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Influence of sheath air humidity on measurement of particle size distribution by scanning mobility particle sizer

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ABSTRACT

Size distribution is a critical parameter that determines the dynamics, transport and deposition of aerosol particles in a given system. Scanning Mobility Particle Sizer (SMPS), based on the principle of particle mobility classification in an electric field is one of the commonly used instruments for measurement of size distribution. To maintain laminarity of aerosol particles, a sheath air flow is generally provided annular to the sampled aerosol particle flow. Available literature suggests drying of the sheath air to avoid effect on charge neutralisation of the sampled particles and to safeguard the central high voltage electrode. However, there are certain ambiguities associated with the use of dried sheath air for SMPS measurements. This study investigates the effect of sheath air drying on particle size distribution measurements. It focuses on experiments performed with substrates of differing hydrophilic properties (e.g., NaCl, $NaNO_3$ and nichrome) at different relative humidity (RH) levels. Results indicated a prominent effect of sheath air drying dependent on RH and material properties. For NaCl aerosol particles, a much lowered (by a factor of 2) mean size was observed at higher RH level with SMPS using a sheath air drier. The results indicate that the effect of sheath air drying on SMPS measurements should be clearly included in algorithms and protocols when interpreting the measurements.

1. Introduction

Electrical mobility techniques for size distribution measurement of aerosol particles have evolved over the last few decades since they were first employed in 1923 (Rohmann, 1923; Hewitt, 1957; Wang and Flagan, 1990). Other extensions of this technique have been developed, such as Tandem Differential Mobility Analyser (TDMA) to determine particle diameter changes (Liu et al., 1978), Hygroscopic TDMA (HTDMA) to measure hygroscopic properties of aerosol particles (Rader and McMurry, 1986) and Volatilisation Humidification–TDMA (VHTDMA) to distinguish between different constituents in mixed particles based on volatility and hygroscopicity (Johnson, Ristovski, & Morawska, 2004).

The most widely used system for measurement of size distribution of sub-micrometer particles is the Scanning Mobility Particle Sizer (SMPS), based on the principle of balancing mobility of a charged particle in an electric field. SMPS is essentially a two component system comprising of i) Differential Mobility Analyser (DMA)for classifying the particles according to their size and ii) Condensation Particle Counter (CPC) for measuring the number concentration. There are two flows moving inside the DMA, the aerosol particle stream and the particle-free sheath air. Sheath air flow provides laminarity for flow of aerosol particles.

Wiedensohler et al. (2012) recommended use of diffusion dryer at the sample inlet and sheath air dryer with heat exchanger to limit the fluctuations of RH inside the DMA and to avoid effect on bipolar charge equilibrium. A study by Joshi et al. (2012) showed

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that the introduction of dryer in the sheath air path resulted in significant shift towards lower sizes. The effect of such shifting was utilized by Shamjad et al. (2012) for study of absorption enhancement due to atmospheric black carbon using a twin SMPS set up with diffusion dryer at the inlet of one SMPS. Birmili et al. (2009) have measured dried and humidified particle number size distribution in Finnish boreal forest using conditioned sheath air and calculated hygroscopic particle growth factor. Similarly, other researchers like Hämeri et al. (2000), Swietlicki et al. (2008), Zhou, Swietlicki, Hansson, and Artaxo (2002), Stanier, Khlystov, and Pandis (2004), Tröstl et al. (2015) and Liu, Hu, Zhang, Yu, and Wang (2016) have used dryer or humidifier in the sheath air path depending on the experimental requirements. Effect of humidity in sheath air path in case of HTDMA has been discussed by Duplissy et al. (2009). However, no recommendation of sheath air drying has been given in ISO 15900 which deals with standardization of protocols for use of differential electrical mobility analysers for measurement of particle size and number concentrations.

For a most ideal measurement, the RH of both the sheath air flow and the aerosol particle flow should be the same. Since there is no physical barrier between the two flows, hygroscopic particles will take water from the humid sheath air or vice-versa. The subsequent growth of particles will depend on the chemical composition and on the initial diameter of the particles as well as on RH of the ambient air (KÖhler, 1936). The objective of this work is to assess the effect of sheath air dryer in the measurement of size distribution of particles with varying hygroscopicities. Twin SMPS set-up was employed for this study with one SMPS having its sheath air path modified by insertion of a dryer. The experiments were performed in controlled chamber conditions at three different RH levels using hydrophobic (nichrome) and hydrophilic (Sodium Chloride: NaCl, Sodium Nitrate: $NaNO_3$) aerosol particles. The size distributions measured by both SMPSs have been analysed to interpret the role of sheath air drying on such measurements.

2. Experimental methodology

Experiments were carried out in a 40 L volume perspex chamber, equipped with sampling ports and a fan for homogenization of the aerosol particle concentration. Aerosol particles of three different materials viz., NaCl, $NaNO_3$ and nichrome, having hygroscopicity in decreasing order, were studied. Both NaCl (1%) and $NaNO_3$ (1%) were generated by compressed air nebulization technique using the laboratory-made nebulizer operated at a flow rate of 10 L min^{-1}. While NaCl particles start growing only after reaching the Deliquescence Relative Humidity(DRH), i.e., the RH at which particles undergo solid to liquid phase transition; $NaNO_3$ exhibits a continuous growth with increasing RH (Hu et al., 2010; Lee et al., 2011). Nichrome aerosol particles were generated by electrical wire heating technique using a hot wire generator, which generates aerosol particles in the nanoparticle regime (geometric mean ≈ 15 nm) with geometric standard deviation of ≈1.4 (Khan et al., 2014). Hygroscopic growth is size dependent and condensational effects are limited for nano-size ranges (Biskos, Russell, Buseck, & Martin, 2006). While the nebulizer used in this work generated particle size distribution with geometric mean between 100 and 150 nm, geometric mean diameter of HWG particles was considerably lesser (< 20 nm). Hence nichrome particles were allowed to grow to targeted size range (100–150 nm) before exposing them to humidity. Humidity has effect on neutralization (Ball, Cameron, Colman, & Roberts, 1991) and counting efficiency of CPC (Gasparini et al., 2006) in SMPS measurement, but to limit this effect is beyond the scope of this paper.

The generated aerosol particles were fed to the experimental chamber through one of the ports after passing through a Nafion dryer as shown in Fig. 1. The Nafion dryer was provided with steady dehumidified air flow rate of 3 L min^{-1} using silica granules. Two SMPSs (S1 and S2), connected in parallel to a single sampling port of the chamber using a T-joint arrangement, were used for size distribution measurements. S2 was modified using sheath air dryer, to obtain dry particle size distribution while S1 was used without any modification. Size ranges of S2 (GRIMM Vienna L-DMA + 5416 CPC) and S1 (GRIMM L-DMA + 5403 CPC) were 10.25 nm to 1093.95 nm and 9.06 nm to 882.20 nm, respectively. Length of the tubing was kept same for both the SMPS so that particle losses due to pipe depositions would be identical. Both the instruments were operated at a sample flow rate of 0.3 L min^{-1} and sheath air flow rate of 3 L min^{-1}. Size calibration of these instruments was performed using nebulized Poly Styrene Latex particles, beforehand. Inter-instrumental difference with respect to measurement of diameter was also found to be nominal.

For each type of aerosol particles, 3 sets of experiments were carried out at 3 different RH levels viz., 15%, 40% and 90% (unless stated otherwise). For $NaNO_3$, additional 3 sets were conducted at 60% RH. Dry/wet air circulation with feedback loop was used for attaining and maintaining the desired RH levels. Temperature for whole range of experiments was also recorded and mostly found to be maintained at ~ 25 °C. Accurate calculation of size distribution from raw data is possible through incorporation of multiple charge correction (He and Dhaniyala, 2013). Data from both the SMPSs were extracted using instrument's software and thereafter, analyzed to see the effect of humidity and sheath air dryer on the particle size distributions. This software includes inversion algorithm

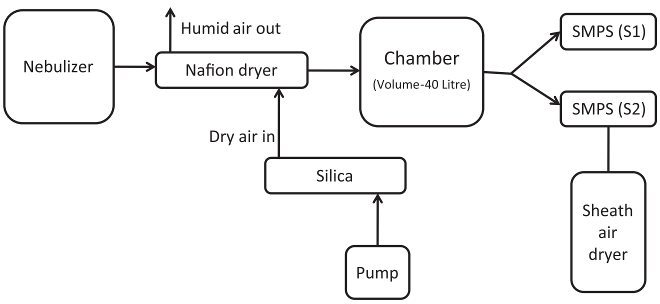

Fig. 1. Schematic of experimental setup.