

Prediction of Gas Exposure in the Conditions of the Oil Fields of the Volga-Urals

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Abstract — Currently, the use of gas methods to increase oil recovery is underexplored. However, the experience of applying these methods, both in Russia and abroad, indicates their high technological and economic efficiency. The article takes the first step towards substantiating the use of gas methods in the conditions of operational facilities in Bashkortostan. The goal of the research was to carry out a forecast of the results of gas exposure on hard-to-recover and residual oil reserves in Bashkortostan fields. The objectives of the research were the creation and adaptation of mathematical models of oil displacement for the conditions of productive objects and the fulfillment of the forecast for an increase in the production of residual oil reserves in the fields. The studies were carried out using models of filtering processes of multicomponent mixtures, a three-dimensional formulation of the problem and complex

boundary conditions of polygon objects. The completeness of the generation of residual reserves was calculated. As a result of the research, a mathematical model of gas exposure to hard-to-recover and residual oil reserves was adapted to the geological and field conditions of the Volga-Urals, which allowed for a reduction in the volume of calculations. The article presents the results of mathematical modeling of the process of displacing oil from the porous medium of the reservoir rocks of the fields of the Republic of Bashkortostan through the use of gas exposure.

Key words — *reservoir; porous medium; formation; formation fluid; filtration; gas phase; multicomponent mixture; carbon dioxide; gas exposure.*

I. INTRODUCTION

It is well known that the fields of application of various methods for enhancing oil recovery are determined by the peculiarities of the geological structure of impact objects [1–6]. The presence of a wide range of these methods is explained by the diversity of oil fields, which requires a justification of their use. One of the most promising and significant methods of influence on the formation are methods of gas exposure.

The process of displacing oil from a porous medium with gas, fringes of solvent and gas, water-gas mixture, fringes of carbon dioxide (CO₂) and water are accompanied by complex phenomena. Separate phases move at different speeds. The composition of the formation mixture in the joint filtration zone changes. Between the phases there is a redistribution of the components of the mixture. This leads to a change in the composition, therefore, the physicochemical properties of the phases, and under certain conditions – to phase transformations (the emergence, development or disappearance of individual phases). Such a process is described by the theory of filtration of multicomponent mixtures [7, 8].

II. METHODS AND MATERIALS

To calculate the three-phase filtration process, the so-called asymmetric Muskat-Merez model is often used, in which the oil phase is represented by two components: gas (volatile oil) and oil (non-volatile) [9–12]. This model is not suitable in our case. It is based on the assumption that the saturation pressure remains unchanged and, respectively, the constancy of the dependences of the volume coefficients, the viscosities of the phases and the solubility of the gas in the oil on pressure.

When solving development problems using the methods of gas impact on the formation, the use of the Muskat-Merez model leads to significant errors [13].

The process that is most fully described is described by compositional models [14–16], but they are used, as a rule, for solving one-dimensional problems.

To describe the particular cases of the process under study, symmetric models of three-phase filtration of three-component mixtures are executed, which are a generalization of the Muskat-Meres model to the case with a temporary value of saturation pressure [15]. In our case, models for calculations are not suitable for a number of reasons: they have a limited dimension; they do not take into account the irregularity of the distribution of geological and physical parameters; gravitational segregation of the phases is also neglected and, most importantly, oil is represented only by two pseudo-components: highly volatile (gas) and non-volatile (commercial oil).

This paper proposes a general three-dimensional model of three-phase filtration of four-component mixtures, which, in turn, is a special case of the compositional model. The model allows to take into account complex geological, physical, chemical and chemical parameters, and the technology of impact on the reservoir:

- inhomogeneity of formations by permeability, porosity, thickness of saturation by formation fluids;

- thermobaric reservoir conditions, depth and total reservoir thickness;
- the presence in the reservoir of fully or partially isolated layers;
- the region of marginal and bottom water;
- the presence of a gas cap;
- elastic properties of reservoir fluids and gas and porous media;
- three-dimensional three-phase filtration of a multicomponent mixture with phase transformations and changes in the physicochemical properties of these phases;
- non-stationary injection of water or gas, or a water-gas mixture with an arbitrary fraction of gas in the mixture;
- non-stationary selection of liquid and gas;
- various technologies of injection of gas, solvent, CO₂ and water rims;
- continuous, sequential, alternating and joint.

The hydrodynamic model of filtration of multicomponent mixtures can be divided into two parts. The first of them is based on the laws of material balance and movement of individual phases, the second on the laws of the phase behavior of the mixture. The equations of conservation and phase equilibria are supplemented by initial and boundary conditions, reflecting the initial state of the reservoir system and the technology of influencing it in the development process.

Take the following assumptions. Let the filtration occur under isothermal conditions, and the phase equilibria in each selected element (cell) of the filtration region occur instantaneously. We believe that the speed of movement of individual phases obeys the generalized Darcy law, and the number of jointly filtered phases can be from one to three. Neglect diffusion and capillary forces.

Consider a three-dimensional flow in a heterogeneous reservoir. Choose a Cartesian coordinate system. Let x , y be horizontal, and z be the vertical coordinate that coincides with the direction of the gravitational acceleration vector g . The formation heterogeneity in thickness will be taken into account by specifying the absolute permeability distribution $k = k(x, y, z)$, porosity $m = m(x, y, z)$, impermeable boundaries inside the filtration area (if any), initial pressure, saturation and composition distributions phases.

A complex mixture of hydrocarbon and non-hydrocarbon components (reservoir oil) can be represented as a mixture of three pseudo-components: 1 - highly volatile pseudo-component (methane, nitrogen) $k = 2$ - volatile NGL, condensate, CO₂, $k = 3$ - low volatile (high-boiling hydrocarbons proper oil itself) . We believe that the 2nd pseudo-component can be contained in the oil and gas, the first in all three, the second (water) only in the aqueous phase.

Taking into account the accepted assumptions and notation, based on the general theory of filtering multicomponent

mixtures [5], the process in question can be represented as the following system of equations:

$$\left[\sum_{\alpha=1}^3 K K_{\alpha} \mu_{\alpha}^{-1} c_{k\alpha} \rho_{\alpha} (\nabla P + \rho_{\alpha} g \nabla z) \right] + \sum_{j=1}^1 \sum_{\alpha=1}^3 q_k \rho_{\alpha} c_{k\alpha} \delta(\vec{r} - \vec{r}_{cj}) = \frac{\partial}{\partial t} m U c_k \quad (1)$$

$$k = 1, 2, 3, \quad x \in [0, L], \quad y \in [0, B], \quad z \in [0, H] \\ \sum_{k=1}^1 C_k = 1 \quad (2)$$

where k_{α} is the relative permeability of the α phase; μ_{α} is the phase viscosity α ; $c_{k\alpha}$ is the mass fraction of the k th component in the α phase; P is pressure; ρ_{α} – phase density α ; q_{α} is the density of the source (sink) phase α ; σ is the Dirac delta function; r_{cj} are the coordinates of the j th source (sink) (j is the number of sources); C_k is the mass fraction of the k th component in the mixture; L, B, H is the characteristic length, width and thickness of the formation element; k — component index, $k = 1, 2, 3$ — pseudo-components of the oil and gas part of the mixture, $k = 4$ — water; α is the phase index, $\alpha = 1, 2, 3$ is gas, oil, and water, respectively = 1.

The coefficients of equation (1) $k_{\alpha}, \mu_{\alpha}, \rho_{\alpha}, c_{k\alpha}$ are functions of pressure, composition, and phase saturation, which are uniquely determined from the solution of the equations of phase equilibria by specifying pressure and composition of the mixture, as will be shown below. Therefore, the following relations are valid for the quantities:

$$k_{\alpha} = k_{\alpha}(P, C_1, C_2, C_3) \\ \mu_{\alpha} = \mu_{\alpha}(P, C_1, C_2, C_3) \\ \rho_{\alpha} = \rho_{\alpha}(P, C_1, C_2, C_3) \\ c_{k\alpha} = c_{k\alpha}(P, C_1, C_2, C_3) \\ U = \sum_{\alpha=1}^3 \rho_{\alpha} S_{\alpha} = U(P, C_1, C_2, C_3), \quad \alpha = 1, 2, 3; \quad k = \overline{1, 4} \quad (3)$$

where S_{α} is the saturation of the porous medium, the phase α , and

$$\sum_{\alpha=1}^3 S_{\alpha} = 1 \quad (4)$$

Thus, the system of equations (1), (2) with regard to relations (3) is formally complete with respect to the independent variables P and C_k ($k = 1, 4$)

The formality lies in the fact that the direct obtaining of partial characteristics (3) is possible only in some exceptional cases (for example, when filtering a single-phase liquid, with piston displacement of one liquid by another).

In the general case, to construct dependencies (3), it is necessary to have a system of equations relating the pressure and composition of the mixture with the composition and volume fractions of the phases. This property has a system of equations describing phase equilibria.

The volume of the article does not allow bringing all the transformations. Let us present the results of transformations and calculations.

III. RESULTS AND DISCUSSIONS

The nonlinearity of second-order partial differential equations describing the filtering of multicomponent mixtures, the three-dimensional formulation of the problem, and complex boundary conditions predetermine the possibility of solving the problem only by numerical methods. One of the most effective of these is in this case the finite-difference method [15].

To solve this problem, a finite-difference scheme was constructed, which differs from the known [9, 15] by the following features. A completely conservative finite-difference end-to-end counting scheme that approximates the filtering equations belongs to the “implicit pressure — explicit saturation”. The calculation for it is based on the effective method of Newton's iterations not only by pressure, but also by the composition of the mixture. In addition, the principle of the minimum derivative is used to approximate the mobility coefficients, a triple phase diagram for calculating the partial characteristics of phase equilibria, and a block for automatic selection of the integration time step. All this significantly improves the efficiency of the numerical model.

To predict the technological efficiency of the development of oil deposits with terrigenous, carbonate (reef) reservoirs, methods of impacting hydrocarbon and carbon dioxide on the displacement of hard-to-recover and residual oil reserves are considered.

Theoretical studies to determine the optimal parameters of the technology of exposure to hydrocarbon gas were carried out on two models of the Devonian strata of the North-Western field, taking into account and without taking into account the vertical flows of the formation fluids. The results of the research after the corresponding generalization were as follows: the total gas consumption of 27–51% of the pore volume of the productive formation, the specific technological efficiency of 0.31 tons of oil per 1 thousand m³ of gas, the increase in ORI – 5.8–6.1 point.

Studies on the displacement of residual oil from carbonate reservoirs of the reef oil field, found that the maximum value of the displacement coefficient will reach 0.92 u.fr. at: restoration of reservoir pressure to the initial values of 13 MPa by injection of a hydrocarbon gas, which largely restores the initial physicochemical properties of the oil; forcing of the NGL fringe with a volume of 5.1% of the pore volume; displacement rate should not exceed the critical phase separation rate.

Numerical simulation of the oil displacement process has shown that when a dry gas is injected into the reservoir, the agent is affected by almost the entire object. To the residual oil saturation, the central and middle parts of the object are produced, and the peripheral – only partially. Calculations showed that technological efficiency will reach 2.1 t / t; the increase in ORI will be 9.5–10.1 points.

Determination of the optimal parameters of the technology of injection of CO₂ + water and the calculation of the technological indicators of the development in the terrigenous reservoirs of the Devonian of the productive layers of the Western field with conventional (baseline) water flooding and using the method are performed using the proposed numerical model. As a result of the calculations, it was established that the

ratio of the volumes of CO₂ fringes and water should be on average 1: 1.23; total consumption of CO₂ - 14% of the pore volume of the reservoir. The application of the proposed method will allow increasing the ORI by 8.3–9.7 points, the specific efficiency will be 0.51 t/t.

IV. CONCLUSION

Thus, a completely conservative finite-difference end-to-end counting scheme, approximating the filtering equations, belongs to the type “implicit pressure — explicit saturation”. The calculation for it is based on the effective method of Newton's iterations not only by pressure, but also by the composition of the mixture. This significantly improves the efficiency of the numerical model.

The model allows you to determine the technological parameters of gas exposure, such as the total gas flow in fractions of the pore volume of the reservoir; ratio of different phases; specific technological efficiency per unit of injected gas; additional gain ORI.

The forecast made shows that the use of gas methods to increase oil recovery at terrigenous and carbonate production facilities in the eastern part of the Volga-Urals will allow an additional increase in oil recovery factor by 5–10 points.

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