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STUDY OF THE HEAT-MASS TRANSFER PROCESS CONSIDERING THE WELL-RESERVOIR SYSTEM IN FRACTURED RESERVOIRS

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Summary. The theoretical study of oil field development processes and the creation of adequate technological schemes, taking into account the possible compound physical processes occurring in the field to ensure optimal exploitation of deposits, highlight the necessity of a complex scientific approach. Besides the geological-geophysical data required for the creation of technological schemes, obtaining the physical data of the deposit is one of the important factors. Obviously, much of these data come from wells drilled into the reservoir. The most important aspect of these studies is the investigation of the mass exchange and phase transition mechanisms of hydrocarbons, taking into account the pressure and temperature changes in the reservoir and the well during liquid filtration. In this paper, the effect of pressure and temperature changes during the processing of hydrocarbon deposits on exploitation indicators is examined by considering the well-reservoir system.

Introduction

Assumed that a circular oil layer with a deformation radius r_k and a height H is exploited by means of a central well with a production rate Q of a radius r_c. It is assumed that the reservoir temperature T_k, the contour and the well bottom pressure p_c and p_k change by the law $\overline{k}(p) = a_k[1 + \alpha_k(p - p_s)]$, which is bed permeability (Jalalov et al., 2018. Here, α_k and a_k are positive constants determined from field or laboratory data.

The hydrodynamic model of the considered problem is taken into account within the following physical assumptions:

- The well is complete according to its opening degree and character,
- Oil filtration obeys Darcy's law and it is non-isothermal,
- The pressure at the bed boundary is constant,
- The initial natural distribution of temperature along the layer is stable,
- The temperature of the fluid and porous medium are the same at any point in the layer,
- Heat transfer in the radial direction of the layer is negligible compared to the convective heat transfer,
- Influence of temperature changes in layer is not taken into account when determining the parameters of the porous medium and fluid,
- The variation of the permeability parameter of the layer based on the deformation of the collector is expressed by a well-known empirical formula.

Taking into account the transition from the radial region to the rectangular region, the dimensionless dynamic distributions of pressure and temperature functions of the reservoir and well are described as the following system of equations within the appropriate initial and boundary conditions (Abasov et al., 1993; Chekalyuk, 1965; Karachinsky, 1975).

$$\frac{\partial \overline{p}_2}{\partial \tau} = \frac{\partial}{\partial x}\left(x\frac{\overline{k}(\overline{p})}{\overline{\mu}}\frac{\partial \overline{p}_2}{\partial x}\right), x_c \le x \le x_s, \tau > 0, \quad (1)$$

$$\frac{\partial\overline{T}_2}{\partial\tau}=A\frac{\overline{k}(\overline{p})}{\mu}x\frac{\partial\overline{p}_2}{\partial x}\left(\frac{\partial\overline{T}_2}{\partial x}+B\frac{\partial\overline{p}_2}{\partial x}\right)+D\frac{\partial\overline{p}_2}{\partial t},x_c\le x\le x_s,\tau>0,\tag{2}$$

$$\frac{\partial\overline{T_1}}{\partial\tau}+\overline{v}\left(A_1\frac{\partial\overline{T_1}}{\partial\overline{z}}+\varepsilon B_1\frac{\partial\overline{P_1}}{L\partial\overline{z}}+v_0\frac{g}{c_f}\right)=$$

$$D_1\left[\frac{\alpha}{c_f}-\gamma E_1\overline{w}\rho_f\right]\left(\overline{T_2}\big|_{r=r_0}-\overline{T_1}\right),0\le\overline{z}\le1,\tag{3}$$

$$\frac{-\partial\overline{P}_1}{\partial\overline{z}}=\rho_f E_1\frac{\partial\left(\overline{v}^2\right)}{\partial\overline{z}}+Q_1\frac{\psi}{4\overline{r}_c}\rho_f\overline{v}^2+\rho_f g,0<\overline{z}\le1,\tag{4}$$

$$\frac{\partial\overline{v}}{\partial\overline{z}}-\gamma C_1F_1K(\overline{p})\frac{\partial\overline{P}_2}{\partial x}\bigg|_{x=x_c}=0,\tag{5}$$

$$\overline{p}_2(x.0)=1,x_c\le x\le x_s,\tag{6}$$

$$\frac{4\pi\overline{k}(\overline{p})}{\overline{\mu}}\left(x\frac{\partial\overline{p}_2}{\partial x}\right)\bigg|_{x=x_c}=\left(Q+C\frac{\partial\overline{p}_2}{\partial t}\right)\bigg|_{x=x_c},\tag{7}$$

$$\overline{p}_2(x_k,t)=p_s,\tau>0,\tag{8}$$

$$\overline{T}_2(x.0)=T_s,T_s=1,\tag{9}$$

$$\overline{T}_2(x_k.0)=T_s,\tag{10}$$

$$\overline{T}_1(z,0)=1+\frac{G}{T_0}\left(L_{pr}-z\right),0<\overline{z}\le1,\tag{11}$$

$$\overline{P}_1(z,0)=\overline{P}_2(r_c,t)+\frac{\rho_f gL_1}{p_0},\tag{12}$$

$$\overline{T}_1(0,t)=1_0+\frac{\sigma L_{pr}}{T_0},\tag{13}$$

$$\overline{v}(z,0)=0.\tag{14}$$

Here, $x_c=\frac{r_0^2}{4}.x_s=\frac{r_s^2}{4}$, p_2,p_1,T_2 and T_1 represent pressure and temperature functions in the reservoir and well, respectively, β $-$ elastic capacity coefficient of the reservoir $\left[\frac{1}{MPa}\right]$, $k-$ permeability coefficient $[mkm^2]$, $\mu-$ dynamic viscosity $[MPa*sec]$, r_c- radius of the well $[m]$, r_k- radius of the layer $[m]$, $t-$ time variable $[day]$, $C_{pl}-$ volumetric heat capacity of the reservoir $\left[\frac{Djol}{m^3*K}\right]$, $C_{sr}-$ specific heat capacity of the rock $\left[\frac{Djol}{kg*K}\right]$, C_f- specific heat capacity of the fluid $\left[\frac{Djol}{kg*K}\right]$, ρ_f- density $\left[\frac{kg}{m^3}\right]$, $m-$ porosity, $\varepsilon-$ Joule-Thomson coefficient $\left[\frac{K}{MPa}\right]$, $\eta-$ coefficient of adiabatic expansion $\left[\frac{K}{MPa}\right]$, p_k- reservoir pressure $[MPa]$, T_k $-$reservoir temperature $[K]$, $H-$ reservoir thickness $[m]$, Q $-$well debit $\left[\frac{m^3}{sec}\right]$, $C-$ borehole influence coefficient $\left[\frac{m^3}{MPa}\right]$, P_1- well pressure $[MPa]$, T_1- well temperature K°, $v-$ fluid velocity in the well $\left[\frac{m}{sec}\right]$, $\psi-$ coefficient of hydraulic resistance, $L-$ length of the wellbore $[m]$, $\alpha-$ thermal conductivity of the well-bore $\frac{KKal}{L^2\cdot T\cdot C^0}$, $\gamma-$ specific gravity of the fluid, $w-$ fluid percolation rate in the reservoir $\left[\frac{m}{sec}\right]$, $g-$ free-fall acceleration $\left[\frac{m}{sec^2}\right]$, $t_{exp}-$ working life of the well $[day]$, $G-$ geothermal gradient $\left[\frac{K^\circ}{M}\right]$, L_1 and L_2 show the coordinates of the formation bottom, ceiling and the device placed in the well [M].

The Finite Differences Method

As is seen, the equations constituting the problem (1)-(14) belong to the mixed type, i.e. parabolic according to the function $p_2(x,t)$, and hyperbolic according to the functions $T_2(x,t)$ and $T_1(x,t)$. Moreover, the equations are non-linear.

It is clear that the pressure change in the oil layer is caused only by the well, which in turn leads to the temperature change in the layer. According to the principle of causality, an excitation moving from one point to another must pass through all points between these two points. That is, the temperature wave generated by the pressure difference $\Delta p = p_s - p_c$ (Joule-Thomson effect) propagates at a finite speed to a finite distance in a finite time and thus causes the temperature wave to propagate at a finite speed. In the literature, homogeneous schemes are applied, which do not take into account the properties that arise in the solution of the problem and discretize the problem with finite differences (Aziz, Settary, 1982). Methods devoted to application of more sensitive schemes in problems with phase transition processes between phases are widely available in the literature (Rasulov, 2011; Le Veque, 2002). The classical finite difference method was mainly used to solve the posed problem.

Now, we establish the following grids on the intervals $[x_c, x_s]$ and $[0,1]$

$$\omega_{h_x,\tau} = \{x_j = x_c + jh_x, j = 0,1,\dots,n;\tau_k = kh_\tau, k = 0,1,2,\dots\},$$
$$\omega_{h_z,\tau} = \{z_\nu = 0 + \nu h_z, \nu = 0,1,\dots,m;\tau_k = kh_\tau, k = 0,1,2,\dots\}.$$

We decompose the finite difference scheme corresponding to problems (1)-(14) into finite differences equations in two cases.

a) The Case of $C = 0$

Firstly, we write the system of equations expressing the layer process in the $\omega_{h_x,\tau}$ grid under the appropriate conditions as follows

$$\frac{P_{j,k+1}^{(2)} - P_{j,k}^{(2)}}{h_\tau} = \frac{1}{h_x}\left[R_{j+\frac{1}{2}}(x)K_{j+\frac{1}{2}}\left(\frac{P_{j+1,k}^{(2)} - P_{j,k}^{(2)}}{h_x}\right) - R_{j-\frac{1}{2}}(x)K_{j-\frac{1}{2}}\left(\frac{P_{j,k}^{(2)} - P_{j-1,k}^{(2)}}{h_x}\right)\right] \tag{15}$$
$$(j = 1,2,\dots,n-1, k = 0,1,2,\dots),$$

$$P_{j,0}^{(2)} = 1, (j = 0,1,2,\dots,n), \tag{16}$$

$$P_{1,k}^{(2)} = P_{0,k}^{(2)} + \frac{h_x\overline{\mu}}{4\pi x_c \overline{k}(\overline{p})}Q, \tag{17}$$

$$P_{n,k}^{(2)} = \overline{p}_s, (k = 0,1,2,\dots), \tag{18}$$

$$\frac{T_{j,k+1}^{(2)} - T_{j,k}^{(2)}}{h_\tau} = Ax_i\frac{\overline{k}(P_{j,k})}{\overline{\mu}}\frac{1}{h_x}\left(\frac{T_{j+1,k}^{(2)} - T_{j,k}^{(2)}}{h_x} + B\frac{P_{j+1,k+1}^{(2)} - P_{j,k+1}^{(2)}}{h_x}\right)$$
$$+D_f^{i,k}\frac{\left(P_{j+1,k}^{(2)} - P_{j,k}^{(2)}\right)}{h_\tau}, (j = 1,2,\dots,n, k = 0,1,2,\dots), \tag{19}$$

$$T_{j,0}^{(2)} = T_s, (j = 0,1,2,\dots,n,) \tag{20}$$

and then following difference scheme describing the motion in the wellbore as its finite difference equivalent at any node $(z| \quad |\nu, \tau_k)$ of the grid $\omega_{h_z,\tau}$

$$\frac{V_{\nu,k+1} - V_{\nu,k}}{h_z} = \gamma C_1 F_1 k(\overline{p})\frac{P_{1,k+1}^{(2)} - P_{0,k+1}^{(2)}}{h_x}, \tag{21}$$

$$\frac{P_{\nu,k+1}^{(1)} - P_{\nu-1,k+1}^{(1)}}{h_z} = \rho_f E_1\frac{V_{\nu,k+1}^2 - V_{\nu-1,k+1}^2}{h_z} + Q_1\frac{\psi}{4r_c^2}V_{\nu,k+1}^2 + \rho_f g, \tag{22}$$

$$\frac{T_{\nu,k+1}^{(1)} - T_{\nu,k}^{(1)}}{h_\tau} + \rho_f V_{\nu,k+1}\left(A_1 \frac{T_{\nu,k+1}^{(1)} - T_{\nu-1,k+1}^{(1)}}{h_\tau} + \frac{P_{\nu,k+1}^{(1)} - P_{\nu-1,k+1}^{(1)}}{h_z} + v_0 \frac{g}{C_f}\right) =$$

$$D_1\left[\frac{\alpha}{C_f} - \gamma E_1 w \rho_f\right]\left(T_{0,k+1}^{(2)} - T_{0,k+1}^{(1)}\right), \tag{23}$$

$$T_{\nu,0}^{(1)} = 1 + \frac{G}{T_0}\left(L_{pr} - z_\nu\right), 0 < \bar{z} \le 1, \tag{24}$$

$$P_{\nu,0}^{(1)} = P_{0,k+1}^{(2)} + \frac{\rho_f g L_1}{p_0}, \tag{25}$$

$$T_{0,k+1}^{(1)} = 1_0 + \frac{\sigma L_{pr}}{T_0}, \tag{26}$$

$$V_{\nu,0} = 0. \tag{27}$$

Here, $T_{\nu,k}^{(1)}$, $P_{\nu,k}^{(1)}$ and $V_{\nu,k}$ are approximate values of functions $\overline{T}_1(z,t), \overline{P}_1(z,t)$ and $v(z,t)$ at any points (z_ν, τ_k), respectively.

b) The Case of $C = 1$

In this case, the boundary condition (17) is written as

$$P_{0,k+1} = P_{0,k} + \frac{4\pi\overline{k}(\overline{p})}{\overline{\mu}} x_c \frac{h_t}{h_x}\left(P_{1,k} - P_{0,k}\right) - h_t\overline{Q}. \tag{28}$$

Conclusion

Taking into account the thermodynamic effects, a new finite difference method is proposed for finding the numerical solution of the system of nonlinear differential equations characterizing the fluid flow in the reservoir, which is fractured during the development process, under the given conditions. Also, a software package is created that allows to determine the nature of changes in pressure processing indicators.

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