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PECULIARITIES OF DEFORMED VISCOUS-PLASTIC LIQUID'S FLOW THROUGH THE POROUS MEDIUM

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Аннотация. Many questions concerning the rational development of oil fields, oil recovery hydromechanics, the filtration process for cases when oil has structural and mechanical properties remain completely unclear. Taking into account the foregoing, in this paper we propose a technique for studying the filtration of a deformed viscous-plastic fluid.

Ключевые слова: structural viscosity, filtration flow, compressibility, pressure gradient, filtration rate, volume flow, piezo-metric heights, trajectory.

Annotation. Many questions concerning the rational development of oil fields, oil recovery hydromechanics, the filtration process for cases when oil has structural and mechanical properties remain completely unclear. Taking into account the foregoing, in this paper we propose a technique for studying the filtration of a deformed viscous-plastic fluid.

Keywords: structural viscosity, filtration flow, compressibility, pressure gradient, filtration rate, volume flow, piezo-metric heights, trajectory.

Under conditions close to natural, studies of a deformed viscous-plastic fluid in a porous medium were carried out, and generalized formulas for filtration in a porous medium were obtained.

Note that the flow rate for such liquids is a functional dependence on the coefficient of volumetric elastic expansion, the initial shear gradient, on the pressure drop, structural viscosity, and on the length of the filtration flow [1–5].

The approach to determining the debit is as follows [5]:

$$Q = \frac{kF}{\eta}\left(\frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}} - i_0\right). \quad (1)$$

Considering that $\ln\frac{\rho_{contour}}{\rho_{gallery}} = \beta\left(P_{contour} - P_{gallery}\right)$, it is able to determine the volume flow as follows:

$$Q = \frac{kF}{\eta}\left(\frac{P_{contour} - P_{gallery}}{L} - i_0\right). \quad (2)$$

From expression (2) we can find the pressure gradient.

$$\frac{kF}{\eta}\left(\frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}} - i_0\right) = \frac{kF}{\eta}\left(\frac{P_{contour} - P_{gallery}}{L} - i_0\right). \quad (3)$$

Then, we get:

$$\frac{P_{contour} - P_{gallery}}{L} = \frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}}. \quad (4)$$

That is to say

$$\Delta P = P_{contour} - P_{gallery} = \frac{1}{\beta}\ln\frac{\rho_{contour}}{\rho_{gallery}}. \quad (5)$$

Note that according to the rules of hydrodynamics, when drawing trajectories, it is also necessary to adhere to the general rule, that is, between any two adjacent trajectories drawn, the flow rate of a compressible viscous-plastic fluid must be the same. At the same time, we point out that in the particular case of the one-dimensional flow under study, the family of trajectories in a given plane should be depicted using straight lines equally spaced from each other and parallel to the axis of motion. The set of such isobars and trajectories of fluid particles is called the hydrodynamic field of a given compressible viscous-plastic flow. This fact of isobars and trajectories represented by equidistant parallel straight lines confirms the constancy of the filtration rate and pressure gradient at any point of the considered flow [6, 7].

Now let's consider the analytical dependence of the distance traveled by liquid particles on time. That is, we define the law of motion of a fluid particle along the trajectory. To do this, let's assume that fluid particles move between two points at the moment (t) and (t + Δt). Then the average actual speed of movement and the speed of filtration are determined by the formula:

$$v = mV = m\frac{dx}{dt}. \tag{6}$$

Substituting the values of the flow rate as

$$\nu = \frac{k}{\eta}\left(\frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}} - i_0\right). \tag{7}$$

We get

$$m\frac{dx}{dt} = \frac{k}{\eta}\left(\frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}} - i_0\right). \tag{8}$$

Where after permutation we get:

$$dt = \frac{m\eta}{k\left(\frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}} - i_0\right)}dx. \tag{9}$$

By integrating this equation within the appropriate limits, taking into account the compressibility and viscous-plastic properties of the liquid, it is possible to determine the law of motion of a liquid particle along the trajectory and the time interval required to pass any given section of the path where the liquid is filtered.

$$t = \frac{m\eta}{k\left(\frac{1}{\beta L}\ln\frac{\rho_{contour}}{\rho_{gallery}} - i_0\right)}x. \tag{10}$$

As can be seen, the dependence of time and coordinates has a linear characteristic, since under the considered filtration conditions, the flow moves at a constant speed.

Note that for further comparison with the formulas of radial motion, let's direct the axis of motion in the opposite direction and choose the origin, as shown in the figure.

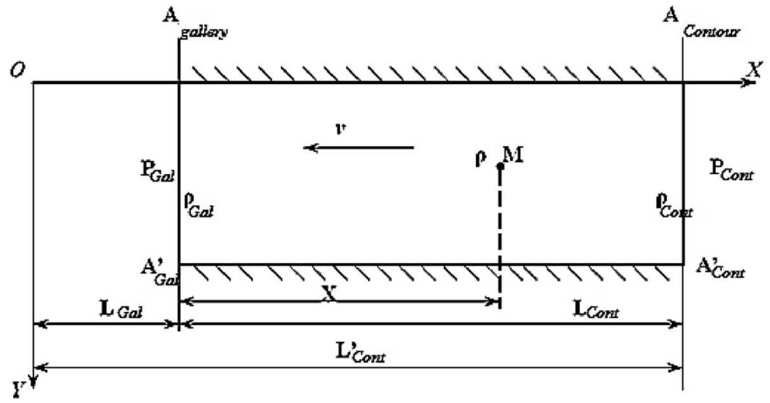

Figure 1 – Horizontal section of reservoir element under conditions of one-dimensional flow

Then we get

$$\left(\frac{Q\eta}{kF} + i_0\right)\beta\int_{L'_{contour}}^{x} dx = \int_{\rho_{gallery}}^{\rho}\frac{d\rho}{\rho}; \tag{11}$$

$$\left(\frac{Q\eta}{kF} + i_0\right)\beta\int_{L'_{contour}}^{L_{gallery}} dx = \int_{\rho_{contour}}^{\rho_{gallery}}\frac{d\rho}{\rho}. \tag{12}$$

Changing the boundary conditions

$$\left(\frac{Q\eta}{kF} + i_0\right)\beta\int_{x'}^{L'_{contour}} dx = \int_{\rho}^{\rho_{gallery}}\frac{d\rho}{\rho}. \tag{13}$$

$$\left(\frac{Q\eta}{kF} + i_0\right)\beta\int_{L_{gallery}}^{L_{contour}} dx = \int_{\rho_{gallery}}^{\rho_{contour}}\frac{d\rho}{\rho} \tag{14}$$

After integration of the given equations, we get:

$$\left(\frac{Q\eta}{kF}+i_0\right)\beta(L'_{contour}-x)=\ln\frac{\rho_{gallery}}{\rho}; \quad (15)$$

$$\left(\frac{Q\eta}{kF}+i_0\right)\beta\left(L'_{contour}-L_{gallery}\right)=\ln\frac{\rho_{contour}}{\rho_{gallery}}. \quad (16)$$

From these formulas, one can determine the value of the volumetric flow rate of a compressible viscous-plastic fluid.

$$\frac{Q\eta}{kF}=\frac{\ln\frac{\rho_{contour}}{\rho_{gallery}}}{\beta(L'_{contour}-L_{gallery})}-i_0. \quad (17)$$

From (17) it is able to find the volume flow:

$$Q=\frac{kF\ln\frac{\rho_{contour}}{\rho_{gallery}}}{\eta\beta(L'_{contour}-L_{gallery})}, \quad (18)$$

or

$$\frac{Q\eta}{kF}=\frac{\ln\frac{\rho_{gallery}}{\rho}}{\beta(L'_{contour}-x)}-i_0. \quad (19)$$

After corresponding transformations, we get

$$Q=\frac{kF\ln\frac{\rho_{gallery}}{\rho}}{\eta\beta(L'_{contour}-x)}-i_0. \quad (20)$$

Consequently, taking into consideration (17)–(20)

$$\frac{\ln\frac{\rho_{contour}}{\rho_{gallery}}}{\ln\frac{\rho_{gallery}}{\rho}}=\frac{L'_{contour}-L_{gallery}}{L'_{contour}-x}. \quad (21)$$

Note that if the pressures on the feed contour and the gallery in given sections were not constant, but given functions of time, then the proposed formulas would remain valid. Since in this study the porous medium is assumed to be non-deformable, any change in pressure instantly spreads to the entire filtration flow.

Considering the above, we can conclude that no matter how the pressure at the «formation boundaries» changes at each moment of time, the pressure distribution in the reservoir and the velocity of fluid particles will be steady, that is, the state of filtration of a compressible viscous-plastic fluid at any moment does not depend on the history movement.

If we accept that the pressure on the contour and on the gallery are functions of time, from the obtained formulas the flow rate, velocity, pressure gradient and pressure are also determined as functions of time.

As you can see, if you perform some transformations, that is,

$$P_{contour}=\rho gH_{contour} \text{ and } P_{gallery}=\rho gH_{gallery},$$

then

$$P_{contour}-P_{gallery}=\rho g\left(H_{contour}-H_{gallery}\right)=\rho g\Delta H. \quad (22)$$

Accordingly, these values should be understood as piezo metric heights corresponding to either absolute or excess static and dynamic pressure at the bottom of the well, where is the decrease in the piezo metric level of the liquid in the well.

Conclusions

1. Regardless of the nature of the change in pressure at the «formation boundaries» at each moment of time, its distribution in the reservoir and the velocity of fluid particles will be steady, that is, the state of filtration of a compressible viscous-plastic fluid at any moment does not depend on the history of movement.
2. If the pressures on the contour and on the gallery are functions of time, from the obtained formulas the flow rate, velocity, pressure gradient and pressure are also determined as functions of time.

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