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Algorithm and software for calculating the main indicators of a gas fields

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Abstract. The article presents the structure of the modules of a software complex that provides a visual representation of numerical results obtained during computational experiments. It addresses the development of a software complex for monitoring and forecasting based on the visual presentation of numerical results obtained during computational experiments on the main filtration process parameters in the development of single- and double-layer gas fields. The focus is on designing software interfaces that ensure convenient interaction for users conducting experiments, as well as creating a software complex that visually presents numerical results in 3D graphics.

Key words: Mathematical model, gas, hydrodynamic parameters, filtration, algorithm, porous medium, method of finite differences, iterative method, quasi-linear method.

I. INTRODUCTION

The use of mathematical modeling methods, as well as modern computer technologies, in solving issues related to the design, management, and research of gas and gas condensate fields simplifies problem-solving and requires less time. This enables the acceleration of the design and research of gas and gas condensate fields. [1-4]

One of the main influences the dynamics of gas filtration processes is the variation in porosity, particularly in response to changes in gas pressure within the porous medium. Understanding and adequately mathematical modeling this phenomenon are essential for optimizing many processes in this context, this study proposes a novel method and algorithm for the numerical solution of the gas filtration problem in a porous medium taking into account porosity changes depending on gas pressure. By using mathematical techniques and algorithms, we aim to provide a comprehensive framework for simulating the intricate interplay between gas flow and porosity variations in porous media [5-7].

The mathematical model of the unsteady gas filtration process in a porous medium is described by nonlinear differential equations of the parabolic type. Let us assume that during the filtration process, the porosity and permeability coefficients of the layer vary depending on pressure changes. In this case, we consider it as a filtration problem describing the process of porosity variation depending on pressure. Based on the assumption made, we formulate the following mathematical model for the boundary value problem of gas filtration:

$$\begin{cases} \dfrac{\partial}{\partial x}\left(\dfrac{kh}{\mu}\dfrac{\partial P^2}{\partial x}\right)+\dfrac{\partial}{\partial y}\left(\dfrac{kh}{\mu}\dfrac{\partial P^2}{\partial y}\right)=2ahm(x,y,P)\dfrac{\partial P}{\partial t}+Q \\ m=m_0\left[1+\beta_c\left(P-P_H\right)\right], \qquad (x,y)\in G,\ \ t>0; \end{cases} \quad (1)$$

The initial and boundary conditions of the [2] problem are as follows:

$$P(x,y,t)=P_H(x,y), \quad t=0, \ \ (x,y)\in G; \quad (2)$$

$$\begin{cases} -k\dfrac{\partial P}{\partial x}=\alpha\left(P_A-P\right), \quad x=0; \quad t>0; \\ k\dfrac{\partial P}{\partial x}=\alpha\left(P_A-P\right), \quad x=L; \quad t>0; \end{cases} \quad (3)$$

$$\begin{cases} -k\dfrac{\partial P}{\partial y}=\alpha\left(P_A-P\right), \quad y=0; \quad t>0; \\ k\dfrac{\partial P}{\partial y}=\alpha\left(P_A-P\right), \quad y=L; \ \ t>0; \end{cases} \quad (4)$$

To solve the given boundary value problem numerically, we make it dimensionless.

Since this boundary value problem (1)-(4) is described by a nonlinear differential equation, we use the quasilinear method and the finite

difference method to solve it. In doing so, we use a simple method of movement in each direction, based on the algorithmic idea of the variable routing scheme [8,9] at each time interval.

In each direction, that is, in the time half-layer, the pressure function is compared with an iteration method.

In each time layer, the calculation is performed in two steps.

The first step of the algorithm for finding main parameters of gas field development is performed by calculating the values of the function of pressure within the layer l+0.5 in the direction of variable x.

- the porosity coefficient value is calculated for the new time layer;

- the a_i, b_i, c_i, d_i coefficients of the finite-difference equation are determined (calculated);

- α_0, β_0 are the initial values of the driving coefficients of the simple encounter determined from the boundary conditions of the left and right part of the discrete filtering domain, that is, from the first equation of the system of equations; - α_i and β_i the values of the coefficients of the normal counter movement method are calculated

- $P_{N,j}$ - the final value of the pressure function is determined by using the right-hand boundary conditions of the discrete filtration field and the third equation of the system of equations.

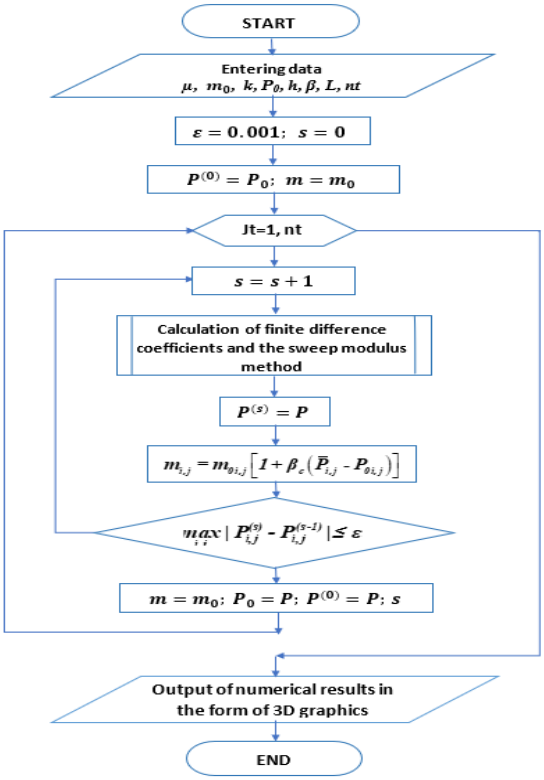
- $P_{i,j}$ - the values of the pressure function is calculated in the reverse direction by a simple counter movement method.

The second step of the algorithm is carried out in the same way, in the direction of the y variable, at intervals of l+1 of the time layer.

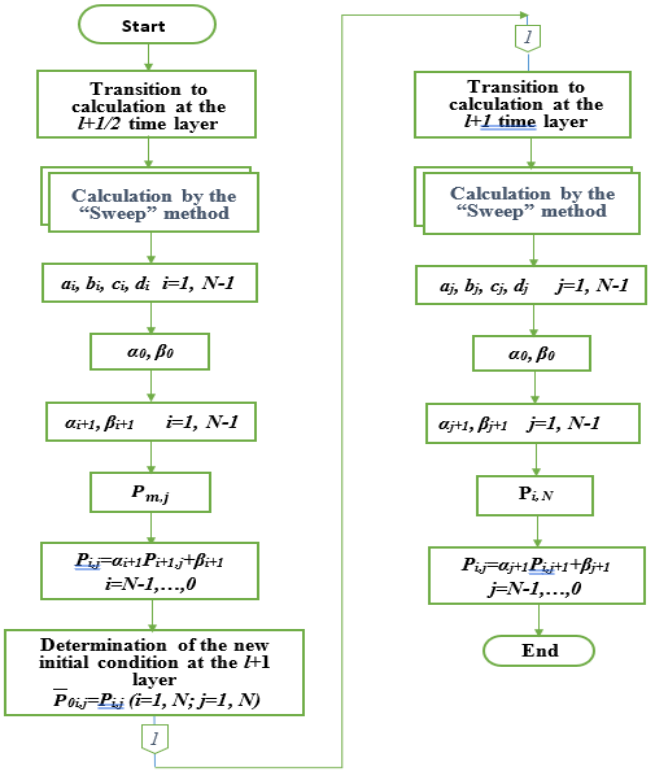
- the iterative process with respect to the pressure function continues until the following condition is met, if the condition is not met, the successive iterations of the step are returned again $\left|P_{ij}^{(s)} - P_{ij}^{(s-1)}\right| < \varepsilon$.

The algorithms for the initial and subsequent stages are reiterated within each time layer, where each solution attained serves as the initial condition for the subsequent time step.

A block diagram of this algorithm is shown in Picture 1 and 2.

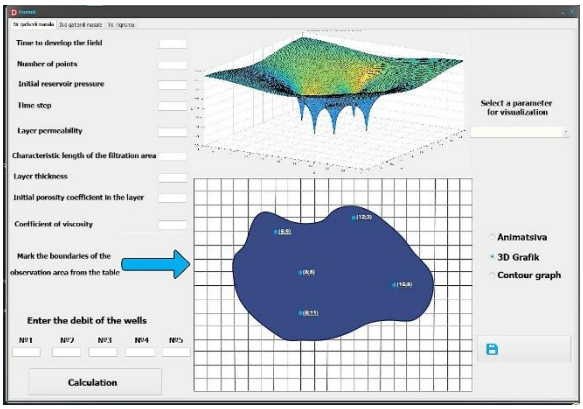


Pic.1. Algorithm for calculating the main indicators (pressure and porosity) in gas field development



Pic.2. Algorithm for calculating finite difference coefficients and the sweep modulus method.

The interface of the program is developed in the Delphi programming language and is integrated with the MatLab programming environment for visualization of results, presentation of graphics in 3D form. An overview of the program interface is shown in the figure below. (pic.3)



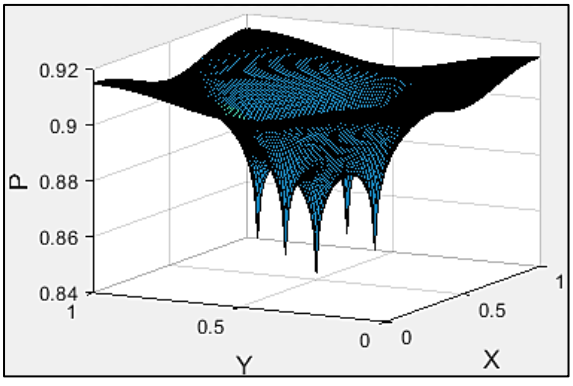
Pic.3. Program interface.

The software package consists of 2 calculation modules and a user guide module.

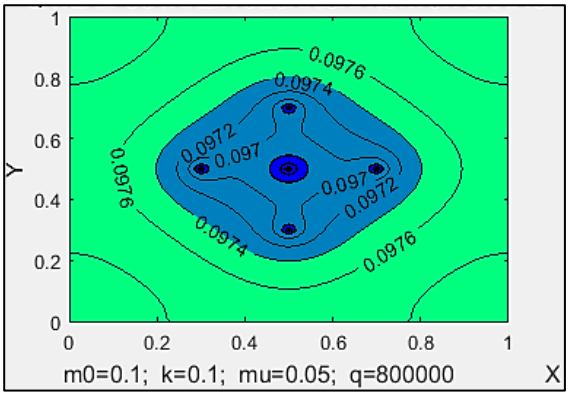
To solve the problem, the user prepares the initial data for the selected task. Here, the user creates a new initial input data file in the data storage directory or edits the existing ones.

The calculation process for the pressure change in the formation during the filtration process over 1080 days of gas field development is presented in the graphs in Figure 4.5. The first graph shows a 3D representation of the pressure distribution in the formation when 5 wells are symmetrically located. The second graph depicts the contour plot of the pressure distribution. The third graph illustrates the pressure variation along a cross-section, and the fourth graph shows the pressure drop in the central well.

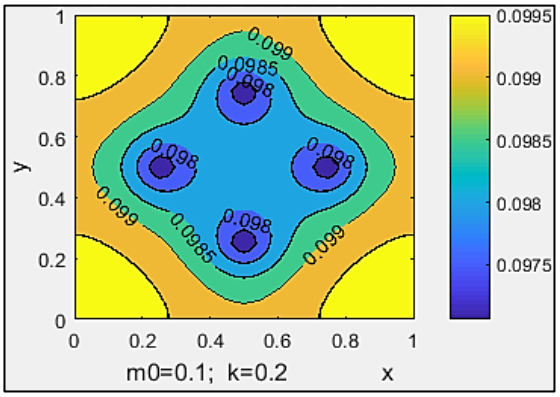
3D GRAPH OF RESERVOIR PRESSURE CHANGE



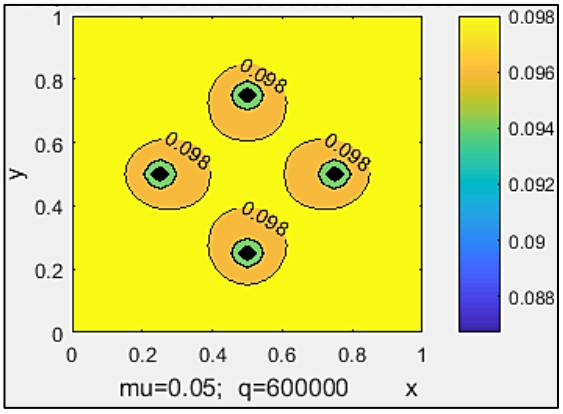
CONTOUR GRAPH OF LAYER POROSITY CHANGE



POROSITY CONTOUR OF LAYER 1.



POROSITY CONTOUR OF LAYER 2.



Pic.4. Graphs of changes in pressure and porosity coefficient in porous media with 1 and 2 layers during gas field development, obtained by calculation using a software package

The software complex visualizes numerical results of the calculation process for gas field filtration domain configurations with both simple

and complex shapes. It provides 3D graphics, as well as cross-sectional pressure distributions and pressure drops in wells. Presenting the numerical results of computational experiments in a visual format plays a significant role in understanding the filtration process, studying the hydrodynamic state of gas field layers during extraction, and, most importantly, in the design, analysis, and forecasting of gas fields.

To conduct computational experiments, it is necessary to input initial data: well development time, pressure, gas parameters (such as viscosity), reservoir permeability, its dimensions, as well as the number and coordinates of the wells, well flow rates, and initial porosity coefficient values. Based on the numerical experiment results, a pressure distribution table within the layers is generated, which can be presented in graphical formats using specialized graphic systems with 3D graphics and animation functions. These tools enable the selection of graphs for presenting data in the desired format, allowing for visualization of 2D pressure cross-sections within the layer and 3D representations of pressure distribution processes across the reservoir. Additionally, the pressure drop dynamics in gas layers near the wells and the porosity changes dependent on pressure are also visualized.

The software provides a function to animate the process by displaying images over time or by predefined steps across the layers. This animation allows for a visual representation of the calculation results. Once all input parameters, including the number of wells, have been entered and the filtration area shape has been selected, the animation begins, taking into account the operation time of the oil and gas field. The animation demonstrates changes in the filtration area shape over time. In accelerated mode, the animation reflects real processes at filtration sites and formations of circular, rectangular, elliptical, or arbitrary shapes. Moreover, the animation enables monitoring of gas extraction from wells and observing how pressure decreases in the reservoir layer surrounding the wells.

CONCLUSION

The developed software complex enables a comprehensive study of both existing and newly commissioned oil and gas wells. It allows for real-time computational experiments and the acquisition of reliable information about the field. The software allows users to conduct various computational experiments on key parameters for solving gas filtration problems in porous media. Based on the results obtained from the computer, users can perform various analyses and predictions, as well as carry out scientific research.

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