Determination of dust disperse composition in energy-efficient aspiration systems for building materials production

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Abstract. In various industries, primarily, the production of building materials, technological processes include multiple transfer operations, during which a large amount of dust is released. The resulting dust causes air pollution and various diseases of workers. To prevent this, different dust removing systems are used. One of them is the aspiration system, which includes air purification devices. For the operation of these systems, it is necessary to obtain the data on the disperse composition of dust and its concentration. Since aspiration systems consume a lot of energy, various improvements are used. Here, basing upon the processed experimental data, the authors proposed a method to determine the main parameters of the dust flow, formed in the bulk materials transfer units of energy-efficient aspiration systems.

1. Introduction

Various technological processes for the production and processing of bulk materials in many industries (construction, mining, metallurgy, etc.) are accompanied by intensive dust emission [1-3]. The analysis showed [3-5] that the greatest dust emission occurs during technological processes of transfer from a conveyor to another conveyor. To maintain the required dust MPC in the work area and MPE of dust during its release to the atmosphere, up to 20% of the company's current assets are spent, which negatively affects the competitiveness. The most effective way to get rid of the dust emission is a complex dust removal system, which include aspiration systems, secondary dust control and general inflow ventilation. It should be noted that it is the aspiration system in this complex that determines the required productivity of the other dust removing systems and, consequently, their energy consumption [6]. For example, the performance of a general inflow ventilation system is required to compensate the air volumes removed by aspiration systems [7].

2. Relevance

As a rule, a simple aspiration system consists of: dust source cover 1, which in our case is a transfer unit; duct system 2; air purification devices 3, 4; and thrust booster 5, ‘Figure 1, a’.

From the aspiration hood 1 the dust-loaded air is supplied by means of a fan 5 to the dust-cleaning system 3, 4 and is released to the atmosphere with the required MPC. Analyzing the operation of this system [8], it can be concluded that the aspiration hood is the key element of both the efficiency of the aspiration system and the energy consumption of the entire dust-removal complex. Therefore, various authors have developed designs for aspiration hoods [9-11], which significantly increase the system efficiency while reducing its energy consumption. However, for effective operation of this system, it is
necessary to make an intelligent design, which is possible only if there are parameters of the dust-gas flow. To date, there is a fundamental methodology, confirmed by numerous experiments [2] to determine the parameters of the hood, but it is true for old power-consuming hoods. In this regard, the development of a methodology for determining dust parameters in energy-saving aspiration systems is a very relevant task.

![Figure 1](image-url)  

**Figure 1.** a) Layout diagram of decentralized aspiration system, b) results of a numerical experiment: 1 – aspiration hoods; 2 – air duct system; 3 – the first stage of air purification (cyclonic); 4 – the second stage of air purification (bag filter); 5 – thrust booster (fan); 6 – emission of aspirated air into the atmosphere.

### 3. Problem statement

The aspiration hood operation is primarily characterized by the following main parameters: the required aspirated air flow \( Q_{asp} \), m\(^3\)/s, of A concentration, mg/m\(^3\) and the dust disperse composition at the aspiration hood outlet. According to these parameters, the selection of the scheme and air purification devices is made.

Dust parameters at the aspiration hood outlet: A concentration, mg/m\(^3\) and the disperse composition depend on a variety of factors, primarily on the properties of the transferred material and the aerodynamic processes taking place in the hood. To date, there is only one engineering method to determine them [5,12], which most fully takes into account these factors, but it is true for simple aspiration hoods with single walls, the use of which is not recommended due to extremely high power consumption. This method is repeatedly confirmed by industrial experiments and is consistent with scientific theories, so it will be most preferable as a basis.

### 4. Theoretical part

It is known that the complete disperse composition of aspirated dust does not obey any known distribution law [13-15]. The reason for disobeying the distribution of dust particles is the violation of the structure of the two-phase aspirated flow: part of the large dust fractions are separated by inertial forces and gravity, precipitating on the conveyor belt. The process of dust formation during the materials processing and its placement in an aspirating funnel is so complicated that the attempts to obtain analytical methods for calculating the concentration and dispersion composition have not been successful so far. To date, there is only one technique that allows describing the aspirated dust disperse composition, which is based on the value of \( d_{max} \) - the maximum possible diameter of dust aspirated from the hood [3].

\[
d_{max} = 5780 \cdot \left[ \frac{U_{sh}}{\rho_d \cdot \left(1 + 0.08 \cdot \frac{U_{sh}}{U_0 \cdot H}\right)} \right]^{1/2}
\]  

(1)
where: \(d_{\text{max}}\) – maximum dust particle diameter carried away from the aspiration hood, \(\mu m\); \(L\) - length of aspiration hood, m; \(H\) - height of the aspiration hood, m; \(U_{vh}\) - air velocity at the inlet to the aspiration funnel, m/s; \(U_0\) - average air speed inside the hood, m/s; \(\rho_d\) – dust density, kg/m³.

Using this method, thanks to processing of the numerous results of the industrial experiment, the average curves for the distribution of the aspirated dust disperse composition were obtained, but they are not valid when using energy-efficient hoods.

5. Study results and discussion

We analyzed the generalized data of the aspirated dust disperse composition obtained with industrial units [16,17,5,19] using Microsoft Exel and MATLAB under existing distribution law. It was found that the disperse composition of the dust aspirated from the hood with single walls is described most accurately by the Gaudin-Andreev-Schumann law in a normal logarithmic net, as follows:

\[
D(d) = N \cdot d^m
\]  

(2)

where \(N\) and \(m\) are the empirical coefficients.

Or substituting instead of \(d_i\) in equation (2) \(\lg(d_i)\), since the distribution of dust particles, as a rule, is represented in a logarithmic net, we obtain:

\[
D(d) = N \cdot \lg^m(d_i)
\]  

(3)

Since the disperse composition of aspirated dust is determined by \(d_{\text{max}}\) parameter, then, therefore, in equation (3) the coefficients \(N\) and \(m\) for each case will have different values. That is why we suppose that these values will depend on \(d_{\text{max}}\) parameter. As a result, we receive:

\[
N = 864 \cdot d_{\text{max}}^{-1.04}
\]  

(4)

\[
m = 0.12 \cdot \ln(d_{\text{max}}) + 0.04
\]  

(5)

The disperse composition, trend lines, their equations and reliability measures for different values of the \(d_{\text{max}}\) parameter are given in ‘Figure 2’. ‘Figure 3’ shows the trend lines for the coefficients \(N\), \(m\) as a function of \(d_{\text{max}}\) parameter.

As ‘Figure 2’ shows, the method of describing the distribution of dust particles proposed by us is valid for fractions with a total run of up to 90%. Therefore, for a more accurate description of the analysis of the dust disperse composition, it is necessary to use the "dissection" method used by Prof. Azarov V.N. [20].

![Figure 2](image_url)

**Figure 2.** Graphs of the aspirated dust disperse composition and the approximation line for various \(d_{\text{max}}\) in a logarithmic net.
Thus, the proposed Gaudin-Andreev-Schumann distribution law is valid up to 90% run, the remaining part of the graph can be constructed by combining with a 90% run, and \( d_{\text{max}} \) parameter at 100% run.

Thus, for the first time, we have obtained a method for describing the disperse composition of the dust aspirated from hoods with single walls.

To determine the disperse of dust particles from energy-efficient aspiration hoods, we proposed to maintain the coefficient of the diffraction degree of dust purification \( E_i(d) \), considering the aspiration hood as an air purification device:

\[
E_i(d) = \frac{D(d_i) - D(d_{i,\text{effect}})}{D(d_i)}
\]

where \( D(d_i) \) - the value of the hood run with single walls; \( D(d_{i,\text{effect}}) \) - the value of the passage for energy-efficient hood.

Then \( D(d_{i,\text{effect}}) \) run for each fraction of the disperse composition from the energy-efficient hood is defined as:

\[
D(d_{i,\text{effect}}) = D(d_i) \cdot (1 - E_i(d))
\]

We have studied the operation of some designs of energy-efficient hoods [9,10], using COSMOSFloWorks software as well “Figure 2”, b [20]. As a result of data processing, we obtained that the graph of the fractional purification efficiency \( E_i(d) \) is described by straight parallel lines in the logarithmic probabilistic net “Figure 4”, as well as in some dust purification devices:

\[
E_i(d_i) = a + c \cdot d_i
\]

where \( a \) and \( c \) coefficients are determined by the type and design of the hood, which are determined at the stage of the hood development.

6. Suggestions
Thus, we can recommend the following sequence of determining the disperse composition of dust particles from modernized hoods:

1. According to the known value of the maximum dust diameter carried away to the aspiration funnel \( d_{\text{max, effect}} \), the coefficients \( N, m \) are used in equation (4) and equation (5);
2. According to equation (3) the \( D(d_i) \) run is defined due to the corresponding fractions;
3. The run value of any $D$ fraction from the observed hood and $d_{\text{max}}^{\text{effect}}$, a graph of the fractional efficiency ‘Figure 4’ is constructed in a normal logarithmic net, the values of the coefficients $a$, $c$ are determined;

4. According to equation (8) the fraction purification grade is determined.

![Figure 4](image)

**Figure 4.** The graphs of fractional purification efficiency of different energy-saving hoods in a normal logarithmic net.

7. Conclusion

Here, the engineering method for determining the dust disperse composition from various modified aspirating hoods is proposed for the first time. The method takes into account previous research, it is based on the results of industrial and numerical experiments. The use of this method will allow engineers to select the most suitable purification device for aspiration systems of bulk material transfer units. Also, the disperse composition of dust aspirated from hoods with single walls is described for the first time using the distribution law, particularly the "dissection" method.

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Acknowledgments
The article was prepared within a development program of the Base University on the basis of BSTU named after V.G. Shoukhov.