MEASUREMENT OF DISTRIBUTION BY THE METHOD OF SMALL ANGLES FROM THE DIMENSIONS OF PARTICLES SUSPENDED IN A FLOW

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A description is provided for the installation and we give the results from experiments on the determination of the distribution function for water droplets atomized with a spray nozzle. The resulting distributions (accurate to within the experimental error) are described by a normal-logarithmic law. It is demonstrated that these results are in satisfactory agreement with those derived by a capture method.

Many industrial and research installations presently use suspensions of a given substance in a gas or in some liquid; this is particularly characteristic of installations involving heat or mass transfer, as well as various types of heating equipment. The effectiveness with which the processes take place within such installations depends significantly on the dimensional distribution of the suspended particles [1-3]. The determination of this parameter becomes a necessary condition for a quantitative analysis of such installations.

The method used to determine the dimensional distribution function for the suspended particles usually include, in one form or another, an individual count, a laborious procedure that is associated with aerodynamic distortions [4].

The small-angle method is based on the fact that the suspended particles scatter light at small angles to the initial direction; moreover, this procedure introduces no aerodynamic distortions, and the measurements can be accomplished over several seconds, with completely satisfactory accuracy. The theory of the method has been developed in [5-7]; the experimental aspects of the method have been tested on nonmoving clouds of water, and this has been described in [8, 9].

When using this method we assume that the scattering particles are spherical and transparent, with the multiple scattering resulting from the limited concentration assumed to be negligibly small.

The angular distribution of the intensity $I(\theta)$ of the radiation scattered on the aerosols in this case can be presented in the form

$$I(\theta)=\pi I_0\int_0^{\infty}F(\theta,\ \rho)f(\rho)\rho^2d\rho, \tag{1}$$

$F(\theta,\rho)$ is a function which determines the radiation scattering within the angle θ by a particle of a given dimension; $f(\rho)$ is the density of the dimensional distribution function for the particles; ρ is a parameter characterizing the relative particle dimension and is equal to $\rho = \pi D/\lambda$.

In studying the scattering of comparatively large particles ($\rho \gg 1$) within a small angle ($\theta < 0.1$) we have

$$F(\theta,\ \rho)=\frac{1}{\pi}\theta^2J_1^2(\rho\theta), \tag{2}$$

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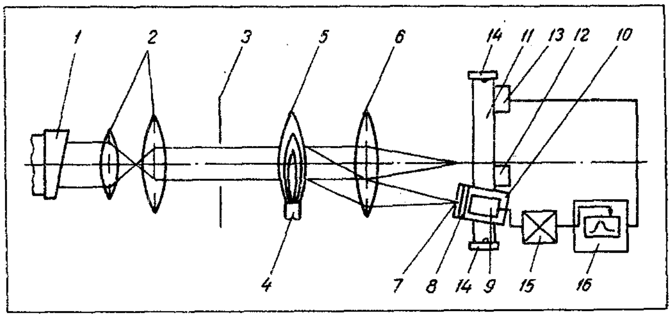

Fig. 1. Diagram of the installation to investigate the dimensional spectrum of atomized particles.

TABLE 1. Basic Parameters for the Dimensional Distribution Functions of the Particles

Air pressure in spray nozzle, atm	D_m, μm small-angle method	D_m, μm capture method	σ, μm small-angle method	σ, μm capture method
0,8	2,2	2,4	2,05	2,2
0,6	2,8	2,9	2,5	2,6
0,4	3,5	4,0	2,8	2,5

and inverting (1), we find

$$f(\rho) = -\frac{c}{\rho^2}\int_0^\infty \frac{d(\theta^3 I)}{d\theta} J_1(\rho\theta)\, Y_1(\rho\theta)\, d\theta, \qquad (3)$$

where c is a constant.

We can also have other solutions which do not lead to the differentiation of the integrand [10]. Then

$$f(\rho) = -\frac{c}{\rho}\int_0^\infty h(\rho,\ \theta)\ S(\theta)\, d\theta, \qquad (4)$$

where the kernel $h = -2\pi Y_1(x)[2xJ_0(x) - J_1(x)] - 4$, while $S(\theta) = I(\theta)\ ^3 - I(\beta)\beta^3$, $I(\theta)$, and $I(\beta)$ are determined experimentally; β is a rather large angle which still satisfies the condition of applicability for the small-angle method.

In our case β was equal to 0.1-0.15 radians, depending on the speed of signal reduction.

The small-angle method is used to determine the density of the dimensional distribution function for water particles produced by atomization in a spray nozzle. A diagram of the installation is shown in Fig. 1: 1) the He–Ne laser with a radiation wavelength of 0.6328 μ; the polarization plane forms an angle of 45° with the measurement plane; 2) a collimator with an angular magnification of 11×; 3) diaphragms limiting the beam; 4) a pneumatic spray nozzle with a nozzle diameter of 0.3 mm; 5) the spray-nozzle cone; 6) an objective with an effective aperture of 45 mm and a focal length of 400 mm; 7) a point diaphragm 0.2 mm in diameter; 8) an interference light filter; 9) an FÉU-51 photomultiplier; 10) a carriage moving along guide rails 11, simultaneously rotating about the vertical axis of objective 6; 12) the drive of the movement mechanism; 13) a potentiometer connected to the moving carriage 10; 14) terminal switches to limit the movement of the carriage.

The signal taken from the photomultiplier is applied to the dc amplifier 15 (type F-359) (the amplification used here went as high as 10^5), and the amplified signal is transmitted to a two-coordinate automatic recorder of the N-359 type (16). The moving carriage sets the angle of recorder drum rotation through potentiometer 13 and the angle and the intensity of the scattered light are thus simultaneously recorded.

The operations were carried out in the following sequence: with the spray nozzle disconnected, we recorded the signal from the light scattered by the lens; the spray nozzle was then connected [sic] and we recorded the light scattered from the lens and the nozzle cone. The magnitude of the light scattered by the cone was found by substrating the first from the second.

Figure 2 shows a typical resultance whose ordinates are proportional to the radiation scattered by the nozzle cone. In processing the experimental results in accordance with (3), in certain cases, we found a "negative" concentration in the region of large θ. Repeated processing of the curve did not markedly alter the results. This phenomenon is apparently associated with the excessive simplification employed in the

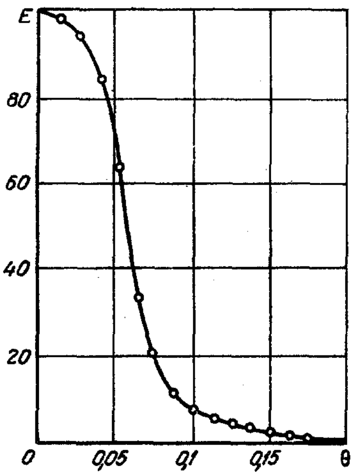

Fig. 2

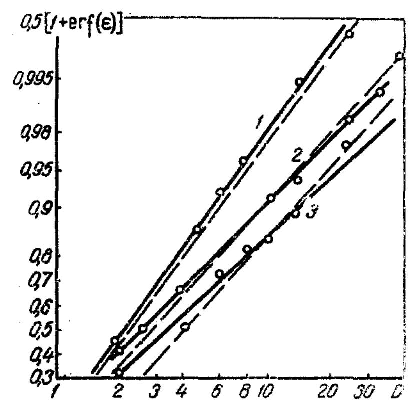

Fig. 3

Fig. 2. Angular distribution of the intensity of the light scattered by the nozzle cone (E in conventional units and θ in radians).

Fig. 3. Accumulated diagrams of the distribution functions derived by the small-angle method (solid lines) and by the capture method (dashed lines) for the following excess air pressures at the inlet to the spray nozzle: 1) P = 0.8 atm; 2) 0.6 atm; 3) 0.4 atm.

selection of the function $F(\theta, \rho)$ for large θ. With a reduction in the limit reckoning angle (in our case, from 0.175 to 0.113 radians) the distribution functions are smoothed and the "negative" concentrations disappear. When processing the signal in accordance with (4), we find that no "negative" concentrations are observed.

The particle distribution in the nozzle cone was also studied by capturing particles on glass plates, and these were subsequently microphotographed. A shutter is set up in front of the plates and the exposure is of the order of 10^{-2} sec; the plates were covered with a mixture of transformer oil and gasoline, in a ratio of 3 : 1; the resolution of the microscope was 0.8 μm. The overall magnification was 700×, and an electrical slide rule was used to count the particles.

The distribution functions derived with these two procedures are satisfactorily described by the normal logarithmic law

$$N(D)\,dD = \frac{1}{\lg\sigma\sqrt{2\pi}}\exp\left[-\frac{\lg D - \lg D_m}{2(\lg\sigma)^2}\right] d\lg D.$$

The accumulated diagrams of the distribution functions derived by the two methods for various air pressures within the spray nozzle are shown in Fig. 3.

As we can see from the figure, the distributions are fairly close to each other; we can see the same thing from the table, which gives their basic parameters.

The slightly higher values of D_m, derived by the capture method, can be explained by the relatively limited capture efficiency for small particles. When P = 0.2, the small-angle method produced a distribution substantially different from the normal logarithmic distribution observed for the same pressure in the capture method. This divergence can be explained by the unstable operation of the spray nozzle at low pressures.

These results thus indicate the possibility of reliably using the small-angle method to measure the dimensional spectrum of particles moving in a stream.

NOTATION

I_0 is the intensity of the incident radiation;
I is the intensity of the scattered radiation;

λ	is the wavelength of the light used;
θ	is the scattering angle;
β	is the maximum theoretical scattering angle;
D	is the particle diameter;
N(D)	is the density of the dimensional particle distribution function;
ρ	is a dimensionless parameter characterizing particle magnitude;
$J_1(\rho\theta)$	is a Bessel function of the first kind;
$Y_1(\rho\theta)$	is a Bessel function of the second kind;
D_m	is the mean geometric particle diameter;
σ	is the standard geometric deviation;
P	is the air pressure in the spray nozzle;
erf(ε)	is the Kramp function of D.

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