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Numerical solution of the problem of thermal effects on high-viscosity oil through a horizontal well

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Abstract. In this paper, the problem of developing a high-viscosity oil reservoir due to the effect of paragravity based on heating the reservoir section between the injection and production wells is considered. The thermal effect on the formation reduces the viscosity coefficient of the oil and increases the mobility of the raw material. The heat transfer equation is solved by the PSSS method. The task is solved in three stages. At the first stage, the oil reservoir is heated, at the second – its exposure, at the third - filtration.

1 Introduction

The possibility of heating the reservoir with high viscosity oil has been numerically realized. The radial one-dimensional formulation presents a solution to the problem of filtration of high-viscosity oil in a reservoir using influential thermal methods with a single horizontal flow, where, for example, water or steam is used as a coolant [1-4].

One flow part is used as a heating and producing well, operating alternately. The solution of the problem is proposed in three stages. At the first stage, the formation is heated, oil extraction is not carried out. At the second stage, the oil reservoir is aged to achieve a uniform temperature distribution in the reservoir. At the third stage, the formation is filtered, which helps to increase the filtration period of the product with a reduced viscosity coefficient [5-7].

2 Methods and Materials

Let's write down a system consisting of the continuity equation and the heat flow equation for an oil-saturated reservoir ($r_c < l < \infty$) in the following form:

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$$\begin{gathered}\frac{\partial m\rho_l}{\partial t}+\frac{1}{l}\frac{\partial}{\partial l}(rm\rho_l v)=0,\\ \rho c\frac{\partial T}{\partial t}+\rho_l mc_l v\frac{\partial T}{\partial l}=\frac{\lambda}{l}\frac{\partial}{\partial r}\left(l\frac{\partial T}{\partial l}\right),\end{gathered} \tag{1}$$

To determine the oil filtration rate, we use Darcy's law in the form:

$$mv=-\frac{k}{\mu(T)}\frac{\partial p}{\partial l} \tag{2}$$

Let's write down the equation of state of oil in a linear approximation:

$$\rho_l=\rho_{l0}\left(1-\alpha^{(T)}(T-T_0)+\alpha^{(p)}(p-p_0)\right) \tag{3}$$

Viscosity-temperature dependence $\mu(T)$ for bitumen oil, we write it as an expression[8-12]:

$$\mu(T)=\mu_0 e^{-\gamma(T-T_0)} \tag{4}$$

From these equations, new equations for temperature and pressure can be obtained, which allow us to detail the process of oil recovery with a high viscosity index:

$$\begin{gathered}\frac{\partial p}{\partial t}=\frac{\alpha^{(T)}}{\alpha^{(p)}}\frac{\partial T}{\partial t}+\frac{k}{m\alpha^{(p)}l}\frac{\partial}{\partial r}\left(\frac{l}{\mu(T)}\frac{\partial p}{\partial l}\right),\\ \frac{\partial T}{\partial t}=\frac{k\rho_l c_l}{\mu(T)\rho c}\frac{\partial p}{\partial l}\frac{\partial T}{\partial l}+\frac{\nu}{l}\frac{\partial}{\partial l}\left(l\frac{\partial T}{\partial l}\right).\end{gathered} \tag{5}$$

From the well into the formation, for the total heat flow, we take the equation:

$$q^{(T)}=2\pi r_c\lambda\left(\frac{\partial T}{\partial l}\right)_{r_c} \tag{6}$$

The total heat consumption is determined by the following equation:

$$Q=\int_0^t q^{(T)}dt \tag{7}$$

In this work, we used the formula that is described in the works:

$$\mu(T)=\mu_o e^{-\gamma(T-T_o)} \tag{8}$$

The mass flow rate of oil from the well is expressed by the following equation:

$$q^{(v)}=2\pi r_c\rho_l mv \tag{9}$$

From where, using Darcy's law (2), we have:

$$q^{(v)} = -2\pi r_c \rho_l \frac{k}{\mu(T)} \left(\frac{\partial p}{\partial l}\right)_{r_c} \tag{10}$$

The total volume of oil production can be calculated using the following equation:

$$M = \int_0^t q^{(v)} dt \tag{11}$$

3 Results and Discussion

Heating of the oil reservoir. At this stage, the oil-saturated rock is warm ($t < t_1$) and the oil is not being pulled out. At the border of the stream ($l = r_c$) The pressure gradient is zero ($\partial p/\partial l = 0$), and the temperature is constant, away from the borehole ($l \to \infty$) reservoir pressure and temperature are equal to their initial values p_0, T_0.

This condition means that the thickness of the oil reservoir is significantly greater than the area where filtration and temperature gradients are observed. At the initial stage of development ($t = 0$) the pressure and temperature are equal, respectively p_0, T_0. After replacing the differential operators with their finite-difference analogues, from (5) we obtain a system of linear algebraic equations [13-15]:

$$p_i^{j+1} = p_i^j + \frac{\alpha^{(T)}}{\alpha^{(p)}}(T_i^{j+1} - T_i^j) + \frac{k \cdot \tau}{m\alpha^{(p)} r_i h^2}\left(\frac{r_{i+1}}{\mu(T_{i+1}^j)}(p_{i+1}^j - p_i^j) - \frac{r_i}{\mu(T_i^j)}(p_i^j - p_{i-1}^j)\right), \tag{12}$$

$$T_i^{j+1} = T_i^j + \frac{k\rho_l c_l \tau}{\mu(T_i^j)\rho c} \cdot \frac{p_{i+1}^j - p_i^j}{h} \cdot \frac{T_{i+1}^j - T_i^j}{h} + \frac{\nu\tau}{r_i h^2} \cdot \left(r_{i+1}(T_{i+1}^j - T_i^j) - r_i(T_i^j - T_{i-1}^j)\right), \tag{13}$$

$$(T_i^j) = \mu_0 e^{-\gamma(T_i^j - T_0)} \tag{14}$$

The boundary conditions have the following form: $p_1^j = p_2^j$; $p_N^j = p_0$; $T_1^j = T_c$; $T_N^j = T_0$.

The boundary condition for $l = \infty$ we take it down to the border of the grid $l = r_{(\infty)}$. Oil reservoir exposure. After the warm-up phase ($t_1 < t < t_2$) It is proposed to consider the aging phase to increase oil recovery. At this stage of reservoir development, it is kept closed until a uniform temperature distribution in the reservoir is achieved. We solve the standard system of linear algebraic equations (12) with boundary conditions: $p_1^j = p_2^j$; $p_N^j = p_0$; $T_1^j = T_c$; $T_N^j = T_0$. There is an alignment of the heating zone in the formation and an increase in the heating zone with reduced viscosity parameters at the immersion stage during the considered time.

Oil filtration. Now let's look at the third stage ($t > t_2$) manipulating the flow. At this stage, the system of equations (5) for pressure and temperature is solved with the following boundary conditions: at the boundary $l = r_c$ there is no heat flow $\partial T/\partial l = 0$ and constant pressure is maintained p_c ($p_c < p_0$), and in part ($l \to \infty$), remote from the borehole, the initial parameters are set T_0 , p_0 for temperature and pressure. The propagation of the filtration wavefront occurs much deeper than the temperature gradient region. Subsequently, there is a noticeable decrease in temperature and an increase in viscosity, which leads to a decrease in the filtration rate of oil in a porous medium [16].

Figure 1 shows the dynamics of viscosity and temperature in a reservoir with high viscosity oil at different time periods during heating t = 10(orange line), 20(grey line), 30 (yellow line) days.

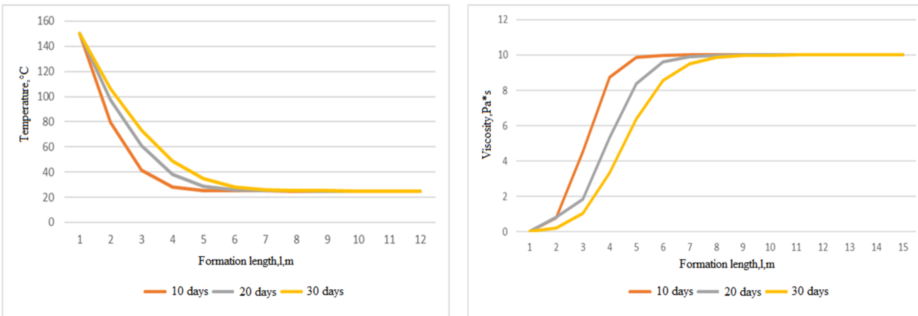

Fig. 1. The distribution of viscosity and temperature along the length of the formation l at various points in time during the heating of the formation t = 10, 20, 30 days.

Figure 2 shows the dynamics of viscosity and temperature in a reservoir with high viscosity oil at different time periods during the formation holding t = 10, 20, 30 days.

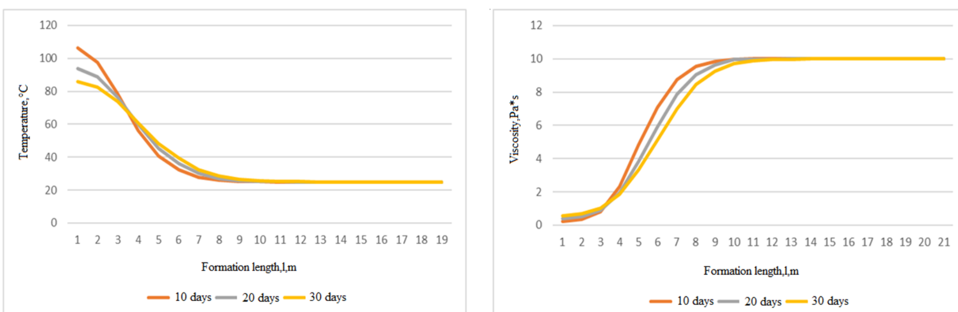

Fig. 2. The distribution of viscosity and temperature along the length of the formation l at various points in time during the holding of the formation t = 10, 20, 30 days.

Figure 3 shows the dynamics of viscosity and temperature in a reservoir with high viscosity oil at different time periods during the filtration process of the reservoir t = 2, 5, 7 days.

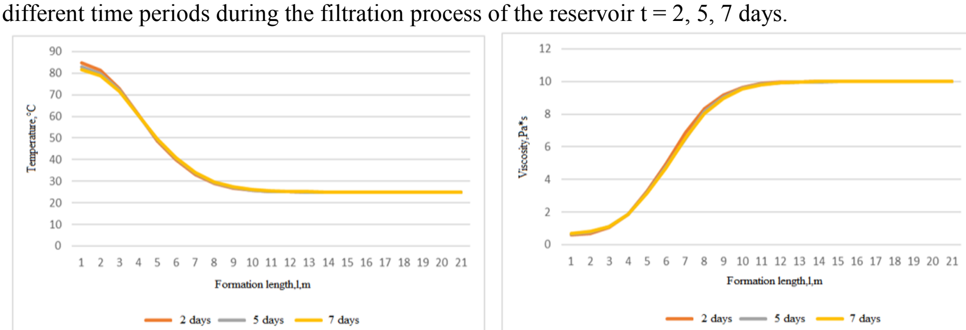

Fig. 3. The distribution of viscosity and temperature along the length of the formation l at various points in time during the filtration of the formation t = 2, 5, 7 days.

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4 Conclusion

A numerical study of the filtration process of high-viscosity oil through one horizontal borehole, used as a reheating wellhead, and then as the mouth of a production well, was carried out. A system of differential equations for pressure and temperature was obtained under given boundary conditions. The task was solved in three stages. At the first stage, the formation is heated to control the process of heating the formation, which depends on the thickness of the underlying rock.

At the second stage, the well is closed until the temperature distribution in the formation becomes the most uniform, which increases oil recovery. In the third stage, the heated oil with reduced viscosity is filtered through the surveyed horizontal channel in the wellbore. The proposed method is beneficial for increasing the efficiency of operation of hard-to-recover reservoirs, since it allows you to evenly warm up the studied area of the oil field.

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