A method analyzing aerosol particle shape and scattering based on imaging

Shiyong Shao[*a], Yinbo Huang [a], Ruizhong Rao [a]

Key Laboratory of Atmospheric Composition and Optical Radiation, Anhui Institute of Optics and Fine Mechanics, Chinese Academy of Sciences

ABSTRACT

Shape is a key parameter of aerosol particle. Light scattering and imaging via microscope are conventional measurement ways for detecting aerosol particle shape, but their conclusion can't be certified by themselves. A new self-consistent method combining scattering and imaging is tried. A concentric hollow spherical chamber is the core portion to get signal, where flying single aerosol particle along diameter perpendicular to horizontal plane intersects with laser beam at the chamber centre. Photo of aerosol particle is gained by CCD after amplified, simultaneously, scattering of the same particle is transferred by optical fibers and conversed by PMT. The intensity and polarization of scattering by single fibre cotton are analysed according self-programming wave theory, and the reason for difference of signal is declared compared with photos by CCD. The result shows that the method is reliable.

Keywords: aerosol particle, shape, Light Scattering, imaging, Wave theory, infinitely long cylinder, Chamber, Intensity coefficient, Polarization, Scattering angle

1. INTRODUCTION

Aerosol particle shape is a key parameter affecting its physical characters, especially scattering properties[1]. The information of shape reveals important application in such fields as atmospheric radiation and remote sensing, climate research, radar meteorology. The convenient availability and simplicity of the Lorenz-Mie theory has resulted in a widespread practice of treating nonspherical particles as if they were spheres to which Lorenz-Mie results are applicable. However, the assumption of sphericity is rarely made after first having studied the effects of nonsphericity and concluded that they are negligible but is usually based on a perceived lack of practical alternatives[2].

Light scattering and imaging by CCD via microscope are routine methods for detecting aerosol particle shape. The scattering profile of light scattered by any particle is determined by its size parameter, its shape, and its orientation with respect to the incident illumination[3]. The spatial intensity distribution of scattered light thus contains information by which the particle may often be classified or even identified. By analyzing pairs of signal from opposite detectors, Diehl differentiate bluffly the shape of suspending particles[4]. Bartholdi reflected majority of scattering light onto a circular photodiodes array, and gained more abundant information about particle shape[5]. To observe micro-particle, the microscope is often preferred instrument and often criterion for its absoluteness. With CCD video microscope, dual-channel particle size and shape analyzer was developed by Ankersmid in Holand[6].

*shaoshiyong@aiofm.ac.cn; phone 86 551 559-2666; fax 86 551 559-2666

Remote Sensing of Clouds and the Atmosphere XV, edited by Richard H. Picard, Klaus Schäfer, Adolfo Comeron,
Proc. of SPIE Vol. 7827, 78270X · © 2010 SPIE · CCC code: 0277-786X/10/$18 · doi: 10.1117/12.864850

CCD video microscope is volume-based, and light scattering is number-based[7]. If combine light scattering and CCD video microscope, not only the classification of particle shape can be realized, also the comparison and analysis of results between experiment and calculation by corresponding shape can bring more info which impossible received by individual method. The paper describes a new instrument, aerosol particle shape and scattering analyzer based on imaging. By analyzing scattering intensity coefficient and polarization of fibre cotton and calculation from wave theory, the affecting factors are pointed out.

2. DESCRIPTION OF THE INSTRUMENT

Figure 1 shows the experimental apparatus to measure the shape and scattering properties of aerosol particle in analog manner at the semiconductor laser wavelength of 0.65um has been designed and built. The instrument realizes the combination of imaging and light scattering[8]. The scattering chamber, a homocentric hollow black sphere showed in Fig.1, is the core portion of the analyzer based on imaging. There is a large aperture at top and bottom on the vertical radial line of the chamber, respectively, sample pipe and waste pipe are assembled. The apertures at front and back on the horizontal radial line are respectively for assembling semiconductor laser and CCD video microscope. 36 small apertures for optical fibre that are positioned to measure the light between the horizontal and vertical scattering angles of 30^o and 150^o in 15^o increments. The respective horizontal and vertical 18 small apertures are symmetrical about horizontal radial line. Unfortunately, the small apertures on the vertical radial line happen to be concurrent with sample pipe and waste pipe.

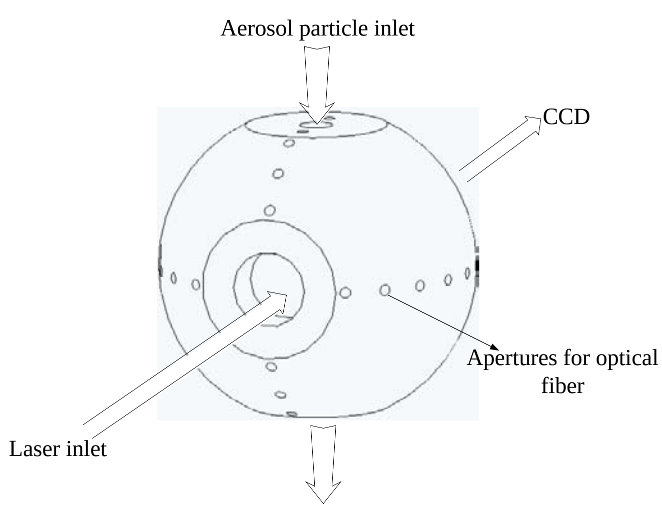

Fig.1 Simplified schematic map of aerosol particle shape and scattering analyzer

When single particle stream passing chamber center, the image is immediately received by the CCD video microscope, at the same time, the scattering light of corresponding particle is collected by optical fibers and transmitted to PMT. Then, the database of the single particle is formed. Since scattering light contains the information about shape of particle, more significant conclusion can be obtained by comparing experimental results and calculation from theory. The whole working process is described as figure 2.

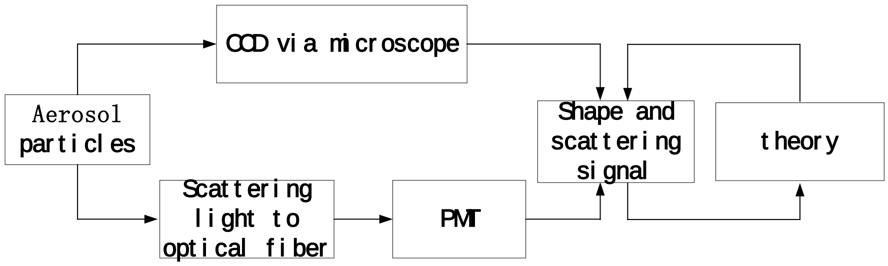

Fig 2.Working process of aerosol particle shape and scattering analyzer

3. RESULT AND DISCUSSION

When the aspect radio exceeds 10, fiber particle, a common shape sort in aerosol, can be considered infinitely long cylinder. Generally, particles with effective radius less than 10um are inhaled. However, in 1990, the U.S. National Institute for Occupational Safety and Health stated "no evidence for a threshold or 'save' level of asbestos exposure"[9]. Flying particles are inclined to keep their long axes consistent with axes of carried gas, which ensures scattering light relatively steady.

3.1 Wave theory for infinitely long cylinder

Detailed report about wave theory can refer paper[10,11]. Now we shall consider two simple cases separately. First, the electric vector $\vec{E}$ is parallel to the incident plane. This is sometimes called the TM mode. For the second case, the electric vector $\vec{E}$ perpendicular to the incident plane. The intensity coefficients for above two cases are defined as :

$$\mathbf{TM}\begin{cases} i_{11} = \left| b_{01} + 2\sum_{n=1}^{\infty} b_{n1} \cos n\phi \right|^2 \\ i_{12} = \left| 2\sum_{n=1}^{\infty} a_{n1} \sin n\phi \right|^2 \end{cases} \qquad \mathbf{TE}\begin{cases} i_{22} = \left| a_{02} + 2\sum_{n=1}^{\infty} a_{n2} \cos n\phi \right|^2 \\ i_{21} = \left| 2\sum_{n=1}^{\infty} b_{n2} \sin n\phi \right|^2 \end{cases},$$

where a_{n1}, b_{n2}, a_{02} and b_{01} are scattering coefficients. i_{11} and i_{22} are the scattered intensities that lies in the same plane as the incident intensities, while i_{12} and i_{21} are the cross-polarized scattered intensities that have directions perpendicular to the incident intensities, what's more, $i_{12} = i_{21}$.

The polarization of light scattering is defined as:

$$\textbf{TM:} \quad p_{11} = \frac{i_{11} - i_{12}}{i_{11} + i_{12}} \qquad \textbf{TE:} \quad p_{22} = \frac{i_{22} - i_{21}}{i_{22} + i_{21}}.$$

LabVIEW ,which accelerates development over traditional programming by 4 to 10 times, is a highly productive graphical programming language for building data acquisition and instrumentation systems, With LabVIEW, we have self-programmed wave theory as a part of the whole measuring system which is shown in Figure 3.

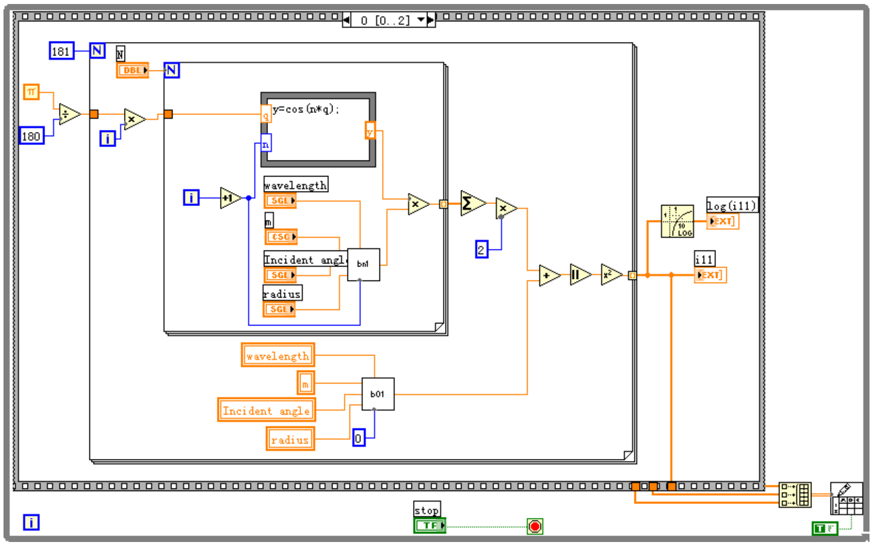

Fig.3 Schematic of programming wave theory

3.2 Analysis of experiment and calculation

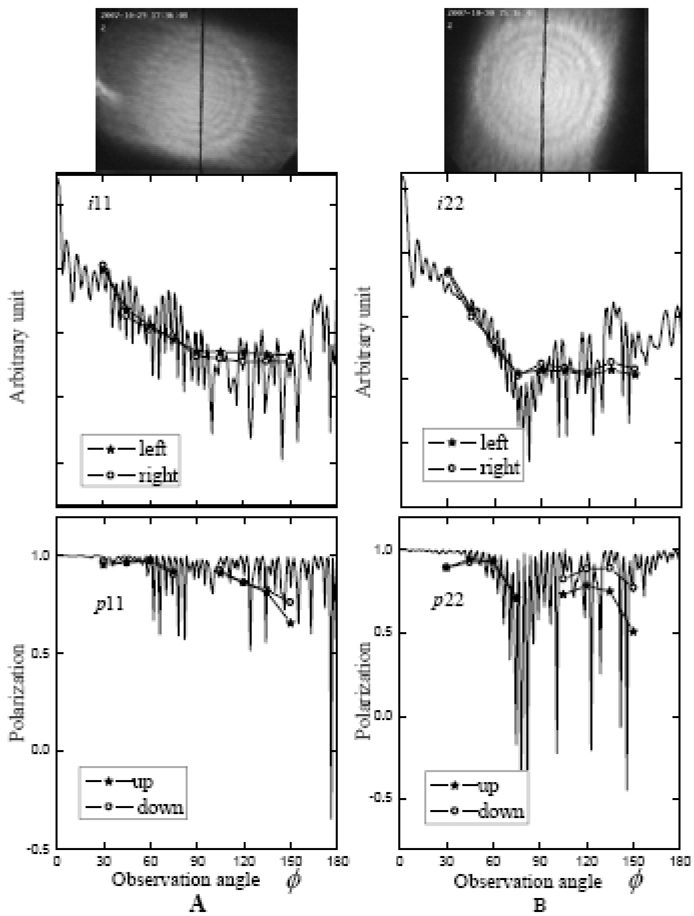

Fig.4 Photo of fiber micro-particle by CCD and respective scattering and polarization

The effective radius of selected fiber cotton particles for experiment are about 10um, compared to 1mm laser beam, the condition of infinitely long for irradiated cotton is satisfied. The incident laser with 0.65um wavelength is transformed to linear polarized light by Glan-Talyor lens. When electric vector $\vec{E}$ is parallel to the incident plane, the refractive index is 1.573-1.581, we choose 1.577 for calculation. When the electric vector $\vec{E}$ perpendicular to the incident plane, the refractive index is 1.524-1.534, we choose 1.529 for calculation. In experiment, the angle between cotton and axes of carried gas is about 5^o.

The "left, right, up and down" in figure 4 refer to figure 1.It can be concluded that the tendency of experiment keeps uniform with calculation for scattering intensity and polarization. A pair of experimental signal lack in polarization p_{11} and p_{22}, since up aperture and sample pipe with a same positions, similarly to bottom aperture and waste pipe, too. i_{11} and p_{11} are more close to calculation than i_{22} and p_{22}, which might be caused by different outline of particles. Clearly, the difference between image A and infinitely long cylinder is larger than that between image B and infinitely long cylinder. The experiment is cursory in describing trendy of scattering intensity and polarization; on the one hand, the angle increments between apertures for optical fiber are limited in manufacturing process, and the cone angle of receiving plane for every optical fiber is 6^o; on the other hand, unlike the elements of calculation, the integral photometric characteristics are much less dependent on particle shape. The scattering intensity of left array is not the same with that of right array, which demonstrates that the structure of cottons are not mirror symmetrical. The unsymmetrical structure of cotton fiber is farther proofed by obvious difference of polarization, especially p_{22}. Under microscope, the cotton fiber shows intertwisting structure, which may strengthen forward scattering and weaken backward scattering. This might explain the phenomenon that experimental data at scattering angle 30^o are all larger than calculation, but at 120^o,135^o and 150^o reversed.

4. CONCLUSION

An experimental apparatus has been built to measure the images and light scattering characteristics of aerosol particles simultaneously. The core portion of the analyzer is a homocentric hollow black chamber. Images, corresponding scattering intensity and polarization of fiber cottons are received. Wave theory for infinitely long cylinder has been compiled with LabVIEW. By comparison of experimental data and calculation, the affecting factors to results are pointed out ,which provides a good foundation to farther study.

Acknowledgments. The authors are very thankful to the reviewers for valuable comments. This work was supported by National Natural Science Foundation (NSFC) Project. The theoretical calculations in this paper have been kindly assisted by Lei Hao and Yongbang Yao helped with the construction of the apparatus.

REFERENCES

[1] Shao,S.Y., Huang,Y.b.,Yao,Y.b.,Rao, R.Z., "Progress in Shape Measurement Technology of Micro-particles in Atmosphere," Journal of Atmospheric and Environmental optics **3**(1),1-10(2008).

[2] Mishchenko, M.I., Lacis,A.A., "Scattering, absorption, and emission of light by small particles," Cambridge university press,New York, 279-359 (2002).

[3] Edwin,H., Paul,H.K., John,R.G.., "Light scattering from non-spherical airborne particles: experimental and theoretical

comparisons," Appl. Opti. **33**(3), 7180-7186(1994).

[4] Diehl,S.R., Smith,D.T., Sydor,M., "Analysis of suspended solids by single-particle scattering," Appl.Opt, **18**(10),1653-1658 (1979).

[5] Bartholdi,M., Salzman,G.C., Hiebert,R.D., Kerker,M., "Differential light scattering photometer for rapid analysis of single particles in flow," Appl.Opt, **19**(10),1573-1581(1980).

[6] Arjen Van Der Schoot, "Dual-channel particle size and shape analyzer," China Particuology, **2**(1),44-45(2004).

[7] Govoreanu,R., Saveyn,H., Meeren,P.V.D,Vanrolleghem,P.A., "Simultaneous determination of activated sludge floc size distribution by different techniques ,"Water Sci. Technol., **50**(12),39–46(2004).

[8] Shao,S.Y., Yao,Y.b., Rao,R.Z., "New instrument for detecting shape and scattering of micro-particles based on imaging," China Patent, No:200710023960.X.

[9] Paul,K., Edwin,H., Zhenni,W.T., "Neural-network-based spatial light-scattering instrument for hazardous airborne fiber detection," Appl. op*t*, **36**(24),6149-6156(1997).

[10] Liou,K.N.,"Electromagnetic scattering by arbitrarily oriented ice cylinders," Appl. Opti., **11**(3),667-674(1972).

[11] Van de Hulst H.C., "Light scattering by small particles," John Willey & Sons, New York, 297-328(1957).