VIBRATORY FLUIDIZATION OF POLYMER POWDER BEDS FOR THE COATING PROCESS

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The state of polymer powder beds is analyzed in barrels vibrating vertically at frequencies from 10 to 200 Hz and at accelerations from 1 g to 35 g.

Polymer powders are fluidized for various purposes in the chemical, the machinery, the dye-and-varnish, and other industries. Such beds are fluidized by various methods: whirling, vibration, whirling and vibration, electrostatically, etc.

Various researchers [1, 2] have found that a bed of disperse material may either thicken or expand under the influence of vibrations. A static pressure higher than the pressure of the material column is produced in the bed. Expansion begins when the relative acceleration exceeds the unity level. According to prevalent opinion [3], 1.1-1.2 is the maximum expansivity of a polymer powder bed under vibration. This would almost preclude the feasibility of using vibratory suspension beds depositing polymer coats on parts. The relative acceleration decreases along the bed height, which results in a segregation of particles with respect to weight as well as size.

The authors studied the feasibility of fluidizing polymer powder beds by vibration, for the coating of metal parts–substrates. The following polymer compounds were used, all specimens of the same 200-250 μ grain size fraction: polycaproamide (PCA), pentaplast (PP), low-pressure polyethylene (LPE), and polyvinyl butyrene (PVB). In some cases, in order to detect the effect of the dispersivity on the state of suspension beds produced by vibration, we also tested powders of the 50-100 μ grain size fraction. Fluidization was effected in transparent barrels 75, 90, 120, 160, 260 mm in diameter with vertical graduation markers to indicate the height. The vibration parameters were varied as follows: frequency (f) from 10 to 200 Hz and acceleration (j) from 1 g to 35 g, the initial bed height in all tests was $H_0 = 100$ mm. A transition of the bed from one state to another was recorded cinematographically at the rate of 32 frames per second. The transition points have been plotted in j, f coordinates and curves through these points represent the boundaries between different zones of fluidization states.

Under the influence of vertical vibration, a powder bed can either thicken, remain stationary (apparently), or expand. The bed expansion, which is characterized by the coefficient $k_e = H_e/H_i$, determines the feasibility of dipping into the bed a piece of definite size and shape for coating its surface with polymer. Expansion by a factor 1.2-1.3 is caused by the movement of polymer particles within the upper bed layer only. Such a state is tentatively called "fluid," to differentiate it from the "boiling" state ($k_e = 1.3$-1.8) with particles moving throughout the volume. The maximum expansivity attained with the given polymer materials in our vibration tests was $k_e = 1.8$.

Polymer powders produced industrially are disperse and anisometric materials. The diversity of shapes, sizes, porosity levels, and polarity explain the different moisture absorption, agglomeration, and electrization characteristics of these materials as well as the formation of fluidized beds with different expansivities and different degrees of homogeneity in the distribution of particles in the barrel. PCA (200-250 μ grain size fraction) becomes "fluid" and then "boiling" at low frequencies (20-40 Hz) under accelerations 4-6 g and 10-12 g, respectively (Fig. 1a). "Fluidization" of PCA within the 50-80 Hz frequency occurs under lower accelerations (3 g or less). The lowest "fluidization" and "boiling" accelerations for PCA

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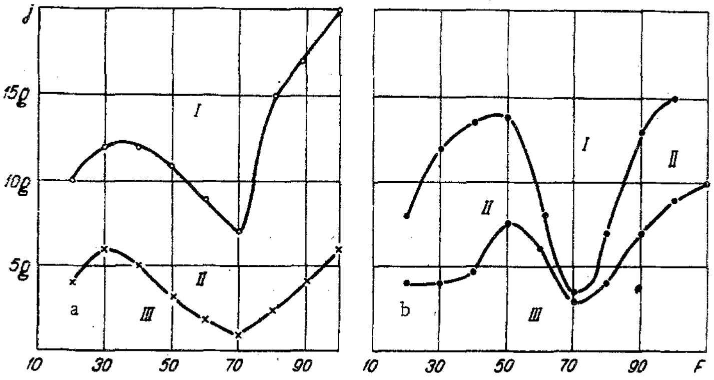

Fig. 1. Boundaries between the states of a PCA powder bed under vibration: a) powder dispersivity 250 μ; b) powder dispersivity 50-100 μ; I) boiling zone; II) fluidization zone; III) thickening zone. Acceleration j (m/sec^2); frequency f (Hz).

correspond to a 70 Hz frequency (1 g and 7 g, respectively). The 70 Hz frequency is, evidently, in a way the resonance frequency of the given system.

As the particle size is decreased from 200-250 to 50-100 μ, the transition of a polymer bed to the "fluid" state by vibration becomes easier. Thus, a PCA bed of the 50-100 μ grain size fraction begins to "boil" at 3.5 g and to "fluidize" at 3 g within the resonant frequency range (Fig. 1b); the respective acceleration levels for the 200-250 μ grain size fraction of PCA are 7 g and 1 g. The difference between the states of polymer beds of different grain size fractions is explained by the different mass of particles and different magnitude of interaction forces which affect the "fluidizing" and "boiling" vibration parameters.

Analogous relations exist for low-pressure polyethylene, polyvinyl butyrene, and pentaplast powders (all materials of the 200-250 μ grain size fraction). The boundary curves between the "thickening" and the "boiling" zone for PP and PVB are closer to the axis of ordinates than the corresponding curves for PCA and LPE, because of the narrower "fluidization" zone in the first case. The more difficult transition of PCA and LPE to the "boiling" state by vibration than such a transition of PP and PVB (indicated by the much larger area of the "fluidization" zone on the diagram) has apparently to do with the higher electrization ability of PCA and LPE powders.

The trend of the curves which bounds the "boiling" zone for PP (Fig. 2) is similar to that of the PCA curve, but in the former case it lies within the range of lower accelerations. Thus, for PP the acceleration of transition to "boiling" is 7 g at 30-40 Hz frequencies and 3.5-6.0 g at 50-70 Hz frequencies; in order to "boil" a bed by vibration at 85 or 90 Hz, the necessary acceleration is respectively 12 g and 16 g. A comparison between curves which separate the "boiling" zone from the "fluidizing" zone for the given polymers (Fig. 2) indicates that a transition to the "boiling" state is easiest for PVB, then for PP, LPE, and most difficult for PCA (at the same bed height and with the same particle size). Our data on polymer powders within the range of low vibration frequencies disagree with the data in [1], where the high porosity of a quartz sand bed was attained at the same acceleration levels but at low vibration frequencies. In the case of polymer beds, the maximum porosity is attained at constant accelerations within the resonant frequency band for a given system (approximately 60-75 Hz).

On the basis of the data obtained here, it is possible to recommend the proper range of frequencies and accelerations for the vibration treatment of polymer powder beds into "boiling"; the data can also be useful in the design of diverse special-purpose coating apparatus for various different substrate materials. A "boiling" bed of PCA or LPE is produced by vibration at 70-75 Hz and a "boiling" bed of PVB or PP is produced by vibration at 60 Hz (at whichever acceleration is lowest for each polymer material).

Changing the barrel diameter from 75 to 260 mm, with all other factors unchanged, will lower the displacement amplitude from 0.75 to 0.15 mm (the minimum acceleration j_{min} necessary for "boiling" a polymer bed changes then from 1 g to 3 g) (Fig. 3, curve 1). This can be explained by a change in the friction forces between polymer particles and barrel walls, which impede the transition of a bed to the "boiling" state, and is confirmed by the analogous trend of curve 2 in Fig. 3 representing S/V as a function of the barrel diameter. With a larger barrel diameter, the free surface becomes larger and the energy

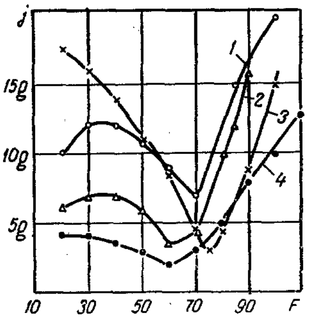

Fig. 2

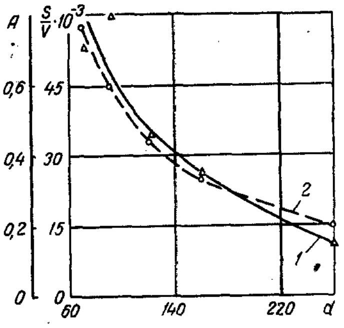

Fig. 3

Fig. 2. Boundaries between the "fluidization" zone and the "boiling" zone for polymer powders: 1) PCA; 2) PP; 3) LPE; 4) PVB. Grain size fraction of all powders 200-250 μ. Acceleration j (m/sec^2), frequency f (Hz).

Fig. 3. Vibration amplitude A (mm, curve 1) and S/V ratio (mm^{-1}, curve 2) as functions of the barrel diameter d (mm), for a PCA bed brought to "boiling" by vibration.

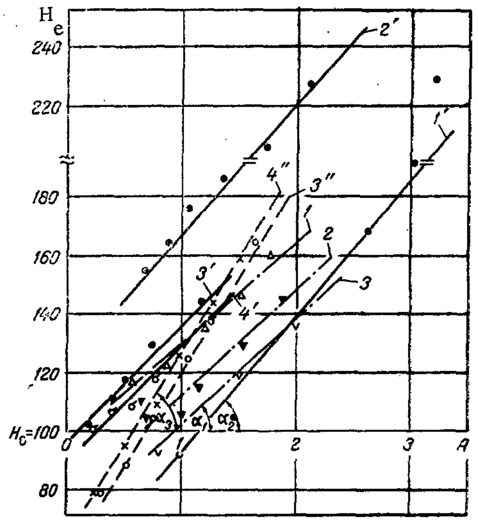

Fig. 4. Height of bed lift H (mm) as a function of the vibration amplitude A (mm); for LPE (solid line); for PVB (dashed line); for PCA (dashed-dotted line): 1, 1') 50 Hz; 2, 2') 60 Hz; 3, 3') 70 Hz; 4, 4') 80 Hz.

loss on overcoming friction forces at the barrel walls decreases, resulting in a lower amplitude for transition to "boiling."

The feasibility of producing polymer coats on parts by dipping the latter into fluidized beds depends on a decrease in the bed density during expansion. Larger and more intricately shaped parts require a greater bed expansivity. It is noted that a higher coefficient k_e results in a more inhomogeneous distribution of the solid phase over the barrel volume and this, in turn, results in a nonuniform coat thickness with discontinuities vertically across the surface – when the entire volume of the fluidized bed is active. In this case the coat must be produced by dipping the part into the most homogeneous region of the bed, namely into the center of the barrel volume. The bed regions near the bottom and the walls should be avoided.

The $H_e = f(A)$ relation, at constant frequencies, is represented by straight lines (Fig. 4) with the slope constant for any given polymer material. The bed expansion at f = const is proportional to the acceleration. Segments of these straight lines below the axis of abscissas correspond to the thickening of polymer particles at relatively low vibration amplitudes.

During the operation of vibrators it is usually possible to regulate the displacement amplitude at a constant frequency. In this case amplitudes ranging from 0.5 to 1.0 mm are sufficient for "boiling" a bed at the system's resonant frequency. The farther away the vibration frequency is from resonance, either above or below, the higher vibration amplitudes are required for "boiling" the polymer material and expanding the bed.

NOTATION

f	is the vibration frequency;
j	is the vibration acceleration;
j_{min}	is the minimum acceleration necessary for the transition of a bed to the "boiling" state;
A	is the vibration amplitude;
k_e	is the bed expansivity;
H_e	is the height of the expanded bed;

H_i is the initial height of a bed;

S is the active surface area of barrel walls in contact with polymer particles;

V is the volume of "fluidized" bed;

d is the barrel diameter.

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