Investigation of chrysotile asbestos dust in air of working zones and environment

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Abstract. The article presents an analysis of the chemical composition of chrysotile asbestos and studies the difference between asbestoses of chrysotile and amphibole groups along with their influence on the health of industrial workers. The dispersion analysis of the dust from aspiration systems serving the technological equipment and processes as well as of the dust from the air at the boarder of the sanitary protection zone of enterprise was carried out. In addition, the article describes a method for the evaluation of technological equipment as a source of dust emissions, that is adapted to the sphere of asbestos cement manufacturing. It also gives an example of determining the air tightness of technological equipment and of calculating the volume of dust emissions in the blank preparation shop of an integrated plant. Furthermore, an investigation of the aerodynamic characteristics of dust of chrysotile asbestos and cement was carried out. The average velocity of dust deposition was determined and the recommendations aimed at reducing the negative influence of dust factor in the air of working zones of enterprises were given.

1. Introduction
The formation of large amounts of dust of various fractions is observed in the sphere of manufacturing of construction materials of chrysotile asbestos and cement. In order to control the dust factor, the technologies of mechanical treatment by means of particle deposition under the action of external forces and filtering by means of particles capturing with filtering material are used. In accordance with the particular features of asbestos fibers structure and the specifics of manufacturing, the finest fractions with particle diameter less than 10 µm and less than 2.5 µm cannot be collected. The concentration of asbestos cement dust in the air of the working zone at a series of enterprises exceeds the value of the maximum permissible one by 5 times, and the concentration at the boarder of the sanitary protection zone of the enterprises shows double exceedance of the normative standards [1].
In order to develop long-term solutions for the problem of protection against dust emissions at workplaces, it is necessary to investigate their chemical composition and the properties of chrysotile asbestos, to analyze the particle size distribution of the dust as well as to study the processes of dusting and to evaluate the technological equipment as a source of dust emissions.

2. Chemical composition of chrysotile asbestos
Asbestoses are a group of fibrous minerals able to split into finest flexible fibers. According to the chemical composition, asbestos minerals belong to the class of hydrous silicates of magnesium, iron, partially of calcium and sodium. They are subdivided into chrysotile asbestos and amphibole asbestos
in accordance with their mineralogical characteristics and crystal structure. Chrysotile asbestos (chrysotile, parachrysotile) also called “white asbestos” is a fibrous variant of serpentine that is a mineral of the subclass of layered silicates. Five minerals belong to the amphibole group – the subclass of band silicates. They are amosite (brown asbestos, grunerite), crocidolite (blue asbestos, riebeckite) and less common anthophyllite (grey asbestos), tremolite and actinolite [1]. The types of asbestos slightly differ in terms of their properties (which includes the thickness and length of fibers), but generally are characterized by a high ultimate tensile strength, a low thermal conductivity and a relatively high chemical resistance.

According to the chemical composition, asbestos is hydrous silicate of magnesium, iron, calcium and sodium - 3MgO · 2SiO3 · 2H2O. The weight percent of these oxides is the following: MgO - 43.46%, SiO2 - 43.5%, H2O - 13.04%.

The fibrous structure is most evident in asbestos of serpentine group that includes only one type of asbestos – chrysotile asbestos, therefore it is most widely used in industry [2]. In terms of the composition, chrysotile asbestos can contain some mineral impurities the amount of which varies even for one and the same deposit field and reaches the following values: FeO + Fe2O3 - up to 8%, Al2O3 - up to 3.6%, CaO is rare in occurrence though its amount can reach up to 1.4%. Among the contaminating impurities, calcium carbonates (CaCO3) pose the most negative influence on the physical and mechanical properties of chrysotile asbestos since they cement elementary crystals and hence increase their aggregate coherency thus leading to a decrease in the elasticity and fiber opening.

3. On the influence of dust of chrysotile and amphibole asbestos on the environment and industrial workers

Currently, according to the data of the World Health Organization, asbestos belongs to the list of the 10 most hazardous chemical substances since it is a carcinogen [3]. Mineral fibers are relatively resistant and remain in the environment for a long time. They can be transferred by air massifs and water flows to large distances. In addition, mineral fibers usually undergo certain chemical changes in both aquatic environment and living organisms, moreover they are able to absorb various organic substances. The most harmful effect on human health is posed by the concentration of asbestos fibers in the air. Although these fibers make up just a relatively small fraction of fibrous aerosol in the atmosphere, they are present practically everywhere. Thus, based on the data of the Agency for Toxic Substances and Disease Registry (ATSDR) in the USA, the concentration of asbestos fibers in the air in rural districts amounts to 0.03 - 3 fibers/m³ [4]. In cities, the amount of asbestos is already 3 - 300 fibers/m³, while near enterprises mining or processing asbestos it can reach the level of 2000 fibers/m³ or even higher.

Average concentrations of asbestos in drinking water amount to 0.3 – 1.5 µg/l. However, the amount of asbestos reduces significantly in the water treated even at municipal purification systems. The intake of asbestos with food by human organism has not been thoroughly studied yet and is accepted as negligible [5].

In the recent years, the rate of mesothelioma cases attributed to asbestos has increased steeply in advanced industrial countries. Based on the data of the National Research and Safety Institute (France), 100 000 people annually die due to diseases caused by asbestos exposure. Asbestos is the main cause of occupational mortality in the world [6]. It has been determined that fibers with the length of more than 5 µm and the diameter of less than 1.5 µm show the maximum carcinogenic activity.

The investigations of the hazardous nature of asbestos were first carried out in the 80-th of the last century when the consequences of massive use of asbestos were revealed. The half-life of amphibole asbestos fibers is 466 days. In the case if they get to mucous membrane, they can cause oncological diseases. Later, amphibole asbestos was refused all over the world. In the USSR and Russia amphiboles were mined at several deposit fields from 1947 to 1994 (about 40 000 tones throughout the whole history of the mining). Amphibole deposits have been closed in our country, and their use has been banned since 1999.
In Russia, only chrysotile asbestos was used for civil purposes. In this connection, there was no increased rate of asbestos-related diseases. Therefore, as the participants of the Session think [7], it is Russia that has a unique opportunity to evaluate the degree of the influence of chrysotile asbestos in its pure form without amphibole admixtures on human organism. Chrysotile asbestos is permitted in Russia and it is safe when used under control. “Chrysotile Association” has been established in order to defend it. The objective of the organization is to prove the fact that the hazardous nature of the mineral is exaggerated.

A battle between polymers and asbestos at the construction materials market has been in progress for several years. Despite the fact that polymer products are more durable than natural asbestos, the cost of their manufacturing is 6-10 times higher [8]. The main substitutes for chrysotile offered by the contemporary industry are cellulose, aramid, PVC, PVAC, polypropylene, polyethylene, mineral wool, glass fiber, ceramic fiber [4]. The given substitutes are positioned as ecologically safe but they have not been studied as thoroughly as chrysotile asbestos, consequently the degree of risk for human health has not been determined yet and is not under control. Cellulose fiber is removed from an organism in 1000 days, while the chrysotile one – in 14 days [8]. This proves the necessity to carry out full-scale scientific research into the substitutes of chrysotile asbestos that would allow evaluating the risks for human health.

4. Method of the evaluation of the volume of dust emissions from technological equipment and the determination of its air tightness for enterprises manufacturing products of chrysotile asbestos and cement

In order to ensure satisfactory conditions of the air environment at workplaces, it is necessary to evaluate the volume of dust emissions from technological equipment, the density of dust deposition, the air tightness of equipment in addition to the monitoring and control of chrysotile asbestos dust concentration. For this purpose, a method has been developed to evaluate the volume of dust emissions from technological equipment and to determine its air tightness for enterprises manufacturing products of chrysotile asbestos and cement.

The authors carried out preparatory works. In the course of the activities, detecting the main spots of dusting occurring in the process of technological equipment operation was of special importance. The analysis of the technological equipment at the blank preparation shop of an integrated plant for asbestos cement products manufacturing allowed revealing the main sources of dust emissions: the places of asbestos unpacking, the machines for sawing up asbestos boards, batchers for asbestos charging, elevators, conveyer edge runners.

The preliminary measurements of dust content carried out according to the standard methods [9-11] at each unit of technological equipment showed that the section near the edge runners of the material pouring node in the working zone is exposed to the highest dust emissions.

In order to calculate the air exchange value and to develop efficient measures to control the emitted harmful substances, it is important to determine the amount of dust getting to the working zone air from the technological equipment Mte.

In accordance with the method based on M.P. Kalinushkin’s developments, the mass of the dust arriving from a source of dust emission is calculated as a sum of the separate masses of dust deposited on various sections of the floor [12]:

\[
M_\text{te} = \left( \tilde{G}_1 F_1 + \tilde{G}_2 F_2 + \tilde{G}_3 F_3 + \ldots + \tilde{G}_n F_n \right) = \sum_{i=1}^{n} \tilde{G}_i F_i \text{kg/h},
\]

where \( \tilde{G}_1, \tilde{G}_2, \tilde{G}_3, \tilde{G}_n \) – is the density of dust deposition at each section of the surface; \( F_i \) – is the area of the section of the deposition surface, \( \text{m}^2 \); \( i = 1\ldots n \) – is the number of sections of the dust deposition surface.

V.N. Azarov and E.I. Boguslavsky [13] suggested that the amount of dust discharging from technological equipment should be determined in the following form:
\[ M_n = \sum_{i=1}^{n} \frac{\pi \varphi}{360} \frac{G_{\text{max}}}{x_i} \left[ \frac{2}{a_i} + \left( \frac{x_i^2 + 2\left(x_i - A\right)}{a_k^2} + \frac{2}{a_k^3} \right) \exp \left(-a, x_i\right) \right], \]  

where \( \varphi \) is the section to which the polluting substances are emitted, angle degrees; \( a_i, a_k \) are the parameters of dust deposition intensity from the source of dust emission; \( x_i, x_k \) are the segments from the measuring point of dust deposition intensity to the source of dust emission, m; \( G_{\text{max}} \) is the intensity of dust particles deposition immediately near the source, g/(m\(^2\)·h); \( \Delta i \) is the segment between the first and the next sources of dust emission, m.

The direction of the dust motion is essential for the calculation of the intensity of dust deposition on a horizontal surface. It can be determined with the help of dust catching plates placed circle-wise at every 2m distance from the source of pollution. Such catching plates are prepared for the investigation under laboratory conditions. Their internal surface is covered with a thin layer of non-drying oils. They are weighted and numbered [14-16]. Further, the catching plates are placed at a distance from the source of dust emissions along the circle perimeter at each angle of \( \pi/4 \). The scheme of the catching plates arrangement is shown in figure 1. It is designed with regard to the specifics of each particular manufacturing enterprise. The dust settled into each of the catching plates is weighted, and the intensity of dust deposition distribution is determined. This particular method allows determining the amount of discharged dust with engineering accuracy. The quantity of dust density takes on the values from 0.1 to 100 g/(m\(^2\)·h).

When the results are obtained, a necessity arises to determine the maximum and minimum values of dust deposition density – \( G_{\min} \) and \( G_{\max} \), respectively. In order to set the midline for the dust deposition zone of a stationary dust emission source, it should be drawn through the values \( G_{\min} \) and \( G_{\max} \). The dust deposition area is divided into sectors, i.e. two sectors with the highest and lowest dust deposition are obtained [17-19]. No less than three arcs are placed inside them. Three catching plates are positioned at the arcs. The duration of the experiment (\( \tau \)) is 3 hours, the area of each of the plates (\( F \)) is 0.003768 m\(^2\).

The dust obtained in the course of the experiment is weighted in order to determine the average distribution density of dust deposition [20,21]:

\[ G_0 = \frac{G}{F \cdot \tau}, \text{kg/(m}^2\text{·h}), \]  

where \( G \) is the mass of the dust caught by the catching plates, kg; \( F \) is the area of a catching plate, m\(^2\); \( \tau \) is the time of dust deposition, h.

The change in the dust deposition density \( G_i \) at the distance \( x \) from the source of pollution can be determined:

\[ G_i = G_{\max} \cdot e^{-ax}, \]  

where \( a \) is the parameter taking into account the air movability and other parameters, 1/m.

**Figure 1.** The scheme of arrangement of catching plates: a – the primary measurement; b – the main measurement.
Employing the system of equations and transformations, we find the parameter $a$ for polydisperse dust of asbestos cement. Let us adopt that the distance $j$ from $i$-th source of dust emissions $j_1 = 1.5$ m, $j_2 = 3$ m, $j_3 = 4.5$ m, then:

$$
\begin{align*}
  a &= \frac{1}{3-1.5} \cdot \ln \frac{45.6}{1.23} = 0.87 \\
  a &= \frac{1}{4.5-1.5} \cdot \ln \frac{45.6}{5.2} = 0.72 \\
  a &= \frac{1}{4.5-3.0} \cdot \ln \frac{12.3}{5.2} = 0.57 \\
  a_{av} &= \frac{0.87 + 0.72 + 0.57}{3} = 0.72
\end{align*}
$$

Thus, the quantity of dust deposition density takes up the maximum values at the blank preparation shop under the influence of the two neighboring sources and is calculated according to the formula:

$$
G_{\text{max}, av} = \frac{134.3 + 106.7 + 132.8}{3} = 124.6 \text{ g/}(\text{m}^2 \cdot \text{h}). \tag{5}
$$

In order to find the total value of dust emissions from the source sector under consideration, the parameters $G_{\text{max}, av}$, $a$, $x_k$ are determined and $M_{av}$ is calculated. For the asbestos pouring node, $M_{we} = 2.6$ kg/h. The dust deposition from a particular source can be found by means of redoubling the sum of the average parameters of dust deposition in the sectors with the largest and the smallest dust deposition. The parameter $M_{av}$ is calculated separately for each of the types of equipment. Let us denote the number of equipment of a certain type as $n_i$, then the total mass of dust from the technological equipment $M_i$, can be determined:

$$
M_i = \sum_{i=1}^{u} M_{av} \cdot n_i, \tag{6}
$$

and the total mass of dust due to incomplete air tightness of the equipment is:

$$
M_T = \sum_{i=1}^{u} \sum_{i=1}^{k} M_{av}, \tag{7}
$$

where $n$ – is the number of items of equipment of a given type; $k$ – is the total number of types of dust emission sources.

Thus, the amount of dust entrained by ventilation and aspiration systems ($M_1$), and the amount of dust entrained through the apertures of the room ($M_2$) in the equation (8) will make up only 0.05-0.1 of the total value of dust emissions in the shop ($M$):

$$
M = M_1 + M_2 + M_T, \tag{8}
$$

then the total mass of the dust emitted into the working zone is calculated as follows:

$$
M_{we} = 1.1 \sum_{i=1}^{u} \sum_{i=1}^{k} M_{av}, \tag{9}
$$

and the capacity of dust emission from a material pouring node will amount to:

$$
M_{we} = 1.1 \cdot M_T = 1.1 \cdot 2.6 = 2.86 \text{ g/h}.
$$
5. Investigation of dust particle size distribution

The authors carried out dust sampling from the aspiration systems serving the technological equipment and processes, as well as at the border of the sanitary protection zone of an enterprise manufacturing asbestos cement products in the Volgograd Region. The dispersion analysis of the samples of asbestos cement dust was conducted [9]. The graphic representation of the results is given in the form of integral functions of mass distribution \( D(d_p) \) according to diameters \( d_p \) (figure 2). Photomicrographs of particles of the dust sampled from the aspiration system at the material pouring node, are presented in figure 3.

\[
D(d_p), \%
\]

\( d_p, \mu m \)

![Figure 2. Integral curves of dust particles mass distribution \( D(d_p) \) according to diameters \( d_p \) in the process of asbestos cement products manufacturing, for the dust: 1 – emitted into the environment at the border of the sanitary protection zone of enterprise; 2 – in the air of the working zone of enterprise; 3 – from the aspiration systems serving the technological equipment and the processes characterized by the most intensive dust formation, prior to treatment.](image)

![Figure 3. Photomicrographs of the dust particles sampled from the aspiration system: a – prior to the cyclone treatment; b – after the cyclone treat. Scale: 1 graduation line = 25 \( \mu m \).](image)

6. Investigation of aerodynamic characteristics of chrysotile asbestos and cement dust

In addition, chrysotile asbestos and cement dust was investigated to determine the aerodynamic characteristics of particles through the method of fraction-by-fraction sedimentation with further analysis of its particle size distribution and the plotting of the dependences of the sedimentation velocity of dust particles on their equivalent diameters in the probabilistic-logarithmic grid.
A unit for the investigation of dust particle size distribution during the particle sedimentation process was used as a device for the determination of dust particle size distribution through the sedimentometry method. Further, the dispersion analysis was carried out applying a microscope and a PC. The method of the determination of dust particle size distribution is based on the photographing of the samples of dust particles fixed at an object glass and magnified by 200-1000 times under the microscope, with further processing of the photographs applying the graphic editor Adobe Photoshop [22].

The next calculation implies the counting of the number of particles in each photograph and the plotting of integral curves in the probabilistic logarithmic grid. The given operations were conducted applying the “SpotExplorer” software.

As a result of the investigations carried out, it was revealed that the diameters of the settling particles were getting smaller throughout 17 seconds. After 3 seconds, the median diameter of dust particles was 81 µm; after 5 s – 56 µm; after 7 s – 42 µm; after 9 s – 35 µm; after 11 s – 27 µm; after 13 s – 22 µm, after 15 s – 17 µm; after 17 s – 11 µm. Based on the results of the measurements, the regularities of the changes in sedimentation velocity on particle equivalent diameter in probabilistic-logarithmic grid were obtained (figure 4).

![Figure 4. The dependence of sedimentation velocity on particle equivalent diameter in logarithmic grid: 1 – minimum equivalent diameters; 2 – median equivalent diameters; 3 – maximum equivalent diameters.](image)

7. Conclusion and findings
The results of the evaluation of emission volume of chrisotile asbestos and cement dust from technological equipment as well the determination of its air tightness showed that the largest dust emission is observed at the distance of 0.5-1m from the source and exceeds the maximum permissible concentration by up to 7 times. The quantity of dust deposition density takes on the maximum values inside blank preparation shops at asbestos cement manufacturing under the influence of the two neighbouring sources and equals to 124.6 g/(m²·h). The capacity of dust emission of a material pouring node amounts to 2.86 g/h.

The present method can be used to specify the amount of dust dispersing in the course of a technological process $M_{te}$ as well as to determine the source of the largest emission at a blank preparation shops and to describe air exchange parameters.

As it follows from the results of the investigation of dust particle size distribution, the particles in the air of enterprise working zone are 1.5-2 times larger than at the boarder of the sanitary protection zone, on average. At the same time, the size of the given particles is considerably smaller than of those in the aspiration system.

In addition, based on the conducted investigations of particle size distribution, it is possible to judge on the presence of fine dust in the air of the working zone, and to evaluate the percentage of particles PM10 and PM2.5 in the total concentration of hazardous pollutants. In Figure 2, the values of the proportion of asbestos cement dust particles in the air of the working zone change from 1.3% to
2.5% for PM10, no particles PM2.5 occur in the air of the working zone. At the border of the enterprise sanitary protection zone, only particles PM2.5 are registered in the air, the percentage of which amounts to 6% -10% of the total mass of dust.

Consequently, it is possible to assert that emissions from enterprises manufacturing asbestos cement products are characterized by a high percentage of fine dust. In accordance with the standard values currently in force [23], the maximum single concentration of fine dust in the air of populated areas should amount to 0.3 mg/m³. If the MPC normative standard for sanitary protection zone is observed (0.2 mg/m³ for asbestos cement dust), the amount of fine dust in the air of populated areas will be 0,012 mg/m³. Hence, the normative standard for the maximum single values of PM10 and PM2.5 in the air of working zone and sanitary protection zone is observed.

Thus, if the normative standard for the specified manufacturing enterprises approved for the maximum single concentration of dust in the air of populated areas is observed, then the normative standard for the maximum single values of PM10 and PM2.5 in the air of working zone and of sanitary protection zone will also be observed.

The investigations of the aerodynamic characteristics of dust show that the particles in suspension have the median diameter from 6 µm to 55 µm at the velocity of the rising air flow from 0.07 m/s to 0.38 m/s in the working zone.

Particles of chrysotile asbestos and cement have the maximum diameter of 81 µm, the median diameter - 55 µm, and the minimum diameter - 7 µm at the velocity of 0.38 m/s. The particles have the maximum diameter of 27 µm, the median diameter - 22 µm and the minimum diameter – 4.5 µm at the velocity of 0.1 m/s. The particles have the maximum diameter of 11 µm, the median diameter - 6 µm and the minimum diameter – 2.2 µm at the velocity of 0.07 m/s. The average velocity of dust deposition equals to 0.18 m/s, however the recommended velocities of air motion in aspiration systems are: 4-5 m/s – for vertical sections located prior to extruders according to the process scheme; 9-11 m/s – after the extruders, 14-15 m/s – for the horizontal sections prior to extruders, and 16-18 m/s – after the extruders. Thus, in the case of sufficient air tightness of equipment, it is necessary to increase the aspiration volume of local exhausts and the average sedimentation velocity of chrysotile asbestos and cement dust in order to reduce the dust level in the air of working zone. If the air tightness of the equipment is not sufficient, a system of pneumatic cleaning can be suggested.

It should be also noted that the results of the investigations give no grounds to speak of an increased risk caused by chrysotile asbestos exposure under controlled conditions. And the use of understudied substitutes poses a potential hazard.

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