HYDRAULIC CONDUCTIVITY AND HYDRAULIC GRADIENT AT SMALL FILTRATION RATES

R. Skavin'ski

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Experimental results are given for the relation between the filtration coefficient of a $CaCl_2$ solution in a porous medium consisting of quartz grains and the hydraulic gradient.

In the description of fluid flow in a porous medium a fundamental role is played by the equation

(1)

It links the unit fluid flow rate (filtration rate) v with the hydraulic gradient H in the flow direction. The hydraulic conductivity (filtration coefficient) k is related simply to the permeability of the porous medium. It depends on the pore geometry and the fluid properties; for each pair consisting of a porous body and a fluid there is a range of filtration rates in which k is constant and Darcy's law applies.

At the same time, in many experiments it has been noticed that the fluid filtration rate varies nonlinearly as the hydraulic gradient falls, so that a reduction in the gradient implies a reduction in k. This was first described by King [1] and later noted by other investigators [2, 3]. Closely connected with this effect is the occurrence of a limiting hydraulic gradient during filtration: at values of the gradient less than the limiting value, filtration practically ceases.

Most experiments to determine the limiting hydraulic gradient were made with various natural porous media (sand, sandstone, crumbled rock, loess, clay).

All these material contain definite quantities of oozy minerals which, because of their small dimensions and the specific crystal structure of their grains, interact strongly with aqueous solutions. At the surfaces of the grains, specific physicochemical phenomena occur, leading to the formation of surface layers of solution whose properties are significantly different from the properties of the pure filtrating solution. If the thickness of these layers is comparable with a typical diameter of the pore channels, their effect on filtration can be very significant. Familiar theoretical clarifications of the effect under discussion also involve the presence of such oozy materials in the porous body.

In this connection there is an important question: Will a nonlinear change be observed in the hydraulic conductivity during filtration in a porous medium which does not contain any oozy materials? This note is devoted to answering this question.

The experiments involved an artificial porous medium, a charge of grains of quartz glass, broken down to a given degree of dispersion. The choice of such a medium was determined by the following fundamental considerations:

1) the medium does not contain any oozy materials or allied alumosilicates;

2) quartz glass is completely insoluble in water and does not contain metallic cations which could change the ionic composition of the filtering solution;

3) the shapes of the grains of different sizes, obtained by breaking down the quartz glass, are approximately the same.

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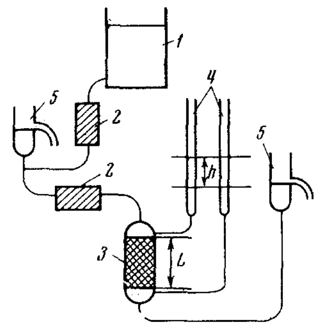

Fig. 1

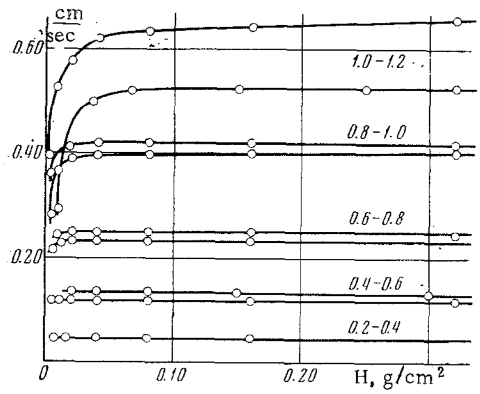

Fig. 2

Charges consisting of grains of the following degrees of dispersion were used in the experiment: 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, and 1.0-1.2 mm.

To prevent uncontrollable deviations in the composition of cations in the filtering solution, a $CaCl_2$ solution of concentration 10^{-3} g-eq/liter was used instead of distilled water.

A diagram of the experimental apparatus is given in Fig. 1. The whole apparatus (including the supply tank 1 is thermostatically controlled in a special chamber at 26.8-27.2°C. The porous charge of height $\sim$ 10 cm is placed in the vertical cylindrical vessel 3 of cross-sectional area 10 cm^2 and it is ensured that the quartz glass grains are completely irrigated and that they are packed as tightly as possible in the vessel. Before introduction into the charge, the solution is purified of possible suspended particles using two porous filters 2 consisting of grains of quartz glass whose degree of dispersion is lower than that of the grains in the charge. To ensure stability of the pressure drop in the charge, overflow vessels 5 were used. The difference between the levels in the piezometric tubes 4 was measured using a cathetometer; the flow rate was measured by weighing the fluid passing through the system in a given time interval.

The filtration coefficient was calculated from the equation

$$k = \frac{QL}{Ah} = \frac{Q}{AH}$$

Here A is the cross-sectional area of the charge, equal to 10 cm^2; Q is the flow rate measured to 0.1%; L is the height of the charge, which was constant in all the experiments and equal to 10 cm to an accuracy of 0.5%; h is the difference, specified in the experiments, in the piezometric levels (the accuracy with which this was determined varied from 10% for $h = 0.05$ cm to 0.1% for $h = 3.2$ cm).

The total measurement error could be as high as 12% for the smallest values of the hydraulic gradient used, and $\sim$ 1% for the largest values.

The values of k calculated from two independent series of experiments are shown in Fig. 2, where the individual experimental points and the corresponding curves for k as a function of H are given for different grain sizes (the sizes are written beside the curves). The curves in Fig. 2 are convincing evidence that the hydraulic conductivity falls as the hydraulic gradient decreases when the gradient is small, even when the filtration in the medium is free of any oozy substances. This effect is particularly marked for charges of coarse grains (1.0-1.2 mm for $H \leqslant 0.08$ and 0.8-1.0 mm for $H \leqslant 0.04$), and it vanishes when we move to finer grains and when H increases. Thus, for grains of sizes 0.2-0.4 mm and 0.4-0.6 mm, no nonlinear change in k was observed in general for H between 0.005 and 0.32. It can only be guessed whether such an effect exists when $H < 0.005$ for these and smaller grains.

A completely new situation, observed in the above experiments, is the increase in the effect of a change in the filtration coefficient as the grain size, and consequently, the pore dimension of the medium increases. Whereas for a medium with grain size 0.8 mm or greater the effect is unmistakeable, for a medium with grain size of 0.4 mm or less the effect either does not occur or is negligibly small.

This confirms that a possible reason for the nonlinear change in the filtration coefficient is to be sought not only in physicochemical, but also in purely hydraulic factors.

LITERATURE CITED

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