Environment International 107 (2017) 33–46

Contents lists available at ScienceDirect

Environment International

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

Review article

Air quality inside subway metro indoor environment worldwide: A review

Bin Xu*, Jinliang Hao

State Key Laboratory of Pollution Control and Resource Reuse, Tongji University, Shanghai 200092, China
Department of Environmental Engineering, Tongji University, Shanghai 200092, China

ARTICLE INFO

Keywords:
Air quality
Metro environment
Air pollutant
Particulate matter
Volatile organic compounds

ABSTRACT

The air quality in the subway metro indoor microenvironment has been of particular public concern. With specific reference to the growing demand of green transportation and sustainable development, subway metro systems have been rapidly developed worldwide in last decades. The number of metro commuters has continuously increased over recent years in metropolitan cities. In some cities, metro system has become the primary public transportation mode. Although commuters typically spend only 30–40 min in metros, the air pollutants emitted from various interior components of metro system as well as air pollutants carried by ventilation supply air are significant sources of harmful air pollutants that could lead to unhealthy human exposure. Commuters' exposure to various air pollutants in metro carriages may cause perceivable health risk as reported by many environmental health studies. This review summarizes significant findings in the literature on air quality inside metro indoor environment, including pollutant concentration levels, chemical species, related sources and health risk assessment. More than 160 relevant studies performed across over 20 countries were carefully reviewed. These comprised more than 2000 individual measurement trips. Particulate matters, aromatic hydrocarbons, carbonyls and airborne bacteria have been identified as the primary air pollutants inside metro system. On this basis, future work could focus on investigating the chronic health risks of exposure to various air pollutants other than PM, and/or further developing advanced air purification unit to improve metro in-station air quality.

1. Introduction

Air pollutant exposure has been extensively studied and approved to be a vital cause of increased perceivable health risk (Pope and Dockery, 2006; Dockery et al., 1993; Araki et al., 2010). Indoor microenvironment was identified as the primary source of human exposure to various air pollutants due to the long time people spent every day (Klepeis et al., 2000). Recently, with the rapid development of subway metro system worldwide, human exposure to air pollutants and the related health risk assessment inside metro indoor environment have become of a significant public concern.

Metro transit, by avoiding congestion and reducing gasoline consumption, is providing rapid and affordable transportation to urban communities in > 60 countries. The number of metro commuters has continuously increased over recent years in metropolitan cities. In some cities, metro system has become the primary public transportation mode. For example, Shanghai, as a prosperous and densely populated city, has one of the largest urban metro traffic systems in the world. Daily ridership averaged 9 million in 2015 and reached a record of about 11.3 million on March 11th, 2017.

With such large population of metro riders, metro systems not only need to provide the economic benefits, but also a safe and healthy environment for both passengers and workers. Since metro system infrastructures and operation condition varied significantly at different countries, this review summarized the findings from previous literature according to different geographic divisions (Asia, America, Europe, others). For all continents, the metro air research work always began from the measurement of pollutant exposure level and the identification of pollutant chemical speciation. In the previous literature, particulate matters, aromatic hydrocarbons, carbonyls and airborne bacteria have been identified as the primary air pollutants in the metro air. Then, the influence of ventilation on metro air quality were generally investigated, and mitigation measures to reduce air pollutant concentrations were developed and evaluated. It was reported that some factors may affect air pollutant exposure levels in metro carriages, including service time, ventilation quality, passenger numbers, platform screen doors and driving conditions, etc. (K.Y. Kim et al., 2008; Kim et al., 2011; Mugica-Álvarez et al., 2012a; Moreno et al., 2014a; Hernández-Castillo et al., 2014a; Martins et al., 2015a; Zhang et al., 2012; Shiohara et al., 2005a). Recent studies, especially in Europe, paid more and more

* Corresponding author at: Department of Environmental Engineering, Tongji University, Shanghai 200092, China.
E-mail address: binxu@tongji.edu.cn (B. Xu).

http://dx.doi.org/10.1016/j.envint.2017.06.016
Received 29 March 2017; Received in revised form 27 May 2017; Accepted 20 June 2017

attention on the health risk from exposure to metro air pollutants. To examine this issue more carefully, this structured review of the literature was conducted to characterize air pollutants, discuss possible determinants, introduce health implications, and suggest future research inside metro indoor environment. Over 160 relevant articles were selected and reviewed.

2. Asia

Asian metro system in urban area was relatively new and developed very fast following to the formation of metropolitan cities in last decade. As the population of people and automobile increased in metropolitan area, metro was recognized as a sufficient solution to road traffic congestion and urban air quality deterioration. Metro indoor air quality was then received increasing public attentions. To date, > 80 articles on the topic of pollutant species, their sources and concentrations, control measures have been published regarding to Asian metro system. Research interests and focus varied with different national regulations and stages of development. Current air quality studies in Asian metro system focused too much on the assessment of pollutant concentration or people exposure levels. Excessive measurements were conducted under the similar conditions. Most of the studies were conducted in East Asia area. The measurement results and information were summarized in Table 1.

2.1. Air pollutants

Various air pollutants were observed in the metro environment, which is mainly ascribed to the emissions from rails, wheels, catenaries, brake pads, pantographs, and infiltration from out-station polluted air (Kang et al., 2008; Park et al., 2014). The difference of metro system designs led to a large variation in occurrence of air pollutants species, levels and hence personal exposure levels. At the beginning, vehicular exhaust emission was recognized as a primary air pollutant source and studied extensively in the Asian metro system. Chan et al. (1999) conducted a comprehensive survey to evaluate commuter exposure to air pollutants inside different commuting microenvironments in Hong Kong. Hong Kong metro system served about 21% of the public transport passengers. Three individual lines namely Tsuen Wan line, Kwun Tong line and Island line were operated mostly on underground tracks. Traffic-related pollutants, e.g. CO, NOx, THC (Total Hydro Carbon) and O_3 were used as the target pollutants. It was found that all the air pollutant concentrations inside metro were comparable to the other transit modes, although it was enclosed from road atmosphere. The same group also examined the commuter's exposure to respirable suspended PM and VOCs while commuting in eight public transportation modes. The PM_{10} concentration (~50 μg m^{-3}) inside metro was found the lowest (Chan et al., 2002a). The VOCs concentrations (3.0–3.8 μg m^{-3}) inside metro was ranked the second place after the roadway transport cabins (Lau and Chan, 2003). The PM and VOCs exposure levels of metro commuters in Hong Kong were lower than those in most overseas cities. The heterogeneity of passenger exposure in different transit microenvironments were then studied in Hong Kong. Traffic-related pollutants were found larger variations than $PM_{2.5}$ across different microenvironments. The lowest average $PM_{2.5}$ concentrations were observed in the metro platform air (F. Yang et al., 2015). An independent approach unravelling the bacterial diversity within the Hong Kong metro system was used. It was found that microbial diversities and assemblages varied depending on architectural characteristics, nearby outdoor microbiomes, and connectedness with other lines (Leung et al., 2014). After Hong Kong, dozens of measurement campaigns were conducted all over the Asian metropolitan cities.

Li et al. (2006) and Li et al. (2007) measured the concentrations of CO_2, CO, TVOC, TSP (Total Suspended Particle), PM_{10}, $PM_{2.5}$, PM_1, benzene, toluene and xylene in Beijing metro transit system. Only CO showed significant seasonal variations (greater in winter than in summer). The concentrations of TVOC, TSP and PM_{10} were significantly higher during rush hours than during regular hours. The in-train concentrations of VOC species were mainly influenced by the ambient pollutant concentrations; while the in-train concentration of CO_2 was mainly influenced by the number of passengers. Exposure to fine particles as well as particulate PAHs (Polycyclic Aromatic Hydrocarbons) in three transportation modes (walking, metro and bus) were examined in Beijing. The lowest median $PM_{2.5}$ mass concentration (56.9 μg m^{-3}) and particle number concentrations (2.2×10^4 cm^{-3}) were observed in metro system (Yan et al., 2015). The characteristics of carbonyl compounds were investigated for taxi, bus and metro in Beijing. Metros energized by electricity without exhaust had the lowest levels with total concentrations of 98.5 ± 26.3 μg m^{-3} (Pang and Mu, 2007). Compared to PM and VOCs, high culturable bacteria (12,639 CFU m^{-3}) and fungi (1806 CFU m^{-3}) concentrations were observed for the metro system, respectively (Dong and Yao, 2010).

Different from Beijing, most of the previous studies in Shanghai focused on the PM exposure levels in metro system. The mean levels of PM_1, $PM_{2.5}$, and PM_{10} were observed at 231 ± 152, 287 ± 177, and 366 ± 193 μg m^{-3}, respectively (Ye et al., 2010; Xu et al., 2013; Qiao et al., 2015a; Xu et al., 2016). Commuters' real-time exposure to PM and BC (Black Carbon) by several common travel modes (bus, walking, cycling, taxi and subway) were measured. The average PM_1 exposure levels and inhalation doses during commuting were 122 ± 77 μg m^{-3} and 28.6 ± 25.9 μg for metro trips (Yu et al., 2012). The average BC exposure concentrations and inhalation doses during commuting were 9.43 ± 2.89 μg m^{-3} and 0.95 ± 0.29 μg for metro trips, respectively (Li et al., 2015). Measurements were conducted to assess PM levels, chemical compositions, morphology and mineralogy. Newer underground metro system showed lower PM pollution than the old aboveground system, which was likely attributable to the advanced ventilation setup and air filter. Fe, Mn, Cr, Cu, Sr, Ba and Pb concentrations in all of the metro lines were significantly higher than those in the urban ambient air, implicating that these metals may be associated with the metro systems operation (Guo et al., 2014; Lu et al., 2015). Fe was observed as the most abundant metal element, following by Ca, Al, Mg, Mn, Zn, Cu, Cr, Ni, Pb and Hg (Qiao et al., 2015b). Only a few studies measured VOCs concentrations inside metro system in Shanghai. The exposure levels of in-train VOCs (benzene, toluene, ethylbenzene, xylene, styrene, formaldehyde, acetaldehyde, acetone and acrolein) were strongly dependent on service time of metro trains, passenger numbers and driving conditions (Gong et al., 2017). The total carbonyl concentrations of in-train were about 1.4–2.5 times lower than in stations. Most carbonyls concentrations were much higher in the morning rush hour than in other time (Feng et al., 2010).

Other than Hong Kong, Beijing, Shanghai, there has not been a large number of relevant research in other Chinese cities. Only a few field measurements intermittently reported the metro indoor air quality in those cities. Chan et al. (2002b) and Chan et al. (2003) examined commuter exposure to respirable PM (PM_{10} and $PM_{2.5}$), CO, and VOCs in various public transport environments (metro, bus and taxi) in Guangzhou. For all the measured pollutants, the exposure levels in metro were noticeably lower than those in the roadway transports. The exposure levels measured in evening peak hours were slightly higher than those in afternoon non-peak hours. The metro air quality assessment in Tianjin showed the average concentration of the $PM_{2.5}$ was 151.43 μg m^{-3} inside the metro train during rush hours (Wang et al., 2016). $PM_{2.5}$ concentrations on the platform were higher than those inside train. The highest element in $PM_{2.5}$ samples was Fe with the level at 17.55 μg m^{-3} (Wang et al., 2016). In Taipei metro system, experimental results demonstrated that PM levels inside trains (8–68 μg m^{-3}) and on platforms (7–100 μg m^{-3}) were lower than those measured for other metro systems worldwide (Cheng et al., 2008; Cheng and Lin, 2010). The same group later extended the investigation to more metro lines as Taipei metro system developed. Measurement results showed that PM_{10}, $PM_{2.5}$ and CO_2 levels inside metro trains travelling