Application of dispersal analysis of dust in the air of working zones in examination of physicochemical properties of ventilation emissions of asbestos-cement enterprises

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Abstract. The authors implemented a dispersion analysis of dust of asbestos cement, selected from the process equipment, aspiration systems of molding shop, general exhaust ventilation and from the air of sanitary protection zone. Were researched aerodynamic performance characteristics of dust. Established the dependence of dust subsidence in relation to the median particle diameter in the logarithmic grid as a random variable. Performed a comparative analysis of the main indicators of technological emissions of dust in the atmospheric air, while using the standard methodology in dispersion of harmful in the atmospheric air, accepted in Russia, and methods for calculating emissions from unorganized sources. Obtained the ratio of dust subsidence for asbestos-cement dust by two methods.

Introduction
In the implementation of many technical processes in asbestos cement industry, a significant amount of small-dispersed dust is released into the working zones of enterprises [1]. Medicine has studied well the pathogenesis of the dust particles influence on the human body. In [2,3] stated, that such parameters, as dispersal composition of dust, the amount of dust-emitting and dust fractional concentration in the air of working and living area have the most impact on intensity of the development of disease among workers.

Chrysotile - asbestos is widely used in Russia. This mineral has a very high durability and good «fuzziness». His fiber has a diameter from 3 to 10 μm. Chrysotile – asbestos is part of the nearly three thousand materials and products. Specialists can’t find an alternative mineral for replacement, although, this material characterized by bio-aggressiveness, including carcinogenicity. In reality, the main danger is amphibole asbestos, which usage and production prohibited in the whole world. Chrysotile fibers are less carcinogens. Rehabilitation of the organism is faster. The safety of chrysotile asbestos, under controlled use, has been confirmed by many studies. [4].

Currently, there are a good number of methods to calculate emissions, that were tested on practice, allowing to calculate emissions into the atmosphere with an error not over than the accuracy of calculation with the use of instrumental methods.

Research of the dispersal composition of dust
Dust samples were taken from the aspiration systems, serving the technological equipment and process, and also at the border of sanitary protection zone of an enterprise for the production of asbestos-cement products. Micrograph of the dust particles, that were taken in the aspiration system from the transfer unit, shown in Fig.1. A graphical representation of the results represented in form of integral distribution curves \( D(d) \) particle masses by diameter \( d \) (Figure 2).

![Figure 1](image1.png)

**Figure 1.** Micrograph of the dust particles in the aspiration system: 1 – before cleaning in the CSF(VZP) unit; 2 – after cleaning in the CSF unit. Scale: 1 segment = 25 μm

### Research of the aerodynamic characteristics of asbestos-cement dust particles

One of the most important characteristics of dust as air pollutant is aerodynamic properties of her particles. To define them, dust of chrysotile-asbestos and cement was researched by the method of fractional subsidence followed with analysis of its dispersal composition and constructing speed dependencies of dust particles subsidence from its median diameter in a probabilistic-logarithmic grid.

As a device for determination of dispersal composition of dust with the sediometry method was used installation for research of the dispersal composition of dust, during particles subsidence. Then was implemented dispersal analysis with the help of microscope and PC. Method for determination of dispersal composition of dust is based on photographing of enlarged, under the microscope in 200-1000 times, samples of dust particles, attached to microscope slide, followed by processing of photos with graphic editor AdobePhotoshop.

Further calculation requires counting the number of particles on every photo and constructing integral curves in a probabilistic-logarithmic grid. These actions were performed in the program «SpotExplorer».

As a result of the research, it was determined, that with the subsidence speed over 0.4 m/s the median diameter of dust was 81 μm; with the speed from 0.24 to 0.4 m/s – 56 μm; with the speed from 0.17 to 0.24 m/s – 42 μm; with the speed from 0.13 to 0.17 m/s – 35 μm; with the speed from 0.13 to 0.11 m/s – 27 μm; with the speed from 0.09 to 0.11 m/s – 22 μm, with the speed from 0.08 to 0.09 m/s – 17 μm; with the speed from 0.07 to 0.08 m/s – 11 μm. Acquired the regularities of subsidence speed change from a median particle diameter in a probabilistic-logarithmic grid (Figure 3).

![Figure 2](image2.png)
**Figure 2.** Integral distribution curves $D(d_h)$ particle masses of dust by diameter $d_h$: 1 – at the border of the sanitary protection zone of the enterprise; 2 – in the air of the working zone of the enterprise; 3 - from aspiration systems, before cleaning

**Figure 3.** The dependence of the subsidence speed of dust from the median particle diameter in a logarithmic grid

**Methodology of calculating the amount of dust emissions**

In accordance with the standard methodology, accepted in Russia, the amount of dust emissions from unorganized sources in the production of asbestos cement can be calculated by the formula (1):

$$M_e = \frac{K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6 \cdot K_7 \cdot B \cdot G \cdot 10^5}{3600}$$

where $K_1$, $K_2$ … $K_8$ – semi-empirical ratios, considering physicochemical properties of building material, local weather conditions and the type of handling device; $K_5$ – ratio, that considering humidity of the dust and fine-grained fractions of material ($d<1\text{mm}$); $K_9$ - correction ratio, considering the factor of «fired» emission; $G$ - total amount of material recycled per hour with, t/hour; $B$ - ratio, considering height of overfilling.

Special attention represents such indicators as, a weight fraction of dust fraction in material ($K_1$) and a proportion of dust, turning in aerosol ($K_2$). Analysis of a reference material data shows, that the value of the ratio for asbestos cement dust in the reference part of the methodology [5] is missing.

In accordance to the results of dispersal analysis $K_1=1$. Further, the authors defined the particle size of the aerosol asbestos cement dust, it is equal to 3 μm. In addition, the amount of asbestos-cement dust particles, which turns into aerosol, in accordence with integral distribution curves $D(d\chi)$ particle masses by diameter is 20 %, $K_2=0.2$.

However, analyzing [5], the table value of $K_1$ must aim to 0.05, and the value of $K_2$ - to 0.01, as material, closer to mineral wool by its physicochemical properties. Then, the product of these ratios will be, for asbestos-cement $K_{as}=0.2$; for mineral wool, according to the method [5], $K_{mw}=0.005$. Proportion of coefficients $K_{as}/K_{mw}=40$.

The authors defined the natural humidity of chrysotile-asbestos, it is equal to 2%. Consequently, $K_3=0.8$. The value of $K_5$ must aim to 1, as material, closer to mineral wool by its Physico-mechanical properties. This condition is fulfilled.

According to the technological scheme for the production of asbestos-cement products, asbestos is delivered to factories in paper bags in railway wagons. At the factory asbestos is kept in closed storage on wooden floor in separate compartments for different marks and varieties. Therefore, in such case, there is no signs of «fired» emission, $K_9=1$. That is, value of $K_9$ coincides with the tabular value for mineral wool.

**Calculation of subsidence ratio of F**
The authors determined the ratio of $F$ for calculations of atmosphere pollution from the small-dispersed suspended particles with the size of 10 $\mu$m (PM$_{10}$) and 2.5 $\mu$m (PM$_{2.5}$) asbestos-cement dust with the use of two different methods. To define the dimensionless ratio of $F$, considering the subsidence speed of particle, in accordance to annex. 2 Methods for calculating the dispersion of emissions of harmful (polluting) substances in the atmosphere [6], accepted in Russia, it is necessary with the help of integral distribution curves particles by diameter (Fig.2) identify such a diameter $d_g$, that the mass of all particles with the diameter more than $d_g$ was 5% from total mass of dust particles and related $d_g$ subsidence speed of particle $V_g$ (m/s). Further, defined the dangerous speed of wind $U_m$ in accordance with annex. 5.10 [6]. After that, the ratio value of $F$ is determined in depending on the ratio of $V_g/ U_m$, as follows: with $V_g/ U_m \leq 0.015$ $F=1.0$; with $0.015 < V_g/ U_m \leq 0.030$ $F=1.5$; for all other values $V_g/ U_m$ the subsidence ratio of $F$ is determined in accordance to table. 2, annex.2 [6]. Subsidence speed of particulate matter $V_g$ is defined by Stokes law. According to real conditions in such case it is determined with:

$$V_g = \frac{1.45 \cdot 10^4 \cdot d^2 \cdot \rho_g}{T}$$

(2)

where $T$ – temperature of flue gas, equal to 273$+t$, K.

For this building material, the authors obtained the value $V_g = 3.51 \cdot 10^4$ m/s. Dangerous speed of the wind $U_m$ for Volgograd accepted in accordance with average multi-year data, the frequency of exceeding is equal to 5%: $U_{m1}=9$ m/s and calm state equal to $U_{m2}=0.5$ m/s. Therefore, parameter of $V_g/ U_m <0.015$ in both cases. Consequently, according to annex. 2 [6] the ratio of subsidence is $F=1$.

In accordance with the methodology [7] speed of impurity subsidence depends from its characteristics of particles and environment, in which it moves, and is determined depending on the Reynolds criterion (Re). the Reynolds criterion for practical calculations is determined by graph in dependence from complex $\xi \cdot Re^2$ [7]. In dependence from Re, according to [8,9,10] the subsidence speed of particle $V_g$ is defined by:

$$V_g = \frac{d^2 \cdot g \cdot (\rho_s - \rho_g)}{18 \cdot \mu}, \text{ m/s; with } 1.0 < \text{Re} < 500$$

$$V_g = \frac{Re \cdot \mu}{d \cdot \rho_g}, \text{ m/s; with } \text{Re} > 500$$

Further, the dangerous speed of wind is defined $U_m$. After that the ratio value of $F$ is set, depending on the ratio $V_g/ U_m$.

The authors determined the value of the parameter $\xi \cdot Re^2 = 0.23 \cdot 10^5$ for asbestos-cement dust. Further, the value of $V_g$ (Re <1.0) is calculated, it is $V_g = 3.6 \cdot 10^4$ m/s. Parameter $V_g/ U_m <0.015$. Therefore, according to annex. 2.6 [7] the ratio of subsidence is equal to $F=1$.

The result analysis and conclusion

Based on the research of dispersal composition, it can be seen, that in the air of the working zone can be found small-dispersed dust, and also evaluate percentage of particles PM$_{10}$ and PM$_{2.5}$ in total concentration of all harmful pollutants. On Fig.2 the fraction of particles of asbestos-cement dust in aspiration system before cleaning in the CSF device is changed for PM$_{10}$ – from 1.3% to 2.5%, particles PM$_{2.5}$ are not present in the air of the working. In aspiration system after cleaning in the CSF device, defined only the particles PM$_{2.5}$, percentage composition of which is 6% to 10% from the total mass of dust.

Consequently, it can be argued, that that emissions from the production of asbestos-cement products are characterized by a high percentage of small-dispersed dust. In accordance with the current normative value, maximum single concentration in the air of populated areas for the small-dispersed dust must be 0.3mg/m$^3$. If the standard for MPC will be fulfilled for sanitary protection zone (0.2 mg/m$^3$ – asbestos-cement dust), the amount of small-dispersed dust in the air of populated areas
will be 0.012 mg/m$^3$. Therefore, normative for maximum single values of PM$_{10}$ and PM$_{2.5}$ in the air of working and sanitary protection zones is fulfilled.

Thus, if the normative, that accepted for maximum single concentration in the air of populated areas for these productions, is fulfilled, then the normative for maximum single values of PM$_{10}$ and PM$_{2.5}$ will be fulfilled in the air of working and sanitary protection zones.

Research of the aerodynamic characteristics of asbestos-cement dust shows, that particles, which are in a suspended state, have median size from 6 μm to 55 μm with the speed of rising air flow from 0.07 m/s to 0.38 m/s in the working zone. With the subsidence speed over 0.4 m/s median diameter of dust is 81 μm; with the speed from 0.24 to 0.4 m/s – 56 μm; with the speed from 0.17 to 0.24 m/s – 42 μm; with the speed from 0.13 to 0.17 m/s – 35 μm; with the speed from 0.13 to 0.11 m/s – 27 μm; with the speed from 0.09 to 0.11 m/s – 22 μm, with the speed from 0.08 to 0.09 m/s – 17 μm; with the speed from 0.07 to 0.08 m/s – 11 μm. The standard subsidence speed of dust is 0.18 m/s, which is much lower from recommended values.

Also, through the experimental research of dispersal composition of dust, acquired the values of ratios of $K_1 = 1$ and $K_2 = 0.2$ for asbestos-cement dust, which can be used in calculations of dust emission by method [5].

The calculation is conducted to enlarged indicators for analogical physical properties of materials. Based on the results, the actual emissions of asbestos-cement dust are 40 times higher than estimated values, acquired in the result of calculation by the method [5] for analogous material. Values of $K_1$ and $K_0$ for asbestos-cement dust coincide with the table values for analogues materials in physical properties.

Based on the acquired values of the ratios of $K_1$, $K_2$ and $F$ it is possible to claim with the high confidence, that this dust can be classified to the category with the high level of polydispersity. It is known, that the calculation of dispersion for the dust of this class is not applied. Calculation methods for the dispersion of harmful substances (pollutants) emissions into the atmospheric air, accepted in Russia, don’t work for the particles with such diameter. The particles are stratified for thousands of kilometers and are suspended for several hours. Consequently, further research of the processes of dispersion with creation of mathematical apparatus, and methodology, that could include data of physicochemical characteristics of particles during their stratification and sedimentation, is required.

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