A MOBILE LABORATORY FOR MONITORING NON-EXHAUST EMISSIONS IN FINLAND

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ABSTRACT

Local vehicular traffic is responsible for a substantial fraction of PM_{10} in urban air mainly due to non-exhaust traffic emissions and resuspension from street surfaces (e.g. Zhao et al., 2006). In Northern areas (e.g. Scandinavia) street dust levels are especially high during spring, and the diurnal average PM_{10} value (the EU directive) is exceeded more than the allowed 35 times per year. In this paper we introduce the sampling system of a mobile research laboratory SNIFFER for studying emission levels of respirable dust from street surfaces. We have measured a unique time series of the street level PM_{10} concentrations in a city of Helsinki, Finland, during the last five springs. A special 20 km route in downtown was selected to cover main streets including bus lanes, tram lanes, canyon streets, open transit streets and some cobblestone covered streets. For every spring the maximun emission level averaged over the whole route was 2000 - 4500 $\mu g\ m^{-3}$ and occurred in the turn from March to April, after which the clear decreasing trend was found. The most highest street concentrations were measured on the street canoyns as well as on the streets covered by copplestone and on the sections which were under work construction.

Keywords: mobile measurements, PM_{10}, resuspension, road wear, street dust.

INTRODUCTION

Local vehicular traffic is responsible for a substantial fraction of PM_{10} in urban air mainly due to non-exhaust traffic emissions and resuspension from street surfaces. In Northern areas, e.g. in Scandinavia, street dust levels are especially high during spring, and the diurnal average PM_{10} value (50 $\mu g\ m^{-3}$) is exceeded more than the allowed 35 times per year (the EU directive). Recent toxicological and epidemiological studies have associated high particulate concentrations with hospital admissions and mortality (e.g. Pope and Dockery, 2006). Also recently reported is epidemiological evidence of coarse non-exhaust airborne particles on health (Brunekreef and Forsberg, 2005).

The formation processes of street dust are complex and the real world dust emissions are difficult to measure. Recently mobile units have been developed to measure street dust in driving conditions (Fitz and Bufalino, 2002; Etyemetzian et al., 2003; Hussein et al, 2008; Pirjola et al., 2009). 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).

The emission level of the spring-time street dust depends on winter maintenance, antiskid methods, dust binding and street cleaning methods. Also vehicle induced turbulence and meteorological factors affect the PM_{10} concentrations. Street sanding increases street dust several fold independently from the tyre type due to the sand-paper effect (abrasive wear of the pavement by sand grains under the tyres). The emission levels with traction sand are also affected by the amount dispersed, by the grain size, and by the quality of the sand (e.g. Kuhns et al., 2003; Kupiainen and Tervahattu, 2004; Kupiainen et al., 2005; Tervahattu et al., 2006). The other antiskid method is the use of studded tyres which enhances the street surface wear especially during dry street conditions (e.g. Kupiainen et al., 2003; 2005; Norman and Johansson, 2006; Hussein et al., 2008).

Dust binding methods such as spreading of calcium cloride or calcium magnesium acetate on the street to keep the street wet have shown to reduce the amount of resuspended dust (e.g. Norman and Johansson 2006; Johansson et al., 2007). Several studies have shown that current street cleaning measures have only limited efficiencies to PM_{10} particles in the short term (Fitz, 1998; Kuhns et al., 2003; Lohmeyer, 2005; Gertler et al., 2006; Norman & Johansson, 2006).

We have measured a unique time series of the street level PM_{10} concentrations in a city of Helsinki, Finland, during the last five springs on a special 20 km route in downtown. The aim of this work is to present these data, and discuss on the factors affected the street level concentrations in different type of street sections. Also included are the actions of winter maintenance and cleaning operations that have been listed by the city authorities.

METHODOLOGY

The mobile laboratory Sniffer provides measurements of traffic exhaust emissions under real driving conditions (Pirjola et al., 2004a, 2004b, 2006) as well as measurements of non-exhaust particles (Pirjola et al., 2009). The instrumentation is set in a Volkswagen LT35 diesel van with a length 5585 mm, width 1933 mm, height 2570 mm, and max total weight 3550 kg.

Exhaust 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). Dust sample is sucked from behind the left rear tyre through a conical inlet with the surface area of 0.20 m x 0.22 m into a vertical tube with the diameter of 0.1 m. 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, i.e. 1 cm less from each side, and the distance of the inlet from the tyre is 5 cm (Figure 1a).

A stainless steel tube runs through the rear part to the top of the van (Figure 1b). A constant flow rate of ~2000 lpm is produced by an electric engine located on the roof of the vehicle. A sampling air branch-off 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 located

a) b)

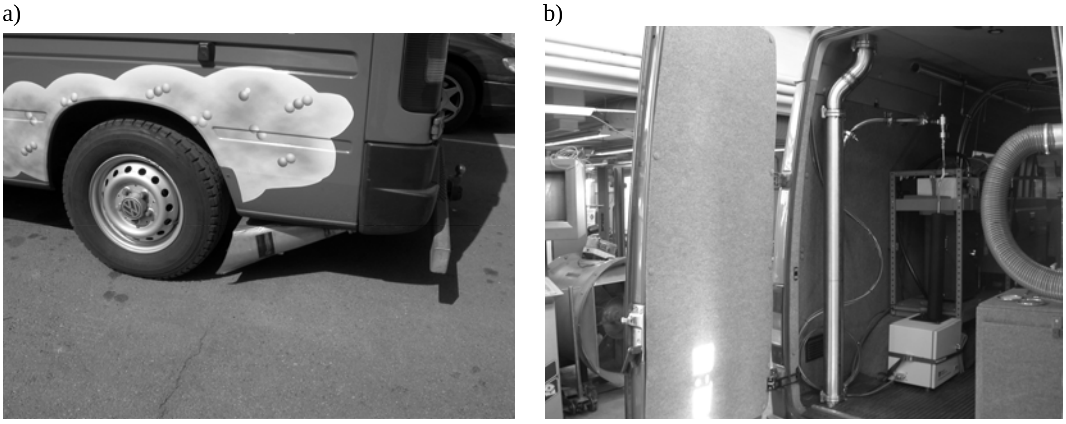

Figure 1. Sampling inlet behind the left rear tyre of SNIFFER (a), inlet system and instruments (b). (Pirjola et al., 2009)

downward in the middle of the thicker tube (Figure 1b) and it was planned to allow 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. TEOM operates at 50 ^{o}C temperature; however, for roaddust evaporation of semivolatile aerosol material such as ammonium nitrate and certain organic compounds is negligible and does not cause any problems. TEOM was installed to save 30 s running average mass concentration every 10 s. Since the TEOM recorders concentrations close to the source they are hereafter also called as emission levels.

Particle number concentration and size distribution are measured by two ELPIs. Another ELPI measures street dust particles behind the tyre, and the other 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 calculate $PM_{2.5}$ from the number concentrations, particle density value of 2000 kg m^{-3} has been used. Recently we have puchased two DustTraks (TSI, model 8530), each of them can sample PM_{10}, $PM_{2.5}$ or PM_1 with the resolution time of 1 s.

Sniffer also provides measurements of gaseous concentrations such as carbon monoxide CO (Model CO12M, 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, the driving route and the heading of the van which are also needed to convert the relative windspeed and direction to the real ones.

RESULTS

Measurements were conducted in Helsinki, Finland, between March and June in 2005-2009, on a 20 km route specially designed for SNIFFER. The route is located totally in the urban environments and includes street sections with different characteristics, e.g. different amount of buses and other traffic, different pavement types (SMA asphalt, cobblestone), uphill and downhill sections. Also the street environments are different; some streets are canyons, some half open and some open transit streets being well ventilated. The route was driven at noontime (outside the rush hours) in average two times per week, always when the street surfaces were dry. In this work mainly the mass recorders PM_{10} by TEOM are considered From the gps-data the 30-second running average speeds were calculated. Although the route average speed during the tests was similar on all days, there were differences in number of stops on some street sections due to traffic. This was taken into account by omitting measured values in speeds lower than 10 km h^{-1}, which provided a better comparability between the street sections as the differences in average speeds became smaller.

As an example, Figure 2 illustrates the time series of PM_{10}, $PM_{2.5}$ and background $PM_{2.5}$ emission levels along with the vehicle speed on April 20, 2006 (Pirjola et al., 2009). The lowest concentrations were observed during stops in traffic jam and in traffic lights. The PM levels depended on speed, showing higher values with high driving speeds. The speed dependency has been observed and discussed by e.g. Etyemetzian et al. (2003) and Hussein et al. (2008).

The annual trend of emission levels in 2006-2009 are shown in Figure 3 (Kupiainen et al., 2010). Comparison of the results in 2005 and 2006 is presented in Pirjola et al. (2009). The values presented in Figure 3 are average values over the Helsinki route. On weeks 13-15 (at the end of March and beginning of April) the emission levels were highest except in year 2006 when the spring came late and the highest value was recorded on week 16. The maximum average values varied in the range of 2000-4500 µg m^{-3} after which the emission levels started to decreasse gradually reaching the lowest values (500-1000 µg m^{-3}) at the end of May. Then the streets can be regarded as clean as they can ever been.

The actions of winter maintenance and cleaning operations have been listed by the city authorities. The times for street cleaning and dust binding activities in each year are also shown in Figure 3. Dust binding and street cleaning operations were usually finished at the end of April (week 17); however, in 2006 they started not until in the middle of April and continued at the end of May. February and March in 2006 were colder and more rainy than usually. Consequently, the antiskid method used was sanding instead of salting which cannot be used if the night temperature is below 0^{o}C. On the contrary, winter 2008 was very mild, the thickness of the snow layer was in maximum 10 cm, and no freezing at nights occurred. Slippery conditions were prevented by salting, sanding was needed only a couple of times. The average emission levels are similar than in 2007. In 2009 snow cover was very thin, and snow melted at the end of March. Salting was the main antisked method. April was dry since no rain occurred, and therefore dust binding by $CaCl_2$ was more frequently used. An extensive street construction work and cobblestone pavement on Mannerheimintie caused a suprisingly high peak in the route average value on week 19 and during the two following weeks. In Helsinki, studded tyres are allowed to be used from the beginning of November to the end of March. Both tyre studs and the use of traction sand increase PM emissions.

Figure 4 shows the 10 second values of PM_{10} concentrations along the Helsinki route on April 9, 2009. Aleksanterinkatu, Unioninkatu and Kaisaniemenkatu are canoyns which have highest street average emission levels of about 10 100, 6 400 and 4 700 $\mu g\ m^{-3}$, respectively. Aleksanterinkatu is a narrow street, covered by cobblestone. Tram rails lie in the middle and driving is allowed only for taxes and delivery vehicles. Sörnäisten rantatie is a busy open well-ventilated street (traffic density 23 400-61 800 vehicles per day) which was rather clean (1 900 $\mu g\ m^{-3}$). Topeliuksenkatu (2 200 $\mu g\ m^{-3}$) is a half-open wide canoyn with 11 300-19 100 vehicles per day. Mannerheimintie is the main street through the city with three driving lanes to both directions and tram rails in the middle. The street is broad and long and can be reagarded as a canoyn from place to place.

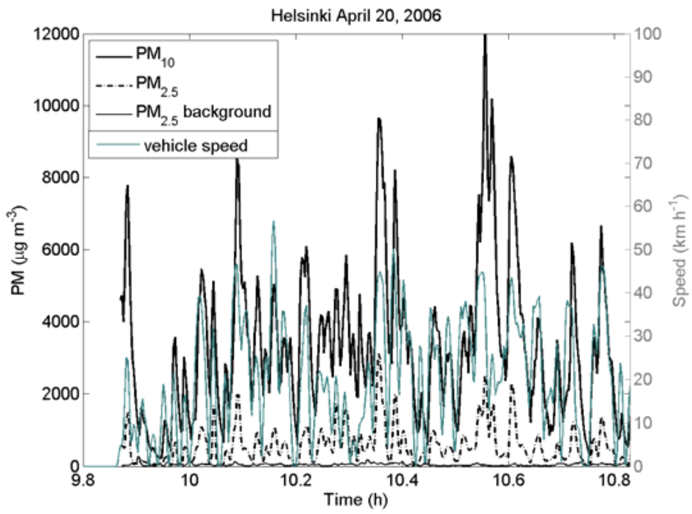

Figure 2. Time series of PM_{10}, $PM_{2.5}$ and vehicle speed measured by SNIFFER in Helsinki on April 20. Also shown is the background $PM_{2.5}$ (Pirjola et al., 2009).

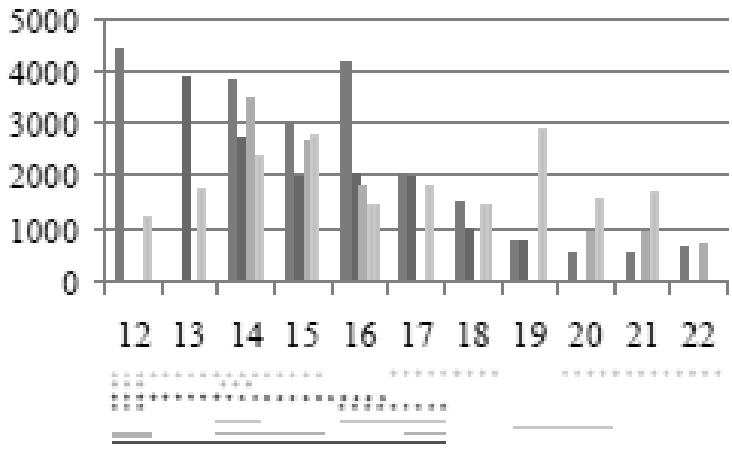

Figure 3. Average emission levels over the Helsinki route in 2006 (dark gray), 2007 (black), 2008 (gray) and 2009 (light gray). x-axis refers to the week number and y-axis to PM_{10} in $\mu g\ cm^{-3}$. Also shown are the times when the street cleaning (solid horisontal line) and dust binding (dotted horisontal line) were performed in each year. (Kupiainen et al., 2010)

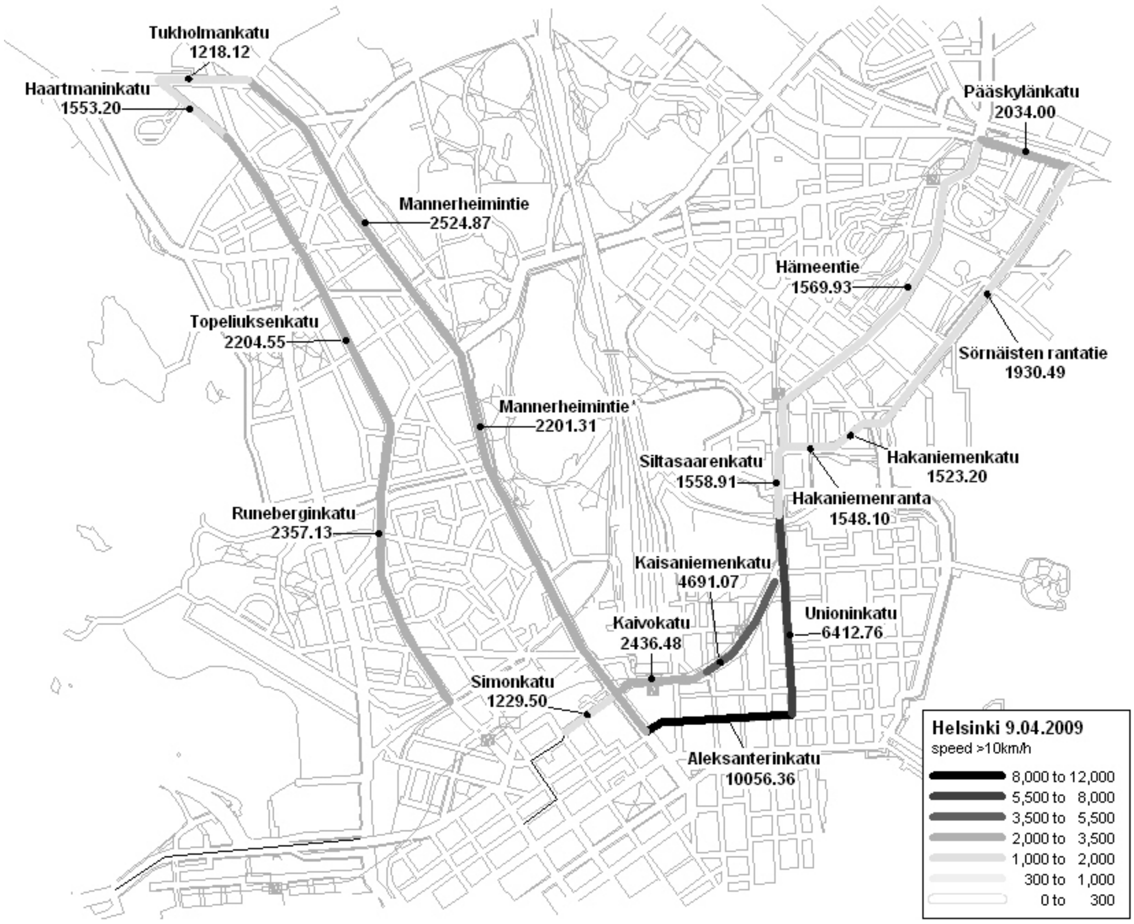

Figure 4. Maximum PM_{10} emission levels on different street sections in the Helsinki route on April 9, 2009 (Kupiainen et al., 2010).

CONCLUSION

The mobile research laboratory SNIFFER was shown to be a useful tool for studying emission levels of respirable dust from street surfaces. A unique time series of the street level PM_{10} concentrations in a city of Helsinki, Finland, has been measured during the last five springs. A special 20 km route covers main streets in the downtown area including bus lanes, tram lanes, canyon streets, open transit streets and some cobblestone covered streets. The list of winter maintenance actions and cleaning operations have been provided by the city authorities.

The maximun springtime emission level averaged over the whole route, 2 000 - 4 500 $\mu g\ m^{-3}$, was recorded in the turn from March to April, after which the clear decreasing trend was found. This occurred in every year although meteorological parameters such as daytime and nighttime temperatures, snow cover, sunshine etc during the winter and spring were rather different. To the end of May the emission level was dropped to the level of 500 - 1 000 $\mu g\ m^{-3}$. The decrease occurred at the same time as dust binding, street cleening and changing studded tyres to summer tyres.

The emission levels in individual street sections varied much. Higher street averaged concentrations occurred on the street canoyns as well as on the streets covered by copplestone and on the sections which were under work construction.

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