Ways to improve production efficiency problems and ways of their solution

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Abstract. The work shows various ways to improve the efficiency of oil production. A comparative analysis was carried out. Considered the most environmentally friendly ways. Considered physical models and the most important averaged parameters for them are defined. Identified ways to influence these parameters. The expressions are shown that allow to calculate the volumes of oil filtered through the sections of the bottomhole zone of the reservoir. The problem of determining the viscosity of oil. The methods of steam-thermal impact on the formation, their advantages and opportunities are considered in detail. Identified problems, shows how to solve them. Solutions were found for turning water into saturated steam in a closed volume of a drilling tool. The quantities that evaluate the effectiveness of the device are determined and calculated quantitatively. The optimal size and shape of the nozzles are determined. Calculated steam flow rate from the nozzles of the device, the reactive forces arising in the device and the torque generated by the forces. The relevance and prospects of these methods are shown.

1. Introduction

The main indicator of the efficiency of oil production is the oil recovery efficiency (ORE):

\[ K = \frac{V_{\text{produced}}}{V_{\text{balanced}}} \]

Using the laws of Poiseuille and Darcy, we can express the volume of oil \( dV \) filtered through the cross section \( dS \) per unit time:

\[ dV = A \frac{k_{\text{res}} \Delta p_{\text{res}}}{\mu L} dS \]

where:
- \( k_{\text{res}} \) - reservoir permeability;
- \( \mu \) - oil viscosity;
- \( p_{\text{res}} \) - reservoir pressure;
- \( \Delta L \) - pressure difference at the ends of the capillary with a length \( \Delta L \); 
- \( A \) - constant for this collector.
\[ V_S = \int_0^S A \frac{k_n p \Delta \rho \mu}{\mu \Delta L} dS = A \frac{k_n p \Delta \rho \mu}{\mu \Delta L} S. \] (3)

Assuming the pressure in the volume of the well is atmospheric, the volume of oil filtered per unit of time through the cross-section \( S \):

\[ V_S \approx A \frac{k_n p \mu}{\mu \Delta L} S. \] (4)

Then \( V_{produced} \) for the final time of oil in the first approximation:

\[ V_{produced} \approx \int_0^T A \frac{k_n p \mu}{\mu \Delta L} S \ dt \approx A \frac{k_n p \mu}{\mu \Delta L} St. \] (5)

One of the main problems is the expression of viscosity of oil in an explicit form, which is a large and urgent scientific task [3, 4]. Nowadays, the viscosity is determined in laboratory conditions for filtered volumes. In this model, an increase in oil production implies an increase in reservoir pressure, a decrease in viscosity and permeability, and the influence of external physical factors. Modern geophysics uses all kinds of physical fields. From the most environmentally friendly ways to develop we indicate:

- Gravitational, \( K < 5 \% \)
- Elastic, \( K \leq 5 \% \)
- Dissolved gas, \( K \) from 5–7 to 20–25 \%
- Water pressure \( K \) from 20–30 to 60–70 \%
- Gas pressure \( K \) 50–70 \%
- Thermal steam on the reservoir, \( K < 70 \% \)
- Electromagnetic, \( K \leq 70 \% \)

It is obvious that the prospect of increasing oil production is the integration and combination of various methods of development.

2. Materials and methods
2.1 Thermal steam

Heating of the reservoir leads to a decrease in the permeability and viscosity of the formation fluids: oil, water and gases (Fig. 1, a–c).

**Figure 1.** Correlations between the main parameters: a) Dependence of density of reservoir oil on pressure and amount of dissolved gas at \( t=70 \) °C; b) Dependence of viscosity on temperature; c) Dependence of viscosity on temperature and amount of dissolved gas.

When the collector is heated, a decrease in viscosity and volume expansion of all components of the reservoir, a change in the permeability and mobility of fluid fluids occurs. In [5, 6] considered non-traditional drilling methods, the “drilling tool” integrating the energy of steam.
2.2 Principle of operation

The operation of the drilling tool occurs in the following sequence. When voltage is applied to the heating elements, the latter are heated, increasing linearly. A linear increase in the heating element leads to a shift of the stop. Accordingly, a retainer rigidly connected to the stop is moved along the through groove. Under the pressure of water in the channel valve-piston moves. Water fills the cavity vacated by the valve-piston and enters the channels. Then the water through the outlets from the channels gets on the heating element and begins to evaporate. The pressure inside the body cavity increases. As a result of an increase in pressure, the valve-piston returns to its original position, in this case water is supplied to the channels and intensive water is injected into the heating element. Abundant evaporation of water on the heating element leads to the formation of the working fluid – steam inside the housing. The channels – nozzles, the working fluid expires out, creating a rotational effect, due to the reactive force. Rotation of the body leads to the destruction of the ground with carbide inserts. After evaporation of water on the heating elements, the latter cool down and assume the same linear dimension, i.e. the system returns to its original position and then the process can be repeated.

3. Quantitative estimation of device parameters

To evaluate the effectiveness of the device, it is necessary to identify the values that determine the torque and calculate them quantitatively. Mechanical work is accomplished by generating steam energy inside the body of the drilling tool and using this energy through the body output channels.

We use the Clapeyron–Clausius equation [7] for processes with phase transformations:

\[
\frac{dP}{dT} = \frac{q}{T(v_1 - v_2)},
\]

(6)

\( q \) – specific heat of vaporization, \( v_1, v_2 \) – specific volumes of water and steam.

Turning water into saturated steam in a closed vessel, where the temperature \( T \) is variable, we get:

\[
\frac{dP}{dT} = \frac{\mu q}{RT^2} P,
\]

(7)

Separating the variables and integrating the resulting expression:

\[
\int_{P_0}^{P} \frac{dP}{P} = \int_{T_0}^{T} \frac{\mu q}{RT^2} dT \ln \frac{P}{P_0} = \frac{\mu q}{R} \left( \frac{1}{T_0} - \frac{1}{T} \right)
\]

And for the final pressure:

\[
P = P_0 e^{\frac{\mu q}{R} \left( \frac{1}{T_0} - \frac{1}{T} \right)}
\]

(8)

were \( P_0 \) and \( T_0 \) – initial pressure and temperature; \( P \) and \( T \) – final pressure and temperature.

For instance, during the evaporation of 1 kg of water for 1 second, inside the cavity of the device with a volume of \( V=10^{-3} \text{ m}^3 \), superheated steam pressure \( P=460 \cdot 10^3 \text{ Pa} \), temperature \( T=998 \text{ K} \approx T_{\text{heat}} \).

When a part of its mass is ejected, where the ejected part changes its impulse, a reactive force acts on the system, equal to the change in the impulse of the ejected part per unit of time. The torque of the device occurs under the action of reactive forces, with the expiration of steam from the horizontal output channels – nozzles. In [6] was determined the pressure – \( p \) and vapor temperature – \( T \) when the specified mass of water evaporates, but to calculate the reactive forces – \( F_p \) and flow rate – \( M_l \), it is necessary to first determine the flow rate of steam from the nozzles of the device (Fig. 2).

During the evaporation of 1 kg of water for 1 second, inside the cavity of the device with a volume of \( V=10^{-3} \text{ m}^3 \), the pressure of superheated steam in front of the nozzle is \( p_1=460 \cdot 10^3 \text{ Pa} \), temperature \( T=998 \text{ K} \).

The pressure behind the nozzle \( p_2 =10^5 \text{ Pa} \). The ratio of pressures in the environment and in front of the nozzle \( \beta = p_2/p_1=2.17 \cdot 10^{-3} \).

The critical value of the ratio (with a sound outflow of steam) is determined by the expression [8]:

\[
\beta_{vp} = \left( \frac{2}{k+1} \right)^{\frac{k}{k+1}},
\]

(9)

\( k \) – Expiration adiabatic index, for superheated steam \( k=1.29 \) and \( \beta_{vp}=0.547 \).

As \( \beta < \beta_{vp} \) in this case, the flow is supersonic.
Figure 2. Steam outflow from nozzles with a velocity $v_2$, reactive forces $F_p$ and torque (moment of forces) $M$ acting on the device.

The speed at the nozzle exit for real gas is determined by the expression [8]:

$$v_2 = \sqrt{2(i_1 - i_2)}.$$  \hspace{1cm} (10)

$i_1$ – Vapor enthalpy at the nozzle entrance; $i_2$ – vapor enthalpy at the nozzle exit.

Enthalpy is on the is – chart.

For the task: $i_1 = 3785 \text{ KJ/kg}$; $i_2 = 2935 \text{ KJ/kg}$. The speed at the exit of the nozzle, respectively, $v_2 = 1304 \text{ m/s}$. With an expanding nozzle shape with an opening angle $\gamma \approx 10^\circ$ (fig. 3), the nozzle velocity coefficient is maximum $\varphi = 0.98$ and the actual flow velocity is $v_2^\varphi = \varphi v_2 = 1278 \text{ m/s}$.

Figure 3. Expanding nozzle, $D_{\text{min}}$ – minimum nozzle diameter; $D_{\text{max}}$ – maximum nozzle diameter; $L$ – nozzle length.

The nozzle parameters are related by the following expression:

$$\tan(\frac{\gamma}{2}) = \frac{D_{\text{max}} - D_{\text{min}}}{2L}. \hspace{1cm} (11)$$

Reactive power $F_p = v_2^3 \mu$, where $\mu = \frac{dm}{dt}$ – ejected mass of steam per unit time from a single nozzle.

Task $\mu = 0.05 \text{ kg/s}$ and $F_p = 63.9 \text{ HN}$. Assuming the nozzles are identical, the resultant force $F = NF_p$. If $N = 20$ to $F = 1278 \text{ HN}$. Torque (force moment) $M = Fd = NF_p d$, here $d = 10 \text{ cm}$. Thereafter $M = 127.8 \text{ Hm}$. Reactive forces and torque can be adjusted by changing the amount of water supplied to the device. With an increase in water consumption by an order of magnitude, the torque increases by the same amount.

4. Conclusion

The tasks on the definition of environmentally friendly ways to improve oil recovery, in particular, steam and thermal effects. The parameters of physical models are determined, and the solution is shown in the first approximation. The problems and their solutions are indicated. Details considered the device "Drilling tool". Calculated steam flow rate from the nozzles of the device, the reactive forces emergent...
in the device and the torque generated by the forces. The ways of parameters optimization are shown. The relevance and prospects of the drilling method under consideration is due to the development of deposits with highly viscous oils: Van-Egansky, Vynga-Purovsky, Russky and other fields. Emitted steam (at a temperature of $T\approx998$ K), in addition to an additional destructive effect on the rock, has a steam-thermal effect on oil, which ultimately allows for enhanced oil recovery.

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