Digital Core Modelling for Clastic Oil and Gas Reservoir

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Abstract. "Digital core" is a multi-purpose tool for solving a variety of tasks in the field of geological exploration and production of hydrocarbons at various stages, designed to improve the accuracy of geological study of subsurface resources, the efficiency of reproduction and use of mineral resources, as well as applying the results obtained in production practice. The actuality of the development of the "Digital core" software is that even a partial replacement of natural laboratory experiments with mathematical modelling can be used in the operative calculation of reserves in exploratory drilling, as well as in the absence of core material from wells. Or impossibility of its research by existing laboratory methods (weakly cemented, loose, etc. rocks). 3D-reconstruction of the core microstructure can be considered as a cheap and least time-consuming method for obtaining petrophysical information about the main filtration-capacitive properties and fluid motion in reservoir rocks.

1. Introduction

The digital core modelling technology is a prominent and growing trend in the evaluation of geological oil reserves in the world. And even its partial replacement by the numerical experiments can provide significant economic benefits [1]. In the context of mathematical modelling of the macroscopic properties of porous media, the problem of 3D reconstruction of the microstructure of rocks arises [2-4]. And the connection between the geometry of a microstructure and macroscopic physical properties has recently attracted increasing interest in research groups. For porous materials, permeability is one of the macroscopic parameters of practical interest, and its measurement is important for predicting flows at the macro level [5]. Recently, there have been significant advances in the construction of the geometry of the microstructure of rocks, and the use of high-performance computing technology has accelerated the development and using of "digital core" tools in addition to natural laboratory examinations.

One of the promising approaches to build the mathematical model of the macroscopic properties of porous media and for the 3D-reconstruction of the rock microstructure is the method of molecular dynamics. This work presents the results of numerical calculations and their comparison with the full-scale examination. In this work, the core material from the Buff Berea (USA) field was investigated. It has a minimal anisotropy of the filtration-capacitance properties. Within laboratory examinations data of the absolute permeability and opened porosity of the samples, the change in the fluid permeability coefficients as a function of temperature when modelling the thermobaric conditions were obtained. The thin sections were also made and a lithological-petrographic description was made. Also, within
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this work geophysical and lithologic-petrographic data from the study reports of the Timan-Pechera oil and gas province fields, represented by terrigenous reservoirs, were analysed. Later these results were used for 3D-reconstruction of the core microstructure. A comparative analysis of the properties obtained in laboratory conditions with the properties obtained by mathematical modelling was carried out.

2. Mathematical modelling

Later these results were used for 3D-reconstruction of the core microstructure. A comparative analysis of the properties obtained in laboratory conditions with the properties obtained by mathematical modelling was carried out. Simulation of the rock pore space is carried out in several stages. During the first stage, primitives of the shapes of grains, granulometric composition, and rock texture were modelled. Shale volume is given. At the last stage, the parameters of the physical model, the calibration algorithm, and the presentation of the results were indicated. As a result, a model of the porous medium is formed. The obtained model is used for modelling of filtration processes in a porous formation environment.

The digital core model being developed consists of several embedded models:
- rock microstructure model;
- numerical permeability models and filtration-capacitance rock properties model;
- numerical models of asphaltene, paraffin and resin precipitation.

The first is the construction of the core 3D geometry, the second is the simulation of micro-flow physics, the third is the chemistry of processes occurring in reservoir conditions. These components are integrated into a single digital core model, created to provide a means of predicting the behaviour of fluids under different conditions. This report examines the approaches to constructing the geometry of the microstructure of the rocks.

The core microstructure model obtained by the stochastic [6, 7] and simulated packing algorithm of microparticles with compaction is used as a basis for the subsequent analysis of pore space. Having made the transition from the representation of particle packing to the representation of the pore network model, the permeability of single channels can be calculated using molecular dynamics. Thus, for the network model of the pore space, a system of linear equations is compiled with respect to the pressure in each pore. The evaluation of the pressure drop on the sample makes it possible to calculate the absolute permeability according to Darcy's law [8].

In this report we consider a simplified model of the geometric structure of rock space, when it is a box, densely filled with balls of different diameters. The distribution of the diameter of the balls can be obtained by the laboratory core studies (figure 1). Packing of balls is made as a result of simulation of molecular dynamics. The box has fixed walls and bottom. Simulation of molecular dynamics has been done with atoms having the radius of the van der Waals interaction corresponded to the distribution, determined as a result of laboratory core studies (figure 1). The Lennard-Jones (LJ) potential (1) is chosen as an interatomic interaction potential because of its simplicity and because it has never led to physically unacceptable results. It can be used to model not only atoms and molecules with spherical symmetry but also other non-polar substances:

\[ U(r) = 4\epsilon \left( \frac{\sigma}{r} \right)^{12} - \left( \frac{\sigma}{r} \right)^{6} \]  

Parameters \( \sigma \) are used according to the radius of a corresponding ball, and the cross-section interaction parameters were defined using the Lorentz-Berthelot mixing rule (2):

\[ \epsilon_{ij} = (\epsilon_{ii} \epsilon_{jj})^{\frac{1}{2}}, \sigma_{ij} = \frac{1}{2} (\sigma_{ii} + \sigma_{jj}) \]  

There was also applied gravitational force. To save computing time the LJ potential was truncated at a cut-off distance of \( r_{\text{cut}} = 2.5\sigma \) and to avoid a jump discontinuity at cut-off distance, the LJ potential was shifted. During the simulation the temperature linearly decreases passing the melting point down to the low values. For the temperature maintenance the Berendsen thermostat [9] was used. Calculations were done in LAMMPS molecular dynamics package [10].

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To determine the pore space, it is enough to pass the coordinate space of the box with a test atom having a specified van der Waals radius. The result is a system of micro-channels, which can be used within the electrodynamic analogy, presenting flows in the form of a network-related electrical resistances. Having solved the problem of finding the impedance, one can be found permeability.

**Figure 1.** The bar graph shows the percentage distribution of the particle size of the core sample. A graph of the cumulative volume is shown by the green line. The value of cumulative data is the percentage of particles whose size is less than the specified. The graph of the cumulative volume with the axis “% Passing” (% of the recorded data) and the axis “Size (microns)” is displayed on a semilogarithmic scale.

### 3. Natural laboratory examination

Petrographic description of 10 thin sections (figure 2) of the terrigenous sandstone rocks of Berea Sandstone field was performed to obtain lithological and petrographic information. The investigated samples are medium-fine-grained and finely-medium-grained light-gray sandstones which are reservoirs with mainly average useful capacity pore-type. In terms of material composition the content of quartz in rocks varies within the limits of 70-85%, feldspars 2-5%, fragments of rocks of different genesis of 10-20%, mica 1-2%. There is locally pervasive contact cementation with conformal contacts of individuals; regenerative quartz does not exceed 1%; feldspar 2-5%; Authigenic carbonate plays the role of porous corrosive cement (2-5%). It was identified that the main factor determining the porosity and permeability of terrigenous reservoirs is the dimension of the grains of rock-forming minerals and their sorting, but there is no direct dependence of porosity and permeability from the granulometric composition of rocks. It should also be noted that in the rocks studied, quartz grains and rock fragments are irregular in shape and has semi-rounded particles. Therefore they are less densely packed, which leads to an increase in porosity [11].

Filtration experiments were carried out on the core samples from the Buff Berea field with a length of 30 mm and a diameter of 30 mm. Modelling of the thermobaric conditions of natural occurrence at different temperatures was accomplished. This allows one to obtain experimental data necessary for computer experiments with digital core model on a supercomputer, and also for a comparative analysis of values obtained in laboratory conditions with values of the same properties obtained by mathematical modeling. An array of data was obtained from 100 kerosene permeability values. An analysis of geophysical data and reports for 6 wells of the Timan-Pechera oil and gas province was carried out to determine the correlation between core samples and well survey study results, as an establishment of formulas and dependences. According to all the data, permeability of oil, determined on core sample, versus porosity, determined by well survey (from 3 to 4 dependences for each reservoir, corresponding to methods for determining porosity by well survey) was constructed. Methods used in well survey were neutron log porosity, acoustic logging measurement, density logging and assumes logging. For the analysis, the porosity obtained by neutron log porosity were chosen because its plotted graphs showed the highest convergence. As a result, the equations of dependences of oil permeability coefficients from porosity in well survey were obtained, and the permeability curves were plotted.

In the wells with small core recovery, or without it, with loss of core recovery and core quality, especially when selecting from prospecting and exploration wells, there is a shortage of real core material for examination, which significantly reduces the efficiency of further work. In such cases, it is proposed to use the obtained dependences to find one of the most important properties of the
formation - oil permeability. Based on the analysis, this equation can be used for terrigenous rocks, when there are mainly monomineralic quartz sandstones in the composition of reservoirs, quartz that are unevenly interbedded with sandstone and siltstone, sandstone, rarely gravel, in the case that these rocks can be attributed to reservoirs of predominantly of pore-type.

4. Results and Discussion

To determine the properties of sandy-silty rocks such as oil and gas reservoirs, it is important to determine their granulometric composition [12]. Determination of the granulometric composition of the sample showed that the average particle diameter by the type of distribution of their number was 5.82 μm, the average particle diameter by the form of their distribution was 54.52 μm. Their porosity according to petrophysical analyses varies in the range of 17-20%. In natural and simulated examinations it has been shown relationship of permeability from temperature of the rocks (figure 3).

The graphs obtained during examinations of the permeability of ten samples are presented. There are also two graphs of permeability calculated for two simulated microstructures and comparison: one is for the microstructure obtained by stochastic packing, the other is for the microstructure from molecular dynamics simulations.

**Figure 2.** Photos of thin sections.

**Figure 3.** Natural and numerical core sample investigation of permeability dependence from temperature. Circles indicates data from natural experiments. Square indicates data from numerical investigations. MD indicates results for
microstructure obtained by molecular dynamics simulations and MC for stochastic packing.

The conclusion is that the main factor determining the porosity and permeability of terrigenous reservoirs—the dimension of the grains of rock-forming minerals is in good agreement with the initial assumptions of the model being developed: the construction of the microstructure of the rock by packing balls with the same size distribution as the grain size distribution of the simulated rocks. The conclusion is that in the rocks studied, quartz grains and rock fragments are irregular in shape and semi-entangled particles and as a result they are less densely packed, which leads to an increase in porosity. This suggests that for a more accurate modelling of rock properties, the elements for constructing a microstructure should be other than spheres, for example, spherical polyhedrons [13].

5. Conclusion
An approach to the solution of the problem of mathematical modelling of macroscopic properties of porous media is proposed, in which the molecular dynamics method is applied for 3D reconstruction of the core microstructure. The results of numerical calculations and their comparison with the full-scale experiment are presented. Despite the good agreement between numerical and natural results, it can be improved by more accurate construction of the rock microstructure and accounting of the shaliness impact.

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References
[1] Renard P, Genty A and Stauffer F 2001 J. Geophys. Res. 106 443
[2] Andra H, Combaret N, Dvorkin J, Glatt E, Han J, Kabel M, Keehm Y, Krzikalla F, Lee M, Madonna C, Marsh M, Mekerji T, Saenger E H, Sain R, Saxena N, Ricker S, Wiegmann A. and Zhan X 2013 Comput. Geosci. 50 33
[3] Andrew M, Bijeljic B and Blunt M J 2013 Geophys. Res. Lett. 40 3915
[4] Blunt M J, Bijeljic B, Dong H, Gharbi O, Iglauer S, Mostaghimi P, Paluszny A and Pentland C 2013 Adv. Water Resour. 51 197
[5] Bear J 1972 Dynamics of Fluids in Porous Media (New York: American Elsevier Publishing Company)
[6] Dong H and Blunt M J 2009 Phys. Rev. E 80 036307
[7] Garcia X, Akanji L T, Blunt M J, Matthai S K and Latham J P 2009 Phys. Rev. E 80 021304
[8] Whitaker S 1986 Transp. Porous Media 1 3
[9] Berendsen H J C; Postma J P M; van Gunsteren W F; DiNola A; Haak J R 1984 J. Chem. Phys.. 81(8) 3684
[10] Plimpton S 1995 J. Comp. Phys. 117 1
[11] Sahibgareev R S 1989 Secondary changes in reservoirs during the formation and destruction of oil deposits (Leningrad: Nedra, Leningrad Branch)
[12] Hanin A A 1969 Reservoir rocks of oil and gas and their study (Moscow: Nedra)
[13] Petrov M, Gaidukov V, Kadushnikov R, Antonov I, Nurkanov E 2004 Powder Metall. Met. Ceram. 43 (7–8) 330–335