Complex dispersed analysis of particles applying in output hydrodynamic criteria decreasing dust leakage’ throw collectors of aspiration in construction industry

S A Koshkarev, I V Stefanenko, K S Koshkarev

1Department Life Safety in Construction and Urban Economy, Volgograd State Technical University, IAaC, 28, avenue Lenina, Volgograd 400005, Russia

E-mail: ks77887762@gmail.com

Abstract. The article is devoted to the issue of improving the environmental safety of the construction industry by improving dust collectors of dust removal systems using additive-complex dispersive analysis of variance of dust emissions by aspiration systems. The article proposes the improvement of complex analysis of variance using hydrodynamic criteria in output functions. Modified output data and additive-simplex approach to the evaluation of characteristics - equivalent sizes and speeds of sedimentation-soiling of dust particles make it possible to determine the ranges of their changes with a higher degree of accuracy of the results. The distributions of the hydrodynamics criteria values allow us to obtain reliable meanings for sedimentation velocities and equivalent particle’s sizes for the studied dust samples of building materials. Analytical approach to determining the density distribution of the numerical values of the criteria allowed clarifying the values of sedimentation-soiling velocities and hydraulic equivalent sizes of particles to get more reliable of their changes ranges. The authors present the most essential regressions and mark to method determining hydraulic work regimes for design dust collectors. This approach is one of the most effective ways to improve the environmental safety of the construction industry.

1. Introduction

In dust-removal systems of aspiration, dust collectors are installed with significant variability of the structures and the physical mechanisms used in them - the principles of trapping solid particles. In cyclones of various types and modifications, counter flow swirled collectors (SFSC – VZP) [1,2], a number of designs of specific model of cyclones and wet cleaning devices, for example [3-5]. The results of determination of removal calculation and energy performance of particle settling in cyclones were presented in [3-5]. It were received and announced results of calculation of efficiency of sedimentation of dispersion particles in a kind of wet cleaning device (rotoklon) [6]. It was obtained interesting results of experimental study of particle separation in a mini-hydrocyclone due to founded fishhook effect that affect on capturing of small dust particle [7]. Optimization of the cyclone separator geometry for minimizing pressure drop using Co-Kriging calculation model was fulfilled in [8]. The issues of mention above studies are determination sizes dust particles, characteristics of geometric and pressures losses values of cyclones and inertial-gravity-type dust collecting devices. There use digital calculation hydrodynamics’ flows methods with experimental studies was used in these researches [2-5,7,8] too.
Methods of dispersed analysis of particles for determination velocity of sedimentation and the equivalent particle size should be applied for designing of high effective dust collectors. It very important to know these characteristics to form hydrodynamic regime within separating cyclones and other collectors using inertial-gravity separations’ methods to cleaned dust-gas aspiration flows, for example, [9-11]. The complex method of dispersed analysis of dust has been tested by practice and has been developed in a number of papers already, for example, [11-13]. Emerging new modifications of dust removal devices involves the design refinement and debugging of the mode of operation in a technological process [14-16].

The leakage parameter of particles of inertial-gravity-type dust collecting devices (cyclones, SFSC and etc.) used for cleaning dust and gas flows in aspiration systems depends on many factors. One of the most significant is the velocity of the sedimentation of the particle motion. Technical problems of designing dust-collecting devices with an insignificant degree of dust leakage throw out should solve by application experimental ways of equivalent dimensions’ particles determination affecting on the sedimentation velocity for specific dust samples.

A lot of works devoted to the study of dispersed analysis and particles size distribution’ functions. These factors including and the velocities of sedimentation $u_p$ affect on the efficiency of the dust-collecting equipment considerably [9,11,13]. It is impossible to cite all literature that dedicated to the study of these issues in this article. It could be noted the a few latter works, for example, [17-21]. Numerical values of the particle shape factors $\Psi$ and dust particle densities affect greatly on the velocities of their sedimentation $u_p$ [17-21]. It was studied influence of dust fine dust particles and their shapes factor during dust cake loading on air filters in [17]. There observed state of mixing, shape factor, number size distribution of dust particles in the paper [18]. Fundamental problems and issues of dispersed analysis and study size distribution’ dependence of dust particles, determination of particle shape factors $\Psi$ considered in [19-21].

Complex dispersed analysis of dust particles by an optical-hydraulic method was applied on a laboratory setup [22]. In [23] the values of the particle shape factors $\Psi$ were determined for the some common types of dust accepted in the construction industry. It was received the experimentally regressive dependences of the sedimentation velocity due to the values of Ar and Ly criterions (distribution density) and their changing probability range in [23]. The problem of the optical method of dispersive analysis of dust is the impossibility of an objectively exactly equivalent particle size due to the location of the particles and their spatial orientations on the microscope slide glass and co-aggregation between it. For the same reasons, it is also difficult to estimate the median average particle size with a sufficient degree of accuracy and adequacy. This way does not allow completely correct all deficiencies.

2. Materials and Methods

In the present work, an attempt has been made attempt to improve the output data of the experimental results taking into account [23]. It was proposed to significantly modify and supplement the type of physical parameters of the output data of the complex analysis of variance using the criteria of hydrodynamics for estimating the velocity of sedimentation and the equivalent particle size $t_p$.

Dust obtained experimentally the output of a comprehensive dispersive analysis of particles of dust samples using the hydrodynamic criteria Lyashchenko $\text{Ly}$ and Archimedes $\text{Ar}$. To determine the hydraulic particle size, calculated indirectly from the known finite velocity of free fall, a parametric complex is used, for instance, the first of the Lyashchenko criteria $\text{Ly}_1$

$$\text{Ly}_1 = \text{Re}^2 \Psi = \pi g t_p^2 (\rho_p - \rho_g) (6\nu \rho_g)^{-1}$$

(1)

where $t_p$ - equivalent particle size, m;

$\rho_p$ - the density of dust particles of dispersed materials, kg m$^{-3}$;
\( \rho_g \) - the density of gas (air), kg m\(^{-3}\);

\( \Psi \) - particle shape factor;

\( \nu \) – coefficient of kinematic viscosity of air.

Density and coefficient of kinematic viscosity of air depends on temperature, and are accepted according to reference data. Criterion \( \text{Ly}_1 \) for particles of dispersed building material dust which density is \( \rho_p \gg \rho_g \) have form

\[
\text{Ly}_1 = \pi g t_3 \rho_p \left( 6\nu^2 \right)^{-1}
\]

The Lyashchenko criterion of the first kind could use for calculating the final sedimentation velocity corresponding to equivalent particular size determining by experiments. It is possible use values of the Lyashchenko criteria to determine sedimentation velocity \( u_p \) relatively to the particles dimensions.

Series of experiments to determine the rate of sedimentation of particles \( u_p \) and the values of Lyashchenko criterion carried out with the aim of determining the refinement of the particle size for various kinds of building materials dust in a laboratory setup [9]. It was measured sedimentation velocities and sizes of particles experimentally to determine the values of the Archimedes \( \text{Ar} \) and Lyashchenko \( \text{Ly} \) criteria (mean-median \( D_{50} \) (\( \text{Ar} \)), \( D_{50} \) (\( \text{Ly} \)) values for the “aggregate” of dust sample particles).

3. Results and Finding

There showed the result of the study at the figure 1. Comparison with the available data of other researchers for the particles of conventionally standard shape forms [16] showed at the figure 1. The values of the particle shape factor \( \Psi \) varied with the kind of building materials and depending on the equivalent particle size. Values of factor \( \Psi \) changed in the places of sampling for the same kind of building materials. It had different meanings in raw warehouses, places of reloading and aspiration schemes including outlet of collectors). At the figure 1 it was showed that for particles with equivalent particle sizes \( t_p \) from 1 to 50 microns the value's factor \( \Psi \) was changed within the range \( 0.82 \leq \Psi \leq 0.94 \). In general case the complex dependence of the criterions \( \text{Ar} \) and \( \text{Ly} \) determines values of particle shape factor \( \Psi \) using figure 1. The results allow to defined that values of shape factor for small particles is closer to a spherical form \( \Psi = 1 \). It was found that shape factor \( \Psi \) meanings is changed corresponding criterion \( \text{Ar} \) in different range of particles size for studied dusts samples. It was obtained regression of the value of the particle shape factor \( \Psi \) depending on the number of Archimedes \( \text{Ar} \) for some dust bulk building materials. It has acceptable for engineering calculation form

\[
\Psi(\text{Ar}) = (A_1 \log^2(\text{Ar}) + B_1 \log \text{Ar} + C_1)
\]

The characteristic plot of complex dependence of the integral density functions of the distribution of numbers \( \text{Ar} \) - \( D(\text{Ar}) \) and \( \text{Ly} \) - \( D(\text{Ly}) \) of dust samples for bulk building materials (inorganic dust with content mass concentration \( \text{SiO}_2 \) from 20 to 70\%) has the form that is shown at the figure 2.
Figure 1. Dependence of changing particle shape factor’s number \( \Psi \) of the dust in corresponding the criterions Ly and Archimedes Ar. 1,6 - spherical particles; 2 - rounded; 3 - angular; 4 - oblong; 5 - plate; 7 - changing particle shape factor’s number \( \Psi \) of the sample.

Figure 2. The complex dependence of the integral density functions of the distribution of numbers Ar and Ly for dust sample particles for inorganic dust studied bulk materials, with mass concentration content SiO₂ from 20 to 70%.

The determination of the redefined values Reynolds criteria \( Re_x \) could get by (4)

\[
Re_x = \left( \frac{Ly_1}{\Psi} \right)^{1/2}
\]

where is \( \Psi (Ar) = (A_1 \log^2 (Ar) + B_1 \log Ar + C_1) \).

Reynolds criteria \( Re_x \) have form

\[
Re_x = u'_p t_{p} v^{-1}
\]

The refined values of criteria \( Re_x \) allowed to meanings of velocities \( u'_p \). The redefined values particle sedimentation’ velocities \( u'_p \) are determined

\[
u'_p = Re_x \nu_{p} v^{-1}
\]

It was received the experimental data results of complex of analysis of variance by additive - simplex way in a laboratory setup [9]. Statistical processing of the results allowed obtaining regressions for the evaluation of the integral functions of the density’s distribution of the numbers Ar and Ly of dust sample particles of dust building materials and had the following forms

\[
\begin{align*}
D(Ly)_1 &= A_2 - B_2 e^{-C_2,ly} \\
D(Ar)_1 &= A_3 - B_3 e^{-C_3,ar} \\
D(Ly, Ar) &= \left(2\pi\right)^{-1/2} \left(\int_0^{\infty} e^{-x^2/2} dx\right)
\end{align*}
\]
where \( A_1 \ldots A_3, B_1 \ldots B_3 \) and \( C_1 \ldots C_3 \) are parametric values of coefficients that take constant values for the studied types of dust dispersed building materials.

The average median values of criterions \( D_{50}(Ar) \), \( D_{50}(Ly) \) was determined for particles of the studied bulk building materials classified as inorganic dust with silicon dioxide \( SiO_2 \) content from 20 to 70\% too (figure 2). Results of analysis of variance by additive - simplex way based on output hydrodynamic criterions for tested sand, cement dust (dust with mass content \( SiO_2 \) of from 20 to 70\%) showed that it have average median particle size \( t_{p50} = 5 \) microns and less. These mentions above fine fractions dust have mass quantity (weight) about 95\% in emissions exhausting into the atmospheric air.

Statistical treatment of experimental data results allowed us to obtain approximation for simplicity of engineering calculations allowed us to obtain regressions for evaluation of the integral density functions of the distribution of the numbers \( Ar \) and \( Ly \) of dust sample particles in form system of equations

\[
\begin{align*}
D(Ly) & = (A_1 \log^2(Ly) + B_1 \log Ly + C_1) \\
D(Ar) & = (A_2 \log^2(Ar) + B_1 \log Ar + C_2) \\
D(\Psi) & = (A_3 \log^2(Ar) + B_3 \log Ar + C_3)
\end{align*}
\]  

(8)

where \( A_4 \ldots A_6, B_4 \ldots B_6 \) and \( C_4 \ldots C_6 \) are meaning of coefficients which was accepted as constant values for the studied types of bulk dust materials.

In the first approximation in engineering calculations, the average-median values of criterions \( Ar \) and \( Ly \) \( D_{50}(Ar), D_{50}(Ly) \) allow to determine not only the range of variation. It could be redefined average-median values of \( D_{50}(Ly, Ar) \) of the sedimentation' velocities of particles \( u_{p50} \) of the “aggregate” of the sample under test the averaged values by system of expressions also

\[
\begin{align*}
D_{50}(Ly, Ar) & = \left( D_{50}(Ly) + D_{50}(Ar) \right) / 2 \\
u_{p50} & = \left( u_{p50}(Ly) + u_{p50}(Ar) \right) / 2 \\
t_{p50} & = \left( t_{p50}(Ly) + t_{p50}(Ar) \right) / 2 \\
u_{p50} & = \Psi_{50} u_p
\end{align*}
\]  

(9)

where \( u_{p50} \) - average - medium of the sedimentation’ velocities of particles;

\( u_{p50}(Ly), u_{p50}(Ar) \) - average - medium of the sedimentation’ velocities of particles which were determined accordingly density’s distribution of the numbers \( Ly \) and \( Ar \) are shown at graphs figure 2;

\( t_{p50} \) - average - medium of the dust particles’ dimensions;

\( t_{p50}(Ly), t_{p50}(Ar) \) - average - medium of the sedimentation’ velocities of particles which were determined accordingly density’s distribution of the numbers \( Ly \) and \( Ar \) are shown at graphs figure 2;

\( \Psi_{50} \) - average - medium values of the shape factor \( \Psi \).

Often it is required to redefine the sedimentation rates of particles \( u_p^{aw} \) for dispersed dust in the corresponding to particle size and changing shape factor \( \Psi \) also. The redefined values sedimentation’ velocities of particles with stochastic arbitrary of shape aggregate \( u_p^{aw} \) in general sample that differs from the speed of spherical particles could be determined by relation

\[
u_p^{aw} = \Psi(Ar) u_p
\]  

(10)

Improved additive-simplex approach of complex analysis of variance using hydrodynamic criteria in output data allowed to define equivalent sizes and sedimentation’ velocities of dust particles with a
higher degree of accuracy of the results make it possible to determine the refine ranges of their changes. The distributions of the hydrodynamics criteria values allow us to obtain reliable data for sedimentation velocities and equivalent particle’s sizes for the studied dust samples of building materials. It was received the most essential regressions determining hydraulic work regimes for design dust collectors with low values of dust leakages throw out by aspiration schemes. This approach is one of the most effective ways to improve the environmental safety of the construction industry.

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