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HIGH-SPEED FILTRATION REGIMES IN THE MAGNETIC SEPARATION OF PARTICLES FROM LOW-CONCENTRATION MONO- AND POLYDISPERSE SUSPENSIONS OF MAGNETITE

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A determination is made of high-speed filtration regimes for magnetite suspensions with particles of the same and different coarseness settling in a bed of magnetized balls.

In practice, particle deposition from suspensions takes place in monodisperse and, more frequently, polydisperse suspensions [1], i.e., in suspensions containing particles of roughly the same or different coarseness, respectively. Methods and equipment differing in the nature of the action on the particle — gravitational, centrifugal, electrical, or magnetic — are used, depending on the processing conditions and the properties and coarseness of the disperse-phase particles.

In those cases when the disperse phase of the suspension has ferromagnetic properties, preference is naturally given to magnetic separation. This method is effective, for example, in magnetized granulated media when these suspensions are passed through them. Such media, forming magnetic field-traps characterized by high intensity and a high degree of nonuniformity [2, 3], make it possible to conduct the deposition process at a fairly high rate of suspension filtration: 200-300 m/h [4-8], and even 1000 m/h under favorable conditions [9]. At the same time, it ensures efficient separation of particles of different coarsenesses, in-

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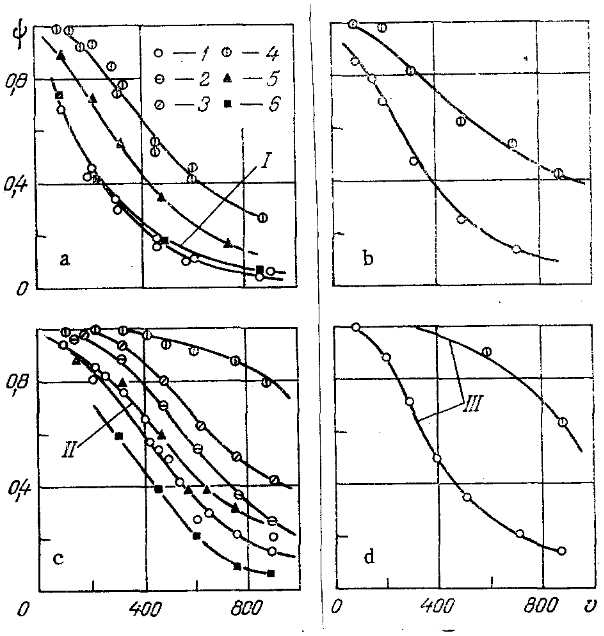

Fig. 1

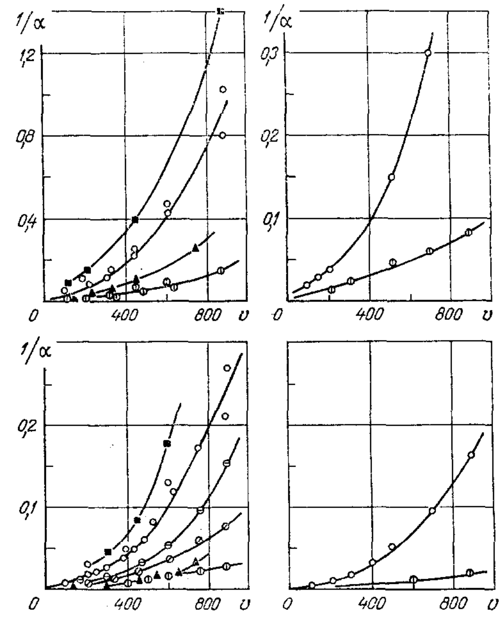

Fig. 2

Fig. 1. Effect of filtration rate v (m/h) on the efficiency of magnetic separation of magnetite particles in the clarification of monodisperse suspensions in magnetized granular media: L = 4.2 cm (with the exception of I, II, III); 1H = 30 kA/m; 2) 52; 3) 75; 4) 125 (1-4, d = 5.7 mm); 5) d = 3.1 mm; 6) d = 7.9 mm (H = 30 kA/m); I) L = 8.4 cm; II) 1.1; III) 2.1. a) δ = 3-5 μm; b) 7-9; c) 10-15; d) 15-20.

Fig. 2. Effect of filtration rate on the inverse coefficient of absorption of the magnetite particles by the magnetized granular medium; same notation as in Fig. 1.

TABLE 1. Fractional Composition of Magnetite Used in the Experiments

Particle size, μm	0–4	4–8	8–15	15–30	More than 30
Percentage of total content, %	37,6	31,1	10,7	7,9	12,7

cluding fine particles (down to 10-0.1 μm and less) from low-concentration suspensions containing on the order of 10^{-6}-10^{-8} mass fractions of an impurity disperse phase [3-8].

It stands to reason that the optimum rate — the rate which, on the one hand, will ensure maximum productivity and, on the other hand make it possible to obtain the required degree of separation (level of extraction) of the ferromagnetic fraction and provide the necessary quality of clarification of the suspension — depends on a whole range of factors, the primary factors being the coarseness of the dispersed particles δ, the intensity of the magnetic field H, and the diameter of the magnetized granules d. This explains the wide range of data obtained for the high-speed regime. Establishing the appropriate quantitative relations would make it possible to predict the required degree of separation and the optimum speed regime. To do this, we conducted experiments (Fig. 1) involving determination of the efficiency of magnetic separation ψ (the relative decrease in particle concentration) during the clarification of a magnetite suspension passed through a magnetizing granular medium. The first step was to take a polydisperse magnetite suspension prepared by the method in [10] and subject it to multiple sedimentation to separate out monodisperse volumes with particle fractions of roughly the same coarseness: 3-5, 7-9, 10-15, and 15-20 μm reducible to a mass fraction of the disperse phase equal to $(1\text{-}3)\cdot10^{-5}$.

The empirical dependences of ψ on v that we obtained (Fig. 1) were analyzed in the coordinates $1/\alpha$ and v [6] (Fig. 2), where α is the absorption coefficient, determined from the physical model of an exponential absorbing shield [3-8]:

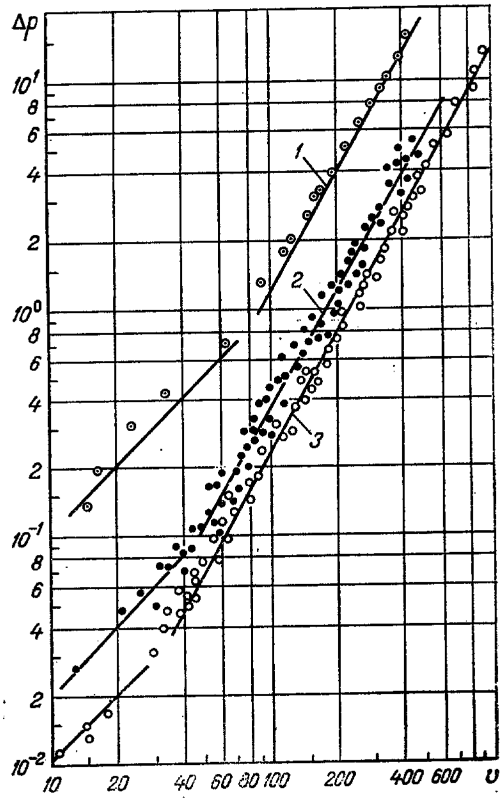

Fig. 3

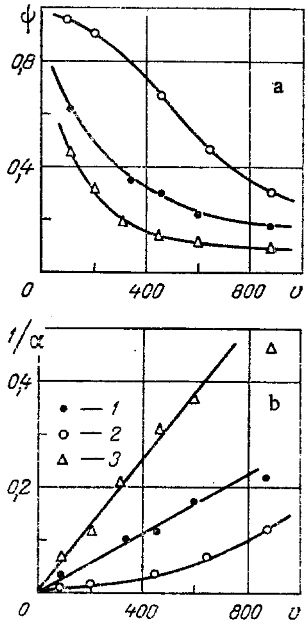

Fig. 4

Fig. 3. Dependence of the hydraulic resistance of the granulated medium on the filtration rate. The "break" corresponds to transition of the liquid flow regime from laminar to turbulent: L = 0.24 m; 1) d = 3.1 mm; 2) 6.0; 3) 7.9.

Fig. 4. Effect of filtration rate on efficiency of magnetic separation (a) and the inverse absorption coefficient (b) in the clarification of polydisperse suspensions of magnetite with broad and narrow particle-coarseness spectra: 1) corresponds to the entire spectrum of coarseness of the investigated magnetite; 2) >8 μm; 3) ≤8 μm; L = 4.2 cm, H = 30 kA/m, d = 5.7 mm.

$$\psi = 1 - \exp(-\alpha L). \qquad (1)$$

Representation of the test data in these coordinates makes it possible to clearly analyze the speed regime: the process may be considered favorable if the dependence of $1/\alpha$ on v is linear. Here, it is best that the adopted regime speed v_r correspond to the end section of this relation, when maximum productivity is assured.

The linear dependence of $1/\alpha$ on v (Fig. 2), i.e., $\alpha \sim v^{-1}$, is actually favorable for the process since, in accordance with the model of an exponential absorbing shield (1), the weakening effect of the velocity v may be easily compensated for by, for example, increasing the length L. Considering that $\alpha \sim H^{0.75}$ [3, 6, 7], it could also be compensated for by the intensity of the magnetic field H. If the dependence of $1/\alpha$ on v becomes nonlinear and parabolic (Fig. 2), i.e., $\alpha \sim v^{-2}$, then such compensation becomes very difficult. Thus, it is undesirable to conduct the process under such conditions.

We can attempt to link the regime speed of this process with the speed at which the regime of motion of the liquid in the pores of the granulated medium changes from laminar to turbulent. However, this case completely excludes the effect of the coarseness of the dispersed particles and the intensity of magnetization of the granulated media on the magnetic separation process. Figure 3 shows the dependence of the hydraulic resistance of granulated media Δp placed in a cylindrical column 30 mm in diameter. It is apparent that the transitional region, which shifts slightly to the right with a decrease in the diameter of the granules d, is located in the range of relatively low filtration rates v_p = 30-90 m/h.

As concerns the regime speed v_r (in accordance with the chosen criterion), with relatively low H = 30 kA/m and δ = 3-5 μm (Fig. 2) it is 200-400 m/h and comes closest to v_p, since at such low H and δ the process of magnetic separation naturally comes to depend more on the hydrodynamics of the flow in the granular medium (evidently the correspondence would be complete with $\delta < 1-3$ μm or $H < 10-30$ kA/m). With an increase in δ to 7-9, 10-15, and 15-20 μm and an increase in H to 75 and 125 kA/m, regime speed can be increased to 600-1000 m/h (Fig. 2) or more. In this case, it is less dependent on the hydrodynamics of the liquid flow (Fig. 3).

Thus, particles can be magnetically separated from suspensions in magnetized granulated media in an efficient manner not only under laminar conditions and with developed turbulence, but also with high values of the intensity of the magnetizing field H and the coarseness of the dispersed particles δ, when the magnetized granules exert a greater effect on the particles.

If we attempt to clarify a polydisperse suspension, i.e., a suspension containing particles with a broad coarseness spectrum (Table 1) (within a range of two orders of magnitude), then the dependence of $1/\alpha$ on v becomes linear (Fig. 4) due to the presence of relatively small particles — which reduces the total separation effect at low v — and the presence of relatively coarse particles — which increases the total separation effect at high v. This linearization indicates the need to force the filtration rate, but with allowance for the percentage of coarse particles. It is typical that with a contraction of the coarseness spectrum in the direction of larger δ ($\delta > 8$ μm), the linear character of this dependence remains throughout the investigated range of v due to the increase in the mean particle coarseness. Conversely, with a contraction of the coarseness spectrum in the direction of smaller δ ($\delta \leq 8$ μm), when there are no relatively coarse particles, the dependence of $1/\alpha$ on v is evidence of the need to limit the regime speed — which is already v_r = 600-700 m/h at such values of δ (Fig. 4) — and it should be reduced to $v_r = v_p$ with a further decrease in δ.

NOTATION

δ, coarseness of the dispersed particles of magnetite in suspension, μm; H, intensity of the magnetizing field, kA/m; d, diameter of the granules of the magnetized medium, mm; ψ, efficiency of magnetic separation; α, coefficient of absorption of magnetite particles by the magnetized granular medium, 1/m; v, filtration rate, m/h; v_r, filtration regime speed, m/h; L, length of granular medium, cm; v_p, filtration speed corresponding to the transition of the regime of liquid flow in the granular medium from laminar to turbulent, m/h; Δp, hydraulic resistance, kPa.

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