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CHARACTERISTICS OF PM_{10} and $PM_{2.5}$ AS MONITORED IN INTERIORS AND PLATFORMS OF SUBWAY TRAIN IN KOREA

Dong Uk Park[1] Kyung Sup Yun[1] and Kwon Chul Ha[2]

[1]Department of Environmental Health, Korea National Open University, Seoul, Korea
[2]Department of Health Science and Biochemistry, Changwon National University Changwon, Korea

ABSTRACT

This study was performed to investigate the concentration of PM_{10} and $PM_{2.5}$ in inside trains and platforms on subway lines 1, 2, 4 and 5 in Seoul, KOREA. PM_{10}, $PM_{2.5}$, and carbon dioxide were monitored using a Portable Aerosol Spectrometer in the afternoon (between 13:00 and 16:00). The concentrations of PM_{10} and $PM_{2.5}$ inside trains was significantly higher than those measured on platform sand in ambient air reported by the Korea Environmental Protection Agency (EPA). This study found that PM_{10} levels inside subway lines 1, 2 and 4 exceeded 150 ㎍/㎥ of the Korea indoor air quality standard (IAQ). The average percentage that exceeded the PM_{10} standard was 83.3 % on line 1, 37.9 % on line 2 and 63.1 % on line 4, respectively. $PM_{2.5}$ concentration ranged from 77.7 ㎍/㎥ to 158.2 ㎍/㎥, which were found to be much higher than the ambient air $PM_{2.5}$ standard promulgated by United States Environmental Protection Agency (US-EPA) (24 hours arithmetic mean: 65 ㎍/㎥). The reason for interior PM_{10} and $PM_{2.5}$ being higher than those on platforms is due to subway trains in Korea not having mechanical ventilation system to supply fresh air inside the train. The percentage of $PM_{2.5}$ in PM_{10} was 86.2 % on platforms, 81.7 % inside trains, 80.2 % underground and 90.2 % at ground track. These results indicated that fine particles ($PM_{2.5}$) accounted for most of PM_{10} and polluted subway air. Further study is required to examine whether differences of the ratio in $PM_{2.5}$ to PM_{10} among several subway characteristics is significant.

Key Words: PM_{10}, $PM_{2.5}$, Fine Particulate, Subway, Inside Train, Platform

1. INTRODUCTION

In Korea, the subway is considered as the most convenient commuter transport mode. About ten million take it everyday in Seoul. Seven subway lines run in Seoul, Korea. Subway line 1 opened in 1974.

Several studies have reported the PM_{10} concentrations on subway platforms in Korea (Kim et al, 2004). However, concentrations of $PM_{2.5}$ in the subway system and interior particulate matter have not been reported.

The objectives of this study are to compare PM_{10} and $PM_{2.5}$ concentrations between the monitoring locations (inside the trains, subway platforms subway, ground and underground) and to probe the ratio of $PM2_{2.5}$ to PM_{10} concentration.

2. METHOD

2.1 Subject

The experiment on platform and inside subway 1, 2, 4 and 5 lines was performed in the afternoon (13:00-16:00) during 4 days of January.

28 stations on line 1(underground track: 12, ground track: 16), 36 stations on line 2(underground track: 29, ground track: 7), 20 stations on line 4(underground track: 19, ground track: 1), and 5 underground stations on line 5 were studied.

2.2 Monitoring method

A Portable Aerosol Spectrometer (Model 1108, Grimm, Germany) calibrated to 1.2 L/min was used to monitor total suspended particles (TSP), PM_{10} and $PM_{2.5}$. The data logging interval was set at 30s. The concentration inside the trains was monitored from the middle of the center car of the subway when it was running. Monitoring on platform was conducted at the center of the platform. The total number of monitoring was 2,709 (1,820 on underground, 899 on platform). In addition, carbon dioxide was measured using Indoor Air Quality Meters (Model 8760, TSI) to assess the efficiency of ventilation.

2.3 Data analysis

SPSS Version 12.0 was used to analyze data monitored. T-test was employed to compare TSP, PM_{10} and $PM_{2.5}$ concentrations between underground and ground as well as platform and inside train.

General linear model (GLM) was used to examine the effect of location (ground and underground, and platform and inside train) on TSP, PM_{10} and $PM_{2.5}$ concentrations.

3. RESULTS

3.1 PM_{10} and $PM_{2.5}$ concentration

Average PM_{10} concentration inside train was 144.0 $\mu g/m^3$, which was far higher than 125.8 $\mu g/m^3$ monitored on platform (p=0.026) and the concentration range (35 - 81 $\mu g/m^3$) measured in outdoor air in Seoul from January to November, 2004 (Seoul city, 2004). There are many stations that exceeded indoor air quality standard for $PM_{10.}$ Subway line 1 constructed in 1974, the oldest line, showed that 10 of 12 investigated stations exceeded for PM_{10}. The highest concentration was 207.5 $\mu g/m^3$, which was monitored inside the underground track on subway line 1. Average PM_{10} concentrations in line 2 and 4 were 144.3 $\mu g/m^3$ and 143.8 $\mu g/m^3$, respectively. The percentages that exceeded Korea IAQ standard inside the train was 37.9 % in line 2 and 63.2 % in line 4. PM_{10} concentration in line 5, which is the most recently operated line, was below standard. Only one station on line 5 was over the IAQ on platform. PM_{10} concentration for Korea's indoor air quality (150 $\mu g/m^3$) was established to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly (Koran EPA, 2004)

$PM_{2.5}$ concentration inside trains was significantly higher than those on platforms regardless of the location of monitoring ($p<0.001$). These results were the same as those found in PM10 concentration. $PM_{2.5}$ concentration inside train ranged from 84.1 $\mu g/m^3$ to 158.2 $\mu g/m^3$. These concentrations greatly exceeded the airborne 24 hours arithmetic mean standard (65 $\mu g/m^3$) promulgated by U.S environmental protection agency (US EPA) as shown in Figure 1.

PM_{10} and $PM_{2.5}$ concentrations monitored on underground track were significantly higher than those on ground tracks regardless of line and location (Table 1 and Figure 1). GLM statistical analysis indicated that two factors such as monitoring locations (underground and ground or inside and platform) significantly influence PM_{10} and $PM_{2.5}$ concentrations ($p<0.001$).

3.2 The ratio of $PM_{2.5}$ to PM_{10}

The percentage of $PM_{2.5}$ that accounted for PM_{10} is shown in Table 2. It was slightly higher on platform and ground track than inside train and underground track. The percentages of $PM_{2.5}$ in PM_{10} on line 1 and 4 were a little higher than those on line 2 and 5 (Figure 2). A similar pattern was found in the percentage of PM_{10} that accounted for TSP. However, the percentage of $PM_{2.5}$ in PM_{10} was far higher than that of PM_{10} in TSP. This result indicated that the subway environment was contaminated with fine particulates.

Table 1. The average concentration($\mu g/m^3$) and standard deviation of PM_{10} and $PM_{2.5}$ by the location of sampling

	Ground track	Underground track	Total
PM_{10}, $\mu g/m^3$			
Platform	123.0±6.6	129.3±20.9	125.8±15.0
Inside train	141.5±13.4	145.3±12.8	144.0±13.1
Total	132.2±13.0	140.6±17.2	137.0±16.4
$PM_{2.5}$, $\mu g/m^3$			
Platform	115.6±8.6	105.4±14.4	111.1±12.6
Inside train	121.7±16.1	116.6±14.2	118.4±15.1
Total	118.6±13.2	113.3±15.2	115.6±14.6

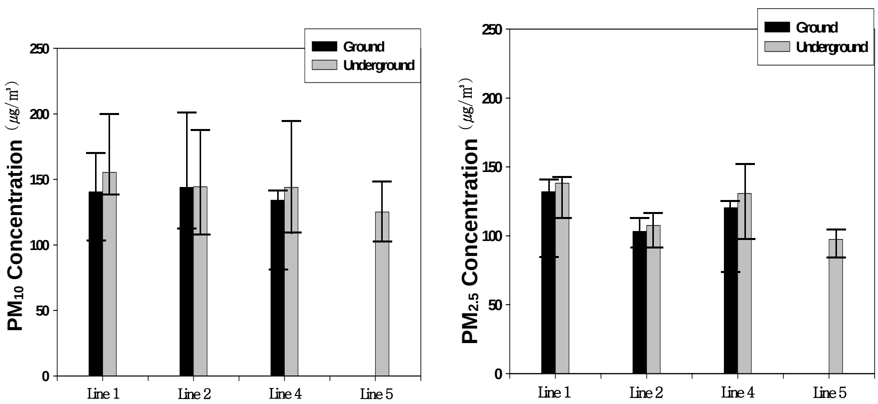
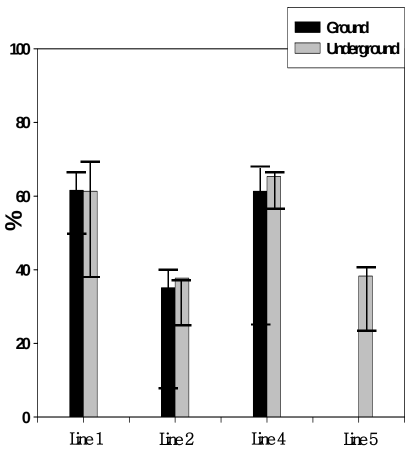
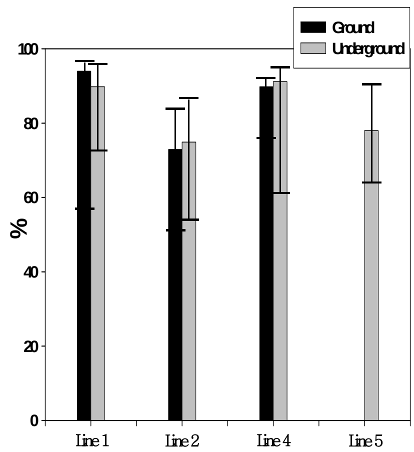


Figure 1. PM_{10} and $PM_{2.5}$ concentration by subway line.

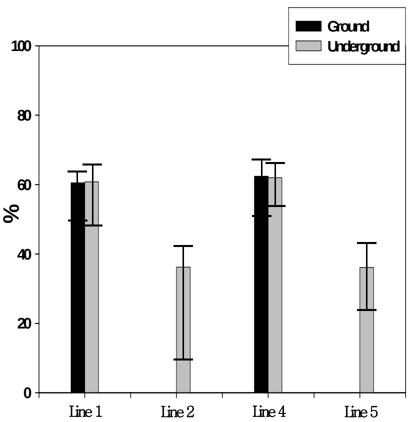
Table 2. The ratios (%) of $PM_{2.5}$ to PM_{10} and PM_{10} to total suspended particulate (TSP)

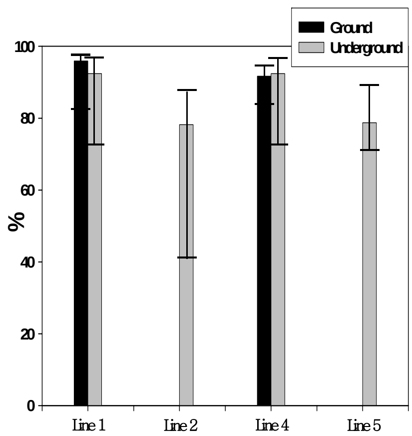
	Ground track	**Underground track**	**Total**
PM_{10} to TSP, %			
Platform	61.4±2.8	40.3±10.6	49.1±13.3
Inside train	53.1±53.1	42.9±12.2	45.7±12.9
Total	57.3±9.4	42.0±11.7	47.1±13.2
$PM_{2.5}$ to PM_{10}, %			
Platform	93.9±2.8	80.7±8.1	86.2±9.1
Inside train	86.5±12.1	79.9±9.1	81.7±10.4
Total	90.2±9.5	80.2±8.8	83.5±10.2





PM_{10} to TSP inside train **$PM_{2.5}$ to PM_{10} inside train**





PM_{10} to TSP on platform **$PM_{2.5}$ to PM_{10} on platform**

Figure 2. The ratio (%) of PM_{10} to TSP and $PM_{2.5}$ to PM_{10} by subway.

4. DISCUSSION

4.1 PM_{10} and $PM_{2.5}$ concentration

In Korea, no study on particulate matter including fine particle inside trains has been reported, although a few studies reported PM_{10} concentration on platforms (Kim et al, 2004; Park et al., 2004). Our study was the first to report PM_{10} and $PM_{2.5}$ concentration inside train and $PM_{2.5}$ on platform.

Our study was conducted during the afternoon (between 15:00 and 18:00), a period of time when passenger and traffic density could be low. PM_{10} and $PM_{2.5}$ concentrations inside train were significantly higher than those on platform (Table 1). PM_{10} and $PM_{2.5}$ concentration could rise during rush hours, in view of the increased passengers and traffic density outside the subway. Even though traffic gives rise to high level of particulate in the urban air, people are exposed to even higher levels in the subway. However, there is a lack of knowledge about this.[14)] There are many factors that could influence PM_{10} and $PM_{2.5}$ concentration in the subway system, e.g. weather, season, estimation of traffic and passenger density.

The main reason for interior PM_{10} and $PM_{2.5}$ concentrations being higher is that subway trains don't have mechanical ventilation systems to supply fresh air to inside the train. CO_2 concentration monitored on line 2 and line 5 ranged from 1,153 ppm to 3,377 ppm (Average: 1,775 ppm), which greatly exceeded 1,000 ppm, limit for efficient ventilation (Figure3). This result indicated a lack of fresh air inside train. Passengers generally could not recognize that fresh air was sufficiently supplied to interior, and just concerned more about heating and cooling. The Seoul Metropolitan Rapid Transit Corporation has been in charge of the safe management of the subway, but has not paid attention to the measures needed to supply fresh air to the interior train or subway stations.

PM_{10} and $PM_{2.5}$ concentrations monitored inside train on underground tracks when train doors were open showed temporary increases. After the doors were closed, they showed again constant pattern before doors of next station were opened (Figure4 right). On the ground track, opposite tendency was found. PM_{10} concentration became lower when train was open because less contaminated air than inside was naturally coming in (Figure4 left). The re-suspension of particulates from the trains floor and entry of particulate from outside the train due to passengers moving around or taking a seat whenever train is open could result in the rise of particulate contamination inside the train.

Interior particulate contaminated by several factors could not be lowered if dilution air from outside train was not supplied. Our study results were similar to those reported by several studies, in that PM concentration inside public transportations was higher than that of outside air.

Praml et al (2000) reported in a comprehensive 4-year survey that interior PM_{10} concentration exposure on Munich's public buses and trams was 244 $\mu g/m^3$ and 279 $\mu g/m^3$, respectively. These concentrations were 1.7 to 4 times above those collected at the static stations.

Chan et al.(2002a) reported that in four kinds of transport modes, particulate level in non-air-conditioned roadway transport was highest recorded level (175 ug/m^3). This concentration was about 3-4 times higher than the value in trains with air-conditioned facilities. The particulate level is greatly affected by transportation mode as well as the ventilation system of the transport.

$PM_{2.5}$ concentrations we monitored ranged from 77.7 $\mu g/m^3$ to 158.2 $\mu g/m^3$, which showed that the subway in Korea was terribly contaminated with fine particle not only inside train, but also on platform.

The average PM_{10} or $PM_{2.5}$ concentration from our study were far higher than those monitored from rush hours on subways in Hong Kong (Chan et al, 2002b), Mexico (Chow et al, 1997) and China (Chan et al, 2002b). Chan et al (2002b) reported that PM_{10} and $PM_{2.5}$ concentration monitored during rush hour on Mass Transit Railway, mostly running on the underground in Hong Kong were 44 $\mu g/m^3$ and 33 $\mu g/m^3$ [10]. Chan et al (2002b) reported similar PM10 (55 $\mu g/m^3$) and $PM_{2.5}$ concentration (44 $\mu g/m^3$) in subway with air-conditioned ventilation in Guangzhou, China. These concentrations were monitored on a subway running mostly on its own underground track during both non-peak hours (14:00-16:30) and evening peak hours (17:00-19:30). The average of $PM_{2.5}$ measured on the Mexico Metro with underground (or subway system) was 61 $\mu g/m^3$ (Chow et al, 1997).

PM_{10} and $PM_{2.5}$ concentration measured from underground tracks in China, Hong Kong and Mexico were far lower than those by our results and reported by Adams et al (2001) even though they were measured from the time including rush hours, where there is high traffic density and a greater number of passengers. Adams et al (2001) reported $PM_{2.5}$ concentration higher than those from our study results. $PM_{2.5}$ concentration measured during winter in the underground track (tube) ranged from 12.2 to 263.5 $\mu g/m^3$ (average 157.3 ug/m^3). $PM_{2.5}$ concentration measured during the summer was far higher (range: 105.3 ug/m^3 – 371.2 $\mu g/m^3$, average: 247.2 $\mu g/m^3$). High concentrations of particles have been reported in the underground previously, e.g. London Transport (1982), and more recently Priest et al.(1999) and Pfeifer et al.(1999).

The difference in monitoring results for PM_{10} and $PM_{2.5}$ in subways among cities might be due to time and season, the type of brake system, the ventilation system and depth of tunnel. The PM_{10} and $PM_{2.5}$ concentrations inside and outside subway is greatly influenced by the ventilation condition of the transport. Most of particulate found in subway had penetrated ventilation grids installed at street level. Most ventilation grids type in Seoul may allow fine particles released from motor vehicle exhausts on the streets, to easily penetrate into the subway.

In Korea, outdoor air from the ventilation grid on street is supplied to the platform subway. We couldn’t study if contaminated outdoor air was appropriately filtered and supplied into subway environment by the ventilation system. It is obvious that subway trains in Korea doesn’t have a mechanical ventilation system to supply fresh air to inside train, resulting in the increase in interior particulate matter.

4.2 The $PM_{2.5}$ and PM_{10} relationship

The $PM_{2.5}$ and PM_{10} ratio was high, ranging from 41.3 % to 97.8 % (Table 2). The highest ratio was 93.9 % on platforms of ground track mode. The average ratio (83.5%) from this study was slightly higher than 73.8 % for the Hong Kong (Chan et al., 200a) and 79 % underground track subway of Guangzhou, China (Chan et al., 2002b).

The $PM_{2.5}$ to PM_{10} ratios on platform of ground track mode were significantly higher than those for underground track. The reason that $PM_{2.5}$ concentrations and $PM_{2.5}$ to PM_{10} ratios on ground track were higher than those in underground tracks was that ground track stations were close to traffic exhaust on street-level, the main source of fine particulate (Table 1). This result may indicate that the air outside, as well as inside the subway, is greatly deteriorated by vehicle exhaust, especially diesel vehicles which may be the main source of fine particulate matter on subway. The average ratio of $PM_{2.5}$ to PM_{10} outside subway were slightly higher than those in interior train both underground and ground track although these ratio differences were not quite obvious.

The ratio of $PM_{2.5}$ to PM_{10} in all transportation modes including subway was found to be relatively high on the interior of an air-conditioned vehicle. Chan et al (2002) assumed that the air-conditioning system filter part of the larger portion (2.5-10 um), resulting in lowering the portion of PM_{10}. These patterns can't be examined in our study because the subway we investigated does not have an air-conditioned ventilation system.

Further study is required to examine the differences of the ratio of $PM_{2.5}$ to PM_{10} among several subway characteristics and to quantify the diesel exhaust concentration on subway air.

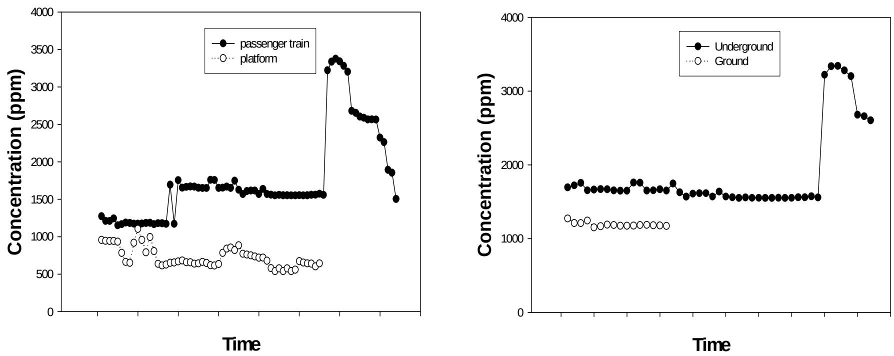


Figure 3. The typical concentration profile of CO_2 on platform and inside train (left: between platform and inside, right: between ground and underground track in inside train).

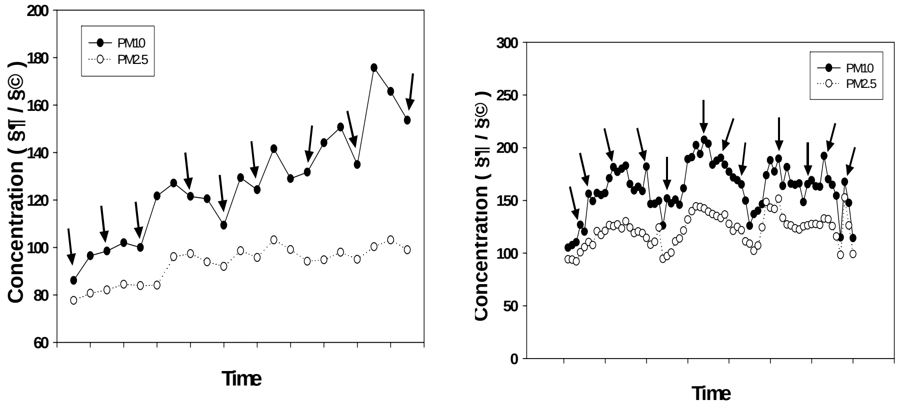


Figure 4. The typical concentration profile of PM_{10} and $PM_{2.5}$ while subway train is running. Arrows show the concentration monitored when door of train is open (left: ground, right: underground).

5. CONCLUSION

The concentrations of PM_{10} and $PM_{2.5}$ inside train were found to be higher than those measured on platform. The percentage of $PM_{2.5}$ that accounted for PM_{10} was slightly higher on platform and ground track than inside train and underground tract. PM_{10} and $PM_{2.5}$ concentrations monitored from underground tracks were significantly higher than those on ground track regardless of line and location. GLM statistical analysis indicated that monitoring locations (underground and ground or inside and platform) significantly influence PM_{10} and $PM_{2.5}$ concentration ($p<0.001$). The average of PM_{10} ratio was 83.5 %. $PM_{2.5}$ to PM_{10} ratios on platform during ground track mode were significantly higher than those in underground track. The highest ratio was 93.9 % on a platform on ground track mode. The percentage of $PM_{2.5}$ in PM_{10} was far higher than that of PM_{10} in TSP. This result indicates that the subway environment was contaminated with fine particulates.

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