Journal of Aerosol Science 113 (2017) 119–129

Contents lists available at ScienceDirect

Journal of Aerosol Science

journal homepage: www.elsevier.com/locate/jaerosci

A Fast Integrated Mobility Spectrometer for rapid measurement of sub-micrometer aerosol size distribution, Part II: Experimental characterization

Jian Wang[a,*], Michael Pikridas[a,1], Tamara Pinterich[a], Steven R. Spielman[b], Thomas Tsang[c], Andrew McMahon[a], Scott Smith[a]

[a] Environmental and Climate Sciences Department, Brookhaven National Laboratory, Upton, NY 11973, USA
[b] Aerosol Dynamics Inc., Berkeley, CA 94710, USA
[c] Instrumentation Division, Brookhaven National Laboratory, Upton, NY 11973, USA

ARTICLE INFO

Keywords:
Fast Integrated Mobility Spectrometer
Aerosol size distribution
High time resolution
Electrical mobility
Transfer function
Mobility resolution

ABSTRACT

A Fast Integrated Mobility Spectrometer (FIMS) with a wide dynamic size range has been developed for rapid aerosol size distribution measurements. The design and model evaluation of the FIMS are presented in the preceding paper (Paper I, Wang et al., 2017), and this paper focuses on the experimental characterization of the FIMS. Monodisperse aerosol with diameter ranging from 8 to 600 nm was generated using a Differential Mobility Analyzer (DMA), and was measured by the FIMS in parallel with a Condensation Particle Counter (CPC). The mean particle diameter measured by the FIMS is in good agreement with the DMA centroid diameter. Comparison of the particle concentrations measured by the FIMS and CPC indicates the FIMS detection efficiency is essentially 100% for particles with diameters of 8 nm or larger. For particles smaller than 20 nm or larger than 200 nm, FIMS transfer function and mobility resolution can be well represented by the calculated ones based on simulated particle trajectories in the FIMS. For particles between 20 and 200 nm, the FIMS transfer function is boarder than the calculated, likely due to non-ideality of the electric field, including edge effects near the end of the electrode, which are not represented by the 2-D electric field used to simulate particle trajectories.

1. Introduction

A Fast Integrated Mobility Spectrometer (FIMS) with a particle diameter range of 8–600 nm has been developed for rapid measurement of aerosol size distribution. The design and model evaluation of the FIMS are presented in the preceding paper (Paper I). By employing a spatially varying electric field (Wang, 2009), the FIMS provides a significant improvement in dynamic size range compared to the previous version (Kulkarni & Wang, 2006a, 2006b; Olfert & Wang, 2009; Olfert, Kulkarni, & Wang, 2008). Inside the separator of the new FIMS, charged particles are first separated by the spatially varying electric field into different flow streamlines based on their electrical mobility. The electric field creates regions with drastically different field strengths, such that particles of a wide size range can be simultaneously classified and subsequently measured. After grown into super-micrometer droplets in a condenser, the spatially separated droplets are imaged by a high speed CCD camera. The images provide mobility-dependent particle positions and counts, which are used to derive particle electrical mobility and concentration. As particles of a wide size range are

---

[*] Corresponding author.
E-mail address: jian@bnl.gov (J. Wang).
[1] Current address: The Cyprus Institute, Environment Energy and Water Research Center, Nicosia, Cyprus.

http://dx.doi.org/10.1016/j.jaerosci.2017.05.001
Received 22 December 2016; Accepted 3 May 2017

Table 1
The type of DMA, its corresponding flow rates, and rate of extra flow (Q_{extra}) used during experiments for each of classified particle diameters. The DMA flow rates include those of aerosol (Q_a), sheath (Q_{sh}), excess (Q_{ex}), and monodispersed (Q_m) flows.

D_p (nm)	DMA type	Q_a (L min^{-1})	Q_{sh} (L min^{-1})	Q_{ex} (L min^{-1})	Q_m (L min^{-1})	Q_{extra} (L min^{-1})
8	Nano DMA	1.12	11.3	11.3	1.12	0.56
9	Nano DMA	1.12	11.3	11.3	1.12	0.56
10	Nano DMA	1.12	11.3	11.3	1.12	0.56
12	Nano DMA	1.12	11.3	11.3	1.12	0.56
15	Nano DMA	1.12	11.3	11.3	1.12	0.56
20	Nano DMA	1.12	11.3	11.3	1.12	0.56
40	Nano DMA	1.12	11.3	11.3	1.12	0.56
60	Nano DMA	1.12	11.3	11.3	1.12	0.56
80	DMA	1.12	11.3	11.3	1.12	0.56
100	DMA	1.12	11.3	11.3	1.12	0.56
150	DMA	1.12	11.3	11.3	1.12	0.56
200	DMA	0.56	5.67	5.67	0.56	N/A
300	DMA	0.56	5.67	5.67	0.56	N/A
400	DMA	0.56	5.67	5.67	0.56	N/A
450	DMA	0.56	5.67	5.67	0.56	N/A
500	DMA	0.26	2.77	2.77	0.26	N/A
600	DMA	0.26	2.77	2.77	0.26	N/A

detected simultaneously, the FIMS provides significant increases in both measurement speed and counting statistics compared to traditional scanning mobility techniques (e.g., Scanning Mobility Particle Sizer, Wang & Flagan, 1990). This paper describes the design and performance characterization of this new FIMS with an improved dynamic size range.

The characterization of the new FIMS followed the same approach used to evaluate the performance of the previous version (Kulkarni & Wang, 2006b), and is briefly reviewed below. Cylindrical DMAs (Model 3081 and 3085, TSI Inc.) were used to generate monodisperse calibration aerosols, which were then measured by the FIMS in parallel with a condensation particle counter (CPC). The diameter of the monodisperse aerosol measured by the FIMS is compared to the DMA centroid diameter to characterize the FIMS sizing accuracy, and the FIMS detection efficiency is derived from the concentrations measured by the FIMS and the CPC as a function of particle diameter. The FIMS transfer function and mobility resolutions are studied by examining the responses of the FIMS to the monodisperse aerosols classified by the DMA. The FIMS responses to DMA classified particles are calculated using the FIMS transfer function simulated in Paper I, and are compared with the measurements. The reasons for the discrepancies between the measured and calculated FIMS responses, and the implications on the FIMS mobility resolutions are examined and discussed.

2. Instrument design and experimental setup

2.1. Instrument design

The design of the FIMS with improved dynamic size range closely resembles that of the original FIMS employing a uniform electric field (Kulkarni & Wang, 2006a). The key differences include the electrode inside the separator and the minor modifications of the physical dimensions as described in Paper I (Wang et al., 2017). The physical dimensions and operation conditions are present in Table 1 of Paper I. A schematic of the FIMS is shown in Fig. 1. The FIMS has three major sections - (i) separator, (ii) condenser, and (iii) detector, which are arranged sequentially to form a rectangular channel with a clear cross-sectional area of 1.12 × 12.7 cm. At the exit of the condenser, grown particles are illuminated by a sheet of laser light and imaged by a CCD camera. The counts and positions of particles within an area of 0.672 × 7.0 cm (i.e., $0.224\ \mathrm{cm} \le x \le 0.896\ \mathrm{cm}$, $-3.5\ \mathrm{cm} \le y \le 3.5\ \mathrm{cm}$, as described in Paper I) in the center of the cross section are retrieved from the recorded images, and are used to derive particle sizes and concentrations. As in Paper I, the coordinate system depicted in Fig. 1 of J. Wang (2009) is used here to describe particle and grown droplet positions.

The sheath flow and the vast majority of the exhaust flow of the FIMS are operated in a closed recirculation loop. The sheath flow is supplied by a blower controlled by a PID module at the desired flow rate (Q_{sh}) of 13 L min^{-1}, which is monitored by a flowmeter (Alicat Scientific Inc.). The aerosol flow rate (Q_a) of the FIMS is monitored by measuring the pressure drop across a laminar flow element, located just upstream of the aerosol inlet. Additional exhaust flow is controlled by a vacuum pump along with a proportional solenoid valve to maintain the desired aerosol flow of 0.26 L min^{-1}. Prior to entering the FIMS, the particle-free sheath flow is saturated with heptanol vapor in a reservoir. The walls of the condenser are cooled to 20 °C below the temperature of reservoir using thermoelectric coolers controlled by a PID module, and the condenser temperature is monitored using thermistors mounted on the outer walls of the condenser. For the experiments reported here the temperatures of the reservoir and condenser were 23 and 3 °C, respectively. The images recorded by the CCD camera are 8-bit grayscale. For derivation of particle positions, each image is first converted to a binary image by applying an intensity threshold that clearly differentiates the particle images from the background. The center of the converted particle binary image is then computed and taken as the particle position in the cross section (i.e., *x*-*y* plane).