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Ultrafine particle air pollution inside diesel-propelled passenger trains☆

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ABSTRACT

Locomotives with diesel engines are used worldwide and are an important source of air pollution. Pollutant emissions by locomotive engines affect the air quality inside passenger trains. This study is aimed at investigating ultrafine particle (UFP) air pollution inside passenger trains and providing a basis for assessing passenger exposure to this pollutant.

The concentrations of UFPs inside the carriages of push-pull trains are dramatically higher when the train operates in pull mode. This clearly shows that locomotive engine emissions are a dominant factor in train passengers' exposure to UFPs. The highest levels of UFP air pollution are observed inside the carriages of pull trains close to the locomotive. In push mode, the UFP number concentrations were lower by factors of 2.6–43 (depending on the carriage type) compared to pull mode. The UFP concentrations are substantially lower in diesel multiple-unit trains than in trains operating in pull mode. A significant influence of the train movement regime on the UFP NC inside a carriage is observed.

1. Introduction

Epidemiological studies have demonstrated that human exposure to air polluted by particles is associated with various adverse health effects, including respiratory and cardiovascular disease (Vallero, 2008; Chuang et al., 2007). The published research results suggest that ultrafine particles are more harmful to human health than larger ones because smaller particles can penetrate cell membranes and are transported within the blood stream to the human brain, liver, among other organs (Slezakova et al., 2013; Knibbs et al., 2011; Hoet et al., 2004).

Previous studies have mainly focused on investigating passengers' exposure to particulate air pollution (PM10, PM2.5, PM1 and UFPs) inside cars, buses, and bicycles; near highways; and at bus stations (Farrell et al., 2016; Gramotnev and Gramotnev, 2005; Kingham et al., 2013; Tartakovsky et al., 2013; Whitlow et al., 2011; Zhang and Zhu, 2010; Zuurbier et al., 2010; Joodatnia et al., 2013). A comprehensive review of passengers' exposure to particulate air pollution while commuting in various transportation modes was performed by Karanasiou et al. (2014). Recently, trains have attracted the attention of researchers, and the main focus has been on train emission factors and subway systems (Yan et al., 2015; Jaffe et al., 2014; Burchill et al., 2011; Abbasi et al., 2013; Salma et al., 2007; Braniš, 2006; Aarnio et al., 2005; Johansson and Johansson, 2003).

The worldwide railway passenger transport activity is constantly growing and was increased by more than 50% from 2003, reaching a level above 3.1 trillion passenger-km in 2012 (UIC–International Union of Railways, 2015). In China, the railway passenger turnover in 2015 was 1.3 trillion passenger-km (Xu et al., 2011). In Russia, passenger turnover by rail in 2010 was 28.7% of the total passenger transportation and almost the same as that by buses (28.9%) (Alexeyev, 2011). At the same time, it is important to note that in 2010 each passenger travelled an average of 146.1 km by railway compared with only 10.4 km by bus (Alexeyev, 2011). Considering the similar speeds of these transport modes, it is clear from the provided example that railway passengers spend much more time in trains than in buses. In the European Union (EU), the relative importance of passenger transport by train is increasing steadily at the expense of using buses and trolley buses (Eurostat, 2016).

Only approximately 1/3 of the total railway line length is electrified worldwide (UIC–International Union of Railways, 2015). Diesel-powered trains are widely used around the globe as a standard technological solution for train propulsion on non-

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electrified rail lines. In some regions, such as North America, almost all railway transportation is based on diesel propulsion (UIC–International Union of Railways, 2015). Railway lines sometimes pass through densely populated areas. The region of Tel Aviv is a good example (Tel-Aviv). Commuters actively use the railway, even for short journeys. The passenger traffic for Israel (the country of 8 million inhabitants) is 4 million people per month (Sela, 2014). On average, commuters spend two and a half hours per day travelling to and from work and waiting for trains at train stations. In countries with long travel distances, passengers are exposed to significant levels of air pollution, including the dangerous particulate matter (PM) produced by diesel engines, for long periods of time. Morawska et al. (2013) showed that indoor sources contribute up to 76% of the integrated daily residential exposure to ultrafine particles, which further stresses the importance of assessing train passengers' exposure to UFPs.

Progress on the investigation of particle emissions from rail vehicles is reviewed in the work by Abbasi et al. (2013). Both exhaust and non-exhaust particle emissions were considered in this review. While exhaust-generated particles are mainly attributed to locomotive engine and diesel-generator emissions, non-exhaust particles normally originate from wheel-rail contact, brakes wear, outdoor particles re-suspended by train motion and particles in passenger compartments that are re-suspended due to carriage vibrations and passenger movement (Tartakovsky et al., 2013; Abbasi et al., 2012, 2013). The authors of a previous study (Abbasi et al., 2013) discussed PM10 and PM2.5 emissions, particle size, morphology, composition, and adverse health effects with various solutions for reducing these emissions. Air pollution by particulates of PM10 and PM2.5 size fractions, as well as the particle number concentrations, have been measured inside electricity-powered trains and on the platforms of subway stations in various cities worldwide, e.g., Budapest (Salma et al., 2007), Prague (Braniš, 2006), Helsinki (Aarnio et al., 2005), Stockholm (Johansson and Johansson, 2003), Gothenburg (Boman et al., 2009), Seoul (Park and Ha, 2008), Taipei (Cheng et al., 2012), and Barcelona (Martins et al., 2016). The authors of these studies found that air pollution by particles inside electricity-powered train carriages was usually higher than in outdoor air. Aarnio et al. (2005) measured the particle number (size < 500 nm) concentrations and size distributions at an underground subway station and found them to be similar to those measured in the outdoor air, concluding that the source of particles of this size was road traffic. However, other researchers (Salma et al., 2007; Martins et al., 2016) reported that the composition of particles measured in subway stations differed from the average outdoor composition, attributing the PM found in the underground stations and inside subway trains to the wear of rails, train wheels and brake pads. Seshagiri (2003) studied the exposure of personnel in the cabs of leading and trailing locomotives of freight trains to gaseous and particle emissions during winter and summer. Negligible levels of elemental carbon (EC) were measured in the leading locomotive. In the trailing one, the measured in winter mean EC levels were 2.9 μg/m3, which is close to the detection limit of 2.0 μg/m3 (Seshagiri, 2003; Pronk et al., 2009). In summer, when windows were open from both sides of the locomotive, mean EC concentrations of 17.1 μg/m3 were measured. Liukonen et al. (2002) studied exposure of the locomotive's crew to diesel exhaust. They investigated the influence of the locomotive orientation ("long-hood" or "short-hood" forward), which affects the exhaust tailpipe position relative the crew cabin, on the air pollution levels inside the cabin. Liukonen and co-workers showed that open windows and an exhaust tailpipe position in front of the locomotive cabin had a substantial influence on the EC levels inside the cabin. Seshagiri and Liukonen, with their co-authors, did not study the UFP levels in passenger train carriages. Abadie et al. (2004) investigated passenger exposure to particulate air pollution in French high-speed train (TGV) smoker cars. Knibbs and de Dear (Knibbs and de Dear, 2010) measured the indoor concentrations of UFP and PM2.5 at the time of commuting along a similar route by train, bus, ferry and car in Sydney, Australia. The average concentration of UFPs in trains was found to be 2.8×10^4 cm^{-3}. The trains were powered by electricity delivered by overhead lines. Knibbs et al. (2011) reviewed 'in-transit' UFP exposure of commuters for six different transport modes: car, bus, bicycle, walking, ferry and train. They pointed out that a majority of train UFP exposure studies were performed on electricity-powered trains rather than the diesel-propelled ones. The limited available data overviewed in Knibbs et al. (2011) suggest that diesel trains may cause a much higher UFP exposure level compared with electricity-powered trains. Despite the data gained on train emissions and particle air pollution in subway systems, information related to the UFP levels in the indoor environment of diesel-propelled passenger trains, dependence of the UFP concentrations inside a carriage on the location relative to the locomotive and diesel-generator, spatial variation of the UFP concentrations inside a carriage, influence of the train operating mode, among other factors is fragmentary and not well documented.

This study aims to assess the UFP concentrations in the indoor environment of different passenger train types as well as to identify the main factors that affect the UFP concentrations in train passenger carriages and railcars. The concentrations of UFPs were analyzed with respect to various parameters, such as the carriage age, type, carriage location in the train, train operating mode (push or pull) and more.

2. Methodology

2.1. Instrumentation

The ultrafine particle number concentrations inside passenger train carriages were measured by a diffusion size classifier (DiSC, Matter Engineering AG, Switzerland). This device is a small, easily portable, battery operated instrument and is therefore well suited for field measurements. The main specification parameters of the DiSC are shown in Table 1. Although DiSC is somewhat less accurate (±30%) and sensitive than other frequently used laboratory devices, such as Condensation Particle Counter – CPC (accuracy ±10%) and Scanning Mobility Particle Sizer – SMPS, the DiSC is highly applicable for field measurements due to its compactness, portability and self-contained power supply.

Previously reported detailed tests with this instrument (Fierz et al., 2008) revealed that the measured UFP number concentrations agree well with those obtained by using CPC. The time resolution of this device allows for measurement of transient engine operation.

The instrument requires recalibration after 500 h of operation (Fierz et al., 2008). Moreover, cleaning the instrument's diffusion stage and replacing the filter in the filter stage are required when the differential pressure through an instrument with an open inlet connection reaches 10 mbar. The Pressure Error LED on the front panel of the device provides a signal when the critical pressure is reached. To ensure the quality of the data collection, both the instrument operation time and Pressure Error LED signal were carefully monitored. When completing the measurement program reported in this paper, no instrument recalibration was required. There was no need to clean and replace the filter during the period of experiments reported in this work. To ensure the best possible accuracy of the measurements, the zero reading of the instrument was checked daily before the start of measurements.

In the reported experiments, we did not use an evaporation