PARAMETERS OF A VIBRATIONALLY FLUIDIZED BED

Yu. I. Chernyaev and A. S. Parfenov

UDC 532.546

Relations are obtained for estimating the frequency and amplitude of vibration at which extremal values of the transfer coefficients are obtained in a fluidized bed. Satisfactory agreement with experiment is found.

A bed of suspended granular particles is very widely used in various branches of industry because of the high rates of transfer processes and the simplicity of transport of friable material. The suspended bed is produced, as a rule, by blowing gas or liquid through the apparatus and also by the action of vibration of various structural elements on the friable material. The diversity and complexity of the physical processes occurring here has so far prevented the development of accurate mathematical methods for determining the optimal parameters of the vibrationally fluidized bed, and the design of equipment is based mainly on experimental data, of which much has been accumulated in the last ten years.

In analyzing the results of experimental investigations, the first noteworthy feature is the appearance of extrema in most characteristics of the fluidized bed with increase in amplitude and frequency of vibration [1]. Such characteristics include, for example, the heat-transfer coefficients at the immersed surface, the effective heat conduction and viscosity of the bed, the intensity of particle mixing, and so on. However, for different materials, the conditions for reaching extrema are different, and therefore the problem of determining the vibrational parameters (amplitude, frequency, or a combination) at which these bed characteristics reach a maximum or minimum is of great practical importance.

In the present work, the approach proposed for a fluidized bed produced by gas or liquid injection through granular material [2, 3] is developed. It is supposed that the greatest intensity of transfer processes in a fluidized bed is reached at the greatest particle mobility, which, in turn, is achieved with an equal distribution of the kinetic energy of their random motion over translational and rotational degrees of freedom. In its hydrodynamic properties, the vibrationally fluidized bed is largely similar to a regular fluidized bed [1], and therefore the analogy is appropriate in the present case.

It was proven in [2, 3] that, in the interval between two successive collisions, the particle tends to a state in which its relative angular velocity is zero, and its relative linear velocity is the free-fall velocity under constrained conditions U_0. The times in which change in linear and angular velocities of the particles occurs are respectively

$$\tau_1 = \frac{u_0}{g}\,\frac{\rho_T}{\rho_T - \rho} \quad \text{and} \quad \tau_2 = \frac{\rho_T d}{60 a \rho u_0}\,, \tag{1}$$

where $\underline{a}$ is a coefficient of the order of unity, depending on the porosity of the bed [3].

The condition of greatest mobility of the particles $\tau_1 = \tau_2$ allows the velocity U_M at which the gas moves relative to the granular material such that extremal values of the transfer coefficients are achieved [2, 3] to be determined from Eq. (1)

$$U_M = \sqrt{\frac{gd(\rho_T - \rho)}{60 a \rho}} \quad \text{or} \quad \mathrm{Re}_M \approx 0{,}13\sqrt{\mathrm{Ar}}. \tag{2}$$

This velocity corresponds to the completely determined eigenfrequency of particle vibration $f_M = \tau_1^{-1} = \tau_2^{-1}$. Taking into account that $\underline{a} \approx 1$ and $\rho_T \gg \rho$, it follows from Eqs. (1) and (2) that

---

All-Union Scientific-Research and Design Institute on Assembled Technological Lines, Moscow. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 52, No. 2, pp. 260-264, February, 1987. Original article submitted January 2, 1986.

$$f_{\text{M}}=7{,}7\sqrt{\frac{\rho g}{\rho_{\text{T}} d}}. \tag{3}$$

Achieving the greatest intensity of transfer processes in a vibrationally fluidized bed entails ensuring resonance conditions, i.e., imposing vibrations at frequency f_M on the granular material. However, imposing such vibrations is only possible at a definite vibrational amplitude A_M, since the particles in the gas cannot fall more rapidly than U_0, and will move away from the vibrating surface unless

$$2\pi f A \leqslant U_0. \tag{4}$$

Substituting $f = f_M$ and $U_0 = U_M$ into Eq. (4), the limiting amplitude value of the vertical vibrations is obtained

$$A_{\text{M}}=0{,}003\frac{\rho_{\text{T}} d}{\rho}. \tag{5}$$

In the given discussions, the gas velocity relative to the motionless structural elements of the apparatus is assumed to be small in comparison with the particle velocity, which is a very rough simplification of the real hydrodynamics of a vibrationally fluidized bed. Therefore, Eq. (5) and all the theoretical relations given below must be regarded only as estimates of the corresponding quantities.

Table 1 gives the values of A_M and f_M calculated from Eqs. (3) and (5) for $\rho = 1$ kg/m³.

Experience shows that no extremal phenomena are observed in vibrationally fluidized beds at vibrational parameters differing considerably from those in Table 1. For example, it is totally impossible to attain vibrational fluidization in finely disperse magnesium-oxide and calcium-oxide powder at frequencies in the range 10-100 Hz [4]. The theoretical values of the optimal frequency for these materials are 1800 and 400 Hz, respectively, which is far outside the range here investigated. Maximum heat-transfer intensity cannot be attained at an immersed surface in corundum beds with a particle size of 0.04 µm at frequencies 25-100 Hz [4] and with a particle size of 5-7 µm at frequencies up to 25 Hz [5]. The theoretical values of the optimal frequency for these materials are 1900 and 160 Hz, respectively. On the other hand, in experiments with quartz sand of particle size 0.165-0.21 mm, at a vibrational frequency of around 40 Hz, minimal rarefaction under the bed is observed [1], which is in good agreement with calculation. In a vibrationally fluidized corundum bed with a particle size of 68 µm, for amplitudes of 1-4 mm, the maximum values of the heat-transfer coefficients at the surface correspond to frequencies of 20-30 Hz [5]. The theoretical values are: $f_M = 45$ Hz; $A_M = 0.8$ mm.

It follows from Eq. (5) and the data of Table 1 that the optimal amplitude of the induced vibrations is approximately an order of magnitude larger than the particle diameter in the fluidized bed. Analysis of the experimental data shows that, in practice, considerably larger vibrational amplitudes are used, especially when working with finely disperse powders. This leads to the above-noted difference in vibration frequencies of the vibrator and the granular material and, consequently, to the impossibility of satisfying the condition of greatest particle mobility $\tau_1 = \tau_2$. However, it is possible to attain coincidence of the vibration frequency and the frequency f_t characterizing only the translational vibrations of the particles. Then, taking account of Eqs. (1) and (4) and the relation $\rho_T \gg \rho$, it is found that

$$f_{\text{t}}=0{,}4\sqrt{\frac{g}{A}}. \tag{6}$$

It follows from Eq. (6) that, for each value of the vibrational amplitude, the maximum intensity of the transfer processes is attained at a frequency f_t which does not depend on the particle size or density or the density of the gas. On substituting $A = A_M$ into Eq. (6), the value $f_t = f_M$ at which the absolute maximum of intensity is achieved is found. This frequency, as is evident from Eq. (3), depends both on the particle diameter and on the density ratio.

If vibration is combined with induced gas injection through the apparatus at a velocity U_{in}, the term $2\pi Af \pm U_{in}$ must appear on the left-hand side of Eq. (4), and the expression for calculating the optimal frequency takes the form

TABLE 1. Vibrational Frequencies and Amplitudes Corresponding to Extremal Values of the Transfer Coefficients

Bed material	ρ_T, kg/m³	$d \cdot 10^6$, m	f_M, Hz	$A_M \cdot 10^6$, m
Magnesium oxide	3580	0,05	1800	0,5
Calcium oxide	3400	1	400	10
Corundum	4000	0,04	1900	0,5
Corundum	4000	6	160	72
Quartz sand	2500	190	36	1400
Corundum	4000	68	45	816

TABLE 2. Comparison of Experimental Data and Results Obtained from Eq. (6)

Bed material	Exptl. data			f_t, Hz, calc. from Eq. (6)
	vibtational ampl. $A \cdot 10^3$, m	vibrational freq. at which max. of transfer coeffs. is obtained, Hz	literature source	
Corundum	7	13	[6]	16
Same	6	16	[6]	17
"	5	19	[6]	19
"	10	20	[7]	13
"	2	22	[5]	29
Electrocorundum	0,5	51	[8]	59
Same	0,4	61	[8]	66
Grain	13	10	[1]	11
Same	10	12,5	[1]	13
"	6	16	[1]	17
"	5	19	[1]	19
Quartz sand	1	40	[9]	42
Same	0,6	60	[9]	54

$$f_t = \sqrt{\frac{U_{in}^2}{16\pi^2 A^2} + \frac{g}{2\pi A}} \mp \frac{U_{in}}{4\pi A} \tag{7}$$

(minus sign corresponds to upward gas injection).

As is evident from Table 2, the mean discrepancy between the experimental measurements and the optimal vibration frequencies calculated from Eq. (6) is 15%.

Thus, Eqs. (3) and (5) may be used to estimate the optimal vibrational parameters in designing apparatus with a vibrationally fluidized bed. If it is impossible to realize the required amplitude or frequency values on account of constructional considerations, calculation must be undertaken by Eq. (6), and with vibrofluidization in combination with induced gas injection by Eq. (7).

NOTATION

A, f, vibrational amplitude and frequency; d, particle diameter; ρ_T, ρ, particle and gas density; g, acceleration due to gravity; U_0, free-fall velocity under constrained conditions; τ_1, τ_2, characteristic times of change in linear and angular velocity of particles; f_t, vibrational frequency at which extremal values of the transfer coefficients are observed; U_M, particle velocity relative to gas which corresponds to the greatest particle mobility; A_M, f_M, vibrational parameters corresponding to the absolute maximum of transfer-process intensity; U_{in}, velocity of induced gas injection through vibrationally fluidized bed; $Re_M = U_M d/\nu$; $Ar = gd^3(\rho_T - \rho)/\rho\nu^2$.

LITERATURE CITED

1. V. A. Chlenov and N. V. Mikhailov, Vibrationally Fluidized Bed [in Russian], Moscow (1972).
2. N. N. Prokhorenko and Yu. I. Chernyaev, Inzh.-Fiz., Zh., 49, No. 5, 854-855 (1985).
3. Yu. I. Chernyaev and A. S. Parfenov, in: Heat and Mass Transfer in Technological Processes and Apparatus [in Russian], Minsk (1985), pp. 59-67.
4. M. F. Bukareva, V. A. Chlenov, and N. V. Mikhailov, Khim. Neft. Mashinostr., No. 2, 17-18 (1970).
5. S. S. Zabrodskii, I. L. Zamnius, S. A. Malyukovich, and A. I. Tamarin, Inzh.-Fiz. Zh., 14, No. 3, 448-453 (1968).
6. I. I. Kal'tman and A. I. Tamarin, Inzh.-Fiz. Zh., 15, No. 4, 4-6 (1969).
7. G. F. Puchkov, in: Heat and Mass Transfer in Disperse Systems [in Russian], Minsk (1982), pp. 29-33.
8. B. G. Sapozhnikov and N. I. Syromyatnikov, Inzh.-Fiz. Zh., 16, No. 6, 1039-1044 (1969).
9. V. A. Chlenov and N. V. Mikhailov, Drying Friable Materials in a Vibrationally Fluidized Bed [in Russian], Moscow (1967).

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

Z. Ormós, T. Szentmarjay, and
K. Erdesz

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 μm) 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

---

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

0022-0841/87/5202-0198$12.50