FILTERED DISCHARGE OF LOOSE MATERIAL FROM HOPPERS

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Test data pertaining to the effect of gas filtration on the discharge of loose material from hoppers are presented systematically covering a wide range of parameter values.

In [1] we considered the discharge of quartz sand (equivalent diameter $d_e = 0.55$ mm) from a flat hopper through a slot across the entire bottom (Fig. 1) with gas filtering through the loose material in the direction of flow.

Empirical relations have been derived to describe the process. Beginning at certain levels of the gas flow rate through the hopper, the parameter n characterizing the effect of gas filtration on the discharge rate of loose material was found to depend only on the dimensionless slot width, namely:

$$n = 38 + 6.3\,\delta. \tag{1}$$

Parameter n was varied in those tests by only varying the actual slot width b.

The purpose of this study was to establish the feasibility of generalizing the results in [1] to cover loose materials of various specific weights and particle sizes.

The tests were performed with the following size fractions of polystyrene particles: equivalent diameter d_e = 0.55, 0.995, 1.45, 1.92, 2.31, and 3.2 mm. Thus, the specific weight of the loose medium (1.05 g/cm^3) was 2.5 times higher than in [1] and the particle size was varied through a factor of 6. The dimensionless width δ was varied over a wide range by varying both b and d_e.

According to the results in [1], the relation $G_S = f(G_G, b)$ is linear. Our polystyrene tests have shown that it remains linear also for the d_e = 0.55 mm fraction, but the initial range becomes nonlinear

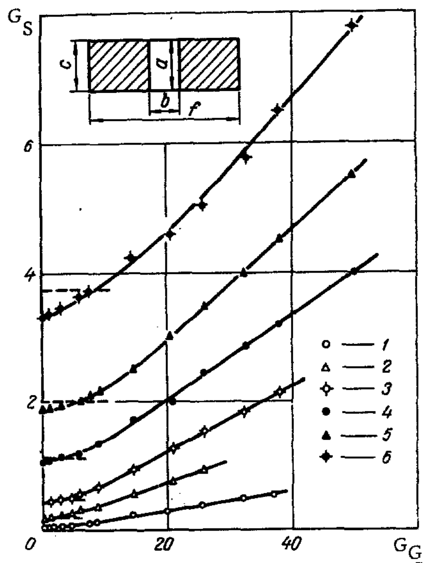

Fig. 1. Flow rate of loose material (G_S, kg/sec, d_e = 3.2 mm) as a function of the gas injection rate (G_G, g/sec): 1) b = 10 mm; 2) 20 mm; 3) 30 mm; 4) 50 mm; 5) 70 mm; 6) 100 mm. Schematic diagram of hopper bottom.

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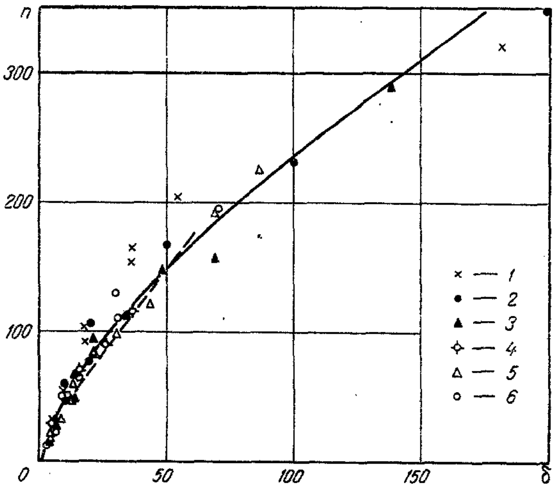

Fig. 2. Comparison between results in [1] (dashed line) and test data of this study: 1) d_e = 0.55 mm; 2) 0.995; 3) 1.45 mm; 4) 1.92 mm; 5) 2.31 mm; 6) 3.2 mm.

with increasing size d_e and wider as the slot width b is increased for a fixed particle diameter d_e (Fig. 1).

It follows from Fig. 1 that, beginning at some gas flow rate G_{GS}, the quantity $dG_S(G_G, b)/dG_G$ becomes independent of G_G. Test data evaluated in δ, n coordinates are shown in Fig. 2 for $G_G > G_{GS}$. The test points fit closely on the curve

$$n = 12(\delta - 2)^{0.65}. \tag{2}$$

It has been mentioned in [1, 3] that the flow rate of loose material from a flat hopper may be affected by the dimensionless width $\delta = b/d_e$ and by the slot elongation $\lambda = b/a$.

The dependence of the flow rate of loose material on the dimensionless width δ can be expressed in terms of Eq. (2). Parameter λ in the criterial flow number for gravity discharge of loose material from a flat hopper [3] was in our study varied over the range $0.077 \le \lambda \le 3.1$ and, according to the results, was found not to govern the filtered discharge of a loose material. This had also been explained in [1] by the fast decrease of the gravity discharge fraction G_{gr} in the expression for the parameter n becoming negligible when $G_G > G_{GS}$.

It has been mentioned in [2] that parameter $\bar{f} = f/b$ affects the flow rate of loose material during gravity discharge, as long as $\bar{f} < 3$. In our tests parameter $\bar{f}$ was varied over the range $1.2 \le \bar{f} \le 24$ during gravity discharge of loose material [2] and over the range $1.71 \le \bar{f} \le 68.5$ during filtered discharge of such a material (quartz sand, polystyrene) mentioned by F. E. Keneman.

It was mentioned earlier here that the specific weight of our material differed from that of the material which had been used in [1]. Taking this into consideration, we will assume, for the sake of comparison, that the increase in the volume flow rate of loose material due to filtration is constant at given values of δ and $G_G > G_{GS}$, i.e., that

$$\frac{\Delta G_1}{\gamma_{S1}} = \frac{\Delta G_2}{\gamma_{S2}}. \tag{3}$$

Relation (1) with (3) taken into account is indicated in Fig. 2 by a dashed line. The results within the test range $18 \le \delta \le 55$ for quartz sand seem to agree closely with formula (2) when $d_e \le 0.995$, which indicates the correctness of our assumption. Rewriting relation (2) with (3) taken into account, we have

$$\bar{n} = 12(\delta - 2)^{0.65} \frac{\rho_G}{\rho_S(1-\varepsilon)}. \tag{4}$$

The density and the volume flow rate of the gas must be determined at the same section. In this study Q_G and ρ_G were calculated from the criterial relations for a converging nozzle through which gas is supplied to a hopper:

$$\rho_G = \left(\frac{2}{k+1}\right)^{\frac{1}{k-1}} \frac{p_0}{gRT_0}; \quad Q_G = F\sqrt{\frac{2kgRT_0}{k+1}}.$$

For air

$$\rho_G = 2.21 \cdot 10^{-3} \frac{p_0}{T_0}; \; Q_G = 18.3 F \sqrt{T_0}.$$

In Eq. (4) there should appear the density of some loose material; we have selected polystyrene ($\gamma_S = 1.05$ g/cm^3).

The porosity ε was determined from an empirical relation applicable to the most compact packing:

$$\varepsilon = 0.422 - \frac{0.0244}{d_e},$$

with d_e measured in mm.

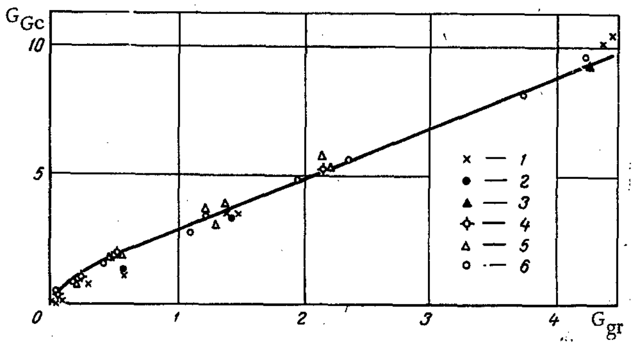

Fig. 3. Compensating gas rate (G_{Gc}, g/sec) as a function of the gravity flow rate of loose material (G_{gr}, kg/sec). Symbols the same as in Fig. 2.

The possibility has been mentioned [1, 4] that, in the case of loose material, the rate of filtered flow may become lower than the rate of gravity flow. The latter is indicated in Fig. 1 by dashed lines parallel to the axis of abscissas and drawn till intersection with the respective filtered-flow curves. These intersection points corresponds to the so-called compensating flow rate of gas G_{Gc}, which during filtered discharge ensures the same flow rate of loose material as during gravity discharge through the same slot. The compensating gas rate has been plotted in Fig. 3 as a function of the gravity flow rate of loose material. The size of loose material particles obviously does not affect this relation.

Thus, the relation $G_S = f(G_G, b)$ is generally nonlinear. Gas filtration through loose material discharging from a hopper increases the flow rate of that material above the level of gravity discharge, but only when $G_G > G_{Gc}$. At a given $G_G > G_{GS}$ the volume flow rate of loose material depends only on the dimensionless slot width. Relation (4) has been derived to describe the process within the following range of parameter values: δ = 2-150, ρ_G = 0.155-1.65 kg · sec^2/m^4, and ρ_S = 107-270 kg · sec^2/m^4.

NOTATION

a, b	are the slot dimensions;
c, f	are the hopper dimensions;
$\lambda = a/b$	is the slot elongation;
G	is the weight flow rate;
Q	is the volume flow rate;
d_e	is the equivalent diameter of loose material particle;
$\delta = b/d_e$	is the dimensionless slot width;
γ_S	is the specific weight of loose material;
ρ	is the density;
ε	is the porosity;
p_0, T_0	are the stagnation pressure and temperature of injected gas;
R	is the gas constant;
F	is the area of smallest section in the converging nozzle;
k	is the exponent of isentropic adiabate;

$n = (G_S - G_{gr})/G_G$;
$\bar{n} = (Q_S - Q_{gr})/Q_G$.

Subscripts

S	denotes the solid phase;
G	denotes gas;
gr	denotes gravity;
c	denotes compensating.

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