

A NUMERICAL APPROACH TO STUDY THE THERMAL INFLUENCE ON GAS HYDRATES BY PHYSICAL PROCESS SPLITTING

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Abstract. The method of numerical simulation based on the splitting by physical processes of gas-hydrodynamic processes, which occur during the dissociation of gas hydrates in a porous medium, is described. In this paper, a coupled discrete model of a two-component (H_2O, CH_4) three-phase (water, methane, hydrate) filtration fluid dynamics and two-phase processes in a thawed zone with absence of gas hydrates in thermodynamic equilibrium has been developed, by using the splitting by physical processes as a valid assumption. The obtained split model is differentially equivalent to the discrete initial balance equations of the system (conservation of the mass components of the fluids and the total energy of the system), written in divergent form. Such an approach to create completely conservative difference schemes in the studied fluid-hydrate medium requires the introduction of a special free-volume nonlinear approximation of grid functions over time, which depends on the volume fraction in the pores occupied by fluids, and is simple to implement. The direct unsplit use of the studied system for the purposes of determining the dynamics of variables and constructing the implicit difference scheme required for calculations of filtering processes with large time steps is difficult. The paper also presents the method of coupled solutions of systems of equations describing the processes in various fields, each of which is characterized by its own set of coexisting phases, and the coordination of computational schemes for them is not an automatic process. In the results of the calculations, the volumetric three-phase phase transitions were numerically investigated using a single calculation with a variable number of phases region of the entire plane of the P and T parameters. Using the example of the Messoyakha's gas hydrate deposit, the local processes of technogenic depressive impact directly near the wells on the dynamics of the gas distribution of gas hydrates thawing and formation of thawed two-phase zones were studied.

Key words. Gas hydrates, filtration, thawed zone, support operators, and completely conservative difference schemes.

1. Introduction

One of the risks arising from the exploration of hydrocarbon deposit in northern areas is a possibility of sudden gas blowout. Such blowouts can be connected with gas hydrates decomposition as a result of technogeneous impact during drilling and exploitation of wells [1] and lead to crashes and environmental incidents especially in case of sea reservoirs.

Mathematical simulation of the gas-hydrodynamic processes during dissociation of gas hydrates in porous medium is an important part of the complex analysis of the problem. The modeling consists of calculation of the pressure field, water and hydrate saturation fields, and investigating the conditions leading to undesirable effects. Whole research should include a joint study of heat transfer, fluid dynamics and stress-strain state of the rocks in the investigated area. For the estimation of the impact of every single factor on the whole process, it is necessary to investigate each of them separately.

In order to solve a wider class of problems, it is necessary to use numerical methods. As a base for mathematical modeling of the underground fluid dynamics with respect to gas hydrates dissociation, the equations of mass, momentum and energy balance are derived assuming that the processes are in thermodynamic equilibrium. This is compliant with the time scale typical to the reservoirs exploration. The filtration area is naturally divided into two zones: the three-phase zone with gas, water and hydrate and thawed zone – without hydrates. Each zone has its own system of partial differential equations describing fluid motion. So it is necessary to sew them together in the whole (P - pressure, T - temperature) area to unified numerical scheme. This is achieved by studying the analytical conditions for the consistency of the equation systems with help of the method of characteristics.

In the proposed approach, in the three-phase zone, the initial system of equations is transformed into a two-block mathematical model describing a multicomponent flow in a porous medium, taking into account the dissociation of gas hydrates with splitting by physical processes. The model includes a block with a system of hyperbolic equations for water saturation and thaw on the background of fixed filtration rates, and a block containing the piezoconductivity equation for determining the pressure in the reservoir with gas hydrate inclusions.

In the gas-water-hydrate thermodynamic equilibrium zone, the pressure and temperature are related by well-studied dependencies, for which one of several approximations is usually chosen [2]. In this paper, $T = A \ln P + B$ was used as the approximation, where A and B are the empiric coefficients.

The initial boundary value problem is solved using the finite difference method. In constructing schemes, an upwind approximation is used for water saturations and a downwind approximation is used for thaw. This technique follows from the analysis of the hyperbolicity of the system of equations against the background of a fixed velocity field determined by Darcy's law (see subsection 2.3).

The use of splitting by physical processes allows us to use an explicit-implicit scheme, to use rather large time steps; it sharply increases the counting rate, which makes it possible to carry out a number of calculations with various parameters and compare the results.

In this work, a special technique is used to combine the calculations of a three-phase zone containing gas, water and hydrate, and thawed zone, with the absence of gas hydrates, into one calculation scheme (see subsection 5.6).

For more complex calculations that take into account non-one-dimensionality, we can use an approach to numerical simulation based on the method of support operators, those application to filtering problems was started in [3, 4]. This method, based on the use of irregular grids, makes it possible to approximate regions of complex geological and lithological structure, to take into account the different scales of heterogeneities within a one difference scheme (from the near-well zone to the size of the reservoir and even the region). In this paper it is expanded in the case of filtration processes involving gas hydrates. In accordance with the proposed algorithm for the splitting of the equilibrium model by physical processes, in the thawed zone and in a medium with gas hydrate inclusions, a joint family of two-layer completely conservative difference schemes of the support operators method with spaced time scales has been constructed.

In the future, the function S_v we will denote the volume fraction in the pores attributable to free water and gas in the hydrate-saturated part of the porous medium. The function S_w we will denote water saturation.