AIR QUALITY IN PASSENGER CARS OF THE GROUND RAILWAY TRANSIT SYSTEM IN BEIJING, CHINA

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ABSTRACT
This study examined the concentration of carbon monoxide, carbon dioxide, TVOC, TSP, \(\text{PM}_{10}\), \(\text{PM}_{2.5}\), \(\text{PM}_{1}\), benzene, toluene and xylene in passenger cars of the Beijing Ground Railway Transit System (Line No. 13). This system connects the northern suburb and downtown, and is equipped with air-conditioned passenger cars. In-train air quality monitoring was performed in both summer (July and August) and winter (December). To obtain representative data, the sampling design considered both rush and regular hours, urban and suburban areas, as well as the number of passengers. Meanwhile, questionnaires were distributed to the passengers. The monitoring results indicated that, overall, the air quality in the passenger cars was acceptable with a few exceptions, which is consistent with the passengers’ perception. Concentrations of some air pollutants showed significant seasonal variations and had the significant difference between rush hour and regular hour. Furthermore, the in-train air quality was greatly influenced by the number of passengers. This paper describes the experimental design, and presents the preliminary results.

INDEX TERMS
Passenger car, Commuter exposure, Indoor air quality, Railway

INTRODUCTION
People in metropolitan areas spend a considerable amount of time commuting between their workplaces and homes. According to a report by U.S. EPA (1989), urban people in the United States spend about 90 minutes commuting every workday. Thus, air quality in transportation vehicles has become a concern to the general public.

A number of studies have been devoted to commuters’ exposure inside public or private transportation vehicles. From 1990 to 2003 there were many papers were published, which were conducted in German, USA, UK, France, Korea and Hong Kong, etc (Rudolf 1990, Lawryk 1996, Dor 1995, Leung 1999, Jo 1998, Lau 2003, Chan 2002a). In China, the public transportation systems are significantly different from those in developed areas in design, operation, and occupancy. Air quality in public transportation vehicles is largely unknown. Only Chan (2003, 2002b) examined the exposure of respirable suspended particulate, carbon monoxide, aromatic VOCs in public transportation modes in Guangzhou.

Beijing is one of the most developed cities in China, and has a population of 15 million. Like many other large cities in developing countries, Beijing relies heavily on mass transit systems to transport people. Among the many modes of public transportsations available in the city, the public railway transit system becomes more and more popular because of its celerity and comfort. This is especially true for the newer Ground Railway Transit System (GRTS). Currently, the system has only one line designated Line No.13. By 2008, more lines will be open. Thus, the GRTS is expected to play an even greater role in the city’s public transportations in the coming years. The objective of this study was to investigate the in-train air quality of the GRTS.

METHOD
Field Study Design
As shown in Figure 1, railway Line No. 13 connects the northern suburb and downtown. Each train has four air-conditioned passenger cars, and is

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powered by an electric engine. In-train measurements were conducted between Stops 1 and 15, which covers nearly the whole span of Line No. 13. The section between Stops 15 and 16 was excluded because it is underground. The total time to travel from stop 1 to stop 15 is about 53 minutes. To investigate the impact of train occupancy and surroundings areas (downtown vs. suburb) on in-train air quality, the whole study range was divided into three segments. Segment one is from Stop 1 to Stop 5. Segment two is from Stop 5 to Stop 9. Segment three is from Stop 9 to Stop 15. Field sampling and measurements were conducted in the summer (July and August) and winter (December) of 2004. The monitoring items in the winter season included temperature, relative humidity (RH), carbon monoxide, carbon dioxide, TVOC, TSP, PM$_{10}$, PM$_{2.5}$, PM$_{1}$, benzene, toluene and xylene. In the summer season, only temperature, RH, carbon monoxide, carbon dioxide and TVOC were measured. During each sampling day, the in-train concentrations were measured in both rush hour (7:00 – 9:00 or 17:00 – 19:00) and regular hour (11:00 – 13:00). For benzene, toluene, and xylene, integrated samples were taken for each of the three segments as mentioned above; other target pollutants were sampled between every two adjacent stops. In addition, about 300 questionnaires were distributed to passengers in the train, and 151 eligible ones were collected. Useful information such as the number of passengers, sampling time, traffic condition and weather condition were recorded in each survey trip.

Measurement Equipment, Method and Quality Assurance
Temperature and RH were measured by electronic thermohydrograph. Carbon monoxide and Carbon dioxide were measured by portable sampler. TVOC was measured by Phocheck 5000 portable TVOC monitor. TSP, PM$_{10}$, PM$_{2.5}$, PM$_{1}$ were all measured by Dustmate fume and dust detector. The monitors were calibrated with standard gases before each field measurements. To stabilize the instruments, they were turned on 30 minutes prior to each trip. For benzene, toluene and xylene, air samples were collected with polished stainless steel canisters. The collected air samples were processed by a preconcentration trap at 10°C, and then thermally desorbed and transferred to the GC (Varian GC3800). The target compounds were identified by their retention times and quantified by external standards. Duplicate samples were regularly collected to check the precision and reliability of the sampling and analyzing method. The relative standard deviations of all duplicates were within 10% for all the target compounds.

RESULTS AND DISCUSSION
In-Train Air Quality
The in-train temperature, RH and concentrations are summarized in Table 1. To assess the air quality in the train, the field data of this study were compared to the China Indoor Air Quality Standards. Sixty percent of carbon dioxide measurements exceeded the standard largely because of the high occupancy, which is typical in the mass transit systems in Beijing. Some temperature measurements also exceeded the standards (higher than 28°C in summer or lower than 16°C in winter), and so did some humidity measurements. These data suggest that the air conditioning system in the train was inadequate under extreme weathers. Other concentrations are well below the China Indoor Air Quality Standards and none of the measurements exceeded standards. Overall, the air quality in the passenger cars was acceptable with a few exceptions. To assess the passengers’ perception of the air quality in the passenger cars, 151 questionnaires were analyzed. Seventy-five percent of passengers did not have any uncomfortable feelings; twenty-four percent felt low degree of discomfort; and only one percent felt uncomfortable at the high degree. Most of the uncomfortable perceptions occurred when the train was overly crowded.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>S.D.</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>197</td>
<td>23.1</td>
<td>5.8</td>
<td>8.8-31.2</td>
</tr>
<tr>
<td>RH</td>
<td>194</td>
<td>53.1</td>
<td>14.9</td>
<td>36.0-87.0</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td></td>
<td>0.8</td>
<td>0.4</td>
<td>0.1-2.3</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>201</td>
<td>432.3</td>
<td>1177.4</td>
<td>560.0-2700.0</td>
</tr>
<tr>
<td>TVOC</td>
<td>210</td>
<td>0.3</td>
<td>0.1</td>
<td>0.1-0.5</td>
</tr>
<tr>
<td>TSP</td>
<td>84</td>
<td>78.7</td>
<td>165.8</td>
<td>57.2-538.5</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>83</td>
<td>56.0</td>
<td>108.4</td>
<td>35.5-373.1</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>83</td>
<td>18.7</td>
<td>36.9</td>
<td>13.1-111.3</td>
</tr>
<tr>
<td>PM$_{1}$</td>
<td>83</td>
<td>6.6</td>
<td>14.7</td>
<td>5.4-39.1</td>
</tr>
<tr>
<td>Benzene</td>
<td>18</td>
<td>5.5</td>
<td>13.7</td>
<td>6.4-31.2</td>
</tr>
<tr>
<td>Toluene</td>
<td>18</td>
<td>4.7</td>
<td>12.4</td>
<td>6.1-24.0</td>
</tr>
<tr>
<td>Xylene</td>
<td>18</td>
<td>2.3</td>
<td>4.1</td>
<td>1.2-10.0</td>
</tr>
</tbody>
</table>

Table 1. The in-train temperatures, RHs and concentrations
Factors Affecting the In-Train Air Quality

(1) Seasonal Variations
Table 2 shows mean concentrations in the passenger cars in winter and summer. Carbon monoxide, carbon dioxide and TVOC were the only pollutants measured in both seasons. The concentration of carbon monoxide is greater in winter than in summer (p<0.01), while the differences of carbon dioxide and TVOC concentrations are not significant between the two seasons. The concentrations of TVOC and Carbon dioxide correlate well with the number of passengers (Table 3) which does not change significantly between seasons. As there is no in-train source of carbon monoxide, only the ambient concentration can influence the in-train concentration. Because of the winter heating in Beijing, the ambient concentration of carbon monoxide is higher in winter than in summer, which is the likely cause of the seasonal variation of carbon monoxide inside the passenger cars.

Table 2. Mean in-train concentrations by season (in ppm)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>0.9±0.4 (n=84)</td>
<td>0.7±0.3 (n=110)</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>1270.3±475.6 (n=84)</td>
<td>1110.7±386.7 (n=117)</td>
</tr>
<tr>
<td>TVOC</td>
<td>0.3±0.1 (n=84)</td>
<td>0.3±0.1 (n=126)</td>
</tr>
</tbody>
</table>

(2) Variations with the Time Of Day
The in-train concentrations measured during rush hour and regular hour are summarized in Table 4. The in-train concentrations of carbon monoxide, PM$_{2.5}$, PM$_{1}$, benzene, toluene and xylene are not significantly different between rush hour and regular hour. Whereas, carbon dioxide, TVOC, TSP and PM$_{10}$ concentrations are significantly different between rush hour and regular hour. It is interesting to note that the pollutants with significant differences between rush hour and regular hour also have good correlations with the number of passengers. The difference of passengers’ number gives the most contribution to the variations of the in-train concentrations.

Table 4. Mean in-train concentrations by the time of day

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Units</th>
<th>Rush hours</th>
<th>Regular hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>ppm</td>
<td>0.7±0.3 (n=84)</td>
<td>0.7±0.2 (n=56)</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>ppm</td>
<td>1415.4±476.1 (n=84)</td>
<td>971.1±291.5 (n=56)</td>
</tr>
<tr>
<td>TVOC</td>
<td>ppm</td>
<td>0.3±0.1 (n=84)</td>
<td>0.2±0.1 (n=56)</td>
</tr>
<tr>
<td>TSP</td>
<td>µg·m$^{-3}$</td>
<td>130.9±61.0 (n=28)</td>
<td>206.1±95.2 (n=28)</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>µg·m$^{-3}$</td>
<td>86.2±44.4 (n=28)</td>
<td>127.5±69.1 (n=28)</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>µg·m$^{-3}$</td>
<td>30.3±15.0 (n=28)</td>
<td>33.4±20.6 (n=28)</td>
</tr>
<tr>
<td>PM$_{1}$</td>
<td>µg·m$^{-3}$</td>
<td>12.1±4.9 (n=28)</td>
<td>11.8±6.0 (n=28)</td>
</tr>
<tr>
<td>Benzene</td>
<td>µg·m$^{-3}$</td>
<td>12.2±5.0 (n=6)</td>
<td>11.9±6.0 (n=6)</td>
</tr>
<tr>
<td>Toluene</td>
<td>µg·m$^{-3}$</td>
<td>11.1±3.0 (n=6)</td>
<td>11.8±6.6 (n=6)</td>
</tr>
<tr>
<td>Xylene</td>
<td>µg·m$^{-3}$</td>
<td>3.5±2.0 (n=5)</td>
<td>2.8±1.3 (n=5)</td>
</tr>
</tbody>
</table>

(3) Variations with the Location of the Train
The mean concentrations of carbon monoxide between every two stops do not significantly vary during whole journey, and the range of variation is from 0.66 ppm to 0.85 ppm. As there is no in-train source of carbon monoxide, the carbon monoxide in the train mainly come from the vehicle emission outside the train. The segment between Stops 5 and 11 has lower concentration level than those in the other two segments. Stops 5 to 11 are in the northern suburb, while the rest stops are in downtown. Thus, the levels of carbon monoxide in the passenger cars were largely controlled by the ambient concentrations.

Carbon dioxide and TVOC have similar concentration profiles during the whole journey and both correlate well with the number of passengers. The in-train carbon dioxide concentrations were always higher than those in the ambient air. Depending on the occupancy, the TVOC concentrations inside the train were either higher or lower.
than those in the ambient air. The different behaviors of these two compounds suggest that carbon dioxide is mainly influenced by the in-train sources, whereas TVOC is influenced by both in-train and ambient sources.

Particles with different sizes have quite similar concentration profiles and good correlations, which suggest that they are from the same sources. The variations of in-train concentrations of particulate matter are influenced by considerably complex reasons. There are many factors, such as the filter in the air-conditioning system (Chan et al. 2002a), the number of the passengers, the frequent passenger movement (Chan et al. 2002a), the out-train concentrations and so on. It is too difficult to account for the variations of in-train concentrations. Table 5 presents the PM$_{2.5}$ to PM$_{10}$ ratios between rush hour and regular hour which can explain the variations of in-train concentrations influenced by those of the out-train concentrations. The main contribution of the particulate matter concentrations in ambient air is vehicle exhaust. Vehicle exhaust emitted from diesel engines is the main source of fine particulate matter in the metropolitan cities (Chan et al. 2002a). As shown in Table 5, the in-train PM$_{2.5}$ to PM$_{10}$ ratios in the rush hour are higher than those in the regular hour, which implies the influence of out-train concentrations. Other factors affecting the in-train concentrations are more complex. Further research is needed to further investigate the impact of these factors.

<table>
<thead>
<tr>
<th>Table 5. PM$<em>{2.5}$ to PM$</em>{10}$ ratios between every two stops</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rush hour</td>
</tr>
<tr>
<td>Stop1-Stop2</td>
</tr>
<tr>
<td>Stop2-Stop3</td>
</tr>
<tr>
<td>Stop3-Stop4</td>
</tr>
<tr>
<td>Stop4-Stop5</td>
</tr>
<tr>
<td>Stop5-Stop6</td>
</tr>
<tr>
<td>Stop6-Stop7</td>
</tr>
<tr>
<td>Stop7-Stop8</td>
</tr>
</tbody>
</table>

Benzene, toluene and xylene have similar concentration profiles and relatively good correlations among them. These results suggest that they were from the same sources. As the pollutants from vehicle exhaust, the ambient concentrations of benzene, toluene and xylene are significantly higher in downtown area than in the suburb. The section with the lowest in-train concentrations is located between Stops 5 and 9, which are located in the northern suburb.

CONCLUSION

In this study, air quality in the passenger cars of Beijing GRTS (Line No. 13) was investigated. Our study shows that in-train concentrations were relatively low except for carbon dioxide. This is consistent with the passengers’ perception that the air quality in the commuter trains is acceptable. Among carbon monoxide, carbon dioxide and TVOC, only carbon monoxide concentration had the significantly difference between summer and winter because of the seasonal variations of the out-train concentration levels. Among all the in-train pollutants, the concentrations of carbon dioxide, TVOC, TSP and PM$_{10}$ had significantly differences between regular hour and rush hour because of the difference in occupancy. From the concentration examined in whole journey, it was found that different compounds had different behaviors. The in-train concentrations of carbon monoxide, benzene, toluene and xylene were mainly influenced by the ambient air concentrations. The in-train concentration of carbon dioxide was mainly influenced by the number of passengers. The in-train TVOC concentration was influenced by both factors. The in-train concentrations of particulate matter were partially influenced by the out-train concentrations. The investigation protocol developed through this study can be applied to the investigation of other types of public transportation systems in China.

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