ON THE SIZE DISTRIBUTION OF DUST AND SMOKE PARTICLES IN THE AIR OF AN INDUSTRIAL CITY

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Abstract

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ON THE SIZE DISTRIBUTION OF DUST AND SMOKE PARTICLES IN THE AIR OF AN INDUSTRIAL CITY

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One of the important characteristics of the physical properties of polydisperse aerosols is the size distribution of their particles. Experimental investigation of this distribution proves to be very laborious, and therefore the establishment of any general regularities in the size distribution of particles is of substantial importance for the study of aerosols.

A. N. Kolmogorov ([1]) showed theoretically that, in the fragmentation of solid particles, the size distribution of the resulting small particles approaches the logarithmic-normal distribution the further the comminution process proceeds.

Later, the logarithmic-normal character of the particle-size distribution was established experimentally for a number of aerosols of both natural and artificial origin, and moreover for aerosols not only of dispersion origin (dust aerosols), but also of condensation origin—clouds and fogs ([2,3]). However, in all these cases only aerosols with particles of the same origin (monogeneous aerosols) were studied. It is therefore desirable to investigate the character of the particle-size distribution also for heterogeneous aerosols containing particles of different origin.

Such a heterogeneous aerosol is the lower layer of atmospheric air in an industrial city. In this layer are suspended dust particles, smoke particles, and small hygroscopic particles that serve as condensation nuclei. Particles of different origin have sizes of different orders, and even with a logarithmic-normal distribution of the sizes of particles of one and the same origin, the general character of the distribution is difficult to foresee.

In 1951–1952 the author investigated the dustiness and smokiness of the air in the city of Zaporozhye. Conclusions concerning the particle-size distribution can be drawn on the basis of the measurements made of the number concentration of particles suspended in the air.

These measurements were made by means of an Owens counter for settling dust (Owens II). Air samples were taken with a cylinder 12 cm in diameter and 15 cm high. The particles suspended in the air settled in the closed cylinder onto cover glasses over the course of 3 hours. The number of deposited particles was counted under a microscope at a magnification of 1200×. According to the magnitude of their diameter, the particles were divided into 4 groups: small particles—with diameter less than 5 μ; particles of medium size—with diameters 5–10 μ and 10–20 μ, and, finally, large particles—with diameter greater than 20 μ. In the measurements, the number of particles in each group was counted.

For the present communication, the results of measurements in the new part of the city, at a distance of 3 km from the main source of industrial smoke, were used. Air samples were taken from windows and from the upper platform.

high building located on the main street of the city (from heights of 3, 13, and 26 m above the ground surface).

In the case of a logarithmic-normal distribution of particles by size, the following relation should hold:

$$f(r)\,dr = \frac{1}{\sqrt{\pi}} e^{-\xi^2}\,d\xi, \tag{1}$$

where r is the particle radius; ξ is a function of the relative particle radius (with respect to the mean geometric radius r_g) and of the standard geometric deviation (the root-mean-square deviation) of the logarithm of the radii β_g:

$$\xi = \frac{\lg r - \lg r_g}{\sqrt{2}\lg \beta_g}. \tag{2}$$

The fraction of particles with radius $r \leq r_1$ can be determined by integrating equation (1) over the limits from 0 to r_1:

$$\int_0^{r_1} f(r)\,dr = \frac{1}{2}\left[1 + \Phi(\xi_1)\right], \tag{3}$$

where $\Phi(\xi_1)$ is the value of the probability integral:

$$\Phi(\xi_1) = \frac{2}{\sqrt{\pi}} \int_0^{\xi_1} e^{-\xi^2}\,d\xi \tag{3'}$$

for

$$\xi = \xi_1 = \frac{\lg r_1 - \lg r_g}{\sqrt{2}\lg \beta_g}.$$

Hence

$$\Phi(\xi_1) = 2\int_0^{r_1} f(r)\,dr - 1. \tag{4}$$

Since the percentage content of particles with radius $r \leq r_1$ is determined from measurements with an Owens counter, then, by formula (4) and a table of probability logarithms, the corresponding value ξ_1 can be determined for each value of r_1.

According to formula (2), in the case of a logarithmic-normal distribution of particles, the relation between the quantities ξ and $\lg r$ should be linear.

The results of processing the observations by the method described above are given in Table 1 and in Fig. 1. As is evident from the graph, the relation between ξ and $\lg r$ is linear. Consequently, in the heterogeneous aerosol—the lower layer of air of an industrial city—the distribution of particles by size is logarithmic-normal.

Table 1

Values of ξ

Height above the ground surface	$2r \leq 5\,\mu$	$2r \leq 10\,\mu$	$2r \leq 20\,\mu$
3	−0.263	0.240	0.770
13	−0.244	0.296	0.793
26	−0.146	0.404	0.871

The data obtained make it possible, for each level, to calculate the mean geometric particle radius r_g and the root-mean-square deviation of the logarithm of the radii β_g. The calculations give, for levels of 3, 13, and 26 m above the ground surface, values of r_g respectively equal to 3.6, 3.4, and 3.0 μ. The decrease in the values of r_g with height indicates a decrease in the number of large particles in the higher layers of air and provides a quantitative characteristic of this decrease.

The values of β_g for the indicated levels are obtained as, respectively, 2.53; 2.56, and 2.61. It may be considered that the discrepancies between these values lie within the limits of measurement errors and that no systematic change in the value of β_g in the layer 3–26 m from the earth' s surface has been established by the observations.

Thus, regardless of the question of the applicability to our data of A. N. Kolmogorov' s theoretical derivation, the logarithmic-normal distribution law approximates them well.

Naturally, the values β_g and r_g determined by the method described, for a logarithmic-normal distribution of particles by size, do not depend on how many

Fig. 1. Graphs of the logarithmic-normal distribution of particles. Height above the earth' s surface: a—3 m; —13 m; —26 m

Figure 1: Fig. 1. Graphs of the logarithmic-normal distribution of particles. Height above the earth' s surface: a—3 m; —13 m; —26 m

and which particular levels within the given layer the measurements were carried out at. This circumstance makes it possible to compare with one another the values of r_g and β_g determined under different conditions and with a not entirely identical measurement technique. Only the dimensions of the cylinder of the Owens apparatus used for counting the settled particles, the magnification of the microscope, and the settling time of the particles in the apparatus must be identical.

Fig. 1. Graphs of the logarithmic-normal distribution of particles. Height above the earth' s surface: *a*—3 m; —13 m; —26 m.

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Note: Figure translations are in progress. See original paper for figures.