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Abstract

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DIFFERENTIAL EQUATIONS OF FILTRATION OF GAS-CONDENSATE SYSTEMS WITH ACCOUNT OF THE CONDENSATION AND SORPTION PROCESSES

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In the development of gas-condensate fields to depletion, the filtering substance in its initial state in the reservoir is usually in a gaseous state. In the process of pressure reduction, the heaviest components of the substance separate out in the form of a liquid condensate, part of which saturates the rock. At the same time, up to a certain degree of saturation (equilibrium saturation), the liquid remains immobile. In (1), differential equations of filtration of gas-condensate systems are derived with account of the condensation process under a number of assumptions, and some approximate and exact solutions are also given.

Experimental studies on the filtration of gas-condensate systems in a porous medium have shown that, along with condensation processes, sorption processes also exert a substantial influence on filtration (2). In the present note, under a number of assumptions, the kinetics of the change in saturation is considered with account of sorption processes.

It is assumed that a thermodynamically equilibrium process takes place in the reservoir. For condensate saturation less than the equilibrium saturation, and under the usual assumption of gas ideality and isothermal flow, filtration of the gas phase can be described by the gas-filtration equation

$$\partial P/\partial t = a^2 \partial^2 P^2/\partial x^2, \qquad a^2 = k/2m\mu_1, \tag{1}$$

where P is pressure; m is the porosity of the rock; k is the permeability of the porous medium; μ_1 is the gas viscosity; t is time.

The differential equation for determining the change in condensate saturation has the form (1)

$$-\frac{\partial S}{\partial t} = \frac{\rho_1}{\rho_0}\frac{\overline{V}_1}{m}\frac{\partial \nu(P)}{\partial x} + \frac{\rho_1}{\rho_0}\frac{\partial \nu(P)}{\partial t}; \tag{2}$$

$$\nu(P) = b_1 P^2 + b_2 P + b_3, \tag{3}$$

where ρ_1, ρ_0 are the gas densities, respectively, under reservoir and normal conditions; $\nu(P)$ is the amount of stable condensate dissolved in the gas phase under normal conditions; b_1, b_2, b_3 are constant coefficients. Here we neglect the change in gas mass as a result of sorption and condensation processes.

Following (3), we compose an equation describing the sorption process with account of condensation:

$$-\overline{V}_1 \partial C/\partial x = \partial C_1/\partial t + \gamma_1 \partial S/\partial t + \partial C/\partial t; \tag{4}$$

$$\partial C_1/\partial t = \beta(C - \Gamma C_1), \tag{5}$$

where C is the concentration of the sorbed substance in the gas phase; C_1 is the concentration of the sorbed substance in the sorbent; β is a kinetic coefficient; $1/\Gamma$ is Henry' s coefficient; γ_1 is the specific gravity of the liquid condensate.

For inertialess motions and when the influence of sorption and condensation processes on the phase permeability is neglected,

for the gas phase, the filtration velocity is determined by Darcy' s law, i.e.

$$\overline{V}_1 = -\frac{k}{\mu_1}\frac{\partial P}{\partial x}. \tag{6}$$

The sorption isotherm is assumed to be known, i.e.

$$C_1 = \Gamma_1 C_1^0, \qquad \Gamma_1 = 1/\Gamma, \tag{7}$$

where C_1^0 is the concentration of the gas in equilibrium with the sorbed amount of gas. Thus, filtration of gas-condensate systems with allowance for sorption and condensation processes is described by the system of differential equations (1)–(7).

Let us consider the case of injection of a gas-condensate system into an empty reservoir, i.e. with the initial conditions $P(x,0) = 0$. The initial conditions are prescribed as

$$S(x,0) = 0, \qquad C(x,0) = 0, \qquad C_1(x,0) = 0.$$

For the pressure, boundary conditions $P(0,t) = B_1 t$ are prescribed. Introducing the new variable $\xi = x - \sigma t$, it is not difficult to obtain (see, for example, [4])

$$P = \begin{cases} (\sigma t - x)\sigma/2a^2, & 0 \leqslant x \leqslant \sigma t, \\ 0, & x \geqslant \sigma t, \end{cases} \tag{8}$$

where σ is the velocity of propagation of the boundary at which $P = 0$. In solving, following (3), we neglect $\partial C/\partial t$.

To determine C_1, it is necessary to solve the ordinary differential equation of second order

$$\frac{d^2C_1}{d\xi^2} - n_1 \frac{dC_1}{d\xi} + n_2\xi^2 + n_3\xi = 0,$$

$$n_1 = \frac{\sigma\mu_1 - k\Gamma B}{\sigma k B}\,\beta, \qquad n_2 = \frac{2B^2\gamma_1 b_1}{\sigma m P_0}\,\beta\left(B + \frac{\sigma\mu_1 m}{k}\right), \tag{9}$$

$$n_3 = \frac{\gamma_1 b_2 B}{m P_0 \sigma k}\,\beta(Bk + \sigma\mu_1 m), \qquad B = -\frac{\sigma}{2a^2}.$$

Thus, it is required to solve the Cauchy problem with boundary conditions $\xi = 0$, $C_1 = 0$ and $dC_1/d\xi = 0$. The solution has the form

$$C_1 = \frac{2n_2 + n_3 n_1}{n_1^4}\left(1 - e^{n_1\xi} + \frac{n_1^2}{2}\xi^2 + n_1\xi\right) + \frac{n_2}{3n_1}\xi^3. \tag{10}$$

For the condensate saturation we obtain

$$S = n_4\xi^3 + n_5\xi^2, \qquad n_4 = \frac{b_1\sigma^3}{12P_0a^6}\left(1 - \frac{k}{4\mu_1a^2}\right), \qquad n_5 = \frac{\sigma^2 b_2}{8P_0a^4}\left(\frac{k}{2\mu_1a^2} - 1\right). \tag{11}$$

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Note: Figure translations are in progress. See original paper for figures.