EXPERIMENTAL RESEARCH ON PARTICLE COLLISIONS WITH WALLS OF PNEUMATIC CONVEYING DUCTS

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The article presents a description of a device designed for experimental study of the number of collisions particles make with the walls of ducting, and results of an investigation of such collisions in horizontal pneumatic conveying ducting.

Close attention is given to the effect of collisions between solid particles and flow boundaries in investigations of the flow of two-component streams through tubes and ducts. This effect of collisions determines, to a great extent, the friction factor and wear on the tube walls, as well as heat transfer and electrotreatment effects.

An experimental determination of the number of particle collisions per unit duct length per unit time is therefore of interest.

Assuming that the particle concentration distribution in the cross section of the horizontal stream is determined by an equation similar to that for the distribution of gas molecules in a gravitational field [1, 2]

$$n = n_0 \exp\left(-\frac{3gh}{u^2}\right), \tag{1}$$

and expressing the number of particle impacts on the surface of a unit length of ducting per unit time in terms of the hydrodynamic characteristics of two-phase flow, we can obtain [2]

$$N = 0.0593\,\frac{GVKDF(a)}{d^3 \lg(\mathrm{Re}/8)}. \tag{2}$$

In Eq. (2), the function

$$F(a) = \frac{\int\limits_0^1 e^{-ay}\sqrt{y(1-y)}\,dy}{\int\limits_0^1 e^{-ay}[y(1-y)]^{-0.5}dy} \tag{3}$$

determines the conditions under which the particles are being conveyed through the horizontal duct and depends on the parameter $a = 3gD/u^2$ characterizing the degree of nonuniformity of the solids distribution over the ducting cross section.

When the particle concentration distribution is uniform, $a \ll 1$ and $F(a) = 8$. If the concentration distribution is nonuniform, $a \gg 1$, and $F(a) = 2a$.

The parameter a can be determined from the formula

$$a = \frac{13.3gD\,[\lg(\mathrm{Re}/8)]^2}{G^2V^2}. \tag{4}$$

Substituting Eq. (4) into Eq. (2), and taking the values of $F(a)$ into account, we obtain:

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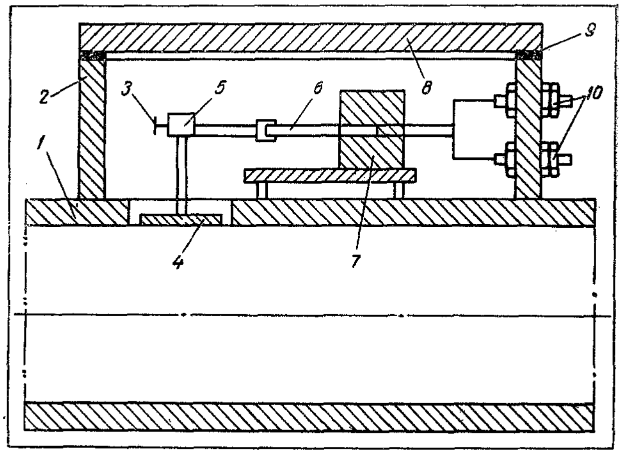

Fig. 1. Piezoelectric crystal sensor arrangement: 1) pneumatic conveying duct; 2) housing; 3) screw; 4) collison impact area; 5) locator; 6) piezoelectric crystal; 7) support; 8) cover; 9) rubber gasket; 10) clamps.

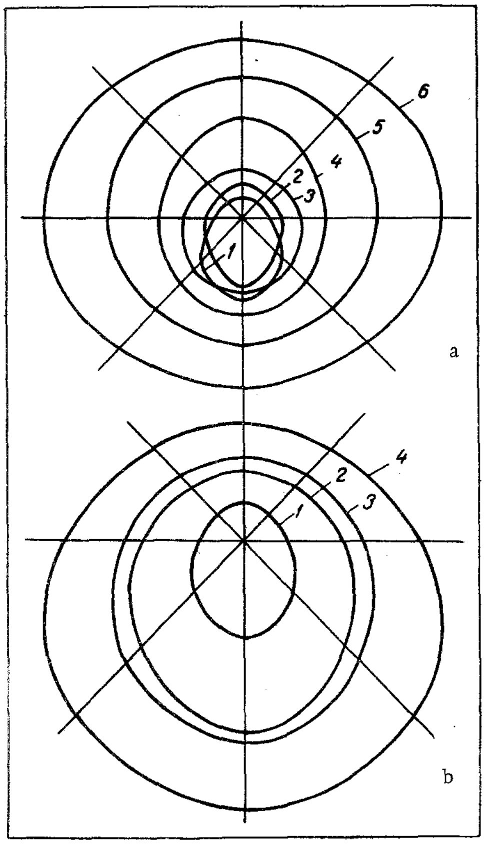

Fig. 2. Profile of distribution of number of particle impacts in unit surface area of duct, at $D = 4.0 \cdot 10^{-2}$ m (M 1 : 2000 1/mm sec $\cdot$ m^2): a) $K = 2.7 \cdot 10^{-3}$: 1) V = 15.1 m/sec; 2) 20.3; 3) 24.9; 4) 29.6; 5) 34.8; 6) 40; b) at V = 23 m/sec: 1) $K = 3.74 \cdot 10^{-3}$; 2) $9.35 \cdot 10^{-3}$; 3) $10.3 \cdot 10^{-3}$; 4) $17.9 \cdot 10^{-3}$.

when $a \gg 1$

$$N = \frac{1.58 g D^2 K \lg(\mathrm{Re}/8)}{G V d^3}, \tag{5}$$

when $a \ll 1$

$$N = 0.475 \frac{GKDV}{\lg(\mathrm{Re}/8)\, d^3}. \tag{6}$$

In Eqs. (2), (4)-(6), G is the weighted average pulsation coefficient in transient flow of stream pulsations around particles, taken over the horizontal duct cross section, and determined by the ratio of the amplitude of the pulsation velocity of the particles to the amplitude of the pulsation velocity of the stream.

In laminar streaming of flow pulsations around particles, G can be determined from the formula [3]

$$G = \left[1 + \left(\frac{\pi d^2 \rho V}{90 \mu D}\right)^2\right]^{-0.5}. \tag{7}$$

However, it does not appear possible to calculate the pulsation coefficient in transient flow of stream pulsations around the particles, and experimental methods for determining that quantity deserve some attention.

The study of particle collisions with duct walls was carried out with a device consisting of a piezocrystal sensor, an electronic amplifier, and a type ESA-3 digital electronic pulse counter.

The element sensitive to particles collisions with the sensor is a piezoelectric crystal 6 (Fig. 1) whose free end is jointed to the collision impact area 4. The other end of the piezoelectric crystal is rigidly joined to a segment of ducting 1 with the aid of the support 7, and is enclosed in a pressure-tight housing 2. The linear dimension of the impact area was chosen such that it would be shorter than the average distance between particles in a stream of maximum concentration.

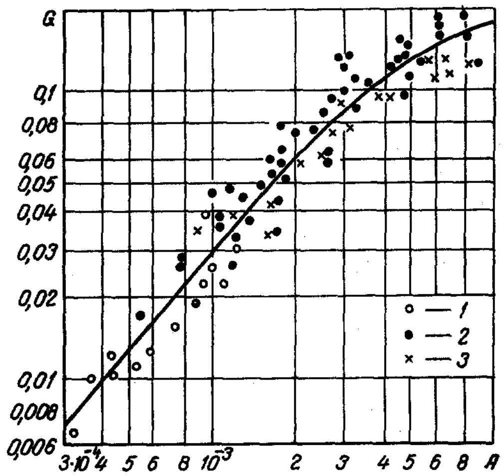

Fig. 3. Dependence of G on $A = K\sqrt{d}/D\,(V_{sp}/V)^{2.5}$ in duct conveying of granulated polypropylene: 1) $D = 2.6 \cdot 10^{-2}$ m; 2) $4.0 \cdot 10^{-2}$; 3) $5.2 \cdot 10^{-2}$.

When a moving particle impacts against the area 4, a bending moment is generated and deforms the piezoelectric crystal. As a result of this mechanical deformation, the piezoelectric crystal generates an emf which is transmitted via the terminals of the sensor to the input of the electronic amplifier.

The emf is amplified in voltage and in power by the transistorized amplifier, and is then sent to a one-shot multivibrator which shapes the pulse for triggering the counter.

The sensor sensitivity was determined from the force with which the particles impact in free fall. Spherical foamed polystyrene particles were selected for the experiment, to aid that purpose. The particle diameters and heights of fall were varied.

The experiments established the sensitivity threshold of the sensor for collisions, i.e., that value of the impacting force at which the frequency of actuation of the device would be unity.

The force with which the particle impacts on the sensor was calculated in line with Hertz impact theory [4], and the actuating frequency was caluclated as the ratio of the number of collisions recorded by the device to the total number of collisions.

As the experiments revealed, the device described is capable of smoothly varying the sensitivity threshold by varying the gain.

Experiments on measurement of the number of collisions were performed in a horizontal pneumatic conveying duct extending 5 m in length and 26, 40, or 52 mm in diameter.

The material to be conveyed pneumatically was a uniform batch of polypropylene with particle size 3.3 mm. The volume concentration ranged from $6.665 \cdot 10^{-4}$ to $1.52 \cdot 10^{-2}$, and the air moved at speeds from 14.1 to 55.2 m/sec.

During the investigations, a segment of ducting with the sensor mounted on it was inserted in a special experiment duct. With no change in the conveying conditions, the sensitivity threshold of the sensor at which the number of particle impacts on the impact area per unit time would remain unchanged and would not be affected in the sequel by increased gain was arrived at. In this case, all of the particle impacts were of necessity recorded by the counter.

The reproducibility of the results was determined by taking 15 measurements of the number of collisions in 30 sec, with the conveying conditions left unchanged. It was found that the average number of impacts calculated from the first three measurements did not deviate by more than ±5% from the average computed from 15 measurements. It was therefore considered sufficient, subsequently, to estimate the number of particle impacts on the duct wall from three successive measurements.

During the experiments, the segment of the duct with sensors mounted on it was rotated about the duct axis in 45° steps through a complete revolution. The number of impacts on the sensor during the selected time interval was noted. The number of impacts per unit duct surface area per unit time was calculated from the known area presented for particle impacts and the time during which the number of impacts was measured.

Plotting the resulting numbers in a selected scale from the duct axis in radii located at the corresponding angles, and then joining the points so plotted, we obtained the distribution of the number of particle impacts on unit duct surface area in unit time (Fig. 2).

Given a duct of radius R, let there be found a set of profiles of the distribution of particle impacts, with the perimeter

$$P = \frac{1}{M} \int_0^{2\pi} n(\alpha)\, d\alpha. \tag{8}$$

We delineate, on the inner surface of the duct, an infinitesimal area $dS = Ldl$ set at an angle α from the vertical diameter of the duct cross section, such that the number of particle impacts in unit time on the unit surface area $n(\alpha)$ can be assumed constant.

Then the elemental number of impacts per unit length in unit time will be

$$dN = n(\alpha)\,dl. \tag{9}$$

Upon integrating Eq. (9) over the duct perimeter, and recalling that $dl = Rd\alpha$, we obtain, on the basis of Eq. (8),

$$N = MR\int_0^{2\pi} n(\alpha)\,d\alpha = MRP. \tag{10}$$

Consequently, the calculations of the number of particle impacts on a unit length of ducting in unit time reduces, in accordance with Eq. (10), to measuring the perimeter of the experimental profiles.

As the experimental data showed, the shape and the perimeter of the profiles are greatly influenced by the bulk concentration of the solids in the stream and by the flowspeed of the conveying air.

When the concentration of particles in the stream remains unaltered, an increase in air flowspeed brings about a decline in the eccentricity and an increase in the perimeter of the profiles, while the shape of the profiles tends toward circular. In turn, an increase in the solids concentration in the stream corresponds to increased eccentricity and increased perimeter of the profiles.

In line with Eq. (5), the N values obtained were used in order to determine experimental values of the pulsation coefficient. The results of calculations carried out for the case where granulated polypropylene is conveyed through the duct are plotted in Fig. 3.

Analysis of the results shows that the variation in the pulsation coefficient as a function of the relationship between the conveying parameters lies in the range from 0.006 to 0.2.

The method of experimental investigation of particle collisions in ducts, outlined here, can be extended to other two-phase systems.

NOTATION

$a = 3gD/u^2$	is a dimensionless ratio characterizing the nonuniformity of the particle distribution over the duct cross section;
d	is the particle dimension;
D	is the duct diameter;
$F(a)$	is a dimensionless function determining the particle suspension conditions;
h	is the height coordinate;
g	is the gravitational acceleration;
G	is the pulsation coefficient;
K	is the bulk concentration;
l	is the tube perimeter;
L	is the tube length;
M	is the scale factor;
n	is the number of particles contained in a unit volume;
n_0	is the concentration of particles on the tube bottom;
$n(\alpha)$	is the number of impacts in unit time on a unit surface area of the duct;
N	is the number of impacts in unit time per unit length of duct;
P	is the perimeter of the profiles;
R	is the tube radius;
$Re = VD/\nu$	is Reynolds' number;
u	is the pulsation rate of the particles;
V	is the average air flowspeed;
V_{sp}	is the falling speed of particles spiralling downwards;
$y = h/D$	is the dimensionless height;
α	is an angle;
ρ	is the density of the particle material;
μ	is the dynamical viscosity.

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