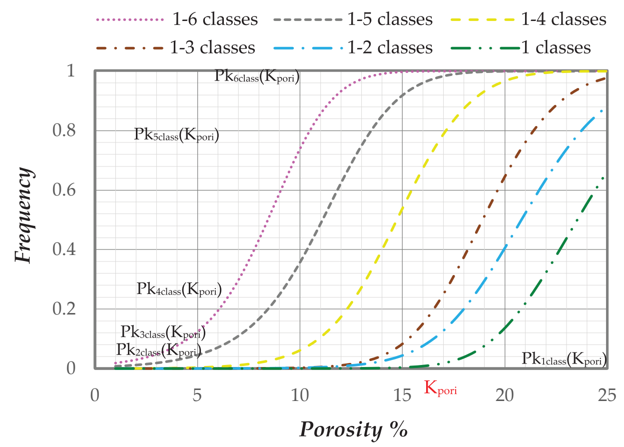

Fig. 2. An example of the dependence of the probability of exceeding the critical value of permeability on cell porosity

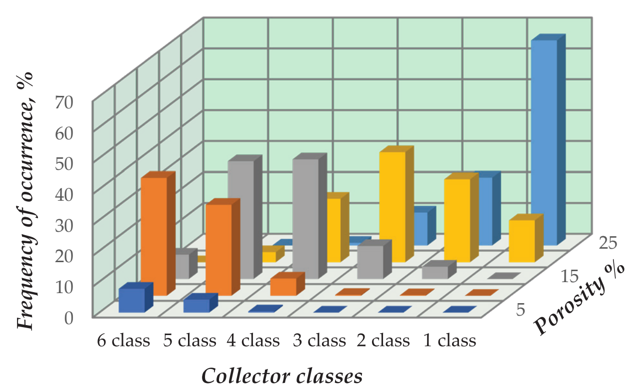

Fig. 3. Schematic example of the relationship between the porosity of the cell and the frequency of occurrence of a class of reservoirs on the scale of the formation of the reservoir of the Lower Cretaceous section of Western Siberia

Conclusion

1. An automated approach to assessing the permeability of geological cells using probabilistic methods, which practically eliminates the subjective factor, allows us to develop more detailed projects of impact on the reservoir during the development of oil and gas deposits.
2. There is an opportunity to increase the reliability of data, which is of interest to specialists involved in the construction of geological and hydrodynamic models.
3. The proposed methodological approach makes it possible to separately assess hydrocarbon reserves contained in rocks of different permeability classes, which is of particular interest in the economic assessment of deposits at the stage of their exploration and preparation for development.

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