VIBRATION MECHANISMS IN THE SOLID PHASE OF A FLUIDIZATION BED

B. I. Savchenko and I. N. Taganov

The phenomenon of periodic vibrations in a fluidization bed is analyzed in the light of two mechanisms of interaction between solid phase particles. Equations are derived for the frequency, the wave velocity, and the wave vector of periodic-bed vibrations.

The authors consider here the vibration of solid phase particles in a fluidization bed resulting from collective interaction and direct collisions between particles. A study and analysis of the motion of the solid phase in a fluidization bed reveals that individual particles and clusters of particles vibrate with different amplitudes and frequencies. Altogether, according to the experimental studies in [5] and [6], the vibration spectrum of solid phase particles is continuous and covers a wide range. As to the causes and nature of vibrations excited and sustained in the solid phase of a fluidization bed, they evidently cannot be attributed to any single mechanism but rather to an interplay between several different processes. Among the various vibratory processes occurring in a fluidization bed, one can single out a few types of processes as, for instance, the "shaking" small-amplitude high-frequency vibration of individual particles and vibrations resulting from an interference between particle clusters.

The interference between individual particles can result not only from a direct momentum transfer from one to another during collisions but also from a meshing of the hydrodynamic boundary layers which surround such particles [1]. At a sufficiently high stirring rate in the solid phase and high relative velocities of the phases, furthermore, the individually moving particles leave turbulent trails which can also interfere with one another as well as with the solid phase particles. The breakaway of turbulent vortices during a fast motion of solid phase particles can also result in a particle-vortex type interference. These interference modes belong to the near-range category, and the kinetics equation [2]

\[ \frac{\partial f}{\partial t} + u \frac{\partial f}{\partial u} + \left( g + \lambda w^2 - \omega \right) \frac{\partial f}{\partial \omega} - \frac{\partial}{\partial u} \left( \lambda u f \right) - D \frac{\partial^2 u f}{\partial u^2} = 0 \]

will account for them in a statistical description of the solid phase motion. The solution to this equation is, to the first approximation,

\[ f(r, u) = n(z) \left( \frac{m}{2n0} \right) \frac{1}{\lambda} \exp \left( -\frac{mu^2}{2\theta} \right), \]

where \( \theta = mD/\lambda^2 \). For an expanding fluidization bed, when \( n \ll \frac{6}{\pi D^3} \), function \( n(z) \) must satisfy the equation

\[ R^n \frac{dn}{dz} = C (R^n - 1) n, \]

where

\[ R = \left( \frac{\lambda w}{g} \right)^{1/3} \omega, \quad C = \left( \frac{\lambda w^3}{g} \right)^{1/3} \frac{D^3}{\lambda}. \]

The solution to Eq. (3) is the following function

\[ n(z) = n_0 \exp \left[ \frac{\lambda_2 g}{D} \left( 1 - \frac{\lambda_1 g}{g} \right) z \right]. \tag{4} \]

Function \( n(z) \), when expressed in this form, is an analog of the barometric formula for a fluidization bed. A formula like (4) was proposed in [3] and exponential factor was evaluated experimentally.

By extending the analogy with the kinetic theory of gases, as far as Eq. (1) is concerned, in the case of elastic collisions between particles one may expect that vibrations of the acoustic kind are propagated through the fluidization bed. The velocity of these acoustic waves is

\[ v^* = \sqrt{\frac{2 \theta}{m}} = \sqrt{\frac{2D}{\lambda_2}}. \tag{5} \]

Energy is transmitted here by sequences of elastic collisions between solid phase particles in the fluidization bed. The motion of individual particles in the bed should be vibratory with small amplitudes and high frequencies.

The quantity \( \lambda_2 \) can be determined from the expression

\[ \lambda_2 = \frac{D}{g} \left( 1 - \frac{\lambda_1 g}{g} \right)^{-1} \frac{\ln n - \ln n_0}{z}. \tag{6} \]

For a bed of \( d = 2.5-4.0 \) mm particles fluidized with air at 2.5-5.0 m/sec velocity, the value of \( \lambda_2 \) is somewhere within 0.012-0.020 sec\(^{-1}\). The diffusivity \( D \) under these conditions, in the velocity space, has been determined experimentally [5, 6] and found to range from 15 to 40 cm\(^2\)/sec\(^{-3}\). Inserting these values into (5) yields the following estimate for the velocity of vibrations in such a fluidization bed:

\[ v^* \approx 0.4 - 0.8 \text{ m/sec}. \tag{7} \]

The frequency of vibrations is estimated from the relation

\[ f^* \approx \frac{v^*}{l}, \tag{8} \]

where \( l \) denotes the characteristic linear dimension of the fluidization bed. Under the given conditions \( f^* \) ranges from 8 to 16 Hz.

We note that these estimates for \( v^* \) and \( f^* \) agree closely with the maximum velocities and vibration frequencies of individual particles observed in the experiments [5, 6] concerning the motion of the solid phase in a fluidization bed.

A consideration of far-range hydrodynamic interference forces in a fluidization bed will explain the mechanism by which collective vibrations of solid phase particles are brought about. The equation of the particle distribution function in the phase space of coordinates and velocities can be derived with the aid of the concept of a self-adaptive field [7]:

\[ \frac{\partial \tilde{f}}{\partial t} + \frac{\partial}{\partial \tilde{r}_1} | \tilde{u}_1 | + \frac{\partial}{\partial \tilde{u}_1} | (a_{ik} \tilde{u}_k + b_k) \tilde{f} | = 0, \tag{9} \]

where \( a_{ik} \tilde{u}_k + b_k \) is the self-adapted hydrodynamic interference force. When \( \theta = 0 \) or when

\[ \tilde{f} = n_0 \delta (u - \langle u \rangle) \tag{10} \]

the phase velocity of collective vibrations in a fluidization bed is determined from the relation

\[ \frac{w}{k} = \frac{k \langle u \rangle}{k (1 - A)}, \tag{11} \]

where

\[ A = \frac{3}{8} n_0 g^2 \frac{\rho_f / \rho_g}{1 + \frac{1}{2} \rho_f / \rho_g}. \]

The generalization of (11) for states with \( \theta \neq 0 \) is given in [7].