ON THE INFLUENCE OF GAS FILTRATION ON THE DISCHARGE OF LOOSE MATERIAL FROM A HOPPER

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Experimental results on the influence of gas filtration on the discharge of loose material from a hopper in a broad range of variation of the parameters are classified.

The regularities to which the discharge of loose material during both its gravitational [1, 2] and pressure [3] escape from a hopper have been examined in a number of recently published papers. Here the pressure escape is understood to be when the gas is filtered through the material being dumped in the direction of the latter's motion.

We have classified the results of a large quantity (about 5000) of tests to determine the discharge of a loose medium under a pressure escape. The experiments were conducted on plane hoppers with c × f × h = 33 × 120 × 520 mm and 64 × 400 × 850 mm dimensions. The hoppers had transparent walls. The loose material escaped through a slot running clear across the bottom of the hopper (Fig. 1), whereupon the following relations were satisfied:

$$a/c = 1,\ b \leqslant 0.83f,\ 0.15 \leqslant \lambda \leqslant 4.$$

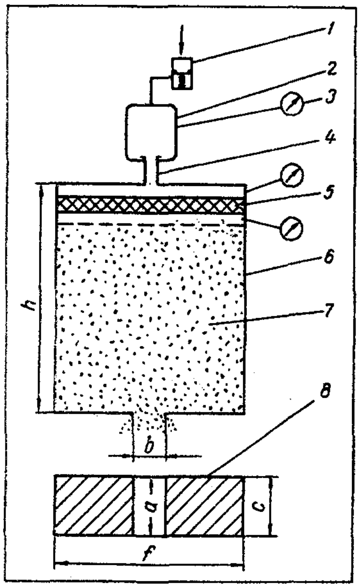

Fig. 1

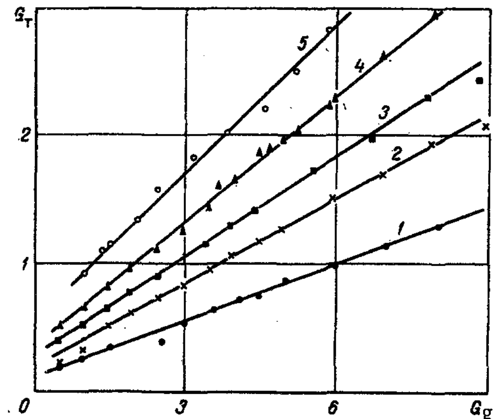

Fig. 2

Fig. 1. Diagram of the experimental apparatus: 1) reduction gear; 2) mixing chamber; 3) manometer; 4) sound nozzle; 5) gas distributor grating; 6) plane hopper; 7) loose material; 8) diagram of the base of the plane hopper.

Fig. 2. Dependence of the discharge of loose material on the discharge of the delivered gas (G_T, kg/sec, G_g, g/sec): 1) b = 10 mm; 2) 15; 3) 20; 4) 25; 5) 30.

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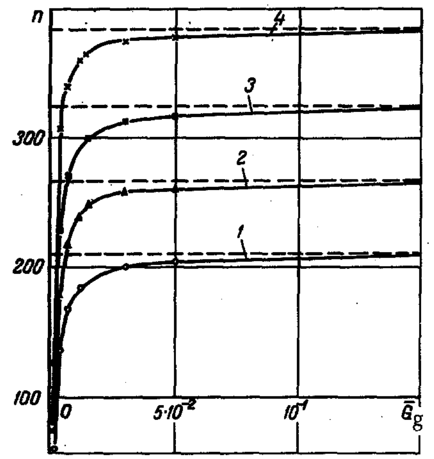

Fig. 3

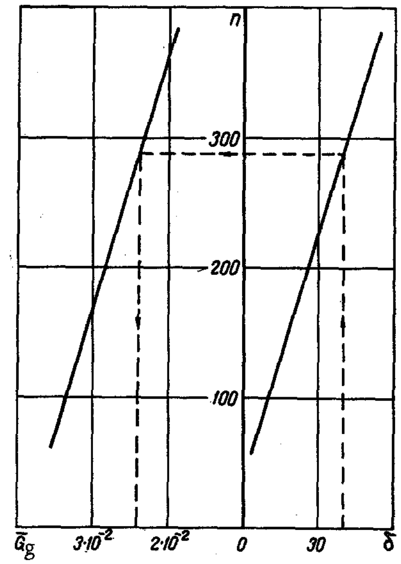

Fig. 4

Fig. 3. Dependence of the relationship between the solid and gas phase discharges on $\bar{G}_g$: 1) $\delta = 28$; 2) 36; 3) 46; 4) 55.

Fig. 4. Nomogram to compute the parameters δ; n; $\bar{G}_{g\,min}$.

The flow of loose material was determined by taking motion pictures of the level of the free surface in the bunker and also measuring the elapse of time; calculations were based on the formula

$$G_T = \gamma_H c \frac{\Delta S}{\Delta t}.$$

The area bounded by the free surface line was determined by using the interferometer IF-2. The time to empty the hopper varied between 2-600 sec, depending on the width of the escape slot. The time interval between two successive measurements of the area varied within 0.3-60 sec. The survey frequency was 48 frames/sec. The exposure time was 1/120 sec. The method used assured comparatively slight scatter of the test points (Fig. 2). An estimate made of the errors showed that the error in measuring the discharge increases as the discharge, but did not exceed 10% in the experiments made.

The discharge of the gas delivered to the hopper through a Venturi contracting nozzle was computed by means of the known formula:

$$G_g = 0.4 \frac{p_0 F}{\sqrt{T_0}} q(\pi_1),$$

in which the dimensionless reduced discharge q was determined by means of the dimensionless pressure π_1 at the nozzle section.

The gas discharge varied between 0-20 g/sec from experiment to experiment. Quartz sand (re-strained between sieves No. 0.355; 0.6 GOST 3584-50) with an equivalent particle diameter of $d_{eq} = 0.55$ mm was used as the loose material.

In contrast to [3], where the experiments were conducted at the maximal 0.04 ati (gage atmosphere) pressure drop, the pressure drop herein reached 3 ati, which permitted detection of peculiarities in the discharge of the solid phase for a sufficiently high discharge of the gas being filtered.

The direct test results are presented in Fig. 2. The dependence $G_T(G_g, b)$ is linear and can be expressed by the equation

$$G_T = A + BG_g, \tag{1}$$

where the coefficients A and B are functions of the slot dimensions. A formal passage to the limit as $G_g \to 0$ in (1) results in the equality $G_T = A$, however, the actual discharge of the solid phase from a hopper with a

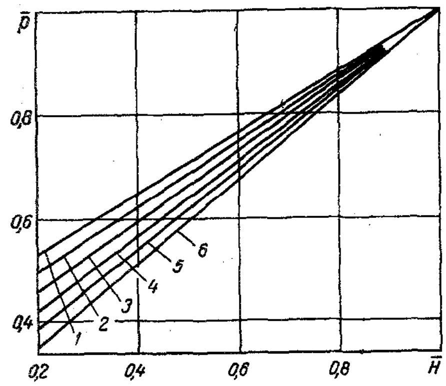

Fig. 5. Nature of the pressure change over the surface of loose material during escape (δ = const): 1) G_g = 6 g/sec; 2) 5; 3) 4; 4) 3; 5) 2; 6) 1.

closed cover differs from both A and G_{grav} in the sense taken in [1]. The coefficient $A < G_{grav}$ is introduced only to determine the location of the appropriate line. The case $G_T < G_{grav}$, which can hold for the pressure escape of loose material from a hopper, requires a special examination and will be elucidated by the authors in another paper.

Transforming (1) to dimensionless form, we obtain

$$n = B - \frac{1}{\bar{G}_g}\left(1 - \frac{A}{G_{grav}}\right), \qquad (2)$$

where the parameter $n = (G_T - G_{grav}/G_g)$ reflects the influence of gas filtration on the pressure discharge of the loose material, and $\bar{G}_g = G_g/G_{grav}$. The quantities A and B in (2) can be considered functions of the dimensionless slot width δ on the basis of a dimensional analysis.

The graphical interpretation of (2) is represented in Fig. 3. It follows from (2) that $n \to B$ as $\bar{G}_g \to \infty$. The difference between the quantities n and B tends to zero quite rapidly as $\bar{G}_g$ grows. Having been given a 5% error corresponding to the spread in the test points (Fig. 2), we obtain $n \approx B$ for small values of $\bar{G}_g = \bar{G}_{g\,min}$, which having been achieved, the relation of discharges of the phases n is practically independent of the parameter $\bar{G}_g$. For $\bar{G}_g > \bar{G}_{g\,min}$ the quantity n depends only on the dimensionless slot width δ. The last dependence is linear (Fig. 4 on the right)

$$n = 38 + 6.3\,\delta. \qquad (3)$$

Shown on the left in the same figure is the relation between the parameter n and the values of $\bar{G}_{g\,min}$:

$$\bar{G}_{g\,min} = 5 \cdot 10^{-5}(770 - n). \qquad (4)$$

Having been given one of the three parameters δ; n; $\bar{G}_{g\,min}$, the figure permits finding the values of the other two.

Taking account of the definition of n and of (3), we find that in the domain of values $\bar{G}_g > G_{g\,min}$ the dimensionless discharges of loose material and gas are related by a simpler dependence than (2):

$$\bar{G}_T = 1 + (38 + 6.3\delta)\,\bar{G}_g. \qquad (5)$$

Experiments were conducted as the level of the loose material was lowered in the hopper. However, a careful check of the discharge during each test showed that the discharge is neither determined by the level of the material nor the absolute pressure over its surface, which varied during the experiment. The governing parameter is the pressure gradient in the loose medium or its equivalent discharge of the gas delivered to the hopper. This is verified by Fig. 5, wherein are shown graphs of the pressure over the surface of the loose medium as a function of the height of the layer above the bottom of the hopper. A parameter on these graphs is the quantity G_g, which is constant on each line. At the same time experiments have shown that a constant discharge of loose material indeed corresponds to each line. The graphs of $\bar{P}(\bar{H})$ are presented only to lines where the influence of the nearness of the escape hole is manifested in the form of a nonlinearity. Naturally the dependences examined earlier are valid only up to the time when the level of loose material in the hopper becomes on the order of the height of the dynamic arch over the escape hole.

NOTATION

a, b	are the slot dimensions;
c, f, h	are the hopper dimensions;
$\lambda = b/a$	is the slot aspect ratio;
γ_H	is the bulk specific density;
S	is the area of the volume occupied by the loose material in the hopper projected on a photographic table;
p_0, T_0	are the stagnation pressure and temperature of the delivered gas in the mixing chamber;
p_1	is the pressure at the Venturi nozzle section;
F	is the least cross-sectional area of the Venturi nozzle;

G is the mass flow;
d_{eq} is the equivalent diameter of loose material particles;
H is the height of the loose material layer;
p is the pressure over the loose material surface;
t is the time;
$\bar{G}_T = G_T/G_{grav}$;
$\bar{G}_g = G_g/G_{grav}$;
$\delta = b/d_{eq}$;
$\bar{H} = H/H_{max}$;
$\bar{p} = p/p_{max}$;
$\pi = p_1/p_0$.

Subscripts

T is solid phase;
grav is gravitation;
g is gas.

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