ELECTRIC FIELD DEPENDENCE OF THE LIMITING CONCENTRATION OF AN EDF-SYSTEM

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Calculation results are reported for the dependence of the limiting concentration of microparticles under electrodynamic fluidization on the electric field intensity. The influence of the electrophysical properties of the surface layer of conducting particles on this dependence is discussed.

In [1] it is shown that for electrodynamic fluidization (EDF) of microparticles with finite conductivity their limiting concentration, with regard for the recombination mechanism of concentration limitation, is determined by \( \tau_c/\tau_\sigma \), where \( \tau_c \) is the time of contact of microparticles in collisions and \( \tau_\sigma = \varepsilon \varepsilon_0 / \sigma \) is the relaxation time of the charge. For microparticles having a high conductivity with \( \tau_c/\tau_\sigma \gg 1 \) the limiting concentration is independent of \( \sigma \) and \( E \) and is \( n_{cr} = 2n_{in} \). For microparticles with a relatively low conductivity and \( \tau_c/\tau_\sigma \ll 1 \)

\[
   n_{cr} = \frac{2n_{in}}{\tau_c/\tau_\sigma}.
\]

(1)

In [1], for this case a dependence of \( n_{cr} \) on particle size is determined, from a comparison of Eq. (1) with experimental data the parameter \( \sigma \) is evaluated, and the conclusion is made that the electrophysical characteristics of the surface layer of metal particles is the governing factor for their limiting concentration.

We will investigate the electric field dependence of the limiting concentration of EDF-particles and its features determined by the properties of the surface layer of conducting microparticles.

Analysis of Eq. (1) at constant conductivity of the surface layer of microparticles shows that the limiting concentration of EDF-particles depends on \( E \) only through the parameter \( \tau_c \), whose value is determined by the relative velocity of colliding particles \( \bar{V} \) [2]:

\[
   \tau_c = 4.53 \left[ \frac{\sqrt{2} \delta m}{\sqrt{\bar{V}}} \right]^{2/5} \sim \bar{V}^{-1/5}
\]

(2)

or

\[
   \frac{\tau_c}{\tau_\sigma} = \tau_c \left( \frac{V_{q_{max}}}{\bar{V}} \right) / \tau_\sigma \left( V / V_{q_{max}} \right)^{-1/5},
\]

(3)

where \( V_{q_{max}} = q_{max}E/s \) is the velocity of microparticles with the charge \( q_{max} \); \( \delta = (1 - \mu^2) / \pi \varepsilon_0 \) is a constant of the material. In order to determine \( \bar{V} \), it is necessary to consider the special features of particle charge distribution for this case. As is shown in [1], the distribution function has a gap at \( q = 0 \) whose width is dependent on the ratio \( \tau_c/\tau_\sigma \). For \( \tau_c/\tau_\sigma \ll 1 \), on attaining the limiting concentration the majority of particles are in the two charge states \( \pm \bar{q} \) separated by a gap with the width

\[
   \Delta = \frac{1}{2} q_{max} \left( \frac{\tau_c}{\tau_\sigma} \right)^2.
\]

(4)

Therefore assuming \( \bar{q} = \Delta / 2 \), we obtain
Fig. 1. Limiting concentration $n_{cr}/n_{in}$ (rel. units) as a function of the electric field intensity $E$ (V/m) for different materials: 1) theoretical dependence at $\tau_{c}/\tau_{o} \gg 1$; 2) iron powder with a particle size of $r = 6 \ \mu m$; points, data of [3]; curve, according to Eq. (7); 3, 4, 5) stainless steel, bronze with $r = 7 \ \mu m$, and graphite with $r = 3.15 \ \mu m$, respectively [5].

$$\tilde{V} = 2 \frac{\bar{q}E}{s} = 2V_{q_{\text{max}}} \frac{\bar{q}}{q_{\text{max}}} = \frac{1}{2} \left( \frac{\tau_{c}}{\tau_{o}} \right)^{2} V_{q_{\text{max}}}.$$  \hspace{1cm} (5)

Substitution of (5) into (3) gives the ratio $\tau_{c}/\tau_{o}$ expressed in terms of the time of contact $\tau_{c}(V_{q_{\text{max}}})$ at $\tilde{V} = V_{q_{\text{max}}}$

$$\tau_{c}/\tau_{o} = 2^{1/\gamma} \left( \frac{\tau_{c}(V_{q_{\text{max}}})}{\tau_{o}} \right)^{\gamma}.$$  \hspace{1cm} (6)

Then, according to (1) the limiting concentration of the EDF-particles may be expressed as

$$n_{cr}/n_{in} = \left( \frac{E}{E_{1}} \right)^{2/\gamma},$$  \hspace{1cm} (7)

where, with regard for the independence of the ratio $E/q_{\text{max}}$ from the electric field, $E_{1}$ is determined as

$$E_{1} = (2.27/\tau_{o})^{5/2} \delta_{m} \left[ \frac{sE}{r_{q_{\text{max}}}} \right]^{1/2}.$$  \hspace{1cm} (8)

Thus, the limiting concentration of microparticles is proportional to $n_{cr} \sim E^{2/\gamma}$ and it will rather slowly increase with electric field intensity. Correspondingly, at the same $E$ the limiting concentration of particles will depend on their size as $n_{cr} \sim r^{-22/\gamma}$ which virtually does not differ from the earlier obtained dependence $n_{cr} \sim r^{-3}$ [1].

Figure 1 shows the limiting concentrations obtained for iron powder particles with $r = 6 \ \mu m$ [3] for $E = (0.5 - 2.2) \cdot 10^{5}$ V/m. In this electric field intensity range the limiting concentration is seen to have almost a two-fold increase. In [3], this growth is explained by involvement of increasingly fine particles, contained in the initial material, in the fluidization process as the electric field intensity increases. However, it is easy to estimate that for microparticles close in size the electric field intensity at which particles rise from the lower electrode, is smaller by an order of magnitude than the values used in [3]. This means that in this case the increase in the limiting concentration with the electric field intensity is caused by an increase in the charge of the microparticles and their relative velocity and a corresponding decrease in the time of contact.

To calculate (7) (Fig. 1), we have used the following parameters: $\mu = 0.28$; $E_{0} = 20.6 \cdot 10^{10}$ N/m; $d = 10^{-2}$ m. Assuming $\varepsilon \approx 10$ [4], we obtain for the oxide layer $\sigma = 5.7 \cdot 10^{-4}$ S/m. This value is quite consistent with data of [4], where $\sigma \approx 10^{-3} - 10^{-5}$ S/m for iron oxides.