Estimating Thermal Effect of a Group of Gas Wells on Permafrost Rock

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Abstract. The article is devoted to a computational experiment on forecasting the thermal interaction of a group of gas wells and permafrost. In connection with the spread of cluster drilling, it becomes necessary to study the thermal effect of a cluster of wells on frozen soils in the specific conditions of Central Yakutia. As input data for the numerical survey, field data on thermal logging, production rates, physicochemical properties of gas, rock properties and parameters of the developed deposits were used. Quantitative results were obtained on the extent and pattern of thawing of frozen rocks in the vicinity of the group of wells, and on well operation modes. The results of the work can be used in planning the development of gas fields in the considered area.

1. Introduction

In Central Yakutia within Lena-Vilyuy oil province four large gas condensate field are located - Srednevilyuyuskoe, Srednetyungskoe, Sobolokh-Nidzhilinskoe and Tolon-Mastakhskoe. The region is located in the permafrost zone, which reaches a depth of about 500 m. In these gas fields, the temperature of frozen rocks is in the range from -2.4 °C to 0 °C according to thermal logging. It easily begins to thaw under the influence of warm gas rising through the well from great depths. Consequences are loss of stability of the upper section, disruption of casing integrity, ground subsidence in the vicinity of wellheads [1-3].

One of the simplest ways to formulate mathematical description for such a process is to state axisymmetric Stefan problem in rock massif at a constant gas temperature in the wellbore. The apparent advantage of this approach is that an analytical evaluation of thawing radius around the well is available [4, 5]. However, both the estimation and the practice show that the gas temperature in the well is not constant. Thus, the problem of determining the temperature of rocks can be solved only in the conjugate setting, i.e. while calculating both the temperature of the fluid in the well and the temperature field of the surrounding rocks simultaneously. In [3, 6, 7], the conjugate problem was solved for single oil and gas wells in an axisymmetric formulation. Although this approach remains relevant to this day, many modern oil and gas fields are being developed by cluster drilling, where wells are located at a short distance between themselves in the zone of their thermal interference. Therefore we need 3D and 2D numerical models to describe thermal interaction between group of wells and rocks. It should be noted that the choice of 2D axisymmetric geometry in the indicated papers [3, 6, 7] was largely due to the use of the finite difference method [8], which works effectively for regions of regular shape and is very complicated in areas of irregular shape. In the case of several
wells, the geometry of the computational domain in the general case can turn out to be rather complicated depending on the chosen development system. Therefore, it is advisable to use the finite element method [9-11]. In work [12], a numerical solution of the 3D Stefan problem is given, which describes the dynamics of thawing of rocks in the zone of influence of two producing wells. The finite difference method was used. Note that this survey neglects cooling of the produced gas during its flow from the bottom hole to the wellhead due to heat losses and throttling effect.

Thus, there is a need to develop a 3D conjugate numerical model of permafrost ground in the vicinity of a group of several production wells using a finite element method. The model will allow to quantitatively evaluate the degree of thermal disturbance of the near-wellbore zone during the development of gas fields in Central Yakutia.

2. Numerical modeling
Consider a cluster of three slant wells, whose heads are located at a distance of 10 m from each other. According to regulations, only vertical boreholes can be drilled in permafrost rocks. In this context the model wells consist of two sections - a vertical in the upper permafrost zone and an inclined in the bottom zone of thawed rocks. In the frozen zone, the temperature of the rocks is approximately constant, while in the thawed zone it gradually increases with depth according to the geothermal gradient. As a result, the gas from the underlying warm reservoir, rising through the well and losing heat to its walls, cools while warming the surrounding rock mass.

The mathematical model of the process under study includes: the heat equation, which describes the heat flow in rocks taking into account their possible thawing and freezing; heat transfer equation describing the temperature change of the produced gas; necessary boundary and initial conditions determined by the nature of the conjugation of heat fluxes on the borehole walls. When constructing a mathematical model, some physical assumptions are used. First, we state that the heat flux in the vicinity of a well propagates strictly radially along a plane perpendicular to the axis of the well, and the heat flow along the axis of the well is negligible due to the symmetry of the problem. Secondly, when calculating the temperature field of rocks, we neglect mass transfer processes.

In the rocks from the bottom hole of the well to the bottom of the permafrost, the thermophysical coefficients in the heat equation are piecewise constant and the corresponding heat conduction problem can be solved by standard methods. A substantive simplification is that in the inclined section the wells are located far from each other, so for the thermal simulation they can be considered as single and the axisymmetric formulation of the problem can be used.

In the permafrost zone, the problem gets complicated by phase transition of the ground water. The Stefan problem is solved using the method of through calculation with smoothing discontinuous coefficients in the heat equation in the vicinity of the phase transition (Samarsky-Moiseenko method). Geometrically, the wells in this area are located within their radius of thermal interference. So in each horizontal section it is necessary to solve the full 2D Stefan problem.

The numerical simulation is performed with the initial parameters including information on the material composition of the rock mass, their thermophysical characteristics, thermal logging data, and physical properties of the gas. The thermophysical properties of sedimentary rocks are taken from core studies of the Lena-Vilyuy oil and gas province, where the considered fields are located. The flow rate of the wells varies depending on the season of year, reaching a maximum in January and a minimum in July. Temperature of rocks during their thermal interaction with the well cluster is forecasted for 10 years of operation.

3. Results
According to the numerical evaluation the gas temperature gradually decreases as the gas rises to the top, however, it does not keep pace with the geothermal gradient. Therefore, the gas comes to the frozen zone with much warmer temperature than rocks and causes their thawing. Also, the gas temperature in the well depends more on the season of the year and mass flow rate than on the year of operation. Thus, the difference between summer and winter temperatures at the wellhead is about 1°C.
Nevertheless, there is a trend of increase in wellhead gas temperature with an increase in the year of operation, which is most likely due to the gradual heating of rocks in the vicinity of the well.

The largest thawing radii are characteristic of the Srednetyungskoe field, the smallest - to Tolon-Mastakhskoe. At the Tolon-Mastakhskoe and Srednetyungskoe fields, there is an increase in the thawing radius with depth, which corresponds to a positive geothermal gradient in the frozen. For the Srednevilyuyskoe field, due to the negative gradient, a decrease in the thawing radius with depth is observed. It is not possible for the Sobolokh-Nidzhilinskoe to establish a reliable trend in depth, since here the upper layers of rocks (up to 150–200 m) are initially in a thawed state, and the thickness of the frozen layer is only slightly more than 200 m.

The numerical experiment revealed that the most favorable conditions are on the Tolon-Mastakhskoe field, where a full merger of the thawing halos occurs on the 9th year of operation. The least favorable conditions exist in the prospective Sobolokh-Nidzhilinskoe field, where the merger of the thawing halos ends after 3.5 years. On the current under production Srednevilyuyskoe the merger generally ends in the 5th year of operation, with the exception of the uppermost near surface layer. However, this field has been developed by single wells from the very beginning, and this computational experiment is not relevant here. Another promising field - Srednetyungskoe. For him, the merger occurs by the end of the 4th year of operation.

4. Conclusion

The thermal interaction between a group of gas producing wells and permafrost rocks for the conditions of Central Yakutia is forecasted for 10 years of operation. It revealed that in the Srednevilyuyskoe and Tolon-Mastakhskoe fields permafrost thawing occurs less intensively than in the future Srednetyungskoe and Sobolokh-Nidzhilinskoe fields. For the latter two, at a distance of 10 m between the wells, the thawing halos of neighboring wells merge by the end of the 4th year of operation. This circumstance must be taken into account in the development plan of these gas fields.

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