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EFFECT OF THE INHOMOGENEITY OF THE GRANULAR CHARGE IN WATER-PURIFYING FILTERS ON THE INCREMENT IN THE HEAD LOSSES DURING COLMATATION

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The results of some experimental investigations into the relationship between the increment in the head losses of the colmatizing granular charge of a water-purifying filter and its degree of inhomogeneity are presented.

Granular filters are widely employed in preparing water for industrial and drinking purposes. Regulation of the structure of the granular bed (granulometric composition, height, microgeometry of the grains, etc.) is one of the chief ways of improving efficiency. Thus, Martensen's proposal [1] to replace quartz sand by crushed lightweight aggregates of various classes having a high intergranular porosity and a well-developed grain surface increased the productivity of ordinary filter constructions [2, 3] by a factor of two or three times and led to the development of new and more perfect systems [4]. In order to make the best possible use of the advantages of the new filter materials it is essential to develop a reliable method of calculating their properties, and, in particular, a method of choosing the optimum inhomogeneity of the bed with respect to grain size.

According to Mints and Krishtul [5, 6] the increment in the head losses of a silting, inhomogeneous charge during the separation of low-concentration suspensions is given by $\Delta h = h_0 \varphi \gamma T_c$, where $T_c = t d_{eq}^{0.5} x^{-1}$, $d_{eq} = \sum_{i=1}^{N} p_i d_i$. As regards charges of quartz sand, it was found that the size inhomogeneity of the grains could conveniently be represented by a power function:

$$\varphi = R^{-2}, \tag{1}$$

where $R = d_{0-20} d_{eq}^{-1}$ is the inhomogeneity coefficient. The quantity d_{0-20} is obtained from a granulometric analysis of the charge. It is here assumed that during the periodic regeneration of the charge in a rising water flow with a 40-50% expansion of the bed a strict classification of the grains is made with respect to geometrical size (in the normal operation of a system of washing-water distribution this requirement is met by quartz sand).

It was shown earlier that lightweight aggregate grains were classified less sharply than quartz in the course of regeneration [7]. This is because of the complex microgeometry of the aggregate grains and also their variable density — the crushing operation is applied simultaneously to the fused crusts and swollen mass of the aggregate gravel. Under these conditions the use of Eq. (1) in calculating filters with a lightweight aggregate charge fails to satisfy engineering requirements. In order to improve the equation we undertook some experiments based on the method described in [6].

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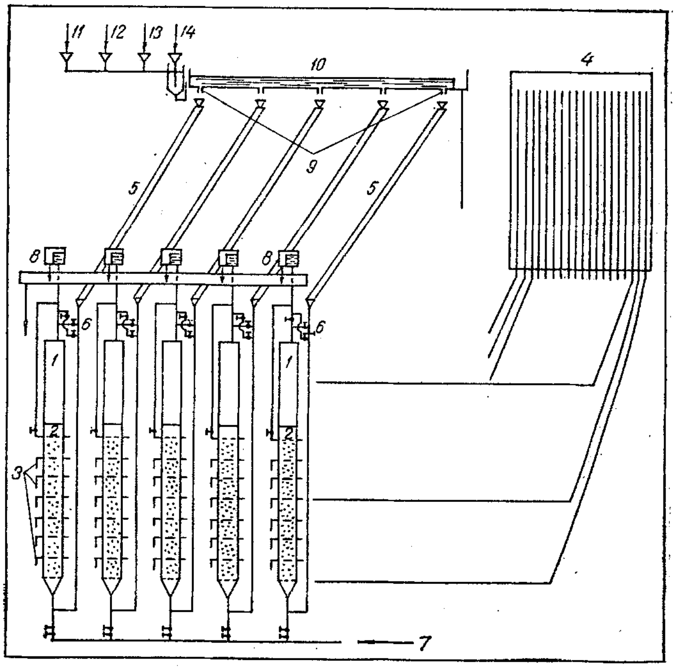

Fig. 1. Arrangement of the experimental apparatus: 1) columns of Plexiglas (d = 0.1 m, H = 3.0 m); 2) drainage tubes (for the two-flow scheme); 3) filtrate samplers; 4) piezometric panel; 5) air-separating pipes; 6) switching unit; 7) supply of water for regenerating the charge; 8) compensating tanks; 9) flow-rate washers; 10) distributing tank; 11), 12), 13), 14), supply of Volga water, turbidizer (for working with artificial suspensions), coagulant, and flocculant, respectively.

The arrangement of the experimental apparatus is shown in Fig. 1. Into the five columns, distinguished solely by the granulometric composition of the granular bed, we passed Volga water at an identical velocity in a specified direction: top to bottom ($R < 1$) or bottom to top ($R > 1$). The filtering charge was composed of fractionated granular material obtained by crushing lightweight aggregate granules of the 550 type (bulk density 550 kg/m^3). Specified fractions were prepared by sifting the dry material through woven wire sieves, and (after wetting) additionally subjecting these to hydraulic sorting in an ascending flow. The characteristics of the charge are presented in Table 1. Five series of experiments were carried out: series I-IV with a rising and series V with a falling flow of Volga water having a turbidity of 4-6 mg/liter and a color index of 25-35°, treated with a coagulating electrolyte (aluminum sulfate) at a dose of 30-60 mg/liter, and in series II-IV with a coagulating electrolyte (same dose) and a flocculant (polyacrylamide) at a dose of 0.05-0.1 mg/liter. The filtration rate was 8.7-8.9 m/h.

In order to determine φ we used the concept of the relative intensity of the increment in head losses,

$$R_i = (\varphi\gamma)_i\ (\varphi\gamma)_0^{-1} = \Delta h_i\ \Delta h_0^{-1}. \tag{2}$$

Here the indices i and 0, respectively, relate to inhomogeneous and homogeneous (standard) charges. Since the amount of water incident upon the charges under comparison was exactly the same in these experiments, we have $\gamma_i = \gamma_0$. For the column with the standard charge $\varphi = 1$. In this case from Eq. (2) we have $R_i = \varphi_i$. The resultant values of $(\varphi,\ \gamma)_i$ and φ_i are given in Table 2. To each type of charge there corresponds a specific value of φ_i. It was desirable to establish the dependence of this quantity on the parameter of the granular layer (the latter being quite easy to determine experimentally). Krishtul showed that among the many relationships tested Eq. (1) was the most successful, but gave no explanation for this. The explanation may be seen from physical considerations of the filtration process: a high degree of astabilization of the suspension, achieved by introducing a coagulating electrolyte into the filtering water, ensures the arrest and rapid accumulation of contaminants, and hence a rapid increment in the head losses within the first layers (beds) of the charge. The thickness of these is comparable with the thickness

TABLE 1. Characteristics of the Granular Charge of the Filters

Grain size, mm			Content of the fractions in the columns, %				
min.	max.	mean	1	2	3	4	5
0,73	1,03	0,88	—	10	10	10	20
1,03	1,25	1,14	—	10	10	10	20
1,25	1,32	1,29	—	20	20	20	10
1,32	1,50	1,41	100	40	20	20	10
1,50	2,30	1,90	—	20	20	20	10
2,30	3,70	3,00	—	—	20	—	6
3,70	4,30	4,00	—	—	—	20	4
4,30	5,70	5,00	—	—	—	—	20
Equivalent diameter			1,41	1,34	1,49	1,53	1,49
Coefficient of inhomogeneity (rising filtration)			1,0	1,42	2,01	2,61	3,36
Coefficient of inhomogeneity (falling filtration)			1,0	0,75	0,68	0,66	0,59

TABLE 2. Determination of the Parameter φ from Experimental Data

No. of series	No. of expt.	Values of $(\varphi\gamma)_i$ for columns					Values of φ_i for columns				
		1	2	3	4	5	1	2	3	4	5
I	4	44,2	34,5	31,1	28,7	25,1	1,0	0,778	0,703	0,649	0,568
	6	39,3	31,1	27,1	25,5	24,9	1,0	0,792	0,690	0,648	0,633
	7	38,7	31,0	28,6	25,5	24,7	1,0	0,800	0,739	0,658	0,638
	8	43,7	34,0	28,7	23,9	22,3	1,0	0,777	0,656	0,548	0,510
	13	38,0	31,0	27,5	23,9	22,1	1,0	0,817	0,725	0,628	0,583
						$\bar{\varphi}_i$	1,0	0,792	0,702	0,625	0,587
II	3	90,6	77,4	64,2	58,0	53,4	1,0	0,854	0,708	0,640	0,589
	9	82,7	65,1	57,0	48,6	44,4	1,0	0,789	0,690	0,588	0,537
	10	80,4	66,2	58,9	52,2	49,1	1,0	0,824	0,733	0,650	0,612
	11	72,6	60,2	53,0	46,1	40,9	1,0	0,828	0,729	0,635	0,563
	12	74,9	59,4	52,3	46,3	42,8	1,0	0,793	0,698	0,617	0,572
						$\bar{\varphi}_i$	1,0	0,818	0,712	0,603	0,575
III	14	61,8	47,2	37,4	35,0	34,1	1,0	0,764	0,605	0,567	0,552
	15	64,7	51,5	45,4	40,7	32,1	1,0	0,798	0,701	0,628	0,496
	16	56,0	52,1	42,7	39,1	31,6	1,0	0,931	0,762	0,698	0,564
	17	56,6	53,0	42,2	38,7	31,1	1,0	0,936	0,744	0,683	0,549
						$\bar{\varphi}_i$	1,0	0,857	0,703	0,644	0,540
IV	18	80,1	70,6	58,9	50,9	46,7	1,0	0,872	0,734	0,634	0,573
	19	71,3	62,6	50,9	42,3	39,7	1,0	0,881	0,713	0,594	0,554
	20	75,9	69,7	53,1	47,4	43,3	1,0	0,918	0,698	0,624	0,570
	21	103,0	86,6	76,7	71,2	69,8	1,0	0,842	0,745	0,692	0,678
						$\bar{\varphi}_i$	1,0	0,878	0,722	0,661	0,596
V	22	57,7	65,4	71,9	73,8	83,3	1,0	1,130	1,245	1,280	1,445
	23	61,8	71,3	67,7	70,8	79,5	1,0	1,153	1,100	1,146	1,290
	24	70,3	74,8	81,4	86,4	93,1	1,0	1,065	1,160	1,230	1,323
	25	60,4	67,3	70,6	73,5	81,7	1,0	1,116	1,168	1,219	1,353
	26	63,2	69,5	70,0	73,9	81,5	1,0	1,110	1,159	1,209	1,350
						$\bar{\varphi}_i$	1,0	1,115	1,166	1,217	1,352

of the bed in which complete mixing of all the components of the flow is achieved, the so-called complete mixing cell (in the particular case of the motion of nonadsorbed solutions this is a function of the Reynolds number) [8]. The length of such a cell in the range of velocities, grain sizes, and charge heights existing in practical filters is 10-30% of the total height of the bed. The mean value of this length proved quite acceptable for explaining the experimental results of [6]. In order to analyze the experimental data for the crushed lightweight aggregate here under consideration we may also use the quantity d_{0-20}. Subsequently, it will be desirable to establish a more rigorous dependence of R on the complete-mixing cell length, which in general depends on the size and microgeometry of the grains, the filtration velocity, the form of treatment with the reagent, the time of contact between the reagent and the water before passing into the granular layer, and so on.

The experimental points for crushed aggregate (Table 2) are approximated by a curve of the hyperbolic type:

$$\varphi = R^{-0.5}. \tag{3}$$

This expression may be used in technological calculations. According to [5] the inhomogeneity of the charge has the greatest effect on the time of operation of the filter before the limiting head losses are reached:

$$t_c = (H_{\lim} - h_0)\varphi^{-1}\left(\frac{h}{t}\right)^{-1}. \tag{4}$$

It is quite clear from an analysis of Eqs. (1), (3), and (4) that the same degree of charge inhomogeneity is less significant for a lightweight aggregate bed. This is in conformity with the results of observations relating to the operation of industrial filters with aggregate and quartz charges, and (as already indicated) may be explained by the less sharp classification of the lightweight aggregate during its regeneration in a rising flow of water. In filters with a falling type of filtration, this latter circumstance ensures a more complete use of the capacity of the charge to accommodate contaminants, by virtue of the easier penetration of the contaminants into its interior. In filters with a rising type of filtration, it may also be appropriate to use charges with an increased inhomogeneity. The normal conditions of regeneration are then preserved, and a more complete use of the crushed lightweight aggregate in creating the filtering charge is achieved.

NOTATION

h, h_0, losses of head in the clean and silted charges; Δh, increment in head losses during the period of operation of the filter t; T_c, criterial complex characterizing the total duration of the filtering cycle; d, diameter of the charge; x, height of the filter bed; γ_0, coefficient allowing for the physicochemical properties of the water being filtered, the mode of treatment with the reagent, and the properties of the granular bed: φ, parameter taking account of the bed nonuniformity; d_{eq}, equivalent diameter; p_i, percentage content of the fractions with average grain diameter d_i (average with respect to the cell dimensions of adjacent sieves); R, inhomogeneity coefficient; d_{0-20}, mean grain diameter of the first (reckoning along the direction of the filtering flow) bed, having a thickness equal to 20% of the total height; t_c, period of operation of the filter before reaching the limiting loss of head $H_{\lim}$.

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