PERCOLATION OF NON-NEWTONIAN SYSTEMS

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Results of an experimental investigation of percolation of non-Newtonian systems are presented. Various approximate models and factors affecting the characteristic constants of these models are considered.

Considerable attention has recently been given to the problem of non-Newtonian fluids in connection with the use of polymer materials in engineering and development of oil and gas deposits.

Percolation of non-Newtonian systems was studied in [1-5, et al.], where it was described by a modified Darcy's law for a viscoplastic medium, first written by Mirzadzhanzade [1] in the form

\[ \bar{v} = \frac{k_s}{\eta_v} \left(1 - \frac{P_0}{(\text{grad} P)}\right) \text{grad} P. \] (1)

The results of an experimental confirmation of Eq. (1) for the example of a model fluid - a mixture of vapor lubricating oil and bright stock oil - are presented in [2], where the following expression was obtained for \( P_0 \)

\[ P_0 = \alpha_3 \eta_v \sqrt{k}. \] (2)

Percolation in the presence of an initial pressure gradient related with the particular behavior of percolating fluids in a porous medium (e.g., water in clay) was investigated by Puzyrevskaya, Florin, et al., and even earlier - at the end of the last century - by King [6-9]. We note that an initial pressure gradient occurs also in the case of percolation of gas through clay containing a comparatively large quantity of residual water.

The investigations of percolation carried out for various non-Newtonian systems at the Azizbekov Institute of Petroleum and Chemistry in Azerbaidzhan showed that in a number of cases, especially at pressure gradients less than \( P_0 \), Eq. (1) cannot be used.

Here we present the results of an experimental investigation of the percolation of non-Newtonian systems for which we used model fluids - mixtures of vapor and bright stock oils, two-phase foam (seawater + air + surfactant), and tarry oils from a number of deposits in Azerbaidzhan. A column, 625 mm long and 42 mm inside diameter, was filled with purified quartz sand and then tamped with a vibrator. The experiments were carried out under isothermal conditions.

Percolation of the fluid occurred at a given pressure gradient. The latter was maintained by gas delivered from a high-pressure cylinder to a tank with a valve which prevented an inrush of the gas into the core holder. The flow rate of the fluid was changed by adjusting the pressure gradient, which was recorded by standard pressure gauges, and was determined by the weight method.

Assuming that, other conditions being equal, the value of \( \Delta P \) changes in direct proportion to the change \( l \), for the pressure gradient we can write the following physical equation:

\[ \frac{\Delta P}{l} = f(v, k, k', n', p). \] (3)
Thus the process of percolation of non-Newtonian fluids at comparatively low velocities can be described by Darcy's law (see Fig. 1, straight line OA) and at high velocities by the modified Darcy's law for a viscoplastic medium (see Fig. 1, line AB) and by an exponential function.

With the use of the exponential function the law of percolation can be formulated so

$$\text{grad } P = \frac{k' f(n')}{\sqrt{k} \sqrt{k'}} \frac{v}{v_0^{n'}}.$$  \hspace{1cm} (5)

The modified Darcy's law for a viscoplastic medium is written in the form

$$\text{grad } P = -\left( \frac{\eta}{k} \frac{v}{v_0} + \frac{\alpha_1}{k} \right) \frac{v}{v_0}.$$  \hspace{1cm} (6)

With the use of Caesson's relation, modified in [1], the law of percolation is expressed by the formula

$$\text{grad } P = -\left[ \left( \frac{\eta v}{k} \right)^{\frac{1}{n}} + \left( \frac{\alpha_1}{k} \right)^{\frac{1}{n}} \right] \frac{v}{v_0}.$$  \hspace{1cm} (7)

Equation (6) follows from (7) when $n = 1$ as a particular case. The graphs of $(v/\sqrt{k})^{1/2}$ vs $(\Delta P \sqrt{k})^{1/2}$ are rectilinear and intercept segments $a_1^{1/2}$ on the x axis. The slope of the straight lines is $a_1^{1/2}$.

The approximation constants of these dependences are presented in Table 1.

We note that the selection of one or the other dependence is determined by the conditions of the problem and by the difficulties arising in its solution. For example, when using dependence (6) the region of percolation is tentatively divided into a region of motion, where the relation between the pressure gradient and the velocity of percolation is linear, and a "stagnant" region, where the fluid is stationary. In connection with this, when solving nonsteady-state problems of percolation with the use of Eq. (6) a special feature arises which consists in that there is an unknown moving boundary. This can be said also about Eq. (7). With the use of dependence (5) the equation becomes complicated, but there is no moving boundary. It is necessary to note that the practical use of Eq. (6) for solving problems of oil-field mechanics is broader than Eq. (5).

Let us look at some factors affecting the approximation constants of the models used.

We will evaluate the effect of the quantity of clay and residual water in a porous medium on the magnitude of the initial pressure gradient according to the data of the experiments carried out by Yu. G. Mamedov, Ya. G. Farzane, and M. Abdullakimov on columns filled with purified quartz sand with different air permeabilities at a constant temperature. Saturation of the specimen with water was carried out under a vacuum.