Instrumental and Technical Approach to Prompt Field Measurements of Size Distributions of Aerosol Absorbing and Scattering Characteristics

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Introduction

The problem of real-time measurements of the size distributions of different optical and microphysical characteristics of atmospheric aerosol in situ has become increasingly urgent in recent years. Detailed empirical data on the size distribution of soot, which is the principal absorbing component of particles, as well as the aerosol scattering and absorption coefficients in the visible wavelength range, are necessary to solve many radiative-climatic problems and to correctly estimate the single scattering albedo and aerosol condensation activity. This paper describes the field-developed and -tested instrumentation and technique for selecting different subranges of the size spectrum in the range of micro- and finely-dispersed particle fractions.

Measurement Instrumentation and Technique

Experimental investigations in situ of the size distributions of optical and microphysical aerosol characteristics significantly expand the information obtainable via methods for aerosol investigations in a local volume of air (Tohno et al. 2001). Cascade impactors were usually applied for these purposes. The problem of performing the more detailed real-time measurements is still urgent. It can be done based on the techniques and instruments that can divide aerosol particles into different-sized subfractions in situ.

To measure the size distributions of aerosol characteristics, we used the diffuse and electrostatic settling of particles from airflow. Aerosol particles were divided into different-sized subfractions through the controlled filtration of air from the side of the lower (from 30 nm and greater) and upper (from 1 μm and less) boundaries. The selector of the size spectrum was created for the filtration of particles. It consists of a five-stage diffuse cutter and an electrostatic cutter.

The operating principle underlying the diffuse cutter (Figure 1) is analogous to the screen's block of the diffuse aerosol spectrometer (Reichl et al. 1991) and is a five-stage diffuse battery of screen-type. Its operational principle is based on the dependence of the particle diffusion coefficient on its size. The

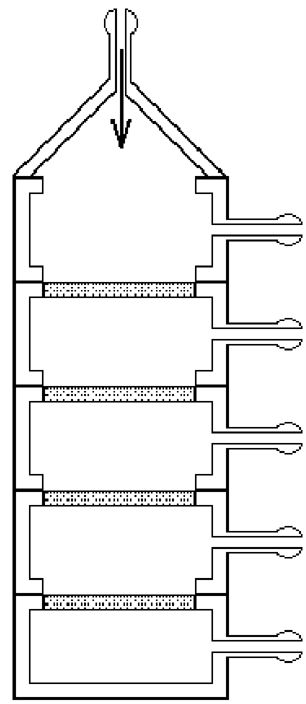

Figure 1. Diagram of the screen-type diffuse cutter.

diffuse cutter removes the microdispersed particles ranging from 30 to 100 nm from the airflow. As the quantity of screens increases, the smallest particles settle first on the battery cascades, and then the cut boundary moves to the range of greater size. The increase of the number of cascades combined with selection of the quantity of screens enables us to reach the desirable discreteness of particle filtration in the range of microdispersed fraction. The calculated dependencies of particle penetration by different cascades of the diffuse filter on the particle size are shown in Figure 2. It should be noted that the mathematical formalism for calculation of the diffuse battery parameters is developed quite completely and tested well (Cheng at al. 1980; Reischl et al. 1991).

An electrostatic cutter was developed to filter particles of greater size (from 1 μm and less) (Kozlov et al. 2001). The corona discharge with controlled voltage from 2 to 4 kV is used. The diagram of the electrostatic filter is shown in Figure 3. The inlet aerosol flow comes to the cylindrical dielectric chamber (1). The corona electric discharge appears between the negative needle electrode (2) and the grounded cone electrode (3). The percussive charging of aerosol particles by ionized molecules of air occurs in the discharge space of the filter. The charged particles settle to the cone electrode, while the uncharged particles pass through it and leave the filter. As the discharge voltage increases, first the large particles are charged in the filter and settle, followed by the smaller particles.

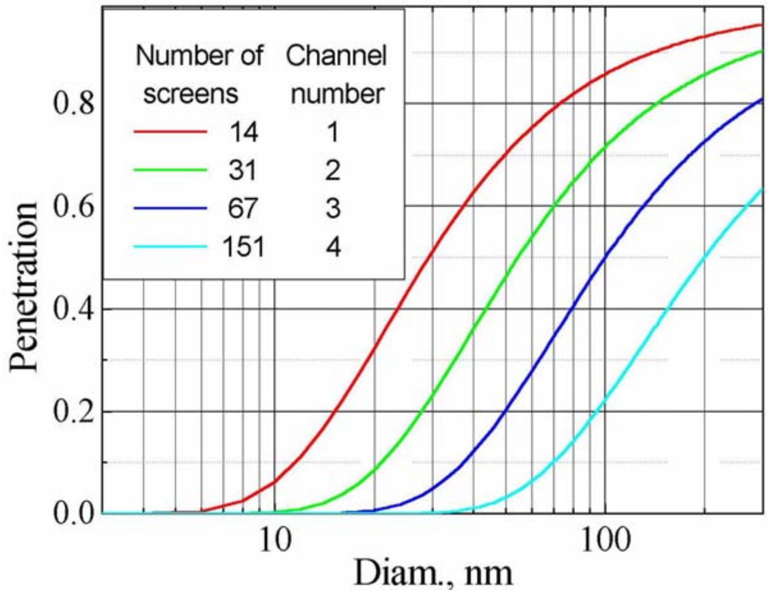

Figure 2. Calculated calibration efficiency of penetration of particles by four cascades of the diffuse cutter (airflow rate is 4 l/min).

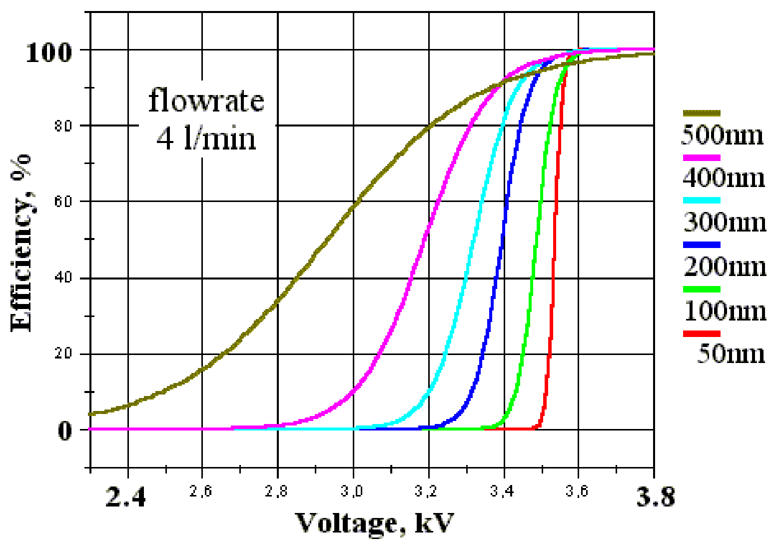

Figure 3. Axial cross section of the electrostatic filter chamber: 1) cylindrical dielectric chamber, 2) negative needle electrode, 3) grounded cone electrode.

The electrostatic filter was calibrated using laboratory measurements of the efficiency of settling of quasi-monodispersed aerosol of NaCl of the size 50, 100, 200, 300, 400, and 500 nm. Aerosol was generated by dispersion of water solution with the determined concentration of salt in a 40 l chamber by means of a sprayer. The efficiency of the filter was estimated based on measurements of the decrease of the number density of particles of the certain size as the discharge voltage increases. The diffuse aerosol spectrometer was used for recording the number density (Reichl et al. 1991).

The results of calibration of the electrostatic filter (efficiency of settling of particles as a function of the discharge voltage) are shown in Figure 4. The dependencies are the result of approximation of the experimental data at the airflow rate of 4l/min. The efficiency of 100% corresponds to complete removal of particles of the noted size from airflow. As is shown, resulting curves are steep. Efficiency increases as the particle size decreases, demonstrating the good resolution ability of the electrostatic cut and the need for stability of the discharge voltage.

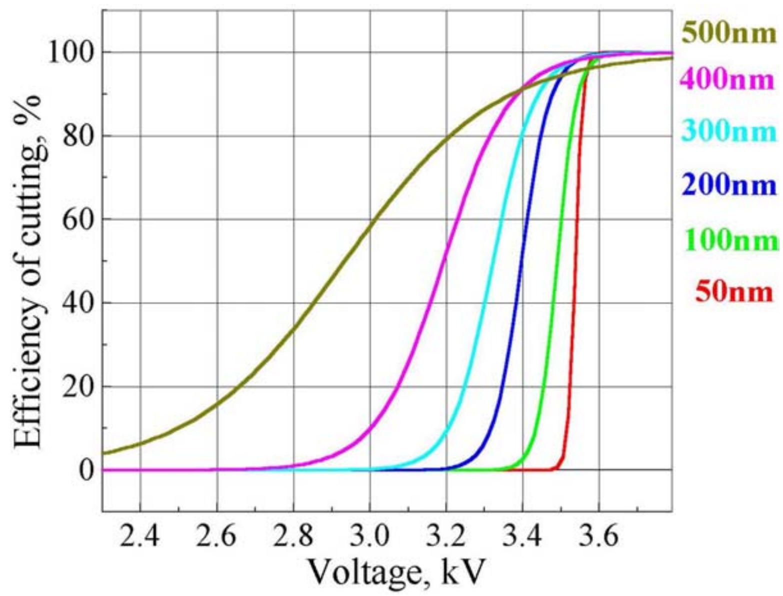

Figure 4. Cutting efficiency of electrostatic filter for 50–500 nm particles.

Preliminary Measurements and Results

The developed approach was used to investigate of the size distribution of the mass concentration of soot aerosol in situ. Measurements were carried out in the near-ground layer of air in December 2001. The experimental setup contained the electrostatic and diffuse cutters installed side by sided in the air path, the air channel switch, an aethalometer, and a personal computer.

The mass concentration of soot in the composition of aerosol particles M_S ($\mu g/m^3$) was recorded by the aethalometer based on the method for measuring the diffuse attenuation of light by a layer of aerosol particles during their settling on an aerosol filter analogous to that of Hansen et al. (1984). Absolute calibration of the device was performed using simultaneous optical and gravimetrical measurements of the concentration of soot produced by a pyrolysis generator in the size range 50 to 200 nm (Baklanov et al. 1998). Sensitivity of the aethalometer is about 0.1 $\mu g/m^3$ at the airflow rate of 20–30 l/min. Duration of single air sampling by the aethalometer is 10 min.

To determine the size distribution of soot, multiple measurements of the soot concentration were carried out without filtration and at different values of the cut by means of electrostatic and diffuse filters. Experimental data were processed taking into account calibration characteristics of the filters. Mean size distributions of soot are shown in Figure 5. Curve 1 shows the measured normalized integral size distribution of soot particles. Processing of the integral dependence makes it possible to obtain curve 2 showing the differential size distribution of soot.

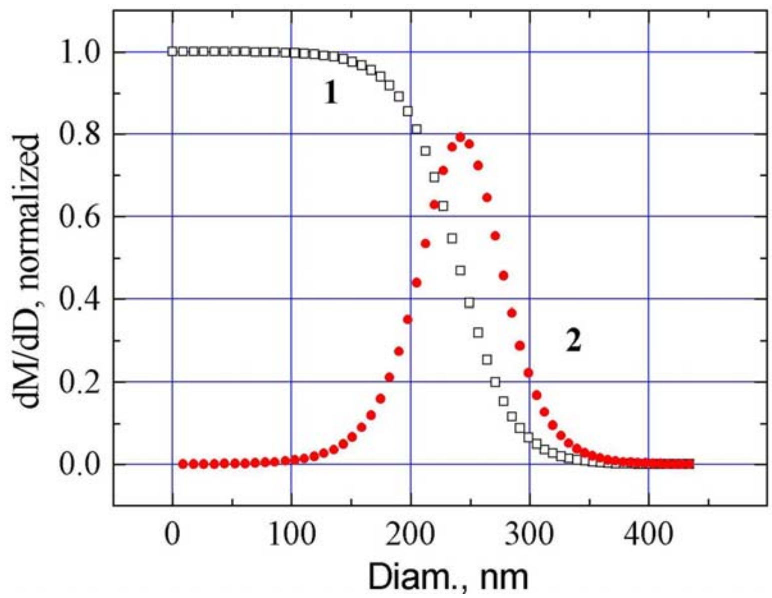

Figure 5. Preliminary results for experimental mean soot size distribution: 1) integral curve (measurements, fitting), 2) calculated soot size spectrum.

Analysis of the results has shown the median diameter of the soot size distribution during the period of measurements was 200 to 250 nm. Although the data obtained are tentative, one can expect that the noticeable portion of absorbing particles lies in the range of the microdispersed fraction and provides for the small contribution into the value of the aerosols scattering coefficient in the visible wavelength range. Under real conditions, this fact can lead to the decrease of synchronicity of temporal variations of the aerosol scattering coefficient and the mass concentration of soot, as it was observed many times in the near-ground air layer.

Conclusion

Preliminary measurements of the size distribution of soot in the near-ground air layer in winter have shown that the median of the mass distribution of soot is about 200–250 nm.

The developed approach can be effective for real-time detailed investigations in situ of the fine structure of different characteristics of atmospheric aerosol. In particular, we propose to use it for the study of the size distribution of the mass of absorbing aerosol, the aerosol absorption and scattering coefficients in visible wavelength range, and growth factor of particles under the effect of relative humidity, as well as for analysis of the chemical composition of aerosol particles.

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