Definition of airflow rate induced by polifractional materials

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Abstract. This paper deals with further analysis of a probabilistic and statistical approach to determine the aerodynamic drag coefficient of particles in a flow of free-falling polifractional material. It also describes the experimental assembly enabling one to determine airflow rate induced by polifractional material and provides comparison of analytical calculations with experimental data.

1. Introduction
As is known [1, 2], the aerodynamic interference of certain particles in a flow of falling material and thus induced air is defined by the sum of aerodynamic forces of all particles of this flow in unit volume \(dV = S \cdot dx\):

\[
d \left( (1 - \beta) \cdot \rho \cdot u \cdot S \right) \cdot u = \left( \sum_{i=1}^{N} R_i \cdot c_i \right) \cdot S \cdot dx,
\]

where \(\beta\) – volume concentration of particles; \(\rho\) – air density, kg/m\(^3\); \(u\) – induced air speed, m/s; \(S\) – flow cross-section, m\(^2\); \(c_i\) – number concentration of these particles in the flow elementary volume, \(S \cdot dx\), 1/m\(^3\); \(R_i\) – aerodynamic force of dynamic interaction of a single particle with diameter \(d_i\) determined by aerodynamic drag coefficient:

\[
R_i = \psi_i \cdot F_{\text{aw}} \cdot \rho \cdot \left( u_i - u \right)^2 / 2,
\]

where \(\psi_i\) – drag index of a particle with diameter \(d_i\) in a material flow.

The main difficulty when determining the aerodynamic drag coefficient of a particle in a flow of a falling material is to consider the cross impact of flow constraints and the influence of particles on each other. This influence depends on multiple factors and is ensured by actual drag coefficient \(\psi^*\), which is defined through experiments for various materials and is described by empirical dependences, which, in case of sharp-grained particles with equivalent diameter \(d_{eq}\), may be presented as follows:

\[
\psi^* = \psi_0 \cdot e^{-1.8 \sqrt{d_{eq}}}.
\]
where $\psi_0$ – drag coefficient of a single (free) particle with diameter $d_i$.

The proposed probabilistic and statistical method [2] implies that active aerodynamic drag coefficient of particles (outside air shadows of neighboring particles) with diameter $d_i$ may be determined by the following formula:

$$\psi_i = \left(1 - K \cdot \frac{\sum \beta_{(i)}}{1 - \beta}\right) \psi_0$$  \hspace{1cm} (4)

where $K$ – proportionality factor, the relation of particle air shadow volume to the volume of a particle.

In order to confirm the assumptions made, there is a need to compare them with experimental data, which was performed via the suggested test stand.

2. Materials and methods

It is rather difficult to measure the speed of air induced by particles in a flow of a falling material. Hence, it is advisable to ensure indirect process of air flow rate moving through material flow, i.e. via the plenum chamber, which is described by Ze Qin Liu [3]. However, the study of relatively large fractional materials caused the need to modify this method.

The test stand (Fig. 1) includes an overhead bin (1) with opening diaphragm (2), a lower bin (3) 1x1x1 m in size, which serves the plenum chamber, a fan (9) with a regulating gate (8).

Crushed granite stone was chosen as the test material. Since this material has discrete structure, it is possible to neglect the flow variation as the overhead bin becomes empty.

The prepared material samples with the given particle size distribution from the overhead bin through a calibrated diaphragm are poured into the plenum chamber. Air gets into the chamber together with the material through a masking aperture (4), thus creating induction pressure.
Figure 1. Test stand: 1 – overhead bin; 2 – opening diaphragm; 3 – plenum chamber; 4 – masking apertures; 5 – discharging indicator; 6 – Pitot tube; 7 – differential pressure gauge; 8 – regulating gate; 9 – fan

The replaceable aperture proposed by Ze Qin Liu (Fig. 2-a), in case of overload of relatively coarse material, was excessively rigid, which, in turn, led to considerable dispersion of particles and was replaced by the original design (Fig. 2-b). The amount of the material that did not fall into the lower bin did not exceed 1%.

Figure 2. Replaceable aperture: a – proposed by Ze Qin Liu, b – proposed by the author.
The flow of aspirated air is defined by a Pitot tube (6) with a differential pressure gauge (7). By regulating the flow of aspirated air via the regulating gate (8), it is possible to obtain equality of outcoming and incoming air flow and, therefore, a zero difference of static pressure in a chamber and outside it. The zero difference of static pressure in the chamber is defined by indicator 5 – tissue paper 0.1x0.1 m in size. A standard paper makes pressure pulsations smooth and allows defining rather precisely the moment of pressure equality in a chamber and in the environment (Fig. 3).

Axial fan SK 160 C was used as the fan 9 (Q=950 m³/h, n=2,480 rpm, Ny =100 W).

Material samples with set grain size were prepared via sieve separation from three fractions 0.94; 3.75; 15 mm (Tab. 1). Mass median diameter $d_{50}$ of all samples was similar, which when calculating according to OST 14-14-98-83 [4], ensures similar amount of intake air.

| Sample No. | Material type | Weight ratio, % | Mass median diameter $d_{50}$, mm | Material class |
|------------|---------------|-----------------|-----------------------------------|----------------|
| No.1       | Polifraction  | 66              | 2.51                              | fine-grained   |
| No.2       | Polifraction  | 76              | 2.51                              | fine-grained   |
| No.3       | Polifraction  | 88              | 2.51                              | fine-grained   |

Comparison of airflow rates obtained by analytical and experimental methods is shown in Fig. 4. Based on the comparison of estimated and experimental data for sharp-grained particle, it is possible to conclude that the data provides for high correlation ratio (the Pearson’s code equals 0.998±0.01),
reliability and efficiency of estimated values (Student reliability criterion equals 0.13, Fischer’s ratio equals 1.31).

Similar mean diameter $d_{cav}$ and various sizes of particles (materials 1-3) provide different consumption of induced air; however, it increases with the growth of the particle size to 2.5 mm, which has as is known the highest induction capacity.

![Figure 4. Induced air flow rates: ■ - estimated value, ◆ - experimental value](image)

3. Conclusions
Air induction with polifractional flow of granular material was studied using the test stand. The dependence of the particle drag coefficient on the material fractional composition was defined. The results of analytical study were confirmed and dependences of induced air flow rate variations on disperse composition of overloaded material were identified.

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