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Monitoring urban air quality with a diffusion charger based electrical particle sensor

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ABSTRACT

Urban air contains considerable amounts of harmful gaseous substances and aerosol particles. In this study, a recently introduced diffusion charger based PPS-M particle sensor (Pegasor Oy, Tampere, Finland) was evaluated for outdoor air quality measurements in urban environment. The PPS-M particle sensor was used in two stationary air quality measurement stations, one located in the roadside environment and the other in residential area, and in a mobile laboratory. The sampling of urban aerosol to the PPS-M sensor was performed without any pre-conditioning of aerosol. The sensor response to $PM_{2.5}$ varied between the measurements, being between 7 and 30 fA/(μg/m^3) depending on the aerosol source. The highest $PM_{2.5}$ response was observed in the roadside study for exhaust particles while the lowest $PM_{2.5}$ response was observed for large long range transported aerosol particles having relatively large mean particle size. The sensor signal was found to produce very linear response, with only minimal deviation, to the lung deposited particle surface area concentration (from 4.5 to 6 fA/(μm^2/cm^3)) and to the condensation sink of urban air particles (from 1.0×10^4 to 1.2×10^4 fA cm^3). The sensor response to particle number concentration was defined to be 0.0044 fA/(1/cm^3) in roadside environment. In this environment, the signal was found to correlate also with NO and NO_2 concentrations of roadside air

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due to the same origin of particulate and gaseous pollutants. Similar correlation between NO_x and the PPS-M signal was not observed in residential area.

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1. Introduction

The most important motivation for air quality monitoring is the health effects of air pollutants. Outdoor air quality is typically analyzed by measuring particle mass concentration: PM_{10} and $PM_{2.5}$ or gas concentrations: NO, NO_2, SO_2 and O_3. However, in the case of particles, it has been proposed that mass based quantities PM_{10} and $PM_{2.5}$ may not be the best metric to describe the harmful health effects. In animal and cell studies, conducted in laboratory conditions, the particle surface area has been found to correlate better with the harmful effects than the mass or number of the particles (Oberdörster, 2001; Waters et al., 2009). Thus, the surface area concentration may be relevant quantity to be measured and by taking the size dependent lung deposition efficiency into account, the term lung deposited surface area concentration has been taken into use (Fissan et al., 2007).

There are several aerosol instruments utilizing unipolar diffusion charging. The diffusion charging is based on unipolar ions attaching on the aerosol particles. The charging efficiency, in this case the average number of elementary charges per particle, is proportional to the particle size. The larger particles gain more elementary charges than the small ones. This charging efficiency has a similar size dependency as the lung deposited particle surface area concentration. Thus, after a calibration, the lung deposited surface area concentration of aerosol particles can be measured with a good accuracy by charging the particles in a diffusion charger, and after that by measuring the electric charge of the particles (e.g., Fissan et al., 2007; Asbach et al., 2009).

In this study a diffusion charger based PPS-M sensor (Pegasor Oy, Tampere, Finland) was used to measure outdoor air particle concentrations. The sensor was originally developed to be used in particle emission measurements (Amanatidis et al., 2013, 2014), at concentrations much higher than found in outdoor environments. However, the high time response of the PPS-M and its comparatively low cost make it an attractive potential outdoor air quality sensor for applications requiring these properties. To test the sensor performance in realistic urban air settings, it was installed as a part of the instrumentation suite of two large air quality research campaigns conducted in the urban metropolitan area of Helsinki, Finland. The sensor signal was compared to the data measured by other aerosol instruments; the raw data consisting of electric currents measured from the stages of an Electrical Low Pressure Impactor (ELPI, Dekati Ltd.), the particle number concentration measured by a Condensation Particle Counter (CPC, Model 3776, TSI Inc.), the lung deposited surface area concentration measured by a Nanoparticle Surface Area Monitor (NSAM, TSI Inc.) and the $PM_{2.5}$ measured by two different instruments: Model 5030 SHARP (Thermo Fisher Scientific Inc.) and TEOM 1400 AB (Thermo Fisher Scientific Inc.). The response of the sensor was also compared to NO and NO_2 concentrations.

2. Experimental

2.1. The PPS-M sensor

The PPS-M is an electrical particle sensor exploiting the unipolar diffusion charging of aerosol particles and the measurement of the electric current generated by the charged particles. The operation of the PPS-M has been extensively introduced and characterized by Rostedt et al. (2014) in laboratory conditions. The sensor can be used in several applications; although it has been designed especially for automotive exhaust emission measurements (e.g., Ntziachristos et al., 2011; Amanatidis et al., 2013, 2014) also power plant emission monitoring, ambient air quality measurements as well as indoor air particle concentration measurements (Lanki et al., 2011) can be performed by the instrument. The

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