ON MEASUREMENT OF THE NUMBER DENSITY OF POLYDISPERSE CONDENSATION AEROSOL

V.V. Beloded, G.A. Kirichevskii, and V.M. Nuzhnyi

T.G. Shevchenko Kiev State University

We propose a modification of the technique for determining the number density of particles in a polydisperse cloud consisting of water droplets which change their sizes during the observation time. The technique is developed for the experiment on determining the nucleation rate in a mixture "supersaturated vapor—noncondensable buffer gas". This experiment makes it possible to answer a number of questions which are urgent for both phase transition physics and practical applications in meteorology, protection of the environment, etc.

A new version of the CAMS (constant angle Mie scattering) technique for determining the aerosol parameters is proposed. At first this method was proposed by Vietti and Schuster in 1973,[1] and developed by Dobbins et al.,[2] Wagner,[3] and the authors.[4] This technique is based on comparison of the temporal dependence of the intensity of light scattered by aerosol with the values calculated by the Mie theory.[5] In the case of a polydisperse aerosol it is necessary to be aware of the droplet size distribution function fir) in order to calculate the values of intensity.

The CAMS technique makes it possible to reconstruct the droplet size spectrum in detail if greater number of observation angles are used. However, the possibility of measuring the scattering phase function is limited by technical difficulties which appear when, for example, the observation time is small. In the case of interest this time is smaller than 0.1 s. This results in using a minimal number of measured signals and forces to employ the different estimates of $f(r)$ inferred from theoretical premises and experimental results.[6,7,8]

A technique for number density measurement based on the determining the portion of light scattered in the volume containing aerosol[2] is a significant part of the CAMS technique. This technique is often used independently. However, in our opinion the question pertaining to the influence of aerosol polydispersity on the result of determining the number density was assigned little importance.

As is well known, the number density of scattering particles can be determined in terms of the extinction of probing light beam transmitted through the scattering volume. According to the Bouguer law

$$J = J_0 \exp\{- \tau \, l \, \}, \tag{1}$$

where J_0 and J are the intensities at the inlet into and the outlet from the scattering volume, respectively, l is the thickness of the scattering volume, and τ is the extinction coefficient. In the case of single independent scattering by monodisperse aerosol

$$\tau = \tau_m = N_m \, \pi \, r^2 \, Q(r, n, \lambda), \tag{2}$$

where N_m is the number density of monodisperse aerosol, r is the droplet radius, $Q(r, n, \lambda)$ is the extinction

efficiency, n is the refractive index of the material of a particle, and λ is the wavelength.

For polydisperse aerosol with particle size distribution function $f(r)$ we have

$$\tau_p = N \pi \int_0^\infty r^2 \, f(r) \, Q(r, n, \lambda) \, dr \, , \tag{3}$$

where N is the total number density of droplets of all the sizes.

We introduce the monodisperse aerosol with such a droplet radius

$$R = \int_0^\infty r \, f(r) \, dr \tag{4}$$

that a light extinction by real polydisperse and selected monodisperse aerosol will be identical.

Then from Eqs. (2), (3), and (4) we obtain

$$N_m \, R^2 \, Q(R, n, \lambda) = \int_0^\infty r^2 \, f(r) \, Q(r, n, \lambda) \, dr \, . \tag{5}$$

We checked a possibility of application of N_m as the estimate of N first of all taking into account the conditions of the experiment for which a technique for determining the aerosol parameters was developed. The peculiarities of using this technique are related, in particular, with the method employed for determining of the mean droplet radius which we discussed in Refs. 4 and 5. This method is based on finding the relation between the peculiarities (the Mie peaks) of the experimental temporal dependences of the light intensity scattered at two fixed angles (30° and 45°) and the Mie peaks on theoretical curves. The latter are the results of calculating the scattered light intensity as a function of the droplet size by the Mie theory.

The use of the technique is limited by the fact that in polydisperse aerosol the Mie peaks are smoothed out.

For the first time the estimate of $f(r)$ effect on the distortion of these peculiarities was given in Ref. 1. We also estimated the smoothing effect of the droplet size

distribution function. We used a scheme for measuring fir) given in Fig. 1. We assumed that at the first stage the droplet spectrum (curves *1, 2,* and *3*) was formed. At the second stage the spectrum as a whole shifted along the size axis (curve *4*).
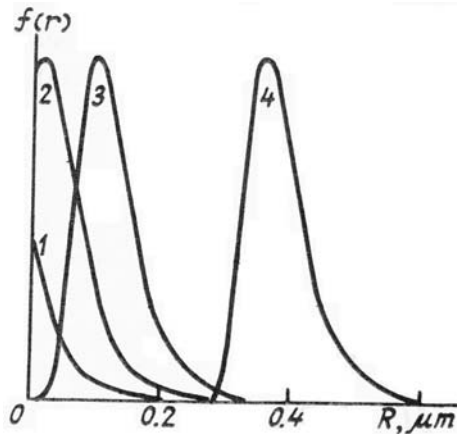

FIG. 1. Evolution of the droplet size spectrum.

The dependence of the scattered light intensity on mean droplet radius was calculated from formula (4). It means that for each position of the *f(f)* function on the size axis the value of intensity was related to the value of *f*. The wavelength of probing light, beam was set equal to 0.63 μm. Calculations were made for water−droplet aerosol with refractive index *n* = 1.33 and values of *R* ranging from 0.01 to 4.00 μm.

The concrete form of droplet size distribution function was selected starting from the fact that papers, for example. Refs. 6, 7, and 8 indicate the lognormal distribution is typical of condensation aerosol. The salient features of cloud formation in the Wilson chamber were also taken into account. Completely formed droplet spectrum (curve *2* in Fig. 1) was calculated from the formula

$$f(r) = \frac{1}{\sqrt{2\pi}\ \sigma\ r} \quad \exp\left\{-\frac{(\ln r - \ln a)^2}{2\sigma^2}\right\}, \tag{6}$$

where *a* is the median and σ is the parameter of distribution.

Different types of spectra were obtained when a fixed value $r_{mod} = a \exp\{-\sigma^2\} = 0.1 = \mu m$ was used and σ varied from 0.1 to 0.75. The distributions obtained are shown in Fig. 2. Here are the curves with σ = 0.2 (*1*), 0.5 (*2*), and 0.75 (*3*). All of the curves were scaled to 1.

An analysis of the results of the computation of the light scattering function for widest *f(r)* from the set showed that the deviation of the Mie peaks of the smoothed curves from corresponding peculiarities of monodisperse aerosol curves did not exceed 2%. It was shown also that subsequent widening of the *f(r)* function gives so strong smoothing effect that the identification of the Mie peaks becomes impossible, especially for small values of *R*.

The same set of distribution functions was used for estimating the quality of determination of the number density when polydisperse aerosol was replaced by monodisperse aerosol. According to Eq. (5), the ratio N_m/N was calculated. It was established that for

$R > 0.4$ μm the ratio N_m/N deviates from 1 by not more than 0.05 and for $R < 0.4$ μm the deviation is not more than 0.2. The calculation with the distribution functions being the specular reflections of those used above, were also made. The deviations of the value N_m/N remained within the same limits.
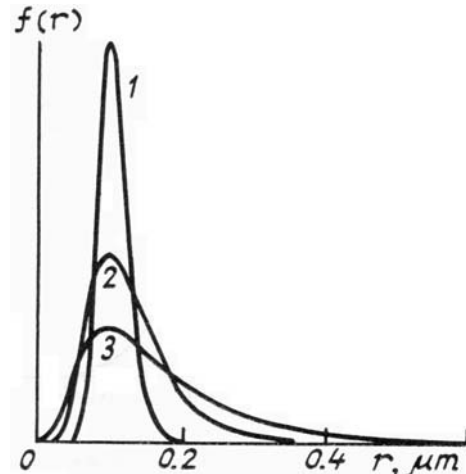

FIG. 2. A part of a set of f(r) functions used for simulation of scattering and extinction.

The results that have been obtained here make it possible to use the technique under study to the experiment on investigating the nucleation and the rate of growth of the small water droplets in the Wilson chamber[9,10]: the temporal dependence of the light intensity scattered at two angles (30 and 45° with respect to the probing beam propagation direction) and light extinction were measured. The light source was an LG 78 laser. Theoretical dependences were calculated by the Mie theory with the help of the phase angle technique using our specially developed programs. The mean droplet radius was determined with the help of the dialogue program including computer graphics.

REFERENCES

1. M.A. Vietti and B.G. Schuster, J. Chem. Phys. **5**, No. 2, 434−441 (1973).
2. R.A. Dobbins, T.I. Eklund, and R. Tjoa, J. Aerosol Sci. **11**, 23−33 (1980).
3. P.E. Wagner, J. Colloid and Interface Sci. **105**, 456 (1985).
4. V.A. Drofa, V.V. Beloded, G.A. Kirichevskii, et al., Kiev, Ukr. NIINTI, No. 698 UkD84 (1984), 18 pp.
5. H.C. Van de Hulst, *Light Scattering by Small Particles* [Russian translation] (Inostr. Lit., Moscow, 1961), 536 pp.
6. V.A. Drofa, G.A. Kirichevskii, and V.M. Nuzhnyi, in: *Liquid State Physics* (Vyshchaya Shkola, Kiev, 1981), pp. 118−122.
7. E.M. Lifshits and L.P. Pitaevskii, *Physical Kinetics* (Pergamon Press, Oxford, 1981).
8. V. Szymansky and P.E. Wagner, Atmos. Environ. **17**, No. 11, 2271−2276 (1983).
9. V.V. Beloded, G.A. Kirichevskii, and V.M. Nuzhnyi, J. Aerosol Sci. **20**, No. 8, 1043−1046 (1989).
10. V.V. Beloded, G.A. Kirichevskii, and V.M. Nuzhnyi, *ibid.*, 1047−1050 (1989).