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Combined pneumatic cleaning and aspiration system using vortex dust collectors

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Abstract. The article discusses the main calculating methods of the dust removal systems. Calculation and design of systems for cleaning is made taking into account the technological features of the production process and operating conditions, the typical equipment designs use and the units and machines sizes minimum number use. As a rule, the dust deposited on the ceilings of the enterprise has smaller fractions than the dust removed from the nodes of the process equipment. What is important is the parameters selection of the dust collecting apparatus for the dust to be cleaned. So, to adjust the vortex dust collectors, when using the existing aspiration systems, for the dust removal purpose, it is proposed to use a probabilistic-stochastic approach to establish fractional efficiency. The vortex dust fractional collectors' efficiency depends on the probability of trapping dust particles of a certain diameter in the areas of installations. The procedure for determining the fractional efficiency of vortex dust collectors to adjust the stationary aspiration systems for dust removal is considered.

Introduction

There are several ways to remove dust from the surface. Widely used dry manual cleaning is inefficient and inefficient, since it increases the level of dust in the room on average from 10 to 15 times [1]. The dust content decreases between the periods of harvesting, but the residual concentration still considerably exceeds the initial (background) concentration. The same result is caused by blowing dust with compressed air. The most progressive and efficient in sanitary-hygienic and technical-economical terms and free from the above-mentioned disadvantages is vacuum cleaning, which prevents the secondary ingress of dust from surfaces into the air environment. This method allows to remove any dust of different nature and purpose of the surfaces, as well as from places difficult for other methods of cleaning and rooms with any temperature and humidity conditions. The vacuum method provides the highest quality surface cleaning and complete removal of settled dust from the room.

Calculation and design of systems for cleaning is made taking into account the technological features of the production process and operating conditions, the use of typical equipment designs and the use of the minimum number of sizes of units and machines.

Modern methods for calculating pneumatic conveying installations provide for the preliminary selection and determination of mainly the following values: estimated performance, estimated duct length, gas velocity and particle soar speed. The difference between the existing calculation methods lies in the further order of determining the dust removal system flow parameters, which depends on the selection method or the expenditure concentration purpose [1].



Methods for calculating dust collection systems

I calculation method. After determining the initial values, the vacuum cleaning systems calculation is performed in the following order. Given the value of the flow concentration, the required flow rate of the carrier gas is calculated. Then by the known gas flow value the pipeline diameter, which is assigned in accordance with the nearest sample size is found. After clarifying the values of concentration and flow rate, the total hydraulic resistance is determined as the sum of pressure losses from clean air friction and material against the pipeline walls, the presence of local resistances, losses in the ventilation part and installation units. According to the known values of flow and total hydraulic resistance, taking into account the reliability coefficient, a blower-shaped unit is selected and the drive power is calculated [2].

II calculation method. The pressure-damping device is selected and according to its characteristics with an efficiency of at least 90% of the maximum, the overpressure and air flow value is taken. Based on these values, the calculation is further carried out according to the first method. As a result of the calculation, the value of the total pressure loss is found, which should not differ from the initial value by 10-15%. In the case of a significant difference between the calculated pressure loss and the pressure created by the adopted device, the calculation is repeated, or a different device is chosen [2].

III calculation method. The method is used if the device has an adjustable drive. In this case, the calculation starts with the choice of the blower device, according to the aerodynamic characteristics, which the air flow is in the maximum efficiency area, the required flow rate and pressure are set in accordance with the accepted air flow value, and the flow concentration value is selected, the first method algorithm continues. According to the parameters obtained as the calculation result, the device rotation speed is assigned and the drive power is calculated [2].

The second and the third should be considered more appropriate among the considered calculation methods, since in these cases the expenditure concentration is not assigned subjectively, but is calculated from the conditions for the best use of the device. The first calculation method is convenient if there are reliable recommendations for choosing the material expenditure concentration value.

The flow rate is the main factor ensuring the dust collection system stable operation. Reliability and cost-effectiveness of the dust collection system operation depend on the correct speed of the air flow. This speed should be such that the transportation is stable, without deposition of material in horizontal sections of the pipeline. From the conditions of economy, it should not be overstated, since the energy consumption for transporting dust is proportional to the third degree of air velocity.

In engineering practice, it is often customary to designate the air velocity in terms of the soar velocity of the particles of material to be transported.

When using existing aspiration systems for the purposes of dusting, the second method of calculation is used [2].

The use of a probabilistic stochastic approach to determine the fractional efficiency of vortex dust collectors

For the dust to be cleaned, the dust collecting apparatus parameters selection is important. As a rule, the dust deposited on the ceiling of the enterprise has smaller fractions than the dust removed from the nodes of the process equipment. Thus, to adjust the vortex dust collectors when using existing aspiration systems for the purpose of dust removal, it is proposed to use a probabilistic stochastic approach to establish fractional efficiency.

Fractional efficiency of vortex dust collectors depends on the probability of trapping dust particles of a certain diameter in the areas of installations [3, 4]. By analogy with the works of E.I. Boguslavsky and other authors [5–8], we consider the dust collector fractional efficiency definition when a mass transfer process occurs in one zone (cyclone).

We use the probabilistic stochastic approach to determine the apparatus fractional efficiency [9 - 15].

Let us consider the dust removal process as a complex probabilistic [6, 7]. We will define in the dust removal apparatus:

- zone A - the zone of the flow inlet from the inlet nozzle into the device body;
- radius of the cylindrical part of the body, exhaust pipe.

The dust particles mass transfer probability with a diameter d in a cylindrical coordinate system can be described by the equation:

$$\frac{\partial P}{\partial \tau} = W_r \frac{\partial P}{\partial r} + \frac{W_\varphi}{r} \frac{\partial P}{\partial \varphi} + 0,5b_r \frac{\partial^2 P}{\partial r^2} . \quad (1)$$

This equation analytical solution according to the equation separation method by physical processes, which allows to reduce the original equation to the solution of two equations was found by Boguslavsky E.I. as:

$$P = \left(1 - ce^{-\lambda r_H(1-W_r/V_r)}\right) \cdot \operatorname{erf}(Y), \quad \operatorname{erf}(Y) = \frac{2}{\sqrt{\pi}} \int_0^Y e^{-t^2} dt, \quad Y = \sqrt{\frac{R^2}{2\mu^2 b(\tau - \tau_0)}}, \quad (2)$$

where c is the integration constant; λ - is a variable separation parameter; r_H is the coordinate of the particle point entering the apparatus; W_r , V_r - are the radial velocities of particles and gas; R is the radius of the apparatus; μ - is a coefficient of dynamic viscosity; b is the diffusion coefficient of dust particles; $\tau - \tau_0$ - is time spent by the particle in the apparatus.

When solving equation (1), the following transformation was used:

$$d\varphi = \frac{W_\varphi}{r \cdot V_r} \quad (3)$$

Equation (3) includes the gas flow rate (tangential), which is a function depending on the radius and zone, which is considered [15].

Thus, the fractional efficiency of dust collection for particles of diameter d entering the apparatus at the point with coordinate $r = r_H$ will be determined by formula (4).

$$P = \left(1 - ce^{-\lambda r_H(1-W_r/V_r)}\right) \cdot \operatorname{erf}(Y). \quad (4)$$

The probability of mass transfer through the inlet of zone A is equal to:

$$P_A = \frac{1}{R_H - R_T} \int_{R_T}^{R_H} P dr_H \quad (5)$$

Or

$$P_A = \left(1 - c \cdot \frac{e^{-\lambda E_A R_T} - e^{-\lambda E_A R_H}}{\lambda \cdot E_A (R_H - R_T)}\right) \cdot \operatorname{erf}(Y), \quad (6)$$

where R_H , R_T are the body and the exhaust pipe cylindrical part radii;

$$E_A = 1 - W_r/V_r. \quad (7)$$

The integration constant is determined from the physically justified condition that $P_A = 0$ for $W_r = V_r$. Then, $E_A = 0$ and to determine the value we obtain the equation:

$$1 = c \cdot \frac{e^{-\lambda E_A R_T} - e^{-\lambda E_A R_H}}{\lambda E_A (R_H - R_T)} \quad (8)$$

We will calculate the limit according to the rule of L'Hôpital:

$$\lim_{E_A \rightarrow 0} \frac{e^{-\lambda E_A R_T} - e^{-\lambda E_A R_H}}{\lambda E_A (R_H - R_T)} = \lim_{E_A \rightarrow 0} \frac{-\lambda R_T e^{-\lambda E_A R_T} + \lambda R_H e^{-\lambda E_A R_H}}{\lambda (R_H - R_T)} = \frac{-\lambda R_T + \lambda R_H}{\lambda (R_H - R_T)} = 1 \quad (9)$$

Therefore, the integration constant is $c = 1$.

Finally, for the zone A, we obtain the probability of mass transfer:

$$P_A = \left(1 - \frac{e^{-\lambda E_A R_T} - e^{-\lambda E_A R_H}}{\lambda \cdot E_A (R_H - R_T)} \right) \cdot \operatorname{erf}(Y). \quad (10)$$

Summary

Using the probabilistic stochastic approach, it is possible to calculate the fractional efficiency of vortex dust collectors and take into account their modification, operation mode, the mass of particles entering the zones, the flow rate at the entrance to the zones and the properties of the incoming dispersed flow, which allows the stationary aspiration systems adjustment for their use for the dust removal purpose.

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