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Review

Optical particle spectrometry—Problems and prospects

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ABSTRACT

Optical particle counters and spectrometers have found broad use in aerosol and atmospheric research, air pollution studies and industrial particle monitoring. The utilization of the elastic scattering of light results in increasingly portable and cost effective instrumentation due to the ongoing miniaturization of building components such as light sources and detectors. However, the non-monotonic size dependence of scattered light intensity and its variability with the changing refractive index of particles influences the function of most single optical particle counters and spectrometers. This problem is a key issue still driving the development of these instruments, first introduced more than half a century ago. Ongoing progress has resulted in not only smaller but also more sophisticated and precise instruments, but the old weakness still remains—varying response to changes of the index of refraction of particles and non-monotonic response curves. Consequently, alternative approaches exploiting elastic scattering are presented here.

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1. Introduction

Airborne particles vary widely in space and time and thus continuous monitoring of their properties is crucial. Single optical particle spectrometry based on elastic light scattering provides a convenient access to real-time measurement of aerosol particles starting at about 100 nm. However, as a result of the intrinsic nature of elastic light scattering from aerosol particles, the non-monotonic size dependence of the scattered light intensity and its variability with changing refractive

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index of particles influences the function of most single optical particle counters (OPC) and spectrometers. This physical problem is a key issue that has been driving the development of this family of instruments since their inception more than half a century ago. Probably one of the first OPC was described by Gucker in 1947 [1]. He named his device "a photoelectronic counter", which indicates the emphasis on particle counting rather than accurate sizing. This philosophy resulted in the general description of all single particle measuring and counting devices as OPC. Further development gradually provided more accurate particle sizing opportunities, at least with certain approaches, which also resulted in a change in terminology from an optical particle "counter" to an optical particle "spectrometer" (OPS). However, in this contribution we will use the acronym OPC for counters and spectrometers. Continuous development of this technique has resulted in more sophisticated instruments with smaller dimensions; however, they still display the old weakness dictated by the physics—sensitivity to the changes of the refractive index of particles and variability in the response curves vs. particle size.

The popularity of OPCs is without doubt due to their principal simplicity of function and the ability of an in-situ, real-time measurement. However, the erratic ambiguity when it comes to sizing of unknown aerosols is still a crucial issue. The major common disadvantage of OPCs is the possible variability in sizing capacity with respect to changing optical properties of the particles in question, which may yield sizing information substantially different from reality [2–6]. Moreover, erroneous sizing may occur with non-spherical particles [7–10], a situation occurring particularly with atmospheric particles larger than about 1 μm [11].

Spatial distribution of light scattered by individual spherical particles can be directly obtained by means of the Mie theory [12]. A description of scattering by non-spherical particles is now available [13], but not yet utilized for single particle spectrometry. Spatial distribution of light scattered by a spherical particle can be described in terms of the polar scattering in the so-called scattering plane containing the scatterer and the beam of incident illumination, and in terms of the azimuthal scattering around the axis containing the incident beam.

In this contribution different light scattering detection geometries related to conventional OPCs and their performance in terms of particle sizing are presented, followed by a discussion of three innovative optical particle measuring approaches. The first one provides the assessment of particle shape, the second one—assuming spherical particle shape—delivers the particle complex refractive index together with its size, and the third one measures the size-segregated mass concentration.

2. Basic types and characteristics of instruments

OPCs measure light elastically scattered from a single particle illuminated by a well defined light source while it is passing through a sensing volume of the instrument. The scattered light intensity is utilized as a measure of the particle's size. In an ideal instrument a monotonic relationship between the particle size and the scattered light intensity

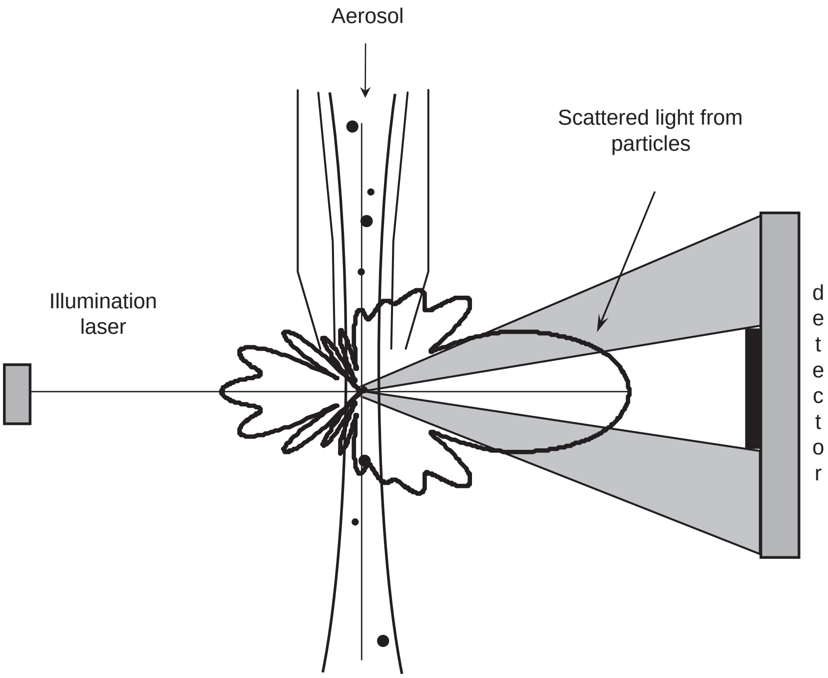

Fig. 1. Schematic diagram of a conventional optical particle spectrometer.