Journal of Aerosol Science 91 (2016) 15–21

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

Technical note

# A method to limit uncertainties in aerosol properties determined from comparative measurements

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ARTICLE INFO

*Article history:*
Received 21 July 2015
Received in revised form
18 September 2015
Accepted 21 September 2015
Available online 30 September 2015

*Keywords:*
Aerosol nanoparticles
Aerosol measurement methodology
Penetration
Wire screen

ABSTRACT

Certain types of aerosol measurements require an experimental set up including two or more routes through which the particles are made to flow alternatively. Indeed, this appears to be critical to limit uncertainties in aerosol properties determined from comparative measurements. Typical examples are the comparison of the performance of different instruments and the measurement of particle filtration efficiency. Except for the presence of the test units (e.g. the instruments or devices to be compared) it is commonly accepted that the two routes must be identical: they should contain the same type and number of tubes, valves, junctions, bends, connectors, etc. For nanometer-sized particles undergoing substantial diffusion losses, the lack of perfect symmetry between the two routes induces discrepancies in measurements performed in both lines. This article provides a general methodology to avoid or reduce the errors arising from these possible asymmetries. The method consists in making two measurements, one with the given setup, the other with an alternative set up in which the test units have been exchanged. The correct result (e.g. filtration efficiency) is the geometric mean of the results obtained with the two alternative setups. The proposed methodology may seem tedious and time consuming, but doing so, the experimental measurement is not affected neither by possible errors due to a test aerosol changing with time nor by the possible asymmetry of the line accessories (valves, T's, connections, etc.).

## 1. Introduction

In aerosol experimental works there are many instances in which it is necessary to make the particles flow alternatively through two different routes. Examples are the determination of filtration efficiency from comparison between the particle concentrations measured at the end of two alternative identical chambers, one empty ("dummy") and the other ("test chamber") containing the filtering medium (Heim, Mullins, Wild, Meyer & Kasper, 2005; Alonso, Alguacil, Santos, Jidenko & Borra, 2007); the measurement of particle charging probability using two identical chambers, one with a radioactive source (test chamber), the other empty (dummy) (Reischl, Mäkelä, Karch & Necid, 1996; Alonso, Kousaka, Nomura, Hashimoto & Hashimoto, 1997); the determination of the counting efficiency of condensation particle counters by comparison with an aerosol electrometer (Hakala, Manninen, Petäjä & Sipilä, 2013; Baltzer, Onel, Weiss & Seipenbusch, 2014); the measurement of particle size growth by condensation (Kousaka, Endo, Alonso, Ichitsubo & Fukui, 1995); the comparison of the performance of different instruments (Wiedensohler et al., 1997; Keller, Tritscher & Burtscher, 2013); etc.

http://dx.doi.org/10.1016/j.jaerosci.2015.09.005
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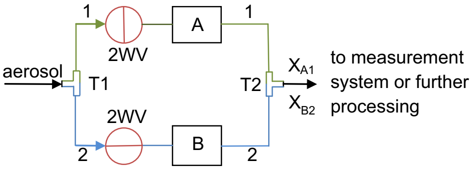

**Fig. 1.** Typical experimental set up with two alternative routes 1 and 2. (2WV=two-way valve; T1, T2=T-shaped junctions.).

The two alternative routes should be equal to each other, except for the presence of the test chamber in one route and the dummy chamber in the other, that is, all the connecting tubes, joints, T-junctions, valves, etc., should be identical for both routes. This is especially important in the case of nanometer-sized particles because of their high loss rates by diffusion to the walls, but this also applies to larger diameters for which particle loss by impaction is the relevant mechanism. The presence of any asymmetry between the alternative routes may lead to differential particle losses and, hence, to measurement errors. It is thus advisable to check always the symmetry of the routes, i.e. to examine whether the valves, T's, etc., yield the same particle losses in both routes.

This article provides a general methodology to avoid or reduce the errors arising from these possible asymmetries. It will be shown that, even when asymmetries are deliberately introduced in the system, the method yields correct results. The general methodology will be described first, and subsequently applied to the measurement of aerosol nanoparticle penetration through wire screens.

## 2. General methodology

Figure 1 shows the basic experimental set up with two alternative routes 1 and 2, each one containing a two-way valve. Of course, the valves must be operated so that at any given time the aerosol flows through only one of them. Besides the two valves there are two T-shaped junctions and the two units (test and dummy) denoted as A and B in the drawing. Regardless of the chosen route, the aerosol flows into a measuring instrument common to both routes, or perhaps may undergo further processing before final measurement.

A route must be understood as the specific combination of tubes, junctions, bends, etc., connecting T1 with the device A or B, plus the remaining piping used to connect the outlet of A or B with T2. Actually, the arms of the T-junctions must also be considered as part of their respective routes. The routes 1 and 2 should be identical to each other, i.e. equal length and diameter of the tubes, same number and type of connectors, same number and curvature of bends, and so on. In general, one may expect, however, slight differences between the two routes. These asymmetries are probably more important for small nanoparticles because of their higher diffusion loss rate. To prevent measurement errors arising from these asymmetries, the following methodology is proposed.

Let $X$ be the aerosol property to be measured. $X$ can be particle number concentration, or number of charges per particle, or particle diameter, depending on the specific experimentation being considered. In Fig. 1, $X_{A1}$ denotes the value of the property for the aerosol coming from device A through route 1 and, likewise, $X_{B2}$ is the value of the property measured for the aerosol flowing through device B along route 2.

Once the values $X_{A1}$ and $X_{B2}$ have been obtained, the method consists in exchanging the devices A and B, so that A is now placed within route 2 and B within route 1, keeping unchanged the rest of the setup. Measurements done with this new configuration yield a new pair of values, $X_{A2}$ and $X_{B1}$. Because of the possible differences between routes 1 and 2, the ratios $X_{A1}/X_{B2}$ and $X_{A2}/X_{B1}$ will usually differ from each other.

The sought ratio $X_A/X_B$ will in general be an unknown function of particle size $d_p$, particle charge $q$, aerosol flow rate $Q$, system geometry $G$, etc., so that we can write

$$\frac{X_A}{X_B}=f\left(d_p, q, Q, G, \ldots\right), \tag{1}$$

where $f$ is the unknown function. From the first series of measurements using the setup shown in Fig. 1, the value

$$f_1 \equiv \frac{X_{A1}}{X_{B2}} \tag{2}$$

is obtained. Likewise, from measurements done after exchanging the devices A and B, one obtains the value

$$f_2 \equiv \frac{X_{A2}}{X_{B1}} \tag{3}$$

(The subscript of $f$ refers to the route where the device A is placed.) Note that, although the function $f$ is not known, we do know the two values $f_1$ and $f_2$, because these are the results of experimental measurements.

The actual $X_A/X_B$ ratio should clearly be equal to

$$\frac{X_A}{X_B}=\frac{X_{A1}}{X_{B1}}=\frac{X_{A2}}{X_{B2}}, \tag{4}$$