Aerosol and Air Quality Research, 12: 1298–1308, 2012

ISSN: 1680-8584 print / 2071-1409 online
doi: 10.4209/aaqr.2012.04.0093

Dry Deposition of Atmospheric Particle-Bound Mercury in the Middle Taiwan

Guor-Cheng Fang[1*], Jen-Hsiung Tsai[2], Yan-Heng Lin[1], Chia-Ying Chang[1]

[1] *Department of Safety, Health and Environmental Engineering, HungKuang University, Sha-Lu, Taichung 433, Taiwan*
[2] *Department of Environmental Science and Engineering, National Pingtung University of Science and Technology, Nei Pu, Pingtung 91201, Taiwan*

ABSTRACT

Atmospheric particle-bound mercury Hg(p) concentrations and dry deposition were investigated at Westing Park and Taichung airport sampling sites in the middle of Taiwan during the years 2011 and 2012.The calculated/measured dry deposition flux ratios of ambient air particles and Hg(p) with Petroff and Zhang's model were also studied. At the Westing Park sampling site, the particle-bound Hg(p) concentration and Hg (p) dry deposition velocity were 0.022 ng/m^3 and 1.74 cm/sec, respectively, while at the Taichung airport sampling site these were 0.027 ng/m^3 and 1.03 cm/sec, respectively.

The average calculated/measured dry deposition flux ratios for ambient air particles and Hg(p) at average particle sizes of 10, 20 and 23 µm in were 0.79, 1.22, and 1.43, and 0.93, 1.43 and 1.69 at the Westing Park sampling site, respectively. The average calculated/measured dry deposition flux ratios for ambient air particles and Hg(p) at average particle sizes of 10, 20 and 23 µm were 0.92, 1.42, and 1.67, and 1.05, 1.61 and 1.90 at the Taichung airport sampling site, respectively. This study also found that Petroff and Zhang's model produced the best for the prediction of ambient air particulates and Hg(p) dry deposition for a particle size of 10 µm at both the Westing Park and Taichung airport sampling sites, and that the results became worse as the particle size increased.

***Keywords*:** TSP; Dry deposition; Model; Particulates bound mercury Hg(p); Particles.

INTRODUCTION

The overwhelming majority of airborne mercury is Hg^0, Hg^{2+} and Hg(p) are more readily dry- and wet-deposited and can have more significant impacts near emission sources (Lai *et al.*, 2007). Dry deposition is considered a main pathway for removal of contaminants from the atmosphere. However while eliminating constituents from the atmospheric environment, these pathways transport constituents to terrestrial surfaces and receiving waters (Artina *et al.*, 2007).

Hg^0 is believed to have an atmospheric lifetime of about 1 yr (Lindqvist and Rodhe, 1985; Slemr *et al.*, 1985; Sakata and Asakura, 2007), while RGM and Hg(p) has a much shorter atmospheric lifetime. Due to its rapidly expanding economic and industrial developments. Urban air pollution is rapidly becoming an environmental problem of public concern worldwide (Lin *et al.*, 2005, 2008). It can influence public health and local/regional weather and climate. China is currently considered to be the engine of the world's economic growth (Bhaskar and Mehta, 2010). China's economic growth has been accompanied by an expansion of the urban area population and the emergence of a number of mega cities since the 1990. This expansion has resulted in tremendous increases in energy consumption, emissions of air pollutants and the number of poor air quality days in mega cities and their immediate vicinities. Air pollution has become one of the top environmental concerns in China (Chan and Yao, 2008; Bian *et al.*, 2011; Xiao *et al.*, 2011; Chen *et al.*, 2012; Han *et al.*, 2012; Wang *et al.*, 2012). The analysis indicates that on an annual basis, when air masses travel from Shanxi, which is home to many coal-fired power plants, Beijing tends to have poor air quality due to high PM_{10} concentrations. When air masses originating over Inner Mongolia, where anthropogenic emissions are low, Beijing tends to have good PM air quality. However, our case study showed that during the spring, air masses originating over Inner Mongolia and Mongolia tend to carry dust and sand to Beijing, leading to poor PM air quality (Xu *et al.*, 2008). Road transport was considered the dominant source of PM_{10} (Senaratne *et al.*, 2005).

High wind speed also could have resulted in high PM_{10} and $PM_{2.5}$ levels due to the re-suspension of particulate matter under well dispersed conditions (Cheng and Li, 2010). Accordingly, high dry deposition velocities are threatening to human health by dry deposition (Chang *et al.*, 2003). High concentrations were recorded in the winter seasons

[*] Corresponding author. Tel.: 886-4-2631-8652 ext. 1111;
Fax: 886-4-2631-0744
E-mail address: gcfang@sunrise.hk.edu.tw

for both particulate pollutants. In winter season, temperature is low and wind speed is generally low (Bhaskar and Mehta, 2010).

The mercury model of Community Multiscale Air Quality modeling system (CMAQ-Hg) has been used extensively as a modeling tool for atmospheric mercury studies in North America (Bullock and Brehme, 2002; Lin and Tao, 2003; Gbor *et al.*, 2006, 2007; Sillman *et al.*, 2007), and for intercontinental transport (Lin *et al.*, 2006). Moreover, it was found that mercury emission fluxes from surfaces in the Idrija region are 3e4 fold higher than the values commonly used in models representing emissions from global mercuriferous belts. Sensitivity and model uncertainty analysis indicated the importance of knowing not only the amount but also the type of mercury species and their binding in soils in future model development (Kocman and Horvat, 2011).

Previous study has used Zhang's model in the prediction of ambient air particulate and particulates bound mercury Hg(p) in central Taiwan. The above study has indicated At the Bei-Shi suburban/coast sampling site, the calculated/ measured ratios for ambient air particle and particle bound mercury Hg(p) dry deposition fluxes for particle sizes of 20 µm by using Zhang's model were ranged from 1.63–40.68 and 1.88–12.98, for the 37 sampling groups. The calculated/measured ratios for particle and particle-bound mercury Hg(p) dry deposition fluxes for particles sizes of 23 µm by using Zhang's model were ranged from 1.65–41.26 and 1.91–13.17, respectively, for the 37 sampling groups (Fang *et al.*, 2011). Previous study also has applied Woods model in the prediction of ambient air pollutants dry deposition at various particles sizes (1, 2.5, 10 and 18 µm) for industrial, suburban/coastal and residential sampling sites (Fang and Huang, 2011).

On this study, ambient air particulates and particulate bound mercury Hg(p) were estimated by using Petroff and Zhang's model in the prediction of ambient air particulate and particulate bound mercury Hg(p) at 10, 20 and 23 µm particles sizes in central Taiwan. The main goal of this study is to: (a) Characterize ambient air particulate and particulate bound mercury Hg(p) concentrations at Westing Park and Taichung airport sampling sites collected between September 12, 2011 to February 7, 2012 in central Taiwan. (b) Modeling ambient air particulate and particulate bound mercury Hg(p) dry deposition by using Petroff and Zhang's model in the size of 10, 20 and 23 µm at these two sampling sites. (c) Find the optimum particulate size in the prediction of ambient air particulate bound mercury Hg(p) at Westing Park and Taichung airport sampling sites.

DRY DEPOSITION MODEL

There are one dry deposition models while are applied in this study. 10 µm (PM_{10}) was used to obtain the calculated dry deposition model for all the models used in thin study. The descriptions of one models all described as followed:

Petroff and Zhang's Model

The deposition velocity for non-vegetated surfaces simply:

$$\mathrm{Vd(ZR)} = V_{drift} + \frac{1}{Ra(Z0, ZR) + 1/(\mathrm{E}_{gu*})} \tag{1}$$

The drift velocity is expressed by:

$$V_{drift} = W_s + V_{phor} \tag{2}$$

with $V_{phor} = 5 \times 10^{-5}$ m/s for LUC 1, 3, 23, $V_{phor} = 2 \times 10^{-4}$ m/s for LUC 2 and $V_{phor} = 0$ elsewhere.

Where Ψ_h is the integrated form of the stability function for heat. Its expression is $\Psi_h(x) = 2\ln[0.5(1 + (1 - 16x)1/2)]$ when $x \in [-2; 0]$ and $\Psi_h(x) = -5x$ when $x \in [0;1]$. For non-vegetated surfaces, whose roughnesses are not explicitly resolved, the aerodynamic resistance is written as:

$$Ra(z_0 + d, z_R) = \frac{1}{Ku_*}\left[\ln\left(\frac{\mathrm{zR-d}}{\mathrm{z_0}}\right) - \Psi_h\left(\frac{\mathrm{zR-d}}{\mathrm{L_0}}\right) + \Psi_h\left(\frac{\mathrm{z_0}}{\mathrm{L_0}}\right)\right] \tag{3}$$

The aerosol deposition on the ground below the vegetation canopy takes into account the Brownian diffusion and the turbulent impaction. Their deposition efficiencies, respectively E_{gb} and E_{gt}, are based on theoretical and empirical results obtained for turbulent flow in pipes. The Brownian diffusion efficiency is expressed as:

$$\mathrm{E_{gb}} = \frac{\mathrm{S_c^{-2/3}}}{14.5}\left[\frac{1}{6}\ln\frac{(1+\mathrm{F})^2}{1-\mathrm{F}+\mathrm{F}^2} + \frac{1}{\sqrt{3}}\mathrm{Arctan}\frac{2\mathrm{F}-1}{\sqrt{3}} + \frac{\pi}{\sqrt[6]{3}}\right]^{-1} \tag{4}$$

where F is a function of the Schmidt number expressed as F = Sc1/3/2.9

$$E_g = \mathrm{E_{gb}} + \mathrm{E_{gt}} \tag{5}$$

$$\mathrm{C_{IT}} \quad \text{if} \quad \tau^{+}_{ph} \geq 20 \tag{6}$$

The above model has described in detail in previous study (Petroff and Zhang, 2010).

EXPERIMENTAL

Sampling Program

Fig. 1 displays the geographical location at two characteristic sampling sites in central Taiwan. All the samples were sampling for 1380–1400 min during the sampling period for each sampling group. They are designated as follows:

Westing Park (24°23'77.94"N, 120°58'54.67"E) is located in the west side of Taichung city. The whole area was about 3.4 square kilometers. The total residential households were 1,463. The main occupation for these households was as farmers. In addition, Hungkuang University and Bei-shi elementary school were nearby. The total number of residential people was 82,108 with a male to female ratio of 1. Also the percentage of people with an age greater than 65 years old was 8.17%.

Taichung airport was located at Shalu district area in central Taiwan. The parking area for air plane was occupied 36280 square metres in air port. The Gung-Ming junior high school (24°14'59.82"N, 120°35'56.45"E) sampling site was located in the south (about 1 km) of TA. There were about 25 airplanes take off and 25 air planes landed at Taichung airport each day. The TA sampling site is about 10 km from the Taiwan Strait. And the Taiwan II Highway was just nearby), TA sampling site were approximately 10–15 m above surface of the earth level. The sampling site was on the about 12 m in highest of a building. And, this building is the only characteristic building in this open area.

PS-1 Sampler

PS-1 collects total suspended particulate mater. So, the maximum collection particle size was appropriate 100 µm (Graseby-Andersen, GMW High Volume Air Sampler).The PS-1 sampler is a complete air sampling system designed to simultaneously collect suspended airborne particles. The flow rate was adjusted to 200 L/min in this study. The quartz filter (diameter 102 mm) with pore size of 3 µm is used to filter the suspended particles in the study. The filters were first conditioned for 24 hours under an electric chamber at humidity 35 ± 5% and temperature 25 ± 5°C prior to both on and off weighing. Filters were placed in a sealed CD box during transport and storage process. The sampling device and procedures are similar to our previous study (Fang *et al.*, 2009).

Dry Deposition Plate

A dry deposition plate (DDP) was used, and is comprised of a smooth, horizontal, surrogate surface that provides a lower-bound estimate of the dry deposition flux. The DDP consisted of a smooth surface plate made of polyvinyl chloride (PVC) that measured 21.5 cm long, 8.0 cm wide and 0.8 cm thick. The DDP also contained a sharp, leading edge that was pointed into the prevailing wind. All filters were maintained in a condition of 35 ± 5% relative humidity and a temperature of 25 ± 5°C for over 24 hours. Prior to sampling use, all filters were weighed to 0.0001 Gram-significant digits (Chu *et al.*, 2008).

Formula and Calculation

After exposure to the atmosphere for equilibration, the following steps were followed.

1. Wash the cut surrogate surface (44 cm^2).
2. Coat the adsorbent (with silicone grease or apenzon L grease).
3. Weigh the filter after moisture equilibrium is obtained (24 hrs) (w0).
4. Expose the filter in the field and record the sampling day and sampling time (t) (24 hrs).
5. Reweigh the filter after the moisture equilibrium (w1) is obtained, and stores it for subsequent Hg analysis.

The following equations are used to determined particle concentration and dry deposition flux.

$$\text{Concentration} = [w1 - w0]/[t\ (\text{min}) \times Q\ (\text{liter/min})] \quad (7)$$

$$\text{Flux} = [w1 - w0]\ (\mu g)/[\text{Area}\ (m^2) \times t\ (\text{min})] \quad (8)$$

$$Vd\ (\text{cm/sec}) = \text{Flux}\ (\mu g/m^2/\text{min})/TSP\ (\mu g/m^3) \quad (9)$$

The above model has described in detail in previous study (Fang *et al.*, 2011).

Chemical Analysis

CVAFS (Cold vapor atomic fluorescence spectrometry) can be applied in the analyzing ambient air particulate bound mercury Hg(p) concentrations, dry deposition related studies successfully in central Taiwan. And it can also help and provide the references for government to set ambient air mercury concentrations related health regulations in Taiwan.

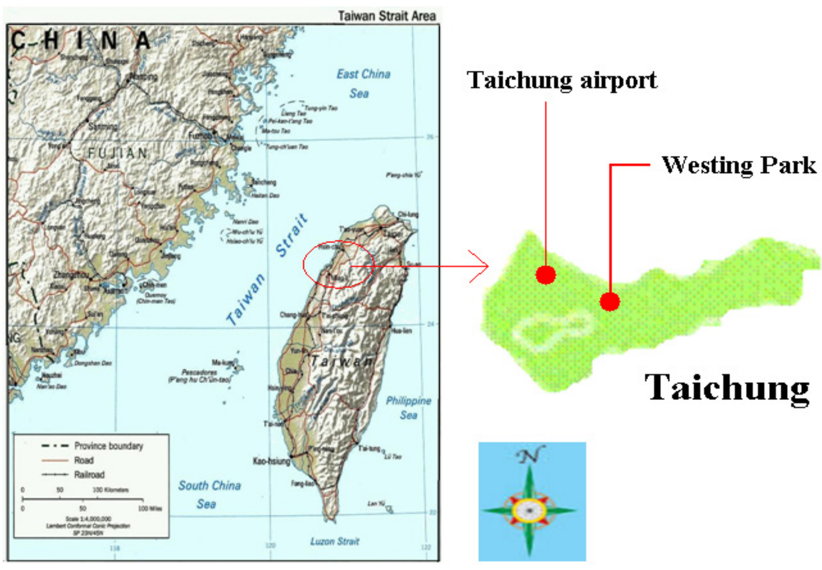

Fig. 1. Geographical location at Westing Park and Taichung airport sampling sites in central Taiwan during year 2011–2012.

RESULTS AND DISCUSSION

Table 1 displayed the relative humidity, wind speed, temperature and prevailing wind direction at the Westing Park sampling site. The results indicated that the relative humidity, wind speed, temperature and prevailing wind direction were 74.55%, 1.31 m/sec and 22.09°C, respectively at the Westing Park sampling site during year of 2011–2012. The main wind direction was blown from southeast in this study.

Table 2 displayed the relative humidity, wind speed, temperature and prevailing wind direction at the Taichung airport sampling site. The results indicated that the relative humidity, wind speed, temperature and prevailing wind direction were 75.27%, 1.30 m/sec and 21.48°C, respectively at the Taichung airport sampling site during year of 2011–2012. The main wind direction was blown from southeast in this study.

Table 3 described the average atmospheric particle dry deposition, total suspended particulate (TSP) concentrations, dry deposition velocities, particle bound mercury Hg(p) dry deposition, concentration, and dry deposition velocities by using projection film as a collection medium at Westing Park sampling site during year of 2011–2012 in Taiwan. The results indicated the average concentrations of total suspended particulates were ranged from 15.28 to 93.75 $\mu g/m^3$. And the average total suspended particulates (TSP) were 57.16 $\mu g/m^3$. Moreover, the results indicated that the average particle bound mercury Hg(p) in TSP were 0.022 ng/m^3. The ranges for Hg(p) total suspended particulates concentrations were from 0.014 to 0.039 ng/m^3. Moreover, dry deposition flux of ambient air particulates were ranged from 22.10 to 295.14 $\mu g/m^2/min$. And the results indicated that the average dry deposition were 103.73 $\mu g/m^2/min$. While the average particle bound mercury Hg(p) in dry deposition were 0.021 $ng/m^2/min$ and the Hg(p) dry deposition flux of particulates were ranged from 0.014 to 0.036 $ng/m^2/min$. In addition, the ambient air dry deposition velocity was ranged from 0.35 to 2.21 cm/sec. And the results also indicated that the average ambient air dry deposition velocity were 1.278 cm/sec, while the results indicated that the average particle bound mercury Hg(p) in dry deposition velocities were 1.741 cm/sec and the Hg(p) in particulate dry deposition velocity was ranged from 0.595 to 4.07 cm/sec at the Westing Park sampling site.

Table 4 described the average atmospheric particle dry deposition, total suspended particulate (TSP) concentrations, dry deposition velocities, particle bound mercury Hg(p) dry deposition, concentration, and dry deposition velocities by using projection film as a collection medium at Westing Park sampling site during year of 2011–2012 in Taiwan. The results indicated the average concentrations of total suspended particulates were ranged from 29.17 to 136.11 $\mu g/m^3$. And the average total suspended particulates (TSP) were 92.21 $\mu g/m^3$. Moreover, the results indicated that the average particle bound mercury Hg(p) in TSP were 0.027 ng/m^3. The ranges for Hg(p) total suspended particulates concentrations were from 0.015 to 0.060 ng/m^3. Moreover, dry deposition flux of ambient air particulates were ranged from 22.10 to 187.03 $\mu g/m^2/min$. And the results indicated that the average dry deposition were 105.56 $\mu g/m^2/min$, while the average particle bound mercury Hg(p) in dry deposition were 0.023 $ng/m^2/min$ and the Hg(p) dry deposition flux of particulates were ranged from 0.015 to 0.047 $ng/m^2/min$. In addition, the ambient air dry deposition velocity was ranged from 0.60 to 3.12 cm/sec. And the results also indicated that the average ambient air dry deposition velocity were 2.038 cm/sec, while the results indicated that the average particle bound mercury Hg(p) in dry deposition velocities were 1.027 cm/sec and the Hg(p) in particulate dry deposition velocity was ranged from 0.592 to 2.906 cm/sec at the Westing Park sampling site.

Fig. 2 displays the average calculated/measured dry deposition flux ratios of particulates at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particulates at the Westing Park sampling site. The results indicated that the average calculated/measured particulates flux ratios for particles of size of 10 μm were ranged from 0.16 to 2.52. And these fluxes ratios were from 0.25 to 3.89 and were from 0.30 to 4.58 for 20 and 23 μm, respectively. Moreover, the average calculated/measured fluxes ratios for 10, 20, and 23 μm were 0.79, 1.22 and 1.43, at Westing Park sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates dry deposition for the particles size of 10 μm at the Westing Park sampling site. And this prediction results decreased as the particles size increased.

Fig. 3 displays the average calculated/measured dry deposition flux ratios of particulates at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particulates at the Taichung airport sampling site. The results indicated that the average calculated/measured particulates flux ratios for particles of size of 10 μm were ranged from 0.26 to 2.79. And these fluxes ratios were from 0.40 to 4.30 and were from 0.47 to 5.06 for 20 and 23 μm, respectively. Moreover, the average calculated/measured fluxes ratios for 10, 20, and 23 μm were 0.92, 1.42 and 1.67, at Taichung airport sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates dry deposition for the particles size of 10 μm at the Taichung airport sampling site. And this prediction results decreased as the particles size increased.

Fig. 4 displays the average calculated/measured dry deposition flux ratios of particulates bound mercury Hg(p) at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particle bound mercury Hg(p) at the Westing Park sampling site. The results indicated that the average calculated/measured particle bound mercury Hg(p) flux ratios for particles of size of 10 μm were ranged from 0.35 to 2.39. And these fluxes ratios were from 0.54 to 3.68 and were from 0.63 to 4.34 for 20 and 23 μm, respectively. Moreover, the average calculated/measured fluxes ratios for 10, 20, and 23 μm were 0.93, 1.43 and 1.69, at Westing

Table 1 Displayed the relative humidity, wind speed, temperature and prevailing wind direction at the Westing Park sampling site during year 2011–2012.

Sample No	1	2	3	4	**September**		5	6	7	8	**October**		9	10	11	12	**November**	
Sample date	Sep. 12/'11	16	22	27	Ave.	SD	Oct. 5/'11	13	20	26	Ave.e	SD	Nov. 2/'11	15	22	29	Ave.	SD
Temp (°C)	29.15	29.82	26.33	28.68	28.50	1.52	25.67	26.80	24.72	23.12	25.08	1.56	26.56	22.69	23.28	23.77	25.08	1.71
RH (%)	70.88	70.28	61.42	73.44	69.01	5.24	75.41	83.45	71.54	65.60	74.00	7.48	74.91	81.36	73.89	81.33	74.00	4.03
WS (m/sec)	1.66	1.20	1.60	1.56	1.51	0.21	1.55	1.13	1.41	1.50	1.40	0.19	1.26	1.20	0.96	1.25	1.40	0.14
PWD	SSE	SW	ESE	SSW	SSE		ESE	SSW	ESE	NNE	ESE		SSW	NE	SSW	SE	SSE	

Sample No	13	14	15	16	**December**		17	18	19	20	**January**		21	22	23	24	**February**	
Sample date	Dec. 12/'11	15	22	29	Ave.	SD	Jan. 3/'12	10	11	17	Ave.	SD	Feb. 1/'12	2	6	7	Ave.	SD
Temp (°C)	18.36	19.56	16.68	18.67	18.32	1.20	16.68	17.84	16.42	17.48	17.11	0.67	17.89	17.74	18.72	19.36	18.42	0.77
RH (%)	79.98	78.67	74.08	77.64	77.59	2.53	73.02	75.74	67.91	77.89	73.64	4.31	79.87	73.42	81.55	81.33	79.04	3.82
WS (m/sec)	1.21	1.39	1.51	1.09	1.30	0.19	1.19	0.94	1.00	1.32	1.11	0.17	1.21	1.05	1.30	0.95	1.13	0.16
PWD	ENE	ENE	ESE	ESE	E		SSW	E	ESE	SE	SE		SE	SSE	SSW	ESE	SSE	

Table 2. Displayed the relative humidity, wind speed, temperature and prevailing wind direction at the Taichung airport sampling site during year 2011–2012.

Sample No	1	2	3	4	**September**		5	6	7	8	**October**		9	10	11	12	**November**	
Sample date	Sep. 12/'11	16	22	27	Ave.	SD	Oct. 5/'11	13	20	26	Ave.	SD	Nov. 2/'11	15	22	29	Ave.	SD
Temp. (°C)	29.13	29.22	25.43	28.57	28.09	1.17	25.65	26.74	24.52	22.61	24.88	1.76	26.33	22.54	23.17	23.56	23.90	1.68
RH (%)	72.92	70.71	61.92	75.00	70.14	5.75	76.50	84.67	71.96	64.29	74.36	8.53	74.83	81.33	73.75	80.88	77.70	3.96
WS (m/sec)	1.77	1.21	1.63	1.57	1.55	0.24	1.56	1.20	1.48	1.53	1.44	0.16	1.28	1.23	1.03	1.34	1.22	0.13
PWD	E	SSW	SSE	SW	S		ESE	ENE	S	E	ESE		SSE	S	S	S	S	

Sample No	13	14	15	16	**December**		17	18	19	20	**January**		21	22	23	24	**February**	
Sample date	Dec. 12/'11	15	22	29	Ave.	SD	Jan. 3/'12	10	11	17	Ave.	SD	Feb. 1/'12	2	6	7	Ave.	SD
Temp. (°C)	18.29	19.13	16.50	18.38	18.08	1.12	16.42	17.83	16.25	17.29	16.95	0.74	15.75	15.50	21.25	15.29	16.95	2.87
RH (%)	79.96	78.50	73.54	77.46	77.37	2.75	72.75	75.38	67.88	77.42	73.36	4.12	79.38	73.06	81.33	80.96	78.68	3.85
WS (m/sec)	1.30	1.40	1.26	1.12	1.27	0.12	1.28	0.98	1.02	1.45	1.18	0.22	1.28	1.06	1.30	0.98	1.16	0.16
PWD	ENE	E	E	E	E		S	S	E	SSE	SSE		ESE	ENE	ENE	ENE	SE	

Table 3. Average atmospheric particulates and particulates bound mercury Hg(p) in dry deposition and total suspended particles (TSP) at Westing Park sampling site during year 2011–2012.

Sample No		1	2	3	4	**September**		5	6	7	8	**October**		9	10	11	12	**November**	
Sample date		Sep. 12/'11	16	22	27	Ave.	SD	Oct. 5/'11	13	20	26	Ave.	SD	Nov. 2/'11	15	22	29	Ave.	SD
Particulate	Dry deposition ($\mu g/m^2/min$)	23.67	23.14	38.09	33.92	29.70	7.47	167.30	64.71	71.02	148.36	112.85	52.58	295.14	101.01	219.38	223.27	209.70	80.84
	TSP ($\mu g/m^3$)	59.38	68.40	67.71	68.40	65.97	4.41	40.28	34.72	44.79	34.72	38.63	4.87	56.94	57.29	52.43	46.88	53.39	4.87
	Vd (cm/sec)	1.40	1.62	1.84	1.55	1.60	0.18	0.89	0.69	1.04	0.88	0.88	0.14	1.27	1.17	1.18	0.96	1.15	0.13
Hg(p)	Dry deposition ($ng/m^2/min$)	0.015	0.018	0.019	0.019	0.0178	0.002	0.015	0.017	0.02	0.017	0.0172	0.0018	0.026	0.024	0.025	0.023	0.0243	0.0012
	TSP (ng/m^3)	0.023	0.016	0.015	0.012	0.0166	0.0048	0.019	0.025	0.015	0.025	0.021	0.0048	0.026	0.026	0.025	0.026	0.0258	0.0006
	Vd (cm/sec)	1.071	1.838	2.123	2.665	1.924	0.664	1.328	1.139	2.155	1.138	1.44	0.485	1.626	1.487	1.667	1.5	1.57	0.09

Sample No		13	14	15	16	**December**		17	18	19	20	**January**		21	22	23	24	**February**	
Sample date		Dec. 12/'11	15	22	29	Ave.	SD	Jan. 3/'12	10	11	17	Ave.	SD	Feb. 1/'12	2	6	7	Ave.	SD
Particulate	Dry deposition ($\mu g/m^2/min$)	173.01	154.67	265.15	53.66	161.62	86.70	63.13	82.07	116.79	39.46	75.36	32.66	31.57	44.19	34.72	22.10	33.14	9.11
	TSP ($\mu g/m^3$)	89.93	70.49	93.75	87.50	85.42	10.28	68.06	62.85	68.40	61.46	65.19	3.56	44.79	15.28	34.03	43.40	34.38	13.60
	Vd (cm/sec)	1.87	1.49	2.11	1.88	1.84	0.26	1.55	1.38	1.68	1.32	1.48	0.16	0.93	0.35	0.70	0.89	0.72	0.27
Hg(p)	Dry deposition ($\mu g/m^2/min$)	0.026	0.028	0.031	0.036	0.0305	0.0043	0.018	0.014	0.018	0.018	0.017	0.0022	0.017	0.017	0.021	0.019	0.0185	0.0017
	TSP (ng/m^3)	0.025	0.026	0.034	0.015	0.025	0.0079	0.019	0.039	0.014	0.018	0.0226	0.0109	0.022	0.021	0.014	0.017	0.0186	0.0035
	Vd (cm/sec)	1.745	1.85	1.502	4.07	2.292	1.194	1.574	0.595	2.148	1.628	1.486	0.648	1.297	1.408	2.444	1.793	1.735	0.518

Table 4. Average atmospheric particulates and particulates bound mercury Hg(p) in dry deposition and total suspended particles (TSP) at Taichung airport sampling site during year 2011–2012.

Sample No		1	2	3	4	**September**		5	6	7	8	**October**		9	10	11	12	**November**	
Sample date		Sep. 12/'11	16	22	27	Ave.	SD	Oct. 5/'11	13	20	26	Ave.	SD	Nov. 2/'11	15	22	29	Ave.	SD
Particulate	Dry deposition (μg/m^2/min)	69.44	55.24	31.57	47.35	50.90	15.80	47.35	22.10	55.24	47.35	43.01	14.43	55.24	91.54	162.56	165.72	118.77	54.47
	TSP (μg/m^3)	29.17	42.36	37.50	29.51	34.64	6.43	89.24	72.22	66.67	81.49	77.40	9.98	135.35	127.43	126.69	112.49	125.49	9.51
	Vd (cm/sec)	0.67	1.00	1.01	0.60	0.83	0.20	1.94	1.42	1.54	2.11	1.76	0.33	3.01	2.61	2.86	2.32	2.70	0.31
Hg(p)	Dry deposition (μg/m^2/min)	0.0182	0.0193	0.0161	0.0179	0.0179	0.0014	0.0147	0.0236	0.0219	0.0202	0.0201	0.0039	0.0257	0.0259	0.0253	0.0255	0.0256	0.0039
	TSP (ng/m^3)	0.0178	0.019	0.0155	0.0164	0.0172	0.0015	0.0154	0.0174	0.0249	0.0196	0.0193	0.0041	0.026	0.0258	0.0243	0.0228	0.0247	0.0041
	Vd (cm/sec)	1.698	1.698	1.726	1.817	1.017	0.057	1.584	2.257	1.468	1.711	1.019	0.349	1.643	1.675	1.736	1.868	1.025	0.349

Sample No		13	14	15	16	**December**		17	18	19	20	**January**		21	22	23	24	**February**	
Sample date		Dec. 12/'11	15	22	29	Ave.	SD	Jan. 3/'12	10	11	17	Ave.	SD	Feb. 1/'12	2	6	7	Ave.	SD
Particulate	Dry deposition (μg/m^2/min)	101.01	153.09	105.74	121.21	120.27	23.52	175.19	104.17	186.24	108.90	143.62	43.11	187.03	151.52	116.79	171.72	156.76	30.36
	TSP (μg/m^3)	110.42	132.64	100.88	108.36	113.07	13.67	136.11	107.99	125.28	130.90	125.07	12.22	95.83	81.94	80.56	52.08	77.60	18.36
	Vd (cm/sec)	2.30	2.82	2.29	2.33	2.44	0.26	3.12	2.39	3.08	2.82	2.85	0.34	2.01	1.87	1.65	1.07	1.65	0.41
Hg(p)	Dry deposition (μg/m^2/min)	0.0244	0.025	0.025	0.0255	0.025	0.0002	0.0469	0.0236	0.0206	0.0201	0.0278	0.0128	0.0212	0.0212	0.0201	0.0201	0.0207	0.0006
	TSP (ng/m^3)	0.0244	0.0271	0.0278	0.0283	0.0269	0.0015	0.0269	0.026	0.0498	0.0278	0.0326	0.0115	0.0596	0.0436	0.0358	0.0294	0.0421	0.013
	Vd (cm/sec)	1.667	1.537	1.5	1.502	1.027	0.1	2.906	1.511	0.69	1.207	1.033	0.948	0.592	0.81	0.938	1.139	1.042	0.229

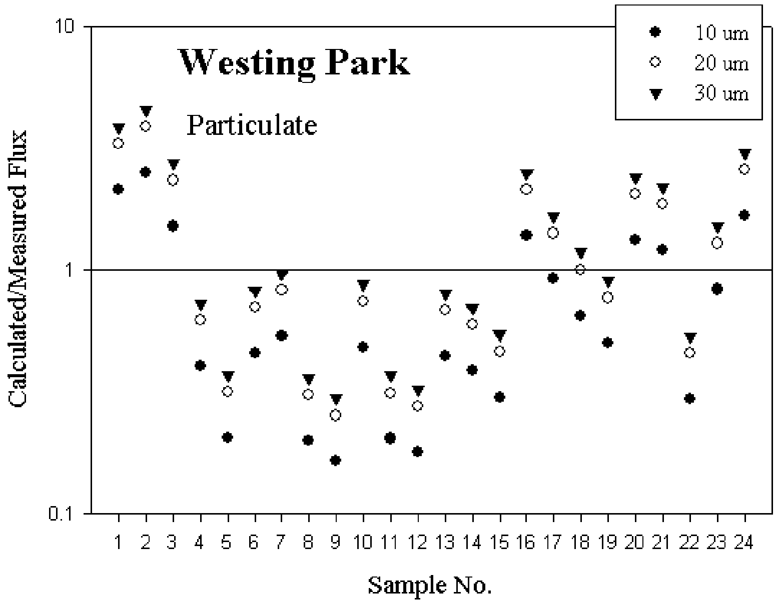

Fig. 2. Average calculated/measured dry deposition flux ratios of particulates at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particulates at the Westing Park sampling site.

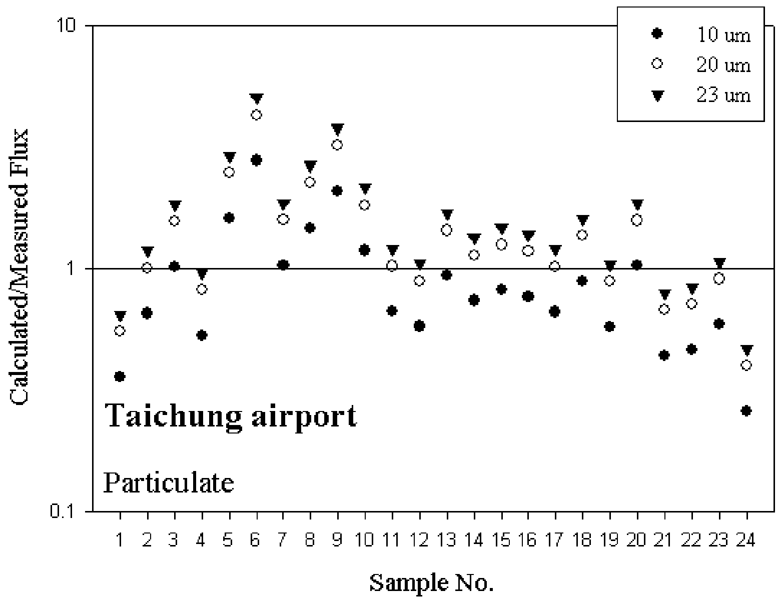

Fig. 3. Average calculated/measured dry deposition flux ratios of particulates at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particulates at the Taichung airport sampling site.

Park sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates bound mercury Hg(p) dry deposition for the particles size of 10 μm at the Westing Park sampling site. And this prediction results decreased as the particles size increased.

Fig. 5 displays the average calculated/measured dry deposition flux ratios of particulates bound mercury Hg(p) at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particle bound mercury Hg(p) at the Taichung airport sampling site. The results indicated that the average calculated/measured particle bound mercury Hg(p) flux ratios for particles of size of 10 μm were ranged from 0.49 to 2.40. And these fluxes ratios were from 0.75 to 3.70 and were from 0.89 to 4.36 for 20 and 23 μm, respectively. Moreover, the average calculated/measured fluxes ratios for 10, 20, and 23 μm were 1.05, 1.61 and 1.90, at Taichung airport sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates bound mercury Hg(p) dry deposition for the particles size of 10 μm at the Taichung airport sampling site. And this prediction results decreased as the particles size increased.

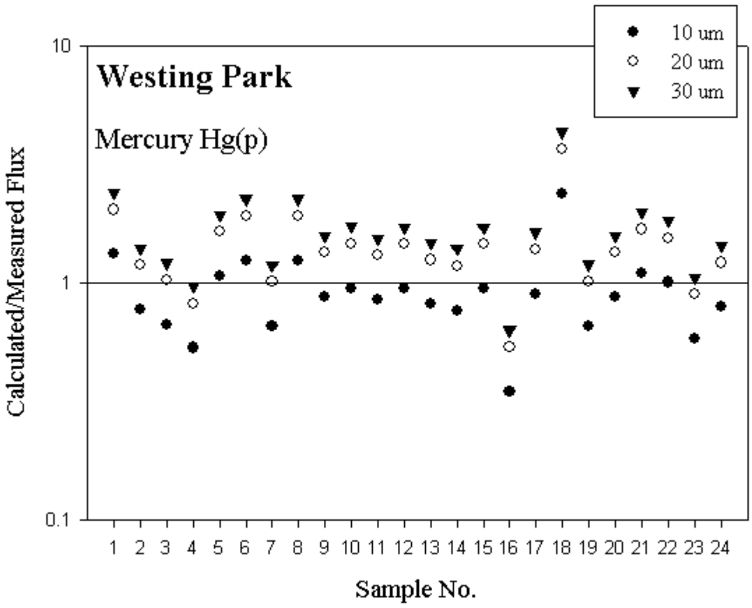

Fig. 4. Average calculated/measured dry deposition flux ratios of particulates bound mercury Hg(p) at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particulates at the Westing Park sampling site.

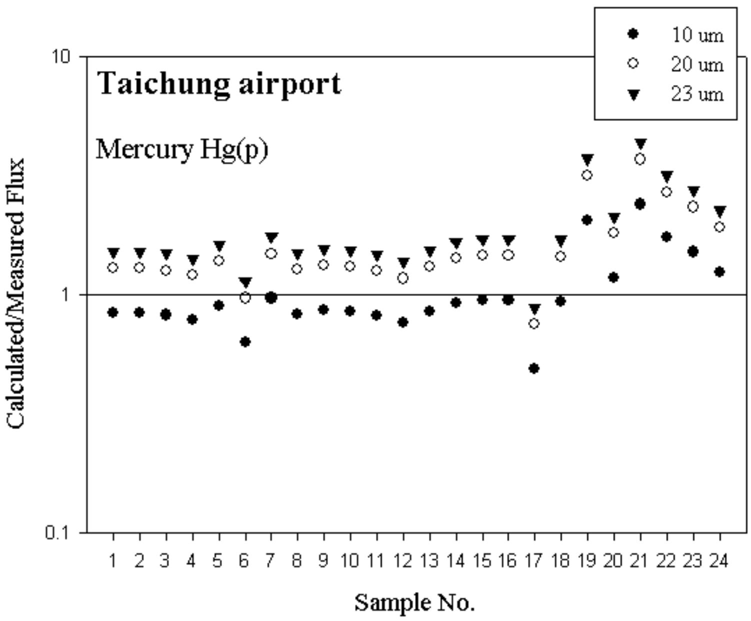

Fig. 5. Average calculated/measured dry deposition flux ratios of particulates bound mercury Hg(p) at average particle sizes of 10, 20 and 23 μm in TSP by using the Petroff and Zhang's model to estimate the ambient air particulates at the Taichung airport sampling site.

CONCLUSIONS

The main conclusions for this study was listed as followed:

1. The average calculated/measured fluxes ratios for 10, 20, and 23 μm were 0.79, 1.22 and 1.43, at Westing Park sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates dry deposition for the particles size of 10 μm at the Westing Park sampling site. And this prediction results decreased as the particles size increased.
2. The average calculated/measured fluxes ratios for 10, 20, and 23 μm were 0.92, 1.42 and 1.67, at Taichung airport sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates dry deposition for the particles size of 10 μm at the Taichung airport sampling site. And this prediction

results decreased as the particles size increased.

3. The average calculated/measured fluxes ratios for 10, 20, and 23 μm were 0.93, 1.43 and 1.69, at Westing Park sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates bound mercury Hg(p) dry deposition for the particles size of 10 μm at the Westing Park sampling site. And this prediction results decreased as the particles size increased.
4. The average calculated/measured fluxes ratios for 10, 20, and 23 μm were 1.05, 1.61 and 1.90, at Taichung airport sampling site, respectively. This result further revealed that the Petroff and Zhang's model performed better results in the prediction of ambient air particulates bound mercury Hg(p) dry deposition for the particles size of 10 μm at the Taichung airport sampling site. And this prediction results decreased as the particles size increased.
5. From the point of view of particle size of 10 μm, the results obtained in this study indicated that the Taichung airport exhibited better dry deposition prediction results than that of Westing Park when applied Petroff and Zhang's model for both ambient air particles and particles bound mercury Hg(p). However, from the point of view of particle size of 20 or 23 μm, the results obtained in this study indicated that the Westing Park exhibited better dry deposition prediction results than that of Taichung airport when applied Petroff and Zhang's model for both ambient air particles and particles bound mercury Hg(p).
6. In average, ambient air particles exhibited better dry deposition fluxes predictions than that of particle bound mercury Hg(p) when applied Petroff and Zhang's model for both Westing Park and Taichung airport sampling sites.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the National Science Council of the R.O.C. (Taiwan) for financial support under project No. NSC 99-2221-E-241-006-MY3.

REFERENCES

Artina, S., Bolognesi, A., Liserra, T. and Maglionico, M. (2007). Simulation of a Storm Sewer Network in Industrial Area: Comparison between Models Calibrated through Experimental Data. *Environ. Modell. Softw.* 22: 1221–1228.

Bhaskar, B.V. and Mehta V.M. (2010). Atmospheric Particulate Pollutants and Their Relationship with Meteorology in Ahmedabad. *Aerosol Air Qual. Res.* 10: 301–315.

Bian, H., Tie, X., Cao, J., Ying, Z., Han, S. and Xue, Y. (2011). Analysis of a Severe Dust Storm Event over China: Application of the WRF-Dust Model. *Aerosol Air Qual. Res.* 11: 419–428.

Bullock, O.R. and Brehme, K.A. (2002). Atmospheric Mercury Simulation Using the CMAQ Model: Formulation Description and Analysis of Wet Deposition Results. *Atmos. Environ.* 36: 2135–2146.

Chan, C.K. and Yao, X. (2008) Air Pollution in Mega Cities in China. *Atmos. Environ.* 42: 1–42.

Chang, K.F., Fang, G.C., Lu, C. and Bai, H., (2003). Estimating PAH Dry Deposition by Measuring Gas and Particle Phase Concentrations in Ambient. *Aerosol Air Qual. Res.* 1: 41–51.

Chen, B., Du, K., Wang, Y., Chen, J., Zhao, J., Wang, K., Zhang, F. and Xu, L. (2012). Emission and Transport of Carbonaceous Aerosols in Urbanized Coastal Areas in China. *Aerosol Air Qual. Res.* 12: 371–378.

Cheng, Y.H. and Li, Y.S. (2010). Influences of Traffic Emissions and Meteorological Conditions on Ambient PM_{10} and $PM_{2.5}$ Levels at a Highway Toll Station. *Aerosol Air Qual. Res.* 10: 456–462.

Chu, C.C., Fang, G.C., Chen, J.C. and Lin, I.C. (2008). Ambient Air Dry Deposition and Ionic Species Analysis by Using Various Deposition Collectors in Shalu, Central Taiwan. *Atmos. Res.* 88: 212–223.

Fang, G.C., Basu, N., Nam, D.H. and Yang, I.L. (2009). Characterization of Ambient Air Particulates and Particulate Merrcury at Sha-Lu, Central Taiwan. *Environ. Forensics* 10: 277–285.

Fang, G.C., Chen, J.C., Wu, Y., Huang, W.J. and Liu, C.K. (2011). Application of Dry Deposition Models to Estimate Ambient Air Particulate and Particulate Bound Mercury Hg(p) Dry Deposition in a Suburban/Coastal Area. *Environ. Eng. Sci.* 28: 63–70.

Fang, G.C. and Huang, C.S. (2011). Apply Woods Model in the Predictions of Ambient Air Particles and Metallic Elements (Mn, Fe, Zn, Cr and Cu) at Industrial, Suburban/Coastal and Residential Sampling Sites. *The Scientific World Journal* 2012: 207620.

Gbor, P.K., Wen, D., Meng, F., Yang, F. and Sloan, J.J. (2007). Modeling of Mercury Emission, Transport and Deposition in North America. *Atmos. Environ.* 41: 1135–1149.

Han, S., Bian, H., Zhang, Y., Wu, J., Wang, Y., Tie, X., Li, Y., Li, X. and Yao, Q. (2012). Effect of Aerosols on Visibility and Radiation in Spring 2009 in Tianjin, China. *Aerosol Air Qual. Res.* 12: 211–217.

Senaratne, I., Kelliher, F.M. and Triggs, C. (2005). Source Apportionment of Airborne Particles during Winter in Contrasting, Coastal Cities. *Aerosol Air Qual. Res.* 5: 48–64.

Kocman, D. and Horvat, M. (2011). Non-Point Source Mercury Emission from the Idrija Hg-Mine Region: GIS Mercury Emission Model. *J. Environ. Manage.* 92: 2038–2046.

Lai, S.O., Holsen, T.M., Han, Y.J., Hopke, P.P., Yi, S.M., Blanchard, P., Pagano, J.J. and Milligan, M. (2007). Estimation of Mercury Loadings to Lake Ontario: Results from the Lake Ontario Atmospheric Deposition Study (LOADS). *J. Atmos. Chem.* 41: 8205–8218.

Lin, C.C., Chen, S.J., Huang, K.L., Hwang, W.I., Chang-Chien, G.P. and Lin, W.Y. (2005). Characteristics of Metals in Nano/Ultrafine/Fine/Coarse Particles Collected

Beside a Heavily Trafficked Road. *Environ. Sci. Technol.* 39: 8113–8122.

Lin, C.C., Chen, S.J., Huang, K.L., Lee, W.J., Lin, W.Y., Tsai, J.H. and Chaung, H.C. (2008). PAHs, PAH-Induced Carcinogenic Potency, and Particle-Extract-Induced Cytotoxicity of Traffic-related Nano/Ultrafine Particles. *Environ. Sci. Technol.* 42: 4229–4235.

Lin, C.J., Pongprueksa, P., Vanjani, T., Ho, T.C., Chu, H.W., Jang, C., Braverman, T., Streets, D.G. and Fu, J.S. (2006). Trans-Pacific Chemical Transport of Mercury: Sensitivity Analysis on Potential Asian Emission Contribution to Mercury Deposition in North America Using CMAQ-Hg, Proc. 5th CMAS Conference, Research Triangle Park, NC, p. 16–18.

Lin, X. and Tao, Y. (2003). A Numerical Modelling Study on Regional Mercury Budget for Eastern North America. *Atmos. Chem. Phys.* 3: 535–548.

Lindqvist, O. and Rodhe, H. (1985). Atmospheric Mercury—A Review. *Tellus* 37: 136–159.

Petroff, A. and Zhang, L. (2010). Development and Validation of a Size-Resolved Particle Dry Deposition Scheme for Application in Aerosol Transport Models. *Geosci. Model Dev. Discuss.* 3: 753–769.

Sakata, M. and Asakura, K. (2007). Estimating Contribution of Precipitation Scavenging of Atmospheric Particulate Mercury to Mercury Wet Deposition in Japan. *Atmos. Environ.* 41: 1669–1680.

Sillman, S., Marsik, F.J., Al-Wali, K.I., Keeler, G.J. and Landis, M.S. (2007). Reactive Mercury in the Troposphere: Model Formation and Results for Florida, the Northeastern US and the Atlantic Ocean. *J. Geophys. Res.* 112: D23305, doi: 10.1029/2006JD008227.

Slemr, F., Schuster, G. and Distribution, W. (1985). Distribution, Speciation, and Budget of Atmospheric Mercury. *J. Atmos. Chem.* 3: 407–434.

Bhaskar, V.B. and Mehta, V.M. (2010). Atmospheric Particulate Pollutants and their Relationship with Meteorology in Ahmedabad. *Aerosol Air Qual. Res.* 10: 301–315.

Wang, Z.S., Wu, T., Shi, G.L., Fu, X., Tian, Y.Z., Feng, Y.C., Wu, X.F., Wu, G., Bai, Z.P. and Zhang, W.J. (2012). Potential Source Analysis for PM_{10} and $PM_{2.5}$ in Autumn in a Northern City in China. *Aerosol Air Qual. Res.* 12: 39–48.

Xiao, Z.M., Zhang, Y.F., Hong, S.M., Bi, X.H., Jiao, L., Feng, Y.C. and Wang, Y.Q. (2011). Estimation of the Main Factors Influencing Haze, Based on a Long-term Monitoring Campaign in Hangzhou, China. *Aerosol Air Qual. Res.* 11: 873–882.

Xu, X., Barsha, N.A.F. and Li, J. (2008). Analyzing Regional Inluence of Particulate Matter on the City of Beijing, China. *Aerosol Air Qual. Res.* 8: 78–93.

Received for review, April 19, 2012
Accepted, June 14, 2012