EXPOSURE TO FINE PARTICLES AMONG BANGKOK MASS TRANSIT AUTHORITY BUS DRIVERS

Tiyaporn Anthayanon¹, Pornpimol Klongtip¹,*, Witaya Yoosook¹, Dusit Sujiarat²

¹Department of Occupational Health and Safety, Faculty of Public Health, Center of Excellence on Environmental Health, Toxicology and Management of Chemicals (ETM), ²Department of Biostatistics, Faculty of Public Health, Mahidol University, Bangkok 10400, Thailand

ABSTRACT: The exposure of 80 bus drivers to fine particles (PM<sub>2.5</sub>), carbon dioxide (CO<sub>2</sub>) and carbon monoxide (CO) were monitored for full shift in air-conditioned (A/C) and non-A/C buses on four routes in Bangkok, Thailand. The results revealed that the overall average of PM<sub>2.5</sub> exposure among the non-A/C bus drivers on the four routes (322.01 ± 157.97 μg/m³) was significantly higher than those of A/C bus drivers (208.42 ± 87.41 μg/m³). The average CO<sub>2</sub> concentrations on the four-route A/C and non-A/C buses were 1274.32 ± 245.47 and 463 ± 42.27 ppm, respectively. The CO concentrations in non-A/C buses (2.71 ± 0.93 ppm) were greater than those in A/C buses (1.92 ± 1.22 ppm); significant differences were found only in two of the four routes studied.

Keywords: Fine particles exposure, indoor air quality, bus driver, single stage personal impactor

INTRODUCTION

Nowadays, large cities in many countries around the world are facing serious air pollution problems. Bangkok, a center of business with more than ten million people is threatened by traffic-related particulate emissions. The Pollution Control Department, Ministry of Natural Resources and Environment reported that, during the past several years, roadside areas in Bangkok had a higher level of particulates than other regions [1]. The adverse health effects of particulates are reduced lung function, increased severity of bronchitis, asthma, and chronic obstructive pulmonary disease (COPD) [2-7]. In addition, several studies revealed that the exposure to fine particles (PM<sub>2.5</sub>) was significantly associated with the increase of morbidity, mortality, and hospital admissions for respiratory disease [8-10].

The occupations with high risk of exposure to fine particles (PM<sub>2.5</sub>) are street vendors, street sweepers, traffic policemen, motorcycle drivers, commuters and bus drivers. The fine particles are the particles with an aerodynamic diameter less than 2.5 micron. The exposure in bus drivers in big cities is very high because of longer working hours than other groups. In a study conducted on traffic related exposure among drivers, vendors, traffic police and gas station attendants, it was found that bus drivers had the highest PM<sub>2.5</sub> exposure for a full shift [11]. Commuters’ exposures to PM<sub>2.5</sub> and CO in A/C and non-A/C buses have been reported in several research studies; air samples were collected during rush hour periods or during no specific time, but for one trip along the bus route. For example, the commuters’ exposures to PM<sub>2.5</sub> in Hong Kong [12] were 51± 19 and 93±12 μg/m³ and in China [13] were 101 ± 61 and 145 ± 56 μg/m³ for A/C and non-A/C buses, respectively. The bus drivers’ exposures to PM<sub>2.5</sub> for a full shift in non-A/C buses have scarcely been studied. The average full-shift PM<sub>2.5</sub> exposure of A/C bus drivers (161±8.9 μg/m³) is only known from one study done in Trujillo, Peru [11]. So, the importance of the current study then is to conduct research in this area for full shifts.

The PM<sub>2.5</sub> exposures of bus drivers largely depend on working hours, traffic and population densities. Bangkok is considering a tropical city. The average temperature is 32.40 °C. The Bangkok population density is approximately 5801 population/km² and average traffic density of 2483 vehicle/h [14]. The fine particle exposures of bus drivers in Bangkok should be different from those in the previous studies with different ambient temperature, population density and traffic density. The study measured PM<sub>2.5</sub>, carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>) exposure levels of 80 bus drivers on four routes of A/C and non-A/C buses in Bangkok and neighboring cities.

MATERIALS AND METHODS

This study is a cross-sectional study to measure exposure to fine particulates in Bangkok Mass Transit Authority bus drivers. The research was reviewed and approved in January 2009, no. MUPH 2009-004, by the Ethics Committee on Human Rights Related to Human Experimentation, Mahidol University.

Study location

The study was carried out in the Bangkok, Samut Prakan, and Phuthumthani provinces from March to December, 2009. The registered population of Bangkok is more than five million [15], but...
approximately five million more come from other provincial cities to work in Bangkok. It is a center of education, commerce, and transportation and it is the capital city of Thailand. The cumulative number of vehicles registered was 5,911,696 in December 2008 at the time of study [16]. The fuel used for buses are compressed natural gas and diesel B5 plus. Most taxis use liquid petroleum and compressed natural gases. Cars, vans and other types of vehicles use diesel, E10 fuel and gasoline.

**Bus routes**
The four routes, A, B, C and D were selected (Figure 1) because of heavy traffic reported by the Pollution Control Department indicating that the total suspended particulate matter (TSP) and particulate mass PM$_{10}$ exceeded the recommended standard [1] of 0.33 mg/m$^3$ and 120 $\mu$g/m$^3$, respectively by notification of National Environment Commission. Route A starts from Rangsit bus depot, Pathum Thani province and ends at Sanam Luang, Bangkok. Route B starts from Suan Siam and ends at the Pak Khlong Talat (Flower Market). Route C starts at Paknam, Samut Prakan province and ends at the Bangkok Bus Terminal. Route D starts from Sathupradit Pier and ends at Victory Monument.

**Study subject**
Study subjects were 80 bus drivers from four transportation routes of A/C and non-A/C buses of the Bangkok Mass Transit Authority. The inclusion criteria of bus drivers were bus drivers aged 20 to 60 yrs old and who agreed to participate in the study with written informed consent.

**Sample collection**
Air samples were collected from ten drivers (n=10) in both A/C and non-A/C buses on four routes of transportation (n=80). The air samples in A/C and non-A/C buses were collected on the same day on the same route. The first day of air sample collection was not specific; once it was started it would continue for 10 d including a weekend for each bus route.

The PM$_{2.5}$ exposures of bus drivers were monitored for full shifts, using 2 $\mu$m pore size, 37 mm. diameter PTFE filters with PMP support ring (Model 225-1709, SKC Inc. USA) with a single stage personal impactor (Personal Environmental Monitor, Model 761-203A, SKC Inc. USA) connected to the collar of the bus driver and personal sampling pumps (Model 224-PCXR8, SKC Inc. USA) drew in air at a flow rate of 4 l per min.

The concentrations of carbon dioxide (CO$_2$) and carbon monoxide (CO), temperature and humidity were monitored for a full shift at the driver’s breathing zone by connecting the probe with the driver’s seat in A/C and non-A/C buses, using an indoor air quality monitor (TSI Model 8552/8554 Q-Trak Plus, USA). The subjects were interviewed using a questionnaire consisting of general characteristics and disease history at the end of the shift.

**Fine particle analysis**
Before and after sampling, the PTFE filters were equilibrated for at least 24 h in a controlled room maintaining a temperature ranging from 20 to 23 °C, with standard deviation (SD) of ±2 °C over 24 h and maintaining a relative humidity of 30-40%, with SD of ± 5% over 24 h. After 24 h, each filter was weighed using a Mettler MT5 microbalance with 1 $\mu$g sensitivity. The concentrations of fine particle exposure were calculated from the mass of fine particles found on the sample filter divided by the volume of air that was drawn through the filter over the sampling period.

**Statistical analysis**
General characteristics of subjects were calculated using mean and standard deviation. Independent t-test and the Mann-Whitney U Test were used to determine the difference between groups. One way ANOVA and Kruskal-Wallis Test were used to examine the differences among groups.

**RESULTS**

**General characteristics**
The studied bus drivers consisted of 76 males and four females with an average age of 45.80 yrs. They worked 6 d/wk; their average working hours were 7.42 h per d ranging from 5.25-9.42 h with an average working experience of 13.2 yrs ranging from 2 - 33 yrs. Only 23.80% of the bus drivers used masks made of cloth while driving buses. The masks can be reused after washing. Forty three % of bus drivers were smokers and 53.8% drank alcoholic beverages. The general characteristics of 8 groups of A/C and non-A/C bus drivers in each bus route are shown in Table 1. Seven bus drivers...
Table 1 General characteristics of studied bus drivers in each route of the Bangkok Mass Transit Authority

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Bus Route A</th>
<th>Bus Route B</th>
<th>Bus Route C</th>
<th>Bus Route D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A/C</td>
<td>Non A/C</td>
<td>A/C</td>
<td>Non A/C</td>
</tr>
<tr>
<td>Age group (year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 30</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>31-40</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>41-50</td>
<td>7</td>
<td>5</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Working hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 8</td>
<td>5</td>
<td>8</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>&gt; 8</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Duration of working (year)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 10</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>11-20</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>21-30</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>&gt; 30</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Mask used</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>10</td>
<td>10</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Smoking</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Yes</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

Figure 2 Average fine particle (n=10) exposure of air-conditioned and non-air conditioned bus drivers in the four routes of transportation

In A/C and non-A/C buses in route B smoked cigarette. Eighteen bus drivers had been diagnose with chronic diseases (22.50%) which were 6 high blood pressure, 6 allergies, 2 diabetes, 2 heart diseases and one each for cancer, gastritis, migraine, thyroid and gout.

PM$_{2.5}$ exposure concentrations of buses drivers

The bus drivers were exposed to average PM$_{2.5}$ concentrations of 208.42 ± 87.41 µg/m$^3$ ranging from 61.59 to 434.33 for four-route A/C buses (n=40) and of 322.01 ± 157.97 µg/m$^3$ ranging from 108.00 to 720.69 for the four-route non-A/C buses (n=40). The average PM$_{2.5}$ exposures of the four-route A/C and non-A/C bus drivers were significantly different with a p-value of 0.002. When comparing A/C and non-A/C bus drivers’ exposure to PM$_{2.5}$ on each route (n=10), it was found that the exposures were significantly different on route A, C and D with p-values of 0.04, 0.035 and 0.043, respectively (Figure 2). Among A/C buses, the exposure of bus drivers on route B was the highest and route D the lowest. In non-A/C buses, the drivers’ exposure was highest on route C and lowest on route B.

Comparison of PM$_{2.5}$ exposure between types of fuel used

In A/C buses, the buses on route A (n=10) used compressed natural gases as fuel, while the (A/C) buses on routes B (n=10), C (n=10) and D (n=10) used diesel B5 plus. The diesel B5 plus is composed of 5% biodiesel and 95% diesel. All non-A/C buses (n=40) used diesel B5 plus. Consequently, the difference between average exposures to PM$_{2.5}$ among A/C bus drivers using compressed natural gas (n=10) and diesel B5 plus (n=30) were not significantly different with a p-value of 0.809. It implies that buses use compressed natural gases as fuel emits fine particles similar to buses use diesel.

Comparison of PM$_{2.5}$ exposure between weekday and weekend

Among the A/C bus drivers exposed to PM$_{2.5}$, there were no significant differences between weekdays and weekends with a p-value of 0.341, but there were significant differences for non-A/C buses with a p-value of 0.042.

Indoor air quality inside buses

CO$_2$ concentration

The average CO$_2$ concentrations in the four-route A/C and non-A/C buses were 1274.32 ± 245.47 and 463 ± 42.27 ppm, which were significantly different with a p-value of <0.001 (Figure 3). The average CO$_2$ concentrations of A/C buses were considerably greater than those of non-A/C buses on every bus route studied. The average exposure of bus drivers on route B was the highest and the exposure on route A was the lowest.
The overall CO concentrations in A/C (1.92 ± 1.22 ppm) and non-A/C buses (2.71 ± 0.93 ppm) were significantly different with a p-value of 0.025. The CO concentrations in non-A/C buses were greater than those in A/C buses; the significant differences were found only on routes A and C. The average exposure of A/C bus drivers on route B was the highest and route A was the lowest.

Temperature and humidity
The overall temperatures inside A/C buses (26.16 ± 2.49 °C) were significantly lower than those of non-A/C buses (32.40 ± 2.90 °C) with a p-value of <0.001; the significance was found on every route studied. The overall relative humidity inside A/C buses (47.27 ± 6.02%) was significantly lower than those of non-A/C buses (53.40 ± 6.44 %) with a p-value of 0.010; the significance was found only on route A and B.

**DISCUSSION**

Usually, bus drivers of the Bangkok Mass Transit Authority continue working with the company until retirement at 60 yrs old. Their health services are under the welfare of Bangkok Mass Transit Authority. This is the reason the average age of the drivers is rather high (45.8 yrs old), and the longest working experience is 33 yrs. One third of bus drivers used masks because they think it prevents dust, aerosol and microorganisms from entering their bodies. It made them feel more protected from toxicants from traffic-related emissions.

With regard to smoking behavior of bus drivers, they are not allowed to smoke while driving. They can smoke only during their break and at lunch time. Their smoking behavior could also relate to their symptoms and health problems in the long run.

**PM\textsubscript{2.5} exposure concentrations of buses drivers**

The full shift PM\textsubscript{2.5} exposure of A/C bus drivers of 208.42 ± 87.41 μg/m\textsuperscript{3} (n=40) reported in Bangkok in this study was considerably higher than the previous study reported of 161 ± 8.9 μg/m\textsuperscript{3} (n=8) in Trujillo, Peru [11]; this was probably due to Bangkok’s higher population density and number of registered vehicles. The population density of Bangkok [14] is 5801 per km\textsuperscript{2}, while the population of Trujillo, Peru [17] is 462.63 per km\textsuperscript{2}. In addition, all A/C buses in the current study have two to three ceiling exhaust fans but the fans are in off position while driving because of inadequate air cooling capacity inside the buses. The other reported PM\textsubscript{2.5} in A/C buses was 56±15 μg/m\textsuperscript{3} in Florence, Italy [18], 53 μg/m\textsuperscript{3} in Mexico City, Mexico [19] and 51±19 μg/m\textsuperscript{3} in Hong Kong [12]. The 8-h PM\textsubscript{2.5} exposure of A/C bus drivers reported in this current study was eight times higher than the 25 μg/m\textsuperscript{3} 24-h PM\textsubscript{2.5} standard recommended by World Health Organization [20] and approximately six times higher than the 35 μg/m\textsuperscript{3} 24-h PM\textsubscript{2.5} standard recommended by National Ambient Air Quality Standard (NAAQS) [21] for particle pollution. The highest PM\textsubscript{2.5} exposure of bus drivers on route B was possibly caused by the high number of old buses, lack of good maintenance and inadequate bus cleaning. In addition, seven of ten bus drivers were smokers. The cleaning of A/C buses will reduce the accumulation of particulate matters and fine particulates on the bus. The lowest exposure levels of A/C bus drivers on route D were perhaps due to the implementation of a good cleaning routine on the part of the bus company in which A/C buses were cleaned after each trip along the route.

With regard to non-A/C buses, the full shift 8-h average PM\textsubscript{2.5} exposure of bus drivers was 322.01 μg/m\textsuperscript{3} (n=40), which was twelve times higher than the 25 μg/m\textsuperscript{3} 24-h PM\textsubscript{2.5} standard recommended by the World Health Organization and approximately nine times higher than the 35 μg/m\textsuperscript{3} 24-h PM\textsubscript{2.5} standard recommended by NAAQS [21]. However, it should be noted that the previous studies did not present full shift PM\textsubscript{2.5} exposure of non-A/C bus drivers. The average commuter’s exposure to PM\textsubscript{2.5} in non-A/C buses was 93±12 μg/m\textsuperscript{3} in Hong Kong [12] and 145±56 μg/m\textsuperscript{3} in Guangzhou, China [13]. The highest PM\textsubscript{2.5} exposure of route C might be due to dust accumulation from tunnel construction on the road; the 1-km tunnel was being built on the road during sample collection. The parking spot of buses on route C was located in the bus terminal. There were a lot of buses with engines on, waiting for passengers in the bus terminal. This may
increase fine particulate emission in the working environment. For non-A/C buses, all routes were rarely scrubbed. It is possible that particles being resuspended from inside the bus. If so, this affects more on the non A/C buses.

**Indoor air quality inside buses**

The CO₂ accumulation in the A/C buses mostly came from expired air of commuters and the ventilation system in buses. The average full shift CO₂ concentrations found (1274.32 ppm) in A/C buses were higher than the 1000 ppm standard recommended by American Society of Heating, Refrigeration and Air – Conditioning Engineers (ASHRAE) [22]. The average full shift CO concentrations found in A/C and non-A/C buses were 1.92 and 2.71 ppm, respectively, which were far below the 9 ppm standard recommended by ASHRAE [22] and 9 ppm 8-h standard recommended by NAAQS [21]. It is probably because average CO in ambient air at roadside with high traffic density ranged from 1.1-1.9 ppm in the Bangkok area as reported by the Pollution Control Department, Ministry of Natural Resources and Environment in the period of air sample collection [23]. The average full shift CO concentrations in A/C buses were similar to those (2 ppm) found in Trujillo, Peru [11]. The CO levels in A/C buses in this study (1.92 ppm) were much lower than those found in other studies, 8.9 ppm in Guangzhou, China [12] and 10.4 ppm in Athens [24] and 5 ppm in Hong Kong [25]. The other studies collected CO air samples in a shorter period of time with different types of instruments. The lowest concentrations of CO, which were found in A/C buses on route A, were most probably due to the compressed natural gases used as fuel. The use of these compressed gases produces less CO residue. The non-A/C bus route A had a lower level of CO than the other routes possibly because bus route A goes into suburban areas which have low traffic density allowing an increase in the speed of the bus. Increased bus speed is significant in terms of reducing the CO level, this having been reported in a previous study [26].

**ACKNOWLEDGEMENT**

The authors would like to thank bus drivers and conductors of Bangkok Mass Transit Authority for participation in this research, Pollution Control Department, Ministry of Natural Resources and Environment for providing laboratory facilities. The authors are particularly indebted to Huachiew Chalermprakiat University, South East Asia University, Bureau of Environmental Health, and Ministry of Public Health for providing instruments for this research. This research work is supported by the grant from Center for Environmental Health, Toxicology and Management of Chemicals (ETM) under Science & Technology Postgraduate Education and Research Development Office (PERDO) of the Ministry of Education.

**REFERENCES**

16. Land Transport Management Bureau. Statistics Sub-Division. Technical and Planning Group [homepage on