The problem of labor protection and monitoring of emergencies in the conditions of the spread of graphite dust

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Abstract. The article deals with the issues of labor protection and monitoring of emergencies in workshops for the production of carbon electrodes. A numerical study of the problem of the spread of coal dust in the production room is carried out. The possible height of dust rise and the distance of movement of the most probable particle size are estimated. The data obtained indicate that in order to prevent coal dust from sticking to clothing and spreading it around the room, it is necessary to provide for labor protection measures. Based on the results obtained, recommendations can be formulated to improve safe working conditions in production associated with the formation of graphite dust: first of all, attention should be directed to the removal of a loose dust layer.

1. Introduction
In modern production of graphite products, they face the problem of the formation of carbon-containing dust. It stands out during the machining of the work piece during the shaping of the product. The formation and spread of fine dust has a negative impact on the environment [1-3]. A number of publications in the scientific literature are devoted to the study of the negative impact of coal dust on humans and the man-made threats associated with it. The main attention of researchers is focused on the issues of explosion hazard of coal dust [4-8]. One of the significant unfavorable factors is considered the emergence and development of occupational diseases associated with the settling of fine dust in the lungs of workers [9-10].

To reduce the impact on workers of the level of dust, a number of measures are proposed, the most widely known is the wetting of dusty areas with specially developed compositions [11-12]. Due to the specific layered structure, carbon exhibits high antifriction properties [13-16], it is actively used in various lubricating compositions. However, it is precisely its high sliding properties that can cause increased injuries among workers. Particles of coal dust, lying on a horizontal surface, under the influence of the air flow generated by the movement of a person, can be lifted and carried over a certain distance. Coal dust lifted from the floor and floating in the air can settle on clothing and also be carried to other areas of the plant, expanding areas of increased injury. The purpose of this work was a numerical study of the problem of spreading coal dust in a production facility.

2. Materials and methods
Forces of coal dust, lying motionless and then lifted by the air flow, are acted upon by forces (1):
\[ F_R = P + F_p + F_t + F_f + F_{ad}, \]  \hspace{1cm} (1)

where \( F_R \) is the resultant force, \( H \), \( P \) is the weight of the particle, \( H \), \( F_p \) is the pressure force on the particle of the air flow, \( H \), \( F_t \) is the lifting force, \( H \), \( F_f \) is the friction force of the particle against the surface, \( H \), \( F_{ad} \) is the adhesion force of the particle to the surface, \( H \).

When constructing the model, the following assumptions were used: the particle is single, does not experience the influence of neighboring particles, the air flow is created only by human movement. To estimate the speed of air movement, the average speed of movement of a person was taken as 3.6 km/h, which corresponds to 1 m/s. In this case, the speed of the air flow caused by the movement of the leg will be about 4 m/s.

3. Results

Particle lifting from the surface. When an air flow from the movement of a walking person's leg passes over a particle of coal dust, an aerodynamic lift occurs (2).

\[ F_t = \frac{C_y \cdot \rho_a \cdot V \cdot S}{2}, \]  \hspace{1cm} (2)

Where \( C_y \) is the lift coefficient, usually taken as \( C_y = 1.005 \), \( \rho_a \) - is the mass density of the medium (air), \( \rho_a = 0.125 \) kg s\(^2\)/m\(^4\), \( V \) - is the average air flow velocity, m/s, \( S \) - is the characteristic area of the particle, m\(^2\).

The characteristic area of a particle can be represented as the area perpendicular to the air flow acting on the particle (3):

\[ S_x = S \cdot \sin \alpha, \]  \hspace{1cm} (3)

At the same time \( \sin \alpha \neq 0 \) (at \( \sin \alpha = 0 \) the particle is plane oriented in the flow, the contact area is determined by the particle thickness, at \( \sin \alpha = 1 \) the particle moves perpendicular to the air flow (figure 1, a)).

Figure 1. The movement of a plane particle in an air stream.

In the process of motion, the particle can rotate, the angle \( \alpha \) will vary from 0 to 90 degrees. Lift is the main cause of particle separation from the surface.

Moving a particle in a horizontal direction. Before lifting, the particle under the action of the air flow moves by dragging under the action of the force of air pressure (4):

\[ F_p = \frac{C_x \cdot \rho_a \cdot V \cdot S_x}{2}, \]  \hspace{1cm} (4)

Where \( C_x \) is the drag coefficient for a plate of square section located perpendicular to the flow, \( C_x = 1.28 \), \( \rho_a \) is the mass density of the medium (air), \( \rho_a = 0.125 \) kg s\(^2\)/m\(^4\), \( V \) is the average air flow velocity, m/c, \( S_x \) - characteristic area of the particle, m\(^2\).

Winding speed. For particles up to 300 \( \mu \)m in size, the soaring speed \( V_s \) is calculated by the formula (5):

\[ V_s = \frac{d \cdot g}{18 \mu_a}, \]  \hspace{1cm} (5)
Where $d$ is the particle diameter, $m$, $g = 9.8 \, \text{m/s}^2$ is the acceleration of gravity, $\mu_a$ is the dynamic viscosity of air, Pa s.

4. Discussion

For a particle with a diameter of 3 $\mu$m (such a particle size [17] is the most common for coal dust) with a value of $\mu_a = 1.81 \times 10^{-6}$ Pa s, the soaring speed is 0.902 m/s. This value is lower than the value of the air flow velocity (4 m/s) acting on the particle. Consequently, the particle will be detached from the surface.

Before detachment, the particle moves over the surface, adhesion forces $F_{ad}$ and friction $F_f$ act on it (6).

$$F_f = \mu_f P = \mu_f m \cdot g,$$  

Where $\mu_f$ - is the coefficient of friction, $m$ - is the mass of the particle, kg.

When assessing the magnitude of the adhesion force, it can be concluded that $F_{ad}$ is small and amounts to a value of the order of $F_{ad} = 2.4 \times 10^{-4} \, \text{r} = 3.6 \times 10^{-10} \, \text{H}$. Here $r = 1.5 \times 10^{-6} \, \text{m}$ is the average value coal dust particle radius. Due to the small value of the adhesion force, it was neglected in further calculations.

The force (7) acts on the particle under the action of the air flow:

$$F = m \frac{dv}{dt},$$  

Where $\frac{dv}{dt}$ is the particle acceleration, m/s$^2$.

If we project the resultant force on the coordinate axis, we get the system of equations (8).

$$\begin{align*}
F_x &= \frac{dv}{dt} \cdot m, \\
F_y &= F_r - P. 
\end{align*}$$  

Under the action of the force $F_x$, the particle will move in the horizontal direction, and under the action of the force $F_y$ - in the vertical plane.

Force projections on the X axis:

$F_x = F_{ad} - F_{fr} - F_{ad}$,

Neglecting the magnitude of the adhesion force, we obtain (9):

$$F_x = F_{fr} - \mu_f P.$$  

Force projections on the Y-axis:

$$F_y = F_r - F_{ad} - P,$$

Neglecting the value of the adhesion force, we obtain (10):

$$F_y = F_r - P.$$  

Thus, in the horizontal plane, the force of the air flow pressure and the friction force act on the particle, and in the vertical plane, the force of weight and the lifting force.

The conditions under which the transfer of a particle in a horizontal plane by sliding, dragging or rolling is possible will be expressed by the following inequalities:

$$F_{fr} - \mu_a \cdot P > 0, \quad (12)$$

$$F_{fr} > F_f, \quad F > 0. \quad (13)$$
The conditions under which particles can be carried away from the surface are expressed by the inequalities:

\[ F_r - P > 0, \quad (14) \]

\[ F_r > P, \quad (15) \]

\[ F_y > 0. \quad (16) \]

Substituting expressions (2), (4) into formulas (8), and taking into account that the mass of the particle \( m = V \rho_m \) (here \( V \) is the volume of the particle, \( m^3 \), \( \rho_m \) is the density of the material, kg / m\(^3\)), we obtain the system of equations (17):

\[
\begin{align*}
V \cdot \rho_m \frac{d^2 x}{dt^2} &= \frac{C_x \cdot \rho_a \cdot S \cdot \sin \alpha \cdot v^2}{2} - \mu_x \cdot V \cdot \rho_m \cdot g, \\
V \cdot \rho_m \frac{d^2 y}{dt^2} &= \frac{C_y \cdot \rho_a \cdot S \cdot \sin \alpha \cdot v^2}{2} - V \cdot \rho_m \cdot g.
\end{align*}
\]

After transformation, taking into account the value of the volume of the material \( V = S \cdot h \) (\( S \) - is the area of the particle, \( m^2 \), \( h \) - is the thickness of the particle, m), we obtain (18):

\[
\begin{align*}
x &= \left( \frac{C_x \cdot \rho_a \cdot \sin \alpha \cdot v^2}{2h} - \mu_x \cdot \rho_m \cdot g \right) \frac{t^2}{2}, \\
y &= \left( \frac{C_y \cdot \rho_a \cdot \sin \alpha \cdot v^2}{2h} - \rho_m \cdot g \right) \frac{t^2}{2}.
\end{align*}
\]

The resulting system of equations (18) characterizes the motion of a particle of coal dust in the acceleration section. After transforming the system of equations (18), we obtain equation (19):

\[
x = \left[ \frac{(C_x \cdot \rho_a \cdot \sin \alpha \cdot v^2) / 2h - \mu_x \cdot \rho_m \cdot g}{C_y \cdot \rho_a \cdot \sin \alpha \cdot v^2 / 2h - \rho_m \cdot g} \right] y. \quad (19)
\]

Equation (19) shows that in the acceleration section the particle moves in a straight line (figure 1, b).

The equation of motion of a body thrown at an angle to the horizon, in projection on the axis, has the form (20):

\[
\begin{align*}
x &= v_0 \cdot t \cdot \cos \alpha, \\
y &= v_0 \cdot t \cdot \sin \alpha - \frac{g \cdot t^2}{2}.
\end{align*}
\]

According to equation (20), the coal dust particle will move along a parabolic trajectory.

To estimate the height to which a particle can rise and the distance to which it can be transferred, we assume that the movement of a person's leg during lifting makes an angle of 30 degrees with the floor plane. In this case, it is possible to estimate the height and length of movement of the coal dust particle for different periods of time (table 1).

| Parameter | Value  |
|-----------|--------|
| \( t, \) с | 0.1    | 0.2    | 0.3    | 0.4    |
| \( x, \) м | 0.346  | 0.693  | 1.039  | 1.386  |
| \( y, \) м | 0.151  | 0.204  | 0.159  | 0.016  |

Table 1. Coal dust particle movement parameters.
For 0.1 s in the horizontal direction.

\[ x = 4 \cdot 0.1 \cdot 0.866 = 0.346 \text{ m}, \quad (21) \]

In the vertical direction.

\[ y = 4 \cdot 0.1 \cdot 0.5 - 9.8 \cdot (0.1)^2 / 2 = 0.151 \text{ m}. \quad (22) \]

Therefore, with the given parameters, the particle will move up to 1.4 m in length and up to 20 cm in height.

5. Conclusion

Thus, a numerical study of the problem of the spread of coal dust in the production room was carried out. The possible height of dust rise and the distance of movement of the most probable particle size are estimated. The data obtained indicate that in order to prevent the adhesion of coal dust to clothing and its spread throughout the room, it is necessary to provide for labor protection measures. In particular, it can be recommended to make protective covers for the lower part of the garment from a sliding material to reduce the adhesion of dust to the garment.

Based on the results obtained, recommendations can be formulated to prevent emergencies and improve safe working conditions in production associated with the formation of graphite dust: first of all, attention should be directed to the removal of a loose layer of dust. This will help reduce the risk of slipping for workers and prevent potential accidents from falling. In order to reduce the spread of dust in the room, the rapid movement of workers around the shop should be avoided.

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