Effect of Platform Screen Doors on Indoor PM$_{10}$ Concentrations in an Underground Subway Station

Hwataik Han$^{1,*}$, Kyung-Jin Jang$^{2}$, Cheolyong Shin$^{3}$, and Jun-Yong Lee$^{3}$

$^{1}$Department of Mechanical Engineering, Kookmin University, Seoul 136-702, Korea
$^{2}$Thermal Environmental Engineering Laboratory, Kookmin University, Seoul 136-702, Korea
$^{3}$Graduate School, Kookmin University, Seoul 136-702, Korea

*Corresponding email: hhan@kookmin.ac.kr

SUMMARY
We evaluate indoor particle concentrations in a subway station, before and after installing platform screen doors (PSDs) in order to investigate the effect of the doors on the indoor environment. We analyze two years of data obtained from an underground subway station in Seoul, Korea using an indoor air tele-monitoring system (TMS). The measured data are averaged over time and compared on an hourly basis. The concentration levels and frequencies are compared for the tunnel and platform zones. With the PSDs installed, the PM$_{10}$ concentration level in the platform is significantly reduced compared to the level in the tunnel. We conclude that a significant portion of particulate matter is generated in the tunnel and entrained into the platform zone, and that using PSDs is an effective way to reduce particle concentrations in underground subway stations.

KEYWORDS
Indoor environment, Subway station, PM10, Tele-monitoring system, Platform screen door, concentration frequency.

1 INTRODUCTION
Metropolitan areas are experiencing increasing air pollution and traffic congestion. Governments recommend public transportation that generates fewer greenhouse gases and less environmental pollution. Individuals increasingly use public transportation to avoid time delays due to road traffic and high gas prices. Due to its many routes and precise operating times, the Seoul subway system is used by many people as their main mode of transportation. The Seoul subway comprises 36% of Seoul’s public transportation system [1]. City dwellers accustomed to a high quality of life have a high interest in public health and react very sensitively to air pollution exposure. Given that residents of large cities such as Seoul use the subway as their primary form of transportation, the interior environments of underground subway stations require proper maintenance. An underground subway station is a limited and enclosed space, so contamination that occurs within the station cannot be easily discharged outside. If proper ventilation cannot occur because natural ventilation is difficult, the concentration of pollutants can easily increase to harmful levels, thereby resulting in very poor indoor air quality. As a facility used by many passengers, an underground subway station requires continuous management of contaminants. Air pollution measurement systems in large cities in the United States, Europe, and Asia indicate high levels of underground subway station contaminant exposure [2-4]. In many countries, target materials are specified as ozone, carbon dioxide, nitrogen dioxide, sulfur dioxide, and particles of 10 micrometers or
less (PM10) in size. United States regulations require that a PM10 concentration in an underground subway station must be maintained at less than an average of 140 μg/m³ over a 24 hr period [5]. PM10 particles have been linked to respiratory and cardiovascular diseases, and numerous case studies show that they have a highly adverse effect on the human body [6-8]. In addition, there are many studies in progress regarding measured pollutants of underground subway stations involving particulate matter such as fine suspended particles and asbestos, and gaseous pollutants such as CO₂ and total volatile organic compounds (TVOCs) [9-12]. Moreover, the dust raised by a rail line’s rails and wheels and the dust accumulated on the ground can greatly affect an underground station’s air quality. Researchers from the University of Southern California measured PM10 concentrations in Los Angeles underground and ground line platforms and carriages at the same time, and determined the cause of PM10 for each line [13]. Gehrig analyzed PM10 concentrations in Zurich, Switzerland lines with a large number of passing trains [14]. Johnansson measured and compared PM10 concentrations before and after tunnel cleaning in an underground station in Stockholm, Sweden [15]. Screen doors were installed on the platform for the first time in the United Kingdom not only because of suspended particulates, but also to reduce train draft, reduce noise, and improve safety. Since then, screen doors have been applied to the subway stations in France, Japan, and Hong Kong. In Korea, doors have been installed in most underground subway stations beginning with the 2004 installation in Gwang-ju subway line 1. With the installation of screen doors on the platform, underground stations are separated into a platform and a train tunnel. Thus, with the air flow cut off between the platform and tunnel, the indoor environmental characteristics of the platform and tunnel differ. As their effect on each other weakens, the pollutants that occur in the tunnel and platform yield different concentrations. A platform is a space used by many people, and it generates much airborne dust. In this paper, we investigated changes in the indoor environment of a platform with PSDs by comparing and analyzing PM10 concentration data for the platform before and after door installation.

2 EXPERIMENTAL METHODS

Subway station layout
The layout of underground stations typically shows the waiting zone on the first basement level and the platform on the second basement level. The waiting zone is comprised of connecting passages and office spaces. The platform is divided into two spaces: a tunnel through which the trains run, and a platform from which passengers get on and off the trains. PM10 in the tunnel is easily transferred to an adjacent platform. The type of underground station PSD used in this study has a complete seal. This system is comprised of a fixed wall and an automatic door on the boundary between the tunnel and platform. The automatic door is coupled with the train door and is operated simultaneously. The platform becomes a disconnected zone from the tunnel after installation of the PSD seal. The platform is difficult to ventilate naturally because there is no direct connection to the outdoors. Ventilation requirements vary according to the number of passengers on the platform. Therefore, the characteristics of contaminants such as PM10 also vary from one zone to another. The method to reduce or eliminate a platform’s PM10 concentration is based on analysis of the environmental characteristics.

PM10 measurements
The indoor air tele-monitoring system (TMS) operated by Korea Environment Corporation (KEC) measures and records indoor temperatures and concentrations of contaminants in real
time. The TMS is an online system connected to a control center which can monitor the air 24 hours a day. This system is currently operating in 38 public facilities, three of which are underground subway stations. The TMS installed in the subway stations measures pollutants including PM$_{10}$, CO$_2$, and NO$_2$. The system uses the β-ray absorption method to measure PM$_{10}$. Ambient air is sucked into the sampling system and particle mass is continuously captured by internal filter. The layer of dust is building up and the increasing dust mass weakens the intensity of the beta beam, which is emitted through the particles. The underground station in which the measurements were made for this study is one of the most crowded stations in Seoul, used by approximately 17 million passengers per year in 2009. There are two platforms located symmetrically on both sides of the two-way rail track in the middle. The PSDs were installed and have been in operation since 2009. The three measurement points were located in the tunnel, the platform, and the waiting zone, as shown in Fig. 1. We analyzed the pattern of concentration by time band average before (2008) and after (2009) PSD installation. We intended to exclude errors due to seasonal effect by analyzing annual data for a whole year. The variation of the concentrations was analyzed based on frequency.

![Figure 1. TMS installation locations on a standard Seoul subway station map shown with dark cylinders. The other figures are exits and subway station facilities.](image)

Table 1, Locations of measurements for each contaminant,

<table>
<thead>
<tr>
<th>Station</th>
<th>Measurement locations</th>
<th>Measurement contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CO$_2$</td>
</tr>
<tr>
<td>Station-S in the 4th Line of the Seoul Subway</td>
<td>Outdoor</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Waiting zone</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Platform</td>
<td>●</td>
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<tr>
<td></td>
<td>Tunnel</td>
<td>-</td>
</tr>
</tbody>
</table>

3 RESULTS AND DISCUSSION

PM$_{10}$ concentration variations in the tunnel and platform
To investigate variations in PM$_{10}$ concentrations within the subway station, data averaged over one year were arranged as hourly mean concentrations (Fig. 2) to enable pattern analysis of the station’s platform and tunnel concentrations. The mean concentration in the tunnel is
higher than on the platform during operating hours, but the platform’s concentration is slightly higher during off-hours, as shown in Fig. 2(a). Mechanical ventilation is not operated when trains do not run. Therefore, PM10 in a platform cannot quickly escape the space, whereas PM10 in a rail zone is diffused into the tunnel. The concentration jump at 3 AM (Fig. 2) was due to tunnel cleaning. The dust from the internal wall and railway floor was temporarily dispersed in the tunnel, and was also entrained into the platform area.

Figure 2(b) shows variations of PM10 concentration versus time after the PSD installation. We note that the concentration pattern in the tunnel in 2009 is similar to that in the pattern in the tunnel in 2008. The concentration decreased during non-operating hours, from 1 AM to 5 AM, but increased during peak operating hours, from 6 AM to 10 AM. The PM10 concentration decreased after peak hours but the variation is relatively small. Even though the patterns of concentration for the platform are similar, the concentration level in 2009 decreased significantly compared to the level in 2008 after the PSD installation. Thus, we conclude that the main source of PM10 was in the tunnel.

![Graphs showing PM10 concentration patterns](image)

(a) Before PSD installation (2008).  
(b) After PSD installation (2009).

**Figure 2. Average PM10 concentration patterns in the tunnel and platform in 2008 and 2009.**

**Concentration frequency distributions**

Figure 3(a) shows the concentration frequency distributions in the tunnel during 2008 and 2009. The distributions are similar before and after installation of the PSD. The generation of PM10 in the tunnel can be considered to have remained nearly uniform year-after-year. Figure 3(b) shows a comparison of the concentration frequency distribution in the platform before and after installation of the PSD. The platform’s PM10 concentration prior to the PSD installation often exceeds the standard concentration level of 140 μg/m³, whereas the concentration in 2009 following the PSD installation does not exceed the standard at all. In Fig. 3, we note that the area with the maximum concentration frequency has moved toward the left on the graph, indicating a decreased concentration interval. In 2008, the frequency of exceeding a level of 140 μg/m³ was 30% of the overall frequency. After PSD installation in 2009, the frequency of exceeding the standard was significantly reduced to 0.5%. This indicates that the PSD isolated the PM10 generated in the tunnel effectively. Therefore, we confirm that the concentration pattern for PM10 that occurred within the subway station changed according to peak hours, and that a significant amount of PM10 generated in the tunnel did not spread to the platform area after the PSD installation.
4 CONCLUSION
We investigated time-varying patterns of PM10 concentrations in a tunnel and a platform in a subway station in Seoul, Korea. To determine the effect of PSD installation, we compared and analyzed the PM10 concentration values in 2008 prior to installation with the values in 2009 following installation.
(1) The data show that both the tunnel and platform PM10 concentrations reached high levels during peak hours, and that the levels changed to low concentration values during non-operating hours.
(2) The concentration of PM10 on the platform exceeded the regulatory standard of 140 μg/m³ by 30% prior to the PSD installation.
(3) PSD installation improved the platform’s environment significantly, and the PM10 concentration remained nearly within the standard.
(4) PM10 concentrations within the tunnel in 2008 and 2009 were at similar levels, and PM10 concentrations that occurred on the platform appeared to be significantly different because air flow was blocked after PSD installation. Therefore, we conclude that the main source of PM10 is train operation in the tunnel.

We investigated the cause of a reduction in a subway train platform’s PM10 concentration generated in the tunnel during train operation after PSD installation. Further studies are required to investigate the characteristics of other contaminant sources and the concentration correlations between the contaminants to improve the subway station environment.

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5 REFERENCES