Science of the Total Environment 605–606 (2017) 929–945

Contents lists available at ScienceDirect

Science of the Total Environment

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

Inter-comparison of personal monitors for nanoparticles exposure at workplaces and in the environment

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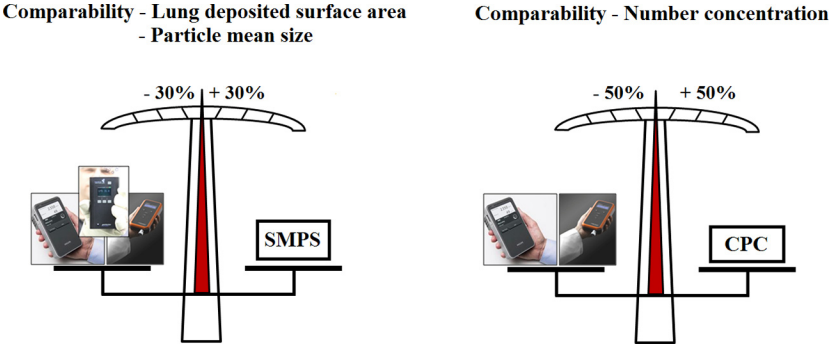
HIGHLIGHTS

- The comparability of unipolar charge based personal monitors was assessed.
- The comparability of the lung deposited surface area concentrations is usually ±30%.
- The comparability of the number concentrations is in the range of ±50%.
- Drastic bias observed in the presence of particles >400 nm

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 30 November 2016
Received in revised form 31 May 2017
Accepted 6 June 2017
Available online xxxx

ABSTRACT

Personal monitors based on unipolar diffusion charging (miniDiSC/DiSCmini, NanoTracer, Partector) can be used to assess the individual exposure to nanoparticles in different environments. The charge acquired by the aerosol particles is nearly proportional to the particle diameter and, by coincidence, also nearly proportional to the alveolar lung-deposited surface area (LDSA), the metric reported by all three instruments. In addition, the miniDiSC/DiSCmini and the NanoTracer report particle number concentration and mean particle size. In view of their use for personal exposure studies, the comparability of these personal monitors was assessed in two measurement

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http://dx.doi.org/10.1016/j.scitotenv.2017.06.041

Keywords:
Personal monitors
Comparability
Alveolar lung deposited surface area concentration
Number concentration
Mean particle size

campaigns. Altogether 29 different polydisperse test aerosols were generated during the two campaigns, covering a large range of particle sizes, morphologies and concentrations. The data provided by the personal monitors were compared with those obtained from reference instruments: a scanning mobility particle sizer (SMPS) for LDSA and mean particle size and a ultrafine particle counter (UCPC) for number concentration. The results indicated that the LDSA concentrations and the mean particle sizes provided by all investigated instruments in this study were in the order of ±30% of the reference value obtained from the SMPS when the particle sizes of the test aerosols generated were within 20–400 nm and the instruments were properly calibrated. Particle size, morphology and concentration did not have a major effect within the aforementioned limits. The comparability of the number concentrations was found to be slightly worse and in the range of ±50% of the reference value obtained from the UCPC. In addition, a minor effect of the particle morphology on the number concentration measurements was observed. The presence of particles >400 nm can drastically bias the measurement results of all instruments and all metrics determined.

1. Introduction

Exposure to airborne particles has been associated with adverse health effects (Dockery et al., 1993; Seaton et al., 1995) like pulmonary (Oberdörster, 2000a) or cardio-vascular diseases (Frampton, 2001). Particles at the nanoscale, i.e. ultrafine or nanoparticles (NPs), can penetrate deep into the alveolar region of human lungs and may hence be more harmful than their larger counterparts (Utell and Frampton, 2009). Traditionally, exposure to airborne particles is quantified by means of the particles' mass concentration of certain size fractions, such as PM_{10} or $PM_{2.5}$ for atmospheric particles and the inhalable, thoracic or respirable fraction in occupational settings (EN 481, 1993). The personal exposure to airborne particulate matter can be appropriately assessed by measuring individual exposure in the breathing zone of a person, according to EN 1540: 2012–03 defined as a 30 cm hemisphere around mouth and nose. This can be done either by using personal samplers that collect particles onto filters or flat substrates for consecutive analysis or personal monitors that detect particle concentrations in real-time. Personal samplers for the determination of the personal exposure in terms of mass concentrations in the aforementioned size classes have been available for a long time, e.g. the personal environmental monitors (PEMs, MSP Corporation), the IOM inhalable, thoracic and respirable samplers. However, since the particle mass scales with the third power of the particle diameter, nanoscale particles typically only contribute a very small fraction to the collected mass concentrations, despite their usually very high number concentrations. Particle surface area concentration (Oberdörster, 2000b) has been reported to be a better predictor of potential health outcomes, e.g. pulmonary and cardio-vascular diseases, and is more sensitive to nanoparticle concentrations than particle mass concentration. Rückerl et al., 2016 found that active surface area and particle length concentration showed strong positive associations with blood biomarkers reflecting inflammation. They concluded that these metrics might reflect harmful aerosol properties better than particulate mass or number concentration. Schmid and Stoeger, 2016, suggested that the lung-deposited particle surface area dose could be the toxicologically most relevant dose metric for inhaled, spherical NPs, but depending on the mode of action, other dose metrics may be more effective, e.g. volume and number for high particle lung burden, as well as for long and stiff fiber-like particles. They also suggested that mass should be further included as dose metric due to its historic and regulatory relevance for NP toxicity. To date, no consensus regarding the metric to be used has been reached. Only recently different personal samplers that collect a sample in the nanometer range have become commercially available. These personal samplers include the Thermal Precipitator Sampler (TPS, RJ Lee Group, Monroeville, PA, USA) (Thayer et al., 2011; Leith et al., 2014), the Personal Nanoparticle Respiratory Deposition Sampler (NRD, Zefon International, Ocala, FL, USA) (Cena et al., 2011) and the NanoBadge (NanoInspect, Alcen group, France and French Alternative Energies and Atomic Energy Commission) (Faure et al., 2017). Except for the TPS, these samplers are used to determine the mass concentrations of certain chemical species.

The real-time monitors available for the determination of the personal exposure are the DiSCmini (Testo GmbH, Titisee-Neustadt, Germany, developed by Fierz et al., 2011 under the name miniDiSC), the NanoTracer (developed by Philips Aerasense (Marra et al., 2010), licensed to Oxility bv., Eindhoven, the Netherlands) and the Partector (naneos GmbH, Windisch, Switzerland, Fierz et al., 2014) and were the subject of the investigations presented in this paper. The DiSCmini and the miniDiSC are essentially identical instruments. The denominations DiSCmini and miniDiSC are therefore used interchangeably in this paper. All three monitors are based on unipolar diffusion charging of the particles to determine the alveolar lung deposited surface area (LDSA) concentration. The DiSCmini and the NanoTracer additionally also determine estimates of the mean particle size and the particle number concentration. A very recent development is the Personal Ultrafine Particle Counter (PUFP C100 and C200, Enmont LLC; Ryan et al., 2015), which is a personal condensation particle counter. This instrument was, however, not yet available during the experiments presented here and is hence not further covered in this paper. Up to now the DiSCmini/miniDiSC and the NanoTracer were most frequently used in studies on personal exposure to airborne nanoscale particles. For example, the NanoTracer has been used to assess the contribution of different activities and microenvironments (e.g. residential and other indoor environments, during transit and outdoors, working place) to the personal exposure (Buonanno et al., 2012, 2013 and Buonanno et al., 2014a; Bekö et al., 2015). The miniDiSC was used to study the personal exposure of dentists (Van Landuyt et al., 2014) and in an extensive study (Meier et al., 2015) to evaluate the spatial and temporal patterns of ultrafine particles within communities and to investigate the representativeness of ultrafine particle concentrations at routine monitoring stations in Switzerland. Personal monitoring may offer the most relevant measurements of exposure to particulate matter, but it also has limitations. According to the manufacturer specifications, these instruments would be less accurate than standard instruments like condensation particle counters or scanning mobility particle sizers and errors up to ±30% can occur. Some studies proposed the use of correction factors obtained by calibration measurements prior to the personal exposure studies to overcome potential systematic differences between instruments (Buonanno et al., 2012, 2013 and Buonanno et al., 2014a; Bekö et al., 2015). Another limitation of the instruments was emphasized by the study of Bekö et al., 2013 on indoor exposure of residents to ultrafine nanoparticles and was related to the inability of the NanoTracer to detect particles smaller than 10 nm, particles that could be generated by nucleation during cooking and candle burning events. This was also observed in the study of Buonanno et al., 2014b, where the NanoTracer underestimated the number concentration during field measurements when a large number of particles smaller than 20 nm were present in