Modeling heat transfer in a well network

A B Feodorov¹,², V I Afanasov¹, A S Lunev¹, T S Spirin¹, Kurochkin¹ and V N Zagorulko¹

¹Siberian Federal University, 79 Svobodny Av., 660041 Krasnoyarsk, Russia
²Elsitech, 1 Robespierre Av., 660021 Krasnoyarsk, Russia

E-mail: feodorov@mail.ru

Abstract. Model representations are used to analyze the technological process of alternating the appointment of wells. The role of producing and injection wells alternates. The purpose of this technology is to reverse heat fluxes. Changing the direction of heat fluxes is a way to preserve the phase state of frozen soils. The development of hydrocarbon deposits in the extreme north requires the preservation of perennial frozen soils in a solid state. These are safety requirements. In an injection well, it is easier to build a process for injecting refrigerant into the top of the well. When using packers to separate the indicated portion, the process of pumping water to maintain reservoir pressure may continue in the usual manner. Packers are installed on the lower boundaries of frozen soils. Perennial frozen soils are cooled an order of magnitude slower than heating. It is promising to use rock fracturing and faults to penetrate the refrigerant. Normal refrigerants are used. Gaseous refrigerants are preferred. After the heating stage of adjacent rocks, they have increased permeability. The product of thermal reverse uses this circumstance. Refrigerant penetration is simplified. And in turn, it leads to blockage of the formed network of microchannels. The convection method of heat exchange is cut off. The convection heat transfer process is responsible for most of the heat fluxes. A sharp change in heat fluxes occurs immediately after the reverse. The proposed technology allows you to use an additional option for the operation of the existing layout of wells in the oil and gas field. The usual practice of the operation of the fishery may remain without noticeable changes. Using existing gas preparation equipment simplifies the implementation of the technology.

1. Introduction

When drilling various wells in the regions of the North-East and the Arctic zone with extreme climatic conditions and with a thick layer of permafrost, special requirements are imposed on the selection of optimal drilling tools and drilling technologies [1]. Deposits of the permafrost zone have significant differences from analogues located in areas with a temperate climate and positive rock temperature. The complicated conditions for the development of wells in permafrost are based on the temperature factor, which determines the efficiency of the process of destruction and changes in the phase state of frozen rocks [2], [3], [4]. Heat generation during development leads to thawing of frozen rocks. The destruction of frozen rock, in contact with the equipment of the well, contributes to the creation of complications and even emergency conditions.

When developing a hydrocarbon reservoir with a fractured-pore reservoir, it is important to select the optimal location of the wells, taking into account the geotechnological features of the reservoir [5]. The authors of the patent propose establishing the location of explosive fault systems on the hydrocarbon reservoir area. The location of production wells near them, and injection wells outside or within areas
limited by these discontinuous faults. Hydrocarbon production through producing wells. Management of filtration resistances between wells and fractures is proposed. Increase the filtration resistance between the wells and fracturing faults. Water-proofing compounds are injected through production or injection wells or through wells that are drilled for this. At the same time, wells are transferred from one category to another.

In our consideration, the approach proposed in [5] is used to counteract the complications resulting from thawing of permafrost around wells in the field.

2. Model for heat transfer calculations
The thermal effect of the well on the surrounding permafrost is considered. Model analysis was carried out as an observation of changes in time between the boundary between thawed and frozen zones. Numerical analysis was based on the calculation method [6]. The main thermophysical characteristics: \( \rho \) is the density, \( c_1, c_2 \) are the heat capacities, \( \lambda_1, \lambda_2 \) are the thermal conductivity coefficients of thawed and frozen soils, \( w \) is ice content, \( T_f \) is the natural temperature of the soil.

The axisymmetric heat conduction problem is used taking into account the phase transition of moisture saturating the soil. Squeezing occurs due to the action of the heater in the well. Integral heat balance allows us to reduce the original problem for partial differential equations to the solution of the Cauchy problem for a system of two ordinary differential equations. The boundary condition is used in the form:

\[
-\frac{\partial T}{\partial r}|_{r=1} = q,
\]

which expresses the constancy of the heat flux on the surface of the well with a heater placed inside.

According to the method of integral heat balance, the radius of heat influence \( R(t) \) is determined from the relations

\[
T = T_f, \quad \frac{\partial T}{\partial r} = 0 \text{ if } r = R(t)
\]  

(1)

Conditions (1) replace the initial condition \( T_2(r, 0) = T_f \) and the condition that the solution is bounded at infinity.

For the dimensionless thawing radius, a system of two ordinary differential equations is used:

\[
\frac{ds}{dt} = \frac{\lambda_1 q}{s} + \frac{\lambda_2 T_f (u - 1)}{s(u \ln u + 1 - u)}
\]

\[
\frac{dR}{dt} = \frac{1}{6(u^2 + u + 1) + 0.25(1-u^2)} \left( \frac{1}{s(u \ln u + 1 - u)} - \frac{ds}{dt} \left( \frac{u^3}{12} + \frac{u}{4} - u \ln u - \frac{1}{3} \right) \right).
\]

(2)

The mathematical model can be used not only for thawing calculations during operation of the heating device, but also freezing of the soil when it is turned off.

As in [6]: the heat of melting ice is 80 kcal / kg; soil moisture - 0.35 and 0.20.

As expected, it follows from the calculations that the thawing rate is significantly higher than the freezing rate. The difference in the speeds of these processes is approximately 15 times.

3. Heat reversal technology
The Based on model representations, well placement options are proposed with a division into production and injection wells. A layout of production and injection wells with the involvement of special wells in the development is proposed.
Significant oil reserves are located in fractured-porous reservoirs, which are represented by discontinuous or disjunctive disturbances - such deformations of the formations in which the integrity of the rocks is violated. Paraclas and diacases form entire systems that must be taken into account when developing fields, including when placing wells [5], [6], [7].

To do this, aerial photography is performed on the surface of the determined area of the oil and gas bearing formation. Then carry out (using the remote method) geological interpretation of aerial photographs (satellite images) of the surface of the field. Decryption allows for any natural and man-made disturbance of the earth's surface to identify regional and local neotectonic and tectonically active zones. Zones of structural deformations and changes in rocks (mainly in the form of macro- and micro-folding of bends), flexures with small amplitude, lineaments (linear anomalies in space images caused by hidden basement faults, fracture zones in the overlapping sedimentary deposits of the tile cover) correspond to them. As a result, it is possible to map their projections onto the oil and gas bearing formation on a scale. Deciphering the complex of satellite images (in the visible region of the spectrum, infrared and radio ranges) makes it possible to establish the presence of inhomogeneities of the studied objects. This makes it possible to more reliably interpolate and extrapolate point (well) and profile (seismic) information to establish the relationship of discontinuous faults, flexures, fracture zones and link them with oil-water, gas-oil and gas contacts.

When drilling wells, the position of discontinuous violations by cavernometry is revealed. The actual borehole diameter varies along the bore and decreases for reservoir rocks into which the drilling fluid penetrates. The changes are due to the passage of the well through a fracture. The intersection of the well with discontinuous disturbances during its drilling is revealed to increase the rate of absorption of the drilling fluid. They also clarify the passage of the well through discontinuous violations using radiometric methods as well. Use the method of pulsed neutron-neutron logging based on the interaction of neutrons with rocks and the fluids contained in them, or the method of carbon-oxygen (C/O) logging.

Clarify the position of discontinuous faults also by vertical seismic profiling. Refinements are performed based on the study of wave fields inside real geological sections. Oscillations are excited by producing explosions at points located on the earth’s surface, and the arrival of waves (transmitted, reflected, refracted) is recorded in the well [8].

After a detailed study of the hydrocarbon reservoir, production wells are drilled near the specified fracture faults. Production wells are placed near the intersection of several fracturing faults. Moreover, in wells drilled near discontinuous faults, but not associated with a system of cracks, directional perforation is performed. The pressure in the well is increased until the formation of cracks in the bottomhole zone of the well. Cracks connect the well with discontinuous faults. The permeability determining structures in the producing well zone determine the conditions of heat transfer processes. The circumstances of thawing frozen soils are established.

When placing injection wells (initially operated as producing) in the interior of the oil-saturated zone, limited by discontinuous disturbances, permeability changes are taken into account. The density of the grid of wells is chosen inversely with the found permeability.

Injection wells are considered as a means of permafrost recreation. The process of heat backflow is 15 times slower. An array of rocks acts as a source of cold. In order to increase the efficiency of restoration of rock stability, the injection processes alternate with the processes of refrigerant injection.

When thawing frozen soils, an injection well system is introduced into the development. For this, they are transferred to the injection part of the producing wells. In this case, wells with the highest values of porosity and permeability and the lowest value of reservoir pressure are selected.

Production wells with a maximum rate of thawing of frozen soils with progressive flooding are also transferred to the category of injection wells. A part of production wells is also transferred to injection wells in order to prevent the formation of duct zones in the formation where the temperature gradient is less than the limit.

In the injection well, a packer is installed on the outside of the pipe and the permafrost zone is blocked. Another packer is installed inside the tubing. If necessary, perform additional perforation.
Refrigerant is pumped through the injection wells into the space behind the tubing. In this case, it is possible to simultaneously pump water into the reservoir. It is heated by heat exchange with rocks.

4. Discussion and conclusion
From the considered works and the model in the proposed form, we can conclude that the redirection of heat flows in the well network is applicable.

The invention [9] relates to the oil industry. Zones with high and low permeability are distinguished in the deposits. The injection of the displacing agent is carried out through injection wells, which are located in areas with low oil saturation. In areas with high oil saturation, production wells are placed through which oil is sampled. The authors pay particular attention to the distinction between high and low oil saturation zones.

The method [10] determines the purpose of the injection and production wells and changes in their intervals of perforations at a known location of the wells. The calculation of the target functional using the formation parameters such as porosity, permeability, effective thickness, volume, critical oil and water saturations, and fluid viscosity is included. To account for additional filtration resistance to the flow of fluid in the near-wellbore space, a skin factor is used in hydrodynamic modeling of oil fields. The change in the objective functional is calculated using a mathematical model.

The integrated development method [11] provides an increase in efficiency by targeted selection of wells and direct control and operational management of treatment parameters. Displacing agents are injected into injection wells and formation fluid is taken through production wells. Explore the natural fracturing of the geological environment of the formation, initiate the creation of additional mass transfer channels into the wells. In or near fracturing zones, production wells are selected or additional ones are drilled. Initiate and create wave channels of energy-mass transfer at the productive intervals of these wells. The seams are affected by the sequential supply of pulses of physical energies. At the same time, acoustic emission signals from the formation are recorded. On the basis of monitoring, the timing of each subsequent pulse is assigned and its energy and frequency parameters are changed.

Method [12] provides an increase in injectivity of injection wells during joint development of formations. Drilling production and injection wells. They are planted with pipes. Wells are perforated in the interval of occurrence of reservoirs. The longitudinal dimensions of the perforation holes of injection wells are selected taking into account the magnitude of the fluid injection pressure, the compression coefficient of the porous medium and the distance from the perforation hole to the median plane of the total interval. In this interval, fluid is injected. Additionally perforated formations with low injectivity. The longitudinal dimensions of the perforation holes of injection wells with additional perforation are selected taking into account the technological parameters. The fluid injection pressure, the compression coefficient of the porous medium and the distance from the perforation hole to the median plane of the total interval into which the fluid is injected are varied.

Most of the thawing problems are solved without taking into account the fact that phase transformations in frozen rocks occur in the temperature range. It is practically important to solve problems with the simultaneous determination of temperatures in the well and in the rocks. The difficulty in solving this issue lies in the mathematical complexity of solving related problems. Heat transfer occurs when the cleaning agent is circulated. Of particular importance is the determination of phase transitions in frozen rocks. Well assignment management is one of the permafrost monitoring tools. An essential complement is multifactor monitoring of temperature fields. Control over temperature gradients in the fishing zone is still a little developed practice.

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