ESTIMATING THE SPECIFIC WEIGHT AND INITIAL STATE OF A BED OF POLYMER MATERIAL

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The specific weight of finely dispersed porous particles is a unique characteristic of the material if the particles forming the bed are identically packed. A measure of this packing is the least volume occupied by the bed when compacted by vibration.

An actual fluidized bed of dispersed particles is characterized by many parameters, including the very important characteristics of the material itself: particle size and nature of polydispersity, specific weight (for porous materials, bulk weight), particle shape, and degree of roughness, moisture absorption, and ability of acquiring charge. A knowledge of the geometric and gravimetric characteristics of the material permits a certain evaluation of the initial state of the fixed bed. This is the starting point for a description of the fluidization kinetics.

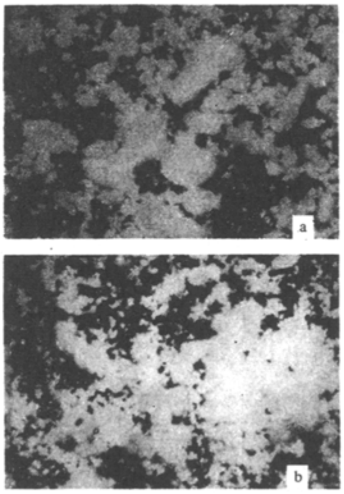

Fig. 1. Photomicrographs of polydisperse polymer materials (× 37): a) polycaprolactam, b) polyethylene.

For plastics in powder form it is very difficult to determine the particle characteristics. The size, shape, surface roughness, and polydispersity of these particles (Fig. 1) cannot be uniquely determined. The considerable internal porosity of the particles combined with the factors enumerated above make it impossible, using ordinary methods, to obtain a unique characterization of the initial state of the bed and to specify a single gravimetric characteristic. Moreover, owing to the indeterminacy of Re, or more exactly d, the method, developed by Ergun, of obtaining γ_m from $\Delta P = f(H, Re, \gamma_b, \gamma_m)$ does not give satisfactory results [1]. None of the methods of averaging d gives reliable values, since it is impossible to obtain a narrow fraction of the polymer. This is attributable to the strong electrization of the particles, which causes unavoidable aggregation. For the same reason an accurate picture of the material polydispersity cannot be obtained. Nevertheless, it is possible to propose an experimental method of evaluating γ_m together with some initial state of a powdered-plastic bed. The specific weight will serve as a unique characteristic of the material if the particles are packed in the same way. Numerous experimental data show that a measure of this packing is the least volume occupied by the material when compacted by vibration.

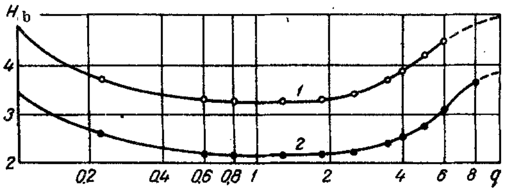

Fig. 2. Thickness H (cm) of dispersed material as a function of relative vibrational acceleration q: 1) polycaprolactam; 2) polyethylene.

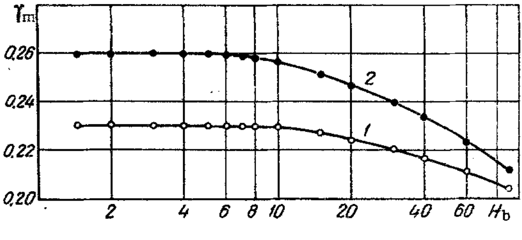

Fig. 3. Specific weight γ_m (g/cm^3) of vibration-compacted material as a function of the bulk thickness of the bed H_b (cm): 1) polycaprolactam; 2) polyethylene.

Vibration can cause both compaction and loosening of the material, depending on the physical properties of the medium and the vibration conditions. At low relative vibrational accelerations ($q \leq 1$) the bed moves together with the vibrating surface and is compacted. Compaction continues until all the gaps and "slack" in the bed have been eliminated. It can be attributed to the action of inertia forces that mechanically compress the bed and to the reduced friction between individual particles vibrated under the influence of gravity. As q increases, an instant arrives at which the bed begins to loosen. Theoretically, this state corresponds to $q = 1$; in practice, significant expansion of the bed begins at $q = 3$–5 (Fig. 2). If the vibrational acceleration is too low, the particles will not be packed to maximum density, since the vibrational energy is rapidly attenuated over the thickness of the bed. For the same reason it is impossible to compact very thick beds. For polycarprolactam and high-density polyethylene, the maximum bed thicknesses at which it is possible to obtain a uniformly dense bed are 7–8 and 4–5 cm, respectively (Fig. 3).

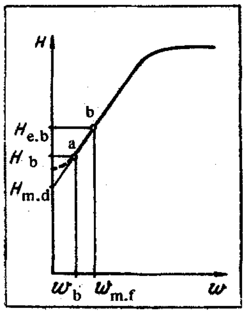

Fig. 4. Determination of maximum-density bed thickness $H_{m.d}$ without vibration of the material.

Vibration so compacts the bed and orders its structure that as soon as the gas is admitted through the vibrating grid the bed monotonically expands. Its thickness increases in proportion to the flow rate of the fluidizing agent. This permits certain simplifying assumptions. Since there is no percolation of gas through the fixed compacted bed, the porosity of the bed is arbitrarily assumed equal to zero. This is difficult to imagine, since the polymer particles are far from being parallelepipeds from which a bed with zero porosity could be obtained. The shape of the polymer particles excludes the possibility of absolutely dense packing, and there will always be pores between the particles. However, the size of these pores is so small that the gas is unable to overcome their resistance. Moreover, a very thin film of gas, enveloping the developed surface of the particle, will not participate in the general motion of the medium, even after fluidization. Accordingly, it is desirable to introduce the concept of an effective porosity and assume it equal to zero for vibrated beds with maximum density. This assumption does not lead to serious error, and provides a convenient, well defined initial state of the bed.

The dependence of the bed volume (thickness) on the gas flow rate in the first stage of the fluidization process offers a simple means of checking the degree of compaction. If the material is not fully compacted or if only the lower part of the bed is compacted while the upper regions are loosely packed the expansion curve deviates from a straight line and bends slightly upward (Fig. 4, dashed line).

Assuming that the effective porosity of the bed is zero, we determine the specific weight of the material, including the gaps between particles in the porosity of the particles themselves. The specific weight of a considerable number of polymer materials have been determined by this method (Table 1).

For high-density polyethylene, treating the pores between the particles in a dense bed together with the internal porosity of the particles themselves does not lead to a serious error. Thus, according to the data of [2], the pore volume of high-density polyethylene is 3.412 cm^3/g. If 0.94 g/cm^3 is the specific weight of the monolithic material, the volume of one gram of porous material will be 3.412 + 1.065 = 4.477 cm^3, which gives a specific weight of 0.224 g/cm^3 (in our experiments 0.26 g/cm^3). The slightly greater density of our material is related to the particle dispersity.

The specific weight γ_m of the densely packed material can be determined without vibrating the bed (Fig. 4). At least two points must be determined at which the material begins to expand from any start-

Table 1

Polydispersity and Specific Weight of Powdered Polymer Materials

Designation of Material (standard, specification)	Granulometric composition, %							Specific weight × 10^{-3}, kgf/m^3
	<56	56–75	75–105	105–150	150–250	250–315	>315	
Polycaprolactam* VTU UkhP-69-58	16	15	37	21	8.5	2.5	—	0.23
Polyamide P-68* GOST 100589-63	23	31	6.5	36	2.5	1.0	—	0.35
Polyamide AK-7* VTU P-328-63	32	11	25	17.5	13	1.5	—	0.22
Kaprolon "V" VTU P-382-64	13.5	17	16.5	42.5	10	0.5	—	0.33
Kaprolon "S" VTU P-382-64	19.5	15	42.5	18.5	4	0.5	—	0.44
Polyethylene, high-density MRTU-0.5-890-64	13.5	4.5	28	34	9.5	5	6.5	0.26
Polypropylene STU 36-13-64	2.5	25	12	8	3.5	7.5	41.5	0.34
Polyformaldehyde STU 36-13-64	24.0	16.5	13	9	8	8.5	21	0.52
Polystyrene GOST 9440-60	6	28	2.5	10	12	12.5	29	0.53
Fluoroplast 3-P VTU MKhP M-518-54	2	3	45.5	36	9	2	2.5	0.70
Polyvinyl butyral GOST 9439-60	0.5	3.0	19	40	32	3	2.5	0.37

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*GOST (TU) for granulated material, powder obtained by chemical reprecipitation.

Table 2

Specific Weight of Powdered Polycaprolactam as a Function of Granulometric Composition

Parameter	Particle size, μ						
	<56	56–75	75–105	105–150	150–250	250–315	315–420
Specific weight × 10^{-3} kgf/m^3	0.282	0.281	0.259	0.253	0.242	0,236	0.234

ing thickness of the fixed bed. For example, take a certain bulk thickness H_b as the initial thickness of the bed. At first the gas filters through the bed, but at a rather specific filtration rate (in our case w_b) the material begins to expand. Thus, we obtain the first point a. The coordinates of the other point are similarly determined. For this purpose it is convenient to take the pre-expanded bed $H_{e.b}$, obtained by returning the fluidized bed to the fixed state. The point b, corresponding to the beginning of expansion of the bed at the stability limit, is quite remote from the point a. This permits us to construct a more accurate expansion curve. Extrapolating the straight line drawn though a and b to $w = 0$ we obtain the maximum compacted-material thickness ($H_{m.d}$).

Since the specific weight of the material in the densely packed state has a definite value we can evaluate the change in the porosity of the particles as they become finer. The data for polycaprolactam are presented in Table 2.

The apparent lack of correspondence between the specific weight of the polydisperse material and that of the monofractional beds is easily explained. In fact, the specific weight of polydisperse polycaprolactam was determined under the same conditions as for narrow-fraction kapron particles, i.e., the vibration time was 10 min. Whereas this is sufficient for monofractional materials, it is not enough for polydisperse materials. When vibrated, polydisperse materials tend to separate, the larger particles migrating upward. After prolonged vibration (several hours) a density of 0.255 g/cm^3 can be attained.

Thus, the tendency to separation prevents the ordered downward motion of the particles during compaction, the larger ones tending to move in the opposite direction. This retards the compaction process. Since separation is too long a process and undesirable in depositing coatings, the values of the specific weights given in the table for polydisperse materials are somewhat too low as compared with the possible "theoretical" values. For practical purposes the difference is insignificant and does not lead to a serious error.

NOTATION

γ_m is the specific weight of the particles; γ_b is the bulk weight of the material; H is the thickness of the bed; H_b is the bulk thickness of the bed; $H_{e.b}$ is the thickness of the expanded bed; $H_{m.d}$ is the thickness of the maximum-density bed; w is the filtration rate; w_b is the rate corresponding to the onset of bulk-bed motion; $w_{e.b}$ is the filtration rate corresponding to minimum fluidization; $q = A\omega^2/g$ is the relative vibrational acceleration; A is the vibration amplitude; ω is the angular vibrational acceleration; g is the acceleration of gravity; Re is the Reynolds number; d is the particle diameter.

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