The process of heat exchange of steam-water flow in a geothermal pipe of a vertical well

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Abstract. The main purpose of the work is mathematical modelling of heat exchange of steam-water flow in a geothermal pipe of a vertical well. Within the framework of the hydraulic approximation, a numerical study of the steady isothermal motion of a thermodynamically equilibrium steam-water mixture in a vertical well has been carried out, taking into account heat losses into the surrounding rocks. In this task, the process of coolant movement along the borehole and its thermal interaction with its wall is considered. Because of the implementation of the described model, the values of specific heat losses in the rock mass for various initial conditions for wells were obtained.

1 Introduction

The problems of modern world energy are connected with the ever-increasing needs of mankind in energy supply. This is due to the limited traditional fuel resources. At the same time, the aggravated environmental situation requires the involvement of new alternative energy sources. In this regard, geothermal fluids are of undoubted interest. Recently, they have been actively used as heat sources. Rational development of the deep heat of the Earth will not only reduce the severity of the energy problem, but also reduce the cost of energy generated [1-4]. This is most relevant for areas where there is a particularly acute shortage of imported fuel, while the region has a huge energy potential contained in geothermal deposits. In the process of developing geothermal deposits, the problems associated with the transport of steam-water currents have become particularly relevant.

International practice in the development of high-viscosity oil fields indicates that among the many well-known methods of increasing oil recovery, thermal methods are the most effective. Among the latter is the method of thermal action on oil reservoirs by equilibrium steam-water mixtures. A positive feature of this method over the others is that when the steam-water medium is injected into the oil reservoir, through the pumping and compressor pipes of the well, heat loss into the surrounding rocks does not lead to a decrease in the temperature of the two-phase coolant, but only reduces the vapor content in the mixture. The increase in the temperature of the mixture along the depth of the well is explained by the heat of the phase transition released during steam condensation due to heat

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transfer into rocks and due to an increase in the equilibrium pressure of the mixture in the direction of gravity.

An analysis of the literature devoted to the mathematical modeling of stationary movements of equilibrium steam-water mixtures in a vertical borehole shows the presence in the descriptions of significant simplifying assumptions related to the specification of hydrodynamic and heat exchange processes [5-8]. In this regard, this paper presents the basic equation of the non-isothermal steady-state motion of an equilibrium mixture of steam and water, taking into account a more accurate description of thermohydrodynamic processes and the actual design of the well.

2 Main Part

As a result of numerous studies, reasonable methods for calculating the dynamics of a steam-water mixture have been developed. When developing a flow model in geothermal wells, a number of assumptions are made that significantly simplify the creation and further solution of a mathematical model. When modelling the flow in a well, the stationarity condition is usually assumed, which greatly simplifies the model. And since all processes are more or less unsteady, they usually talk about quasi-stationarity, considering a virtually stationary model, but allowing relatively slow changes in parameters over time due to the process of heat exchange of the well with the surrounding rocks.

Let the two-phase steam-water medium be a thermodynamically equilibrium mixture; the motion of this mixture is stationary, one-dimensional and inertia-free; the thermal conductivity in the axial direction of the well is negligible compared to convective heat transfer; in each flat section of the well and the surrounding rocks, the temperature field is axisymmetric; the temperature of the rocks surrounding the well varies according to the geothermal law; thermophysical parameters boreholes and surrounding rocks do not depend on temperature.

To determine the magnitude of the heat flow, it is necessary that the temperature field in the rock mass surrounding the well is known. Suppose there is a vertical well, through the mouth of which a thermodynamically equilibrium steam-water mixture is fed into the reservoir. It is required to determine the temperature inside the pump and compressor pipe of the well. To do this, we consider the well as a hollow axisymmetric cylinder. With the assumptions made, this process is described by the heat inflow equation, which has the form [9]

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\lambda r\frac{\partial T}{\partial r}\right)=0 \tag{1}$$

where: T is the temperature in the surrounding rock. Thermal conductivity λ is a piecewise constant function determined by the thermophysical properties of the well structure, thermal insulation coatings and the surrounding soil.

The following conditions are taken into account. The outside temperature is equal to the ground temperature Tc

$$T\big|_{r=R}=T_c \tag{2}$$

on the inner surface, heat exchange with the mixture occurs according to Newton's law

$$-\lambda gradT\big|_{r=r_0} = \alpha(T - T_0) \tag{3}$$

where: α is the heat transfer coefficient, T_0 is the temperature of the mixture. Integrating the expression (1)

$$\frac{dT}{dr} = \frac{C_1}{\lambda r} \tag{4}$$

Re-integrating, we get

$$T = \frac{C_1}{\lambda} \ln r + C_2 \tag{5}$$

To determine the integration constants, we first use a boundary condition of the first kind (2)

$$T_c = \frac{C_1}{\lambda} \ln R + C_2 \tag{6}$$

from where the second constant is equal to

$$C_2 = T_c - \frac{C_1}{\lambda} \ln R \tag{7}$$

Substitute expression (7) in (5)

$$T = T_c + \frac{C_1}{\lambda} \ln\left(r/R \right) \tag{8}$$

Now let's use the boundary condition of the third kind (3)

$$\frac{RC_1}{r_0} = \alpha\left(T_c - T_0 + \frac{C_1}{\lambda} \ln\left(r_0/R \right) \right) \tag{9}$$

from where the first constant is equal to

$$C_1 = \frac{\alpha(T_c - T_0)}{\frac{R}{r_0} - \frac{\alpha}{\lambda} \ln\left(r_0/R \right)} \tag{10}$$

As a result, the temperature field of the well will take the form

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$$T = T_c + \frac{\alpha}{\lambda} \frac{(T_c - T_0)}{\frac{R}{r_0} - \frac{\alpha}{\lambda} \ln\left(r_0 / R \right)} \ln\left(r / R \right) \quad (11)$$

To determine the magnitude of heat losses in the surrounding rocks, it is necessary to know the density of the heat flow. Taking into account the Fourier law, it is equal to

$$q = -\lambda gradT \quad (12)$$

then the distribution of the heat flux density over the cross section is equal to

$$q(r) = \frac{\alpha}{r\lambda} \frac{(T_c - T_0)}{\frac{R}{r_0} - \frac{\alpha}{\lambda} \ln\left(r_0 / R \right)} \ln\left(r / R \right) \quad (13)$$

For a cylindrical wall, the heat flux density through any isothermal surface depends on the radius, and through the unit of the inner surface is determined by the formula

$$q_r = \frac{\lambda \frac{\partial T}{\partial r}}{r_0 \ln\left(R / r_0 \right)} \quad (14)$$

Taking into account the expression (13), we obtain an expression for determining the value of the heat flow

$$q(r) = \frac{\alpha}{r\lambda} \frac{(T_c - T_0)}{\ln\left(R / r_0 \right) - \frac{\alpha r_0}{\lambda}} \ln\left(r / R \right) \quad (15)$$

Below is a graph of the temperature field (fig. 1), according to the obtained formula (11).

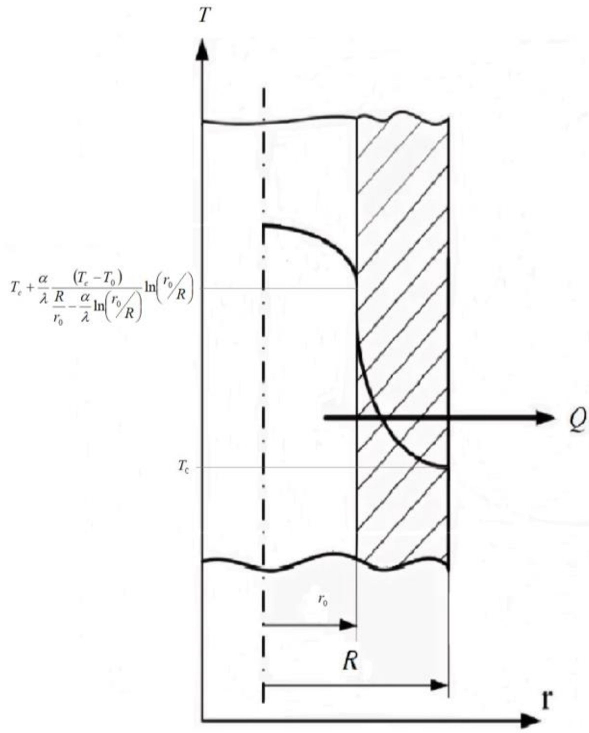

Fig. 1. Graph of the behaviour of the geothermal pipe temperature field.

3 Conclusions

In this paper, a mathematical model of the steady isothermal motion of a thermodynamically equilibrium water mixture in a vertical borehole is developed. Within the framework of the hydraulic approximation, a numerical study was carried out of the steady isothermal motion of a thermodynamically equilibrium steam-water mixture in a vertical well, taking into account heat losses into the surrounding rocks. The problem considers the movement of the coolant along the wellbore and its thermal interaction with its wall. The heat flow in the mountain massif is taken into account, and the two-dimensional problem of thermal conductivity, written in cylindrical coordinates, is solved by numerical methods.

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