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Компьютерное моделирование процессов разработки нефтегазовых месторождений

Аннотация. В статье рассматривается математическая модель процесса фильтрации многокомпонентной смеси в пористых средах, которая может быть использована при определении перераспределения давлений и насыщенностей в нефтегазовых залежах, что имеет практическое применение при создании математического обеспечения автоматизированных систем проектирования нефтегазовых месторождений. Также рассматривается программный продукт для расчёта процессов проектирования и разработки нефтегазовых месторождений.
Ключевые слова: математическая модель, численный алгоритм, программные средства, скважина, фильтрация, газ, нефть, вода.

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Computer modeling of process of oil and gas fields development

Abstract. The paper discusses a mathematical model of the process of multicomponent mixture filtering in porous media, which can be used while determining redistribution of pressure and saturation in oil and gas reservoirs. That has practical application in the development of automated systems for de-signing oil and gas fields. The software product meant for carrying out calculations of the process is also considered.
Keywords: mathematical model, numerical algorithm, software, gas wells, filtering, gas, oil, water.

Introduction. The value of the fuel and energy sector in the economy is very large, and not only because it provides all branches of the real sector of the economy with the fuel and energy, but also any human activity cannot be considered without energy.

Development of methods for mathematical modeling of real objects and complex processes causes the further growth of the oil-gas industry. Currently, the most of oil and gas fields are being developed under artificial impact conditions, where the natural gas or water is used as an agent.

Improvement of existing and implementation of new methods of mathematical modeling is necessary for in-depth study of the mechanism of physical systems in which there is a moving mass of liquid and gas, and energy transfer from one species to another.

The study of many of these processes causes necessity of creation adequate mathematical models and computational algorithms to determine the dynamic state and control of reservoir filtration systems, taking into account the dynamics of transients. Recently, many researchers in the world have received considerable theoretical and practical results on considered issues

In [1] there is a model of multicomponent filtration medium in which the relative permeability of the gas phase is replaced by a new expression that takes into account the effect of viscosity, density and capillary effect of the mixture.

The study of capillary pressures corresponding triangular capillary diffusion tensor in three-phase fluid was discussed in [2]. Filtering with such tensor is described by solutions for degenerate parabolic system of equations. This system is integrodifferential, as total flow and the distribution of phase saturations are sought in a given pressure drop in one of the phases at the boundaries of the flow domain. It was shown that the problem of displacement degenerating capillary system can be studied on the basis of a special maximum principle.

The problem of transport three-phase mixture "water-gas-oil" in a porous medium was considered in [3] in the case where the water contains fine gas phase in form of micro- or nano-scale bubbles. It is assumed that the transport of bubbles is mainly determined over a disperse phase (water). In this case, large accumulations of gas phase in the pore space, as well as water and oil carried in accordance with the modified Darcy law for multiphase mixtures. A mathematical model of the mixture motiontion, when the main phase (water, gas, oil) are subject to the equations of the filter, and the fine gas phase is described by the kinetic equation of the Boltzman.

The problem of filtration of three viscous, incompressible and mutually immiscible fluids in porous media without taking into account the mass forces and capillary pressures between phases was considered in [4]. There was obtained a solution for three-phase flow similar to solutions of Buckley-Leverett for two phases and it also was shown that the nature of the distribution of the saturations significantly depends on the initial saturation of the porous layer and the phase composition of the injected mixture. While developing the oil fields the problem of collaborative filtering several phases occurs.

In [5-8] was numerically solved and studied the problem of one-dimensional and three-phase filtration in a heterogeneous reservoir subject to solubility of the gas in the oil and aqueous phases, compressibility of the phases and porous medium, and force of gravity.

The study of the problem of two-phase and three-phase fluid filtration was discussed in [7]. And in [8] in a more general way, subject to many features it was posed and solved the problem of filtration of multiphase mixtures. Currently, the process of joint motion of oil and water, oil, water and gas when phases moving is immiscible are fairly well understood. However, the filtering multiphase mixtures with immiscible phases still isn't studied sufficiently.

Mathematical models of multiphase fluid and gas in multilayer porous systems which are being developed are based on the general laws of mechanics and they reduce to systems of nonlinear differential equations with appropriate initial, boundary and internal conditions, characterized by a change of variable states of the system which are not possible to be solved analytically. Therefore, while mathematical modeling of seepage flows of multicomponent mixtures, authors use various simplifications in the physical formulation of the problem and thereby simplify the mathematical model of the object of study.

Materials and Methods. In order to present the mathematical model of the filtering process of multicomponent media, considering the Darcy's law- which is the equation of continuity, phase state and the condition of equality of the sum of saturated mixtures unity, we obtain a closed system of nonlinear differential equations translated to dimensionless form [9-12]:

$$\begin{cases} \frac{\partial}{\partial x}(K\frac{\partial P}{\partial x}) = \frac{\partial}{\partial t}\left(PS_{\text{Г}}\right) + B\frac{\partial}{\partial t}\left(S_{\text{Н}} + B_{\text{ВН}}S_{\text{В}}\right), \\ \frac{\partial}{\partial x}(K_{H}\frac{\partial P}{\partial x}) = B\frac{\partial S_{H}}{\partial t}, \\ \frac{\partial}{\partial x}(K_{\text{В}}\frac{\partial P}{\partial x}) = B\frac{\mu_{\text{В}}}{\mu_{\text{Н}}}\frac{\partial S_{\text{В}}}{\partial t}, \\ S_{H} + S_{\text{В}} + S_{\text{Г}} = 1 \end{cases} \tag{1}$$

with the initial, boundary and internal conditions for production and injection galleries:

$$P\left(x,0\right) = P^{\circ}(x),\ S_{\text{Н}}\left(x,0\right) = S_{\text{Н}}^{\circ}(x),\ S_{\text{В}}\left(x,0\right) = S_{\text{В}}^{\circ}(x), \tag{2}$$

$$K\left(\frac{\partial P}{\partial x}\bigg/\xi_{i+0} - \frac{\partial P}{\partial x}\bigg/\xi_{i-0}\right) = q_{\text{ж}\,j},\ \ j = \overline{1,n}, \tag{3}$$

$$\alpha_1\left[K\frac{\partial P}{\partial x} - q_{\text{ж}\,o}\right] + \left(1-\alpha_1\right)\left(P - P_{\text{Н}}\right) = 0, \quad at\ \ x = 0, \tag{4}$$

$$\alpha_2\left[K\frac{\partial P}{\partial x} - q_{\text{ж}\,n+1}\right] + \left(1-\alpha_2\right)\left(P - P_{\text{Н}}\right) = 0, \quad at\ \ x = 1. \tag{5}$$

In order to integrate the problem numerically there was developed conservative numerical algorithm based on combined use of integro-interpolation method and the sweep method [9-12].

On the basis of the algorithm, has been developed a program for the calculation of the design and development of hydrocarbon deposits. The program is designed for the analysis of the dynamic state of the object based on the joint motion of a three-phase medium under various conditions of the system in which the change in pressure and saturation fields in time and space depending on the hydrodynamic parameters of the object. The program involves the interface mode for maximum visualized, of man-machine interaction.

Results. For analyzing and studying the "oil-gas-water" filtration process in porous media and identifying the results of key parameters of filtration processes and their range of variation there was conducted series of computational experiments (Fig.2-4). The experiments were conducted with following initial values (Fig.1).

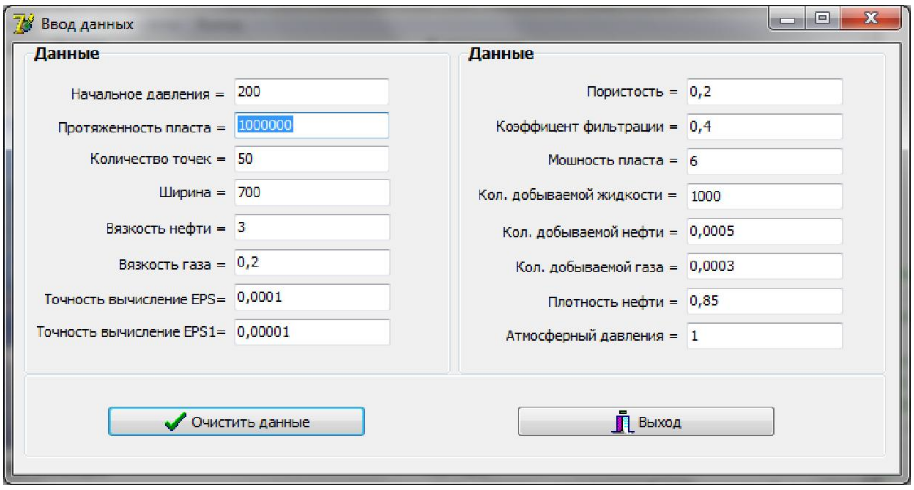

Fig.1. Main window of the program

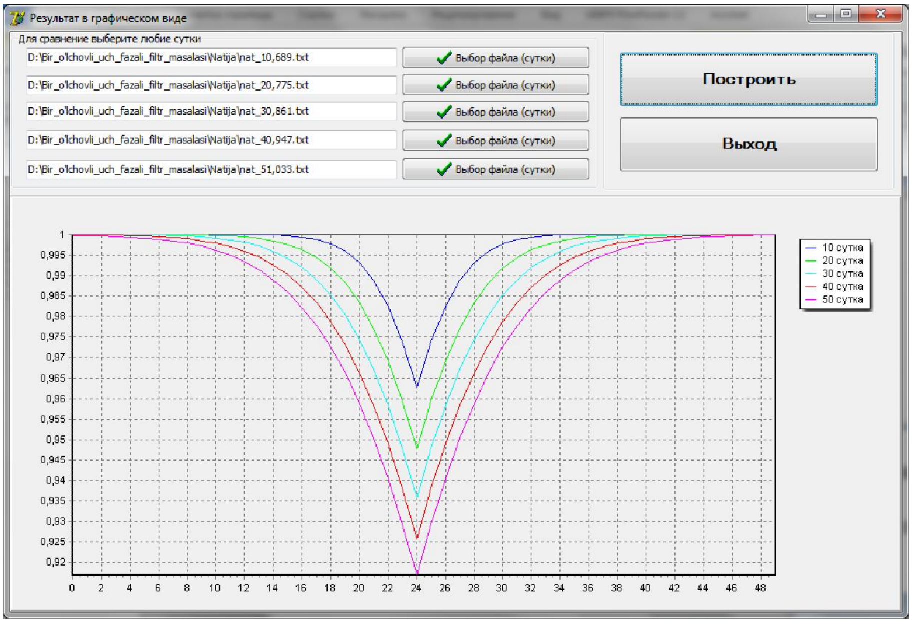

Fig.2. Redistribution of pressure in the reservoir (days) when only one well is acting

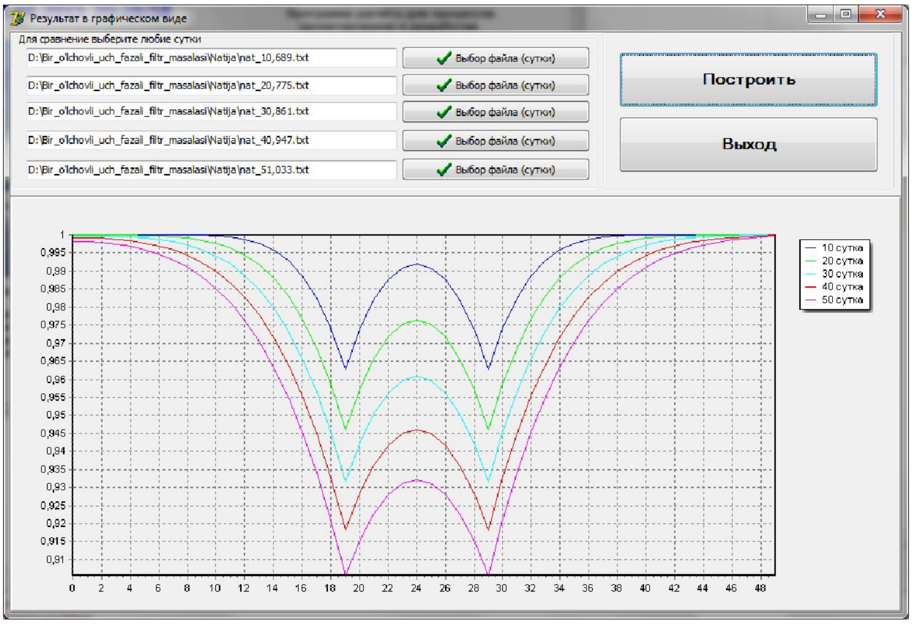

Fig.3. Redistribution of pressure in the reservoir (days) when two wells are acting

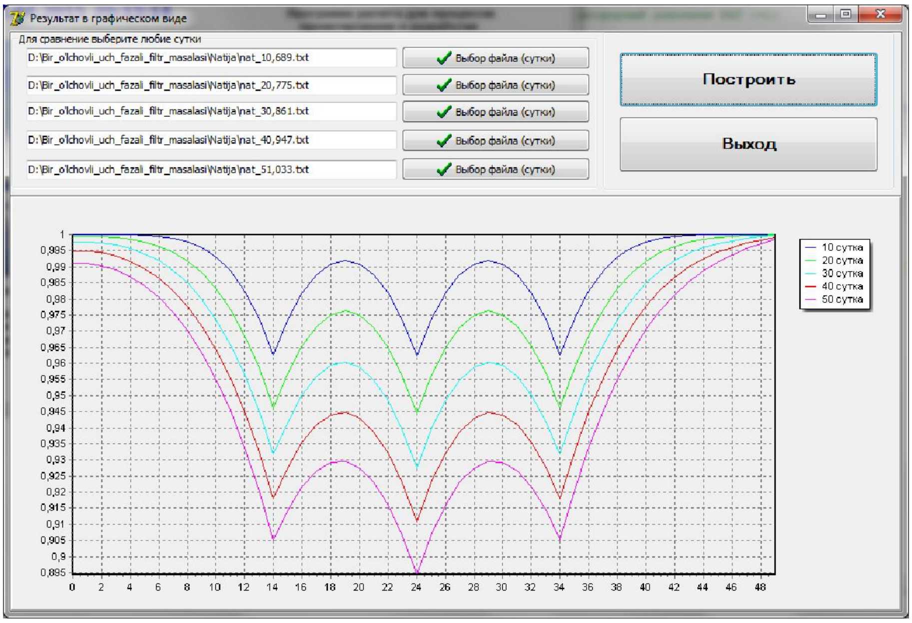

Fig.2. Redistribution of pressure in the reservoir (days) when three wells are acting

Conclusion. The analysis of obtained results of numerical experiments is showing that for the various time intervals and the same intensity of extraction the pressure drop in the well is faster with filtering oil than with filtering gas. When we assume the existence of gas in oil composition the fluidity of the mixture increases. The numerical calculations showed that essential parameters influencing the development technology of hydrocarbon production from the reservoir systems are filtration coefficient and structure of porous rocks. Dynamic layer pressure redistribution depends essentially on the length of the reservoir. With the increasing of length of reservoir the pressure in the well and adjacent points is reduced.

The software can be used by specialists and organizations that are engaged in the production of hydrocarbons, in order to improve the efficiency of fields.

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