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ESTIMATE OF POWDER AGGREGATION AFTER THEIR RE-DISPERSION IN LIQUIDS

The article discusses main aggregation-desaggregation processes that take place upon mixing fine powders in a liquid medium. It is shown that the re-dispersion degree of the powders is affected by two successive processes, spreading of the liquid on the surface of the particles by penetrating through open polydisperse pores, and the penetration of the liquid into closed pores. The final result of the powder re-dispersion depends on the quantitative ratio of each of these re-dispersion stages.

The re-dispersion method for micro- and nanodispersed powder in liquid media of different chemical nature is proposed in terms of the number of primary particles (P_n) in their aggregates. The method is based on the estimate of the re-dispersion from the initial turbidity of suspensions. This approach makes it easy to determine the aggregation of powders after the re-dispersion in liquids from experimental data.

Re-dispersion; aggregation-disaggregation; fine powders; liquid medium.

The volumes of fine powders that are re-dispersed in liquid media during their treatment in the technological processes are currently continuously rising. Modern nanotechnologies also cause the increase of the dispersion of the industrial powders. This increase of the dispersion of powders makes the problem of the re-dispersion (repeated dispersion) in liquid media of current research interest. Obtaining high-quality, uniform in properties disperse systems can only be achieved on the condition of complete destruction of particle aggregates that exist in powders in air. Given this, the problem of determining their aggregation after the re-dispersion in liquids becomes an urgent challenge.

The long-range surface tension forces cause the formation of the aggregates of the disperse particles in air if the particle diameter varies [1]

$$\text{from } d_{\min} = \frac{24H_0kT}{A} \quad \text{to} \quad d_{\max} = \left(\frac{6kT}{\pi g \rho H_0} \right)^{1/3}, \quad (1)$$

where k is Boltzmann constant,

T is temperature,

A is Hamaker constant,

g is the gravity acceleration,

ρ is the density of the substance of the disperse particles,

H_0 is the equilibrium distance between the particles which varies due to the surface roughness between 0.2 and 1 nm.

The degree of powder re-dispersion in liquid media depends on many factors which affect the nature and magnitude of interparticle interactions. Liquid dispersion medium reduces the force of attraction between the particles, so they can contribute to the destruction of particle aggregates that exist in air.

The addition of air-aggregated powders in liquid medium is accompanied by the following physico-chemical processes:

- the re-dispersion of powder particles (destruction of aggregates that exist in the air);
- the interaction of the components of liquid medium with the surface groups of solid particles and the establishment of a new interface equilibrium;
- the interparticle interaction according to the changes in the balance of far-range surface forces due to the establishment of the new interface equilibrium.

The re-dispersion of powders in liquids takes place in two successive stages

- spreading of the liquid on the surface of the powders and the formation of the regions of enclosed air;
- seepage of fluid into closed air regions.

Since the contribution of each of the above steps has the opposite effect, the final degree of the powder re-dispersion depends on their quantitative ratio.

Experimentally, the re-dispersion degree of the powders in various dispersive media may be estimated from the initial turbidity of the suspension by calculating the coefficient of the number of

the primary particles in the aggregates. The passage of light through disperse systems is accompanied by the light absorption, scattering and reflection. The light intensity I_1 that is transmitted through the system equals:

$$I_1 = I_0 - I_2 - I_3 - I_4, \quad (2)$$

where I_0 is the intensity of the incident light,

I_2 is the intensity of the reflected light,

I_3 is the intensity of the scattered light,

I_4 is the intensity of the absorbed light.

Dividing both sides of equation (1) by I_0 and taking the turbidity of suspensions as [2]

$$\tau = \frac{1}{h} \ln \left(\frac{I_0}{I_1} \right) = \frac{2,3D_s}{h}, \quad (3)$$

we obtain

$$\exp(-2,3D_s) - 1 = -\frac{I_3}{I_0} - \frac{I_2}{I_0} - \frac{I_4}{I_0}, \quad (4)$$

where D_s is the optical density of the suspension,

h is the thickness of the suspension layer.

The ratio of the intensity of the scattered light to the intensity of the incident light, according to Rayleigh's law, equals:

$$\frac{I_3}{I_0} = k_0 v_a V_a^2 h, \quad (5)$$

where k_0 is the proportionality constant which is in inverse function of wavelength to the power from 4 to 2 [1],

v_a is the particulate concentration of the particle aggregates,

V_a is the volume of the particle aggregates.

The portion of the reflected light is proportional to the ratio of the area of the aggregates of the particles S_2 to the area of the luminous flux S_0 :

$$\frac{I_2}{I_0} = k_1 \frac{S_2}{S_0} = \frac{k_1 N_a S_a}{S_0} = k_1 v_a S_a h, \quad (6)$$

where k_1 is the proportionality constant,

S_a is the area screened by one particle aggregate,

N_a is the number of the aggregates in the way of the light flux.

The proportion of absorbed light is determined for colored media by the optical density of the liquid above the suspension sediment:

$$\frac{I_4}{I_0} = 1 - \exp(-2,3D_l), \quad (7)$$

where D_l is the optical density of the liquid above the suspension sediment.

Substituting (3-7) into (4), we obtain

$$\exp(-2,3D_s) - 1 = -k_0 v_a V_a^2 h - k_1 v_a S_a h - (1 - \exp(-2,3D_l)). \quad (8)$$

Let us assume the following notation:

$$v_a = \frac{V_0}{n}, \quad (9)$$

$$V_a = n k_2 V_0, \quad (10)$$

$$S_a = \pi r_a^2 = \pi \left(\frac{3V_a}{4\pi} \right)^{2/3}, \quad (11)$$

$$v_0 = \frac{C}{V_0 \rho}, \quad (12)$$

where v_0 is the particulate concentration of the suspension in terms of the primary particles,
 n is the number of the primary particles in the aggregates,
 V_0 is the volume of the primary particle,
 ρ is the density of the substance of the powder particles,
 C is the mass-volume concentration of the suspension,
 k_2 is the proportionality factor that takes into account the density of stacking of primary particles in aggregates.

Substituting (9-12) into (8), we obtain

$$P_n = \frac{\rho [\exp(-2,3D_l) - \exp(-2,3D_s)]}{Ch} = nk_3 V_0 + \frac{k_4}{(nV_0)^{1/3}}, \quad (13)$$

where P_n is the coefficient of the number of the primary particles in their aggregates,
 D_l is the optical density of the dispersive medium over the suspension precipitate,
 D_s is the initial optical density of the suspension,
 ρ is the density of the investigated powder substance,
 C is the mass-volume concentration, l is the thickness of the suspension layer,
 k_1, k_2 are the constants that depend only on the chemical nature of the powders,
 V_0 is the volume of the primary particles,
 n is the number of the primary particles in aggregates.

The left part of Eq. (13) contains values that are determined experimentally: D_l is the optical density of the dispersive medium over the suspension precipitate, D_s is the initial optical density of the suspension, ρ is the density of the investigated powder substance, C is the mass-volume concentration, l is the thickness of the suspension layer, therefore the coefficient P_n is easily calculated. For the powders of the same nature the two constants k_3 and k_4 and the volume of the primary particle V_0 which are on the right side of the equation are constants, while the number of the primary particles n in their aggregates depends on the nature of the dispersive medium and on the suspension concentration. Thus quantity P_n allows us to determine the aggregation degree of the particles and to estimate how the nature of the dispersive medium affects it.

Only minor light scattering is expected of the investigated suspensions, as the diameter of the particles is greater than one-tenth of the wavelength used for the measurements of optical length, therefore [3]

$$k_1 n V_0 < k_2 / (n V_0)^{1/3} \text{ and } P_n \approx k_2 / (n V_0)^{1/3}. \quad (14)$$

Neglecting light scattering, we may estimate the number of the primary particles in an aggregate upon the addition of the powder into various media and the re-dispersion ability of the media. The larger the P_n value for the powders of the same nature, the smaller the number of the primary particles in an aggregate is and thus the greater the re-dispersion ability of the medium is.

Thus the developed technique permits one to determine easily the degree of particle aggregation and to estimate the effect of the nature of the dispersion medium from experimental data.

The proposed technique was successfully tested for the investigation of the re-dispersion of fine powders of aluminium oxide, titanium dioxide, manganese and cobalt carbonates, basic carbonates of copper and nickel in liquid media of various chemical nature: bidistilled water, 1,4-dioxane, ethyl, isopropyl and isobutyl alcohols. The influence of industrial surfactants Hyamine 1622, Dinoram, Atlas G-3300, Emal-270D, Triton X-100, OC-20 on the re-dispersion of these powders in their aqueous solutions was also investigated.

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