Atmospheric Environment 63 (2012) 156–167

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

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

Spatial and temporal characterization of traffic emissions in urban microenvironments with a mobile laboratory

L. Pirjola [a,b,*], T. Lähde [a], J.V. Niemi [c,d], A. Kousa [c], T. Rönkkö [e], P. Karjalainen [e], J. Keskinen [e], A. Frey [f], R. Hillamo [f]

[a] Department of Technology, Metropolia University of Applied Sciences, P.O. Box 4021, FI-00180 Helsinki, Finland
[b] Department of Physics, University of Helsinki, P.O. Box 64, FI-00014 Helsinki, Finland
[c] Helsinki Region Environmental Services Authority HSY, P.O. Box 100, FI-00066 HSY, Helsinki, Finland
[d] Department of Environmental Sciences, University of Helsinki, P.O. Box 65, FI-00014 Helsinki, Finland
[e] Department of Physics, Tampere University of Technology, P.O. Box 692, FI-33101 Tampere, Finland
[f] Finnish Meteorological Institute, P.O. Box 503, FI-00101 Helsinki, Finland

HIGHLIGHTS

- ► Major part of traffic particles are smaller than 40 nm and volatile.
- ► Street canyon effect accumulates particulate and gaseous concentrations to upwind side.
- ► Exposure at the pavement upwind is even higher than while driving.
- ► Downwind concentrations highly depend on wind direction and roadside structure.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 19 April 2012
Received in revised form
27 August 2012
Accepted 12 September 2012

Keywords:
Ultrafine particles
Mobile measurements
Street canyon
Traffic pollutants
Pedestrian exposure

ABSTRACT

A measurement campaign by a mobile laboratory van was performed in urban microenvironments bounded by a busy street Mannerheimintie in the city center of Helsinki, Finland. The characteristics of spatiotemporally high-resolution pollutant concentrations were studied such as ultrafine particles in the size range of 3–414 nm, black carbon BC, fine particle mass $PM_{2.5}$, as well as nitrogen oxides NO and NO_2. In addition, the effects of street geometry and roadside structure on the local dispersion of traffic emissions were analyzed as well. Meteorological conditions stayed stable and the wind direction was perpendicular to Mannerheimintie during the campaign. The highest particle concentrations were $\sim 8 \times 10^5$ cm^{-3}, of which around 94% was smaller than 40 nm. At the pavement, the average concentration was in maximum 5×10^4 cm^{-3}; around 80% of the particles was smaller than 40 nm. The volatility fraction was 75% by number. Due to the street canyon effect by the surrounding buildings, the downwind concentrations were around 24% of the upwind concentrations for particle number, 28% of NO, 39% of BC and 70% of NO_2 concentrations. Furthermore, the upwind concentrations were higher than the simultaneously measured concentrations within the traffic flow. In fact, the particle count was around 3-fold, BC 2.5-fold, $PM_{2.5}$ and NO_2 1.5-fold compared to the concentrations while driving. Thus, for this measurement site and under these meteorological conditions, the exposure to pedestrians and cyclist on the upwind pavement is even higher than the driver's exposure. If the downwind buildings were parallel to Mannerheimintie, the concentrations dropped significantly at the pavement and continued decreasing slightly in the courtyards. When the downwind buildings were perpendicular to

* Corresponding author. Department of Technology, Metropolia University of Applied Sciences, P.O. Box 4021, FI-00180 Helsinki, Finland. Tel.: +358 20 783 6117; fax: +358 20 783 5002.
E-mail addresses: liisa.pirjola@metropolia.fi, liisa.pirjola@helsinki.fi (L. Pirjola).

1352-2310/$ – see front matter
http://dx.doi.org/10.1016/j.atmosenv.2012.09.022

Mannerheimintie, a gradual reduction in the concentrations between the buildings was observed. However, at a distance of approximately a hundred meters a parallel side street which was a street canyon, started to affect the concentrations resulting in an increased exposure risk for pedestrians and cyclists. Understanding the local transport and the dispersion of traffic emissions are important for city planning and air quality assessment.

1. Introduction

In urban environments, traffic emissions are the dominant source of ultrafine particles (i.e., <100 nm in diameter) and gaseous pollutants, such as NO_x, CO and volatile organic compounds (e.g. Wehner et al., 2002; Hellen et al., 2006; Kumar et al., 2010, 2011). Traffic particles affect the urban visibility and global climate, directly by scattering or absorbing (soot particles) solar radiation, and indirectly by participating in cloud formation. Furthermore, numerous epidemiological studies have demonstrated adverse health effects of a short-term and long-term exposure to traffic-related air pollution (e.g. Pope III and Dockery, 2006; Sioutas et al., 2005; Kettunen et al., 2007; Su et al., 2008; Jacobs et al., 2010).

Typically, urban areas consist of street canyons where pollutant concentrations can be several times higher than in open areas due to reduced exchange of air and dispersion of pollutants inside the canyon. The climate of street canyons is primarily controlled by the micro-meteorological effects of urban geometry. Canyons are classified to symmetric canyons if the buildings on both sides have approximately the same height; otherwise they are asymmetric. According to the aspect ratio H/W (H = building height, W = canyon width), canyons are regular (H/W ~1), deep (H/W ~2) or avenue (H/W ≤ 0.5) canyons (Vardoulakis et al., 2003). Different dispersion conditions occur depending on the roof-level wind. For example, if the roof-level wind >1.5 m s^{-1} is perpendicular to an avenue canyon, a single vortex within the canyon is formed (Vardoulakis et al., 2003). The strength of the vortex depends on many factors, such as the wind speed at the roof-top level (Nazridous and Ahmadi, 2006), the turbulence induced by traffic and the roughness of buildings and trees within the street, and the atmospheric stability (Vardoulakis et al., 2003; Kumar et al., 2011). The traffic-produced turbulence dominates the mixing over the wind produced turbulence during calm wind conditions, whereas thermally produced turbulence may play a role during hot sunny weather and light winds (Kumar et al., 2011). Model studies by Nazridous and Ahmadi (2006) showed that the gaseous pollutant concentrations and particle deposition on the upwind side of the canyon is much higher than downwind.

Emissions from the traffic source and dilution with background air are the key processes in modifying particle number and size distributions in street scale. Aerosol dynamical processes such as nucleation, condensation, coagulation, and deposition play a minor role; time scales of those processes are discussed in the review paper by Kumar et al. (2011). Typically, in traffic environments number size distributions possess two modes peaking at 10–20 nm and 60–90 nm (e.g. Kumar et al., 2008; Voigtländer et al., 2006). Only a few mobile platform studies have been published in urban canyons and microenvironments (Hagler et al., 2010; Isakov et al., 2007; Kaur and Nieuwenhuijsen, 2009; Buonanno et al., 2011; Bowker et al., 2007).

The Finnish national research program MMEA (Measurement, Monitoring and Environmental Assessment, 2010–2014) aims to study particle chemistry in combustion processes in energy production and in traffic. One objective of the program is to develop advanced methods and utilize them in identifying different sources of particles from the urban atmosphere. As a part of the MMEA, a two and a half weeks street canyon campaign was performed in November–December 2010 in Helsinki, Finland. The physical and chemical characteristics of particles and gaseous concentrations were measured by a mobile laboratory van within the main city street Mannerheimintie and its side streets. In addition, stationary measurements were conducted by the air quality stations along the driving route. A manuscript concerning the general trends and wider perspective of traffic emissions during the measurement campaign at Helsinki downtown area is under preparation. The objective of this work is to describe the characteristics of spatiotemporally-produced high-resolution data in three different microenvironments, and particularly, to explore the effects of street geometry and roadside structure on the near-field dispersion of traffic emissions.

2. Experimental methods

2.1. Measurement design

Mobile measurements were performed along a main street Mannerheimintie (MA) and side streets on 29 November–14 December, 2010. Mannerheimintie passes through the city of Helsinki up to 5.4 km to north-west possessing four traffic lanes and two tramway tracks. Our measurements covered 3.8 km of MA from the city center. Although many sections of MA can be classified to street canyons, also half-open environments exist. Generally, MA is about 40 m wide and surrounded by ~21 m tall buildings at both sides. The aspect ratio is relative shallow ~0.5, but due to the large traffic intensity the street can be considered as a street canyon (Vardoulakis et al., 2003). In these cases the perpendicular air flow encounters the downwind building resulting in a wake interference flow which is characterized by the formation of a vortex within the canyon.

The mean traffic flow in the busy sections of MA is about 40 000 vehicles per workday, of which approximately 10% was estimated to be heavy duty diesel vehicles (HSY, 2011). The vehicle speed has been limited to 40 km h^{-1}; however, due to many crossings and traffic lights the mean velocity during rush hours was around 25 km h^{-1}. This campaign was scheduled to December since in winter the traffic-related particle number concentrations are 2–3 times higher than in summer (Pirjola et al., 2006; Virtanen et al., 2006).

On weekdays 29 November–12 December, a mobile laboratory van "Sniffer" was driving back and forth on MA during the morning rush hours at 8 am–11 am, afternoon rush hours at 3–6 pm, and occasionally also at noon at 11 am–2 pm. Furthermore, on Monday 13 December at 1–7 pm, and on 14 December at 8 am–2 pm, the mobile sampling were taken in three microenvironments M1, M2, and M3 by driving the routes shown in Fig. 1 (the arrows show the driving directions). Because the concentration field varied not only spatially but also temporally, the same routes were traversed five times. During these two days the northeastern wind was perpendicular to MA (Fig. 2) resulting in the favorable weather for the local dispersion studies in these microenvironments. Under these wind conditions, M1–M3 located in the downwind side of MA, and a stationary air quality station (AQS) in the upwind side (Fig. 1).