VERTICAL FORCES ACTING ON HORIZONTAL DISKS IN A FLUIDIZED BED

A. P. Baskakov and B. A. Michkovskii

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Experimental studies of vertical forces were made with a turbulimeter. A dimensionless expression was obtained for the determination of the average vertical forcing acting on horizontal disks submerged in a fluidized bed.

In setting up fragile heat-treated components (ceramic forms intended for precision casting from fusible patterns, thin-walled "sovelite" sheets, thin aluminum sheets) in apparatuses having a fluidized bed, it is necessary to know the forces acting on the components which can lead to their rupture or buckling in order to design components having the proper strength. There is little data on the forces in the literature and no generalized results. The aim of the present work is the study and generalization of data for the simple "canonical" case of horizontal disks having an area not exceeding 10% of the area of the apparatus.

The vertical force K_z acting on a body submerged in a fluidized bed can depend on the following independent variables [1, 2]:

$$K_z = f(w,\ D_b\ \nu_{fa}\ \rho_{fa}\,\rho_{fm}\ g,\ d_e,\ H_t,\ H_0,\ t,\ l). \tag{1}$$

Investigations of the pulsational characteristics of heat transfer in a fluidized bed [3] show that the viscosity ν_{fa} and the density ρ_{fa} of the fluidizing agent affect the hydrodynamic situation at the surface of the body around which flow occurs only in so far as they affect the critical velocity of fluidization w_f. Phyically this is understandable, because from the position of the two-phase theory of nonuniform fluidization [4], the hydrodynamics of the bed depend on the volume, number, and velocity of the bubbles, which are determined by the excess velocity $(w - w_f)$ of the fluidizing agent, the particle diameter d_e, and the height H_t above the grid. In analogy with [3], therefore, it is convenient to select the Froude number $Fr = (w - w_f)^2/gd_e$ as one of the defining criteria without considering the effects of ν_{fa}, ρ_{fa}, and w separately. With an increase in the spacing t between the caps of the gas-distribution grid, large-scale circulation of material because of deterioration of the equilibrium of gas distribution over the cross section of the apparatus leads to a change in K_z. The effect of the height H_t of the turbulimeter above the gas-distribution grid and the thickness H_0 of the bed is explained by the increase in bubble size and velocity with height [5]. The acceleration of gravity g has an effect only in so far as the rate of bubble rise depends on its value. The effects of d_e, D_b, and ρ_{fm} are obvious.

Besides the factors mentioned, the size and shape of the cross section of the device may have an effect, as well as the location of the body in the cross section of the apparatus. The resistive force depends on the shape of the body and also on its orientation in the bed. In this paper, we confine ourselves to consideration of forces acting on thin $(l = 0)$ horizontal disks located at the center of the cross section of the apparatus.

The studies were made in an apparatus with a rectangular cross section 0.3 × 0.15 m in size and 1 m high. The gas-distribution system consisted of 32 caps with a 1% fractional useful cross section. The turbulimeter [6, 7] used for measurement of dynamic forces consisted of a steel (U8 steel) uniform-resistance arm rigidly fastened at its base having strain gauges with a 10-mm base and 180-Ω resistance glued to it. Test disks were rigidly fastened to the free end of the arm. The strain gauges were connected in the bridge circuit of a strain test stand, the output of which was sent to the input of an MN-7M analog computer. The signal was sent in parallel to the galvanometer of an N-700 loop oscillograph, where it was

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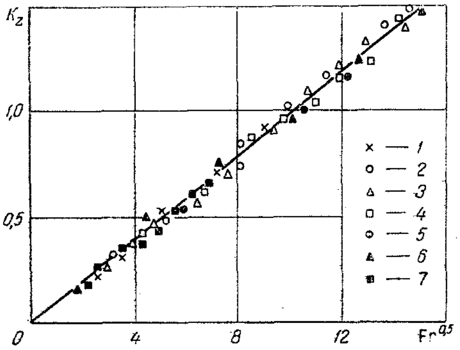

Fig. 1

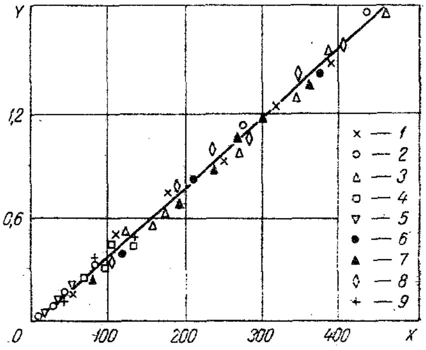

Fig. 2

Fig. 1. Dependence of average force K_z, N, on Froude number for various corundum fractions: $H_t = 0.35$ m; $H_0 = 0.5$ m; $D_b = 0.03$ m; 1) $d_e = 74\ \mu$; 2) 196 μ; 3) 212 μ; 4) 245 μ; 5) 290 μ; 6) 400 μ; 7) 695 μ.

Fig. 2. Comparison of some experimental data with the theoretical relation (4): 1) $d_e = 400\ \mu$, $H_t = 0.35$ m, $H_0 = 0.5$ m, t = 0.033 m, $D_b = 0.03$ m; 2) corresponding values are 400, 0.35, 0.5, 0.033, 0.08; 3) corresponding values are 196, 0.5, 0.5, 0.033, 0.03; 4) corresponding values are 196, 0.15, 0.15, 0.033, 0.03; 5) corresponding values are 196, 0.15, 0.15, 0.033, 0.06; 6) corresponding values are 400, 0.5, 0.5, 0.033, 0.02; 7) corresponding values are 212, 0.35, 0.5, 0.033, 0.03; 8) corresponding values are 290, 0.35, 0.5, 0.099, 0.03; 9) corresponding values are 760, 0.35, 0.5, 0.033, 0.03; 1-8) corundum; 9) chamotte.

recorded on photographic paper for 10 sec. For the selected integration time of the MN-7M (2 min), the mathematical expectation with respect to various realizations differed by no more than 3%, which also determined the accuracy of the vertical force measurements. We investigated the forces which acted on horizontal disks with diameters $D_b = 0.02$, 0.03, 0.04, 0.06, and 0.08 m located in the bed at heights $H_f = 0.15$, 0.35, and 0.50 m from the exit openings in the caps for bed thicknesses $H_0 = 0.15$, 0.35, and 0.50 m (the useful cross section of the openings remained unchanged and was equal to 1%; when the spacing t between caps was increased from 0.033 to 0.099 m, the number of openings in the caps was increased). We used corundum particles with equivalent diameters $d_e = 74$, 196, 212, 245, 290, 400, and 696 μ and a density $\rho_{fm} = 3880\ \mathrm{kg/m^3}$, chamotte particles with $d_e = 760\ \mu$ and $\rho_{fm} = 1810\ \mathrm{kg/m^3}$, and magnesium oxide particles with $d_e = 500\ \mu$ and $\rho_{fm} = 3270\ \mathrm{kg/m^3}$.

The function $K_z = f(\mathrm{Fr})$ which was obtained for a large range of fluidizing-agent velocities with the diameter of corundum particles varying from 74 to 695 μ, is expressed by the following power function:

$$K_z \sim \left[\frac{(w - w_f)^2}{g d_e}\right]^{0,5}. \tag{2}$$

The equivalent particle diameter d_e is calculated from

$$\frac{1}{d_e} = \sum \frac{X_i}{d_i}, \tag{3}$$

where X_i is the mass fraction of particles in a narrow band around the diameter d_i. The minimum fluidization velocity w_f was determined from the Todes formula [8] for a porosity $\varepsilon_0 = 0.4$. Since all experimental points are well described by Eq. (2) (Fig. 1) independently of particle diameter, one need not additionally take into account the effect of d_e on K_z, other conditions being equal.

Having constructed the corresponding dependences of K_z on Froude number for varying D_b, H_t, H_0, and t, and having determined the numerical values of the slopes of the corresponding straight lines passing through the experimental points, we have succeeded in obtaining the following dimensionless formula for the determination of the average vertical force on a body submerged in a fluidized bed:

$$\frac{K_z}{g D_b^3 \rho_{fm}} = 12.8 \left[\frac{(w - w_f)^2}{g d_e}\right]^{0.5} \left(\frac{H_t}{D_b}\right)^{0.86} \left(\frac{H_0}{D_b}\right)^{0.38} \left(\frac{t}{D_b}\right)^{0.28}. \tag{4}$$

Some experimental data shown in Fig. 2 for comparison are in good agreement with the theoretical relation (4). Here

$$Y = \frac{K_z}{gD_b^3\rho_{fm}}, \tag{5}$$

$$X = \mathrm{Fr}^{0.5}\left(\frac{H_t}{D_b}\right)^{0.86}\left(\frac{H_0}{D_b}\right)^{0.38}\left(\frac{t}{D_b}\right)^{0.28}. \tag{6}$$

The approximation obtained is valid for the following limits on parameter ranges: Fr = 1-250; H_t/D_b = 2-25; t/D_b = 0.4-5; H_0/D_b = 2-25. The range of K_z is 6.5 m · kg / sec^2.

It should be particularly emphasized that Eq. (4) is only valid for the calculation of the time-averaged vertical force acting on a body located in the center of the cross section of the apparatus. When the body is shifted closer to the walls of the apparatus, the force K_z is correspondingly reduced and is directed downwards where there is a descending motion of the material. This is typical of apparatuses with a fluidized bed in which the solid particles are displaced upwards by the rising bubbles predominantly in the center of the apparatus and descending motion of the material occurs at the walls.

In strength design for bodies submerged in a bed, it is necessary to keep in mind the maximum short-time loading, which is greater than the average force. The ratio between the maximum load acting on a submerged body in the upward direction and the average force decreases from 15-11 to 8-7, respectively, for horizontal disks 0.02-0.04 m in diameter as the fluidization velocity increases. For horizontal disks 0.06 and 0.08 m in diameter, this ratio becomes practically constant and is 5.5-6.5. The ratio between the maximum load acting on a submerged body in the downwards direction and the average force changes from 6.5-3 to 3-2, respectively, for horizontal disks 0.08-0.02 m in diameter as the fluidization velocity increases.

NOTATION

K_z	is the mean vertical force, m · kg / sec^2;
w	is the fluidization velocity at free section of the apparatus, m / sec;
D_b	is the diameter of body, m;
ν_{fa}	is the kinematic viscosity of fluidizing agent, m^2/ sec;
ρ_{fa}, ρ_{fm}	are the density of fluidizing agent and fluidized material, kg / m^3;
g	is the acceleration of gravity, m / sec;
d_e	is the equivalent particle diameter, m;
H_t	is the height of turbulimeter position in the bed calculated from exit holes in caps, m;
H_0	is the height of packing, m;
l	is the thickness of body, m;
t	is the space between caps, m.

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