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# STABILIZATION OF WATER SUSPENSIONS OF METAL POWDERS

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*Sedimentation stability of water suspensions of dispersed metal powders with water-soluble high-molecular compounds (HMC) added is investigated by a method of analyzing the kinetics of their sedimentation. When stabilizing by polyvinyl alcohol (PVA) the concentration regions of sedimentation stability for the suspensions are determined. The stabilization is explained according to the model of formation of coagulation HMC layers on metal particles. The dependence of the coagulation layer thickness on the concentration of PVA in the solution is estimated.*

Metal powder suspensions find application in various technological processes of powder metallurgy [1, 2]. When preparing and using the suspensions it is necessary to strive for their sedimentation stability. Nonstability of the suspensions leads to segregation even in technologically short time intervals.

The present work has investigated the stabilization of water suspensions of dispersed metal powders of carbonyl iron and nickel, chromium, molybdenum whose characteristics are given in Table 1. The specific surface of the powders was determined by desorption of argon.

The powder suspensions were prepared on water solutions of high-molecular stabilizers (HMS). Use was made of type PVS7/2 polyvinyl alcohol (PVA), type MTs-65 methylcellulose, and type KMTs 85/500 carboxymethylcellulose (CMC) as HMS. Solutions of the HMS were prepared on distilled water by standard procedures. The stabilizing action of the HMS was studied by the method of sedimentation of suspensions with the initial volume fraction of metal powders 5-15 vol. %. A suspension with the known initial metal powder concentration and HMS concentration in the water solution was poured into a measuring glass cylinder 100 mm high, thoroughly mixed, and the kinetics of powder sedimentation was studied in a time up to 300 hours. The suspension sedimentation in water and in HMS solutions is of a "slipping down" character [3]. In a small time interval in the upper portion of the suspension column a clear boundary emerges between the suspension and the transparent suspending liquid. The boundary moves down with a delay. Such a character of sedimentation is due to the interaction of dispersed particles of the powder in suspensions of medium concentration. From the initial instants the particles collide with each other. There occurs no sedimention classifying into sedimentation rates for the particles with various degree of dispersion.

To choose the optimal stabilizing substance, we analyzed the sedimentation kinetics of nickel powder suspensions in water and high-viscous HMS solutions with the initial powder concentrations 10 vol.%. From the obtained results it is evident (Fig. 1) that a sediment in the water is formed in less than one hour, and further its level is practically unchanged. The packing density of powder particles in water is close to their packing density after shaking down in air. The CMC insufficiently stabilizes the suspension; the suspension slowly sediments during the entire experiment. The suspensions on PVA and MC sediment to sediment densities substantially smaller than in water in a time of the order of 45 h. Stabilized sediments with PVA and MC added practically do not sediment in technologically acceptable, of the order of several days, time intervals. The kinetics of their sedimentation can be investigated when observing in very long time intervals. In practical application these suspensions may be considered stable from the viewpoint of sedimentation.

One may consider PVA as the best stabilizer since with the initial suspension viscosities close to MC the stabilized sediment is less concentrated with respect to the metal powder. For the iron, nickel, chromium, and molybdenum powders we performed the same investigations with varying amount of PVA in the solution. The kinetics

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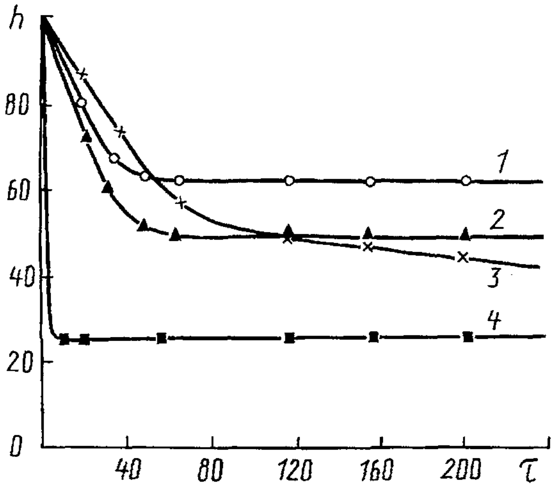


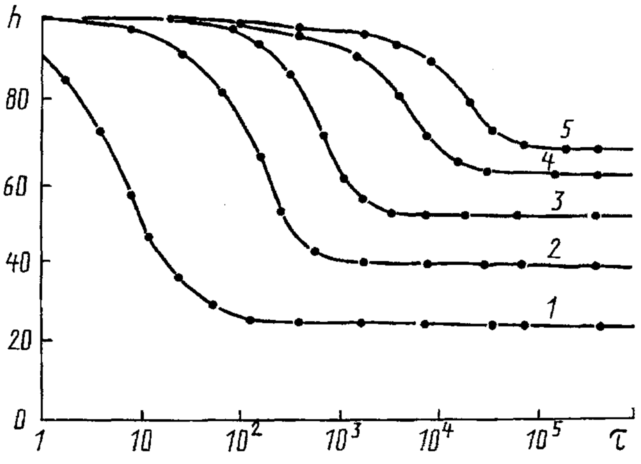


Fig. 1. Sedimentation kinetics for water suspensions of nickel powder: 1) 9% PVA; 2) 1.5% MC; 3) 4% CMC; 4) water. h, mm; τ, h.

Fig. 2. Sedimentation kinetics of nickel powder in water solutions of PVA: 1) 0; 2) 2.5%; 3) 5; 4) 9; 5) 11% PVA. τ, sec.

TABLE 1. Properties of Powders

| Powder | Type | $S_s$, $m^2/g$ | Density of shaking down, $g/cm^3$ |
|---|---|---|---|
| Iron | R-20 | 0.32 | 3.6 |
| Nickel | PNK OT-3 | 0.34 | 4.2* |
| Chromium | PKhS-1 | 0.19 | 3.1 |
| Molybdenum | MP4 | 0.27 | 3.3 |

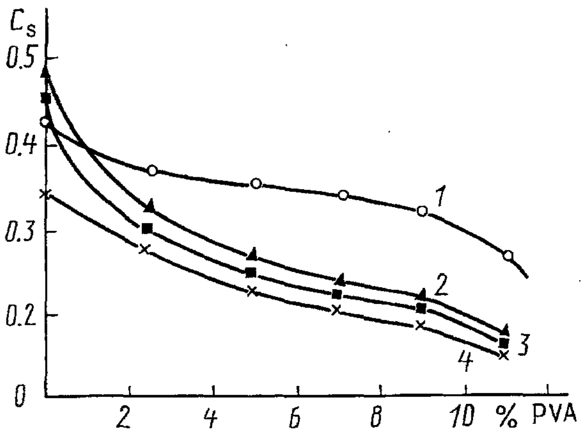
* To increase the shacking-down density, the powder is treated in a mixer.

of "slipping down" is most noticeable when the time is fixed at the logarithmic scale (Fig. 2). The figure shows in semilogarithmic coordinates the kinetics of "slipping down" of the nickel powder suspensions in water solutions of PVA of various concentration. Such a character of slipping down is also observed in the iron, chromium, and molybdenum powders.

With increasing PVA concentration and with compaction the rate of sedimentation for the suspensions slows down. From Fig. 2 it is seen that as a certain time interval passes, the height of the suspension column remains practically unchanged. On compaction the suspensions become stabilized. In this case as the amount of PVA in the solution increases, the height of the stabilized suspension column becomes larger. The resulting powder sediment in water lacks fluidity; as for the sediments, on the water solutions of HMS they are fluid suspensions. The concentration of the stabilized suspension $c_s$, which practically has ceased to sediment is related to the initial concentration $c_0$ by a simple relation

$$c_s = c_0 \frac{h_0}{h_s}.$$

With increasing PVA concentration the stabilized suspension becomes sedimentationally stable for a progressively smaller concentration of the metal powder. Figure 3 shows the variation in the volume concentration of the powders used in the investigations, which are stabilized by polyvinyl alcohol as its content in the solution grows. It is evident from the figure that the same amount of PVA variously affects the variation in the minimal concentration



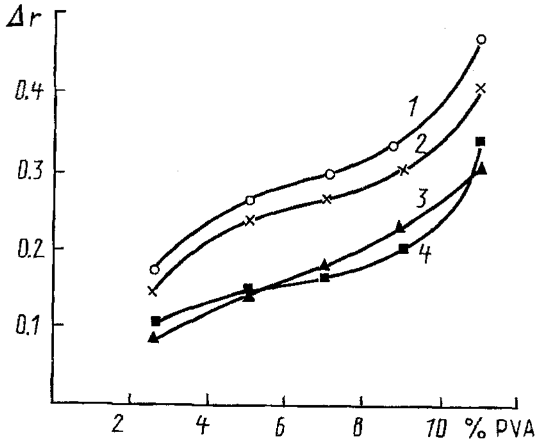


Fig. 3. Concentration of stable water suspensions of metal powders vs PVA content in water: 1) chromium; 2) nickel; 3) iron; 4) molybdenum.

Fig. 4. Calculated thickness of coagulation layers on metal particles vs PVA concentration in the water solution: 1) iron; 2) nickel; 3) molybdenum; 4) chromium. $\Delta r$, $\mu$m.

of the stabilized suspension. The powders with a more developed surface are more dispersed and are stabilized in the suspensions better, as evidenced by the run of the curves in Fig. 3. With the volume fraction of the powder in the prepared suspension smaller than the minimal one, below the line in Fig. 3, it will be unstable. In a time interval as a result of "slipping down" in the upper portion a clear suspending liquid separates. If one takes a larger concentration of the powder the suspension will be stagnant since there is not enough liquid to fill the interparticle gaps. It is only in the region between these concentration limits that the suspension is fluid and sedimentationally stable alike

An explanation of the stabilizing action of HMS on suspensions of metal powders can be offered on the basis of the ideas, developed by the schools of P. A. Rebinder and V. V. Deryagin [4, 5], of formation of special layers on the particle surface. Owing to the HMS on the powder particles in the suspension there form separating coagulation layers with increased viscosity, whose thickness depends on the HMS amount in the suspending liquid. These layers are coalesced to the particles and their thickness is comparable to the dimensions of particles of the metal powders used. Protective layers smooth out microirregularities and have a "lubricating" action, which explains fluidity of stabilized suspensions. By recognizing that the height of the sediment in the stabilized suspension is proportional to its volume and an increment in the volume occurs in the presence of HMS at the expense of an increment in the radius of the powder particles as a result of formation of the HMS coagulation layers it can be written as

$$\frac{h_s}{h_w} = \frac{\sum\limits_{i=1}^{N}(r_i+\Delta r)^3 K}{\sum\limits_{i=1}^{N} r_i^3 K_w} \approx \frac{(r+\Delta r)^3 N_s K}{r^3 N_w K_w}. \tag{1}$$

The transformation $\sum\limits_{i=1}^{N}(r_i+\Delta r)^3/\sum\limits_{i=1}^{N}(r_i)^3 \approx (r+\Delta r)^3 N_s/r^3 N_w$ is possible where the metal powder has a moderately narrow fractional composition.

Assuming that the introduction of HMS insignificantly affects the character of the particle packing in the sediment we may consider $K_w = K$; then from (1) we obtain

$$\Delta r \approx r\left(\sqrt[3]{\frac{h_s}{h_w}} - 1\right) = r\left(\sqrt[3]{\frac{c_w}{c_s}} - 1\right). \tag{2}$$

The average particle radius is expressed in terms of the specific surface ($S_{sp}$) and the powder material density ($\rho$) :

$$r = \frac{3}{S_{sp}\rho}. \tag{3}$$

According to Eqs. (3) and (2) for the powders used we estimated the change in the thickness of the coagulation layers of PVA on the particles with change in its concentration in the water solution (Fig. 4).

Despite the series of the assumptions made, taking into account that the error of determining the value of the specific surface for the powders is about 10%, the dependences of the thickness of the calculated values of the coagulation layers on the PVA concentration in the water solution for the powders of different metals have a similar-slope character. Smaller calculated values for the chromium and molybdenum powders are apparently explained by the fact that these powders have a wide fractional composition from 0.5 to 40 μm, and applying Eq. (2) for them is incorrect. As the PVA concentration increases to 3-4% the layer thickness grows to 0.13-0.24 μm; over the interval 5-9% the dependence of the layer thickness on the PVA concentration becomes weaker, and over the interval 10-11% a new noticeable growth of the coagulation layer thickness is observed. This agrees with the fact that the PVA concentrations with 10-11% approach the saturation limit of the water solution.

From the obtained dependence it follows that the efficiency of the stabilized suspension substantially depends on the average dimension of the metal particles and on the PVA concentration in the water solution, a certain relation between the average dimensions of the particles and the thickness of the PVA coagulation layers being observed.

It follows from the experiment that for efficient stabilization $\Delta r/r$ is to be in the interval 0.20-0.30.

When using metal powders an 11% water solution of PVA can efficiently stabilize powder suspensions with the average dimensions of particles 4-5 μm. To stabilize powder suspensions with the average particle dimensions smaller than 1 μm a 2% PVA solution would suffice.

Thus, the kinetics of sedimentation of water suspensions of dispersed metal powders stabilized by HMS is experimentally investigated. The possibility to produce sedimentationally stable suspensions is identified. The dependence for the thickness of stabilizing coagulation layers of PVA on metal particles on its concentration in the water solution is obtained.

The results presented make it possible to determine, by the known average dimension of the metal particles, the concentration of PVA in the water solution necessary for stabilization and the permissible concentration intervals of the volume content of metal powder in the suspension with a guaranteed sedimentation stability.

## NOTATION

$S_{sp}$, specific surface of metal powders, $m^2/g$; $h_0$, $h_w$, $h_s$, height, respectively, of the initial suspension column, of the sediment in water, and of the stabilized sediment in a water solution of polyvinyl alcohol, mm; $c_0$, $c_w$, $c_s$, volume fraction of metal powder, respectively, in the suspension at the initial instant, in the settled-down sediment in water, and in the stabilized sediment in the PVA water solution; r, average radius of metal particles, μm; $\Delta r$, thickness of the PVA coagulation layer on metal particles, μm; , material density of metal particles, $kg/m^3$; $K_w$ and K, coefficient, taking account of metal particle packing density respectively in the sediment in water and in the stabilized suspension; $N_w$, N, number of metal particles in water and in the PVA water solution, $N_w \cong N$.

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