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Experimental studies of the properties of metal dust

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Introduction. The issues of ensuring the environmental safety of metalworking industries are still very relevant. Moreover, the primary role in these issues is played by the protection of atmospheric air from the emissions of industrial enterprises in this industry. For the successful implementation of measures aimed at ensuring the environmental safety of atmospheric air, it is important to study in detail the composition and properties of the emission components.

Problem Statement. The aim of the study is to analyze the entire range of modern methods for measuring the parameters of the properties of metal dust, as the main component of emissions from metalworking industries; to select the method of experimental research; to conduct a dispersion analysis of metal dust particles.

Theoretical Part. As a rule, the productivity of experimental studies of the parameters of the properties of pollutants largely depends on the methods that were used in the performance of the work. To solve these problems, the authors have analyzed modern methods for measuring the parameters of the properties of metal dust. The choice is made according to the basic principles: relativity, relevance, completeness, labor intensity. The conditions for the final results of the research, their accuracy and reliability, the conditions for the terms, resources, technical means of research used, and the positive and negative aspects of each of the methods under consideration are also taken into account.

Conclusion. The article presents the result of the choice of the research method and the results of experimental studies of the properties of metal dust.

Keywords: metalworking, metal dust, dust properties, property parameters, dispersion composition, microscopic method, dispersion analysis.

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Introduction. Currently, humanity faces a number of problems, among which the problems of ensuring environmental safety occupy a special place. Meeting the needs of modern society has led to the rapid development of all industries, which has significantly affected the quality of the environment [1].

As numerous studies in the field of environmental safety of urban areas show, the development of some industries leads to particularly destructive consequences. Being a natural resource user, a person brings changes to the environment, negatively affecting its natural processes. Therefore, not only the development of industrial production is extremely important, but also the simultaneous rational use of natural resources and environmental protection [2].

Analyzing the features of the production activities of enterprises, it can be concluded that among the main sources of environmental pollution, there are enterprises of ferrous and non-ferrous metallurgy, fuel and energy complex, mechanical engineering and metalworking [3]. Such enterprises cause significant damage to atmospheric air. As a result of emissions of pollutants, there is a gradual change in the composition of the atmosphere, an increase in the amount of carbon dioxide and dust. Concentrated in the lower layers of the troposphere, industrial emissions significantly increase the background air pollution of cities.

Metal dust near the metalworking industry enterprises is the component of background air pollution, which is very dangerous for human health [4]. The formation and release of metal dust at such enterprises are associated with the peculiarities of the implementation of technological processes. As an example, the authors consider the metalworking production, which produces extruders and bag-making machines. The gross emission of pollutants at this enterprise amounted to 7,483 tons/year. According to the results of the inventory, 21 items of pollutants entering the atmospheric air were identified. The need to ensure environmental safety at this enterprise was a prerequisite for further research.

Problem Statement. The production site of the metalworking enterprise was taken for the research, which gave the maximum amount of pollutants, namely, metal dust. The formation and release of metal dust occurs from a number of cutting and grinding machines when separating metal particles from the total amount of technological raw materials (metal sheets and pipes). Since metal dust is the main object involved in the process of air pollution, it is important to study its properties. At the same time, the properties of metal dust undergo qualitative and quantitative changes during the entire process of air pollution [4].

Metal dust is an aerosol of a two-phase system consisting of a dispersed phase (solid metal particles) and a dispersed medium (air medium). The size of solid particles of metal dust varies significantly and can reach 300 microns. According to the division accepted in the literature, particles with a size of less than 1 micron are classified as fine dust, with a size from 1 to 10 microns — as medium-dispersed, with a size of 40 to 140 microns — as coarse. There is also a subgroup of very large dust with a particle size of more than 140 microns. This division into subgroups allows us to characterize the dispersed composition of metal dust, its mass and quantity.

The following groups of dust parameters are distinguished:

1) physical-chemical:

— aggregate state — solid;

— color — dark gray;

— resistance to high temperatures (melting point at a pressure of 101.3 kPa — 1565°C);

— density at 20°C — 5240 kg/m^3

— heat capacity at 0°C — 113.91 J/(mol×K);

— bulk density ρ = 1920 kg/m^3;

— breaking strength of the layer — 300-600 Pa;

2) hydrodynamic:

— solubility in water — insoluble at 25°C;

— wetting angle — 45%.

Chemical properties of metal dust include its chemical composition, toxicity, explosion and fire hazard. The lower concentration limit of ignition (LCLI) of iron oxides is 105 g/m^3. Dusts with an LCLI of more than 65 g/m^3 are classified as fire-hazardous [5].

Theoretical Part. At the initial stage, to solve the problem, the authors identified the most significant property of metal dust — its dispersed composition. The choice of a particular method for capturing and cleaning emissions containing metal dust depends on the size of the particles and their quantity. Depending on the size of the metal dust particles, the efficiency of the designed cleaning system can be reduced by up to 40%.

When determining the measurement method, the authors have made a choice based on the principles of relativity, relevance, completeness and labor intensity.

For comparison, the following methods for determining the dispersed composition of dust particles were chosen: sieve, microscopic, sedimentation and hydrodynamic [6]. The most acceptable of them is the microscopic method. The advantages of this method are the possibility of determining the geometric parameters of metal dust particles, considering the structure of the surface, structure and shape. It is important that when using the microscopic method of research, particle measurement can be carried out in the range from 0.3 to 100 microns. However, electron microscopes with higher accuracy are often used to determine the size of metal dust particles less than 1 micron.

As a disadvantage of the microscopic method, its considerable labor intensity should be noted. Accurate results of determining the dispersed composition can be obtained only by studying several hundred particles. This explains the long duration of experimental studies. To reduce the time for processing the measurement results, computer technologies were used to determine not only the average size of metal dust particles, but also to set the parameters of the distribution law.

Thus, the chosen method of experimental studies of the dispersed composition of metal dust meets a number of requirements:

— the positive aspects of the method under consideration prevail;

— there is data on such analyses, the samples under study;

— the conditions for the time, resource and technical means required for the analysis are feasible;

— the requirements for the final indicator of research and the reliability of the results are provided.

When conducting the experimental studies, the method of microscopic analysis was used [7]. Table 1 presents preliminary theoretical results of the size distribution of metal dust particles.

The median diameter d_{50} characterizes the dispersion of aerosols, that is, the particle size by which the aerosol mass is divided into two equal parts. At the same time, the mass of particles smaller than d_{50} is 50% of the total mass of metal dust, as well as the mass of particles larger than d_{50} [5].

As a result of the conducted studies, the median diameter was d_{50}=35 microns.

The specific surface area of the particles equal to 560 m^2/kg and the suspension velocity $v_{вит}$ = 0.5–9 m/s are also determined.

Table 1

Distribution of metal dust particles by size

Particle size at the fraction boundaries, σ, microns	5	15	25	35	45	55	65	75	85	95
Fractions, D, % of the total mass of particles	4.75	8.02	2.78	8.18	7.04	7.86	16.37	26.51	11.62	6.87

Let us consider the form in which the results of the analysis of variance are displayed.

When constructing an integral graph of the distribution of the sizes of metal particles, the most voluminous fractions of particles (Q) that have a size smaller than the current one are deposited on the ordinate axis (Fig. 1). Therefore, the integral distribution curve can be represented as a certain function Q=f(d).

In the case of a granulometric graph, the linear size (d) of the measured particles is transferred along the abscissa axis.

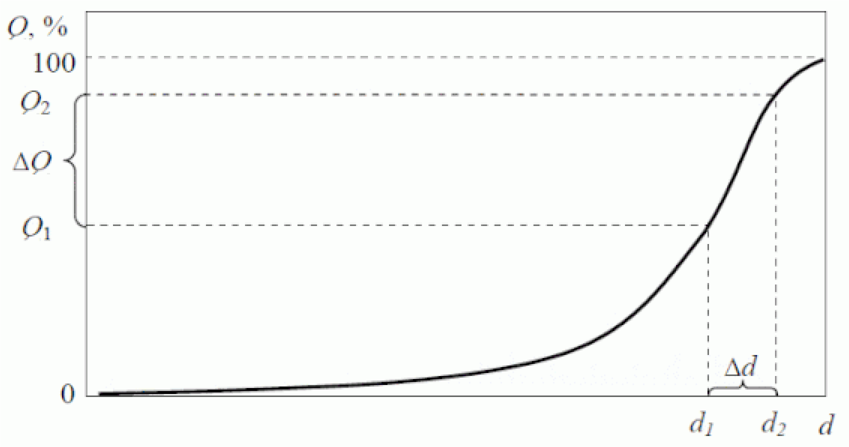

Fig. 1. Integral curve of particle size distribution [8]

When determining the volume fraction of metal dust particles with a size less than d_1, it is necessary to identify the size of d_1 on the lower scale and draw a vertical line from this point to the intersection with the integral distribution curve. The value of the ordinate of the obtained point will represent the volume fraction occupied by metal dust particles with a size less than d_1, in this case it is Q_1. At the same time, there is a correspondence between the size interval from d_1 to d_2 and the volume fractions from Q_1 to Q_2 [9].

To obtain a series of intervals ΔQ_i, we divide the integral curve along the abscissa axis into intervals. We construct ordinates for the points of intersection of vertical lines with an integral curve.

Moreover:

$$\sum_{i=1}^{N} \Delta Qi = 100\%, \qquad (1)$$

where N — the number of selected intervals (fractions) of particle sizes.

The intervals of volume fractions are represented as columns with height Fi=ΔQi. Thus, a differential histogram of the distribution of metal dust particles by size is constructed (Fig. 2).

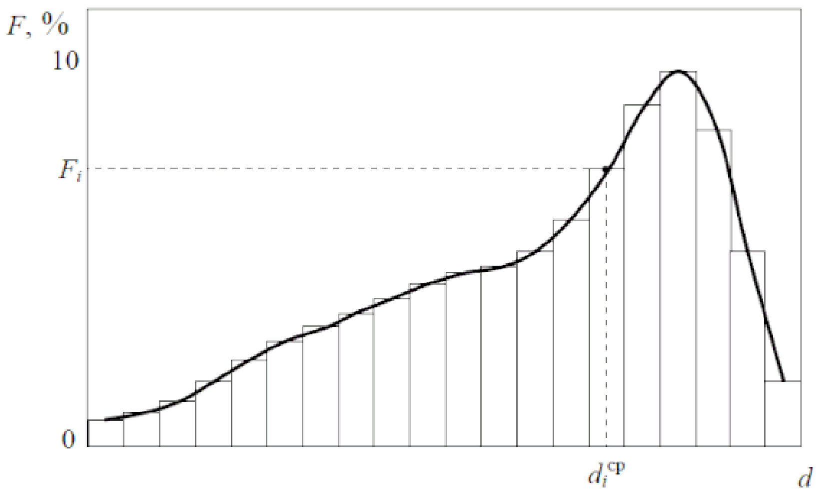

Fig. 2. Particle distribution on the differential histogram [8]

When connecting the upper part of the columns of the differential histogram of the distribution, we get a smooth differential curve. Such a curve means that particles with average sizes located in the middle of one column (d_{icp}) occupy F_i, % by volume in the measured mass.

When constructing a differential distribution curve, the ratios $\Delta Q_i/\Delta d_i$ are often marked instead of the intervals of volume fractions F_i. The area of each rectangle corresponds to the content of the fraction of the material in certain interval sizes Δd_i.

To determine the most probable diameter ($d_{н.в.}$) in the considered dispersed system, it is necessary to construct a differential distribution curve and connect the midpoints of the upper parts of the rectangles with a smooth line (Fig. 3).

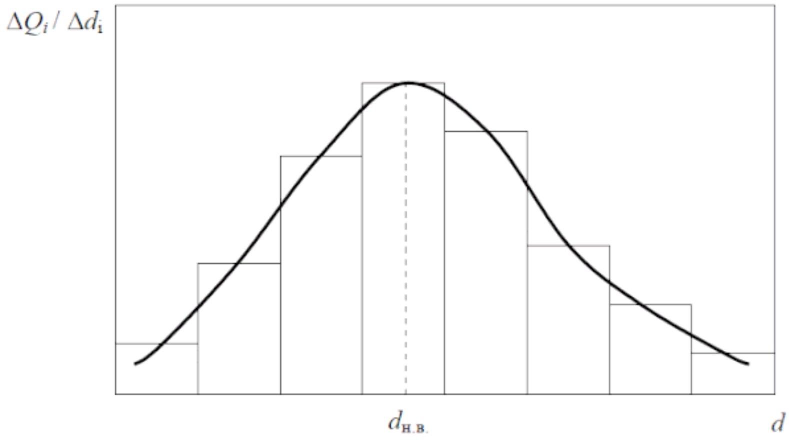

Fig. 3. The most probable diameter of metal dust particles [8]

As a rule, the main statistical indicators of the differential curves of the particle size distribution are the average value, mode and median of the distribution (Fig. 4).

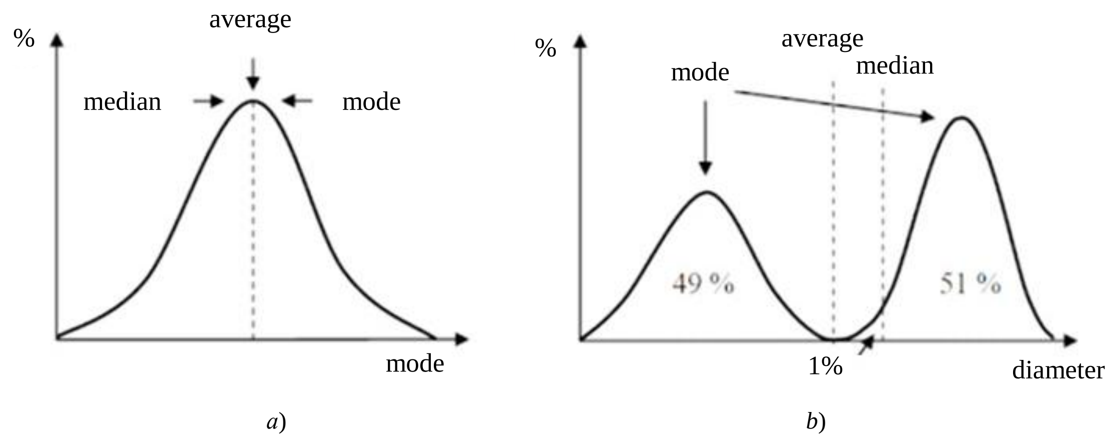

Fig. 4. Basic statistical characteristics for normal or Gaussian (a) and bimodal (b) particle size distribution [8]

The average value is the average particle size, the result of averaged data.

The mode is the position of the maximum of the differential distribution curve, or the most likely particle size in the population.

Three statistical indicators coincide in the case of a normal distribution (Fig. 4a). However, with a bimodal distribution, the average is between two distribution intervals (Fig. 4b). There are also no particles with a diameter equal to the average. The median diameter is shifted to the right side of the distribution. The differential curve has two pronounced maxima (two modes). The largest mode corresponds to the position of the maximum of the right part of the distribution [10].

The results of microscopic analysis and the results of calculations are presented in Tables 2 and 3.

Table 2

Results of microscopic analysis

Particle diameter σ, microns	Number of particles					
	I field	II field	III field	IV field	V field	Number of particles in all fields N
5	10	12	7	-	-	29
15	9	-	6	14	20	49
25	6	8	3	-	-	17
35	16	-	-	11	23	50
45	-	15	7	21	-	43
55	8	11	1	12	16	48
65	20	31	14	20	15	100
75	32	20	37	33	40	162
85	31	14	8	18	-	71
95	14	11	-	17	-	42
ΣN =611						

Table 3

Data for constructing an integral curve for the distribution of the number of particles by size

Particle diameter σ, microns	Number of particles of the fraction N	Percentage content Fraction Q, %	Increasing total content of fractions D, %
5	29	4.75	4.75
15	49	8.02	12.77
25	17	2.78	15.55
35	50	8.18	23.73
45	43	7.04	30.77
55	48	7.86	38.63
65	100	16.37	55
75	162	26.51	81.51
85	71	11.62	93.13
95	42	6.87	100
	ΣN =611	ΣQ=100	

Below is the information for constructing a differential distribution curve obtained by processing the integral curve (Table 4).

Table 4

Data for constructing a differential curve for the distribution of the number of particles by size

σ, microns	5	15	25	35	45	55	65	75	85	95
Δσ, microns	5	10	10	10	10	10	10	10	10	10
ΔQ,%	4.75	8.02	2.78	8.18	7.04	7.86	16.37	26.51	11.62	6.87
ΔQ/Δσ	0.95	0.80	0.28	0.82	0.70	0.79	1.64	2.65	1.16	0.69

The integral distribution curve constructed according to Table 3 is shown in Fig. 5.

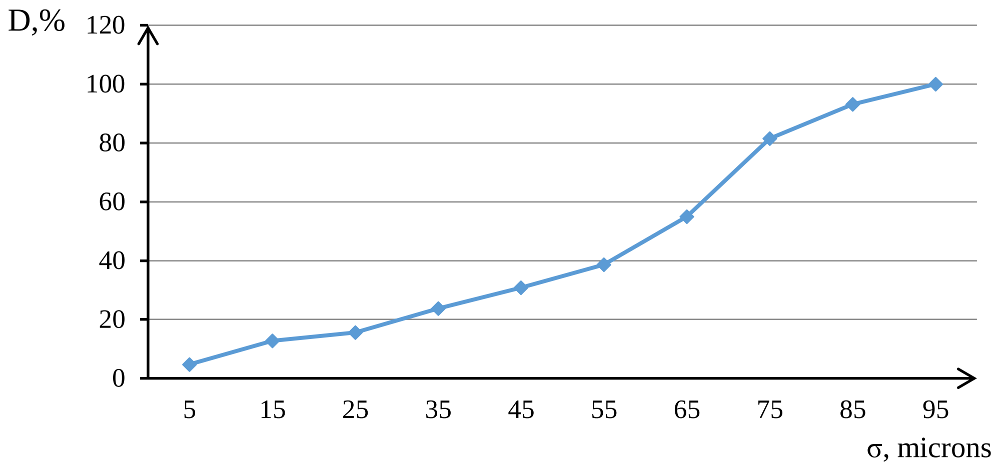

Fig. 5. The integral distribution curve of particles by size

According to Table 4 and the differential curve constructed from it (Fig. 6) it is obvious that its maximum falls on 75 microns.

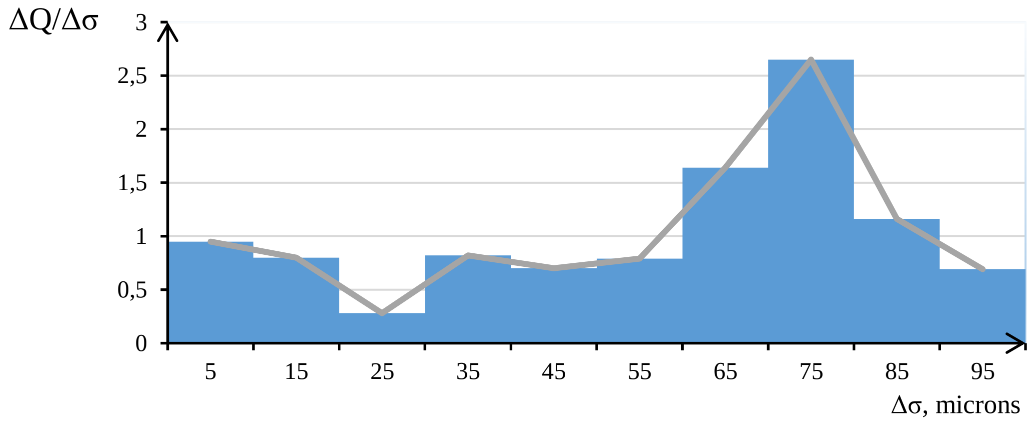

Fig. 6. Differential curve of particle size distribution

Particles of irregular granular shape with the inclusion of metal chips. Particle faces with jagged edges [7, 9, 11].

Conclusion. The analysis of the experimental research methods used to determine the dispersion composition of metal dust particles allowed us to choose the microscopic method that suited best the tasks set. According to the experimental data obtained, it is clear that particles with a size of 75 microns predominate in the total mass of metal dust. Therefore, the metal dust formed during cutting and grinding can be attributed to the medium-dispersed. The conducted research allows us to proceed further to the consideration of the most promising methods and ways for ensuring environmental safety at metalworking enterprises.

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Contribution of the authors:

L. V. Dikova — determination of the purpose and objectives of the study, analysis, preparation of the text, formulation of the conclusions; N. S. Samarskaya — formulation of the concept of the article, selection of the topic, scientific supervision, analysis of the results, revision of the text.