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Field comparison of instruments for exposure assessment of airborne ultrafine particles and particulate matter

Andrea Spinazzè [a,*], Giacomo Fanti [a], Francesca Borghi [a], Luca Del Buono [a], Davide Campagnolo [b], Sabrina Rovelli [a], Andrea Cattaneo [a], Domenico M. Cavallo [a]

[a] *Dipartimento di Scienza e Alta Tecnologia, Università degli Studi dell'Insubria, Via Valleggio 11, 22100 Como (CO), Italy*
[b] *Dipartimento di Scienze Biomediche e Cliniche, Ospedale L. Sacco, Università degli Studi di Milano, Via G.B. Grassi 74, 20157 Milano, Italy*

HIGHLIGHTS

- The performances of different devices for measurement of UFP and PM were compared.
- The results were analyzed using linear regression analysis and absolute deviations.
- The overestimation error increased with increasing PM and UFP concentrations.
- The studied direct-reading methods can be generally classified as comparable.
- The absolute error is correlated with relative humidity in filter-based techniques.

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ABSTRACT

The objective of this study was to compare the use of co-located real-time devices and gravimetric samplers to measure ultrafine particles (UFP) and size-fractionated PM mass concentrations. The results contribute to evaluating the comparability of different monitoring instruments for size-fractionated PM concentrations. Paired light scattering devices and gravimetric samplers were used to measure the PM_1, $PM_{2.5}$, $PM_{4/5}$, PM_{10} and TSP mass concentrations during 8-h monitoring sessions in an urban background site (Como, Italy) in winter. A total of 16 sampling sessions were performed: measurements were analyzed using linear regression analysis. Absolute deviations between techniques were calculated and discussed. The UFP concentrations measured using a condensation particle counter were clearly over-estimated compared with the reference instrument (portable diffusion charger), with an absolute deviation that appeared to increase with the UFP concentration. The comparison of different light-scattering devices (photometers - 'PHOTs') indicated an over-estimation of two of the tested instruments (PHOT-2 and PHOT-3) with respect to the one used as the reference (PHOT-1) regarding the measurement of the size-fractioned PM, with the only exception being $PM_{4/5}$. Further, the comparison of different light-scattering devices with filter-based samplers indicated that direct-reading devices tend to over-estimate (PHOT-2, PHOT-3) or under-estimate (PHOT-1) the PM concentrations from gravimetric analysis. The comparison of different filter-based samplers showed that the observed over-estimation error increased with increasing PM concentration levels; however, the good level of agreement between the investigated methods allowed them to be classified as comparable, although they cannot be characterized as having reciprocal predictability. Ambient relative humidity was correlated with the absolute error resulting from the comparison of direct-reading vs. filter-based techniques, as well as among different filter-based samplers for the same PM fraction.

1. Introduction

Particulate Matter (PM) is considered to be one of the main air pollutants (World Health Organization, 2005, 2006). Epidemiological and toxicological studies show that a number of negative effects on human health are possibly related to PM exposure (Brook

Abbreviations: CPC, Condensation Particle Counter; DSC, Diffusion Size Classifier; PHOT, Photometer; PCIS, Personal Cascade Impactor Sampler; PM, Particulate Matter; UFP, Ultrafine Particles.

* Corresponding author.
E-mail address: andrea.spinazze@uninsubria.it (A. Spinazzè).

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et al., 2010). The health effects strongly depend on different factors of PM, such as the chemical composition (Eiguren-Fernandez et al., 2010; Janssen et al., 2011), assumption rate (Manigrasso et al., 2013) and size (ICRP, 1994). Recently, scientific attention has moved toward ultrafine particles ('UFP': particles < 100 nm) because these particles can easily enter the human respiratory system and deposit in the deepest areas of the lungs, carrying toxic compounds. A number of recent studies have related particle effects on health to the number of particles (Peters et al., 1997; Franck et al., 2011a,b; Oberdorster et al., 1994; Oberdorster, 2000) and surface area concentrations (Donaldson et al., 1996; Brown et al., 2001; Hamoir et al., 2003; Tran et al., 2000; Oberdorster, 2000; Nel et al., 2006; Waters et al., 2009; Cauda et al., 2012). Concern about health risks related to PM and UFP exposure in urban populations is growing rapidly (Samoli et al., 2013; Stafoggia et al., 2013; WHO, 2013; Hänninen et al., 2014). Further, concern about the inadequacy of current air quality monitoring approaches is also growing, due to limitations in the consolidated measurement approaches. The existing measurement networks exhibit poor spatial and temporal resolutions and are often inadequate for characterizing the exposure of a population, identifying pollution hotspots and providing real-time information suitable for modeling and prediction purposes (Carminati et al., 2015; Kumar et al., 2015). Traditional stationary sampling device are usually expensive and complex to use, but currently, this paradigm is changing. The introduction and development of portable sensors for the measurement of concentrations airborne pollutants have provided data with high temporal resolution characterized by a real time response (Snyder et al., 2013). In this regard, the quality of future exposure assessment studies depends strongly on the improvement of routine applications of direct-reading, portable monitors and sensors for PM and UFP measurements, in terms of their compactness, portability, reliability, accuracy, and costs (Carminati et al., 2015). Portable devices are usually characterized by a worse metrological performance than the commonly used standard techniques in aerosol research in terms of their accuracy, minimum detectable particle diameter and maximum measurable concentrations (Buonanno et al., 2011). For this reason, previous studies have intensively tested newly developed portable direct-reading devices; however, most of them have tested the instruments under laboratory conditions, testing the instruments with purposely generated aerosol (Asbach et al., 2012; Fierz et al., 2011; Tasić et al., 2012; Kaminski et al., 2013; Liu et al., 2014; Price et al., 2014; Stabile et al., 2014; Zimmerman et al., 2014). Fewer studies have tested the instruments in real-world operating conditions (Heim et al., 2008; Weber et al., 2012; Belosi et al., 2013 Giorio et al., 2013; Cambra-López et al., 2015; Viana et al., 2015; Burkart et al., 2010).

In the present work, portable direct-reading instruments were field tested in an urban background scenario, with ambient UFP and PM concentrations being measured. The aim was to compare their performance against widely used 'reference' direct-reading instruments or versus filter-based sampling techniques for gravimetrical analysis. The performance of the portable monitors is assessed in terms of the particle number concentration (UFP) and size-fractionated PM mass concentration (PM_1; $PM_{2.5}$; PM_5; PM_{10}; TSP - Total Suspended Particles). The final goal is to evaluate whether the instruments under study are comparable to each other, to their reference (or widely accepted) counterparts and to gravimetrical techniques for outdoor air quality studies. If their performance is validated, these monitors could be viable additions to existing air quality monitoring networks to achieve a broader spatial coverage and a more representative characterization of exposure.

2. Methods

2.1. Study design

Experimental data were collected within the area of the University of Insubria in Como (Italy), during N = 16 repeated 8-h sessions, performed over a one-month period (November - December 2015). Measurements were performed in winter, under different meteorological scenarios, which were characterized by main meteorological variables. The selected site for sampling could be classified as an urban background site, according to the Guidelines regarding the Air Quality Monitoring Network, provided by the Agency for the Environmental Protection and Technical Services (APAT, 2004). Thus, the performed sampling could be considered representative of the average pollution levels in an urban environment (urban background concentration) resulting from the transport of air pollutants from outside the urban area and from emissions in the city itself, without dominating or prevailing emission sources, such as traffic or industrial activities (EEA, 2012). The measurement design consists of the combination of (i) direct-reading instruments (UFP and size-fractionated PM) and (ii) filter-based PM sampling used for the determination of size-resolved particles concentrations. Table 1 summarizes the monitoring design and strategy. The sampling equipment was placed in a dedicated sampling box, at street level, and sampling lines were placed with the air inlets at approximately 1.5 m above the ground, which approximately corresponds to the breathing zone of humans; sampling tubes were 50-cm long straight silicon tubing with 7-mm internal diameter (tubes were kept to a minimum to minimize diffusion losses). At the sampling site, the monitoring devices were far from obstructions and pollution sources. The direct-reading instruments were placed with sufficient distance from each other to avoid interferences and sampled at approximately the same height. The clocks of all instruments were synchronized prior to the first measurement in each session; data were measured with a 1-min frequency (averaging time).

2.2. Direct-reading instruments

The concentrations of airborne UFP were measured using a miniature diffusion size classifier (DSC) (DiSCmini, Matter Aerosol AG, Wohlen AG, Swiss) and a portable condensation particle counter (CPC) (P-Trak Ultrafine Particle Counter model 8525; TSI Inc., Shoreview, MN, USA) to perform a field comparison among these two instruments. Both of these instruments can provide real-time measurement of ultrafine particles (i.e., sub-micrometer), although each type of instrument has its own sensitivity to specific particle characteristics. DSC measures the number concentration of particles (10^3–10^6 particle/cm^3) in the size range of 10–700 nm. DiSCmini is based on the unipolar charging of aerosol, which is followed by detection in two electrometer stages (Fierz et al., 2011). CPC quantifies the number concentration of particles (up to $5*10^5$ particle/cm^3) in the size range of 0.02–1 μm, using isopropanol to artificially enlarge particles through the condensation of vapors on the particle surface. DSC was selected as a reference measurement method for UFP measurements because previous studies reported that the DiSCmini provides accurate particle number concentrations (PNC) in urban environments (Meier et al., 2013; Spinazzè et al., 2015; Rizza et al., 2017).

Size-Fractionated PM concentrations (PM_1; $PM_{2.5}$; $PM_{4/5}$; PM_{10}; TSP) were measured using two photometers, which both use an active sampling mode (flow rate = 2.83 L/min) and are based on the principle of light scattering of a linear radiation produced by a