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Concentrations of polycyclic aromatic hydrocarbons in resuspendable fraction of settled bus dust and its implications for human exposure

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ABSTRACT

This preliminary study measured Polycyclic Aromatic Hydrocarbons (PAHs) concentrations in the resuspendable fraction of settled dust on 39 bus lines, to evaluate the impact of engine type (gasoline and compressed natural gas) on exposure for commuters and drivers. Benzo(b)fluoranthene(BbF) was the predominant PAH in resuspendable fraction of settled bus dust. The concentration of total PAHs was 92.90 ± 116.00 μg/g (range: 0.57–410) in gasoline buses and 3.97 ± 1.81 (range: 2.01–9.47) in compressed natural gas (CNG) buses. Based on Benzo[a]pyrene (BaP) equivalent concentrations for the sum of 16 PAHs, the average daily dose (ADD) via dust ingestion and dermal contact was calculated. The ADD of PAHs was higher for commuters and drivers in gasoline-powered buses than in buses using CNG buses. For both short and long duration journeys, young commuters were exposed to higher levels of PAHs via dust ingestion and dermal contact than adult commuters.

1. Introduction

Dust particles with a diameter below 75 μm can settle out of the atmosphere under their own weight, but may remain suspended for long periods (ISO, 1994). According to the Glossary of Atmospheric Chemistry Terms (ISO, 1994), small, dry, solid dust particles can be projected suspended into the air by natural forces (such as wind) and by mechanical or man-made processes. Dusts particles are usually in the size range from about 1 to 100 μm in diameter, and they settle slowly under the influence of gravity (IUPAC, 1990). After being suspended and resuspendable, dust particles containing pollutants can have a detrimental effect on human health via ingestion and dermal contact (Shi et al., 2011; Luo et al., 2011; Komarek et al., 2008; Lu et al., 2011). Urban residents are in frequent proximity to traffic emissions. The microenvironment of urban transportation systems such as buses can pose potential health risks to passengers and drivers due to exposure to the resuspendable fraction of settled dust. After being suspended and resuspendable by different air exchange systems and passenger activities, dust particles (particles < 100 μm) readily adhere to the hands of passengers and drivers, and can then be subsequently ingested through hand-to-mouth contact and enter the respiratory system (Brauer et al., 2002; USEPA, 2009). Therefore, pollutants in the resuspendable fraction of settled dusts pose potential health risks to passengers and drivers in the microenvironment of buses.

Polycyclic aromatic hydrocarbons (PAHs) are among the most widespread organic pollutants. In addition to their natural occurrence in fossil fuels, most PAHs in the environment are produced as byproducts of incomplete combustion. As a group of pollutants, PAHs are of concern because some of them are known animal carcinogens and possible human carcinogens (IARC, 2010; USEPA, 2013). Previous studies have also indicated that exposure to PAHs can result in adverse birth outcomes, subclinical immunological changes, and childhood asthma (Choi et al., 2008; Nadeau et al., 2010; Gale et al., 2012; Padula et al., 2012, 2013a, 2013b, 2013c). Moreover, prenatal exposure to PAHs has been associated with a delay in cognitive developmental, IQ deficit and increased

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behavioral problems in school age children (Perera et al., 2006, 2009, 2012).

Because it has been reported that the levels of traffic related air pollutants are substantially higher in vehicle cabins than in ambient air (Perera et al., 2012; Behrentz et al., 2005; Duffy and Nelson, 1997; Jo and Park, 1999; Leung and Harrison, 1999), in-vehicle exposure may have a significant impact on an individual's overall exposure to these pollutants (Gomez-Perales et al., 2004; Fruin et al., 2004; Apte et al., 2011; Bigazzi and Figliozzi, 2012). However, despite the fact that motor vehicle emissions have been identified as a major source of PAHs, information on the occurrence of PAHs within urban public transportation systems and the subsequent human exposure is limited.

Public transportation remains an integral part of urban transportation systems, but occupational and non-occupational exposures to pollutants in public transportation have received little research. Most previous research has focused on the concentration and distribution of indoor and outdoor environmental pollutants. However, no study has been conducted on the health effects of exposure to pollutants inside public transportation systems. Considering the relatively little time spent by urban populations in outdoor environments, the dilution effects of natural wind, and the shorter cleaning cycle of indoor environments than of buses, studying the microenvironment of the urban transport system is essential for understanding how non-dietary exposure to PAHs affects urban populations. Elucidating the concentrations of PAHs is thus essential for estimating their inputs into the bus microenvironment and the commuter respiratory system, tracing their origins, and understanding their transformation and transportation. As both a source and sink of suspended particulate matter in the microenvironment of a bus, settled dust may play an important role in the exposure to PAHs in urban public transport systems. In this study, we undertook a preliminary study to measure PAH concentrations in the resuspendable fraction of settled dust on major bus lines in Harbin, China and estimated the subsequent human exposure.

Harbin is an old industrial city in the northeast of China with a population of 5 million. Buses are the major public transportation tools in the city. According to Harbin Bureau of Statistics, the 5020 buses that operate on 154 bus lines carry over 2.85 million trips, which accounts for 34.8% of city's daily commuter trips (CTNN, 2011). For people who rely on bus services for daily transport, PAHs in the resuspendable fraction of settled dust may contribute substantially to their overall daily PAH exposures. Given the large number of people using buses every day, PAH exposure during commuting may have potential health effects.

To evaluate the exposure in buses with different engines, we collected the resuspendable fraction of settled dust samples from both gasoline- and compressed natural gas (CNG)-powered buses, respectively. The specific aims were (1) to measure PAH concentrations in the resuspendable fraction of settled dust from major public bus services that were fueled by either gasoline or CNG; (2) to estimate the average daily dose associated with exposures to the PAHs in the resuspendable fraction of settled dust via ingestion and dermal contact for passengers and drivers; and (3) to assess the impact of engine type on PAH concentrations in the resuspendable fraction of settled bus dust and thus on the estimated exposure.

2. Materials and methods

2.1. Sample collection

Settled dust samples were collected on days when no rain had occurred during the previous week, from 39 major bus routes in Harbin, in August 2012. Sampling temperature was around 21 °C in the microenvironment of buses. Settled dust samples were collected from the PVC plastic floor in the front, middle and back sections of the buses. In this study, a commercial vacuum cleaner (Philips FC6130) was connected to a polyvinyl chloride tube containing a nylon cloth filter in the middle to remove small stones and debris. No carriage was in a closed state in the use of a vacuum cleaner to collect settled dust. In the 39 bus lines chosen in this study, the bus driving was mainly through the windows to make air circulation of inside and outside environment and adjust the temperature. Each sample was an amalgamation of dust collected from two to three buses from each bus route. This enables a sufficient amount of settled dust to be collected to get the resuspendable fractions of settled bus dust and undertake a chemical analysis of PAHs. Settled dust samples were collected on the floors of aisles in the front, middle, and back sections of the buses. The samples were air-dried at room temperature and then sieved to obtain the resuspendable fraction of settled bus dust (diameter <20 μm) using a mechanical sieve shaker (Whitehead et al., 2013). All 39 bus lines were used by buses powered by either gasoline ($n = 22$) or CNG ($n = 17$), allowing the impact of engine type on human exposure to be evaluated. The bus lines were selected at random, and were defined as trans-regional lines that covered the main urban areas of Harbin. For each bus line, only a small number of bus stops were located in the neighborhood of factories. Therefore, in this study, no consideration was made of the impact of industrial pollution on pollutants attached to settled dust.

2.2. Extraction and analysis of PAHs

Dust samples (about 0.5 g) were spiked with four internal standards (deuterated naphthalene-d8 (Nap-d^8), acenaphthene-d10 (Ace-d^{10}), phenanthrene-d^{10} (Phe-d^{10}), and benzo(a)pyrene-d^{12}(BaP-d^{12})), extracted with 100 ml acetone/dichloromethane/n-hexane (1:1:1, v/v/v) in Soxhlet apparatus for 16 h (USEPA, 1996a). The concentrated extract was cleaned using a florisil column according to an EPA Standard Method (USEPA, 1996b). The extractions were analyzed for PAHs using a Hewlett–Packard (HP) 6890N gas chromatograph (GC) coupled with an HP-5973mass selective detector (MSD) and a 30 m × 0.25 mm × 0.25 μm DB-5 capillary column (J & W Scientific Co. Ltd., USA) using the EPA Standard method (USEPA, 1996c). Sixteen U.S. EPA priority 2- to 6-ringPAHs were examined: Naphthalene (Nap), Acenaphthylene (Acy), Acenaphthene (Ace), Fluorine (Flu), Phenanthrenes (Phe), Anthracene (Ant), Fluoran-thene(Flu), Pyrene (Pyr), Benzo(a) anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF), Benzo(a)pyrene (BaP), Indeno(1,2,3-c,d)pyrene (Ind), Dibenzo(a,h)anthracene (DaA), and Benzo(g, h, i) perylene (BghiP).

Quality assurance and quality control (QA/QC) included method blanks, standard spiked recoveries and duplicate samples. One laboratory blank was run with every five dust samples. None of 16 PAHs was detected in the method blanks. Four surrogate standards (Nap-d^8, Ace-d^{10}, Phe-d^{10}, and BaP-d^{12}) were spiked directly into all dust samples to monitor the procedures of sample extraction, cleanup, and analysis. The average recoveries of deuterated PAHs varied from 83% to 97%. The average recoveries in the spiked samples ranged from 74% (for Flu) to 100% (for DaA) for the 16 PAHs. We also ran duplicated samples for every ten samples. The relative standard deviation for duplicate samples was below 10% for each PAH. The instrument detection limit is defined as the lowest concentration of analyte that gives a signal to noise ratio of 3:1, while method limit of detection was practically determined from the lowest concentration of the calibration standards for each PAH in this study. The sample detection limit in this study ranged from 0.3 to 1.12 ng/g dry weight.