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Research Article

# Particulate Matter in the Korea Train eXpress (KTX) Cabin and its Exposure

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**ABSTRACT** This study aims to assess the particulate matter ($PM_1$, $PM_{2.5}$, $PM_{10}$) and black carbon (BC) in the Korea Train eXpress (KTX) cabin during train running, and the personal exposure of $PM_{2.5}$ for the female/male passengers who use the KTX 20 days a month to commute. Intensive measurements were made on the day when the outside ambient PM concentration was much higher than usual. To compare with the PM concentration in the subway cabin, a measurement was also performed in some sections of the Seoul Metro subway (from Namyoung Station (hereafter referred to as the "Sta.") to Jonggak Sta.). The amount of $PM_{2.5}$ exposure ($Exposure_{PM_{2.5}}$ (μg)) was calculated for the male/female passengers who regularly board the KTX. The $Car\text{-}exposure_{PM_{2.5}}$ (μg), which is the amount of $PM_{2.5}$ exposure when moving by car in the same section, was also calculated. The PM concentration in the KTX cabin elevated and fallen off at train staying and train running, respectively. The $PM_{2.5}$ concentrations inside KTX cabin at the stop station exhibited a remarkable positive correlation with those of outdoor. Compared to the PM concentration measured in the cabin of Seoul Metro subway, $PM_1$, $PM_{2.5}$, and $PM_{10}$ in the KTX passenger cabin were 74.9%, 73.3%, and 62.7% of those in the cabin of Seoul Metro subway, respectively. The $PM_{2.5}$ exposure amount (exposure $PM_{2.5}$ (μg)) when moving the same section using the KTX and passenger cars was calculated, and as a result, the exposure $PM_{2.5}$ (μg) for both male and female were 5.7 times lower in the KTX than that in car. The mapping result of BC concentration drawn on the KTX line from Iksan Sta. to Gwangmyeong Sta. shows that it fluctuated greatly for each service section or stop station.

**KEY WORDS** Particulate matter, $PM_{2.5}$, BC, Exposure, KTX

## 1. INTRODUCTION

The super high-speed train is operated in many advanced countries such as France, Japan, Germany and Spain. Korea also joined the league of the super high express rail by opening the Korea Train eXpress (KTX) in April 2002. Because of its safety, speed, and convenience, the KTX users were 66,128,000 in 2019. This is an increase of 76.4% compared to 2009 with 37,477,000 passengers (Statistics KOREA Government, 2021).

With the increasing of passengers year by year, it is very meaningful to evaluate the air quality in the train cabin and its health effects of passengers, especially

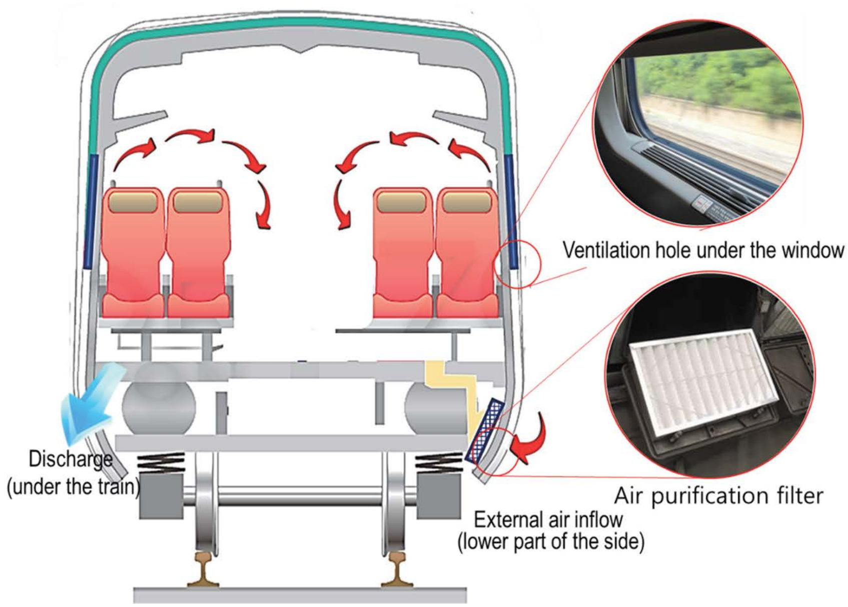


**Fig. 1.** Ventilation and air purification system in the KTX train cabin.

those who use it regularly, such as going to work.

Of course, the Korea Railroad Corporation (KORAIL) regularly checks the filters inside and outside the train to manage air quality in the in the train cabin. As shown in Fig. 1, the external air treated by the air purification filter installed at the lower part of the train side flows into train cabin through the vent hole under the window, and internal air is discharged to the lower part of the train.

It can be generally thought that the exhaust emission of CO, $NO_x$ and PM from rail transport including high-speed train is less than those from the road transport (Uherek *et al.*, 2010). However, it is absolutely required to evaluate the air quality in the cabin of high-speed train due to pollutants inflow from the outside during opening/closing the door as well as those of the train cabin itself.

According to the Korea's standard for recommending indoor air quality for public transportation vehicles revised in 2013, the standard for $PM_{10}$ (average value for one run of the route) is 200 μg/m$^3$ or less for urban railways and 150 μg/m$^3$ or less for trains such as KTX. Fortunately, in the indoor air quality recommendation standard for public transportation vehicles under the Indoor Air Quality Management Act, which was implemented in April 2021, the items of $PM_{2.5}$ were newly set, and its standard is less than 50 μg/m$^3$.

So far, there have been only a few air quality surveys in the KTX cabin (So and Kang, 2006), and it was also about $PM_{10}$. Of course, there is no research on $PM_{2.5}$ because the regulation was not established until 2021.

Meanwhile, some studies (Front *et al.*, 2020; Jeong *et al.*, 2017) have reported significant concentrations of nanoparticle and BC, and $PM_{2.5}$ in railway environments. But unfortunately, there have been no surveys on the KTX cabin fine/ultra PM ($PM_{2.5}$ and $PM_1$) known to be much more harmful to human health.

The goal of this study is to assess the PM ($PM_1$, $PM_{2.5}$, $PM_{10}$) and BC concentrations in the cabin of the running KTX. In addition, as an evaluation of the health effects of PM, the personal exposure of PM for the female/male who regularly uses trains to commute.

## 2. EXPERIMENTAL METHODS

### 2.1 Field Study Design

The section from KTX Iksan Sta. to Gwangmyeong Sta. was the subject of cabin measurement in this study. Iksan Sta. is one of the main KTX stations where Honam Line and Jeolla Line intersect. Gwangmyeong Sta. is the station where the four KTX lines overlap except the KTX Gangneung Line. Fig. 2 shows the service section of the KTX cabin measurement covered in this study.

In selecting the in-cabin measurement time, the forecasted ambient outdoor air quality near the target service section of the KTX was referenced. Fig. 3 shows the out-


**Fig. 2.** The service section of the KTX train cabin measurement covered in this study.

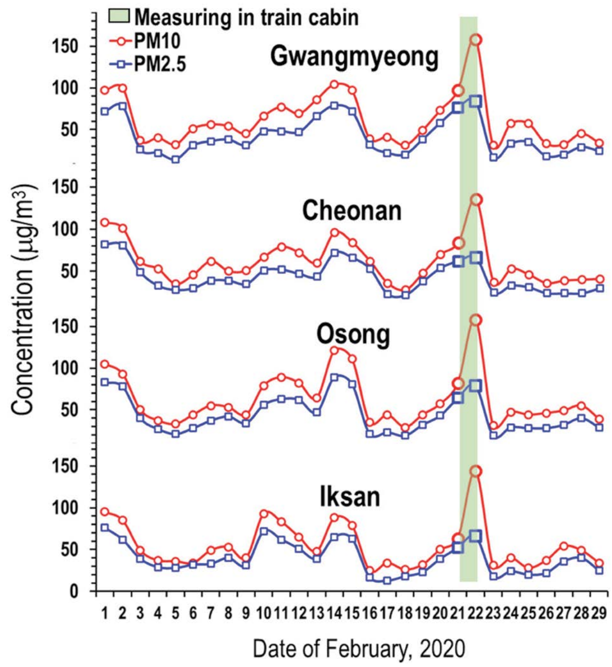


**Fig. 3.** The out-door $PM_{10}$ and $PM_{2.5}$ measured at air quality monitoring stations near four KTX stations during February 2020.

door $PM_{10}$ and $PM_{2.5}$ measured at air quality monitoring station (AQMS) near four KTX stations during February 2020. The PM data of four AQMSs were provided by the Korea National Institute of Environmental Research (https://www.nier.go.kr/NIER/kor/research).

Our intensive measurement was made at noon on February 21 referring to the daily fine PM forecast by the Korea Meteorological Administration (https://www.weather.go.kr/w/index.do). In Fig. 3, as forecasted, relatively high PM concentrations ($PM_{10}$: 63–158 μg/$m^3$, $PM_{2.5}$: 52–84 μg/$m^3$) were observed at all four AQMSs between February 21 and 22. For comparative research, the additional PM measurements were also made outside the station of KTX Iksan and in the cabin of Seoul Metro subway (from Namyoung Sta. to Jonggak Sta.) on the same day.

## 2.2 Real-time PM and BC Measurements

Mass concentration for the size-resolved PM ($PM_1$, $PM_{2.5}$, $PM_{10}$) was monitored every 5 seconds by the AirBeam (HabitatMap, Inc., V3). This portable device is based on the light scattering to determine the particle size. The scattered light by the PM drawn through a sensing chamber is registered by a detector and converted into the size-resolved PM mass concentrations. The measured data can be wirelessly transmitted to the AirCasting Android app, which maps and graphs the data on a smartphone via Bluetooth (AirBeam Technical Specifications, Operation & Performance, 2019). This portable small monitor has been used in many previous studies, and its performance has also been proven (Badura *et al.*, 2018; Mukherjee *et al.*, 2017; Jiao *et al.*, 2016). A thorough evaluation of its precision has been carried out by the US EPA by comparing the $PM_{2.5}$ data measured by an existing proven device, respectively. According to Jiao *et al.* (2016), a fairly high correlation ($R^2 = 0.99$) was recognized between the two sets of data measured by the two devices.

As a BC monitor, the Aethalometer® (AE51) (Aethlabs, USA) was selected. It can quantify the BC concentration from the attenuated light (a near-infrared with 880 nm wavelength) by the BC accumulation on a special square filter. It can successfully monitor the real-time BC concentration with the good sensitivity (0.001 μg/$m^3$) and precision (±0.1 μg/$m^3$).

Above monitoring devices were installed in the cabin of KTX-Sancheon train bound for Gwangmyeong Sta. departing from Iksan at 12:15. The KTX-Sancheon train has a total of 10 cars (2 motive power units and 8 passenger cars). Its total length and weight are 201 m and 403t (before passenger boarding), respectively. Total seats in a KTX-Sancheon train set are 375. Monitor devices were installed in the aisle of the 7th seat of train 12 with 52

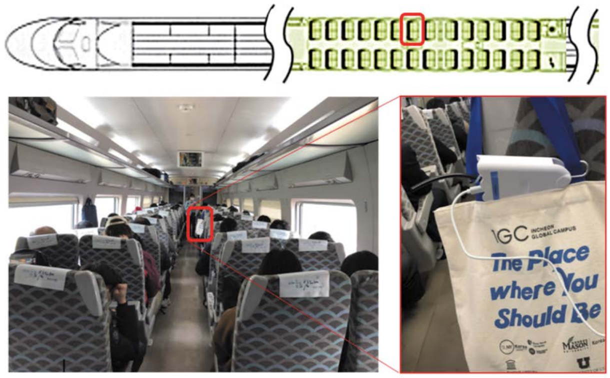

**Fig. 4.** The schematic diagram of the train No. 12 (standard class) of the KTX (top), the view of the inside of the train cabin (bottom left) where measurements were made, and BC/PM monitors at the 7th aisle (bottom right).

seats, and the height of the air inlet of the device was located at the height of the seated passenger's nose. Fig. 4 shows the schematic diagram of the train No. 12 (standard class) of the KTX (top), the view of the inside of the passenger cabin (bottom left) where measurements were made, and BC/PM monitors at the 7th aisle (bottom right).

The number of passengers (52) was full at Iksan Sta., and there were passengers getting on and off at each station, but the average number of passengers to Gwangmyeong was 48.

During the KTX service, the temperature and relative humidity in passenger cabin were maintained around 21°C and 50%, respectively.

For comparison with PM concentrations in other places, additional on-site measurements were made inside cabins of Seoul Metro Subway and outside the KTX Iksan Sta., respectively on the same day.

### 2.3 Calculation of PM Exposure

It is well-known that the deposition of $PM_{2.5}$ in the body causes many respiratory diseases such as lung cancer (Wagner *et al.*, 2012). The situation of subway PM and their health hazards have been studied a lot (Ripanucci *et al.*, 2006; Seaton *et al.*, 2005; Chillrud *et al.*, 2004). However, so far, little has been reported on the PM of high-speed trains including the KTX.

In this study, the amount of $PM_{2.5}$ exposure ($exposure_{PM_{2.5}}$ (μg)), which is basic data in evaluating health hazards, was calculated. The target passengers were adult men and women who used the KTX to go to work on weekdays.

The $exposure_{PM_{2.5}}$ (μg) of the KTX in-cabin ($KTX\text{-}exposure_{PM_{2.5}}$ (μg)) at alveolar-interstitial (AI) region of passenger was calculated by the following empirical equation (Löndahl *et al.*, 2007).

$$KTX\text{-}exposure_{PM_{2.5}}(\mu g) = C_{PM_{2.5}\text{-}cabin} \times F_{Dep.} \times T_{Exp.} \times R_{Bre.}$$

where $C_{PM_{2.5}\text{-}cabin}$ is the actual measured $PM_{2.5}$ concentration at the KTX passenger cabin in each service section, $F_{Dep.}$ is the deposition fraction in the AI region, $T_{Exp.}$ is exposure time (h), and $R_{Bre.}$ is breathing rate ($m^3$/h). The $F_{Dep.}$ is the maximum deposition efficiency (%) in the AI region by the activity patterns (Yamada *et al.*, 2007). In this study, the passenger's activity pattern was assumed to a sitting/rest. Assuming that the target passengers used the KTX to commute only on weekdays, the numbers of day used per month and year were set to 20 days and 240 days, respectively.

It will be meaningful to compare the $KTX\text{-}exposure_{PM_{2.5}}$ (μg) with the $exposure_{PM_{2.5}}$ (μg) of car driver ($Car\text{-}exposure_{PM_{2.5}}$ (μg)) during driving in the same section as KTX service by personal car.

The $Car\text{-}exposure_{PM_{2.5}}$ (μg) was calculated by the following equation. It was calculated under the same conditions as the KTX, that is, windows were closed, and the in-vehicle ventilation system was operated.

$$Car\text{-}exposure_{PM_{2.5}}(\mu g) = \frac{C_{PM_{2.5}\,D\text{-}AQMS} + C_{PM_{2.5}\,A\text{-}AQMS}}{2} \times R_{In/Out} \times F_{Dep.} \times T_{Exp.} \times R_{Bre.}$$

where $C_{PM_{2.5}\,D\text{-}AQMS}$ and $C_{PM_{2.5}\,A\text{-}AQMS}$ are the $PM_{2.5}$ concentration measured the AQMS near the KTX departure station and arrival station, respectively, and $R_{In/Out}$ is the ratio (0.754) of $C_{PM_{2.5}}$ in-car cabin to outside the car suggested by Ma and Kang (2020).

If $C_{PM_{2.5}}$ was actually measured by driving on the road, it would have been affected by many variables on the driving route such as traffic density, stop/driving, intervehicle distance, and local atmospheric diffusion along the route. However, in this study, the $C_{PM_{2.5}}$ in-car cabin while vehicle driving was simply calculated as described in the above equation.

## 3. RESULTS AND DISCUSSION

### 3.1 Variation of PM Concentrations in the KTX Passenger Cabin

Fig. 5 shows the mapping results of BC (left) and

$PM_{2.5}$ (right) concentrations drawn on the KTX line from Iksan to Gwangmyeong. According to these visualized concentrations, both BC and $PM_{2.5}$ fluctuated greatly for each service section or stop station.

In general BC is formed through incomplete combustion of fossil fuels in automotive internal combustion engines and other combustion facilities. Therefore, one of the reasons why BC concentration fluctuated so much even though it was measured in a passenger cabin during service is thought to be the inflow of the road traffic BC at each service section and stop station via the ventilation system and/or opening the train door.

Fig. 6 shows the variation of the size-resolved PM concentration at the KTX service section between Iksan and Gwangmyeong Sta. At all kinds of PM sizes, the mass concentration fluctuated significantly and showed high concentrations near each stop station. In the entire service section, the concentrations of $PM_1$, $PM_{2.5\text{-}1}$, and $PM_{10\text{-}2.5}$ in the passenger cabin ranged from 17.4–30.3 μg/m$^3$ with an average of 23.2 μg/m$^3$, 3.1–7.0 μg/m$^3$ with an average of 5.7 μg/m$^3$, and 10.6–32.7 μg/m$^3$ with an average of 21.9 μg/m$^3$, respectively. It is worth noting that the average $PM_1$ concentration of whole service section was the highest compared to $PM_{2.5\text{-}1}$ and $PM_{10\text{-}2.5}$. This is because smaller particles can penetrate deeper respiratory systems more easily. Moreover, compared to $PM_{2.5}$, it can stay in the lungs longer and cause more inflammation (Schraufnagel, 2020).

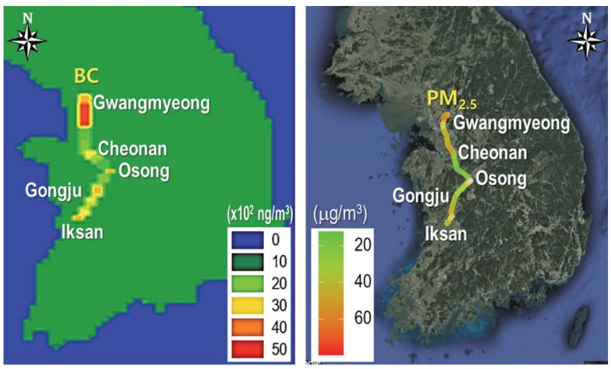


**Fig. 5.** Mapping results of BC concentration (left) and $PM_{2.5}$ (right) drawn on the KTX line from Iksan Sta. to Gwangmyeong Sta.

The average $PM_1$ and $PM_{2.5\text{-}1}$ concentrations of each service section were high in the order of Iksan–Gongju, Gongju–Osong, Cheonan–Gwangmyeong, and Osong–Cheonan. Meanwhile, in the case of BC concentration, the Gongju–Cheonan service section, which recorded 2.25 μg/m$^3$, was the highest, followed by Cheonan-Gwangmyeong (2.15 μg/m$^3$), Gongju-Osong (2.05 μg/m$^3$), and Iksan-Gongju (1.85 μg/m$^3$).

The reason why PM concentrations of all sizes were observed high at all service stops was because the external PM flowed into the passenger cabin during opening and closing the door at each stop station. Meanwhile, a lower PM level during service was probably due to the gravitational deposition and a series of ventilation facilities equipped with filters.

Also, according to Fig. 6, as 54% (39 minutes) of the total KTX operating time (71 minutes) exceeded the recommended standard (50 μg/m$^3$) for $PM_{2.5}$, efforts to reduce $PM_{2.5}$ concentration in the KTX cabin are urgently needed.

Fig. 7 shows the correlation among $PM_1$, $PM_{2.5}$, and

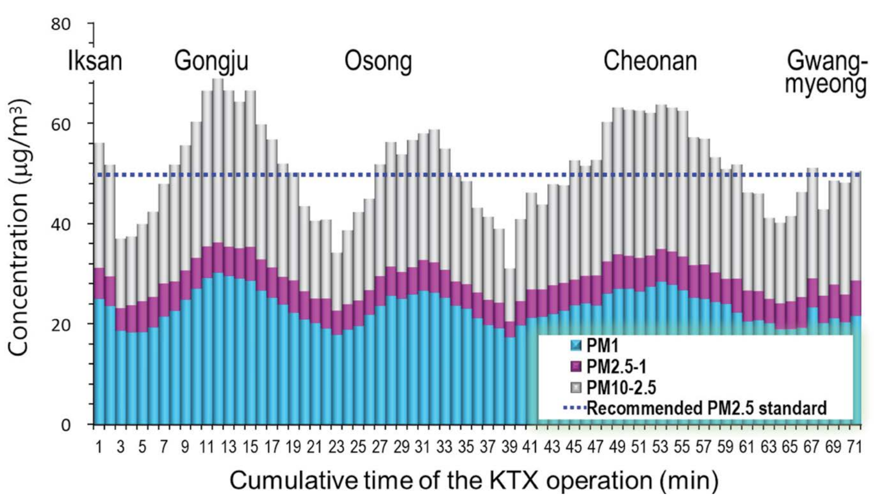


**Fig. 6.** Variation of the size-resolved PM concentration at the KTX service section between Iksan Sta. and Gwangmyeong Sta.

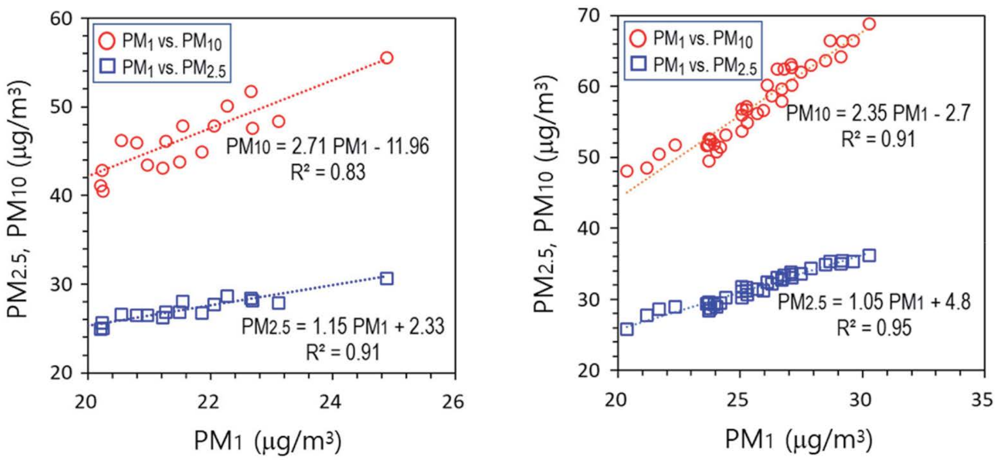


**Fig. 7.** Correlation among $PM_1$, $PM_{2.5}$, and $PM_{10}$ during the KTX service (left) and stop (right) from Iksan Sta. to Gwangmyeong Sta.

$PM_{10}$ during the KTX service and stop from Iksan to Gwangmyeong. Although it may be considered natural, the correlation with $PM_1$ was slightly higher in $PM_{2.5}$ than $PM_{10}$ during both service and stopping. More meaningful is the fact that the correlation was higher during train stopping than service. Unlike the transportation with an internal combustion engine, there is no possibility of the $PM_1$ generation by fuel combustion in the KTX, therefore the inflow of external air might have affected the ultrafine PM in passenger cabin. Here, the external inflow may be referred to as an inflow of surrounding ambient atmosphere, but the influence of ultrafine PM generated by the train itself near the stop station may be large. It is well-known that the frictional heat of the train wheels and rails generates a great number of ultrafine particles, mostly iron vapor (Kim and Ro, 2010; Lorenzo *et al.*, 2006). The new fine-particle generation from the frictions between train wheel and rail as well as between brake pad and train wheel was well explained with the visible illustrations by Ma *et al.* (2015).

In order to evaluate the inflow of PM into the passenger cabin from the outside, the correlation between the PM ($PM_{2.5}$ and $PM_{10\text{-}2.5}$) concentration in the passenger cabin and the that measured at the AQMS near four KTX stations was estimated (Fig. 8). In the $PM_{10\text{-}2.5}$, the internal and external correlations were not recognized, but in the $PM_{2.5}$, a fairly high correlation ($R=0.79$) was shown. According to these results, it can be said that the concentration of fine PM in the passenger cabin was much more affected by external inflow than that of coarse PM. In addition to the coarse PM of outside air, it might be the influence of coarse PM introduced by

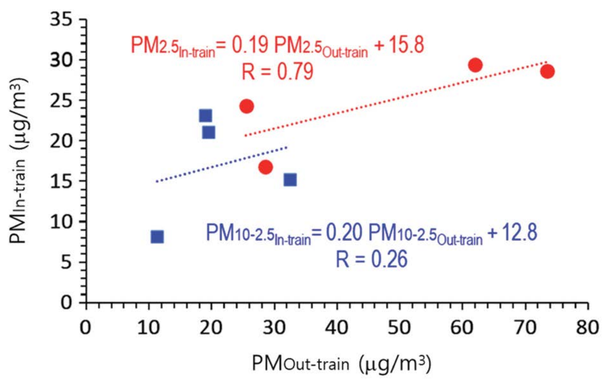


**Fig. 8.** The scattering plot between $PM_{In\text{-}train}$ ($\mu g/m^3$) and $PM_{Out\text{-}train}$ ($\mu g/m^3$) during the KTX service from Iksan Sta. to Gwangmyeong Sta.

clothing or shoes of passengers. In addition to this, it might be because the air purification system of the KTX could remove coarse PM more efficiently than fine PM.

Table 1 summarizes the size-resolved PM concentration measured in the passenger cabin of Seoul Metro subway and the KTX during the train operation on the same day. In the case of subways, a slightly higher PM concentration was observed in the underground section than the ground section. The same cases have already been reported on the subways in Taiwan and Japan (Cheng *et al.*, 2019; Ma *et al.*, 2012). The PM contents in Taiwan Metro trains were approximately 20–50% higher during running through the underground than during through on the ground. Meanwhile, in this study, there was no significant difference in PM concentration between the ground and underground sections, probably

**Table 1.** The size-resolved PM concentration (average ± standard deviation) measured in the passenger cabin of Seoul subway and the KTX during the train operation on the same day. (unit: μg/m³)

| | Section | Route | $PM_1$ | $PM_{2.5}$ | $PM_{10}$ |
|---|---|---|---|---|---|
| Subway* | Yongsan–Namyoung | Ground | 27.4 ± 3.5 | 35 ± 3.9 | 65.5 ± 10.2 |
| | Hoehyeon–Myeongdong | Underground | 26.3 ± 2.6 | 34.3 ± 3.3 | 69.4 ± 8.8 |
| KTX | Iksan–Gwangmyeong | Ground | 20.1 ± 3.4 | 25.4 ± 3.8 | 42.3 ± 9.2 |

*Seoul Metro Subway

**Table 2.** The levels of $PM_{10}$ and $PM_{2.5}$ in the passenger cabins of electric powered train in several cities in the world. (unit: μg/m³)

| Location | Route | $PM_{2.5}$ | $PM_{10}$ | % of $PM_{2.5}$ to $PM_{10}$ | Reference |
|---|---|---|---|---|---|
| Los Angeles | Underground | 14 | 16 | 87.5 | Kam *et al.*, 2011 |
| Hong Kong | Ground | 46 | 60 | 76.7 | Chan *et al.*, 2002 |
| Beijing | Underground | 37 | 108 | 34.3 | Li *et al.*, 2007 |
| Seoul | Underground | 35 | 67 | 52.2 | Current study |
| KTX* | Ground | 25 | 42 | 59.5 | Current study |

*The average value of whole KTX service section from Iksan Sta. to Gwangmyeong Sta.

because the out-door PM concentration on the day of measurement was abnormally high.

The concentrations of $PM_1$, $PM_{2.5}$, and $PM_{10}$ in the KTX passenger cabin were 74.9%, 73.3%, and 62.7% of those in the cabin of Seoul Metro subway, respectively. One important fact, however, is that the fraction of $PM_1$ to $PM_{10}$ was higher in the KTX than in subway. The fractions of $PM_1$ to $PM_{10}$ were 39.9 and 47.5 in the subway cabin (average of ground and underground) and the KTX cabin, respectively. Moreover, the $PM_1/PM_{10}$ ratio in the KTX cabin (0.48) was slightly higher than that measured in the outside atmosphere of the KTX Iksan Sta. (0.47).

Table 2 shows the levels of $PM_{10}$ and $PM_{2.5}$ in the passenger cabins of electric powered train in several cities in the world. The $PM_{10}$ concentration in the KTX passenger cabin was 2.6 times higher than that of Los Angeles and 2.5 times lower than that of Beijing. In the case of $PM_{2.5}$, its range of other four cities were from 14 to 46 μg/m³, and the $PM_{2.5}$ in the KTX passenger cabin measured in this study was 25 μg/m³. The fraction of $PM_{2.5}$ to $PM_{10}$ in the KTX cabin (59.5%) was also not extremely high or low compared to other cities.

### 3.2 PM Exposure for the Regular Users of the KTX

The calculated $KTX\text{-}exposure_{PM_{2.5}}$ (μg) for the female/male who used the KTX regularly was summarized in Table 3. In the table, the $PM_{2.5}$ of non-episode is the measured $PM_{2.5}$ concentration in the same service section on a non-episode day. Although it is a natural result, the $KTX\text{-}exposure_{PM_{2.5}}$ (μg) increased in the section with high $PM_{2.5}$ concentration in passenger cabin. Due to the differences of $F_{Dep.}$ and $R_{Bre.}$ between male and female, the $KTX\text{-}exposure_{PM_{2.5}}$ (μg) in the KTX service section was calculated much larger for men than for women.

Table 4 shows the $KTX\text{-}exposure_{PM_{2.5}}$ (μg) and the $Car\text{-}exposure_{PM_{2.5}}$ (μg) at the AI region for the female/male users during the round trip in the same section. The $KTX\text{-}exposure_{PM_{2.5}}$ (μg) and the $Car\text{-}exposure_{PM_{2.5}}$ (μg) for female at each service section ranged from 0.9–2.2 μg with an average of 1.58 μg and 4.4–14.0 μg with an average of 8.98 μg, respectively. The $Car\text{-}exposure_{PM_{2.5}}$ (μg) to male driver increased compared to female driver in proportion to the increase in $F_{Dep.}$ and $R_{Bre.}$. In terms of whole service section (from Iksan Sta. to Gwangmyeong Sta.), the $exposure_{PM_{2.5}}$ (μg) for both male and female were 5.7 times higher in cars than in the KTX. One reason might be that the driving time (i.e., $T_{Exp.}$) was much longer than that of the KTX, and it is also thought that the in-cabin air quality of the car was more affected by the outside air quality than that of the KTX.

## 4. CONCLUSIONS

We assessed the PM concentration in the cabin of the

**Table 3.** The *Exposure* $_{PM_{2.5}}$ (μg) in the AI region of the females/males who use the KTX regularly.

| | KTX service section | Round-trip time (h) | KTX service period | | $PM_{2.5}$ in KTX (μg/m$^3$) | | $F_{dep.}$ in AI | $R_{bre.}$ (m$^3$/h) | *Exposure* $_{PM_{2.5}}$ (μg) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1-month | 1-year | Non-episode | Episode | | | 1-month | 1-year |
| Female | Iksan–Gongju | 0.56 | 20 | 240 | 23.08 | 27.66 | 0.365 | 0.307 | 28.9–34.7 | 347.6–416.6 |
| | Gongju–Osong | 0.50 | 20 | 240 | 12.98 | 26.90 | 0.365 | 0.307 | 14.5–30.1 | 174.5–361.7 |
| | Osong–Cheonan | 0.38 | 20 | 240 | 18.47 | 20.15 | 0.365 | 0.307 | 15.7–17.1 | 188.8–205.9 |
| | Cheonan–Gwangmyeong | 0.83 | 20 | 240 | 17.04 | 23.26 | 0.365 | 0.307 | 31.8–43.4 | 381.9–521.3 |
| | Whole service section | | | | | | | | 91.1–125.5 | 1092.8–1505.5 |
| Male | Iksan–Gongju | 0.56 | 20 | 240 | 23.08 | 27.66 | 0.452 | 0.432 | 50.5–60.5 | 605.7–725.9 |
| | Gongju–Osong | 0.50 | 20 | 240 | 12.98 | 26.90 | 0.452 | 0.432 | 25.3–52.5 | 304.1–630.0 |
| | Osong–Cheonan | 0.38 | 20 | 240 | 18.47 | 20.15 | 0.452 | 0.432 | 27.4–29.9 | 328.9–358.8 |
| | Cheonan–Gwangmyeong | 0.83 | 20 | 240 | 17.04 | 23.26 | 0.452 | 0.432 | 55.5–75.7 | 665.5–908.4 |
| | Whole service section | | | | | | | | 158.7–218.6 | 1904.2–2623.4 |

**Table 4.** The *KTX-exposure* $_{PM_{2.5}}$ (μg) and the *Car-exposure* $_{PM_{2.5}}$ (μg) at the AI region of the female/male users during the round trip in the same section.

| | KTX service section | Round-trip time (h) | | $PM_{2.5}$ (μg/m$^3$) | | $F_{dep.}$ in AI | $R_{bre.}$ (m$^3$/h) | *Exposure* $_{PM_{2.5}}$ (μg) | |
|---|---|---|---|---|---|---|---|---|---|
| | | KTX | Car | KTX | Car | | | KTX | Car |
| Female | Iksan–Gongju | 0.56 | 2.26 | 27.66 | 55.45 | 0.365 | 0.307 | 1.7 | 14.0 |
| | Gongju–Osong | 0.50 | 2.12 | 26.9 | 46.77 | 0.365 | 0.307 | 1.5 | 11.1 |
| | Osong–Cheonan | 0.38 | 1.84 | 20.15 | 21.50 | 0.365 | 0.307 | 0.9 | 4.4 |
| | Cheonan–Gwangmyeong | 0.83 | 2.96 | 23.26 | 19.24 | 0.365 | 0.307 | 2.2 | 6.4 |
| | Whole section | | | | | | | 6.3 | 36.0 |
| Male | Iksan–Gongju | 0.56 | 2.26 | 27.66 | 55.45 | 0.452 | 0.432 | 3.0 | 24.5 |
| | Gongju–Osong | 0.50 | 2.12 | 26.9 | 46.77 | 0.452 | 0.432 | 2.6 | 19.4 |
| | Osong–Cheonan | 0.38 | 1.84 | 20.15 | 21.50 | 0.452 | 0.432 | 1.5 | 7.7 |
| | Cheonan–Gwangmyeong | 0.83 | 2.96 | 23.26 | 19.24 | 0.452 | 0.432 | 3.8 | 11.1 |
| | Whole section | | | | | | | 10.9 | 62.7 |

KTX, and the personal exposure of $PM_{2.5}$ for the female/male passengers. In all particle size of PM, the concentration in the passenger cabin of the KTX was relatively low compared to that of the Seoul Metro subway. However, the fraction of $PM_1$ to $PM_{10}$ was higher in the KTX than in subway. The $PM_1/PM_{10}$ ratio in the KTX cabin was also higher than that measured at the outside atmosphere of the KTX Sta. Despite the same mechanisms of PM generating on railroads, the reason the KTX cabin has a higher $PM_1/PM_{10}$ ratio than subway cabin may be due to the KTX's ventilation system located close to rails and wheels. As mentioned earlier, a lot of submicron PM can be easily generated when trains are running and stopping. Therefore, it will be necessary to improve the ventilation system of the KTX and minimize the inflow of external PM, especially ultrafine PM. Above all, an improvement should be made to reduce PM inflow from the outside while the KTX is stopping. Finally, in this study, the results of one intensive measurement were discussed for limited the KTX operation sections, but more specific data will be provided through repeated measurements for other sections in the future.

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