Journal of Engineering Physics and Thermophysics, Vol. 70, No. 6, 1997

MEASUREMENT OF TANGENTIAL FRICTION IN GAS FLOWS WITH SOLID PARTICLES

P. V. Ovsienko, L. I. Krupnik, and
V. G. Ainshtein

UDC 66.021:532.5

We present the results of direct measurements of the force interaction between a gas flow carrying solid particles and the walls of a cylindrical pipe.

Pneumatic conveying systems have received wide acceptance in many branches of chemical technology. This form of transport is also an integral part of a number of reactor systems and units for carrying out chemical and heat exchange processes. The efficiency of such apparatuses is greatly determined by the hydrodynamic situation in the flow of a gas that carries solid particles.

Calculation of the mass flow and regimes of motion of solid particles requires knowledge of the dependence of the pneumatic conveying pipe resistance on the flow rate of solid particles. Individual aspects of this problem have been studied by many authors [1-10].

Despite the relative simplicity of the process of pneumatic transport (in comparison, for example, with fluidization) no integrated and generally accepted physical model of the entire process has been developed as yet. This has brought about an abundance of empirical information in the form of various dimensionless equations that often are contradictory.

In this situation the most reliable outcome is the development of measuring devices for direct determination of the parameters that characterize the process of pneumatic transport. Among these parameters the most important is the magnitude of shear stress on the surface of a cylindrical pipe through which a gas flow with solid particles moves.

Probably, Pal'tsev [11] was the first of the researchers dealing with a gas–solid flow who measured the magnitude of the tangential friction on the wall of a cylindrical pipe. His setup for measuring the skin friction force was similar in principle to facilities for determining the lift force acting on models of aircraft. When a vertical pipeline, resting on a balance, was blown from below upwards by a mixture of air and solid particles (wheat and the products of its grinding), it decreased its weight by a value equal to the force of flow friction against the pipeline walls. In experiments he used pipes 76 and 100 mm in diameter.

The experiments carried out in [12] were more perfect. The setup for determining the force of the skin friction of a gas flow having solid particles (a catalyst of petroleum cracking) consisted of a fixed section of pipeline and a movable section, 180 mm in diameter and 570 mm in length, with its end faces entering into the fixed section. The movable and fixed sections were connected hermetically by rigid bellows into which a secondary gas was introduced through openings in the body of the fixed pipe for blowing out particles that can occur in the gap between the movable and fixed sections of the pipe. The movable section was connected to an electronic balancer and was located outside the zone of acceleration, i.e., over a stretch with an approximately constant pressure gradient.

For high-pressure piston pneumatic transport a device was developed which allowed one to measure the friction force between the pistons of solid particles in the flow and the wall of the pipeline [13].

For measuring tangential friction in gas–solid flows we developed the facility whose basic diagram is presented in Fig. 1a. It includes a pipeline, consisting of fixed sections 1 and a movable section 2 of length 1 m and diameter 50 mm suspended on springs 3. The fixed and movable sections of the pipeline are joined by means

---

State Scientific-Research and Design Institute of Chemical Technologies "Khimtekhnologiya," Severodonetsk, Ukraine; M. V. Lomonosov Moscow Institute of Fine Chemical Technology, Moscow, Russia. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 70, No. 6, pp. 914-918, November-December, 1997. Original article submitted December 26, 1995; revision submitted November 5, 1996.

1062-0125/97/7006-0873$18.00

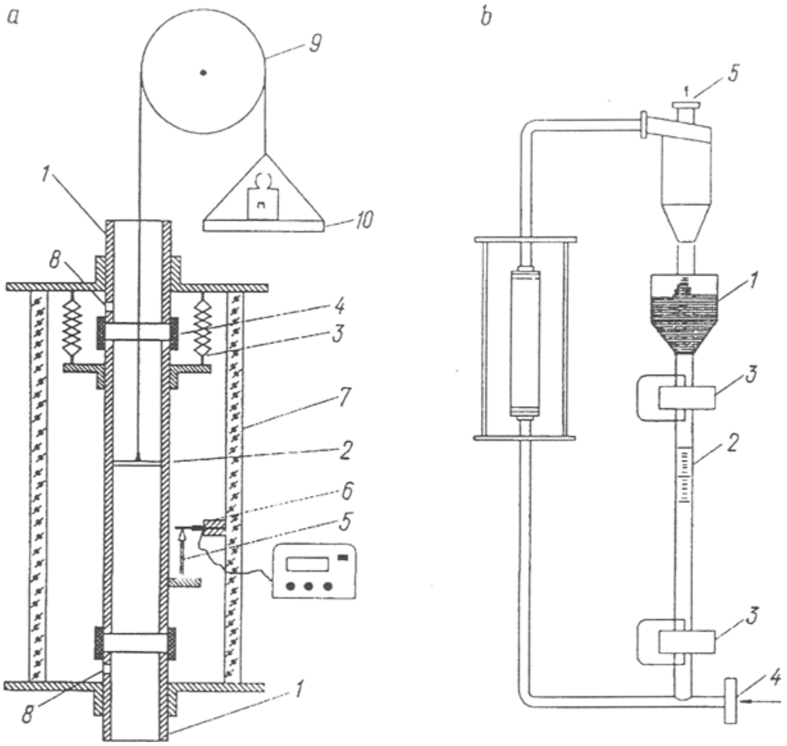

Fig. 1. Towards measurement of the interaction of a gas suspension with the walls of a pneumatic transport pipeline: a) basic diagram of measuring device; b) diagram of hydrodynamic rig (1) bin for loose material, 2) scale for reckoning the speed of loose material, 3) disk shutter, 4) gas inlet, 5) cyclone).

of rubber cuffs 4. A rod 5 in the form of a needle and bearing up against a resistance strain gauge displacement transducer 6 is rigidly connected to the movable section 2. Hermetically sealed to the fixed sections of pipeline 1 is a chamber 7, which communicates with the pipeline through 1 mm-diameter openings 8.

The device for measuring the force of skin friction operates as follows. A gas flow with solid particles is supplied to pipeline section 1 from below. The moving flow develops an upward friction force that disturbs the equilibrium between the rigidity force of springs 3 and the weight of the movable section 2, resulting in compression of the springs and upward displacement of the movable section 2. Due to the presence of openings 8 the pressures inside of the pipeline and chamber 7 equalize. This prevents deformation of the rubber cuffs 4, which could introduce errors into the measurements of skin friction. When the movable section 2 moves upward, needle 5 deforms transducer 6, which delivers an electrical signal to an IDTs-1 device, which records the degree of the deformation of the transducer. As a result, a correspondence is fixed between the magnitude of the deformation of the transducer and the flow velocity in the pipeline at a given effective mass concentration of solid particles. As the displacement transducer we used wire resistance strain gauges glued on the both sides of an elastic metal plate 0.25 mm thick. After complete assembly of the measuring device the transducer was calibrated using a block 9 30 mm in diameter and balance weights 10. The calibration scheme is clear from Fig. 1a.

The structural features of the developed facility and of those available are compared in [14].

Measurements of the skin friction force were made on a hydrodynamic rig, a basic diagram of which is presented in Fig. 1b. The rig is a circulation loop that is closed for solid particles and open for gas.

The gas flow rate was controlled by PM-V rotameters. The mass flow of solid particles was regulated by a disk shutter installed near the place of gas entry into the rig. The mass flow magnitude was determined from the speed with which the level in the overflow pipe descended with the shutter at the exit from the bin closed.

The solid particles used were sand, glass beads with a diameter of 1.18 mm and density 2600 kg/m^3, and glass beads with a diameter 0.113 mm and density 6800 kg/m^3.

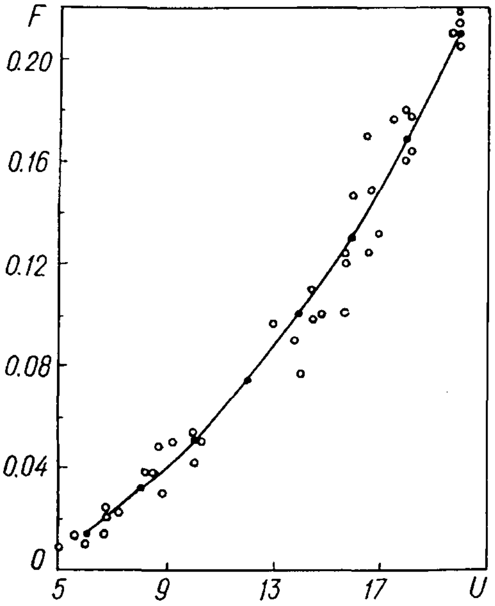

Fig. 2. Dependence of friction force acting on movable portion of measuring device on the gas velocity: curve, calculation by Eq. (2); points, measurements by means of the device developed.

In all of the runs, conditions were realized in which particles near the wall of the vertical pipe moved upwards.

Separate experiments were carried out for determination of the gas flow rate through the openings (8) of the measuring facility, since the excess pressure near the lower opening was higher than that near the upper one. For this purpose the end faces of the fixed section of pipeline 1 near the rubber cuffs were plugged and the resistance on the measuring facility was measured at different gas flow rates. The resistance range was made the same as in experiments with a flow carrying solid particles. It was found that the relative magnitude of gas flow did not exceed 5% of the overall gas flow rate in the rig.

To have an arbitration estimate of the possibility for carrying out measurements by the facility proposed, we performed a series of experiments on determination of the skin friction force of a pure gas flow in a cylindrical pipe. The basic idea of the experiment was to compare the measured friction force F of the gas flow against the wall of the cylindrical pipe with that calculated from the general phenomenological relation between the pressure drop ΔP over the length l and the shear stress τ on the wall of the pipe of diameter D [15]:

$$\tau = \frac{1}{4}\frac{\Delta P}{l} D . \tag{1}$$

Thus, having measured only the pressure difference, we can easily calculate the friction force F of the gas flow against the cylindrical pipe wall using the relation

$$F = \tau S_{\text{sur}} , \tag{2}$$

where $S_{\text{sur}} = \pi D l$ is the area of the inner surface of the pipe.

The friction force calculated from Eq. (2) and that measured are compared in Fig. 2. Their satisfactory agreement indicates the possibility of using the facility for measuring the skin friction force in single-phase and pneumatic transport flows.

The mean value of the deviation of experimental data from the predicted ones, coming to 5%, is taken as the value of the relative error of measurements. It characterizes the accuracy of measurements by the facility developed.

Figure 3 presents dependences of the shear stress on the pipe wall τ on the effective mass concentration μ of solid particles at different velocities of the carrying gas flow U.

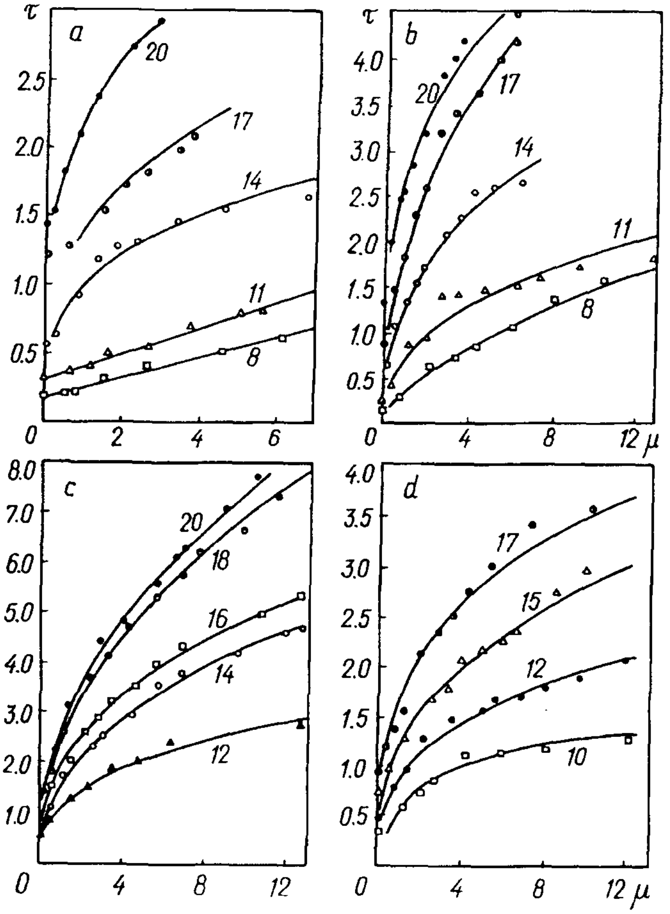

Fig. 3. Dependence of shear stress τ on the pipe wall on the magnitude of the effective mass concentration μ (the figures at the curves denote the gas velocity, m/sec): a) sand, diameter of the particles 0.1 mm; b) same, 0.2 mm; c) glass beads, 1.18 mm; *d*, same, 0.113 mm.

In the studied ranges of effective mass concentrations μ and gas flow velocities U the following regularities were revealed. At a fixed gas velocity, with an increase in the mass concentration μ the value of τ increases monotonically for all the materials; moreover, the lower the gas velocity, the closer the function $\tau(\mu)$ is to a linear one.

Small-size particles of various materials show a practically sufficient coincidence of the values of τ at identical velocities U and effective mass concentrations μ (Fig. 3a and d). Similar conclusions were also drawn by the authors of [16], but they also found an influence of the pipeline diameter.

The data on the shear stress of the gas–solid flow against the channel walls are suitable for calculating the hydraulic resistance of pneumatic conveying tubes, while the facility developed may turn to be a useful instrument for experimental investigations of the hydrodynamics of two-phase gas–solid flows.

NOTATION

τ, shear stress on pipe wall, Pa; ΔP, pressure drop in flow, Pa; l, length of pipeline section, m; D, diameter of pipe, m; F, force, N; S_{sur}, area of inner surface of pipe, m^2; μ, effective mass concentration of solid particles, (kg/sec)/(kg/sec); U, gas velocity, m/sec.

REFERENCES

1. Z. R. Gorbis, Heat Exchange and Hydromechanics of Disperse Through Flows [in Russian], Moscow (1970).

2. R. Buthroyd, Flow of Gas with Suspended Particles [Russian translation], Moscow (1975).
3. G. L. Babukha and M. I. Rabinovich, Mechanics and Heat Exchange of Polydisperse Gas–Suspension Flows [in Russian], Kiev (1969).
4. A. A. Shreiber, V. N. Milyutin, and V. P. Yatsenko, Hydromechanics of Two-Component Flows with a Solid Polydisperse Material [in Russian], Kiev (1980).
5. V. N. Milyutin, Investigation of the Hydromechanics of Vertical Gas–Suspension Flows with a Solid Disperse Material, Author's Abstract of Candidate's Dissertation, Kiev (1977).
6. G. I. Sergeev, Investigation of the Process of Interaction Between Two-Phase Flow Disperse Material and Channel Walls and Its Effect on External Heat Transfer, Author's Abstract of Candidate's Dissertation, Kiev (1968).
7. N. I. Gel'perin, V. G. Ainshtein, and L. I. Krupnik, Teor. Osnovy Khim. Tekhnol., 2, No. 4, 595-604 (1968).
8. N. I. Gel'perin, V. G. Ainshtein, and L. I. Krupnik, Teor. Osnovy Khim. Tekhnol., No. 8, 239-334 (1977).
9. L. I. Krupnik, V. N. Oleinik, and V. G. Ainshtein, Inzh.-Fiz. Zh., 43, No. 4, 533-541 (1982).
10. N. I. Gel'perin, V. G. Ainshtein, and V. N. Oleinik, Inzh.-Fiz. Zh., 32, No. 5, 860-865 (1977).
11. V. Pal'tsev and N. Volodin, Mukom.-Élevatorn. Prom., No. 9, 21-24 (1965).
12. W. P. M. Van Swaij, Chem. Eng. Sci., 25, No. 11, 1818-1820 (1970).
13. V. M. Egorov, L. F. Mel'nik, and V. A. Smolovik, in: Problems of Pulse Pneumatic Transport, Gas Purification and Pneumatic Mixing of Disperse Materials [in Russian], Tomsk (1997), pp. 62-74.
14. P. V. Ovsienko, Development of Methods for Calculating the Inner Circulation Contour of Finely Dispersed Particles in Reactors with a Packed Catalyst Bed, Author's Abstract of Candidate's Dissertation, Moscow (1995).
15. L. G. Loitsyanskii, Mechanics of Liquids and Gases [in Russian], Moscow (1978).
16. Y. Morikawa and T. Tanaka, J. Soc. Powder Technol. Japan, 21, No. 2, 87-88 (1984).