IOP Conference Series: Materials Science and Engineering



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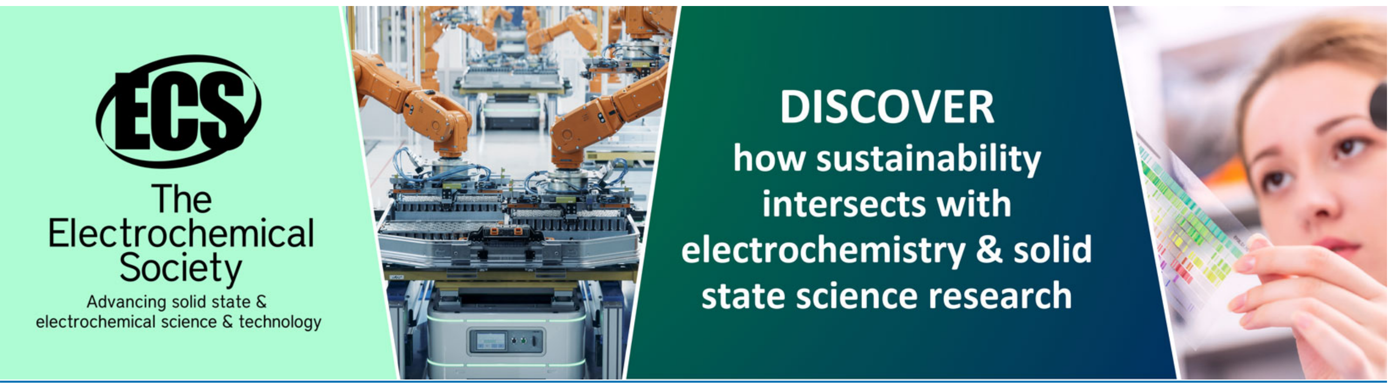
To cite this article: I Stefanenko *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **698** 055035





IOP Conf. Series: Materials Science and Engineering **698** (2019) 055035 doi:10.1088/1757-899X/698/5/055035

# The study of the secondary dust resuspending in industrial premises

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**Abstract.** The article is devoted to the sedimentation study and settled dust subsequent resuspending. An assessment of the dust distribution patterns, knocked out of the process equipment by the method of Azarov-Boguslavsky. A mathematical model description of the dust resuspending process is proposed.

## Introduction

At the building industry enterprises, producing building materials and products, there are various technological processes, accompanied by the formation, release and distribution of various harmful impurities. Dusty conditions in these enterprises are formed as a result of dust entering the air from industrial premises, which stand out not only from the process equipment, but also as a result of the settled dust resuspending due to the air streams movement, people and equipment [1, 2]. The dust particles release from the process equipment can occur during loading and unloading, through leaks and free openings. Dust particles, starting from a certain mass value, are practically not absorbed even in the immediate dust collectors' vicinity. Therefore, at first there is a particles' mass transfer from the process equipment to the working area, and then the dust settles on the working platform surface. Resuspending dust, moving, increases the total dust content in the working area air [3, 4].

## Dust settling

To determine the aspiration systems effectiveness, as well as its calculation and the effective measures development to combat the evolving hazards, it is necessary to know the dust emission amount or mass transfer from the process equipment [5, 6]. The amount of dust released, for example, from equipment, can reach 100 kg per day per stream [7]. However, it is difficult to distribute this figure among individual devices due to the fact that a significant amount of leakiness in the equipment does not allow to clearly determine the dusting places and the amount of dust entering the air of the working area [8].

The process of mass transfer from process equipment can be represented as follows:

- the particles movement speeds direction coincidence and air flow;
- the particles movement opposite direction and air flow;
- non-point or linear source of dust emissions, i.e. particles are emitted from a surface and at different angles to the outlet [9, 10].

For the cases considered, the mass transfer equation probability of dust particles from the process equipment takes the form:

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$$\frac{\partial P}{\partial \tau} = W_x \frac{\partial P}{\partial X} + W_y \frac{\partial P}{\partial Y} + W_z \frac{\partial P}{\partial Z} + 0{,}5 \sum_{i=1}^{3} b_i \frac{\partial^2 P}{\partial X_i^2} \tag{1}$$

The sum of the forces (Figure 1) acting on the particle is equal to: $\sum_{i=1}^{n} \overline{F} = \overline{F_D} + \overline{F_G} + \overline{F_A}$, (2)

where $F_D$ – is the particle aerodynamic drag force; $F_T$ – is the force of gravity; $F_A$ – is Archimedean power.

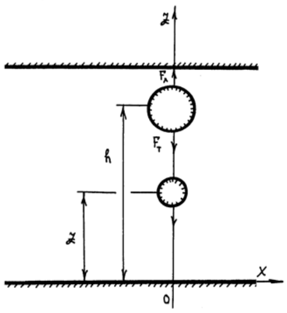

**Figure 1.** The settling dust process model in a limited production volume

After a series of transformations, we obtain the equation for the mass transfer probability:

$$P = 1 - \left[1 - \exp\left(\left(-\frac{XW_Z}{W_{XY}} - Z\right)\frac{\ln(a/K)}{(H-h)} + \frac{h \ln a_0}{(H-h)}\right)\right] erf(\Upsilon_Z), \tag{3}$$

$$(\Upsilon_Z) = \left[\frac{H_\tau^2}{2\overline{\mu^2} b_Z (\tau - \tau_0)}\right], \tag{4}$$

where $H_\tau$ - is a distance the particle overcomes along the axis $Z$ to the subsidence plane $X=H$; $\overline{\mu^2}$ - is an entrainment degree of a particle by a pulsating gaseous medium; $b_Z$ - is a gas diffusion coefficient; $\tau - \tau_0 = \tau_\Pi$ - defines the particles mass transferring process on the sedimentation plane $X=H$.

According to the Azarov-Boguslavsky method, the intensity of $G_0$ dust sedimentation has been adopted to assess the distribution patterns of dust dislodged from the process equipment. This value represents the amount of dust deposited per 1 m$^2$ of area per unit of time [8, 11]:

$$G_o = \frac{G}{F\tau}, \tag{5}$$

where $G$ – is the amount of settled dust, kg; $F$ – is a subsidence area, m$^2$; $\tau$ - dwell time in the dusty zone, h.

The amount of dust dislodged from the dusting source is defined as the masses sum of the dust deposited on the floor surface:

$$M_{\text{то}} = \left(\overline{G}_1 F_1 + \overline{G}_2 F_2 + \overline{G}_3 F_3 + ...... + \overline{G}_n F_n\right) = \sum_{i=1}^{n} \overline{G}_i F_i, \tag{6}$$

where $i = \overline{1-n}$ - is the sedimentation dust surface areas number; $F_i$ - is the subsidence surface area, m$^2$

Having carried out a number of mathematical transformations, the expression for determining the amount of dust dislodged from the process equipment will take the form:

$$M_{Ti} = \pi \overline{G}_{\max} \frac{\varphi}{360}\left[\frac{2}{a^3} + \left(\frac{X_K^2}{a} + \frac{2X_K}{a^2} + \frac{2}{a^2}\right)\exp(-aX_K)\right], \tag{7}$$

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where φ is the hazard propagation sector, degrees; a is a parameter determined from experimental data on the dust precipitation intensity; XK is the distance from the dusting source to the remote point at which the dust settling intensity is determined, m; - ist he intensity of dust settling at the source, g / ($m^2$h).

The Azarov-Boguslavsky‘s method [8, 11] allows, with engineering precision, to determine the amount of dust knocked out of the equipment, with the density of dust deposited on the floor surface and technological platforms, in the range of 0.1 - 100 g / ($m^2$ h).

**The settled dust resuspending**

It is necessary to distinguish the primary dust resuspending and the settled dust resuspending (transition from the bonded dispersed to free dispersed state). Primary dust resuspending occurs during the process equipment operation. The most intensively dust resuspending deposited on building structures. This is facilitated by unorganized air flow arising from the opening of various openings, unorganized aeration, manual dust cleaning, traffic or mechanisms, blowing compressed air process equipment, etc. [11].

The mechanism of raising dust is complex and diverse. Dust particles are lifted one by one, and can form dust bunches, and also make vibratory movements on the surface or rotate around its axis [11].

When resuspending dust, settled in the production volume on building structures (technological equipment), on the surface of these structures (equipment) the boundary layer is formed. In the boundary layer, the air flow rate decreases sharply. The boundary layer, depending on the Reynolds number, has a laminar or turbulent flow regime. The thickness of the turbulent layer can be several times more laminar.

In the production volume of the boundary layer on the surface of the building structure is in the range of 200-700 microns. The dust particles size deposited on these surfaces and susceptible to resuspending is 1-5000 microns. Thus, the settled dust is almost completely (in some cases partially) immersed in the boundary layer. If the dust deposits are significant in height and exceed the possible boundary layer on the sedimentation surface, then the boundary layer is formed on top of the dust deposition. The most unfavorable for whipping is the case when the dust particles are in the laminar boundary layer (Figure 1) [11].

The air flow impact on the dust particle is made up of the drag force $F_d$ and the lift force Fl, which tend to move and lift the particle into the air flow. At rest, the particle is held by the gravitational force Fg and its adhesion force to the surface (adhesion force) Fa. The dust particles will pass into suspension under the condition [12]:

$$F_{\mathrm{D}} + F_1 > F_g + F_{\mathrm{a}} \tag{8}$$

If the sum of all active forces is equal to zero, the particle will be in equilibrium [12]:

$$F_D + F_1 = F_{\mathrm{g}} + F_{\mathrm{a}} \tag{9}$$

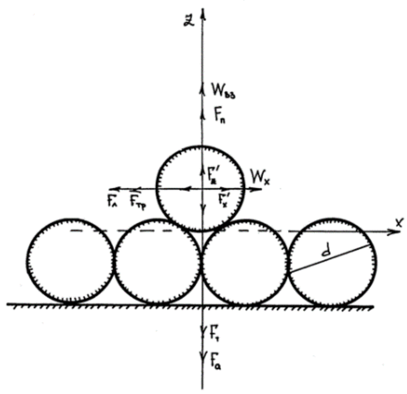


**Figure 2.** Model of the raising dust process from the surface

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When resuspending the dust particles, their speed of movement is determined by the equation [11]:

$$m_1 \frac{d\overline{W}_1}{dt} = \overline{F}_D + \overline{F}_{\mathrm{g}} + \overline{F}_1 + \overline{F}_{\mathrm{fr}} + \overline{F}_{\mathrm{a}}, \tag{10}$$

where $F_{\mathrm{fr}}$ – is friction force, H.

The research has established that the critical air velocity at which the dust starts resuspending depends on its size, roughness and humidity. With a decrease in the particle size of dust to 0.175 mm, the rate of dust blowing off decreases. For particles with a particle size of 0.05–0.175 mm, it remains constant, and for particles with a particle size of less than 0.05 mm, the blow-off speed increases. Highly dispersed dust, due to the prevailing value of the adhesion forces, is carried away by the air flow more difficult than larger dust.

The critical speed of resuspending precipitated dust increases with an increase in its humidity in 1.5 - 2 times compared with dry dust. Therefore, artificial surface moistening and dust in most cases is an effective means of preventing an increase in dustiness. In the future, the particle movement speed and direction is determined by the velocity distribution in the oncoming air flow [11]:

$$d\overline{W}_1 = \frac{1}{m_1} \cdot \left( \overline{F}_{\mathrm{g}} + \overline{F}_1 + \overline{F}_{fr} + \overline{F}_{\mathrm{a}} \right) dt, \tag{11}$$

In the case when the resuspending occurs with bunches immersed in the boundary layer, then $d_{\mathrm{bl}} = d_{\mathrm{b}}$. A dust clot is characterized by the presence of air gaps between the particles. The volume occupied by a clot of dust with a size of dsg is greater than the total volume of all its constituent dust particles.

The volume of the air gap c is determined by [3]:

$$c = \left( V_{\mathrm{b}} - \sum_{i=1}^{n} V_{\text{пi}} \right) V_{\mathrm{b}}, \tag{12}$$

where $V_{\mathrm{b}}$, $V_{\mathrm{pi}}$ is the volume of the bunch and all dust particles, its components, $m^3$.

The process of resuspending dust in the production volume, like other dust transfer processes, is a random process. The ejection efficiency is represented as the probability of particles escaping beyond the boundary layer. When a particle leaves the boundary layer, it is considered that the uplifting has occurred and a dust distribution process in the production volume can be observed in the future (Figure 3) [11].

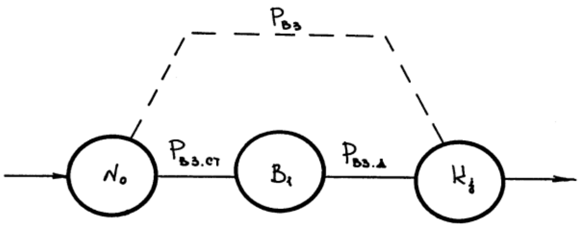

**Figure 3.** Probability graph of the process of resuspending dust from the limiting surfaces in the production volume

The efficiency of resuspending is determined by the air flow speed over the dusty surface and the flow regime in the boundary layer. For the larger particles efficient trapping or the particles with high density, an increase in free-stream velocity is required. When δ = δt (turbulent regime in the boundary layer), the exit probability increases. An increase in turbulent pulsations is accompanied by the resuspending process intensification [11].

In production volumes, various sizes particles settle. The overall resuspending effectiveness in the presence of air flow, capable of resuspending dust particles of different fractions, is determined [11]:

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$$\eta_{\text{o res}} = m_{\text{res}} / m_{\text{set}} \ , \tag{13}$$

where $m_{res}$, $m_{set}$ - are respectively, the mass of resuspending and settled dust.

The resuspending dust mass cannot exceed the mass fraction of those fractions that have settled, i.e. probability of resuspending is not more than one.

To describe the mathematical model of the take-off process, let us define the differential equation of dust distribution in the air of the working area:

$$d_t = m_t(\tau)d\tau - m_{set}(\tau)d\tau + m_{res}(\tau)d\tau \tag{14}$$

where $m_t$ is the mass of dust reaching the working area; $m_{set}$ - the settling dust mass; $m_{res}$- is the resuspending dust mass (the mass of the secondary take-off).

To study the dispersion composition of chalk dust, the samples in the working area air during the process of dust sedimentation were taken and after they were taken out every 2 seconds. The dust during sedimentation dispersed composition analysis results are presented in the mass distribution integral functions form of particles by diameter in a probabilistic-logarithmic grid in Figure 4. The dispersed composition analysis results of dust after resuspending are presented in the mass particles distribution integral functions form by diameter in the probabilistic-logarithmic grid in Figure 5.

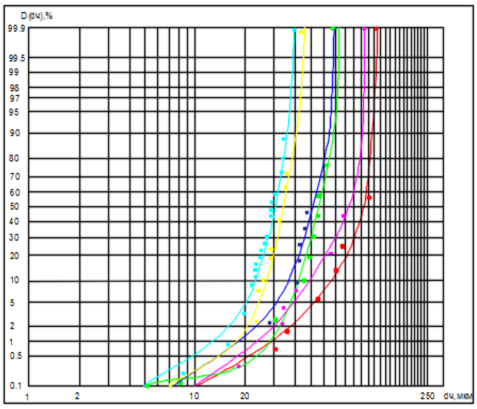


**Figure 4.** The dust particles mass integral distribution functions by diameter in the probabilistic-logarithmic grid during the settling: ■ – for dust settling in 2 seconds; ■ – in 4 seconds; ■ – in 6 seconds; ■– in 8 seconds; ■ – in 10 seconds; ■ – in 12 seconds

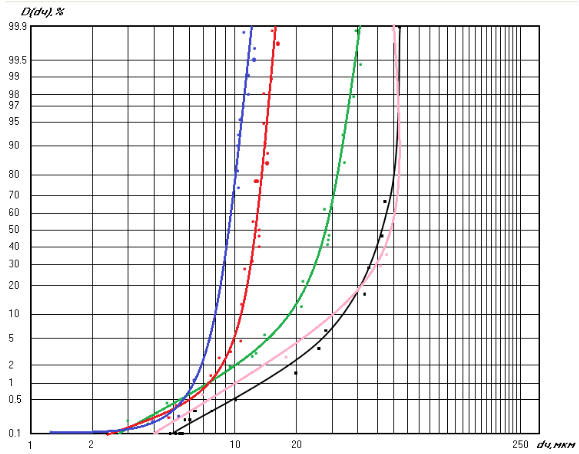


**Figure 5.** The integral distribution functions of the mass of dust particles by diameter in the probabilistic-logarithmic grid after take-off: ■ – for dust settling in 2 seconds; ■ – in 4 seconds; ■ – in 6 seconds; ■– in 8 seconds; ■ – in 10 seconds

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**Summary**

When predicting the dust concentration in the air of the working area, it is necessary to take into account the dust that is not only removed by aspiration systems and entered into the working area from the equipment, but also the dust that has previously settled on horizontal surfaces and entered the working area as a result of resuspending. The obtained equations for stochastic processes of sedimentation and dust extraction with experimental values of the coefficients allow calculating the dust content of the working area air.

The dispersed analysis results showed that the dust particles after resuspending are smaller and represent a great danger to the workers. So d50 for chalk dust in the process of primary sedimentation is in the range from 30 to 105 microns, and d50 for chalk dust after resuspending is in the range from 9.5 to 57 microns. It is necessary to provide measures for localization or fine dust removal from the air of the working area, to develop dust removal systems taking into account the production process technological features.

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