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DRYING OF DISPERSE MATERIALS IN FLUIDIZED AND  
VIBROFLUIDIZED BEDS WITH INERT PACKINGS

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UDC 66.096.5

The results are given of an experimental investigation of the drying of very moist materials. It is shown that for this purpose it is preferable to use specially developed original dryers with fluidized and vibrofluidized beds, and also to use inert packings in them.

In recent times considerable attention has been turned to the drying of very moist monocrystalline materials. These are characterized in the first place by the dimensions of the primary crystals ( $d = 1-50 \mu\text{m}$ ) and the moisture content of the filtered or centrifuged material (30-70%), which make it possible to place them in the group of pastelike or lumpy materials. The drying of such materials in standard fluidized beds operating under batchwise conditions is not very efficient, since process anomalies (channel formation, in particular) impede fluidization [1-3]. This difficulty can be eliminated if mechanical agitation is used. The effectiveness of the latter is increased under continuous operating conditions.

Figure 1 shows schematically modifications of the process of drying using fluidization. The first case (Fig. 1a) is the traditional one, characterized by the direct removal of the dried product. Here dust entrainment can be avoided only at small gas velocities, which reduces the throughput of the dryer. When mechanical agitation is introduced into the process a part of the moist feed material falls into the dried product. Analogous drawbacks are also inherent in multichamber dryers (Fig. 1b) in which the removal of moisture in the various chambers occurs at different rates. Here, however, the dust entrainment is reduced, and it is possible to ensure the attainment of the required moisture content in the final product. Carryover can also be eliminated by removing the dried product by pneumatic transport (Fig. 1c). However, the process of drying in the dilute phase which occurs here reduces the operating stability of the equipment due to lump formation and the irregular growth of the fluidized bed. These difficulties can be avoided by adding a third phase (an inert packing) to the fluidized bed (Fig. 1d). As a result of the intensive motion of the particles, the

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Scientific-Research Institute for Technical Chemistry of the Academy of Sciences of the Hungarian Peoples' Republic, Veszprem, Hungary. Translated from *Inzhenerno-Fizicheskii Zhurnal*, Vol. 52, No. 2, pp. 264-271, February, 1987. Original article submitted December 5, 1985.

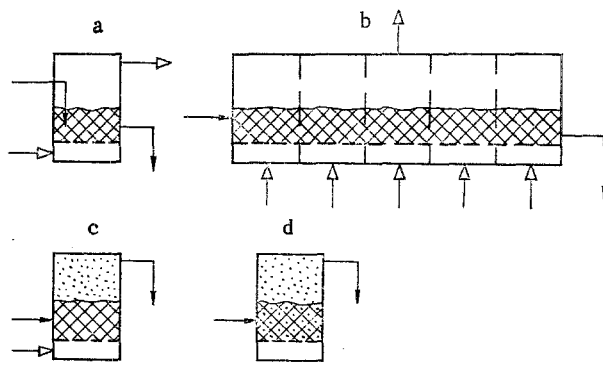


Fig. 1. Types of drying methods in fluidized beds.

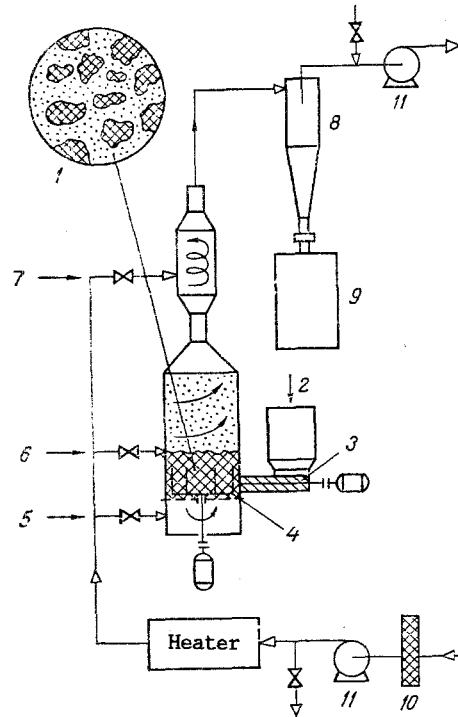


Fig. 2. Method of drying in a fluidized bed with an inert packing: 1) fluidized bed with inert packing; 2) moist materia; 3) screw feeder; 4) mechanical agitator; 5) fluidizing gas (air); 6) tangential air feed; 7) after-drying chamber; 8) dust removal; 9) dried product; 10) filter; 11) blowers.

pastly material is deposited on the surfaces of the inert solids, and the drying process occurs in the thin layers which cover the packing. In the process of agitation or during vibration the lumps or solid particles are broken up [4].

Figure 2 shows a drying arrangement having a fluidized bed with an inert packing. There is an intensification of the drying of the material being entrained in a vortex zone created above the bed by a tangential feed of a gas stream. An analogous input can also be made below the bed, but here the overall velocity of the stream must be below the entrainment velocity of the inert particles from the bed.

Experiments which have been carried out showed that a convective heat flux introduced into the bed has a large effect on the throughput of the drying process.

Since many materials possess the property of having moisture which is difficult to remove, their residual moisture during their motion through the pneumatic conveying line amounts to 1-2%. In order to intensify the after-drying, a vortex chamber 7 with a tangential feed of

a gas stream was fitted to the upper part of the equipment. The results of experiments on the drying of very moist materials in this type of dryer showed that the dryer which has been developed here with an inert packing and mechanical agitation can also be used successfully for drying materials such as those which have a tendency to form lumps, disintegrate with difficulty or not at all, or are not susceptible to fluidization.

The particle size of the dried product falls in the range of sizes of the primary crystals, and can be controlled by an appropriate choice of the operating parameters. The stable and continuous operating conditions for this dryer are ensured by the relatively high heat capacity of the packing and the fact that the retentive capacity of the packing can be varied over a wide range. It is also less sensitive to perturbations in the operating characteristics of the industrial process as a whole.

For making engineering calculations of this type of dryer, mathematical modeling of the drying process was carried out with the assumptions described in [5, 6]. An important parameter of the bed is its retentive capacity, which can be expressed by the following formula:

$$\Theta = \frac{G_b - G_i}{G_i} \quad (1)$$

The parameters for drying on the inert packing can be obtained from the solution to the differential balance equations [1] with the boundary conditions  $t = 0$  when  $\bar{x} = x_0$ . The expression describing the moisture content of the dried material will then have the form

$$\bar{x} = x_0 \left[ 1 - \frac{1 - e^{-\zeta}}{\zeta} \right], \quad (2)$$

where

$$\zeta = \frac{d\rho_i x_0 \Delta H' G_w}{6\alpha (T''_{out} - T) G_i (1 + x_0)}$$

The temperature of the material leaving the bed varies as a function of the bed height according to the following relationship [5]:

$$T''_{out} - T = (T''_{in} - T) \exp \left[ - \frac{\alpha \omega (1 - \epsilon)}{u'' c_p''} Y \right]. \quad (3)$$

This fact is based on the incomplete mixing of the gas within the bed.

Experiments were carried out in a laboratory variant of this type of dryer on the drying of 20 different organic and inorganic materials [7, 8], with the most important parameters being the economy and the specific throughput. A comparison of these results with results obtained in other equipment was not possible because of the lack of literature data.

The thermal efficiency of the dryer was calculated as follows. Since the thermal losses from the well-insulated drying chamber with the fluidized bed and the heat required for pre-heating are both small compared with the quantity of heat required for evaporating the solvent, the efficiency of utilizing the heat energy is characterized by the value of the reduction in temperature during the drying process. The efficiency parameter is therefore expressed by the following formula:

$$\eta = \frac{T''_{in} - T''_{out}}{T''_{in} - T_0} = \frac{\Delta T''}{\Delta T''_h} \quad (4)$$

and its maximum (theoretical) value is given by

$$\eta_{theor} = \frac{\Delta T''_{theor}}{\Delta T''} \quad (5)$$

where  $\Delta T''_{theor}$  is the maximum theoretically possible value of the adiabatic temperature difference determined from the  $i-x$  diagram.

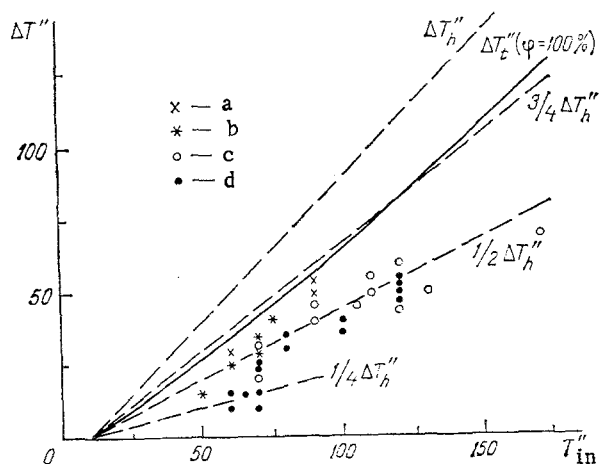


Fig. 3. Temperature drop as a function of the temperature of the incoming air. Drying in a fluidized bed (a, b) and on an inert packing (c, d); a, c) inorganic materials; b, d) organic materials.  $\Delta T''$  and  $T''_{in}$  in  $^{\circ}\text{C}$ .

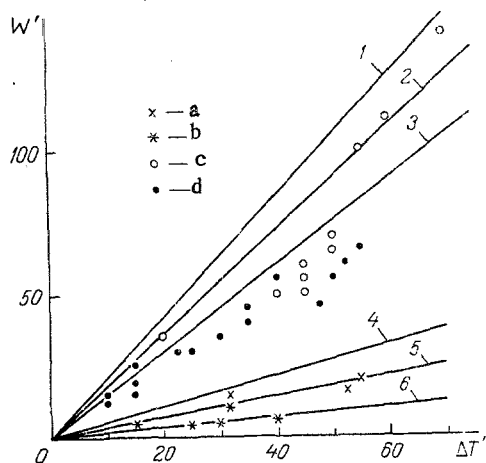


Fig. 4. Variation of the specific throughputs of fluidized bed equipment with the temperature of the incoming air (a, b, c, d: see Fig. 3); 1)  $W'' = 4200 \text{ m}^3/\text{m}^2 \cdot \text{hr}$ ; 2)  $W'' = 3600 \text{ m}^3/\text{m}^2 \cdot \text{h}$  ( $u'' = 1.0 \text{ m/sec}$ ); 3)  $W'' = 3000 \text{ m}^3/\text{m}^2 \cdot \text{h}$ ; 4)  $W'' = 1080 \text{ m}^3/\text{m}^2 \cdot \text{h}$  ( $u'' = 0.3 \text{ m/sec}$ ); 5)  $W'' = 720 \text{ m}^3/\text{m}^2 \cdot \text{h}$  ( $u'' = 0.2 \text{ m/sec}$ ); 6)  $W'' = 350 \text{ m}^3/\text{m}^2 \cdot \text{h}$  ( $u'' = 0.1 \text{ m/sec}$ ).

Figure 3 shows the change in the temperature drop as a function of the temperature of the incoming air for a fluidized bed dryer using an inert packing. It can be seen that over the range of temperatures which has been studied the theoretical value of the thermal efficiency amounts to  $\sim 75\%$ . During drying in traditional fluidized bed equipment it does not exceed 50-70%, while in the case of drying on inert packings without mechanical agitation it is 40-60%, or in the drying of thermosensitive materials at low temperatures, 20-40%.

From the point of view of the specific throughput of the fluidized bed equipment, the important question is the specific flow rate of air (the drying agent) with respect to the transverse cross-sectional area of the equipment  $F$ :

$$W'' = \frac{V''}{F}. \quad (6)$$

Usually the linear gas velocity is governed by the particle-size distribution and the density of the material, and is given by

$$u'' = 0,1-0,3 \text{ m/sec} (W'' \approx 0,1-0,3 \text{ m}^3/\text{m}^2 \cdot \text{sec}).$$

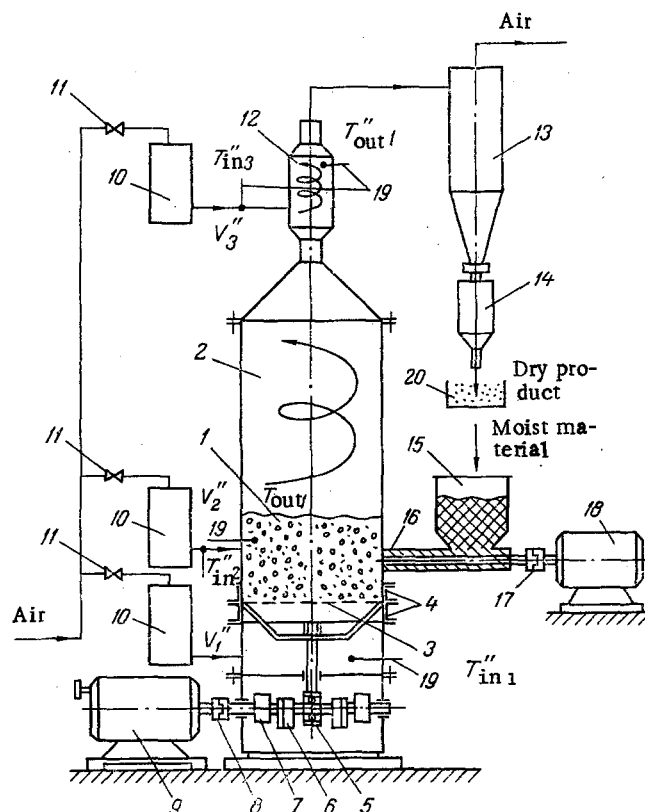


Fig. 5. Sketch of equipment with vibrofluidized bed and an inert packing: 1) bed with inert packing; 2) glass cylinder; 3) gas distribution screen; 4) rubber spacers; 5) crank mechanism; 6) eccentrics; 7) counterweights for the unbalanced mass; 8) coupling; 9) electric motor; 10) heat exchangers; 11) regulating valves; 12) after-drying chamber; 13) cyclone; 14) reservoir for dry material; 15) reservoir for feeding moist material; 16) screw feeder; 17) coupling; 18) electric motor; 19) thermocouples; 20) conveyer for removing dry material.

In the case of drying with an inert packing the overall air flow rate varies in the following range depending on the physical properties of the material being dried:

$$W'' = 0,8 - 1,2 \text{ m}^3 / \text{m}^2 \cdot \text{sec.}$$

Figure 4 shows the specific throughput of equipment with fluidized beds as a function of the temperature difference for heating. It can be seen that when the inert packing is used there is an increase in the specific throughput of 4-5 times, and sometimes 8-10 times, compared with traditional dryers. Calculations of the economics also show that in this type of equipment the specific cost of drying is reduced by 20%.

Another variant of the organization of the agitation process in the fluidized bed is to use a vibrated bed, i.e., the excitation of a pulsating motion of the mass of particles by the transfer of kinetic energy from a vibrator (mechanical, electromagnetic, pneumatic, or hydraulic) through the structural elements of the equipment [9, 10].

On the basis of our previous studies of the hydrodynamics [11, 12] and literature data on heat and mass transfer [13, 14] during the drying of materials in vibrofluidized beds with inert packings, it was established that in this case there is a considerable intensification of the process as a result of the uniform and more intense spread of the mechanical energy in the bed. In addition, with an appropriate choice of the geometry and the physical properties (for instance, the density) of the packing particles it is possible to ensure a greater efficiency of the break-up of the dried material than when mechanical agitation is used.

TABLE 1. Results of Drying Pasty Materials on Inert Packings in Fluidized and Vibrofluidized Beds

No. of expt.	Vibration parameter $\Gamma$	$x_0, \%$	$x, \%$	$V_1'', \text{m}^3/\text{h}$	$V_2'', \text{m}^3/\text{h}$	$V_3'', \text{m}^3/\text{h}$	$\dot{G}_w, \text{kg}/\text{h}$	Inert packing $\bar{d}$	Dryer throughput, $\text{kg}/\text{m}^2 \cdot \text{h}$
Rigecoccin									
1	0	48	0,5	24	6	4	1,0	Quartz sand (0,8—1,0 mm)	57
2	1,39	35	0,13	6	10	6	0,5	$\text{Al}_2\text{O}_3$ (4—5 mm)	35
3	5,29	35	0,15	6	8	2	1,2	$\text{Al}_2\text{O}_3$ (4—5 mm)	85
4	9,10	35	0,26	6	8	2	1,2	$\text{Al}_2\text{O}_3$ (4—5 mm)	85
Aluminum hydroxide gel									
5	0	70	1,2	28	8	6	1,5	$\text{Al}_2\text{O}_3$ (0,6—0,8mm)	48
6	5,29	70	23,4	6	12	4	1,0	$\text{Al}_2\text{O}_3$ (4—5 mm)	25
7	5,29	70	17,2	10	14	4	0,8	$\text{Al}_2\text{O}_3$ (4—5 mm)	22
8	7,50	70	18,0	10	18	4	1,5	$\text{Al}_2\text{O}_3$ (4—5 mm)	40
9	7,50	70	13,9	13	18	4	1,5	$\text{Al}_2\text{O}_3$ (4—5 mm)	42

A sketch of the experimental equipment which has been developed on the basis of these principles is shown in Fig. 5. Its characteristic feature is that the vibration energy is transferred to the bed not from the whole apparatus but only from a vibrating gas-distributing screen. The inertia forces are reduced in this way and the operating economics of the dryer on a plant scale are improved.

Drying experiments were carried out in this equipment with the following materials: the base material of medicines for animal rigecoccin (moisture content  $W = 35\%$ ) and aluminum hydroxide gel ( $W = 70\%$ ). They were obtained directly from the production process after centrifugation. In the usual state, these materials are very sticky, which facilitates the formation of lumps, and the size of the primary particles does not exceed  $50 \mu\text{m}$ . The objective of the experiments was to explain the effect of the input of vibrational energy on the drying process. The parameters which were varied were the magnitude of the vibration and the volumetric flow rate of the air (the drying agent). In order to evaluate the intensity of the vibrational energy introduced into the bed, use was made of the vibration parameter  $\Gamma = A\omega^2/g$ , which is widely used in the literature, and which expresses the ratio of the inertia and gravity forces acting on the particles in the vibrofluidized bed. The results of the experiments are given in Table 1. Based on an analysis of these results, it was established that the flow rate of the air in the vibrofluidized bed was reduced by a factor of two compared to the flow rate required for fluidization in the case when mechanical agitation was used under optimum conditions (experiments Nos. 3 and 9 in Table 1), while the throughput increased by 1.5 times. Thus, substantial economies in the operation of the drying equipment are achieved with a simultaneous intensification in the process of drying very moist materials which tend to stick together and form lumps. A further important factor is that it now becomes possible to indirectly control the throughput of the drying equipment and the quality of the product.

#### NOTATION

$A$ , amplitude of vibration, m;  $c_p''$ , specific heat capacity of air,  $\text{J}/(\text{m}^3 \cdot ^\circ\text{C})$ ;  $d$ , diameter of inert particles, m;  $\bar{d}$ , mean diameter of dried product, m;  $G_b$ , equilibrium mass of bed, kg;  $G_i$ , mass of inert packing, kg;  $G_w$ , loading rate with respect to moist material,  $\text{kg}/\text{sec}$ ;  $g$ , acceleration of gravity,  $\text{m}/\text{sec}^2$ ;  $T$ , temperature of particle,  $^\circ\text{C}$ ;  $T_0$ , temperature of air entering heater,  $^\circ\text{C}$ ;  $T_{in}$ , temperature of air at inlet to bed,  $^\circ\text{C}$ ;  $T_{out}$ , temperature of air at exit from equipment,  $^\circ\text{C}$ ;  $V''$ , volumetric gas flow rate,  $\text{m}^3/\text{sec}$ ;  $u''$ , lineal gas velocity,  $\text{m}/\text{sec}$ ;  $W''$ , specific volumetric flow rate of gas,  $\text{m}^3/(\text{m}^2 \cdot \text{sec})$ ;  $x_0$ , initial moisture content of material,  $\text{kg}/\text{kg}$ ;  $x$ , mean moisture content of product,  $\text{kg}/\text{kg}$ ;  $Y$ , bed height, m;  $\alpha$ , heat-transfer coefficient,  $\text{W}/(\text{m}^2 \cdot ^\circ\text{C})$ ;  $\Delta H'$ , heat of vaporization,  $\text{kJ}/\text{kg}$ ;  $\Delta T''$ , useful temperature drop,  $^\circ\text{C}$ ;  $\Delta T_h''$ , temperature drop for heating,  $^\circ\text{C}$ ;  $\Delta T_{theor}$ , maximum theoretically possible temperature difference,  $^\circ\text{C}$ ;  $\varepsilon$ , bed porosity;  $\zeta$ , parameter for drying on inert packing;  $\eta$ , thermal efficiency;  $\eta_{theor}$ , maximum theoretically possible thermal efficiency;  $\theta$ , retentive capacity of inert packing,  $\rho$ , density

of material being dried,  $\text{kg/m}^3$ ;  $\rho_i$ , density of inert particles,  $\text{kg/m}^3$ ;  $\omega$ , angular frequency of vibration,  $1/\text{sec}$ ;  $\omega_i$ , specific surface area of inert packing,  $\text{m}^2/\text{m}^3$ ;  $\Gamma$ , vibration parameter.

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