Atmospheric Environment 109 (2015) 42–51

Contents lists available at ScienceDirect

Atmospheric Environment

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

Heterogeneity of passenger exposure to air pollutants in public transport microenvironments

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HIGHLIGHTS

- Air pollutants were measured in categorized public transport microenvironments.
- High heterogeneity of pollutants concentrations exists in public transport system.
- Bus riders have higher integrated dose of exposure than railway riders.
- Self-pollution may be an important source of in-cabin pollutants in buses.

ARTICLE INFO

Article history:
Received 26 August 2014
Received in revised form
3 March 2015
Accepted 6 March 2015
Available online 6 March 2015

Keywords:
Black carbon
CO
Bus cabins
Roadside bus stop
Bus terminal
$PM_{2.5}$
Subway platform
Ultrafine particles

ABSTRACT

Epidemiologic studies have linked human exposure to pollutants with adverse health effects. Passenger exposure in public transport systems contributes an important fraction of daily burden of air pollutants. While there is extensive literature reporting the concentrations of pollutants in public transport systems in different cities, there are few studies systematically addressing the heterogeneity of passenger exposure in different transit microenvironments, in cabins of different transit vehicles and in areas with different characteristics. The present study investigated $PM_{2.5}$ (particulate matter with aerodynamic diameters smaller than 2.5 μm), black carbon (BC), ultrafine particles (UFP) and carbon monoxide (CO) pollutant concentrations in various public road transport systems in highly urbanized city of Hong Kong. Using a trolley case housing numerous portable air monitors, we conducted a total of 119 trips during the campaign. Transit microenvironments, classified as 1). busy and secondary roadside bus stops; 2). open and enclosed termini; 3). above- and under-ground Motor Rail Transport (MTR) platforms, were investigated and compared to identify the factors that may affect passenger exposures. The pollutants inside bus and MTR cabins were also investigated together with a comparison of time integrated exposure between the transit modes. Busy roadside and enclosed termini demonstrated the highest average particle concentrations while the lowest was found on the MTR platforms. Traffic-related pollutants BC, UFP and CO showed larger variations than $PM_{2.5}$ across different microenvironments and areas confirming their heterogeneity in urban environments. In-cabin pollutant concentrations showed distinct patterns with BC and UFP high in diesel bus cabins and CO high in LPG bus cabins, suggesting possible self-pollution issues and/or penetration of on-road pollutants inside cabins during bus transit. The total passenger exposure along selected routes, showed bus trips had the potential for higher integrated passenger exposure compared to MTR trips. The present study may provide useful information to better characterize the distribution of passenger exposure pattern in health assessment studies and the results also highlight the need to formulate exposure reduction based air policies in large cities.

1. Introduction

Numerous epidemiological studies have demonstrated

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http://dx.doi.org/10.1016/j.atmosenv.2015.03.009
1352-2310/

associations between exposure to air pollution and increased mortality (Dockery et al., 1993; Lin et al., 2013), while airborne fine particulate matter ($PM_{2.5}$, $d_p < 2.5$ μm) plays an especially important role in adverse impact on pulmonary and cardiovascular outcomes (Dreher, 2000). However, many epidemiological studies have assumed that routinely monitored ambient pollutant concentrations are surrogates for actual exposure, and few studies have addressed whether there is a predictable relationship between exposure and concentration in different locations within a city (Cao and Frey, 2011). This is especially true to urban areas where there is a heterogeneous distribution of pollutant concentrations in the ambient air and the public have different time/activity patterns in various microenvironments that contribute to daily exposure (Ostro et al., 2006).

Hong Kong is a highly urbanized city with a population of over 7 million, and a well-developed public transport system accounting for some 12 million passenger journeys every day, of which 41% are by Mass Transit Railway (MTR), followed by 32% with diesel-fuelled franchised buses and 15% with Liquefied Petroleum Gas (LPG) public light buses (HKTD, 2013). Such heavy reliance on public transport makes individual exposure to air pollutants inside the transport system a potentially significant component of daily integrated exposure. Although most commuters spend only a short fraction of time daily in the transport system, high pollution levels experienced during travel may contribute significantly to total individual exposures (Nieuwenhuijsen et al., 2007). Seaton et al. (Seaton et al., 2005) investigated commuter exposure to $PM_{2.5}$ in London and found spending 2 h in the metro system per day would increase personal 24-h exposure by 17 μg m^{-3}.

Studies in various cities have also shown that public transport system may represent a combination of unique microenvironments with different source characteristics making them quite different from those typical outdoors or even indoors (Both et al., 2013; Knibbs et al., 2011). Passengers can be exposed to the air pollutants substantially different from those at street level air in terms of gas concentrations and PM concentrations and chemical composition (Aarnio et al., 2005; Kam et al., 2011b). For example, investigators (Cheng et al., 2012; Nieuwenhuijsen et al., 2007) observed a considerable increase (~20–50 % greater) of $PM_{2.5}$ mass concentration compared to outdoor air. Thus ambient air monitoring data cannot be effectively used to estimate the daily dose of exposure with different characteristics of air pollutants in transit system.

During the last decade, a few studies in Hong Kong investigated passenger pollution exposure levels. Chan et al. (Chan et al., 2002) measured $PM_{2.5}$ and PM_{10} mass concentrations in four different transport modes including the railway system and buses. Recently, Wong et al. (Wong et al., 2011) measured carbon monoxide and $PM_{2.5}$ concentrations inside bus cabins in Hong Kong. These previous studies clearly demonstrated that $PM_{2.5}$ displayed different characteristics in comparison with ambient environments. However, there were no systematic investigations of the distribution of traffic-related pollutants, such as black carbon (BC), ultrafine particles (UFP) in different transport microenvironments, which limits our accurate understanding of the daily dose of exposure and knowledge of exposure mitigation measures. This study investigates $PM_{2.5}$, BC, UFP and CO distributions in transport microenvironments and in cabins of different transit modes, including diesel franchised buses, LPG public light buses and the MTR system. Total exposure on typical commute routes by different transit modes was also compared. The results of the study should allow more accurate estimates of population daily dose for epidemiologic research and provide a basis for exposure reduction based air policy making.

2. Experimental methodology

2.1. Portable instrumentation

Pollutant concentrations were measured using a Mobile Exposure Measurement System (MEMS) with a trolley case housing portable air monitors, a data acquisition system and a global positioning system (GPS) as shown in Fig. 1. A portable condensation particle counter (CPC, TSI 3007) was used to measure ultrafine particle (UFP) number concentration. Although the CPC measured particles in the size range of 10–1000 nm, number concentration is dominated by smaller sized particles (diameter <100 nm) (Morawska et al., 2008). A micro Aethalometer (microAeth® Model AE51, Aethlabs) was used for measuring black carbon (BC) concentration. An Optical Particle Sizer (OPS, TSI® model 3330) was used for $PM_{2.5}$ concentration measurement and a Q-trak (TSI® model 7575) was installed in a backpack to monitor carbon dioxide (CO_2), carbon monoxide (CO), relative humidity (RH) and temperature (T) at high temporal resolution (one second). All instruments were connected to a mini-PC (NUC, Intel®) and the real-time data were collected and transferred to a mobile phone through Bluetooth. The measurements were displayed on the screen through a cell phone application developed by the investigators to track instrument conditions and tag special events during the campaign. Screenshot of the app is included in Fig. 1b. All instruments and batteries were wrapped with sponge sheets and fitted snugly into the suitcase. A diffusion dryer was installed upstream of the OPS and microAeth to avoid interference from water vapour (Zieger et al., 2013; Cai et al., 2013), respectively.

2.2. Description of transport microenvironments

The campaign covered three dominant transit modes of the public transport system of Hong Kong: the MTR, diesel franchised buses and LPG public light buses. During transit, a passenger may experience a variety of microenvironments depending on the mode of transport, the characteristics of surrounding sources and the built environment. Thus the air pollutant concentrations experienced are characterised by a unique pattern of local activities. The present study investigated six main microenvironments including busy and secondary roadside bus stops, open and enclosed bus termini, aboveground (AG) and underground (UG) MTR platforms. Detailed descriptions of the microenvironments characteristics are listed below and Fig. 2 shows the coverage of the microenvironments in the study areas and routes.

2.2.1. Busy and secondary roadside bus stops

Transport by diesel franchised buses and LPG public light buses carries 3.8 and 1.9 million daily passenger journeys (HKTD, 2013). Waiting at roadside bus stops is an important component of a commuter's daily exposure because of the proximity to road traffic emissions. We separated the roadways by their annual average daily traffic (AADT) into busy road (AADT>30,000 vehicles per day) and secondary road (AADT<20,000 vehicles per day), which also reflects the distribution of the public transport such as bus routes and number of bus stops, as well as roadway characteristics (HKTD, 2013).

2.2.2. Open and enclosed termini

Different from roadside bus stops where there exists continuous flow of traffic during a passenger's wait, the bus terminus is a unique microenvironment as a transport interchange busy with buses collecting or discharging passengers and exposure can be enhanced by emissions during vehicles idling, acceleration and deceleration. Dependent on the ventilation and the surrounding