

# Exposure to Particulate Matter, CO<sub>2</sub>, CO, VOCs among Bus Drivers in Bangkok

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**Objective:** To measure the exposure of particulate matter, CO<sub>2</sub>, CO, VOCs among Bangkok Mass Transit Authority (BMTA) Bus Drivers.

**Material and Method:** The exposure of 60 bus drivers to PM<sub>2.5</sub>, PM<sub>10</sub>, VOCs, CO<sub>2</sub>, CO was monitored for full shifts on three routes of air-conditioned (A/C) and non-A/C buses.

**Results:** The average PM<sub>2.5</sub> exposure concentrations among non-A/C bus drivers (323.81 mg/m<sup>3</sup>) were significantly higher than that of A/C bus drivers (206.46 mg/m<sup>3</sup>) (p-value = 0.016). The average benzene, toluene and xylene exposure concentrations were 429.15, 225.11, 127.60 mg/m<sup>3</sup> for non-A/C bus drivers. The average CO<sub>2</sub> levels in A/C buses were significantly higher than those in non-A/C buses (p-value < 0.001). The CO levels in non-A/C buses were significantly higher than those in A/C buses (p-value = 0.037).

**Conclusion:** The bus drivers were exposed to high concentrations of air pollutants. The increase of ventilation and cleaning of buses will reduce the exposure of air pollutants.

**Keywords:** PM<sub>2.5</sub>, PM<sub>10</sub>, VOCs, CO, CO<sub>2</sub>, Bus drivers, Bangkok Mass Transit Authority (BMTA)

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Bangkok, the capital city of Thailand, is a center of business and prosperity in every aspect. The number of new, registered cars in Bangkok has increased every year from 1998 to 2009<sup>(1)</sup>. This increased number of cars causes traffic jams and generates toxic air pollution. The Pollution Control Department (PCD), 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<sup>(2)</sup>. The adverse health effects of particulates are reduced lung function, increased severity of bronchitis, asthma, and chronic obstructive pulmonary disease<sup>(3-8)</sup>.

Volatile organic compounds (VOCs) become a problem of concern due to the toxicity of chemicals and the effect on human health and environment. Vehicular exhaust emission is a major air pollution source of VOCs in big cities<sup>(9)</sup>. The VOCs of concern are benzene, methyl tertiary butyl ether (MTBE), toluene, ethyl benzene, xylene and styrene. Benzene is

a cancer-causing agent which is believed to cause leukemia. MTBE can have an association with some symptoms such as headache, dizziness, eye irritation and vomiting. Other chemicals such as toluene, ethyl benzene, xylene and styrene have effects on nervous system<sup>(10,11)</sup>.

BMTA, operating under the jurisdiction of the Ministry of Transport and Communications, has a role and function to provide bus services to people living and working in Bangkok and the nearby provinces. The BMTA operated a total of 113 routes, served by 3,526 buses, of which 1,665 are non-A/C buses and 1,861 are A/C buses. There are also privately-owned buses operated under the BMTA. Overall, there are 17,372 vehicles on 463 routes providing services to the Bangkok population. An average of 3.4 million people uses these services daily<sup>(12)</sup>.

The occupations with high risk of exposure to traffic-related air pollutants are traffic policemen, motorcycle drivers and bus drivers, etc. Bus drivers are a group of workers who always stay on buses giving services to passengers for the whole day including rush hours in the morning and in the evening. They are exposed to traffic-related air pollutants, such as PM<sub>2.5</sub>, PM<sub>10</sub>, VOCs, CO<sub>2</sub>, CO every work day. Buses have been the most popular type of transportation

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mode in Bangkok because their service routes cover all areas in Bangkok and neighboring cities. Taking a bus is the cheapest mode of transportation when compared with other types of transportation in Bangkok. Much research has been published related to exposure of bus drivers to traffic-related air pollutants<sup>(13-20)</sup>, but most of studies collected air samples at rush hour or during one trip only. In order to evaluate exposure of bus drivers to traffic-related air pollutants, the monitoring of a full shift is still lacking. Therefore, the present study evaluates exposure concentrations of bus drivers to PM<sub>10</sub>, PM<sub>2.5</sub>, CO, CO<sub>2</sub>, VOCs, temperature and humidity during a full shift in A/C and non-A/C buses in three routes in Bangkok and neighboring cities.

### Material and Method

The present study is a cross-sectional study to assess PM<sub>2.5</sub>, PM<sub>10</sub>, VOCs, CO, CO<sub>2</sub> exposure levels of BMTA bus drivers. This research was reviewed and approved in January 2009: Ref No. MUPH 2009-001, by the Ethics Committee for Human Research, Faculty of Public Health, Mahidol University.

### Sample size

The present study subjects were 60 bus drivers of BMTA from three different routes. Ten A/C and ten non-A/C bus drivers were selected from each route. There were 30 bus drivers in A/C buses and 30 bus drivers in non-A/C buses.

### Instrumentations

The GC-2010 gas chromatograph (Shimadzu, Kyoto, Japan) with a DB-1 capillary column (30 m x 0.25mm ID [J&W, USA]), equipped with a flame ionization detector was used for VOCs analysis. The carrier gas was helium at a flow-rate of 10 ml/min. The column temperature was set at 35°C and held for 2.7 min and ramped from 40°C/min up to 70°C and then held for 4 min with 180°C injector and 200°C detector temperatures.

### Bus routes

Three bus routes were selected for monitoring multiple air pollutant exposure concentrations of bus drivers. The details of the three routes are shown in Fig. 1.

### Characteristics of buses

On route X, A/C buses were Mercedes-Benz (model of OF1617) with 50 seats and aged 19 years. Non-A/C buses were Mitsubishi Fuso (Model RP117)

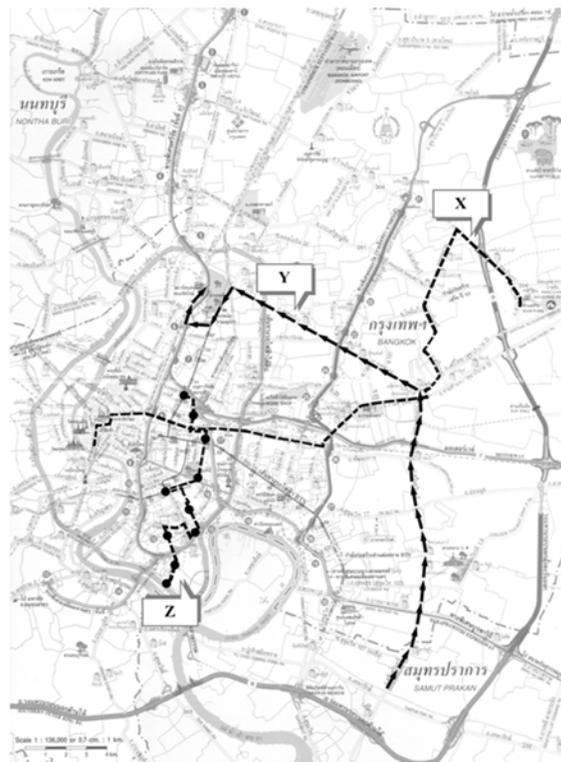


Fig. 1 Location of the three bus routes, X, Y and Z

with 34 seats and aged 19 years.

On route Y, A/C buses were Hino (model RU1JSS) with 35 seats and aged 12 years. Non-A/C buses were Hino (Model AK176) with 34 seats, aged 19 years.

On Route Z, A/C buses were Hino (model of RU1JSS) with 35 seats, aged 12 years. Non-A/C buses were Hino (Model of AK176) with 34 seats and aged 19 years.

Considering the ventilation system in the buses, all A/C buses have two to three ceiling exhaust fans but the fans are in an off position while driving because of inadequate air cooling capacity inside the buses. The non-A/C buses have three opening roof windows and one ceiling fan above the bus drivers' seat. Air can get through all windows and opening roof windows while driving.

### Sample collection

Air samples were collected full-shift for PM<sub>10</sub>, PM<sub>2.5</sub>, CO, CO<sub>2</sub> and VOCs.

The PM<sub>2.5</sub> was collected using a single stage personal impactor (Model 761-203A, SKC Inc. USA) with 37 mm PTFE filter using a personal sampling (Model 224-PCXR8, SKC Inc USA) at a flow rate of 4.0 liter/

min. The device was attached to a collar of the driver to collect air at the breathing zone of bus drivers.

The  $PM_{10}$  concentrations were monitored using 5  $\mu\text{m}$  pore size, 37 mm diameter polyvinyl chloride filters assembled in aluminum cyclone (Model 225-01-02, SKC Inc) and personal sampling pumps (Model 224-PCXR8, SKC Inc USA) calibrated at a flow rate of 2.5 liters per minute. The cyclone was attached to the collar of research staff sitting behind the driver's seat.

The CO concentrations were monitored using ToxiPro (ToxiPro single gas detection, Sperian Inc).

The  $CO_2$  concentration, temperature and humidity were monitored using Q-Trak Plus indoor air quality monitor (IAQ) (Q-Trak Plus, TSI Inc Model 8552/8554). An IAQ monitor was installed at the back of bus drivers' chairs to collect air in the breathing zone of the bus drivers.

The VOCs in the air were collected by connecting 3M organic vapor monitors<sup>(21)</sup> on the collars of bus drivers for a full shift. The organic vapor monitor was kept in the refrigerator until analysis.

The air samples from A/C and non-A/C buses were collected on the same route and on the same day. The drivers were interviewed using a questionnaire consisting of general characteristics and chronic disease.

### Sample analysis

#### *Preparation and weighing of $PM_{2.5}$ , $PM_{10}$ filter*

Before and after sampling, the PVC filters were equilibrated for at least 24 hours in a controlled room maintaining a temperature ranging from 20 to 23°C and a relative humidity of 30-40%. Each filter was weighed using a Mettler MT5 microbalance.

#### *VOCs analysis*

The VOCs in passive samples were analyzed following the 3M Occupational Health and Environmental Safety Division<sup>(22)</sup>. The method detection limit of measured MTBE, benzene, toluene, ethyl benzene, xylene and styrene were 0.33, 0.18, 0.16, 0.19, 0.12 and 0.22  $\text{mg}/\text{m}^3$ , respectively, based on a sampling rate of 30.8, 35.5, 31.4, 27.3, 27.3 and 28.9  $\text{cm}^3/\text{min}$  (3M company Occupational Health and Environmental Safety Division<sup>(22)</sup> for the 3M Organic Vapor Monitor for 7.4-hr average sample collection time. Non-detected VOCs were reported at detection limit. The recoveries of MTBE, benzene, toluene, ethyl benzene, xylene and styrene were 81.34, 88.59, 95.63, 98.37, 97.26 and 89.65%, respectively, with the relative standard deviations of

less than 2%.

### Statistical analysis

General characteristics of subjects were presented as mean and standard deviation. Independent t-test and the Mann-Whitney 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 of bus drivers*

In the three bus routes, most of the bus drivers (95%) were male; their average age was 46.08 years old (Table 1). They worked 7.40 hour/day on average and six days per week. Their average working experience was 13.97 years and average sleeping hours were 6.7 hours/day. Some of them wore cotton masks while working. With regards to chronic diseases, eleven had chronic diseases, namely three high blood pressure, three allergy, two diabetes, two heart diseases and one gout.

### *$PM_{2.5}$ and $PM_{10}$ exposure concentrations of bus drivers*

$PM_{2.5}$  and  $PM_{10}$  exposure concentrations of bus drivers are presented in Table 2. All the buses used dieselB5 plus as fuel, composed of 5% biodiesel and 95% diesel. The  $PM_{2.5}$  exposure concentrations of bus drivers on routes X, Y and Z were not significantly different in both A/C and non-A/C buses with p-values of 0.214 and 0.587, respectively. The overall average  $PM_{2.5}$  exposure concentrations in non-A/C bus drivers ( $323.81 \pm 169.19 \mu\text{g}/\text{m}^3$ ) were significantly higher than those in A/C bus drivers ( $206.46 \pm 94.31 \mu\text{g}/\text{m}^3$ ). The driver on route X had the highest  $PM_{2.5}$  exposure for A/C buses.

The overall average  $PM_{10}$  exposure concentrations of bus drivers in non-A/C buses ( $0.66 \pm 0.46 \text{ mg}/\text{m}^3$ ) were not significantly higher than those in A/C buses ( $0.55 \pm 0.45 \text{ mg}/\text{m}^3$ ). The concentrations of  $PM_{10}$  on the three A/C bus routes studied were not significantly different ( $p = 0.572$ ), but the concentrations were significantly different in non-A/C buses with a p-value of 0.016 and a significant difference was found between route X and Y and route X and Z with p-values of 0.023 and 0.034, respectively. For A/C and non-A/C buses, bus drivers on route Y had the highest  $PM_{10}$  exposure. It is noted that the  $PM_{10}$  exposure concentrations of A/C bus drivers were higher than those in non-A/C bus drivers in route X.

**Table 1.** General characteristics of studied bus drivers

Characteristic	Number of bus drivers					
	Bus Route X		Bus Route Y		Bus Route Z	
	A/C (n = 10)	Non A/C (n = 10)	A/C (n = 10)	Non A/C (n = 10)	A/C (n = 10)	Non A/C (n = 10)
Age group (year)						
≤ 30	-	-	-	2	-	-
31-40	-	2	1	4	-	3
41-50	7	4	6	3	7	7
> 50	3	4	3	1	3	-
Working hours						
≤ 8	7	6	10	10	10	9
> 8	3	4	-	-	-	1
Duration of working (year)						
≤ 10	3	2	3	6	1	5
11-20	7	1	7	3	5	5
21-30	-	3	-	1	1	-
> 30	-	4	-	-	3	-
Mask used	2	1	3	3	5	5
Smoking	7	7	1	5	3	1

**Table 2.** PM<sub>2.5</sub> and PM<sub>10</sub> exposure concentrations of bus drivers in A/C and non-A/C buses

Routes	PM <sub>2.5</sub> (µg/m <sup>3</sup> )				PM <sub>10</sub> (mg/m <sup>3</sup> )			
	n	Mean	SD	Range	n	Mean	SD	Range
X								
A/C bus	10	241.92	89.73	140.51-358.68	10	0.48	0.44	0.12-1.50
Non-A/C bus	10	297.87	150.89	121.84-518.23	10	0.37	0.31	0.16-1.15
p = 0.330								p = 0.705
Y								
A/C bus	10	209.93	97.66	101.62-434.33	10	0.63	0.38	0.15-1.09
Non-A/C bus	10	369.97	191.98	140.43-720.69	10	0.85	0.48	0.18-1.52
p = 0.035*								p = 0.270
Z								
A/C bus	10	167.53	89.30	61.59-302.01	10	0.53	0.55	0.10-1.68
Non-A/C bus	10	303.61	170.43	108.00-521.48	10	0.75	0.46	0.14-1.54
p = 0.043*								p = 0.151
Total								
A/C bus	30	206.46	94.31	61.59-434.33	30	0.55	0.45	0.10-1.68
Non-A/C bus	30	323.81	169.19	108.00-720.69	30	0.66	0.46	0.14-1.54
p = 0.016*								p = 0.209

Note \* Significant at p < 0.05

#### **The indoor air quality inside the studied buses**

The air quality inside buses was monitored for CO<sub>2</sub>, CO, temperature and humidity (Table 3). For the CO<sub>2</sub> level measured, the average CO<sub>2</sub> concentration on three A/C and non-A/C bus routes were 1,296.96 ±

278.52 and 460.20 ± 46.89 ppm, respectively. The average CO<sub>2</sub> concentrations in A/C buses were considerably higher than those in non-A/C buses on every route of buses studied.

For the CO level measured, the overall

**Table 3.** The indoor air quality inside air-conditioned and non air-conditioned buses

Routes	n	CO <sub>2</sub> (ppm) Mean ± SD	CO (ppm) Mean ± SD	Temp (°C) Mean ± SD	RH (%) Mean ± SD	
X	A/C bus	5	1,325.44 ± 319.49	3.23 ± 1.05	29.46 ± 2.80	45.58 ± 6.71
	Non-A/C bus	5	473.60 ± 41.98	3.30 ± 0.69	33.08 ± 2.03	56.58 ± 10.22
	p-value		0.004*	0.911	0.047*	0.079
Y	A/C bus	5	1,280.25 ± 314.20	1.19 ± 0.42	25.36 ± 0.99	49.85 ± 4.60
	Non-A/C bus	5	413.75 ± 30.11	2.55 ± 0.45	33.21 ± 1.91	50.55 ± 3.70
	p-value		0.003*	0.001*	0.009*	0.799
Z	A/C bus	5	1,285.19 ± 263.00	2.53 ± 0.76	24.20 ± 0.85	52.02 ± 4.81
	Non-A/C bus	5	493.24 ± 27.19	3.41 ± 0.81	28.53 ± 1.84	50.10 ± 3.08
	p-value		0.002*	0.115	0.001*	0.473
Total	A/C bus	15	1,296.96 ± 278.52	2.32 ± 1.14	26.34 ± 2.86	49.15 ± 5.76
	Non-A/C bus	15	460.20 ± 46.89	3.08 ± 0.73	31.61 ± 2.88	52.41 ± 6.77
	p-value		< 0.001*	0.037*	< 0.001*	0.443

Note \*Significant at  $p < 0.05$

CO concentration on three routes of A/C buses ( $2.32 \pm 1.14$  ppm) and non-A/C buses ( $3.08 \pm 0.73$  ppm) were significantly different with a p-value of 0.037. The average CO concentrations in non-A/C buses were greater than those in A/C buses on every bus route studied, a significant difference was found only on route Y.

For the temperature, the overall temperatures inside A/C buses ( $26.34 \pm 2.86^\circ\text{C}$ ) were significantly lower than those of non-A/C buses ( $31.61 \pm 2.88^\circ\text{C}$ ) at  $p < 0.001$ , this difference was found on every route studied. For A/C buses, the temperature on route X was the highest ( $29.46 \pm 2.80^\circ\text{C}$ ) and the temperature on route Z was the lowest ( $24.20 \pm 0.85^\circ\text{C}$ ). For non-A/C buses, the temperatures on route X and Y were similar at  $33^\circ\text{C}$ .

For the relative humidity, the average relative humidity inside buses on the three routes of A/C buses ( $49.15 \pm 5.76\%$ ) was not significantly lower than those inside non-A/C buses ( $52.41 \pm 6.77\%$ ) with a p-value of 0.443.

#### **VOCs exposure concentrations of studied bus drivers**

The VOCs measured were MTBE, benzene, toluene, ethyl benzene, xylene and styrene (Table 4). Each VOC exposure concentrations for bus drivers were not significantly different for both A/C and non-A/C buses for the three routes studied.

The exposure concentrations of MTBE for bus drivers were found mainly on route Z. The average MTBE concentrations found in A/C ( $135.40 \mu\text{g}/\text{m}^3$ ) and non-A/C bus drivers ( $145.85 \mu\text{g}/\text{m}^3$ ) were similar.

With regards to benzene, the average benzene

exposure concentrations for the three routes of A/C and non-A/C bus drivers were  $391.56$  and  $429.15 \mu\text{g}/\text{m}^3$ , respectively. The average benzene exposure concentrations for A/C bus ( $553.96 \mu\text{g}/\text{m}^3$ ) and non-A/C bus drivers ( $564.50 \mu\text{g}/\text{m}^3$ ) in route Y were the highest of the three routes studied.

The average toluene exposure concentrations of the three-route A/C and non-A/C bus drivers were  $219.45$  and  $225.11 \mu\text{g}/\text{m}^3$ , respectively. The average toluene exposure concentrations for A/C and non-A/C bus drivers on route Z were the highest among the three routes studied.

For ethyl benzene, the average exposure concentrations were found only on route X. The average ethyl benzene exposure concentrations found were quite low for bus drivers in both A/C and non-A/C buses.

The average xylene exposure concentrations for the three-route A/C buses and non-A/C drivers were  $91.39$  and  $127.64 \mu\text{g}/\text{m}^3$ , respectively. The average xylene exposure concentrations for bus drivers were the highest in both A/C and non-A/C buses on route X.

Styrene concentrations were found at low concentration in some A/C and non-A/C buses.

## **Discussion**

### **General characteristics of bus drivers**

Generally, most of the BMTA bus drivers were male. Their ages ranged from 26 to 58 years old and they tended to continue working until retirement at 60 years old. Their health services are under the welfare of BMTA, which is similar to welfare of Thai

**Table 4.** VOCs exposure concentrations ( $\mu\text{g}/\text{m}^3$ ) of bus drivers

Route	Condition	MTBE		Benzene		Toluene		Ethyl benzene		Xylene		Styrene	
		Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD	
X	A/C	27.70 $\pm$ 86.54	331.93 $\pm$ 126.07	209.53 $\pm$ 28.98	24.03 $\pm$ 50.36	142.65 $\pm$ 52.01	34.68 $\pm$ 73.81						
	Non-A/C	0.33 $\pm$ 0.00	417.55 $\pm$ 150.04	217.07 $\pm$ 26.89	42.68 $\pm$ 69.68	162.14 $\pm$ 9.63	13.40 $\pm$ 41.69						
Y	A/C	0.33 $\pm$ 0.00	553.96 $\pm$ 224.21	217.07 $\pm$ 13.90	0.19 $\pm$ 0.00	19.18 $\pm$ 60.28	50.01 $\pm$ 105.56						
	Non-A/C	0.33 $\pm$ 0.00	564.50 $\pm$ 150.57	216.31 $\pm$ 11.12	0.19 $\pm$ 0.00	89.37 $\pm$ 94.24	47.46 $\pm$ 100.20						
Z	A/C	135.40 $\pm$ 174.39	288.80 $\pm$ 121.89	231.76 $\pm$ 23.04	0.19 $\pm$ 0.00	112.33 $\pm$ 97.04	0.22 $\pm$ 0.00						
	Non-A/C	145.85 $\pm$ 188.15	305.41 $\pm$ 174.38	241.90 $\pm$ 433.70	0.19 $\pm$ 0.00	131.40 $\pm$ 91.59	47.03 $\pm$ 101.13						
Total	A/C	54.47 $\pm$ 123.61	391.56 $\pm$ 197.75	219.45 $\pm$ 23.95	8.14 $\pm$ 30.29	91.39 $\pm$ 88.00	28.30 $\pm$ 74.81						
	Non-A/C	48.84 $\pm$ 125.92	429.15 $\pm$ 187.36	225.11 $\pm$ 27.60	14.35 $\pm$ 43.84	127.64 $\pm$ 79.43	35.96 $\pm$ 84.22						
		p = 0.896	p = 0.318	p = 0.784	p = 0.600	p = 0.135	p = 0.721						

Note: Non-detection used method detection limit

governmental officers. Their working hours per day depend on traffic conditions on each day. One-third of bus drivers wear a mask made of cotton, because they think it can prevent dust, aerosol and microorganism from entering their bodies. However, this only makes them feel more protected from toxicants from traffic-related emissions rather than actually protecting them. Fifty-one percent of studied bus drivers drank alcoholic beverages. It is probably because the nature of their work requires a lot of mental strength, hard work and tolerance. A significant number of bus drivers (18.3%) had chronic diseases, which were high blood pressure, allergy, diabetes and heart disease. High blood pressure may occur due to improper eating, lack of exercise, stress at work, smoking and alcohol consumption. Allergy may be caused by the work environment.

#### *PM<sub>2.5</sub> exposure concentrations of studied bus drivers*

The full shift 8-hr PM<sub>2.5</sub> exposure of A/C bus drivers was 206.46  $\pm$  94.31  $\mu\text{g}/\text{m}^3$  (n = 30) in the present study, which was considerably higher than the previous study (161  $\pm$  8.9  $\mu\text{g}/\text{m}^3$ ) (n = 8) in Trujillo in Peru<sup>(17)</sup>; probably because Bangkok had higher population density and a higher number of registered vehicles. The other reported PM<sub>2.5</sub> levels in A/C buses were 101  $\pm$  61  $\mu\text{g}/\text{m}^3$  in Guangzhou, China<sup>(13)</sup>, 53  $\mu\text{g}/\text{m}^3$  in Mexico City, Mexico<sup>(16)</sup> and 51  $\mu\text{g}/\text{m}^3$  in Hong Kong<sup>(14)</sup>. The recommended standard or safe exposure level of PM<sub>2.5</sub> for 8 hours was not attained. The 8-hr PM<sub>2.5</sub> exposure of A/C bus drivers reported in the present study was eight times higher than the 25  $\mu\text{g}/\text{m}^3$  24-hr PM<sub>2.5</sub> standard recommended by World health Organization<sup>(23)</sup> and approximately six times higher than the 35  $\mu\text{g}/\text{m}^3$  24-hr PM<sub>2.5</sub> standard recommended by the National Ambient Air Quality Standards (NAAQS)<sup>(24)</sup>. Among the three routes studied, the highest level of exposure was that of bus drivers on route X and was possibly caused by the high number of old buses, lack of good maintenance and inadequate bus cleaning. The lowest exposure levels of bus drivers was on route Z and was achieved by implementation of a good cleaning system of the buses; a rule had been set that every bus must be cleaned after every trip.

With regard to non-A/C buses, the full shift average exposure of bus drivers was 323.81  $\pm$  169.19  $\mu\text{g}/\text{m}^3$  (n = 30), which was approximately thirteen times higher than the 25  $\mu\text{g}/\text{m}^3$  24-hr PM<sub>2.5</sub> standard recommended by the World Health Organization and approximately nine times higher than the 35  $\mu\text{g}/\text{m}^3$  24-

hr  $PM_{2.5}$  standard recommended by (NAAQS)<sup>(24)</sup>. The previous studies did not present full shift exposure of non-A/C bus drivers. The average commuter's exposure to  $PM_{2.5}$  in non-A/C buses was  $93 \pm 12 \mu\text{g}/\text{m}^3$  in Hong Kong<sup>(14)</sup> and  $145 \pm 56 \mu\text{g}/\text{m}^3$  in Guangzhou, China<sup>(13)</sup>. Among the three routes studied, the highest exposure of route Y might be due to dust accumulation from tunnel construction on the road during air sample collection.

#### ***PM<sub>10</sub> exposure concentrations of studied bus drivers***

The  $PM_{10}$  exposure concentrations of non-A/C buses drivers depend on environment outside the buses, traffic related air pollutants and frequency of bus cleaning. However, the  $PM_{10}$  exposure concentrations of A/C buses drivers depend mostly on environment inside the buses, number of passengers, age of buses and maintenance and cleaning of buses. The  $PM_{10}$  exposure concentrations for non-A/C bus drivers were generally higher than those for A/C bus drivers except that the A/C buses drivers on route X had higher  $PM_{10}$  exposure concentrations than the non-A/C bus drivers. This was probably because the A/C buses (50 seats) had a higher number of seats than the non-A/C buses (34 seats) and the age of the buses was 19 years. While this higher  $PM_{10}$  exposure concentration on A/C buses seemed to contradict our expectations, a study by Jones et al<sup>(18)</sup> presented higher  $PM_{10}$  exposure concentrations of bus drivers in A/C buses ( $265 \pm 83 \mu\text{g}/\text{m}^3$ ) than those in non-A/C buses ( $161 \pm 103 \mu\text{g}/\text{m}^3$ ). Actually, the  $PM_{10}$  exposure concentrations for the non-A/C bus driver on route X was the lowest on the three-route non-A/C buses studied. The  $PM_{10}$  exposure concentrations of non-A/C bus drivers on route Y was the highest because this route traversed an area where a tunnel was being built on the road. On route Y, the  $PM_{10}$  exposure concentrations for non-A/C bus drivers was the second highest probably because the buses went along streets with sky trains running overhead. The ventilation in this area is not so good and a lot of dust accumulates on the streets, which may be due to a lack of wind that would otherwise clear the dust, but which is blocked by the sky train tracks.

Comparison between the results of the present study and other studies shows that the  $PM_{2.5}$  and  $PM_{10}$  exposure concentrations of bus drivers in the present study were the highest and the duration of sample collection was the longest, having been collected for a full shift. It was probably because of differences in traffic conditions, traffic density, geography, buses'

condition, weather conditions and instruments used.

#### ***Indoor air quality in the studied buses***

The average full shift  $CO_2$  concentrations found (1,296.96 ppm) in A/C buses were higher than the 1,000 ppm 8-hr standard recommended by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)<sup>(25)</sup>. At this high concentration level, it indicates inadequate ventilation. The A/C buses had two to three ceiling exhaust fans, but the drivers did not turn on the fans because of inadequate air cooling capacity of the buses. The average full shift  $CO_2$  concentrations were 460.20 ppm in non-A/C buses due to exchange of air inside and outside of buses through windows. The  $CO_2$  accumulations from commuters' respiration are diluted with air from outside of buses.

The average full shift CO concentrations in A/C and non-A/C buses were 2.32 and 3.08 ppm, respectively, which were far below the 9 ppm standard recommended by ASHRAE<sup>(25)</sup> and 9 ppm 8-hr standard recommended by NAAQS<sup>(24)</sup>. The average CO in ambient air at roadside reported by PCD ranged from 1.1-1.9 ppm in the Bangkok area<sup>(2)</sup>. The CO levels in A/C buses in the present study (2.32 ppm) were much lower than those found in other studies, 8.9 ppm in Guangzhou, China<sup>(13)</sup> and 10.4 ppm in Athens<sup>(26)</sup> and 5 ppm in Hong Kong<sup>(27)</sup>.

The average temperatures inside A/C buses (26.30°C) were appropriate for work, but the average temperature was relatively high inside non-A/C buses (31.61°C). Working in such high temperature conditions results in fatigue. Bus drivers' comfort inside the buses depends on the exchange of air and humidity with the outside air. If the temperature inside the buses is high, but has a lot of air movement and low relative humidity, bus drivers will feel comfortable because the heat in their bodies will evaporate through sweating. The ceiling fan installed near the non-A/C bus drivers' seat can help lower drivers' body temperatures by heat convection and help evaporate the sweat more easily.

The average relative humidity inside all A/C ( $n = 15$ ) and non-A/C buses ( $n = 15$ ) were  $49.15 \pm 5.76\%$  and  $52.41 \pm 6.77\%$ , respectively. This level is compliant with indoor air quality standards (30-60% RH) recommended by ASHRAE<sup>(25)</sup>.

#### ***The VOCs exposure concentrations of studied bus drivers***

The highest concentration of VOCs that drivers were exposed to was benzene, followed by

toluene and xylene. All three of these chemicals, benzene, toluene and xylene were found as compounds in diesel. MTBE concentrations in air samples were found only in the buses on route Z, while ethyl benzene was found at low concentration on route X only. MTBE was used as oxygenate in gasoline octane 91 and gasoline octane 95. During the period during which this research was being conducted, the Thai government was promoting the use of gasohol 91 and gasohol 95 or E10 fuel. Therefore, the MTBE concentrations in the environment were lower and it was found only on route Z. Styrene was found on some routes, X and Y. The VOCs exposure concentrations of non-A/C bus drivers found in the present study were much higher than the other studies<sup>(27,28)</sup>. The difference between the results in the present study and the other studies may be caused by differences of geography, traffic density, duration of sampling, sampling instruments and seasonal variation. However, the average benzene exposure concentrations for bus drivers found in non-A/C buses in the present study ( $429.15 \mu\text{g}/\text{m}^3$ ) was still lower than those found in a Kolkata city study ( $527.3 \mu\text{g}/\text{m}^3$ )<sup>(19)</sup>. The bus drivers in A/C buses were exposed to almost the same benzene concentrations as those in non-A/C buses on the same route on the same day. This means that the VOCs from the outside environments can flow or penetrate into the environment inside A/C buses through a door opening or a leak around doors and windows. On route Y, the bus drivers were exposed to the highest benzene concentrations on both A/C and non-A/C buses. It is probably because their parking areas were in the north Bangkok terminal where many buses started their engines in the parking area while waiting to start their journey. In Thailand, benzene accounts for 3.5% by volume of unleaded fuel<sup>(28)</sup>. In addition, Suwattiga and Limpaseni<sup>(29)</sup> reported that the fraction of benzene was higher than that of toluene in tail-pipe emissions from diesel vehicles. Leong et al<sup>(30)</sup> found that there were higher benzene concentrations along road sides with slow movement of vehicles. The two million motorcycles in Bangkok are also a major contributor to benzene emissions<sup>(1)</sup>. However, the VOCs exposure levels of bus drivers were far below the recommended Threshold Limit Value-Time-Weighted Average of VOCs by the American Conference of Governmental Industrial Hygienists.

### Conclusion

The A/C and non-A/C bus drivers were exposed to nearly highest concentrations of  $\text{PM}_{2.5}$ ,

$\text{PM}_{10}$ , VOCs,  $\text{CO}_2$  compared to the former studies; the exposure of  $\text{CO}$  in bus drivers was low. To reduce exposure of BMTA bus drivers, bus cleaning will reduce exposure to fine particulate matters. Good ventilation system will help reduce  $\text{CO}_2$  concentrations in buses.

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### Potential conflicts of interest

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## การสัมผัสฝุ่นละออง CO<sub>2</sub>, CO, VOCs ของพนักงานขับรถโดยสารประจำทางในกรุงเทพมหานคร

พรพิมล กองทิพย์, ดิยาพร อัมทยานนท์, วิทยา อยู่สุข, ชมพูนุช อ่อนช้อย

**วัตถุประสงค์:** เพื่อประเมินการสัมผัสฝุ่น CO<sub>2</sub>, CO, VOCs ของพนักงานขับรถโดยสารประจำทางขององค์การขนส่งมวลชนกรุงเทพ

**วัสดุและวิธีการ:** ประเมินการสัมผัส PM<sub>2.5</sub>, PM<sub>10</sub>, CO<sub>2</sub>, CO, VOCs ของพนักงานขับรถโดยสารประจำทางขององค์การขนส่งมวลชนกรุงเทพ ทั้งประเภทรถปรับอากาศและรถธรรมดาจำนวน 60 คน ใน 3 เส้นทางตลอดกะการทำงาน

**ผลการศึกษา:** ความเข้มข้นเฉลี่ยของ PM<sub>2.5</sub> ของพนักงานขับรถโดยสารประเภทธรรมดา (323.81 ไมโครกรัม/ลูกบาศก์เมตร) สูงกว่าในประเภทปรับอากาศ (206.46ไมโครกรัม/ลูกบาศก์เมตร) อย่างมีนัยสำคัญทางสถิติ (p = 0.016) ค่าเฉลี่ยความเข้มข้นของเบนซีน โทลูอีน และไซลีนที่คนขับรถโดยสารประเภทธรรมดาได้รับสัมผัสเป็น 429.15, 225.11, 127.60 ไมโครกรัม/ลูกบาศก์เมตร ความเข้มข้นเฉลี่ยของ CO<sub>2</sub> ในรถโดยสารประเภทปรับอากาศสูงกว่าในรถโดยสารประเภทธรรมดาอย่างมีนัยสำคัญทางสถิติ (p<0.001) ความเข้มข้นเฉลี่ยของ CO ในรถโดยสารประเภทธรรมดาสูงกว่าในรถโดยสารประเภทปรับอากาศอย่างมีนัยสำคัญทางสถิติ(p=0.037)

**สรุป:** คนขับรถได้รับมลพิษอากาศที่ความเข้มข้นสูง การเพิ่มการระบายอากาศและการทำความสะอาดรถโดยสารจะลดการรับสัมผัสมลพิษในอากาศ

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