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Non-exhaust emission measurement system of the mobile laboratory SNIFFER

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ABSTRACT

In this paper we describe and quality assure the sampling system of a mobile research laboratory SNIFFER which was shown to be a useful tool for studying emission levels of respirable dust from street surfaces. The dust plume had bimodal structure; another mode rising to higher altitudes whereas the other mode remained at lower altitudes. The system was tested on a route in Helsinki, Finland, during spring 2005 and 2006. The $PM_{2.5}$ and PM_{10} were positively correlated and the PM levels increased with the vehicle speed. SNIFFER was able to identify the characteristic emission levels on different streets. A clear downward trend in the concentrations was observed in all street locations between April and June. The composition of the street dust collected by SNIFFER was compared with springtime PM_{10} aerosol samples from the air quality monitoring stations in Helsinki. The results showed similarities in the abundance and composition of the mineral fraction but contained significantly more salt particles.

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1. Introduction

Recent toxicological and epidemiological studies have associated high particulate concentrations (PM) in urban air with increased morbidity such as respiratory symptoms, lung cancer and cardiovascular diseases, and with increased mortality (e.g. Delfino et al., 2005; Pope et al., 2002; Saxon and Diaz-Sanchez, 2005). Also recently reported is epidemiological evidence of effects of coarse non-exhaust airborne particles on health (Brunekreef and Forsberg, 2005).

Non-exhaust particles are mainly abrasion products originating from interaction processes of the road surface and tyre. Minor possible processes are brake and clutch wear as well as corrosion. An important source is also particles that are re-suspended from surfaces, e.g. due to vehicle induced turbulence or tyre shear. In Northern areas, e.g. Scandinavia, street dust levels are especially high during spring due to the use of antiskid methods, like street sanding and studded tyres (Kupiainen, 2007). For example, the EU directive controlling the diurnal average PM_{10} value (50 mg m^{-3}) was exceeded more than the allowed 35 times during both years 2005 and 2006 in the traffic dominating monitoring stations in Helsinki. Most of the exceedings happened during spring due to street dust.

The formation processes of street dust are complex and the emissions are difficult to measure. For instance, road surface condition and properties such as pavement type and year of construction as well as meteorological factors including road surface moisture (Omstedt et al., 2005) affect emissions. Emissions of non-exhaust particles have

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been studied with street side measurements (e.g. Lohmeyer et al., 2004; Norman and Johansson, 2006), additionally the dust formation processes have been studied in test facilities (Gustafsson et al., 2008; Kupiainen et al., 2003, 2005a; Dahl et al., 2006). However, it is difficult to relate the test results to actual street conditions and street side measurements are limited by the location. Therefore mobile units to measure street dust in driving conditions have recently been developed (Fitz and Bufalino, 2002; Etyemetzian et al., 2003; Hussein et al., 2008). Mobile systems provide also interesting possibilities to study the effects of winter maintenance and street cleaning on dust formation and emissions (e.g. Gertler et al., 2006).

This paper describes the design and quality assurance of a mobile system SNIFFER to measure non-exhaust particulate emissions from street/road surface behind the left rear tyre of SNIFFER. The system has been used for measurements of $PM_{2.5}$ and PM_{10} on a specially designed route in Helsinki, Finland, during spring 2005 and 2006 to study the impact and trend of springtime dust. Also composition of the street dust collected with SNIFFER was studied.

2. Experimental methods

2.1. Mobile laboratory

The mobile laboratory SNIFFER was first developed to measure traffic exhaust emissions under real driving conditions as well as emissions of an individual vehicle by the chasing method (Pirjola et al., 2004a, 2004b). In 2005 the measurement set up was extended to include also measurements of non-exhaust particles during a Finnish national project VIPEN (Vehicle Induced Particulate Emissions from Non-exhaust Sources). The instrumentation is set in a Volkswagen LT 35 diesel van with a length 5585 mm, width 1933 mm, height 2570 mm, and max total weight 3550 kg.

Samples can be collected through two different inlet systems opening towards the driving direction. One is situated above the windshield at the height of 2.4 m (main inlet) and the other above the bumper at the height of 0.7 m (chasing inlet). These inlets are used when studying exhaust emissions, see detailes in Pirjola et al. (2004a, 2004b, 2006).

Road dust emissions are sucked from behind the left rear tyre through a conical inlet with a trapezoidal surface area of 0.034 m^2 into a vertical tube with the diameter of 10 cm. The lower edge of the conical inlet is 7 cm above the street surface and the upper edge is as high as the geometry of the fender of the wheel allows. The width of the inlet is around 2 cm less than the width of the tyre ie. 1 cm less from each side, and the distance of the inlet from the tyre is 5 cm (Fig. 1a). The tube (stainless steel AISI 316) runs through the rear part to the top of the van (Fig. 1b). A constant flow rate of ~2000 lpm is provided by an electric engine located on the roof of the vehicle. The engine is sheltered against larger particles or chipping by filters.

A sampling air branch-off (Fig. 1b) into the tube of 0.025 m diameter was constructed for the particle mass monitors TEOM (Tapered Element Oscillating Microbalance, Series 1400A, Rupprecth & Patashnick) and ELPI (Electrical Low Pressure Impactor, Dekati Ltd.). The orifice of the smaller tube was mounted downward in the middle of the thicker tube (Fig. 1b) allowing isokinetic sampling. The total flow rate is 13 lpm (3 lpm for TEOM and 10 lpm for ELPI). With this flow rate a sampling cyclone (SAC-65, Dekati) gives a 9.2 μm cut size for the particulate matter; however, PM_{10} is used hereafter (Fig. 1b). TEOM operates at 50 °C temperature. Hitzenberger et al. (2004) reported about underestimation of mass concentration ($PM_{2.5}$) due to evaporation of semivolatile aerosol material (such as ammonium nitrate and certain organic compounds) when heating the sampling element to 50 °C. However, road dust particles consist mostly of nonvolatile material. SNIFFER samples the particles at ambient humidity so the water content of the particles (if any) is accounted for PM.

TEOM was installed to save 30 s running average mass concentration every 10 s; however, if the mass concentrations are high enough, also 10 s running averages can be used but shorter running average times increased unphysical negative mass values.

Particle number concentration and size distribution are measured by two ELPIs. One ELPI measures street dust particles behind the left tyre and the other ELPI measured background particles via the chasing inlet in front of the van. ELPI with the electrical filter stage enables real time particle number concentration and size distribution (1 s time resolution) in the size range of 7 nm–10 μm (aerodynamic diameter) with 12 channels (Keskinen et al., 1992). To convert the number size distributions to PM concentrations we need to know the density of particles. Due to the bounce phenomenon in the coarse size range, ELPI is used to estimate $PM_{2.5}$ instead of PM_{10} (Hitzenberger et al., 2004); more accurately, in this work we have also eliminated the exhaust particles and calculated $PM_{2.5}$–$PM_{0.6}$. The density of these particles was estimated to be 2000 kg m^{-3}. This is somewhat smaller than the density of mineral dust (~2500 kg m^{-3}) since in this size range particles also include salt, organics, nitrate and sulphate. Note that to avoid sampling SNIFFER's own exhaust the exit of the exhaust tube was turned far from the dust sample inlet.

SNIFFER also provides the measurements of gaseous concentrations such as carbon monoxide CO (Model CO12 M, Environnement S.A.), nitrogen monoxide NO, nitrogen oxides $NO_x = NO + NO_2$ (Model APNA 360, Horiba) as well as carbon dioxide CO_2 (Model VA 3100, Horiba) via the main inlet or the chasing inlet in front of the van. A weather station on the roof at 2.9 m height provides meteorological parameters. Relative wind speed and direction are measured with an ultrasonic wind sensor (Model WAS425AH, Vaisala). Temperature and relative humidity are measured with temperature and humidity probes (Model HMP45A, Vaisala). Additionally, a global position system (GPS V, Garmin) saves the van's speed and the driving route. Also available is a video camera in the cab to record the traffic situations.

2.2. Quality assurance

2.2.1. Sampling losses

With the flow rate in the vertical tube (0.1 m diameter) of 2000 lpm the conical inlet velocity is constant ~1 m s^{-1}.

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