Research of Air Pollution by Dust Aerosols During Construction

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Abstract. Due to the population growth and economic stability in Russia, a tendency to increase the pace of construction, both for civil and industrial purposes, has arisen. Facilities’ construction is a temporary source of discomfort for the residents of a surrounding area and has a significant impact on the environment. The study of the surface air pollution from aerosol dust, a method for calculating the distribution of aerosol dust formed during the construction for civil and industrial purposes in the surface layer of the atmosphere.

According to the Russian Federation Federal State Statistics Service, the population of Russia has been increasing during recent years. In connection with this fact and economic stabilization in Russia, there is a tendency of building speed increasing, both civil and industrial objects. Objects construction is a temporary discomfort source for inhabitants of nearby areas, and also has significant impact on environment condition.

Building of civil and industrial facilities includes the following works: clearance of building areas; foundation pits engineering; installation of underground and aboveground parts of buildings; engineering of tranches for engineering communications and their charging; stone, reinforced concrete and piling works; welding works, for example, during installation of LMT filling stations storage tanks, as well as other types of excavation. All these works lead to dust aerosols formation, which adversely affect the atmosphere and are located near apartment houses and other facilities. In addition, it is important to remember that building is carried out with help of vehicles and construction machines that give off not only dust, but also harmful gases because of running engines [1-3].

It is worth noting that, unfortunately, there are no methods for dust aerosols spreading calculation in the surface layer of the atmosphere during construction. The current method of OND-86 [4] is directed at heated and cold emissions calculation. In order to use this method, it is necessary to know a number of such factors that are not typical for objects construction. For example, the stratification factor of the atmosphere [1], that provides mainly for high emissions, and not for low and ground-based sources. A relevant question about the spreading distance of dust aerosols from a source during construction stays unsolved. The existing standards do not solve the problem.

From the point of view of theoretical hydromechanics, dust and fumes spreading in atmospheric air is the process of dynamic interaction between a solid body and an unlimited flow of gas.

When a particle of dust flows by air streams force P influences upon a particle and can be separated into two components: Pₓ is the coincident speed of oncoming flow Wₓ and Pᵧ - normal to its direction.

Forces Pₓ and Pᵧ are defined by correlations
Frontal resistance force:

\[ P_x = c_x \rho F W_\infty^2 / 2 \]  

(1)

Lifting force:

\[ P_y = c_y \rho F W_\infty^2 / 2 \]  

(2)

c_x, c_y - dimensionless coefficients of frontal resistance force and lifting force, accordingly, depending on the position and shape of the streamlined particle, as well as on Reynolds criterion; F - is the area of a streamlined dust particle [5].

Thus, all quantities in the presented equations are known, except the indicated dimensionless coefficients, additional information on the methods of determination of the coefficient \( c = f(c_x, c_y) \) can be found, for example, in the courses "Heating and ventilation" [6,7].

Taking into account all forces acting on it or based on the equation of motion, it is possible to calculate the motion of dust particles to determine their velocity concerning the carrier stream speed, their trajectory, residence time and other parameters.

In case of dust overshoot in the surface layer of the atmosphere, the equation of motion of the dust particle can be represented as:

\[ m \frac{dW}{dt} = P_x + A - G_r \]  

(3)

Where \( A \) is the Archimedean force; \( G_r \) is the weight of the particle; \( W_r \) is a particle rate of motion.

From (3) we obtain an expression for determination the gas flow velocity \( W_\infty \), at which a particle in the flow is in a state of immobility

\[ W_\infty = \left( 4 \rho_r \frac{g \cdot d_r}{\rho_\infty c_r} \right)^{1/2} \]  

(4)

This velocity is a particle characteristic at given form and density and expresses the particle sailing capacity, i.e. its ability to be carried away by the flow. The particle moves in the flow if \( W_\infty > W_r \), and the particle falls out of it if \( W_r > W_\infty \).

There is no concept of vertical flows in method of OND-86 [4] that regulates pollutant concentrations calculation in ambient air contained in emissions from industrial buildings. Only non-vertical flows that are characterized by the critical velocity \( W_{cr} \), called in the technical literature as "hydraulic size" [8,9], are taken into account. In case where the critical velocity is greater than the average velocity of a two-phase flow, dust particles fall out of it; and when it is smaller, the flow completely entrains the particle.

Fog and rain influence on the distribution of pollutant concentrations in the surface layer of the atmosphere was considered in [10,11].

So, aerosol particles of dust scatter in the atmospheric air under the influence of the wind flow.

Because the motion of the horizontal two-phase flow is taken into account, the equation of particle motion in the horizontal direction is represented as

\[ \rho_r \frac{\pi d_r^3}{6} = c_r \rho_r \frac{\pi d_r^3}{4} \left( W_\infty - W_r \right)^2 \]  

(5)

Where \( c_r \) is the drag coefficient; \( \rho_r \) is a particle density; \( W_r \) is dust particle speed; \( W_\infty \) is the wind speed.

It is known that \( c_r = f(\text{Re}) \) [4]. Therefore
where \( v \) is ductility of atmospheric air.

From equation (5) it follows:

\[
d\tau = -\frac{4}{39} \frac{\rho_r - \rho_\infty}{\rho_\infty} \cdot \sqrt{d_r/v} \cdot d(W_\infty - W_r) \left[ (W_\infty - W_r)^{3/2} - (W_\infty - W_r)^{1/2} \right]
\]

If we integrate (7)

\[
\tau = \int_0^t d\tau = -\frac{4}{39} \frac{\rho_r - \rho_\infty}{\rho_\infty} \cdot \sqrt{d_r/v} \left[ (W_\infty - W_r)^{3/2} - (W_\infty - W_r)^{1/2} \right] = \frac{8}{39} \frac{\rho_r - \rho_\infty}{\rho_\infty} \cdot \sqrt{d_r/v} \left( \frac{1}{(W_\infty - W_r)^{1/2}} - \frac{1}{\sqrt{W_\infty}} \right)
\]

We express a particle velocity of \( W_r \) as the time \( \tau \), we have:

\[
W_r = W_\infty - A^2 \left( \tau + \frac{A}{\sqrt{W_\infty}} \right)^{-2} = \frac{dL_r}{d\tau}
\]

Where \( L_r \) is a particle distance from the source of dust release in the wind flow direction before its precipitation to the ground surface.

Then

\[
dL_r = \left[ W_\infty - A^2 \left( \tau + \frac{A}{\sqrt{W_\infty}} \right)^{-2} \right] d\tau
\]

If we integrate (10)

\[
L_r = \int_0^\tau dL_r = W_r \tau + A^2 \left( \tau + A/\sqrt{W_\infty} \right)^{-1} - A^2 \left( A/\sqrt{W_\infty} \right)^{-1} = W_r \tau + A^2 \left( \tau + A/\sqrt{W_\infty} \right)^{-1} - A/\sqrt{W_\infty}
\]

Equations (8) and (11) allow us to describe the path of an aerosol dust particle in the surface layer of the atmosphere with known design speed of wind.

In addition, with the help of the “Atlas of Industrial Dusts” [12], it is possible to solve the following problems:

- on the dispersed composition of dusts indicating the part with particles whose dimensions are greater than the Stokes diameter \( d, \mu m \);
- on particles’ shape and the median particles’ diameter; on dusts with a particle distribution over size obeys a log-normal law.

Reference to particles’ shape (for different diameters) make it possible to solve the problem of a particle speed rotation that provide horizontality of its trajectory.

According to N.E. Zhukovsky’s formula:

\[
P_y = \rho_r \cdot W \cdot N \cdot l
\]

where \( P_y \) - lifting force; \( N \) - velocity circulation along the contour at issue; \( l \) - generatrix.
So if $\rho_w \ll \rho_r$, Archimedeans force should be neglected in formula (3) and it should be assumed that if $P_y = G_r$, a particle does not drop out of the flow. The particle itself has a spherical shape, and not a cylindrical shape with a length of generatrix $l$. Then (12) can be applied to a sphere infinitesimal layer with thickness $dr$ of radius $R$ (figure 1).

**Figure 1.** Sphere particle, cut in half

Then

$$dP_y = \rho_r (W_\infty - W_r) \cdot u \cdot 2\pi R \, dr = \rho_r (W_\infty - W_r) \cdot \frac{2\pi R n}{60} \cdot 2\pi R \, dr = \rho_r \frac{n^2}{15} (W_\infty - W_r) R^2 \, dr.$$  \hspace{1cm} (13)

But $R^2 = r_o^2 - r^2$, then

$$dP_y = \rho_r \frac{n^2}{15} (W_\infty - W_r) (r_o^2 - r^2) \, dr.$$ \hspace{1cm} (14)

If we integrate (14) for a sphere half, we obtain

$$P_y = 2 \rho_r \frac{n^2}{15} (W_\infty - W_r) \int_0^{15} (r_o^2 - r^2) \, dr = 2 \rho_r \frac{n^2}{60} (W_\infty - W_r) [r_o^3 - r^3]_0^{15} = 2 \rho_r \frac{n^2}{60} (W_\infty - W_r) \frac{2}{3} r_o^3 = \frac{\rho_r \pi^2 d_o^3}{90} (W_\infty - W_r).$$ \hspace{1cm} (15)

It is known for a particle $r_o = d_r/2$.

Setting equal all particles $G_r$ and lifting force $P_y$, we obtain the value of a particle of dust rotation speed that provides ensures the horizontal direction of its movement

$$n = G_r \left( \frac{\rho_r \pi^2 d_o^3}{90} (W_\infty - W_r) \right)^{-1} = \frac{g \rho_r \pi d_o^3}{6 \pi (W_\infty - W_r)} \left( \frac{\rho_r \pi^2 d_o^3}{90} (W_\infty - W_r) \right)^{-1} = 15 \frac{\rho_r}{\rho_w} \frac{g}{\pi (W_\infty - W_r)} \text{ rpm}.$$ \hspace{1cm} (16)

From the resulting equation (16) it follows that if $P_y = G_r$, velocity of particle rotation is a function of flow speed around the particle $W_\infty - W_r$ varies as it moves.
Thus, as a result of contamination of the surface layer of the atmosphere by dust aerosols research, we can conclude that:

- a method for dust aerosols spreading calculation in the surface layer of the atmosphere during construction was proposed. Unlike the known methods, the proposed dependences allow to determine the length of a particle distance from the source of dust release before its precipitation to the ground surface, the time of particle motion and its velocity for unorganized low and terrestrial sources of emissions;
- it is established that dust particles, depending on their density, shape and size, make rotational motion, which allows to keep its horizontal direction;
- obtained boundary conditions allow to establish when a particle of dust drops out on the ground surface.

The obtained dependencies can be used to justify the ecological safety of the construction of facilities regarding to the nearby residential development or forest park area and to ensure the reduction of impacts on the environment from the projects under construction, both in stationary conditions and in cases of emergency situations.

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