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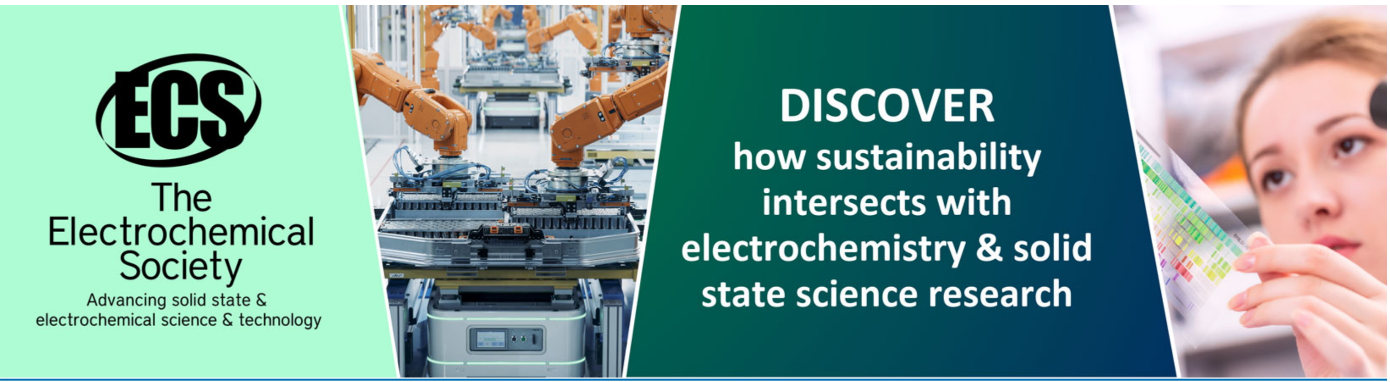

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Investigation of the Parameters of Discarded Dust in the Manufacture of Products from Chrysotile Asbestos and Cement

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Abstract. The authors carried out a dispersion analysis of the asbestos-cement dust sampled from the process equipment, the aspiration systems of the moulding shop, the general exhaust ventilation system and the air of the sanitary protection zone. A comparative analysis of the key parameters of process emissions of dust into the atmospheric air was performed through the standard method of calculation of hazardous substances emissions diffusion in the atmosphere, which is adopted in Russia, as well as through the method of calculation of hazardous substances emissions from non-organized sources. The deposition coefficient F for asbestos-cement dust was obtained through the two methods. The authors revealed that the standard method does not allow obtaining reliable results for dust with high polydispersity.

1. Introduction

Large amounts of fine dust are emitted into the air of enterprise working zones in the course of various engineering processes in asbestos-cement industry [1]. Today, the pathogenesis of dust particles impact on workers' organisms has been carefully studied from the medical point of view. The issues concerning the investigation of dust particles size distribution, the volume of dust emissions and the fractional concentration of dust in the air of working and residential zones have gained a special significance [2].

Chrysotile asbestos is widely used in Russia. The given mineral shows high strength and a good "flaking ability". Its fiber has the diameter from 3 to 10 µm. Chrysotile asbestos is included into the composition of nearly three thousand materials and products. Specialists find no worthy substitution to the mineral, though bio-aggressiveness including carcinogenic potency is inherent to it. Actually, amphibole asbestos poses the majour hazard, the use and excavation of which is prohibited practically the whole world round. Chrysotile fibers are less carcinogenic. Rehabilitation of organisms takes less time. The safety of chrysotile asbestos has been proved by numerous investigations when it is used under control [3].

Nowadays, a variety of methods for the calculation of emissions are in effect; they have been fairly tested in practice and allow determining the emissions into the atmosphere with the error being within the limits of the that allowed in the course of determination applying instrumental methods.

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2. Method of calculation of dust emissions volume

According to the method adopted in Russia [4], the volumes of dust emissions from non-organized sources in the process of asbestos-cement manufacturing can be calculated according to the formula (1):

$$Mg = \frac{K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_7 \cdot K_8 \cdot K_9 \cdot B \cdot G_h \cdot 10^6}{3600} \quad (1)$$

where K_1, K_2 … K_8 - are semi-empirical coefficients taking account of the physico-chemical characteristics of construction material, local meteorological conditions and the type of loading-transferring equipment; K_5 - is the coefficient taking into account the moisture of dust and fine-grain fractions of the material (d<1мм); K_9 - is the correction coefficient taking account of the factor of “instantaneous” character of the emission; G_h – the total amount of processed material per hour, t/h; B – the coefficient taking into account the height of the material pouring.

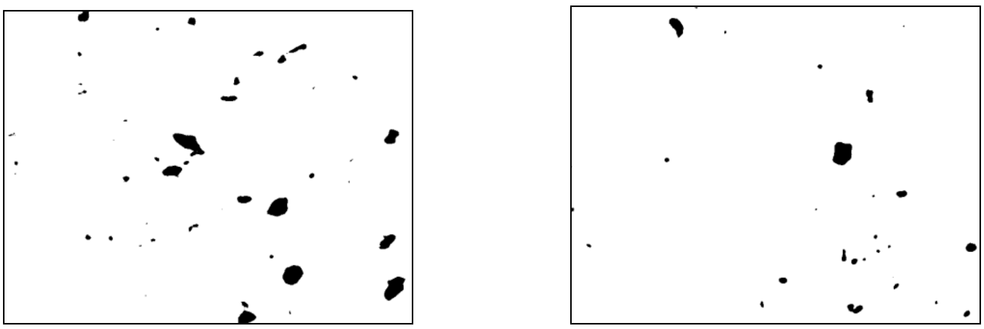
A special attention is paid to such parameters as the proportion by weight of dust fraction in the material (K_1) and the proportion of dust transferring into aerosol (K_2). The analysis of the reference literature data shows that the values of the given coefficients for asbestos-cement dust are absent in the reference part of the method documentation [4].

3. Investigation of dust particle size distribution

The authors conducted sampling of dust from the aspiration systems servicing the technological equipment and processes as well as from the air of the working zone of an enterprise manufacturing asbestos-cement products in the Volgograd region; and the dispersion analysis of the samples of asbestos-cement dust was carried out.

According to the results of the dispersion analysis, the diameters of dust particles do not exceed 60 µm. Thus, the mass of the dust fraction with the particle size from 0 to 200 µm coincides with the total mass of the dust weighed for the analysis. Consequently: K_1=1.

In the course of the investigation, samples of dust were also taken at the moulding shop of the enterprise in order to determine the particle size distribution. The dust content was measured near the pouring unit and the belt conveyer at 12 spots. The photomicrographs of the dust particles sampled from the aspiration system of the pouring unit are presented in figure 1.



a b

Figure 1. Photomicrographs of the dust particles sampled from the aspiration system: a – prior to the cyclone treatment; b – after the cyclone treatment.

The investigations were carried out applying the SpotExplorer software. The key parameters for various fractions (figure 2) are given in table 1. The graphic representation of the results can be shown in the form of integral functions of particle mass distribution $D(d_p)$ according to diameters d_p, which follow the truncated logarithmic-normal distribution law [5].

In accordance with Kolmogorov’s hypothesis, the integral functions of particle mass distribution $D(d_p)$ according to diameters d_p for the dust generated as a result of crushing, wearing etc. are described, as a rule, with logarithmic-normal function. However, a series of works [6] show that dust in the working zone and the aspiration system follows the truncated logarithmic-normal distribution law and can be approximately described through a two-segment or three-segment spline.

Based on the results of the conducted measurements of the particle size distribution of the asbestos-cement dust sampled from the working zone air of the moulding shop, the authors plotted the integral curves of particle mass distribution $D(d_p)$ according to diameters (figure 2). To describe the dust particle size distribution, two-segment splines in the probabilistic-logarithmic coordinates system were used, one segment of which included finer fractions while another segment included the larger ones. The coordinates of the nodal points and the angles of straight lines inclination were determined through the least squares method.

Table 1. The values of the distribution median and the standard deviation of logarithms of diameters from their mean values for fine and large fractions of asbestos-cement dust, nodal point coordinates.

№ of spot	Fine fractions		Nodal point coordinates		Large fractions	
	d_{50}	lg σ	D_0	d_0	d_{50}	lg σ
1	22	1.09	36	51	28	0.19
2	33	0.82	29	63	36	0.19
3	38	1.01	29	41	31	0.26
4	40	1.06	24	32	29	0.35
5	29	0.91	29	51	28	0.12
6	23	1.02	22	49	21	0.17
7	19	0.85	20	51	18	0.15
8	21	0.83	31	69	26	0.19
9	28	0.85	30	51	28	0.10
10	101	1.42	67	43	54	0.08
11	26	1.02	40	55	30	0.23
12	78	1.23	53	37	36	0.03

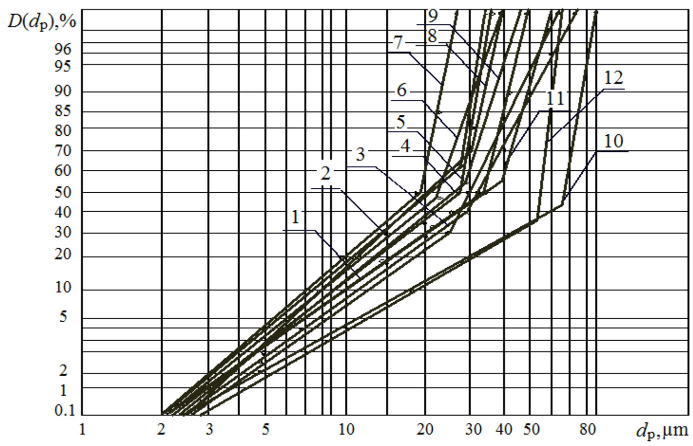


Figure 2. The integral curves of particle mass distribution $D(d_p)$ according to diameters: 2, 4, 5, 6, 8, 9, 10, 11 – near the belt conveyer; 1, 3, 7, 12 – near the pouring unit.

However, the obtained data cannot show the accurate situation since the values of the integral curves of particle mass distribution $D(d_p)$ according to diameters are not consistent. The reason is that the fraction of large particles having no stable distribution poses the largest influence on the integral curves of particle mass distribution $D(d_p)$ according to diameters. Consequently, it is reasonable to consider the given functions not as determinate but as random ones. The method of "dissection" was used in order to describe the random function [5]. According to the given method, the particle size distribution takes constant values for fine particles, and the form of the integral curves of particle mass distribution $D(d_p)$ according to diameters is determined by the proportion of large fractions. To separate fine fractions from the large ones, the following designation is used in the mathematical description: d_o – the abscissa of the point of graph fracture (of a nodal point).

Then the integral curve of particle mass distribution $D(d_p)$ according to diameters for fine fractions will have the form:

$$D_f(d_p) = \begin{cases} \dfrac{100}{D(d_0)} D(d_p), \text{if } d_p \le d_0 \\ 0, \text{if } d_p > d_0 \end{cases}, \tag{2}$$

for large fractions:

$$D_l(d_p) = \begin{cases} 0, \text{if } d_p \le d_0, \\ \dfrac{100}{100 - D(d_0)} D(d_p), \text{if } d_p > d_0. \end{cases} \tag{3}$$

The integral curves of particle mass distribution $D(d_p)$ according to diameters for particles with the diameter smaller than 20 μm and larger than 20 μm were plotted applying the method of "dissection". Such a dissection was performed to each integral curve and the obtained integral curves of particle mass distribution $D(d_p)$ according to diameters are presented in figure 3.

As a result of the plotting, all the 12 curves appeared to practically coincide (figure 3) at the segment (0, 20). Consequently, the particle size distribution shows constant values for particles of small diameter, and such dust can be described by a determinate curve [7,8].

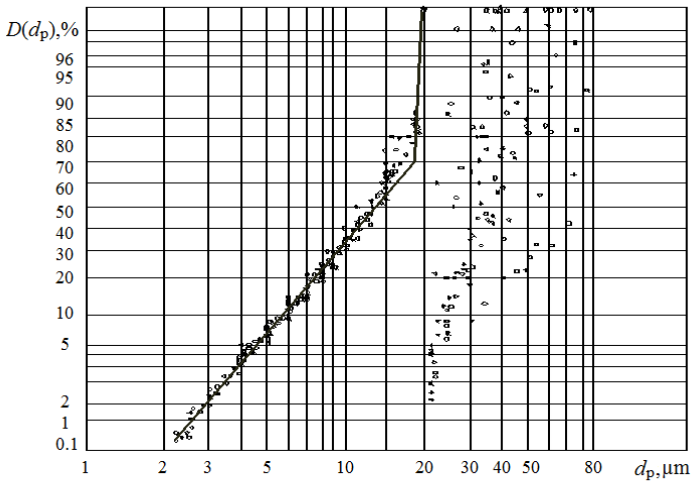


Figure 3. The integral curves of particle mass distribution $D(d_p)$ according to diameters for large and fine fractions of dust sampled from the air of the working zone of the moulding shop.

4. The calculation of coefficients taking account of the physico-chemical characteristics of construction material, local meteorological conditions and the type of loading-transferring equipment

Then the authors determined the size of particles of asbestos-cement dust aerosol, it equaled to 3 μm, which agrees with the reference literature data [9]. Thus, for the sample taken from the air duct:

$$K_2 = \frac{m_{aer}}{m_{d.fr.}}.$$

In addition, taking into account that the proportion of particles of asbestos-cement dust transferring into aerosol amounts to 20% as shown by the integral curves of particle mass distribution $D(d_p)$ according to diameters: $m_{aer} = 0.2 \cdot m_{d.fr.}$; K_2=0.2.

However, based on the analysis of [4], the tabulated value K_1 should tend to 0.05, and the value K_2 - to 0.01, like those of the material most similar to mineral wool in its physico-mechanical properties. Then the product of these two coefficients will amount to K_{ac}=0.2 for asbestos-cement; and to K_{mw}=0.005 for mineral wool when obtained through the method [4]. The ratio of the coefficients is K_{ac}/K_{mw}=40.

The authors determined the natural moisture of chrysotile asbestos, it amounts to 2%, which agrees with [9]. Consequently, K_5=0.8. The value of K_5 should tend to 1, like that of the construction material most similar to mineral wool in its physico-mechanical properties. The given condition is satisfied.

According to the technological production flow scheme of asbestos-cement products manufacturing, asbestos is delivered to plants in paper bags in railway cars. At the plants, they are kept on wooden floors at an indoor storage site with separate sections for various brands and sorts. Consequently, in this case, no "instantaneous" character of the emission is observed, K_9=1. That is, the value of K_9 coincides with the tabulated value for mineral wool.

5. The calculation of dust deposition coefficient F

Further, the authors determined the coefficient F for the calculation of atmospheric pollution with fine suspended particles of asbestos-cement dust with the size of 10 μm (PM_{10}) and 2.5 μm ($PM_{2.5}$) through two different methods. In order to determine the non-dimensional coefficient F taking into account the velocity of particle deposition, which is obtained applying appendix 2 of the Methods of calculation of diffusion of hazardous (polluting) substances emissions into the atmospheric air [10] being in effect in Russia, it is necessary to reveal such a diameter dg at which the mass of all the particles with the diameters larger than dg amounts to 5 % of the total dust particles mass, as well as the velocity of particle deposition V_g (m/s) matching to dg, through the integral curve of particle mass distribution according to diameters (figure 1). After that, the hazardous wind velocity $U_м$ is determined based on the point 5.10 [17]. Then the value of the coefficient F is set depending on the ratio of $V_g/U_м$, i.e.: at $V_g/U_м \leq 0.015$ F=1.0; at $0.015 < V_g/U_м \leq 0.030$ F=1.5; while for all the other values of $V_g/U_м$ the deposition coefficient F is set according to table 2, appendix 2 [10]. The velocity of solid particles deposition V_g is determined through the Stokes's law. Taking into account the actual conditions, in this particular case, it is determined as follows:

$$V_g = \frac{1.45 \cdot 10^6 \cdot d_g^2 \cdot \rho}{T^{0.683}} \tag{4}$$

where T – is the temperature of flue gases which equals to 273+t, K.
The authors obtained the value of $V_g = 3.51 \cdot 10^{-4}$ m/s for the given construction material.
The hazardous wind velocity $U_м$ for the city of Volgograd is adopted in accordance with the long-term average data, with the exceedance frequency of 5%: $U_{м1}$=9 m/s and the still-air value of $U_{м2}$ = 0.5 m/s. Thus, the parameter $V_g/U_м < 0.015$ in both the first and the second cases. Consequently, according to appendix 2 [10], the deposition coefficient is F =1.

In accordance with the method [11], the velocity of the polluting admixture deposition depends on the characteristics of its particle and the medium in which the particle moves. It is determined depending on the Reynolds criterion (Re). The Re for practical calculations is determined through the graph and depends on the complex of $\xi \cdot Re^2$ [12,13]. Depending on Re and in accordance with [14-16], the velocity of particle deposition V_g is determined as follows:

at Re<1.0 $V_g = \dfrac{d_g^2 \cdot g \cdot (\rho_p - \rho_{med})}{18 \cdot \mu}$, m/s; at 500 > Re >1.0 $V_g = \dfrac{\mathrm{Re} \cdot \mu}{d \cdot \rho_{med}}$, m/s;

$$\text{at Re>500 } V_g = 5.45 \cdot \sqrt{\frac{(\rho_p - \rho_{med}) \cdot d}{\rho_{med}}} \text{, m/s.}$$

Further, the hazardous wind velocity $U_м$ is determined. After that, the value of the coefficient F is set depending on the ratio $V_g/U_м$.
The authors of the article determined the value of the complex $\xi \cdot Re^2 = 0.23 \cdot 10^{-7}$ for asbestos-cement dust. Then the value of V_g (Re<1,0) was calculated, it amounted to $V_g = 3.6 \cdot 10^{-4}$ m/s. The parameter $V_g/U_м < 0.015$. Consequently, according to point 2.6 [10,17-20], the deposition coefficient is F=1.

6. Conclusion and findings

The investigation showed that dust particle size distribution in the working zone air for particles smaller than 20 µm is governed by the logarithmic-normal distribution law and can be represented in the form of a determinate curve. Large particles with the size more than 20 µm are distributed in the form of random functions for which choosing a law does not seem to be possible.

In addition, the conducted experimental investigations of dust particle size distribution allowed obtaining the values of the coefficients K_1=1 and K_2=0.2 for asbestos-cement dust, those coefficients can be used for the calculations of dust emissions according to the method [4].

The calculation is carried out based on consolidated indices for materials similar in their physical properties. The results of the work showed that actual emissions of asbestos-cement dust are 40 times higher than the tentative values for analogous materials obtained through the calculation according to the method [4]. The values of K_5 and K_9 for asbestos-cement dust coincide with the tabulated values for materials with analogous physical properties.

Based on the obtained values of the coefficients K_1, K_2 and F, it is possible to state with a high degree of accuracy that the given dust belongs to highly polydispersive ones. It is known that diffusion of dust of that class is not calculated. The methods of the calculation of the diffusion of hazardous (polluting) substances in the atmospheric air which are in effect in Russia do not work for particles of such diameter. The particles are stratified over thousands kilometers and remain suspended for several hours. Consequently, further investigations of the diffusion processes are required in order to produce the mathematical apparatus and methods which will be able to take an account of the data of physico-chemical properties of particles in the course of their stratification and sedimentation.

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