Journal of Aerosol Science 96 (2016) 24–37

Contents lists available at ScienceDirect

Journal of Aerosol Science

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

Lung-deposited surface area concentration measurements in selected occupational and non-occupational environments

Otmar Geiss*, Ivana Bianchi, Josefa Barrero-Moreno

European Commission, Joint Research Centre, Institute for Health and Consumer Protection, Via E. Fermi, 2749, 21027 Ispra, VA, Italy

ARTICLE INFO

Article history:
Received 1 December 2015
Received in revised form
16 February 2016
Accepted 27 February 2016
Available online 10 March 2016

Keywords:
Lung-deposited surface area
Diffusion chargers
Occupational environments
Chamber studies
LDSA

ABSTRACT

Previous experimental and epidemiologic studies suggested that exposure to ultrafine particles (UFP) may result in adverse health effects. Metrics such as the number-concentration and especially the surface-area or lung-deposited surface area (LDSA) appear to be appropriate metrics of dose for predicting pulmonary inflammation of insoluble and poorly soluble ultrafine particles. Currently not much data including LDSA concentrations is available. The aim of this study was therefore to measure LDSA concentrations in a variety of occupational and non-occupational environments as well as in chamber tests. To this end, novel handheld online-monitors were deployed and evaluated for their suitability to be used in a variety of micro-environments and under different conditions. Chamber emissions tests included incense and candle burning, 3D printing and cigarette/e-cigarette smoking. The LDSA concentration was measured in occupational environments such as a canteen kitchen, a welding workshop and in a car. Measurements were also conducted in a private house with a wood-burning stove and with ongoing parallel cooking activities. Depending on the type of micro-environment, the ongoing activities or the material investigated in the chamber-tests, large differences were observed in terms of measured LDSA concentrations, some exceeding up to 1000 times that of the baseline concentration detected before activities initiated. In some of the investigated environments LDSA concentrations were measured for the first time. The data might therefore serve as reference for future studies. The handheld instrument used to measure this data worked well both for stationary measurements as well as for personal monitoring and proved to be an alternative to bulkier benchtop instruments.

1. Introduction

Experimental and epidemiologic studies conducted in the past indicated that exposure to ultrafine particles (UFP) may result in adverse health effects (Hoek et al., 2010; Mills et al., 2009; Rückerl, Schneider, Breitner, Cyrys, & Peters, 2011). Currently there is however no common agreement on an appropriate metric of exposure for ultrafine particles.

Exposure to coarse airborne particles has typically been assessed by measuring the mass-concentration. For ultrafine particles however, other metrics such as the number-concentration and especially the surface-area seem to be more appropriate metrics of dose for predicting pulmonary inflammation caused by insoluble and poorly soluble particles (Aitken, Chaudhry, Boxall, & Hull, 2006; Oberdorster, Oberdorster, & Oberdorster, 2005; Sager & Castranova, 2009; Waters et al.,

* Corresponding author. Tel.: +39 0332 786323; fax: +39 0332 786012.
E-mail address: otmar.geiss@ec.europa.eu (O. Geiss).

http://dx.doi.org/10.1016/j.jaerosci.2016.02.007

2009). The Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR, 2006) concluded in its 'opinion on the appropriateness of existing methodologies to assess the potential risk associated with engineered and adventitious products of nanotechnologies' that for exposure evaluation, dose requires information on the number of nanoparticles and/or their surface area in addition to traditional mass concentration characterization and that the equipment used for routine measurements, in various media, for representative exposure to free nanoparticles is currently inadequate. Surface area reflects the surface of particles, but can be interpreted in several ways. Which surface area (geometric surface area, Brunauer-Emmett and Teller (BET) surface area, active surface area) is the most relevant depends on the fact that which information is important for the user. The BET surface area (Brunauer, Emmett, & Teller, 1938) measurement technique, for instance, which relies on the absorption of gases on the particles surface can only be applied for powders and moreover measurements are influenced by particle porosity. The geometric surface area can be calculated through the particle number-size distribution, assuming perfect sphericity of particles. The active or 'Fuchs' surface area of aerosols can be determined with an epiphaniometer by measuring the attachment rate of radioactive ions to the sampled particles. The necessity of a radioactive source makes this technique less attractive for widespread use. An alternative to measuring the total surface area is measuring the lung-deposited surface area (LDSA) concentration instead which can be more easily measured. This metric takes into account the deposition efficiency of particles in different compartments of the lung based on a model published by the International Commission for Radiological Protection and defined for a reference working person (ICRP, 1994). LDSA concentration can be measured with so-called 'unipolar diffusion chargers' which are based on the same measurement principle as the epiphaniometer but without the requirement of a radioactive source. They consist of 3 basic elements: the unipolar charger (usually a corona charger), where ions are generated and mixed with the particles to charge them, the ion trap, where excess ions are removed, and finally a filter, where all particles are captured and the current deposited by the particles onto the filter is detected with a sensitive electrometer. It has been shown that, following unipolar diffusion charging, the resulting charge level of an aerosol is proportional to the fraction of the particle surface area concentration that would deposit in either the alveolar (gas-exchange) or the thoracic region of the human lungs. This relationship does however only apply in the size-range 20–400 nm (Asbach, Fissan, Stahlmecke, Kuhlbusch, & Pui, 2009; Kaminski et al., 2012). In a recent study, Todea et al. (Todea, Beckmann, Kaminski, & Asbach, 2015) determined the accuracy of instruments measuring the alveolar LDSA concentration based on unipolar diffusion charging and found that the measured concentrations were within 30% of accuracy in the size-range 20–400 nm. Provided the majority of particles are in this range of size, it is therefore possible to directly determine the LDSA concentration with unipolar diffusion chargers such as those used in this study.

Generally, little data, including LDSA concentrations, is available. Ambient LDSA background concentrations were measured in a number of national measuring campaigns e.g. in Switzerland (Eeftens et al., 2015), Barcelona (Reche et al., 2015), Lisbon (Gomes, Bordado, & Albuquerque, 2012) and Como (Spinazzè, Cattaneo, Scocca, Bonzini, & Cavallo, 2015). Other studies related the active surface of particles to spirometric results on 7–10 year old children in Upper Austria (Moshammer & Neuberger, 2003), quantified exposure to particles emitted by wood-fire ovens in pizzerias (Buonanno, Morawska, Stabile, & Viola, 2010), determined real-time individual exposure of more than 100 children aged 8–11 years during typical school days to particle number concentrations and average particle diameter, as well as alveolar and tracheobronchial deposited surface area concentration (Buonanno, Marini, Morawska, & Fuoco, 2012).

The aim of this study was to measure current scarcely available LDSA concentrations in a variety of occupational and non-occupational environments as well as during emission chamber tests. To this end novel handheld online monitors were deployed and evaluated on their suitability to be used in a variety of micro-environments and under different conditions. In a number of selected environments, the LDSA was measured for the first time and could therefore serve as a reference for future studies.

2. Materials and methods

2.1. Instrumentation

2.1.1. Lung-deposited surface area

Two commercially available instruments, based on the diffusion charging principle, were used in this study.

2.1.1.1. Aerotrak 9000. The Aerotrak Nanoparticle Aerosol Monitor 9000 (TSI Incorporated, Shoreview, USA) measured the LDSA concentration with 1-second resolution and an inlet flow of 2.5 L min^{-1}. Particles larger than 1 μm are removed by a cyclone. The voltage of the ion trap can be changed to adjust the instrument's response to either alveolar or tracheobronchial LDSA concentrations. The concentration range (alveolar) is advertised by the manufacturer as being 1–10,000 $\mu m^2\ cm^{-3}$. This instrument has been extensively characterised in previous studies (Asbach et al., 2009; Bau, Witschger, Gensdarmes, & Thomas, 2012; Fissan, Neumann, Trampe, Pui, & Shin, 2007; Leavey, Fang, Sahu, & Biswas, 2013; Shin, Pui, Fissan, Neumann, & Trampe, 2007).

2.1.1.2. Partector. The Partector (Naneos Particle Solutions GmbH, Windisch, Switzerland) is a small, light (400 g) battery-operated personal monitor (Fierz, Meier, Steigmeier, & Burtscher, 2013) which measures the alveolar LDSA concentration