Determination of size and morphology of the coarse aerosol particles from computer analysis of microimages

E.I. Dyukhina and O.A. Belenko

Siberian State Geodesic Academy, Novosibirsk
Institute of Chemical Kinetics and Combustion,
Siberian Branch of the Russian Academy of Sciences, Novosibirsk

Received January 28, 2004

We present in this paper the method for determining the size and morphology of the coarse aerosol particles based on analysis of digital microimages and on the results of its testing using particles of two types. We analyzed about 300 particles originating from fires. These particles were collected during the combined international field mission in Krasnoyarsk Region. Using computer analysis, we determined the following characteristics of particles: shape, area, perimeter, and the number of particles. These data made the basis for analyzing the disperse composition of the coarse aerosol fraction in the smoke plume of forest fires. For soot particles and carbon dust sampled at the Barnaul heating plant, we obtained stereo images, which were then used to estimate the volume and surface area and to develop a 3-D model of the particle under study.

Introduction

Various technological and natural processes produce aerosol particles of different shape and chemical composition. These particles play the decisive role in many atmospheric processes (cloud and precipitation formation, radiative heat exchange, visibility). The powerful sources of atmospheric aerosols in Siberia are forest fires and heat and electric power plants.[1–5] The particles produced there significantly affect the quality of the environment, climate, and chemistry of the atmosphere. To study regularities in the formation of aerosol emissions from forest fires, it is necessary to collect data on the microphysical characteristics of aerosol particles. Important factors determining the properties of aerosols are their disperse and chemical composition. The data on the chemical composition of aerosol particles in both submicron ($d < 1$ μm) and coarse fractions are rather voluminous by now.[1–4] The coarse fraction mostly originates from biomass burning. At the same time, the information about the disperse composition of the coarse fraction is deficient yet.[5] The first estimates of the total mass concentration of aerosol emissions indicate that the contribution of the coarse fraction may be significant.[6] Another, and no less important circumstance is the irregular geometric shape of the coarse particles.[6] Thus, current heat and electric power plants use coal in the form of carbon dust consisting of large ($d < 20$ μm) particles of irregular shapes.[7]

Traditional methods for determination of the disperse composition of such particles are based either on the direct measurement of some characteristics using a microscope, which is a cumbersome process, or on a comparative analysis of microscopic images of particles. Modern computer technologies present efficient tools for analysis of morphology of particles having irregular geometric shapes.[8]

This paper discusses the possibilities of applying geoinformation technologies to determination of morphological characteristics of aerosol particles. The images of the particles were obtained with an optical microscope. The experiment involved analysis of two types of particles: particles produced in a fire, which were sampled during the combined international field mission in the Krasnoyarsk Region and carbon dust particles sampled at the Barnaul heating plant.

The aim of the work was to evaluate the possibility of applying geoinformation technologies to determine morphological characteristics of aerosol particles from their microimages.

Technique

Aerosol particles of the first type were collected during the combined international mission "Fire Bear" in the Krasnoyarsk Krai.[9] The mission was carried out as a part of combined many-year investigations associated with recovery of the forest plant cover after fires, atmospheric pollution with burning products, study of the fire intensity and speed depending on the plant species, weather and climate conditions, the level of humidity of forest combustibles, as well as the local terrain. Aerosol was sampled with an open-type impactor, in which aerosol particles were deposited onto rotating glass plates.[10] Then a photo of the glass with the deposited particles was taken under the microscope. Figure 1 shows a microscopic image of such particles, while Fig. 2 presents a stereo pair of particles of carbon dust used in furnaces.

The particle characteristics were determined using the photogrammetric technique of image processing realized with the aid of the Map Info GIS.[14] The technique involved the following operations:

1. Referencing of the raster image using at least three image points with the preset coordinates in the chosen coordinate system.

0235-6880/04/05–06 462-04 $02.00

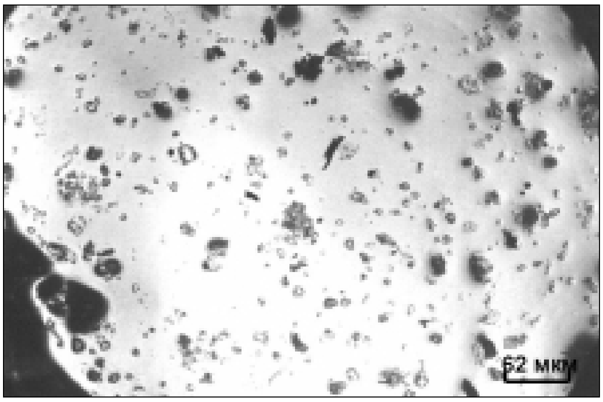

Fig. 1. Example of a micro image of a particle.

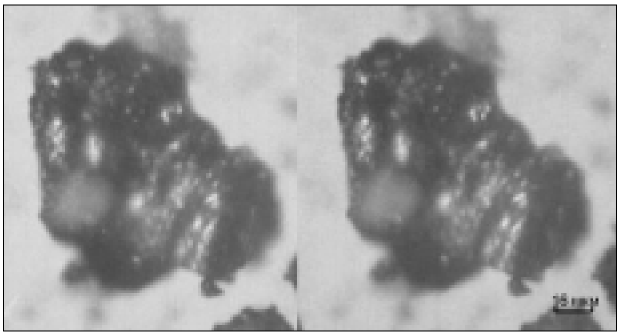

Fig. 2. Stereo pair of the image of a carbon dust particle.

2. Vectorization of the raster image for identification of the particle shape. This operation was performed manually because of the complex shape of the objects under study.

3. Determination of the morphological characteristics of the studied objects with the use of the Map Info standard functions. At the first stage, the Map Info tools were used to find the area and perimeter of every particle. At the second stage, the characteristic diameters were calculated as[11,12]:

$$d_{1\mathrm{equ}} = \sqrt{\frac{4S}{\pi}},\quad d_{2\mathrm{equ}} = \frac{P}{\pi}, \tag{1}$$

where $d_{1\mathrm{equ}}$ is the diameter of the equivalent sphere, whose area is equal to the area of the analyzed particle having the irregular shape; $d_{2\mathrm{equ}}$ is the diameter of the equivalent sphere, whose perimeter is equal to the perimeter of this particle.

The calculations were carried out using the MS Excel tables. A total of 300 particles were measured. The calculations were performed in the following order: the obtained values of the equivalent diameters, areas, and perimeters were sorted in the increasing order, minimum and maximum values of these characteristics were determined, and the results were divided into six fractions in the geometric series:

$$q = \sqrt[6]{d_{i\mathrm{equ}}^{\max} / d_{i\mathrm{equ}}^{\min}},\ i = 1,\ 2, \tag{2}$$

where the subscript 1 corresponds to the equivalent size in terms of the area, and the subscript 2 corresponds to the equivalent size in terms of the perimeter; the superscripts max and min correspond to the maximum and minimum equivalent diameters.

The results of this sorting are given in Table 1.

Table 1

	Area, μm²			Perimeter, μm		
1	2	3	4	5	6	7
i	S_i	n_i	$n_i/300$	P_i	n_i	$n_i/300$
1	12.48	1	0.003	3.46	1	0.003
2	31.47	17	0.057	5.95	23	0.0767
3	88.64	111	0.37	10.3	139	0.463
4	227.84	221	0.737	12.89	229	0.763
5	616.64	268	0.833	30.91	280	0.933
6	1577.44	295	0.983	51.39	295	0.983
7	4560.64	300	1	92.85	300	1

The first column of Table 1 presents the number of the size fraction having the measured areas shown in the second column and perimeters (fifth column). Columns 3 and 6 give the number of particles (n_i), whose size does not exceed the S_i and P_i values. Columns 4 and 7 present the relative fractions (cumulative probability) of S_i and P_i values. To determine the regularity describing the perimeter and area distribution functions, we used the lognormal approximation of the following form:

$$\frac{\delta s}{\delta \ln d_{1\mathrm{equ}}} = \frac{\exp\left[\left(-\ln^2 \frac{S}{S_{50}}\right) / 2\delta_S^2\right]}{\sqrt{2\pi}\delta_S}$$

and

$$\frac{\delta p}{\delta \ln d_{2\mathrm{equ}}} = \frac{\exp\left[\left(-\ln^2 \frac{P}{P_{50}}\right) / \delta_P^2\right]}{\sqrt{2\pi}\delta P}, \tag{3}$$

where $\delta_S = \ln\delta_{gS}$, $\delta_P = \ln\delta_{gS}$.

The parameters of the distributions in Eq. (3) were determined by the least-squares method from the equation

$$Y = a + bX, \tag{4}$$

where $Y_i = \Phi^{-1}(y_i)$; $X_i = \ln(n_i/300)$; $\Phi^{-1}(y_i)$ is the function inverse to the probability integral, its values were determined in Ref. 13 [Table 2]; the coefficients a and b, as well as the coefficient r in Eq. (4) approximating the experimental data are presented in Table 2. The values of a and b were used to calculate the parameters P_{50}, S_{50} (median equivalent perimeter and the area), δ_{gP} and δ_{gS} (variance of logarithms of equivalent diameters in terms of the perimeter and the area) by the following equations:

$$P_{50}\,(S_{50}) = \exp(-a/b),$$

$$\delta_{gP}\,(\delta_{gS}) = \exp(1/b). \tag{5}$$

The equivalent diameters were calculated by Eq. (1).

Table 2

Area					
a	*b*	*r*	S_{50}, μm	δ_{gS}	d_{50equ}, μm
−2.2518	0.987	0.994	157	2.75	14.1
Perimeter					
a	*b*	*r*	P_{50}, μm	δ_{gP}	d_{50equ}, μm
−4.6181	1.7827	0.989	53.4	1.78	13.3

In addition, a 3D computer model of a coal particle was constructed from the stereo pair.

The stereo pairs of particle microimages were obtained with the optical microscope equipped with a camera adapter. Shooting was carried out with a semi-professional compact Nikon camera; images have been taken with the magnification factor of 50.

For obtaining a stereo pair, the object was displaced by a substage between exposures in parallel with the longitudinal frame side. In this case, the shooting is performed with the parallel position of optical rays and, consequently, the depth resolution is the same for both of the images, which is important for formation of stereo images.

Hard copy images were converted into digital ones through scanning.

Computer processing of the obtained digital stereo images was carried out by the Mathlab program implementing photogrammetric processing.

This program can process different-scale stereo pairs, and the external orientation of the model is performed with the aid of both the two reference points and the known separations between the points. The series of the processing operations includes:

1. Filling in the certificate and internal orientation of photos.[15]
2. Mutual orientation of images using six conventionally arranged points.[15]
3. External orientation of the model.[15]
4. Determination of spatial coordinates of the points of the identifying elements of the studied structures of biological and other objects.
5. Calculation of quantitative characteristics (distances, areas, etc.).

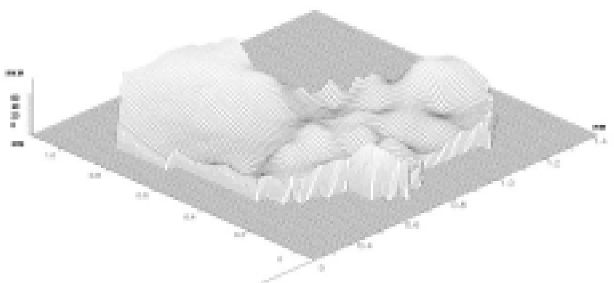

Fig. 3. Digital model of a particle.

In the process of processing, about 110 points of the particle image were measured, and the coordinates x, y, z of these points were determined. The area and perimeter were found. To visualize the results, the obtained files of spatial coordinates were exported into the Surfer program, which constructed a 3D model of the object through approximation of the initial information. The model obtained as a 3D surface is shown in Fig. 3.

Conclusions

1. The investigations carried out have shown the efficiency of computer technologies in determination of morphological characteristics of aerosols of the coarse fraction. The application of such technologies provides for high level of automation of the investigations, extension of the set of determined quantitative characteristics, and improvement of the accuracy as compared with the standard methods.
2. The size spectrum of areas and perimeters of the coarse aerosol particles is well described by the lognormal distribution.
3. The parameters of these distributions are determined for both areas and perimeters of the coarse particles.
4. The results of statistical analysis of aerosol particles originating from forest fires have shown that the median equivalent sizes determined from the values of the perimeter and area are close to each other. However, the size range (δ_g) calculated from the perimeter values significantly differs from the analogous range calculated from the particle area. This indicates that the particle shape is nonisomorphic for particles of different size.

Acknowledgments

The authors are thankful to L.K. Trubina and K.P. Koutsenogii for the help in writing this paper.

This work was partly supported by the IP SB RAS No. 169.

References

1. K.P. Koutsenogii and P.K. Koutsenogii, Sib. Ekol. Zh. **7**, No. 1, 11–20 (2000).
2. K.P. Koutsenogii, V.I. Makarov, G.A. Kovalskaya, A.I. Smirnova, B.S. Smolyakov, and L.A. Pavlyuk, in: *Proc. of the Joint Fire Sciences Conference and Workshop*. Grove Hotel, Boise, Idaho, June 15–17, 1999; *Grossing the Millennium: Integrating Special Technologies and Ecological Principles for a New Age in Fire Management* (University of Idaho, 2000), Vol. II, pp. 219–222.
3. K.P. Koutsenogii, Y.N. Samsonov, V.I. Makarov, S. Conard, S. Baker, W.M. Hao, and D.McRae, in: *Proc. of XXI Workshop*, 2002, Leipzig; ed. by M. Anke, R. Muller, U. Schafer, and M. Stoppler (Schubert-Verlag, Leipzig, 2002), pp. 464–470.
4. K.P. Koutsenogii, Yu.N. Samsonov, T.V. Churkina, A.V. Ivanov, and V.A. Ivanov, Atmos. Oceanic Opt. **16**, Nos. 5–6, 424–427 (2003).
5. K.P. Koutsenogii, Yu.N. Samsonov, E.I. Dyukhina, and O.A. Belenko, in: *Abstracts of Reports at X Workshop on Siberian Aerosols*, Tomsk (2003), p. 25.
6. K.P. Koutsenogii, E.N. Valendin, N.S. Bufetov, and V.B. Baryshev, Sib. Ekol. Zh. **5**, No. 1 (1996).

7. H.L. Green and W.R. Lane, *Particulate Clouds: Dusts, Smokes and Mists* (E. & FN Spon, London, 1964).
8. R.A. Fletcher, E.A. Small, and J.H.J. Scott, in: *Aerosol Measurement*, ed. by P.A. Baron and K. Willeke (Wiley Interscience, 2001), pp. 295–363.
9. Yu.N. Samsonov, K.P. Koutsenogii, A.V. Ivanov, and V.A. Ivanov, in: *Proc. of 5th Int. Conf. "Natural Fires: Arising, Propagation, Fighting, and Ecological Aftereffects"* (Tomsk State University Publishing House, Tomsk, 2003), pp. 170–171.
10. K.E. Noll, Atmos. Environ. **4**, 9–19 (1970).
11. N.A. Fuks, *Mechanics of Aerosols* (AS USSR, Moscow, 1955), 351 pp.
12. P.A. Baron, C.M. Sorensen, and J.E. Brockmann, in: *Aerosol Measurement*, ed. by P.A. Baron and K. Willeke (Wiley Interscience, 2001), pp. 705–749.
13. B.L. Van der Waerden, *Mathematical Statistics* (Springer Verlag, 1969).
14. *Map Info Professional*. User Guide. Russian Version.
15. A.N. Lobanov, M.I. Burov, and B.V. Krasnopevtsev, *Photogrammetry*. Student's Book (Nedra, Moscow, 1987), 308 pp.