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Mathematical Model of Filtration Process for Two-Phase "Oil-Gas" System in Two-Layer Dynamic Connection

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***Abstract*—The article also analyzes field studies on the mathematical model of the two-phase filtration process in layers of a porous medium and the process of two-phase non-stationary filtration in an interconnected two-layer porous medium and the numerical solution of the problem based on it, a boundary value problem was developed and accurate and efficient methods for solving two-dimensional filtration problems were used.**

Keywords: Filtration, saturation, permeability, viscosity, porosity

I. Introduction

Even now, much attention is paid to the creation of many mathematical models, calculation algorithms and software for the problem of oil and gas filtration in a porous medium. [1]. Without mathematical modeling, these things are very difficult to do in industries with high economic indicators, so we can solve such cases and problem situations economically by modeling the process as a whole with the help of mathematical models.

Accordingly, mathematical modeling of such complex processes (in forecasting), numerical study of their solutions and presentation of the situation in a visual form are currently the most optimal solutions.

Based on this, it will be necessary to perform the following tasks, namely: the formation of information models used in the mathematical modeling of the oil and gas system, the development of a calculation algorithm by numerical simulation, and the conduct of computational experiments on the main indicators of the oil and gas system. oil and gas system, development of a software complex for monitoring and forecasting.

When implementing these tasks, the identical equation of mathematical modeling of the theory of multiphase filtration, the equation of motion and the equation of state, Darcy's law are used.

To date, a number of scientists involved in the filtration of oil and gas systems have obtained a number of important theoretical and practical results, including [3-4,6], which have complex effects in their scientific work, considered the modeling of flows containing p-component oil mixtures and a diffusion interface model of a one-component two-phase flow in a porous medium under various conditions is presented. When modeling the filtration processes of a non-stationary two-phase system, the authors used an integral method for solving a system of nonlinear differential equations, performed calculations of the two-phase filtration process and pressure distribution in analytical solutions [5], and applied simplifications. In numerical modeling of filtration processes, determining the hydrodynamic parameters of a reservoir based on a multiphase flow model of an oil and gas condensate system, hydrodynamic studies of processes in oil and gas condensate reservoirs and calculating fluid saturation, pressure and other hydrodynamic parameters from finite difference approximation methods and iterative series, one can obtain various distributions [12].

When constructing a mathematical model of the two-phase filtration process, the processes of filtration of a two-phase liquid consisting of oil and water in a non-deformable porous medium were considered without taking into account capillary pressure and gravitational forces [2]. were considered in their scientific papers, the general hydrodynamic problem of capillary pressure was considered without taking into account capillary and gravitational forces, and the two-phase flow was calculated based on the Buckley-Leverett model [10].

Complex dynamic processes occurring in reservoir conditions with two-sided displacement of oil by gas and water, as well as a model and a numerical algorithm for the problem of three-phase filtration of oil, gas and water in a porous medium are considered [8,14].

Numerical analysis of the Dorovsky filtration theory model shows that the smaller the thickness of the saturated porous layer between the elastic half-spaces, the greater the wave amplitude.

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Mathematical modeling of multiphase fluid flows in porous media is of great practical importance in oil and gas production. Filtration of liquids and gases in a porous medium, which occurs during hydrocarbon production, is characterized by the basic laws of conservation of mass, momentum, and energy [7]. However, it is very difficult to directly apply these laws to describe the filtration process in a porous medium; therefore, in practice, instead of the momentum conservation equation, a semi-empirical approach based on the application of Darcy's law is used.

The adequacy of the mathematical model and the determination of the analytical form of the functions of the coefficient of relative phase permeability depending on the reservoir parameters, especially the saturation coefficient, play an important role in carrying out computational experiments in two-phase oil-gas filtration system [13].

The following filtration theory equations are used for mathematical modeling of the process of non-stationary filtration in two-dimensional formulation of two- and three-phase liquids in a porous medium.

II. Mathematical Model

The process of joint filtration of two or more liquids and gases in a dynamically connected two-layer porous medium is a very complex problem, characterized by the following features: the coefficients of the equations depend on t and spatial coordinates, as well as on liquid saturation; capillary pressure and relative phase conductivities in the system (P_{cog}, K_g, K_o) is determined from the experimental data through the saturation function.

The considered mathematical model is based on the following assumptions:

- the movement of oil and gas in porous media obeys linear and linear Darcy's law;
- the permeability coefficient of both layers in the vertical direction is the same;
- the upper and lower layers are dynamically connected by poorly permeable structures;
- the thickness of both layers is constant;
- properties of liquids do not change over time;
- gas dissolves in oil;
- liquids and gases in both layers are at a constant temperature and in a state of thermodynamic equilibrium.

If we take into account these assumptions and the properties of two-phase filtration in one-dimensional conditions for a dynamically connected two-layer porous medium, the mathematical model of the problem can be written in the form of the following system of differential equations:

$$\begin{cases} \dfrac{\partial}{\partial x}\left[\dfrac{K_{1o}}{\mu_o}k_1\rho_{1o}\left(\dfrac{\partial P_{1o}}{\partial x}\right)\right]=\dfrac{\partial}{\partial t}\left[m\rho_{1o}(1-S_{1g})\right], \\ \dfrac{\partial}{\partial x}\left[R_s\dfrac{K_{1o}}{\mu_o}k_1\rho_{1o}\left(\dfrac{\partial P_{1o}}{\partial x}\right)\right]+\dfrac{\partial}{\partial x}\left[\dfrac{K_{1g}}{\mu_g}k_1\rho_{1g}\left(\dfrac{\partial P_{1g}}{\partial x}\right)\right]= \\ =\dfrac{\partial}{\partial t}\left[m\rho_{1o}R_s(1-S_{1g})+m\rho_{1g}S_{1g}\right]-\dfrac{\rho_{1g}k}{h_1h_l\,\mu_g}\left(P_{2g}-P_{1g}\right); \\ \\ \dfrac{\partial}{\partial x}\left[\dfrac{K_{2o}}{\mu_o}k_2\rho_{2o}\left(\dfrac{\partial P_{2o}}{\partial x}\right)\right]=\dfrac{\partial}{\partial t}\left[m\rho_{2o}(1-S_{2g})\right]+\sum_{i=1}^{n}q_{oi}\delta(x-\xi_i); \\ \dfrac{\partial}{\partial x}\left[R_s\dfrac{K_{2o}}{\mu_o}k_2\rho_{2o}\left(\dfrac{\partial P_{2o}}{\partial x}\right)\right]+\dfrac{\partial}{\partial x}\left[\dfrac{K_{2g}}{\mu_g}k_2\rho_{2g}\left(\dfrac{\partial P_{2g}}{\partial x}\right)\right]= \\ =\dfrac{\partial}{\partial t}\left[m\rho_{2o}R_s(1-S_{2g})+m\rho_{2g}S_{2g}\right]+\dfrac{\rho_{2g}k}{h_2h_l\,\mu_g}\left(P_{2g}-P_{1g}\right)+ \\ +\sum_{i=1}^{n}(R_sq_{oi}+q_{gi})\delta(x-\xi_i); \\ P_{1o}-P_{1g}=P_{1cog}; \qquad P_{2o}-P_{2g}=P_{2cog}; \\ S_{1o}+S_{1g}=1; \qquad S_{2o}+S_{2g}=1. \end{cases} \tag{1.1}$$

with the following initial and boundary conditions:

$$P_{1o}(x,0)=P_{1o}^{H}(x), \quad P_{2o}(x,0)=P_{2o}^{H}(x); \tag{1.2}$$

$$P_{1g}(x,0)=P_{1g}^{H}(x), \quad P_{2g}(x,0)=P_{2g}^{H}(x); \tag{1.3}$$

$$S_{1o}(x,0)=S_{1o}^{H}(x), \quad S_{2o}(x,0)=S_{2o}^{H}(x); \tag{1.4}$$

$$S_{1g}(x,0)=S_{1g}^{H}(x), \quad S_{2g}(x,0)=S_{2g}^{H}(x); \tag{1.5}$$

$$\begin{cases} -\dfrac{k_1}{\mu_o}\dfrac{\partial P_{1o}}{\partial x}=\alpha\left(P_A-P_{1o}\right); \quad -\dfrac{k_1}{\mu_g}\dfrac{\partial P_{1g}}{\partial x}=\alpha\left(P_A-P_{1g}\right); \quad x=0; \\ -\dfrac{k_2}{\mu_o}\dfrac{\partial P_{2o}}{\partial x}=\alpha\left(P_A-P_{2o}\right); \quad -\dfrac{k_2}{\mu_g}\dfrac{\partial P_{2g}}{\partial x}=\alpha\left(P_A-P_{2g}\right); \quad x=0; \end{cases} \tag{1.6}$$

$$\begin{cases} \dfrac{k_1}{\mu_o}\dfrac{\partial P_{1o}}{\partial x}=\alpha\left(P_B-P_{1o}\right); \quad \dfrac{k_1}{\mu_g}\dfrac{\partial P_{1g}}{\partial x}=\alpha\left(P_B-P_{1g}\right); \quad x=L; \\ \dfrac{k_2}{\mu_o}\dfrac{\partial P_{2o}}{\partial x}=\alpha\left(P_B-P_{2o}\right); \quad \dfrac{k_2}{\mu_g}\dfrac{\partial P_{2g}}{\partial x}=\alpha\left(P_B-P_{2g}\right); \quad x=L; \end{cases} \tag{1.7}$$

It is necessary to apply and use the following functions in the system of equations:

$$P_{1cog}=f_1(S_{1g}), \quad P_{2cog}=f_1(S_{2g}); \; K_{1g}=f_3(S_{1g}); \; K_{2g}=f_4(S_{2g});$$
$$K_{1o}=f_5(S_{1g}); \; K_{2o}=f_5(S_{2g}); \quad \rho_{1o}=const; \quad \rho_{1g}=P_{1g}/RTZ;$$
$$\rho_{2o}=const; \quad \rho_{2g}=P_{2g}/RTZ.$$

Here

R - universal gas constant;

T - temperature;

Z - gas compressibility coefficient.

The following symbols are accepted in the equation and boundary conditions:

- Index 1 refers to variables belonging to the upper layer, index 2 to the lower layer
- l=o,g l – phase detection index: "o" – oil phase; "g" – gas phase.
- q_o, q_g - well discharge, for the bottom layer;
- δ - Drak delta function $\delta=\delta(x-x_i)$;
- $P_{1o}^{H}, P_{2o,}^{H} P_{1g}^{H}, P_{2g}^{H}$ - initial pressure for oil and gas in the upper and lower layers, respectively;
- P_A, P_B - pressure on the right and left border;

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- $\alpha = \begin{cases} 0, \text{the boundary condition is closed}, \\ 1, \text{ the mass exchange condition.} \end{cases}$
- P_{1cog}, P_{2cog} - capillary pressure in the oil-gas system:
- $P_{1o} - P_{1g} = P_{1cog}(S_{1o}, S_{1g}), \quad P_{2o} - P_{2g} = P_{2cog}(S_{2o}, S_{2g})$;
- $S_{1o}^H, S_{2o,}^H S_{1g}^H, S_{2g}^H$ - saturation in upper and lower layers for oil and gas, respectively;
- k_1, k_2 - absolute permeability coefficient;
- K_l - relative phase conductivity coefficients l – for phases;
- m - layer porosity;
- μ_l - viscosity l – for phases;
- ρ_l -l – phase density;
- k_l - coefficient of conductivity of weakly conductive layer;
- h_1, h_2, h_l - layer thickness.

(1.1)-(1.7) in the boundary value problem, we pass to dimensionless variables according to the following formulas

$$x^* = \frac{x}{L}; \quad k_1^* = \frac{k_1}{k_x}; \quad k_2^* = \frac{k_2}{k_x}; \quad k_\Pi^* = \frac{k_\Pi}{k_x}; \quad h_1^* = \frac{h_1}{h_x}; \quad h_2^* = \frac{h_2}{h_x};$$

$$h_\Pi^* = \frac{h_\Pi}{h_x}; \quad P_{1o}^* = \frac{P_{1o}}{P^H}; \quad P_{2o}^* = \frac{P_{2o}}{P^H}; \quad P_{1g}^* = \frac{P_{1g}}{P^H}; \quad P_{2g}^* = \frac{P_{2g}}{P^H};$$

$$\tau = \frac{P^H k_x t}{m \mu_o L^2}; \quad q^* = \frac{\mu_g L^2}{k_x h_x P^H 2\pi} \mathrm{q}.$$

III. The Method of Solving the Problem

Here

h_x, k_x, P^H - characteristic values of layer thickness, permeability coefficients and pressure. Using these formulas, we write the following dimensionless boundary value problem.

$$\begin{cases} \dfrac{\partial}{\partial x}\left[K_{1o}k_1\left(\dfrac{\partial P_{1o}}{\partial x}\right)\right] = \dfrac{\partial}{\partial \tau}(1-S_{1g}), \\ \dfrac{\partial}{\partial x}\left[R_s K_{1o}k_1\left(\dfrac{\partial P_{1o}}{\partial x}\right)\right] + \dfrac{\mu_{1o}}{\rho_{1o}\mu_{1g}}\dfrac{\partial}{\partial x}\left[K_{1g}k_1\rho_{1g}\left(\dfrac{\partial P_{1g}}{\partial x}\right)\right] = \\ = \dfrac{\partial}{\partial \tau}\left[R_s(1-S_{1g}) + \dfrac{\rho_{1g}}{\rho_{1b}}S_{1g}\right] - \dfrac{\rho_{1g}\mu_{1o}}{\rho_{1o}\mu_{1g}}\dfrac{k_l L^2}{h_x h_1 h_x h}\left(P_{2g} - P_{1g}\right); \\ \\ \dfrac{\partial}{\partial x}\left[K_{2o}k_2\left(\dfrac{\partial P_{2o}}{\partial x}\right)\right] = \dfrac{\partial}{\partial \tau}(1-S_{2g}) + \dfrac{\mu_{2o}L^2}{k_x\rho_{2o}P^H}\sum_{i=1}^{n} q_{oi}\delta(x-\xi_i); \\ \dfrac{\partial}{\partial x}\left[R_s K_{2o}k_2\left(\dfrac{\partial P_{2o}}{\partial x}\right)\right] + \dfrac{\mu_{2o}}{\rho_{2o}\mu_{2g}}\dfrac{\partial}{\partial x}\left[K_{2g}k_2\rho_{2g}\left(\dfrac{\partial P_{2g}}{\partial x}\right)\right] = \\ = \dfrac{\partial}{\partial \tau}\left[R_s(1-S_{2g}) + \dfrac{\rho_{2g}}{\rho_{2b}}S_{2g}\right] + \dfrac{\rho_{2g}\mu_{2o}}{\rho_{2o}\mu_{2g}}\dfrac{k_l L^2}{h_x h_2 h_x h}\left(P_{2g} - P_{1g}\right) + \\ + \dfrac{\mu_{2o}L^2}{k_x\rho_{2o}P^H}\sum_{i=1}^{n}(R_s q_{oi} + q_{gi})\delta(x-\xi_i); \ ; \\ P_{1o} - P_{1g} = P_{1cog}; \qquad P_{2o} - P_{2g} = P_{2cog}; \\ S_{1o} + S_{1g} = 1; \qquad S_{2o} + S_{2g} = 1. \end{cases} \tag{1.8}$$

We assume that the oil is incompressible, i.e $\rho_o = const$, and gas is compressible, its density is expressed by pressure according to the equation of state, i.e $\rho_{1g} = \frac{P_{1g}}{RTZ}; \ \rho_{2g} = \frac{P_{2g}}{RTZ}$. This is related to the above $P_{1o} - P_{1g} = P_{1cog}$ $P_{2o} - P_{2g} = P_{2cog}$ taking into account the dependencies, we write the system of equations (1.8) in relation to gas as follows

$$\begin{cases} \dfrac{\partial}{\partial x}\left[K_{1o}k_1\left(\dfrac{\partial P_{1g}}{\partial x} + \dfrac{\partial P_{1cog}}{\partial x}\right)\right] = \dfrac{\partial}{\partial \tau}(1-S_{1g}), \\ \dfrac{\partial}{\partial x}\left[R_s K_{1o}k_1\left(\dfrac{\partial P_{1g}}{\partial x} + \dfrac{\partial P_{1cog}}{\partial x}\right)\right] + \dfrac{\mu_{1o}}{\rho_{1o}\mu_{1g}}\dfrac{P^H}{RTZ}\dfrac{\partial}{\partial x}\left[K_{1g}k_1 P_{1g}\left(\dfrac{\partial P_{1g}}{\partial x}\right)\right] = \\ = \dfrac{\partial}{\partial \tau}\left[R_s(1-S_{1g}) + \dfrac{1}{\rho_{1b}}\dfrac{P^H}{RTZ}P_{1g}S_{1g}\right] - \dfrac{\mu_{1o}}{\rho_{1o}\mu_{1g}}\dfrac{k_l L^2}{h_x h_1 h_x h}\dfrac{P^H P_{1g}}{RTZ}\left(P_{2g} - P_{1g}\right); \\ \\ \dfrac{\partial}{\partial x}\left[K_{2o}k_2\left(\dfrac{\partial P_{2g}}{\partial x} + \dfrac{\partial P_{2cog}}{\partial x}\right)\right] = \dfrac{\partial}{\partial \tau}(1-S_{2g}) + \dfrac{\mu_{2o}L^2}{k_x\rho_{2o}P^H}\sum_{i=1}^{n} q_{oi}\delta(x-\xi_i); \\ \dfrac{\partial}{\partial x}\left[R_s K_{2o}k_2\left(\dfrac{\partial P_{2g}}{\partial x} + \dfrac{\partial P_{2cog}}{\partial x}\right)\right] + \dfrac{\mu_{2o}}{\rho_{2o}\mu_{2g}}\dfrac{P^H}{RTZ}\dfrac{\partial}{\partial x}\left[K_{2g}k_2 P_{2g}\left(\dfrac{\partial P_{2g}}{\partial x}\right)\right] = \\ = \dfrac{\partial}{\partial \tau}\left[R_s(1-S_{2g}) + \dfrac{1}{\rho_{2o}}\dfrac{P^H}{RTZ}P_{2g}S_{2g}\right] + \dfrac{\mu_{2o}}{\rho_{2b}\mu_{2g}}\dfrac{k_l L^2}{h_x h_2 h_x h}\dfrac{P^H P_{2g}}{RTZ}\left(P_{2g} - P_{1g}\right) + \\ + \dfrac{\mu_{2o}L^2}{k_x\rho_{2o}P^H}\sum_{i=1}^{n}(R_s q_{oi} + q_{gi})\delta(x-\xi_i); \ ; \\ P_{1o} - P_{1g} = P_{1cog}; \qquad P_{2o} - P_{2g} = P_{2cog}; \\ S_{1o} + S_{1g} = 1; \qquad S_{2o} + S_{2g} = 1. \end{cases}$$

From this system of equations to obtain the equations for the general mixture, adding the first and second and the third and fourth equations, we get the following system of equations

$$\begin{cases} \dfrac{\partial}{\partial x}\left[(R_s+1)K_{1o}k_1\left(\dfrac{\partial P_{1g}}{\partial x} + \dfrac{\partial P_{1cog}}{\partial x}\right)\right] + \dfrac{\mu_{1o}}{\rho_{1o}\mu_{1g}}\dfrac{P^H}{RTZ}\dfrac{\partial}{\partial x}\left[K_{1g}k_1 P_{1g}\left(\dfrac{\partial P_{1g}}{\partial x}\right)\right] = \\ = \dfrac{\partial}{\partial \tau}\left[(R_s+1)(1-S_{1g}) + \dfrac{1}{\rho_{1b}}\dfrac{P^H}{RTZ}P_{1g}S_{1g}\right] - \dfrac{\mu_{1o}}{\rho_{1o}\mu_{1g}}\dfrac{k_l L^2}{h_x h_1 h_x h}\dfrac{P^H P_{1g}}{RTZ}\left(P_{2g} - P_{1g}\right); \\ \\ \dfrac{\partial}{\partial x}\left[(R_s+1)K_{2o}k_2\left(\dfrac{\partial P_{2g}}{\partial x} + \dfrac{\partial P_{2cog}}{\partial x}\right)\right] + \dfrac{\mu_{2o}}{\rho_{2o}\mu_{2g}}\dfrac{P^H}{RTZ}\dfrac{\partial}{\partial x}\left[K_{2g}k_2 P_{2g}\left(\dfrac{\partial P_{2g}}{\partial x}\right)\right] = \\ = \dfrac{\partial}{\partial \tau}\left[(R_s+1)(1-S_{2g}) + \dfrac{1}{\rho_{2b}}\dfrac{P^H}{RTZ}P_{2g}S_{2g}\right] + \dfrac{\mu_{2o}}{\rho_{2o}\mu_{2g}}\dfrac{k_l L^2}{h_x h_2 h_x h}\dfrac{P^H P_{2g}}{RTZ}\left(P_{2g} - P_{1g}\right) + \\ + \dfrac{\mu_{2o}L^2}{k_x\rho_{2o}P^H}\sum_{i=1}^{n}((R_s+1)q_{oi} + q_{gi})\delta(x-\xi_i); \end{cases}$$

Now this system of equations can be reduced to finite difference equations for solving in a sonly method.

Algorithm for calculating the boundary value problem. An algorithm for solving the problem was developed on the basis of the given calculation scheme. The algorithm includes a very complicated process. It is mainly based on the finite difference and iterative method and is implemented as follows:

1. Giving initial data values:
- number of iterations over time – *nt*;
- the value of the conductivity coefficient –*k*;
- the value of the porosity coefficient –*m*;

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- layer length –L;
- oil viscosity coefficient value -μ;
- pressure of oil in the formation –P;
- saturation coefficient of oil and gas – S_o, S_g;

2. Time repetition cycle $k=1...nt$;

3. Step of calculating pressure values. The step is to perform calculations in k+1 time layer.

3.1. Coefficients of finite difference equations a_i, b_i, c_i, d_i, f_i va $a_i^{'}, b_i^{'}, c_i^{'}, d_i^{'}, f_i^{'}$ $(i=1..n-1)$

3.2. $A_0; B_0; C_0; A_0^{'}; B_0^{'}; C_0^{'}$ the drive coefficients are determined from the left boundary conditions;

3.3. $A_i; B_i; C_i; A_i^{'}; B_i^{'}; C_i^{'}$ $(i=1,n-1)$ the coefficients of the race are calculated from left to right;

3.4.P_{1gn} and P_{2gn} consciousness is determined from the boundary condition;

3.5.P_{1i} иP_{2i} $k+1$ – is calculated in the time layer;

3.6. In this time layer, the iterative process is checked $\left|P_{1gi}^{(r)} - P_{1gi}^{(r-1)}\right| \le \varepsilon_p$ va $\left|P_{2gi}^{(r)} - P_{2gi}^{(r-1)}\right| \le \varepsilon_p$.

If this iteration condition is met, that is, it goes to step 3.7, which is the next condition, otherwise it goes back to 3.1.

Here

$P_{1g}^{(r)}, P_{1g}^{(r-1)}, P_{2g}^{(r)}, P_{2g}^{(r-1)}$ - two have values close to each other P_{1g}, P_{2g} pressure functions (r is the current calculated value, r-1 is one previous calculated value, its zero value is taken from the initial value, and the next values are one previous value);

ε_p - iteration accuracy.

3.7. P_{1g}, P_{2g} the oil pressure in the first and second layers is calculated with sufficient accuracy;

3.8. P_{1o}, P_{2o} The gas pressure in the first and second layers is calculated with sufficient accuracy from the following formula: $P_{1o} = P_{1g} - P_{cog}; \quad P_{2o} = P_{2g} - P_{cog}$.

4. Calculation of saturation coefficients.

4.1. Saturation coefficients by approximating the first and third equations of the system of equations S_{1g} va S_{2g} is calculated by the following formulas:

$$S_{1o} = \hat{S}_{1o} + \frac{\Delta\tau}{\Delta x^2}\frac{\mu_{1o}}{\mu_{1w}}\left(K_{1oi-0.5}\hat{P}_{1oi-1} - (K_{1oi-0.5} + K_{1oi+0.5})\hat{P}_{1oi} + K_{1oi+0.5}\hat{P}_{1oi+1}\right);$$

$$S_{2o} = \hat{S}_{2o} + \frac{\Delta\tau}{\Delta x^2}\frac{\mu_{2o}}{\mu_{2o}}\left(K_{2oi-0.5}\hat{P}_{2oi-1} - (K_{2oi-0.5} + K_{2oi+0.5})\hat{P}_{2oi} + K_{2oi+0.5}\hat{P}_{2oi+1}\right)$$

.

4.2. Since the system of equations is nonlinear with respect to the saturation functions, the iteration process is used. The iterative process continues until the following conditions are met

$$\left|S_{1oi}^{(r)} - S_{1oi}^{(r-1)}\right| \le \varepsilon_s \text{ and } \left|S_{2oi}^{(r)} - S_{2oi}^{(r-1)}\right| \le \varepsilon_s.$$

Here

$S_{1o}^{(r)}, S_{1o}^{(r-1)}, S_{2o}^{(r)}, S_{2o}^{(r-1)}$ - two values close to each other S_{1o}, S_{2o} bosim funktsiyalari (r is the current calculated value, r-1 is one previous calculated value, its zero value is taken from the initial value, and the next values are one previous value);

ε_s - iteration accuracy.

4.3. S_{1o}, S_{2o} The saturation of oil and gas in the first and second layers is determined with sufficient accuracy from the following formula:

$S_{1g} = 1 - S_{1o}; \quad S_{2g} = 1 - S_{2o}$.

4.4. If the iterative process is completed, then jump to point 3.1, otherwise go back to point 5;

5. The solutions found in the k+1 layer will be the starting point for the next k+2 steps.

6. Numerical results are displayed on the screen in the form of tables and graphs.

7. Recurrence in time. If the given number of repetitions matches the repetition cycle time, programming stops, otherwise it returns to point 2.

The developed calculation algorithm allows you to easily create its program on a computer for all similar problems without any difficulties.

IV. Computational Experiments

Calculation experiments were carried out on various parameters of the layer and the flow rates of the wells. To illustrate, we present numerical solutions to a number of initial data problems. The initial data for the problem are: both layers have the same length L=8000 m, both layers have the same initial pressure P_1=300ат.м., P_2=300ат.м.; the initial saturation is that of oil in both layers S_o=0.75, and that of gas S_g=0.25; oil viscosity μ=4cП; the second oil layer has five wells with the same flow rate $Q=500\ kg/m^3$.

It is known that the relative conductivities of the phases and the analytical view of the capillary pressure play an important role for the two-phase oil-gas system. Practical relative phase conductivity for two- or three-phase systems is determined from experimental data. According to the results of the research, the following correlations determined from the experience of UZBEKNEFTGAZ for the oil-gas system were obtained in determining the relative phase conductivities.

$$\mathrm{K}_o = 0.839379\,S_g^3 + 1.12471\,S_g^2 - 1.0396\,S_g + 0.182166$$

$$K_g = -3.27135\,S_g^3 + 7.73761\,S_g^2 - 6.25468\,S_g + 1.73322,$$

The solubility function of gas in oil has the following form

$R_s = 113 + 0.75P_o$;

From the beginning of the exploitation of the oil field For 1080 days, calculation experiments were conducted on

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the distribution of oil pressure in the formation. The results of computational experiments are presented in Fig 1, 2, 3. The first two graphs in these images show the distribution of oil pressure in the top and bottom layers in 3D. It can be seen that the results of computational experiments show a very slow decrease of the upper layer pressure. This means that the flow of oil from the upper layer to the lower layer is very low. This change is due to the fact that the conductivity of the weakly conductive layer between the layers is very small. The first graph of Fig 2 shows the contour plot of oil pressure distribution in the second layer. The second graph shows the oil pressure drop over time in the central well located in the lower layer. The first graph of Fig 3 shows the pressure distribution in the sections of the second layer (by x and y), and it clearly shows the intensity of the pressure drop in the lower layer. The second graph shows the oil saturation in and around wells in the lower layer, where the increase in oil saturation is observed. Observing these images shows that oil saturation can increase over time around wells, while oil saturation can decrease.

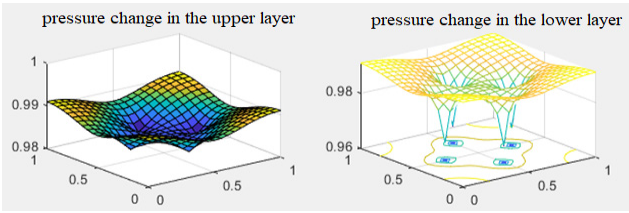


Fig. 1: 3D Graphics of Pressure Distribution on Top and Bottom Layer (Top View)

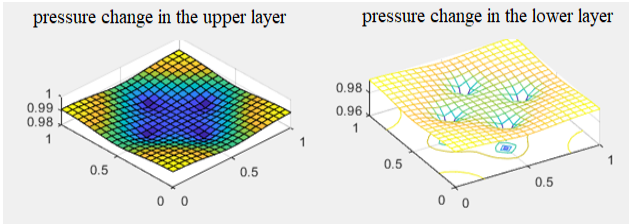


Fig. 2: 3D Graphics of Pressure Distribution on Top and Bottom Layer (Top View)

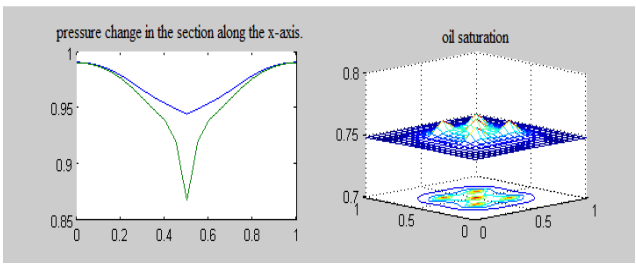


Fig. 3: Graphs of Pressure Distribution in the Section of the Upper and Lower Layers (by x and y) and the Increase in Gas Saturation in the Lower Layer (k_1=0.1d;k_2=0.1d;k_{II}=0.0001d;μ=0.001;m=0.1).

Computer modeling and calculation experiments in it allow to determine the main indicators for various parameters of the system of two-layer gas fields and to analyze, design and predict the operation of gas fields based on the obtained results.

V. Conclusion

The properties of both layers in our proposed mathematical model the influence of the descriptive parameters on the distribution of pressure and saturation of fluids, as well as on the pressure drop in the wells was studied. The mathematical formulation of the problem of multiphase filtration and their numerical solution depend on the type of physical system and the assumptions made in the development of its mathematical model. Mathematical models of two-phase filtration of an oil-gas system in a two-layer porous medium and finite difference methods for solving these problems show that they are suitable for the process of calculating the pressure and saturation fields for initial and boundary conditions, and the mathematical model is considered adequately describes the output process.They can be used to calculate the main indicators in the design and analysis of the development of oil and gas fields.

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