Miniaturized, Lightweight, Cost-effective and Fast Response Particle Sizer

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Introduction

The most efficient tool for determining the size of aerosol particles in the sub-micrometer and nanometer range is the Differential Mobility Analyzer (DMA). The popular DMA design employs two coaxial cylindrical electrodes between which a potential difference is applied, forcing incoming charged polydisperse particles to migrate from one electrode to another. Only particles having an electrical mobility within a narrow range pass through the classifier (Knutson and Whitby, 1975). One of the limitations of the classical DMAs is the significant amount of time (in the order of a minute) to scan over the entire particle size range and obtain the size distribution of the sampled aerosol. Different studies have focused on reducing the scanning time of DMAs using different approaches (e.g., Chen et al., 2007; Stolzenburg et al., 2017; Lee et al., 2020). In addition, efforts have been made to reduce the weight and the cost of DMAs (Barmpounis et al. in 2016). This study describes the manufacturing of a DMA with good performance, suitable for airborne measurements using unmanned aerial vehicles (UAVs) or other moving platforms.

The aim of this project is to design and manufacture a lightweight, cost-efficient and fast response instruments, for measuring aerosol size distributions on fast moving platforms such as cars or airplanes, or of rapidly changing aerosol (in terms of particle size and/or concentration) that occur for example during new particle formation events. We have built and characterized two 3D-printed-DMA with the same characteristic dimensions (i.e., diameters of the inner and outer electrodes, and distances of the outlets from the inlet), and their performance has been compared to the theoretical model of Giamarelou et al. (2012). The first one is collecting the particles at the inner electrode (referred to as the Concentric-3MO-DMA; C-3MO-DMA), and the second at the outer electrode (referred to as the Reverse-3MO-DMA; R-3MO-DMA).

Experimental setup and calculation methods

Most of the parts of the two DMAs were 3D printed (see Figure 1) and their surfaces were coated with a conductive finish. Two types of 3D-printing methods were used to make the parts of the two DMAs: ABS filaments coated with electro-less metal plating for the C-3MO-DMA, Resin coated with a graphite layer for the R-3MO-DMA. The inner electrode of both 3MO-DMAs is made out of aluminum (see Figure1a).

The performance of the two systems was tested in a tandem DMA setup (see Figure 2). Polydisperse particles of ammonium sulfate (AS) were produced by atomization of 0.1 w/v AS solution. The particles were dried by a silica gel diffusion drier and neutralized subsequently by passing them through a X-Ray-source. A DMA (TSI Model 3081) classified nearly monodisperse particles of different sizes. An Electrometer (TSI 3068A) was used as a reference instrument downstream the first DMA and three Condensation Particle Counters, (TSI 3022A; TSI 3022 and an ultrafine TSI 3025A), were placed after the C-3MO-DMA or R-3MO-DMA. The DMA was operated at sheath flow rates of 6, 9 and 12 lpm. The aerosol flow was determined by the CPC flow rates and thus was kept constant at 0.9 lpm at the inlet of the test DMA, and at 0.3 lpm at each individual outlet (outlet 1, outlet 2, and outlet 3).

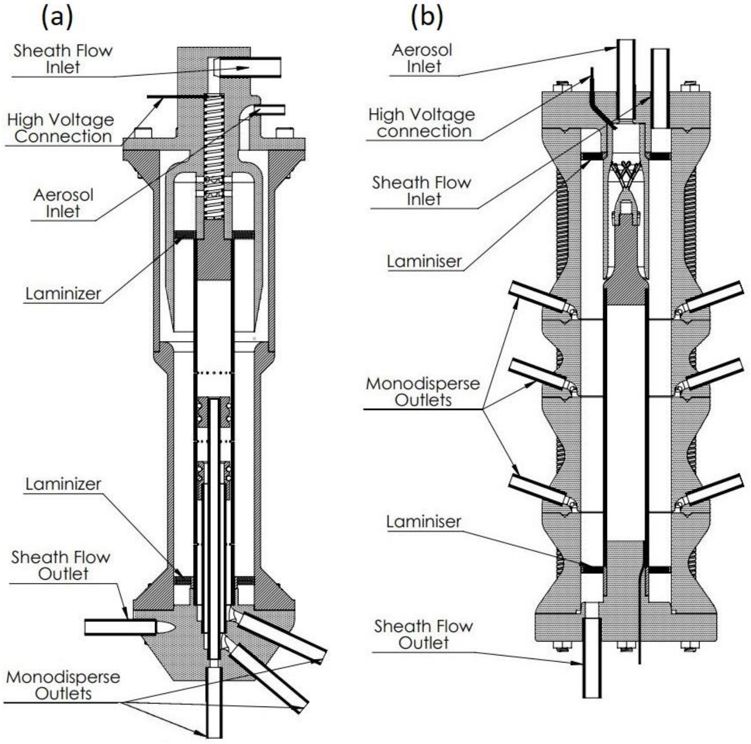

Figure 1. Layout of (a) Concentric-3MO-DMA, and (b) Reverse-3MO-DMA.

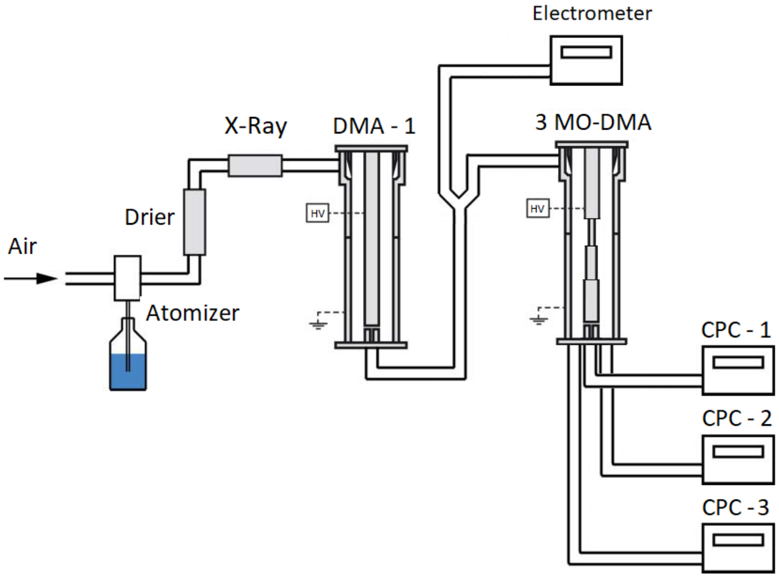

Figure 2. Schematic diagram of the experimental setup.

Results and Discussion

The measured GMD has been determined by fitting a log-normal function to the data. A good agreement has been found between the theoretical and the measured GMD within 5% accuracy for each outlet and all the operation conditions as shown in Figure 3 and 4.

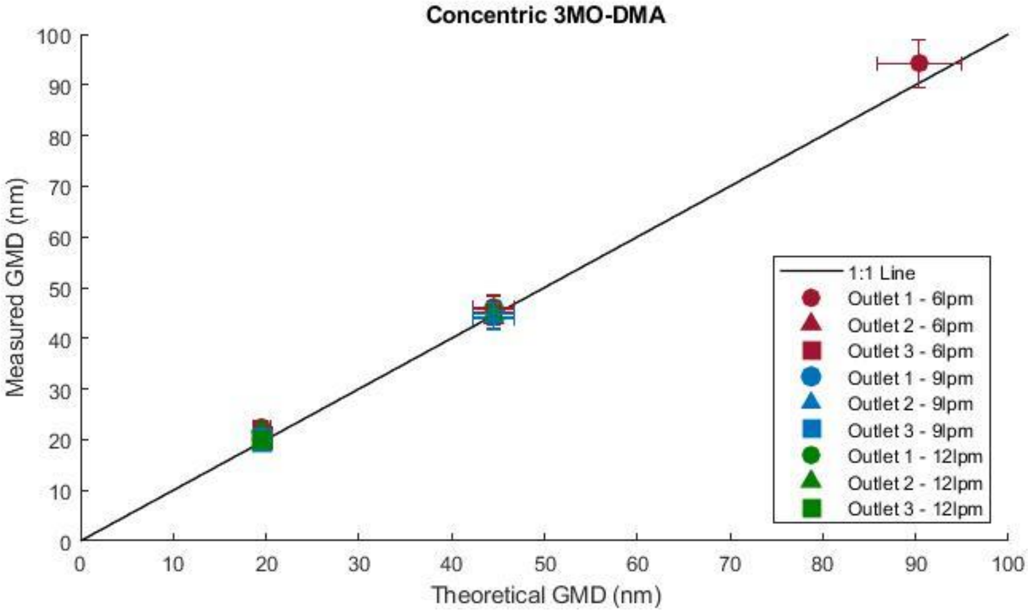

Figure 3 Measured vs. theoretically predicted geometrical mean diameters (GMD) of particles classified through each outlet of the Concentric 3MO-DMA, when operated with sheath to aerosol flow ratios of 6/0.9 lpm, 9/0.9 lpm and 12/0.9 lpm.

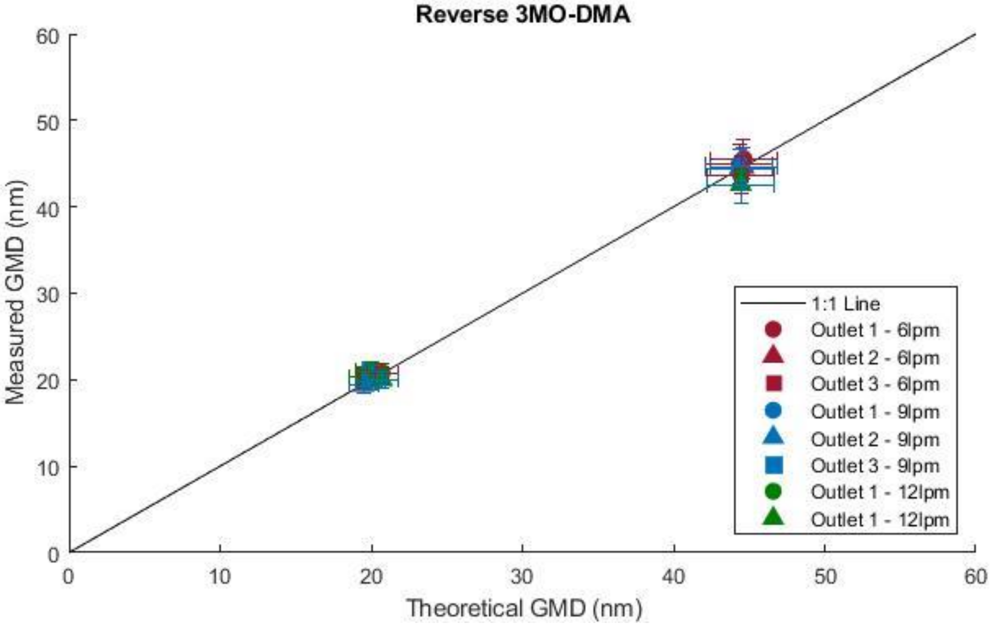

Figure 4 Measured vs. theoretically predicted geometrical mean diameters (GMD) of particles classified through each outlet of the Reverse 3MO-DMA, when operated with sheath to aerosol flow ratios of 6/0.9 lpm, 9/0.9 lpm and 12/0.9 lpm

Figures 5 and 6 show the experimental results of the tandem measurement, for both DMA types. The x-axis corresponds to the particle diameter and the y-axis is ratio of the downstream to the upstream concentration (N_2/N_1), measured by the CPC (separate value for each outlet) and by the electrometer, respectively.

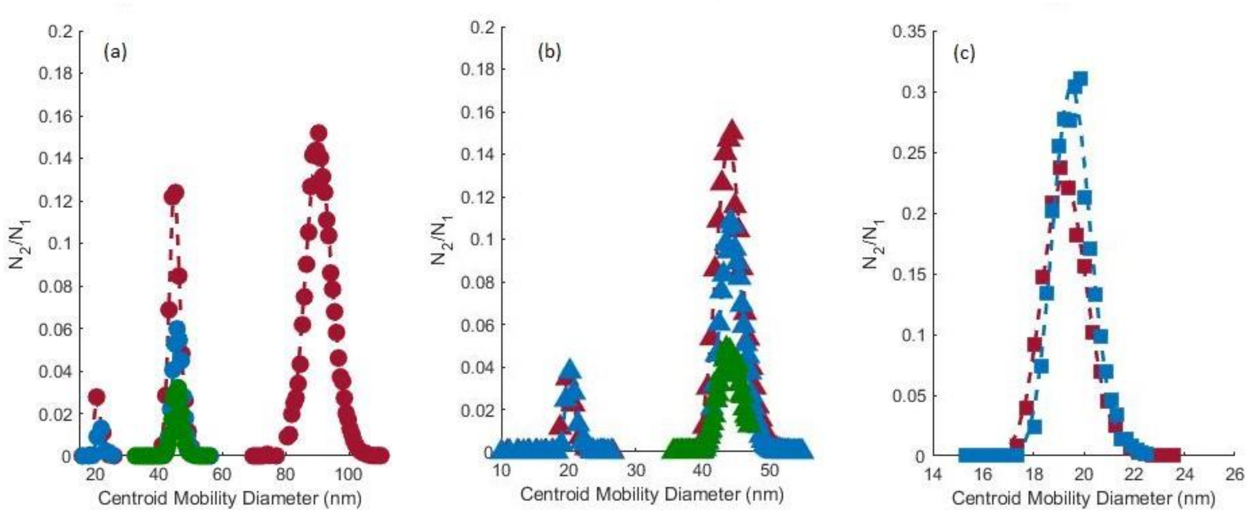

Figure 5. Measured transmission and fitted lognormal distribution, showing the response of the Concentric 3MO-DMA operated with sheath to aerosol ratios of 6 lpm/0.9 lpm (red symbols), 9

lpm/0.9 lpm (blue symbols) and 12 lpm/0.9 lpm (green symbols) for the 1st outlet, circles (a), 2nd outlet, triangles (b), 3rd outlet, squares (c).

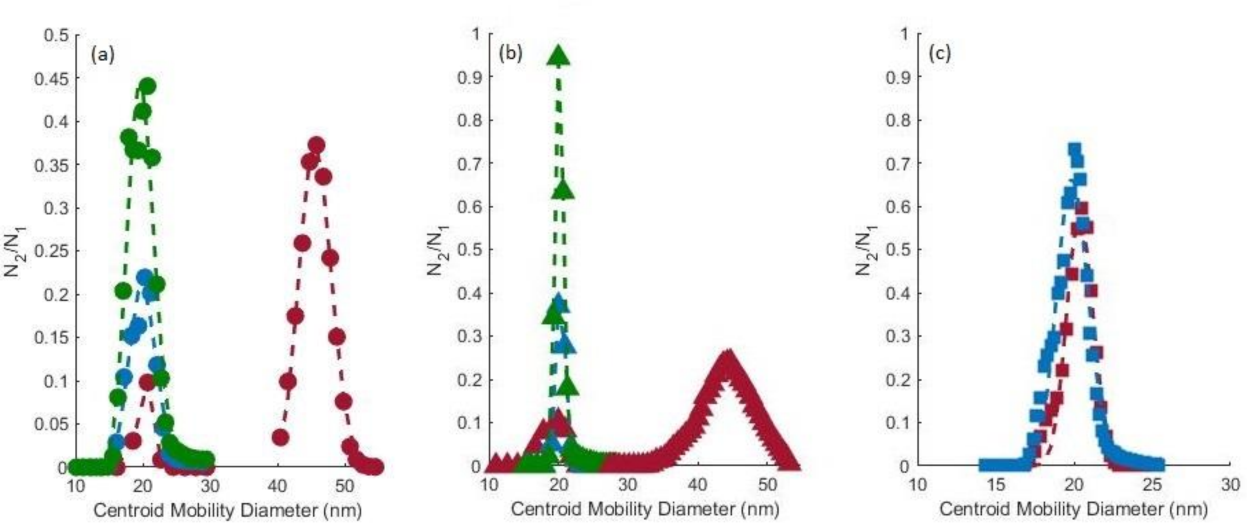

Figure 6 Measured transmission and fitted lognormal distribution, response of the Reverse 3MO-DMA coupled with 3 CPCs, when operated with sheath to aerosol ratios of 6 lpm/0.9 lpm (red symbols), 9 lpm/0.9 lpm (blue symbols) and 12 lpm/0.9 lpm (green symbols) for the 1st outlet, circles (a), 2nd outlet, triangles (b), 3rd outlet, squares (c).

Conclusions

Our results show that both DMA designs have the capability to simultaneously separate three discrete monodisperse sizes from a polydisperse aerosol. The sizing capability can be predicted accurately by the existing theory of Giamarelou et al., 2012. A good agreement has been found between the obtained measurements and the theory.

The transmission of both designs Fig. 5 and 6 increases with increasing particle size. This trend is in agreement with the theory. Broadening of the transmission curves can be explained by possible flow turbulences in the classification zone and construction imperfections, such as variability of the coating thickness and misalignments of the inner electrode. This problem can be avoided by operation at lower sheath flow rates.

Acknowledgements

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