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Abstract

Full Text

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HYDRAULIC RESISTANCE OF A GRANULAR POROUS MEDIUM IN THE PROCESS OF COLMATATION

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The question of the hydraulic resistance of a granular porous medium in the process of colmatation during the filtration of suspensions is of great importance in hydraulic engineering, hydrogeology, irrigation, water supply, oil production, and other branches of technology.

As is known, in the range of validity of the linear law of filtration the following relation holds:

$$K/K_0 = (m/m_0)^3(\omega_0/\omega)^2, \tag{1}$$

where K and K_0 are filtration coefficients, m and m_0 are the values of the fraction of free volume (porosity), and ω and ω_0 are the values of the specific surface of the pore channels, respectively, at a given degree of colmatation and at the initial moment of suspension filtration.

Usually the degree of colmatation is characterized by the saturation of the pore space with sediment

$$\delta = (m_0 - m)/m_0 \tag{2}$$

and the ratio of the filtration coefficients is expressed as a function of saturation. However, the dependences proposed by various authors ([1–4]) give widely differing results (Fig. 1).

Fig. 2. Characteristic curves of the change in porosity (1) and specific surface of the pore channels (2) during filtration. *a* –suspension of peat extract with the addition of $Al_2(SO_4)_3$; *b* –natural water of the Skhodnya River with the addition of $Al_2(SO_4)_3$.

Figure 2: Fig. 2. Characteristic curves of the change in porosity (1) and specific surface of the pore channels (2) during filtration. *a* –suspension of peat extract with the addition of $Al_2(SO_4)_3$; *b* –natural water of the Skhodnya River with the addition of $Al_2(SO_4)_3$.

Fig. 1. Results of calculations of the filtration coefficient. 1–Kozeny formula, 2–Mints formula, 3–Schechtman formula, 4–Mackrle formula.

Some authors ([1,2]) determine the dependence theoretically, starting from an *a priori* adopted model of the change in the geometric structure of the porous medium during its silting; others do so experimentally, calculating the saturation from the weight amount of deposits with an approximate estimate of the density of the deposits and assuming that the sediment is incompressible during colmatation ([3,4]). Direct measurements of saturation were not carried out because of the difficulty of measurements without disturbing the structure of the sediment. As was noted ([5]), this is the weakness of the modern theory of suspension filtration through a granular porous medium and the reason for discrepancies in calculation results.

One of us developed a method for experimentally determining saturation by measuring the true mean velocity of motion of an indicator solution through a porous medium. The method is based on the known procedure for determining flow velocities with the aid of indicators ([6–8]), modified for the conditions of the present problem.

Into a filtration column $D = 32.6$ mm, between two pairs of silver electrodes, the filtering material was placed: homogeneous quartz sand with grain diameters of 1.07 and 1.49 mm and a layer thickness of 30 mm. Elec-

electrodes served to measure the true velocity of motion of the indicator solution through the filtering layer, determined from the change in electrical conductivity. The third pair of electrodes was placed at a distance of 30 mm above the layer to determine the velocity of motion of the indicator in the free volume of the column, in order to check the accuracy of the measurements by comparison with volumetric determinations of the flow rate of the indicator solution through the column cross section.

A 1.25% NaCl solution was used as the indicator. The change in electrical conductivity during the motion of the indicator was recorded continuously on photographic paper by an K4-51 optical self-recorder.

Fig. 2. Characteristic curves of the change in porosity *(1)* and specific surface of the pore channels *(2)* during filtration. *a* –suspension of peat extract with

the addition of $Al_2(SO_4)_3$; b —natural water of the Skhodnya River with the addition of $Al_2(SO_4)_3$.

The series of experiments described here was designed with reference to the operating conditions of filters for water purification.

Various suspensions simulating natural waters, and water from the Skhodnya River with the addition of coagulants and flocculants used in water treatment, were filtered through the column.

The experimental procedure consisted in alternating cycles of filtration of suspensions (from top to bottom) at a constant filtration rate within the range from 4 to 12 m/h and cycles of measuring saturation, with passage of the indicator through the silted sand layer (from bottom to top) at a filtration rate of 0.7 m/h. The saturation was determined every 20 min after measuring the head loss in the layer.

The choice of the thickness of the filtering layer, grain size, indicator concentration, and the velocity and direction of its motion was determined by obtaining acceptable measurement accuracy, which proved to be within ±3%.

From the results of measurements of the true velocity of motion of the indicator u and the velocity of its motion in the column above the sand layer u_ϕ, the fraction of free pore volume (dynamic porosity) m at different stages of clogging of the layer was determined by the formula

$$m = u_\phi / u \quad , \tag{3}$$

the saturation of the pore space with deposit by formula (2), and the ratio ω/ω_0 from formula (1).

The investigations showed that, during filtration of suspensions at a constant rate under conditions in which no deposit forms above the surface of the filtering layer and suspended particles are retained within the body of the layer (conditions characteristic of the filtration of finely dispersed, low-concentration suspensions on water-treatment filters), complete clogging of the pores is never reached. In all experiments the porosity decreased only to a certain limit (Fig. 2). The value of the limiting porosity differed depending on the type of suspension being filtered, the filtration rate, and the grain size.

Thus, new experimental confirmation has been obtained for the fundamental hypothesis of the theory of filtration of dilute suspensions: the existence of a limiting saturation $\delta_{\text{pr}} < 1$, upon reaching which an elementary filtering layer ceases to retain suspension particles and further colmatation of the pores stops (9).

Experiments also showed that, in the process of colmatation, the specific surface washed by the flow changes: at the beginning of the process it increases, then decreases, and, as it approaches the limiting value, further change in the specific

Fig. 3. Points—experimental data on the change in the filtration coefficient. Curve $K/K_0 = (1-\delta)^3$

Figure 3: Fig. 3. Points—experimental data on the change in the filtration coefficient. Curve $K/K_0 = (1-\delta)^3$

surface ceases (Fig. 2). The curves of change in specific surface, while retaining the same character for different suspensions and filtration velocities, nevertheless show the absence of an unambiguous dependence of ω/ω_0 on saturation. Consequently, there can be no unique dependence of the filtration coefficient on saturation over the entire range of variation of the latter.

Fig. 3. Points—experimental data on the change in the filtration coefficient. Curve
$K/K_0 = (1-\delta)^3$

The increase in hydraulic resistance throughout the entire thickness of the filter during its colmatation is formed mainly at the expense of the first layers in the direction of motion, which, under sufficiently prolonged filtration, are in a state of limiting saturation.

As our experiments showed (Fig. 3), for such layers the best results are given by the formula

$$K/K_0 = (m/m_0)^3 = (1-\delta)^3. \tag{4}$$

However, the root-mean-square deviations between the experimental and calculated values are rather large, $\pm 30.2\%$. The main reason for the discrepancies apparently consists in the fact that, at limiting saturation, the ratio of specific surfaces may be somewhat greater or less than 1. So far it has not been possible to detect any regularity in the formation of the surface of deposits at limiting saturation of the filtering layer under various conditions of suspension filtration.

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