

Particulate Matters Levels in Subway Tunnels and Cabins

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Abstract: This research aims to discern the characteristics of PM₁₀ concentrations measured in subway cabins, tunnels and outdoors at the Seoul Metropolitan subways. PM₁₀ concentrations in cabins were found between the range of 45.3 and 101.9 µg/m³, and in tunnels the ranges were between 155.3 and 230.6 µg/m³. PM₁₀ concentrations in cabins and tunnels during rush hours were 16.5% and 3.8% respectively higher than non-rush hours. Fine particles were higher than that of coarse particles both in subway cabins and tunnels.

Keywords: Indoor Air Quality, PM₁₀, Subway Cabin, Tunnel

1. Introduction

From the time its first line began operations in 1974, the Seoul Metropolitan Subway has been expanding to connect the entire city area. In 2011 a total of 2.4 billion people had used the subway from lines 1 to 8, with about 6.66 million. The subway takes up a 35.2% share of total transportation usage. As additional subway lines are planned for other metropolitan cities, the number of passengers using subways nationwide is expected to grow significantly (Seoul, 2009).

Air quality in subway cabins is comparatively worse than in the indoor spaces of other public buildings at ground level. Therefore, passenger health becomes an increasing concern as they are exposed to such pollutants over a prolonged period of time (Kim et al., 2006). PM₁₀ is a major pollutant in subway stations that is known to be generated from various factors such as subway train operation, passenger movement, and the inflow of outside air through the ventilation system. Epidemiological studies show that exposure to PM₁₀ is highly hazardous to the body, since it rises the sensible pollution level and along with it is the possible occurrence of disease and death rates. As PM₁₀ concentrations measured in subways are generally higher and more toxic than those in the air (Nieuwenhuijsen et al., 2007), they play a major role in deteriorating subway air quality and as such require proper control.

Many studies have measured PM₁₀ concentrations in the subway of major cities such as Beijing (Li et al., 2006), Hong Kong (Chan et al., 2002), Prague (Branis, 2006), London (Seaton et al., 2005) and New York (Chillrud et al., 2004). Other studies have measured PM₁₀ levels in Seoul subway stations and tunnels (Park and Ha, 2008; Park et al., 2004; Lee et al., 2010).

In this study, we measured the PM₁₀ concentrations of the Seoul Metropolitan subway lines from 5 to 8 using the light scattering method in order to observe PM₁₀ characteristics in subway cabins and tunnels. We also compared the PM₁₀ concentrations of outside air with those inside the cabins and tunnels, and analyzed the significance.

2. Research Methods

We used the light scattering method for this study as it is easy to control and enables continuous measurement. In this research, we measured the PM₁₀ concentration with Sky-OPC (Grimm 1.108). For measurement, the dust spectrometer divides PM₁₀ in the air into 32 channels by size at about a 1.2 l/min flow rate. The device can store data at 6-second intervals.

The measurement was conducted outdoors, in the cabins and tunnels of the Seoul Metropolitan subway lines 5 to 8 during rush and non-rush hours. Details of the measured lines

are described in table 1 (Seoul Metropolitan Rapid Transit Corporation, 2011). Line 5 has a 52.3 km in length and transported 296.5 million passenger traffic.

The measurement was carried out at the center of the subway cabins to minimize the influence of outside air. Measurement in the tunnels was conducted by putting tubes out through the windows to suction the ambient air. The sampling places for each individual measurement are shown in figure 1. SPSS ver. 13.0 was used to analyze the data.

Table 1. Seoul subway lines from 5 to 8.

Line No.	Section	No. of passengers (1,000/year)	Operation extension (km)
5	Banghwa – Sangil-dong, Macheon	296,458	52.3
6	Eungam – Bonghwasan	177,622	35.1
7	Jangam- Onsu	315,541	46.9
8	Amsa - Moran	84,404	17.7



Figure 1. Measurement places and apparatuses in subway.

3. Results and Discussion

3.1. PM_{10} Concentrations in Subway Cabins

Table 2 shows the results of PM_{10} concentrations in cabins of lines 5 to 8. The average PM_{10} concentration was higher during the rush hours than non-rush hours in all lines. During the rush hours, each line showed $115.8\mu\text{g}/\text{m}^3$, $83.1\mu\text{g}/\text{m}^3$,

$90.7\mu\text{g}/\text{m}^3$, and $66.0\mu\text{g}/\text{m}^3$ for lines 5, 6, 7 and 8, respectively. Line 5 showed the highest level and line 8 as the lowest. Most of the results were lower than $150\mu\text{g}/\text{m}^3$, which is the level of guidelines for public transportations in Korea with the exemptions of lines 5 and 7. In terms of hourly measurement results by line, PM_{10} concentrations during rush hours were 22.2%, 35.3%, 12.4%, and 23.1%, higher than during non-rush hours, for lines 5, 6, 7 and 8, respectively. This is probably because particles carried in by the number of passengers and suspended particles by the operation of trains during rush hours affect the PM_{10} concentration in cabins. Brains *et al.* (2005) and Fromme *et al.* (2007) reported that the indoor PM_{10} concentration was greatly affected by the activities of the people in a room. In a passenger cabin, there is an increase in passenger activity when the passengers enter and exit the cabin. However, quantitative measures to observe passenger activities inside a cabin were not available for this study.

Table 2. PM_{10} concentration in subway cabins in line 5.

Line 5		1 st	2 nd	Total
Rush hours	Ave.	101.9	132.8	115.8
	SD	15.3	22.2	24.2
	Max.	163.3	182.8	182.8
	Min.	73.9	75.5	73.9
Non rush hours	Ave.	93.1	96.5	94.8
	SD	13.5	14.0	13.8
	Max.	138.4	150.2	68.0
	Min.	68.0	73.7	150.2

Table 3. PM_{10} concentration in subway cabins in line 6.

Line 6		1 st	2 nd	Total
Rush hours	Ave.	70.7	95.5	83.1
	SD	12.2	14.1	18.1
	Max.	95.0	126.4	126.4
	Min.	32.6	40.1	32.6
Non rush hours	Ave.	45.8	77.0	61.4
	SD	3.9	14.6	18.9
	Max.	62.1	159.9	159.9
	Min.	31.3	52.2	31.3

Table 4. PM_{10} concentration in subway cabins in line 7.

Line 7		1 st	2 nd	Total
Rush hours	Ave.	75.3	106.0	90.7
	SD	8.9	20.4	22.0
	Max.	113.9	164.7	164.7
	Min.	51.4	49.3	49.3
Non rush hours	Ave.	76.8	84.5	80.7
	SD	9.0	14.7	12.8
	Max.	113.2	133.3	133.3
	Min.	63.9	56.9	56.9

Table 5. PM_{10} concentration in subway cabins in line 8.

Line 8		1 st	2 nd	Total
Rush hours	Ave.	66.4	65.6	66.0
	SD	4.6	14.4	10.6
	Max.	80.9	109.6	109.6
	Min.	56.9	27.2	27.2
Non rush hours	Ave.	53.2	54.1	53.6
	SD	6.2	6.1	6.2
	Max.	67.2	68.3	68.3
	Min.	41.6	42.7	41.6

3.2. PM_{10} Concentration in Subway Tunnels

Table 6. PM_{10} concentration in subway passenger tunnels (line 5).

Line 5		1 st Measurement	2 nd Measurement	Total
Rush hours	Ave.	327.0	383.1	355.6
	SD	56.2	63.0	66.0
	Max.	615.2	558.2	615.2
	Min.	215.5	255.6	215.5
Non rush hours	Ave.	161.1	232.3	195.8
	SD	22.3	51.9	53.2
	Max.	226.8	437.9	437.9
	Min.	114.1	113.6	113.6
	Min.	193.6	72.8	72.8

Table 7. PM_{10} concentration in subway passenger tunnels (line 6).

Line 6		1 st Measurement	2 nd Measurement	Total
Rush hours	Ave.	187.7	229.0	206.9
	SD	21.5	39.2	37.2
	Max.	255.9	353.5	353.5
	Min.	128.4	105.3	105.3
Non rush hours	Ave.	181.8	189.4	185.6
	SD	18.5	38.8	30.6
	Max.	247.2	408.3	408.3
	Min.	136.9	102.3	102.3

Table 8. PM_{10} concentration in subway passenger tunnels (line 7).

Line 7		1 st Measurement	2 nd Measurement	Total
Rush hours	Ave.	224.9	260.2	242.7
	SD	30.7	72.9	58.8
	Max.	372.8	543.6	543.6
	Min.	172.4	97.2	97.2
Non rush hours	Ave.	230.6	165.2	197.7
	SD	21.7	63.2	57.5
	Max.	342.8	555.8	555.8
	Min.			

Tables 6 to 9 show the results of PM_{10} concentration measurement in tunnels on lines 5 to 8. PM_{10} concentrations were higher during the rush hours than non-rush hours for all lines. During rush hours, $355.6\mu\text{g}/\text{m}^3$, $206.9\mu\text{g}/\text{m}^3$, $242.7\mu\text{g}/\text{m}^3$, and $148.6\mu\text{g}/\text{m}^3$ were for lines 5, 6, 7 and 8

respectively, with line 5 having the highest level and line 8 got the lowest. In terms of hourly measurement results by line, PM_{10} concentrations during rush hours were 81.6%, 11.5%, 22.8%, and 13.9% higher than during non-rush hours for lines 5, 6, 7 and 8, respectively.

Table 9. PM_{10} concentration in subway passenger tunnels (line 8).

Line 8		1 st Measurement	2 nd Measurement	Total
Rush hours	Ave.	184.8	110.5	148.6
	SD	22.6	24.4	44.0
	Max.	250.1	178.4	250.1
	Min.	145.4	55.5	55.5
Non rush hours	Ave.	158.8	106.0	130.5
	SD	26.3	20.1	33.4
	Max.	204.4	146.7	204.4
	Min.	115.8	68.4	68.4

3.3. Correlations of PM_{10} Concentrations

Figure 2 shows PM_{10} concentrations in subway cabins and tunnels of lines 5 to 8. For all subway lines, the PM_{10} concentrations were higher in tunnels than in cabins and it also shows that is higher during rush hours than non-rush hours. The concentration in cabins of line 5, which shows the highest concentration in tunnels, was also high in comparing the cabins between the other lines, while line 8, the lowest concentration in tunnels, was also low in cabins. This is probably because the PM_{10} concentration in subway cabins affects PM_{10} concentration in tunnels. An outdoor PM_{10} concentration was measured for three places, at the same time it was measured in subway cabins and tunnels.

We selected station G of line 5 to measure PM_{10} concentration in tunnels, subways and outdoors, simultaneously. Though Station G is not a transfer station, it is widely used at ordinary times.

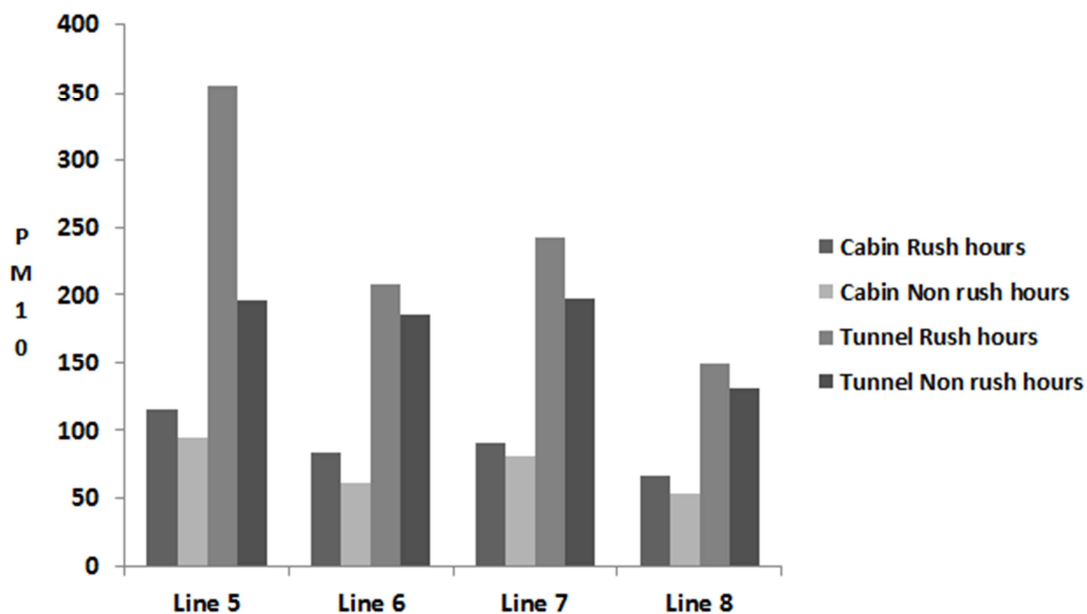


Figure 2. PM_{10} concentrations in subway cabins and tunnels.

Figure 3 shows the concentration distribution of PM₁₀ for Station G. The concentrations of fine particles are higher than that of coarse particles in the three places (outdoors, subway tunnels and cabins). Figure 4 shows the concentration distribution of PM₁₀ by size at the three places. In the case of outdoors, the concentration is highest when the particle sizes are between 0.35 μm and 4.5 μm . For tunnels, the concentrations are at its highest level when the particle size is between 0.25 μm and 0.35 μm , and at 1.6 μm . Subway cabins show peak concentration at 0.35, 2.5 and 6.5 μm , demonstrating that PM₁₀ concentrations are affected by outside air and tunnels.

According to the PMF study for subway cabins and

tunnels the PM₁₀ consisted of 52.5% inorganic components, 10.2% anions, and 37.3% other materials including cations, organic and inorganic carbons, and other unmeasured components. The iron content was the highest, generally accounting for 10–70% of the PM₁₀ concentration. The four sources identified by the PMF model were soil and road dust, railroad-related pollution sources, secondary nitrate, and Cl⁻ factor mixed with secondary sulfates and the sources accounted for 27.2%, 47.6%, 16.2%, and 9.1% of the PM₁₀, respectively (Park *et al.*, 2014; Park *et al.*, 2012).

Thus, it is required to install ventilation facilities to block the PM₁₀ brought in from tunnels and reduce the PM₁₀ carried in by the passengers.

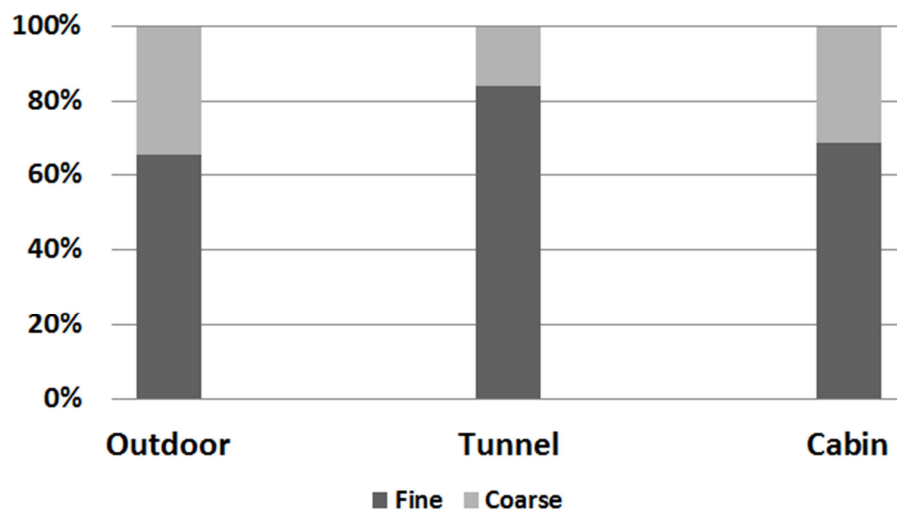


Figure 3. PM size distributions in station G.

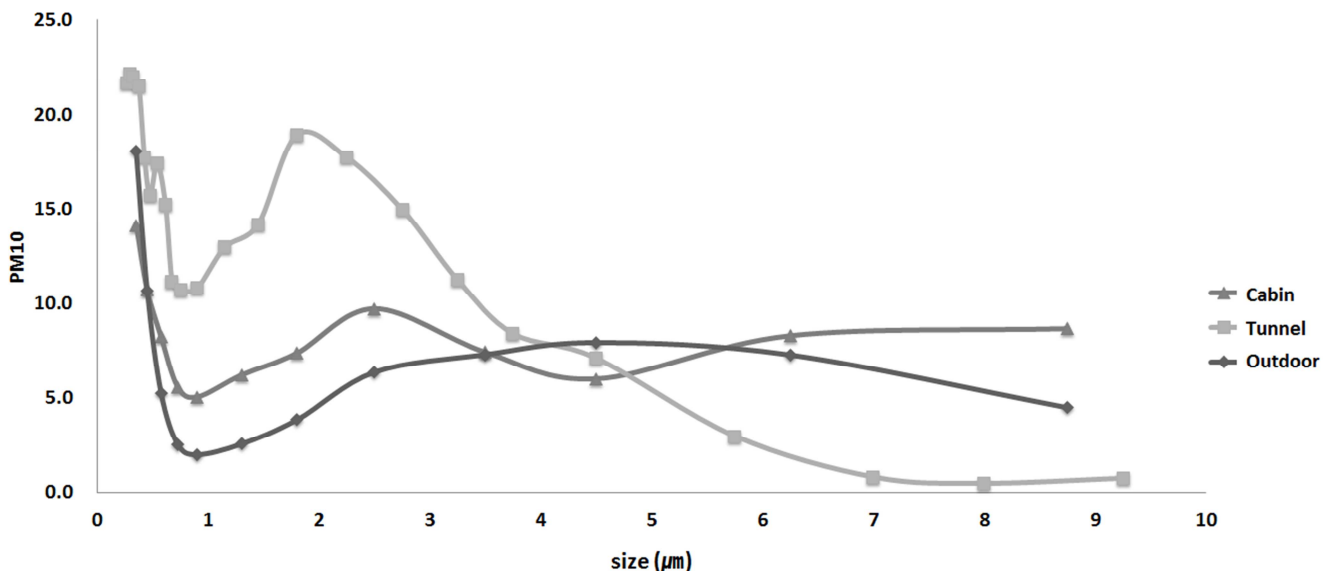


Figure 4. PM size distributions in subway cabins and tunnels.

4. Conclusion

In this study, we measured the PM concentrations of the Seoul metropolitan subways. Sky-OPC was used in order to

characterize PM concentrations in subway cabins and tunnels. We also compared the PM concentrations of outside air with those in cabins, tunnels, and analyzed the significance.

The average PM concentration in cabins of lines 5 to 8 is significantly higher during rush hours than non-rush hours

among all the lines used. In addition, the average PM concentrations in tunnels of lines 5 to 8 are also relatively higher during rush hours than non-rush hours for all lines.

Outdoor PM₁₀ concentration was measured for three points at the same time it was measured in cabins and tunnels. The concentrations of fine particles are higher than that of coarse particles in three places (outdoors, tunnels and cabins). Subway cabins show the peak concentrations at 0.35, 2.5 and 6.5µm, demonstrating that PM concentrations are affected by outside air and tunnels. Thus, as it has been mentioned, it is essential to install ventilation facilities to block the PM₁₀ brought in from tunnels and reduce the PM carried in by passengers.

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