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심포지엄 6) Particulate Behavior in Subway Airspace

Jo-Chun Kim[1),2)] · Jong Ryeul Sohn[3)] · Min Young Kim[4)] · Youn-Suk Son[2]
[1)]Department of environmental engineering Konkuk university
[2)]Department of Advanced Technology Fusion, Konkuk university
[3)]Department of Environmental Health, Korea University
[4)]Seoul Metropolitan Government Research Institute of Public Health and Environment

1. Introduction

Seoul, a metropolitan city, has been using more energy than any other areas in South Korea due to its high density of population; therefore, it gives very high emissions of air pollutants. The air pollution intensity in the city is 1.7 to 3.5 times more serious than that of advanced countries. This environmental air quality is closely associated with indoor air quality(IAQ) depending upon air pollutants. That is to say, Most of the people in urban areas, who stay indoor most of their time are threatened because of outdoor dirty air infiltrated into indoor airspace through a ventilation system. US EPA reported that the residential time in indoor was 21hr, the outdoor one 1.5hr, and the duration in the vehicles 1.3hr, on the other hand, GerES II of Germany reported that the durations were 20, 3, 0.9hr, respectively. Especially, urban people in modern society are spending most of their time in indoor airspace such as houses, buildings, schools and vehicles, however, these people are sometimes endangered by exposure to a contaminated environment; therefore, IAQ has been more recognized as a significant factor in determinating our health and welfare. Our indoor has been increasingly airtight in order to cut down energy and its efficiency. Also, various air pollutants generated physically, chemically, and biologically are emitted from mixed emission sources unlikely with atmospheric environment. Indoor air quality is not only serious in buildings, but also in underground communities and public transportation systems such as, an underground subway and market. Government and local autonomous entity have been pursuing a measure for IAQ improvement as well as outdoor air quality for the metropolitan areas including Seoul; however, there was no distinct improvement of air quality due to its high population density and busy economic activities. This infavorable circumstance is, also, the same as in indoor environment including a subway. Especially, a part of subway systems in the Seoul metropolitan area is expected to have the prospect that different species of hazardous pollutants may remain cumulated indoor due to too old ventilation and accessory systems(Kim et al., 2007). This subway system is serviced as lines 1 to 8 in the city, and occupies more than 34.1% among all means of transportation. It is estimated that approximately six million to ten million citizens in Seoul use the subway(Park and Ha, 2008). However, the problem of indoor particulate matters has been more serious because the subway airspace is a sort of enclosed system.

The most pivotal approach to improve subway IAQ is to examine the emission sources and particulate behaviors. Therefore, the main objective of this study is to investigate the particulate beh-aviors in the subway.

2. Experimental methods

In this study, in order to examine indoor air quality in the subway, a sampling and measurement campaign was carried out(performed, conducted) for 35 sites during the summer and winter seasons from May, 2005 to February, 2006. Sampling date and construction status are summarized in Table 1. Particulate sampling was conducted continuously for 20 and 24hr. Hence, twenty hour sampling depicts that subway stop duration(i.e., 4 hrs) was excluded.

Table 1. Sampling date and construction status in subway stations.

Line	Summer			Winter		
	Site	Date	Construction condition	Site	Date	Construction condition
A line	A-1	05/18/05		A-1	12/13/05	○
	A-2	05/19/05		A-2	12/12/05	
	A-3	05/23/05		A-3	12/09/05	
	A-4	05/24/05		A-4	12/08/05	
	A-5	05/26/05		A-5	12/06/05	
	A-6	05/30/05		A-6	12/05/05	
	A-7	05/31/05	○	A-7	12/02/05	
	A-8	07/19/05		A-8	12/01/05	
B line	B-1	06/02/05	○	B-1	12/19/05	○
	B-2	06/07/05	○	B-2	12/20/05	○
	B-3	-		B-3	12/21/05	
	B-4	06/09/05		B-4	12/22/05	○
	B-5	06/20/05	○	B-5	12/13/05	
	B-6	06/21/05		B-6	12/14/05	○
	B-7	07/11/05		B-7	12/23/05	○
	B-8	07/12/05		B-8	12/26/05	○
	B-9	07/13/05		B-9	12/27/05	○
	B-10	07/14/05		B-10	12/28/05	
	B-11	07/18/05		B-11	12/14/05	
C line	C-1	06/22/05		C-1	12/29/05	○
	C-2	06/23/05		C-2	12/30/05	
	C-3	06/27/05		C-3	01/02/06	
	C-4	06/28/05		C-4	01/03/06	
	C-5	06/29/05	○	C-5	01/04/06	○
	C-6	06/30/05		C-6	01/05/06	○
	C-7	07/04/05		C-7	01/06/06	
	C-8	07/05/05		C-8	01/09/06	
	C-9	07/06/05		C-9	01/10/06	
	C-10	07/07/05		C-10	01/11/06	
D line	D-1	05/09/05		D-1	01/19/06	
	D-2	05/10/05		D-2	01/18/06	○
	D-3	05/11/05		D-3	01/17/06	
	D-4	05/12/05		D-4	01/16/06	○
	D-5	05/16/05		D-5	01/13/06	
	D-6	05/17/05		D-6	01/12/06	

3. Results and discussions

3.1 Measurement sites

It has been reported that the source of particulate matter(PM) which affects the IAQ of the subway could be associated with complicated conditions, such as movement of passengers, operating process of subway, outside air for ventilation. The concentrations of PM obtained from platform and waiting room are presented in Table 2. In case of 24 hour measurement, the mean concentrations of platform and waiting room were 156.18±53.79$\mu g/m^3$ and 111.00±53.31$\mu g/m^3$($P<0.05$). Besides, as a result of 20 hour measurement, the mean concentrations of platform and waiting room were 156.18 ±53.79$\mu g/m^3$ and 111.00±53.31$\mu g/m^3$, respectively, and it was also found that concentrations of platform with respect to the two different sampling durations were higher than those of waiting room for the most time as shown in Figure 1.

Table 2. PM distributions with respect to sampling durations and sites on subway stations.

Sampling duration	Site	N	mean	STD	Min	Max	p-Value
PM_{10}-24hr ($\mu g/m^3$)	Platform	60	156.18	53.79	40.28	256.67	<0.05
	Waiting room	67	111.00	55.31	16.67	290.56	
	All	127	132.35	57.93	16.67	290.56	
PM_{10}-20hr ($\mu g/m^3$)	Platform	66	146.09	53.71	26.67	258.33	<0.05
	Waiting room	63	99.08	42.77	18.98	222.33	
	All	129	123.13	53.92	18.98	258.89	

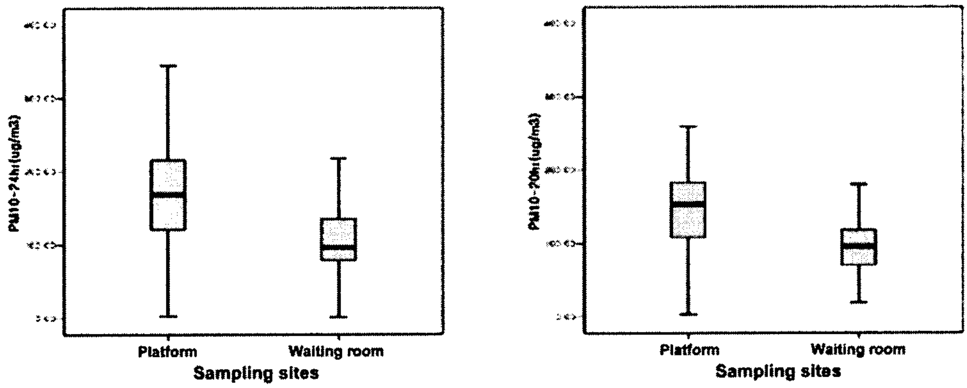

Fig. 1. PM_{10} concentration distribution by sampling site.

3.2 Variations of PM by season

In order to find out seasonal characteristics of PM in the subway during summer and winter seasons, a seasonal comparison study was performed, as a result, PM concentration(PM_{10}-24hr) measured for 24hr in winter was 146.71±58.85$\mu g/m^3$, which was higher than a summer value, 118.20± 53.80$\mu g/m^3$($P<0.05$). On the other hand, a particulate level(PM_{10}-20hr) measured for 20hr in summer was 126.31±56.74$\mu g/m^3$, which was similar to a winter value, 120.18±51.43$\mu g/m^3$($P>0.05$). In addition, PM concentration distribution with respect to sampling locations and seasons is revealed in Table 3. As a result of PM_{10}-24hr measurement, PM concentrations in platform were higher than in waiting room during summer and winter seasons($P<0.05$). In case of PM_{10}-20hr measurement, PM concentrations in platform were also higher than in waiting room during the two seasons($P<0.05$); however, it was observed that those in winter was higher than in summer($P>0.05$).

Table 3. concentration distributions of PM by season.

Sampling duration	Season	Site	N	Mean	STD	Min	Max	p-Value	
PM_{10} 24hr ($\mu g/m^3$)	Summer	Platform	31	141.79	43.82	40.28	215.28	<0.05	<0.05
		Waiting room	33	96.05	53.41	16.67	230.56		
		All	64	118.20	53.80	16.67	230.56		
	Winter	Platform	29	171.57	59.70	58.33	256.67	<0.05	
		Waiting room	34	125.51	49.77	59.26	290.56		
		All	63	146.71	58.85	31.67	290.56		
	All		127	132.35	57.93	16.67	290.56		
PM_{10} 20hr ($\mu g/m^3$)	Summer	Platform	33	150.84	54.46	26.67	211.11	<0.05	>0.05
		Waiting room	29	98.41	45.93	21.67	228.33		
		All	62	126.31	56.74	21.67	228.33		
	Winter	Platform	33	141.34	53.36	51.39	248.61	<0.05	
		Waiting room	34	99.65	40.58	18.98	223.61		
		All	67	120.18	51.43	18.98	248.61		
	All		129	123.13	53.92	18.98	258.98		

3.3 Statistical analysis with reference to sampling time

The difference of the PM_{10} concentration by sampling time is shown in Table 4, which was obtained from T-test analysis. It should be statistically concluded that PM_{10}-24hr was the same as that for PM_{10}-20hr during summer months for all sampling locations because p value was greater than 0.05. It was found that PM_{10}-24hr was higher than PM_{10}-20hr in both platform and waiting room during winter months($p<0.01$). Also, it was observed that PM_{10}-24hr and PM_{10}-20hr in winter had a high correlation($r=0.836$). In general, PM_{10}-24hr was higher than PM_{10}-20hr($p<0.01$), and both PM concentrations showed a high correlation coefficient($r=0.803$). This result implies that PM_{10} should be suspended in underground stations for 4 hr when the train was not run.

Table 4. comparison between PM_{10}-24hr and PM_{10}-20hr.

Season	Sampling location and duration		n	mean	STD	r	p-value
Summer	Platform	24hr	24	158.08	31.72	0.617**	>0.05
		20hr	24	152.31	33.81		
	Waiting room	24hr	22	104.37	47.09	0.732**	>0.05
		20hr	22	101.67	36.72		
	Total	24hr	46	132.39	47.8	0.785**	>0.05
		20hr	46	128.09	43.22		
Winter	Platform	24hr	27	175.76	57.68	0.825**	<0.01
		20hr	27	148.11	54.36		
	Waiting room	24hr	29	124.45	47.78	0.76**	<0.01
		20hr	29	103.86	38.69		
	Total	24hr	56	149.19	58.34	0.836**	<0.01
		20hr	56	125.2	51.54		
Total	24hr		102	141.61	54.24	0.803**	<0.01
	20hr		102	126.5	47.76		

* Correlation is significant at the 0.05 level
** Correlation is significant at the 0.01 level

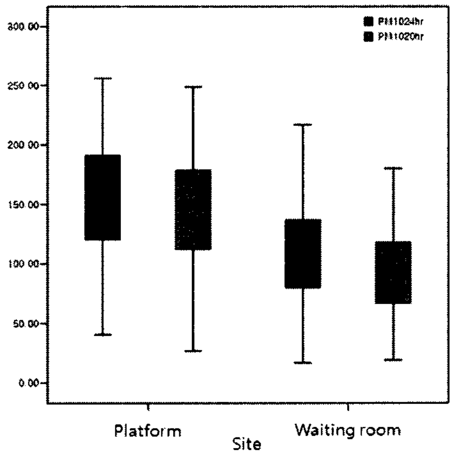

Fig. 2. PM_{10} concentration distributions with respect to sampling time.

3.4 Characteristics of $PM_{2.5}$

In this study, the difference of $PM_{2.5}$ concentration with all sampling sites could not be observed since only platform measurement was conducted, and it was found that the $PM_{2.5}$ concentration (109.56±28.24㎍/㎥) in winter was higher than that(83.66±57.82㎍/㎥) in summer. $PM_{2.5}$ is assumed to be one of the most significant factors of PM_{10} increase in the subway; therefore, the correlation analysis beween the two concentration levels was carried out. Correlation coefficients between PM_{10} and $PM_{2.5}$ in the subway are shown in Table 5. In case of underground subway stations, correlation coefficient between PM_{10} and $PM_{2.5}$ was 0.487 and positive($p<0.01$).

Table 5. Correlation analysis of PM_{10} and $PM_{2.5}$.

Site	Pollutant	$PM_{2.5}$	PM_{10}
Subway station	$PM_{2.5}$	1	
	PM_{10}	0.487**	1

**Correlation is significant at the 0.01 level (2-tailed).

3.5 Characteristics of particulate behavior

Additional experiments were performed at 5 subway stations in line A so as to find out the characteristics of particulate behavior according to particle size distributions. This result revealed that the highest PM_{10} concentration, 162.2㎍/m^3, appeared at station Ⅱ. The mean PM_{10} and $PM_{2.5}$ concentrations in the stations of concern were 85.4~190㎍/m^3 and 51.4~113.2㎍/m^3, respectively. These concentration distributions were very different according to the installation of platform screen door(PSD), ventilation rates, characteristics of the outdoor air quailty and the structure of the subway. In this study, however, it was found that the ratio of $PM_{2.5}$ to PM_{10} was higher than 50% excluding station II. Therefore, in general, $PM_{2.5}$ contribution to PM_{10} concentration seems to be significant in the subway stations concerned, and this output suggested that the environmental standard on $PM_{2.5}$ level should be necessary as well as PM_{10} standard.

Table 6. Distribution characteristics of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$.

A line	Subway station with PSD		Subway station without PSD		
	I	Ⅱ	Ⅲ	Ⅳ	Ⅴ
PM_{10}	85.4	162.2	190	188.6	131.2
$PM_{2.5}$	51.4	50.4	113.2	96.8	78.0
$PM_{1.0}$	42.8	34.2	82.2	72.6	59.4
$PM_{2.5}/PM_{10}$(%)	60.2	31.1	60.0	51.3	59.5

References

Imre Salma, Tamas Weidinger, and Willy Maenhaut (2007) Time-resolved mass concentration, composition and sources of aerosol particles in a metropolitan underground railway station, Atmospheric Environment, 41, 8391-8405.

Kim, K.Y., Y.S. Kim, Y.M. Roh, C.M. Lee, and C.N. Kim (2007) Spatial distribution of particulate matter(PM_{10} and $PM_{2.5}$) in Seoul Metropolitan Subway stations, Journal of Hazardous Material, in press.

Park, D.-U. and K.-C. Ha (2008) Characteristics of PM_{10}, $PM_{2.5}$, CO_2 and CO monitoring in interiors and platforms of subway train in Seoul, Korea, Environment International, in press.