DIFFERENTIAL EQUATIONS OF FILTRATION OF GAS-LIQUID SYSTEMS WITH ALLOWANCE FOR MASS TRANSFER OF RESIDUAL WATER

HYDRAULICS

1967

SovietRxiv

Abstract

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UDC 622.323:532.5

HYDRAULICS

A. Kh. MIRZADZHANZADE, Z. M. AKHMEDOV, T. A. SAMEDOV

DIFFERENTIAL EQUATIONS OF FILTRATION OF GAS–LIQUID SYSTEMS WITH ALLOWANCE FOR MASS TRANSFER OF RESIDUAL WATER

(Presented by Academician L. I. Sedov on 24 XII 1966)

The differential equations of filtration of aerated liquid, and approximate and exact methods for solving them, have been discussed in detail in a number of works (see, for example, ([1]-[7])).

It is known that gas–oil reservoirs contain a certain quantity of water, called bound, residual, connate, etc. In what follows we shall use the term residual water.

In studies of the filtration of aerated liquid, the amount of residual water was taken to be constant, and its influence was taken into account through the phase permeabilities.

In recent years, a number of works have considered the problem of isothermal unsteady filtration of gas with allowance for the process of water mass transfer (see, for example, ([8], [9])). Most likely, in unsteady isothermal filtration of aerated liquid, mass transfer of residual water occurs. In the present article a formulation is given of the problem of filtration of aerated liquid with allowance for mass transfer of residual water.

It is known that the moisture content of gas depends on pressure, temperature, and composition. For simplification we neglect: a) change in the composition of the gas; b) change in the mass of gas as a result of mass transfer of residual water; c) transition of residual water into the liquid phase.

The adopted assumptions make it possible to apply the traditional equations of filtration of aerated liquid.

For example, under the usual assumptions of ideality of the gas, applicability of Henry' s solubility law, isothermality of the flow, negligibility of liquid shrinkage, and dependence of the viscosity of the liquid and gas on pressure, the differential equations of filtration of aerated liquid have the form (see, for example, ([1])):

$$\operatorname{div}\mathbf{V}_1 = -m\,\partial s_1/\partial t, \tag{1}$$

$$\operatorname{div}[(a\mathbf{V}_2 + s\mathbf{V}_1)P] = -m\frac{\partial}{\partial t}[sps_1 + aPs_2], \tag{2}$$

where m is the porosity; $\mathbf{V}_1, \mathbf{V}_2$ are the filtration velocities of the liquid and gas, respectively; s_1, s_2, s_3 are the saturations of the pore space by liquid, gas, and residual water, respectively; P is pressure; a is the constant in the equation of state; s is the constant in Henry’ s law.

For inertia-free motions of gas-liquid systems in a porous medium, the filtration velocities $\mathbf{V}_1$ and $\mathbf{V}_2$ are determined from (^{1}):

$$\mathbf{V}_1 = -k\frac{f_1(s_1,s_2)}{\mu_1}\operatorname{grad}P, \qquad \mathbf{V}_2 = -k\frac{f_2(s_1,s_2)}{\mu_2}\operatorname{grad}P; \tag{3}$$

here k is the permeability of the porous medium; $f_1(s_1, s_2)$, $f_2(s_1, s_2)$ are the relative phase permeabilities for the liquid and gas, respectively; μ_1, μ_2 are the viscosities of the liquid and gas, respectively.

Let us formulate differential equations for determining the mass transfer of residual water. The volume of residual water in some arbitrary volume τ over the time dt, as a result of mass transfer, is determined by the volume integral

$$dt\iiint\limits_{\tau} ms_2\frac{\rho_2}{\rho_0}\frac{dw(P)}{dt}\,d\tau, \tag{4}$$

where $w(P)$ is the moisture content; ρ_2 is the gas density; ρ_0 is the gas density under normal conditions.

Mass transfer leads to a change in the amount of residual water in the volume τ over the time dt by the amount

$$-dt\iiint\limits_{\tau} m\frac{ds_3}{dt}\,d\tau. \tag{5}$$

Equating the quantities (4) and (5) and using the arbitrariness of the volume τ, we obtain an equation for determining the change in the saturation of residual water

$$-\frac{\partial s_3}{\partial t} = \frac{\rho_2}{\rho_0}\left(\frac{V_2}{m}\operatorname{grad}w(P) + s_2\frac{\partial w(P)}{\partial t}\right). \tag{6}$$

Let us note that

$$s_1 + s_2 + s_3 = 1. \tag{7}$$

The derivation of equation (6) is carried out analogously to the derivation of the differential equation for the gas-hydrodynamic study of the process of condensate accumulation ([10]).

With the gas composition unchanged and the flow isothermal, $w(0)$ is determined from ([11])

$$w(P) = A/P. \tag{8}$$

Let us note that there are a number of expressions for determining $w(P)$. We have adopted a comparatively simple one.

Thus, filtration of a gasified liquid is described by the system (1)–(3) and (6)–(8).

It presents no difficulty to generalize the obtained system to a more general case (allowance for the real properties of gas-liquid systems, nonisothermal flow, etc.). It is necessary to specify initial conditions for s_1, s_3, and P. For P the corresponding boundary conditions must be specified.

Let us note that there is a class of corresponding self-similar problems. It is not difficult to establish that, in the case under consideration, stationary filtration of a gas-liquid system cannot occur.

For a quantitative estimate of the influence of mass transfer of residual water on the filtration of a gasified liquid, the method of successive replacement of stationary states was applied. The results of the calculations show that mass transfer of residual water substantially affects the gas flow rate, and the near-wellbore zone is, with time, dried out to a practically appreciable degree.

Azerbaijan Institute of Oil and Chemistry
named after M. Azizbekov

Received
24 XII 1966

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

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