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DOUBLE PHASE CONSIDERING HOT WATER USED COMPRESSION OF NON-NEWTONIAN OILS ALONG THE PROCESS OF RADIAL FILTRATION

Abstract

The article considers the ussue of hot water used compression of non-Newtonian oils reservoir for the purposes of radial filtration. By use of very active oxides, considered to be a hot liquid, it is possible to derive heat directly from reservoir bottom. In its turn, this allows effective compression of oil in reservoir with no loss of flooded hot water temperature alongside the well bore. Theoretical statement of the issue makes cool water used compression possible after a hot water barrier is developed. As a result, being a mathematical issue this will lead to conclusion that solution of partial derivatives differential equation is possible only with the help of computer system. In its turn, this will help to ease the work of engineers in field conditions.

It is known that the thermal methods of action to oil pool for raising of oil recovery of oil pool containing the great amount of paraffin oil and resiniferous oil are applied.

The analysis of the known literary facts shows that the investigations of the compression of non-Newtonian and Newtonian oil from the porous medium are led both experimentally and theoretically mainly by the cool water with active admixture, hot water, steam and so on practically for linear case. One can consider the results of this articles as comparison of experimental and calculated curves for the linear flow, but it is impossible to extend to the case of radial flow, in general. Because in particular in the case of the radial flow the velocity of the liquid decreases proportionally to the distance from oil will axis, where as in the case of linear flow the velocity does not depend on distance.

The case when one can use such model for the compression of oil by the hot liquid when the heat source is formed as a result of exothermal reaction immediately in the face zone of the injection well, is very interesting. On the one hand this present the loss of heat on shaft, and on the other hand as a preliminary untill obtaining the maximal heat the face zone is cleaned off deposits of severe components of oil, by the same token promoting to increasing of acceptability of oil wells. The led numerous laboratory investigations show than in the direct case the compression coefficient increases significantly more that in the case when the hot water compression is led, even if its temperature exceeds the temperature arising in a result of reaction. Below the theoretical estimation of the considered problem is reduced.

The equation of continuity of oil and water flow (in our case- water opening) characterizing the radial flow, different from equations for the linear case has the form

$$\frac{\partial \upsilon_{\text{вр}}}{\partial r} + \frac{\upsilon_{\text{вр}}}{r} + m\frac{\partial \sigma}{\partial t} = 0, \tag{1}$$

$$\frac{\partial \upsilon_{\text{н}}}{\partial r} + \frac{\upsilon_{\text{н}}}{r} + m\frac{\partial (1-\sigma)}{\partial t} = 0. \tag{2}$$

Allowing for the equations (1) and (2) in obtaining the basic differential equation describing the radial filtration by the Bakley-Leveret theory and accounting that the motion of the water opening is subjected to Darcy law

$$\upsilon_{\text{вр}} = -\frac{kk_{\text{вр}}\{\sigma(r,t),T(r,t)\}}{\mu_{\text{вр}}(T)}\frac{\partial P}{\partial r}, \tag{3}$$

and the motion of non-Newtonian oil to the Darcy generalized low proposed by A.Kh.Mirzadjanzadeh [7, 8]:

$$\upsilon_{\text{н}} = -\frac{kk_{\text{н}}[\sigma(r,t),T(r,t)]}{\mu_{\text{н}}(T)}\left\{\frac{\partial P}{\partial r} + P_0[T(r,t)]\right\}, \tag{4}$$

where $\sigma(r,t)$ is the distribution function of saturation of the pumped hot water opening.

$k_{\text{вр}}$, $k_{\text{н}}$ are relative phase permeabilities for the water opening and oil;

P_0 is the initial gradient for oil;

$T(r,t)$ is the function of temperature field of oil pool on pump of water opening.

Summing of (3) and (4) we obtain:

$$\upsilon_{\text{н}} + \upsilon_{\text{кр}} = \upsilon, \tag{5}$$

where $\upsilon = \frac{Q}{F}$; $F = 2\pi rh$, then we obtain

$$\upsilon_{\text{н}} + \upsilon_{\text{вр}} = \frac{Q}{2\pi\, r\, h}. \tag{6}$$

Substituting the value (3) and (4) into the formula (6) and denoting $\frac{\mu_{\text{н}}(T)}{\mu_{\text{кр}}(T)} = \mu(T)$, we obtain:

$$-k\left[k_{\text{вр}}(\sigma,T) + \frac{k_{\text{н}}(\sigma,T)}{\mu(T)}\right]\frac{\partial P}{\partial r} = \frac{Q\mu_{\text{вр}}(T)}{2\pi\, rh} + \frac{kk_{\text{н}}(\sigma,T)}{\mu(T)}P_0(T). \tag{7}$$

From the formula (7) substituting the value $\frac{\partial P}{\partial r}$ in the formula (4) we find velocity of water in the following from:

$$\upsilon_{\text{вр}} = Qf_1(\sigma,T) + f_2(\sigma,T)P_0(T),$$

where

$$f_1(\sigma,T) = \frac{\mu(T)k_{\text{кр}}(\sigma,T)}{2\pi\, rh\left[\mu(T)k_{\text{вр}}(\sigma,T) + k_{\text{н}}(\sigma,T)\right]};$$

$$f_2(\sigma,T) = \frac{kk_{\text{н}}(\sigma,T)k_{\text{кр}}(\sigma,T)}{\mu_{\text{вр}}(T)\left[\mu(T)k_{\text{вр}}(\sigma,T) + k_{\text{н}}(\sigma,T)\right]}.$$

Substituting the obtained value $\upsilon_{\text{вр}}$ to the equation of continuity (1) for flow of the water opening, we have

$$\frac{\partial}{\partial r}\left[Qf_1(\sigma,T) + f_2(\sigma,T)P_0(T)\right] + \frac{Qf_1(\sigma,T) + f_2(\sigma,T)P_0(T)}{r} + m\frac{\partial\sigma}{\partial t} = 0. \tag{8}$$

Assuming that $\frac{k_{\text{н}}(\sigma)}{k_{\text{кр}}(\sigma)} = f(\sigma)$, we have

$$f_1(\sigma,T) = \frac{1}{2\pi\, rh\left[1 + \mu(T)f(\sigma)\right]} \quad \text{and} \quad f_2(\sigma,T) = \frac{k}{\dfrac{\mu_{\text{н}}(T)}{k_{\text{н}}(\sigma,T)} + \dfrac{\mu_{\text{кр}}(T)}{k_{\text{вр}}(\sigma,T)}}.$$

Substituting the values $f_1(\sigma,T)$ and $f_2(\sigma,T)$ into the formula (8) we obtain

$$\frac{\partial}{\partial r}\left[\frac{Q}{2\pi rh\left(1+\mu(T)f(\sigma)\right)}+\frac{kP_0(T)}{\dfrac{\mu\ (T)}{k\ (\sigma,T)}+\dfrac{\mu\ (T)}{k\ (\sigma,T)}}\right]+$$

$$+\frac{1}{r}\left[\frac{Q}{2\pi rh\left[1+\mu(T)f(Q)\right]}+\frac{kP_0(T)}{\dfrac{\mu\ (T)}{k\ (\sigma,T)}+\dfrac{\mu\ (T)}{k\ (\sigma,T)}}\right]+m\frac{\partial\sigma}{\partial t}=0\,. \qquad (9)$$

Louwerye's scheme is used to determinate the temperature field of oil pool for the radial case, which allows for two inverse directed heat flow, where the first is from the source (the walls of oil well) into the depths of the pool, and the second stipulated by inflow of the liquid is from the oil pool to the oil well. The oil pool is get warm exceptionally by means of heat conductivity, moreover immediately only the part of the heat flow is consumed to the heating and the part is spended to the compensation of the convective flow from the oil pool. The dependence of phase permeability of the oil and the water (in our case-the water opening) is defined by the formula proposed by Boxerman A.A., Shalimov B.V. and Jacubi S.I. [3]

$$k_{\text{н}}^{*}(\sigma,T)=\frac{\left[0{,}789+0{,}00056T(r,t)-\sigma\right]^3}{0{,}216} \qquad 0{,}9\ge\sigma\ge0{,}2\,,$$

$$k_{\text{н}}(\sigma,T)=1 \qquad 0{,}2\ge\sigma\ge0\,,$$

$$k_{\text{вр}}^{*}(\sigma,T)=\frac{\left[\sigma-0{,}189-0{,}00056T(r,t)\right]^3}{\left[0{,}789+0{,}00056T(r,t)\right]^3} \qquad 0{,}9\ge\sigma\ge0{,}2\,,$$

$$k_{\text{вр}}(\sigma,T)=1 \qquad 0{,}2\ge\sigma\ge0\,.$$

The dependence of change of oil viscous on the temperature was assumed in the form [1]

$$\mu(T)=\mu_{\text{пл}}\ell^{-\alpha_t\Delta T}\,,$$

where $\alpha_t=(11{,}0-37{,}0)10^{-3}\,\text{град}^{-1}$; $\Delta T=T_{\text{вр}}-T_{\text{пл}}$.

In contrast to the linear case the obtained differential equation in partial derivatives doesn't reduce to solution by the method of characteristics and therefore further the calculation is realized numerically in IBM, where the solution reduced in [6] is assumed as basis.

The calculations show that for obtaining the cylindrical wall with radius 10 meters, with temperature 130^0 C (that more than pool) around the injection well, it will be sufficient to pump liquid down the face zone as hot edging in the volume from 300 m^3 to 3500 m^3 depending on power of productive pool (2-60 meters). Further increase of the pump volume of cold water for the compression of edging can't negatively infuse to the compression result, since the temperature and the heat conductivity of the pumped volume of the liquid (hot edging) guarantee practically full compression of oil from the face zone, and also increase the acceleration characteristics of the oil well.

As known from the literary sources pump (or edging) of hot water down the oil-bearing pools is applied basically for the increasing of the acceleration characteristics of the injection wells. For the well permeable pools saturated by very viscous oil the pump of the hot water for the increasing of oil recovery of the pool has been justified economically.

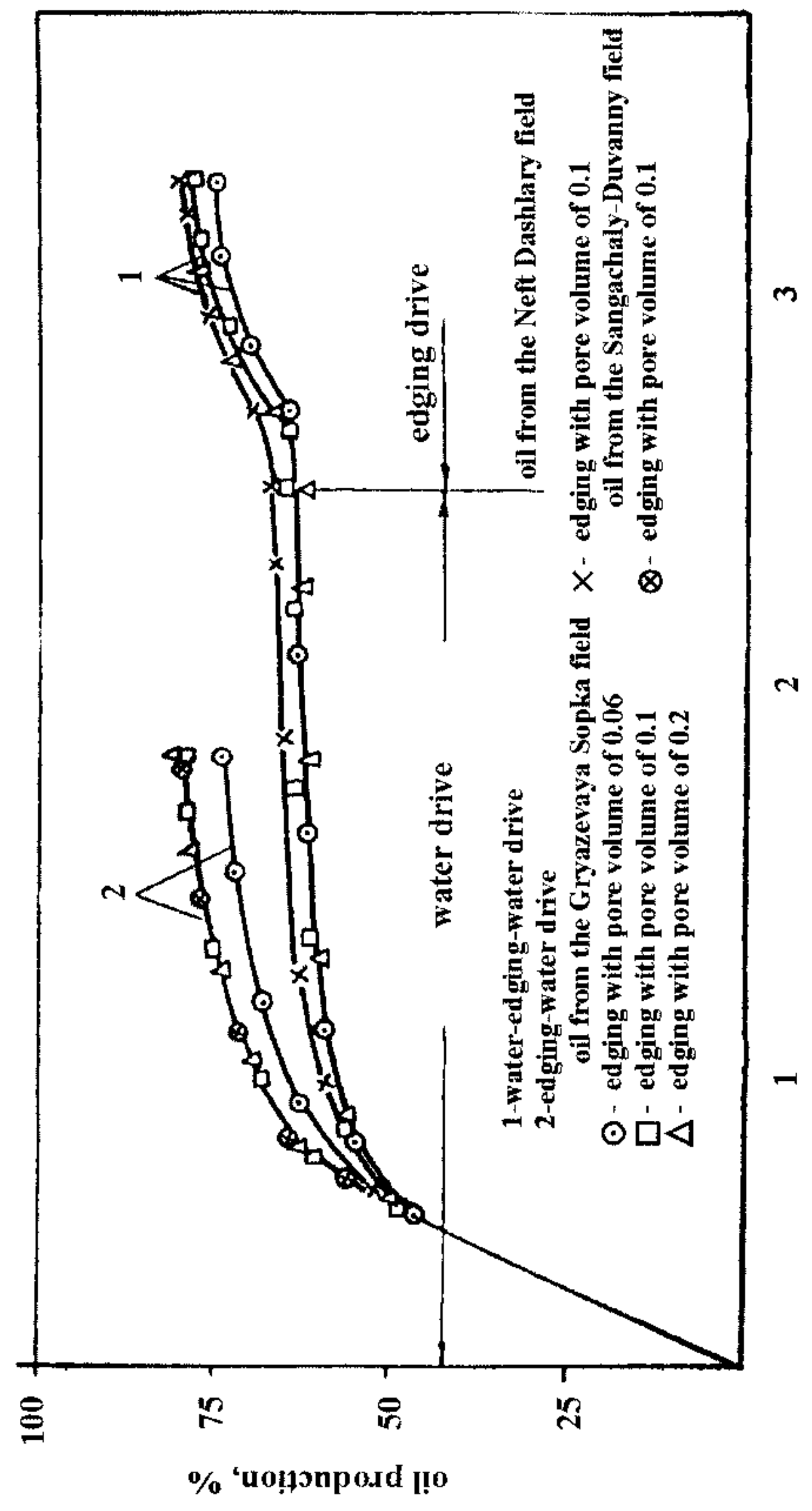
oil production, %
100
75
50
25
1
2
3
water drive
edging drive
1
2
1-water-edging-water drive
2-edging-water drive
oil from the Gryazevaya Sopka field
⊙ - edging with pore volume of 0.06
□ - edging with pore volume of 0.1
△ - edging with pore volume of 0.2
oil from the Neft Dashlary field
× - edging with pore volume of 0.1
oil from the Sangachaly-Duvanny field
⊗ - edging with pore volume of 0.1

Fig. 1.

The laboratory investigations show the increase of the compression coefficient from 2 to 7% on the jump of the hot water depending on the viscous oil.

Producer's investigations confirm also the increase of oil recovery with temperature growth of pumped water for the higher-viscous oil [4, 5 and so on].

The growth of oil recovery on pump of hot water is stipulated by a number of factors. On increasing of temperature:

- the viscosity of oil is fall, the relation of viscosity $\mu_0 = \frac{\mu_в}{\mu_н}$ and the value of saturations on the compression front is decreased;
- the compression coefficient is increased (the remainder oil-stipulation is decreased);
- the relative permeability of oil is increased;
- the damping of the pool is improved;
- the surface tension on the boundary of oil with water and so on is decreased.

But from the literary facts it is known that the water is get warm in installation up to 95^0 C when the hot water pump down the pool. Passing through the surface communication the oil pools have the temperature $70\text{-}75^0$ C on the mouth and $60\text{-}62^0$ C on the face of injection well [2].

As was denoted in our case the loss of heat on the mouse and inside of the well, is excepted. This in turn influses to improvement of the above mentioned properties in several times.

As a result as is obvious from the figure the compression coefficient in comparison with hot water is increased almost twice, i.e. on 13%. In laboratory conditions value of the surface tension on the boundary of the suggested edging with kerosine is defined. It is 1,2-1,8 mH/m. Two series of experiments on compression have been led for the purpose to study the influences of water-saturation of the face zone to the result of the led articles. The first series was led thus that untill creation of the edging the oil was compressed by the water , by the same token forming the water-saturation on the face zone then was compressed by the edging.

The second series of experiments was led by the immediate creation of the edging and the oil compression by it. As is obvious from the figure the suggested edging one can apply for the compression of oil from the porous surrounding both at the beginning and at any moment of elaboration, i.e. it's application isn't bounded by degree of irregation.

Thus, the creation of hot edging immediately in the face zone by means of the exothermal reaction, significantly increases the effectivity of heat influence to the pool in comparison with hot water.

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