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Estimation of inhaled airborne particle number concentration by subway users in Seoul, Korea☆

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ABSTRACT

Exposure to airborne particulate matter (PM) causes several diseases in the human body. The smaller particles, which have relatively large surface areas, are actually more harmful to the human body since they can penetrate deeper parts of the lungs or become secondary pollutants by bonding with other atmospheric pollutants, such as nitrogen oxides. The purpose of this study is to present the number of PM inhaled by subway users as a possible reference material for any analysis of the hazards to the human body arising from the inhalation of such PM. Two transfer stations in Seoul, Korea, which have the greatest number of users, were selected for this study. For 0.3–0.422 μm PM, particle number concentration (PNC) was highest outdoors but decreased as the tester moved deeper underground. On the other hand, the PNC between 1 and 10 μm increased as the tester moved deeper underground and showed a high number concentration inside the subway train as well. An analysis of the particles to which subway users are actually exposed to (inhaled particle number), using particle concentration at each measurement location, the average inhalation rate of an adult, and the average stay time at each location, all showed that particles sized 0.01–0.422 μm are mostly inhaled from the outdoor air whereas particles sized 1–10 μm are inhaled as the passengers move deeper underground. Based on these findings, we expect that the inhaled particle number of subway users can be used as reference data for an evaluation of the hazards to health caused by PM inhalation.

1. Introduction

With the ever increasing number of city commuters, concerns over the air quality on modes of transport has become an important issue and many studies have analyzed the exposure level of commuters to airborne particles (Cheng et al., 2009; Kingham et al., 2013; Knibbs et al., 2011; Kumar and Gupta, 2016; Ramos et al., 2015; Wang and Gao, 2011; Xu et al., 2016; Yan et al., 2015). Since subway systems carry large numbers of passengers in small, enclosed spaces compared to other modes of transportation, there is the potential for exposure to indoor pollution if the air conditioning and ventilation system of the facilities and vehicles are not effectively managed.

Ozgen et al. (2016) reported that the number concentration of ultrafine particles (UFP: dp < 0.1 μm) outdoors was around two times higher than that within the subway system and that the mass concentration of PM within the subway system was two to four times higher than it was outdoors. Wang and Gao (2011) measured the number concentration of particles (5 nm–3 μm) and the mass concentration of PM of less than 2.5 μm ($PM_{2.5}$) in New York subway stations. They reported that while the number concentration of particles outdoors was higher (at 60,629 #/cm^3) than on the platform (at 37,657 #/cm^3) the $PM_{2.5}$ mass concentration on the platform was higher (at 68.29 μg/m^3) than it was outdoors (at 29.60 μg/m^3). Lonati et al. (2011) measured the mass concentration of PM in the size ranges of 0.3–0.5 μm and 2.5–10 μm and found that the mass concentrations of 0.3–0.5 μm PM outdoors and on the platform were similar while the mass concentration of 2.5–10 μm PM in the subway was much higher than it was outdoors. A study that compared the mass concentrations of PM_{10} and $PM_{2.5}$ at different passenger locations in a subway station in Seoul, Korea, showed that the PM_{10} concentrations were 155 μg/m^3 outdoors, 312 μg/m^3 on the concourse and 359 μg/m^3 on the platform,

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while the $PM_{2.5}$ concentrations were 102 μg/m^3, 126 μg/m^3, and 129 μg/m^3 for each location, respectively. The concentration of larger particles was more than 3 times higher within the subway station than it was outdoors, while the difference was significantly lower for smaller particles (Kim et al., 2008).

As reported in the preceding studies, the difference in PM concentration as measured outdoors and within the subway stations varied by PM size and that the specific particles which people were exposed to differed by location. As such, many recent studies have now focused on the actual inhalation dose of μg per individual instead of simply examining concentration level. Ramos et al. (2015) compared the mass concentrations of PM_{10} and $PM_{2.5}$ in various public transit systems and presented PM inhalation dose/km using the average inhalation rate of adults, moving distance, and stay time. Yu et al. (2012) calculated the PM_1 inhalation dose using the stay time in public transit system, PM_1 mass concentration and inhalation rate. Lei et al. (2016) measured the $PM_{2.5}$ mass concentration in indoor spaces, outdoors and on public transit systems, and presented the exposed PM inhalation dose per person at each location for a period of one day.

Summarizing these studies, a person using the subway is exposed to a greater extent to smaller PM outdoors and to larger PM when in underground subway stations. Therefore, mass concentration is commonly used as a reference value for a person's exposure to PM and many governments also use mass concentration as a reference for the regulation of PM in the atmosphere and indoor environments. However, this approach has its short comings. This is because smaller particles contribute little to the findings when converted to total mass concentration but these particles are actually more harmful to the human body since they can become secondary pollutants by bonding with other atmospheric pollutants, such as nitrogen oxides (NOx), which have relatively large surface areas (Nel et al., 2006). Moreover, while larger particles can be filtered out of inhaled air by nasal mucosa and the upper airways, particles of 1 μm or less have been found all the way down to the bronchioles and alveoli (Londahl et al., 2006; Oberdorster et al., 2005). To reflect this phenomenon, Koehler and Peters (2015) proposed an analysis using number concentration instead of mass concentration to better reflect the concentration of UFP when evaluating the relationship between PM and health. Furthermore, Penttinen et al. (2001) argued for the consideration of number concentration at the same time as mass concentration when evaluating indoor air quality.

This study measured the number concentration of PM, according to particle size, to which subway users are exposed to whilst traversing along actual movement paths. Subways were chosen as they have the largest transport share - at 39% compared to 27% for buses and 22.8% for passenger cars - among means of transportation in Seoul (Statistics of Seoul, 2014). This study will present the number of PM inhaled by subway users as reference material for analysis of the hazards to the human body arising from the inhalation of PM.

2. Methods

Two transfer stations in Seoul that handle the largest daily number of passengers were selected in order to measure PNC according to particle size and to observe subway users' exposure to PM. Two measurements were conducted on Line 1 in the afternoons of October 7–9, 2015 and on Line 2 in the afternoons of December 14–15, 2015. The measuring devices used in this study were a Nanoscan SMPS (TSI, Model 3910, USA) and an optical particle sizer (OPS; TSI, Model 3330, USA). The Nanoscan SMPS can measure particles sized between 0.01 and 0.420 μm while the OPS can measure particles sized between 0.3 and 10 μm. For the measurement of PM number concentration with the Nanoscan SMPS, particles were grouped into 13 sizes of 11.5, 15.4, 20.5, 27.4, 36.5, 48.7, 64.9, 86.6, 115.5, 154, 205.4, 273.8 and 365.2 nm. Since the Nanoscan SMPS requires around 1 min of time to measure UFP particles, it was fixed at three locations: outdoors (A, near the access to the station); the concourse (B, pathway between the outdoors and the platform); and the platform (C, passenger waiting area for the train). The sampling flow rate of Nanoscan SMPS was 0.75 L/min, and three measurements were made repeatedly at intervals of 60 s. For measurement with the OPS, a tester put the OPS on a backpack and took measurements whilst moving. Particles were grouped into 14 sizes of 0.3, 0.316, 0.422, 0.562, 0.75, 1, 1.334, 1.778, 2.371, 3,162, 4.217, 5.623, 7.499 and 10 μm. A conductive tube connected to the sampling inlet of the OPS measuring device minimized sampling loss and measurements were taken at 1.2 m from the floor. The sampling flow rate of the OPS was 1.2 L/min and measurements were taken at 5-s intervals during a period of 30–40 min as the tester moved around. To analyze the distribution of PM inhaled by subway users, measurements taken were at four locations: outdoors (A); on the concourse (B); on the platform (C); and whilst getting on the train, as shown in Fig. 1.

The continuous measurement of PM took place for approximately 40 min and included both the stated measurement points as well as the time spent waiting for the subway train, transferring lines and ascending/descending the stairs. The PM_{10} concentration in the outdoor air during the measurement period refers to that provided by the Korea Environment Corporation (KECO; www.airkorea.or.kr) while the outdoor temperature and relative humidity refer to that provided by the Korea Metrological

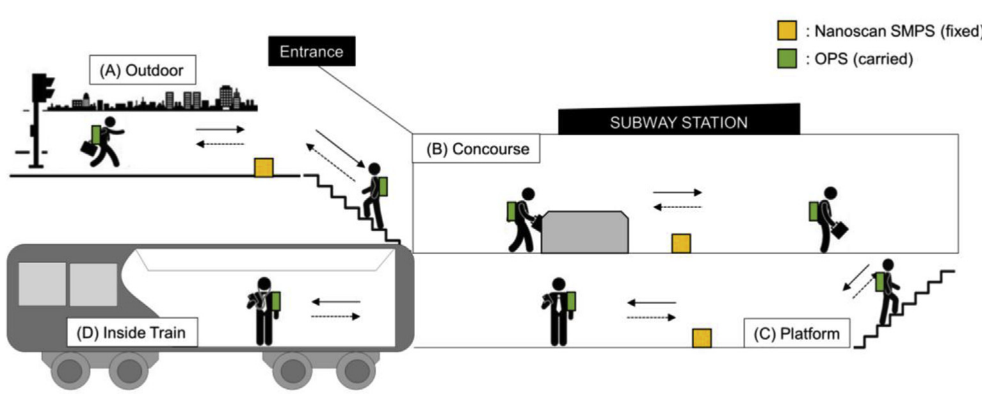

Fig. 1. Moving path of subway users as reproduced in this study.