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Determination of the efficiency of a complex of dust removal systems for industrial enterprises

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Abstract. In various industries, there are often technological processes that are characterized by the release of dust into the working area. This dust is the cause of various diseases of the workers of the enterprise. To maintain the required air parameters in terms of the dust factor in industrial premises, it is necessary to use a complex of systems, including an aspiration system, a centralized vacuum dust removal system and general ventilation. Each of the listed systems will fulfill its specific task, but their efficiency and productivity are interrelated. There are numerous works that consider the operation of systems separately, however, the final concentration of dust in the room, in the end, will depend on their simultaneous operation. The article presents a developed method for calculating the efficiency of a complex of dedusting systems, which will allow at the design stage to assess the concentration of dust in the air of industrial premises and, if necessary, make the necessary adjustments.

1. Introduction

Most of the technological processes in the production of bulk materials in the construction, metallurgical, food and other industries are associated with the transportation and processing of bulk materials (reloading, crushing, mixing, etc.) [1-3]. The most intense and numerous sources of dust emission are bulk material handling [3-5]. All of these processes are accompanied by intense dust emission into the atmosphere of industrial premises, which is characterized by high dispersion and is one of the main causes of dust etiology in workers. The following reasons for the occurrence of dust in the indoor air during production can be distinguished:

a) strict framework of technological requirements for feedstock (restrictions on moisture content, dispersion of processed materials, etc.);

b) the widespread use of conveyor transport, which is one of the main both concentrated and distributed sources of dust release;

c) use of equipment without adequate dust control (shelters, dust collectors, fans, etc.);

d) the use of only one dedusting system (for example, aspiration or general ventilation), each of which individually does not provide a decrease in dust concentration to the level of maximum permissible concentration;

e) the absence of scientifically grounded relationships, algorithms between the parameters of technological processes, the characteristics of the raw materials used in this case and the parameters of dedusting systems (aspiration, central control room, general ventilation).

Maintaining the required MPC for dust in the working area and MPE for emissions into the atmosphere to varying degrees is spent on both fixed and circulating assets of the enterprise, which affects their competitiveness. The total energy consumption of the entire dedusting complex can reach more than 20% of the total energy consumption of the enterprise, which ultimately affects the final cost of the products. Thus, improving the energy efficiency of dedusting systems today is a very urgent task.

In general, the classical methods of maintaining the required microclimate parameters for the dust factor are a set of measures: aspiration (local exhaust ventilation), centralized vacuum dust extraction and general ventilation [6-7]. Each of these systems performs its own specific task: aspiration allows you to localize as much as possible concentrated sources of dust release, centralized vacuum dust removal is necessary for surface dust removal of settled dust, general ventilation is necessary to compensate for air volumes and maintain the required microclimate parameters. Only the efficient operation of all of these systems makes it possible to maintain the MPC (maximum permissible concentration) of dust in the working area of the premises.

There are interactions between the individual dedusting systems that must be taken into account when designing them. Interaction is determined both by the relative position of individual systems and their actual performance. The decisive role in determining the required performance of a complex of dust removal systems is the aspiration system: general ventilation compensates for the air volumes removed by aspiration systems, centralized vacuum dust removal is designed to remove settled dust that did not enter the aspiration network [8-13]. However, at present, the design of systems is carried out separately, which ultimately leads to a non-compliance of the dust content in the air with the required standards. In this case, in order to maintain the required MPC for dust in the air, enterprises are forced to significantly increase the productivity of systems, which significantly increases the energy intensity of production.

Considering the production process in a room, it is necessary to note the uneven distribution of dust concentration values at its various points. [14-15] This unevenness is primarily a consequence of the high intensity of dust release from some sources: transfer points, crushers, etc. However, for the design and for assessing the operation of dedusting systems in general, it is necessary to know the average value of the dust concentration in the air of the industrial premises. This task is not easy, since its solution is complicated by the need to take into account the many factors of the systems included in the complex under consideration. However, in this material we will present the methodology developed by us for calculating the efficiency of the entire complex of the dust removal system.

2. Materials and methods

The use of a complex of dust control systems ensures effective dust removal of premises that form dust concentrations in the premises at levels lower than the maximum permissible. Interaction arises between individual dedusting systems, which must be taken into account when calculating a complex of systems.

The calculation of the efficiency of dedusting systems is performed on the basis of the methodology for calculating the concentration of dust in rooms.

As the initial data when calculating the integral concentration in the room, you can take:

W − volume of the considered room, m^3;

G − the total intensity of dust release in the room under consideration, g/h;

C_n − dust concentration in the supply air, mg/m^3;

C_{MPC} − maximum permissible concentration of dust in the room air, mg/m^3;

k_0 − dust deposition coefficient, hour^{-1};

Q − supply air consumption of general ventilation systems, m^3/h.

The dust deposition coefficient averaged over the area of the workshop k_0, hour^{-1}, taking into account that the distribution of dust inside the room is uneven, can be determined as:

$$k_0 = \frac{\sum_{i=1}^{n} G_{oi} \cdot C_i}{\sum_{i=1}^{n} W_k \cdot C_i^2} \tag{1}$$

where C_i – dust concentration measured at n, different points of the workshop at the breathing level in the respective zones W_k, mg/m^3;
G_{oi} – dust deposition rate, mg/hour, corresponding to concentration C_i.
W_k – volumes of zones of constant concentration, m^3.

The G_{oi} value is determined by weighing standard sheets of paper with an area ΔS before and after dusting:

$$G_{oi} = \frac{\Delta m_{в}}{\Delta t} \cdot \frac{S}{\Delta S} \tag{2}$$

where Δt – is the measurement time, hour;
$\Delta m_{в}$ – is the mass of settled dust, mg;
S – total area of the room, m^2;
ΔS – is the total area of the room, m^2;

With general dust release in the air of the room G from concentrated sources, G_s is supplied, and from dispersed G_p, i.e.:

$$G = G_s + G_p \tag{3}$$

the absence of aspiration $\eta_i = 0$). Then:

$$G_s = \sum_{i=1}^{n} G_i (1 - \eta_i) \tag{4}$$

3. Results and discussion

Suppose that all local sources of dust emissions, in total n have the same intensity ($G_i = G_1$), of which m is equipped with aspiration with efficiency η_a, then the intensity of dust emissions from them will be:

$$G_s = (n - m) \cdot G_1 + mG_1 \cdot (1 - \eta_a) = G_1 n \cdot (1 - \frac{m}{n}\eta_a)\,. \tag{5}$$

We denote $\frac{m}{n} = P_a$, $G_1 \cdot n = G_{s.n.}$, then:

$$G_s = G_{s.n.}(1 - P_a \eta_a)\,,\ \eta_a^{\max} = 1\,. \tag{6}$$

With complete aspiration of all concentrated sources in the room $P_a = 1$.

The intensity of surface dusting is denoted by G_n. In the absence of centralized dust collection systems, the amount of dust on surfaces increases due to the deposition of dust from the indoor air. The value of G_p also increases in this case, and in the equilibrium state it becomes equal to G_0, i.e. $G_n^{\max} = G_0$

The operation of centralized dust collection systems reduces G_p to a certain extent. If G_c is the average performance of the dust removal system, then for G_p:

$$G_n = (G_0 - G_c)\eta_c\,, \tag{7}$$

where η_c is the efficiency of centralized vacuum dust removal systems.

We will assume that the deposition of dust increases with an increase in its concentration in the air according to a linear law:

$$G_0 = k_0 WC \,. \tag{8}$$

Then, taking into account (8):

$$G_n = k_0 CW\eta_c - G_c\eta_c \,. \tag{9}$$

In an equilibrium state during the operation of a centralized vacuum dust extraction:

$$G_p + G_s + G_n + QC_n = QC + G_0 \,. \tag{10}$$

Taking into account (10), we get:

$$G_p + G_s + k_0 CW\eta_c - G_c\eta_c + QC_c = QC + G_0 \,; \tag{11}$$

$$G_p + G_s - G_c\eta_c + QC_n = QC + k_0 CW(1-\eta_c) \,; \tag{12}$$

$$G_p + G_s - G_c\eta_c + QC_n = C(Q + k_0 W(1-\eta_c)) \,; \tag{13}$$

$$C = \frac{G_p + G_s - G_c\eta_c + QC_n}{Q + k_0 W(1-\eta_c)} \,; \tag{14}$$

or

$$C = \frac{G + QC_n - G_c\eta_c}{Q + k_0 W(1-\eta_c)} \,. \tag{15}$$

Let us introduce the notation:

$$P_\mathrm{p} = \frac{G_\mathrm{p}}{G};\ P_s = \frac{G_s}{G};\ P_c = \frac{G_c}{G};\ q = \frac{Q}{Q_\mathrm{max}};\ k_\mathrm{max} = \frac{Q_\mathrm{max}}{W} \ ; \tag{16}$$

where $Q_{\max}$ − maximum possible flow rate of supply air into the room for diluting dust to, m^3/h;
m − number of local dust emission sources equipped with aspiration;
n − total number of local sources of dust emissions;
G_c − average intensity of dust removal, g/h;
G_p, G_s − intensity of dust release from distributed and local sources, respectively, g/h;
G − the total intensity of dust release in the room under consideration, g/h;
$k_{\max}$ − maximum rate of air exchange in the room, hour^{-1}.

The value of Q_{max} can be determined from the condition of dilution of harmful substances to the level of C_{MPC}:

$$Q_\mathrm{max} = k_\mathrm{max} \cdot W = \frac{G}{C_{MPC} - C_n} \,. \tag{17}$$

Substituting (16), (17) and (6) into (15) we obtain:

$$C = \frac{P_p + P_s(1 - P_a\eta_a) - P_c\eta_c + \frac{Q}{Q_{\max}} \cdot \frac{Q_{\max}}{G} \cdot C_n}{\frac{Q}{Q_{\max}} \cdot \frac{Q_{\max}}{G} + \frac{k_0 W(1-\eta_c)}{Q_{\max}(C_{MPC} - C_n)}} = \frac{P_p + P_s(1 - P_a\eta_a) - P_c\eta_c + \frac{q}{C_{MPC} - C_n} \cdot C_n}{\frac{q}{C_{MPC} - C_n} + \frac{k_0}{k_{\max}}(1-\eta_ц)\frac{1}{C_{MPC} - C_n}} = \frac{(C_{MPC} - C_n)\left[P_p + P_s(1 - P_a\eta_a) - P_c\eta_c\right] + q \cdot C_n}{q + \frac{k_0}{k_{\max}}(1-\eta_c)} \quad (18)$$

or:

$$\frac{C}{C_{MPC}} = \frac{\left(1 - \frac{C_n}{C_{MPC}}\right)\left[P_\text{p} + P_s\left(1 - P_\text{a}\eta_\text{a}\right) - P_c\eta_c\right] + q\frac{C_п}{C_{MPC}}}{q + \frac{k_0}{k_{\max}}\left(1 - \eta_c\right)} \quad (19)$$

The maximum permissible concentration of dust in the atmosphere of the shop C_{MPC}, is determined according to sanitary standards, depending on the content of SiO_2 in the dust:

- with SiO_2 up to 10% C_{MPC} = 4 mg/m^3;
- more 10 % - C_{MPC} = 2 mg/m^3;
- more 70 % - C_{MPC} = 1 mg/m^3;
- not contained SiO_2 – C_{MPC} = 10 mg/m^3.

In each type of production, dust contains a different amount of SiO_2. Consider, as an example, the dust that is formed in the foundry, during the processing of molding sand. As shown by earlier studies [92], the dust of the molding sand contains on average 95% SiO_2, hence the C_{MPC} = 1 mg/m^3. Then, taking into account the MPC norms, dependence (4.19) will take the form:

$$C = \frac{\left(1 - C_n\right) \cdot \left[P_\text{p} + P_s\left(1 - P_\text{a}\eta_\text{a}\right) - P_c\eta_c\right] + qC_n}{q + \frac{k_0}{k_{\max}}\left(1 - \eta_c\right)}. \quad (20)$$

We carried out measurements in the molding and casting department of the iron casting of one of the enterprises to determine the average deposition coefficient k_0. The main sources of dust formation in the molding and casting department are the processes of overloading and transportation of the molding sand. Measurements were made at 10 points of separation. The intensity of the deposition of dust in the air of the room was determined by weighing sheets of A4 paper with an area of ΔS =0.063 m^2 before and after dusting. The area of the room was S =50x27=1350 m^2; the volume of the entire workshop was W = 10800 m^3. Sheets of paper were placed along conveyors and at characteristic points near processing equipment. The residence time of the paper sheets was Δt= 5 h.

At the points where the paper sheets were located, the concentration of dust in the air of the working area Ci was determined. The measurement results are shown in table 1.

Since the coefficient of dust deposition k_0 depends on the properties of dust floating in the air of the working area, namely, on the density and its dispersed composition, it should be assumed that this coefficient will also be valid for similar production, where there is a processing of the molding sand.

Table 1. The results of measurements of air dust content in the area of the molding and casting department.

Measuring point no.	1	2	3	4	5	6	7	8	9	10
C_i, mg/m^3	20.1	19.7	16.8	4.2	17.6	23.5	9.4	23.3	6.9	18.7
G_{oi}, 10^3 mg/m^3	56	52	47	17	60	47	27	60	21	46
Δm_b, mg	12.44	11.56	10.44	3.78	13.33	10.44	6.00	13.33	4.67	10.22
W_k, m^3	880	900	920	2488	888	612	800	248	2664	400

As a result of processing the obtained values, the dust deposition coefficient was obtained for the molding and casting department, 1/hour:

$$k_o = 3.74.$$

Taking this into account, equation (20) will take the form:

$$C = \frac{(1-C_n)\cdot\left[P_\text{p} + P_s(1-P_\text{a}\eta_\text{a}) - P_c\eta_c\right] + qC_n}{q + \frac{3.74}{k_\text{max}}(1-\eta_c)}. \tag{21}$$

Equation (21) allows calculating the average concentration of dust in the air of foundries, where there are technological operations associated with the processing of molding sand, with various options for the use of dust removal systems (aspiration, centralized dust removal and general ventilation).

4. Summary

The article presents a methodology developed by the authors for determining the average concentration of dust in production workshops during the operation of a complex of dedusting systems. The presented methodology allows you to determine the efficiency of the entire complex as a whole, taking into account the efficiency of each system. The article separately considered the case for foundries during the processing of molding sand, the results obtained can be used in a similar production.

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