

# Dry deposition study by using dry deposition plate and water surface sampler in Shalu, central Taiwan

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**Abstract** This study presents the chemical composition of dry deposition by using dry deposition plate and water surfaces sampler during daytime and nighttime sampling periods at a near highway traffic sampling site. In addition, the characterization for mass and water soluble species of total suspended particulate (TSP), PM<sub>2.5</sub> and PM<sub>10</sub> were also studied at this sampling site during August 22 to October 31 of 2006 around central Taiwan. The samples collected were analyzed by using Ion Chromatography (DIO NEX 100) for the ionic species analysis. Results of the particulate dry deposition fluxes are higher in the water surfaces sampler than that of the dry deposition plate. In other words, the results also indicated that water surface can absorb more ambient dry deposition inorganic pollutants than that of dry deposition plate

in this study. The results obtained in this study indicated that the ionic species of Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> occupied about average 60~70% downward flux out of total ionic species for either dry deposition plate or water surfaces sampler during August to October of 2006 at this near highway traffic sampling site.

**Keywords** Dry deposition · Water surface sampler · Water soluble ionic · Total suspended particulate

## Introduction

Atmospheric deposition is an important mechanism controlling the fate of toxic airborne pollutants and their transfer from the atmosphere to the natural surfaces. Atmospheric pollution of airborne fine particles is an environmental issue of major concern, principally due to the evidence of their adverse human health effects observed in epidemiological studies (Horvath 1996; Berico et al. 1997; Dockery et al. 1998; Samet et al. 2000; Stieb et al. 2002). In addition, air pollution in the traffic centers is characterized by the emissions and concentrations of primary pollutants which have extremely strong spatial and temporal variations and the characterization of urban air pollution is fairly complicated.

Atmospheric deposition is defined as the process by which atmospheric pollutants are transferred to

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terrestrial and aquatic surfaces (Valigura et al. 1996), and is commonly classified as either dry or wet. Until recently, research on atmospheric deposition was primarily associated with precipitation events. Atmospheric deposition of particles to ecosystem takes place via both wet and dry processes. Over the years efforts have been made to get knowledge about the composition of atmospheric aerosols as a function of size (Almeida et al. 2005; Putaud et al. 2004). The sources, characteristics, and potential health effects of the larger (coarse) particles (diameter 2.5–10  $\mu\text{m}$ ) and smaller (fine) particles (diameter smaller than 2.5  $\mu\text{m}$ ) are different. Fine particulates not only readily penetrate into the lungs but also are likely to increase respiratory and mutagenic diseases (Fang et al. 2002). Atmospheric deposition can take place in two forms dry and wet deposition, which is together is called as bulk deposition. Deposition of pollutants takes place by two main mechanisms: wet deposition and dry deposition (Park 1995). Wet deposition comprises removal by falling precipitation (washout) and rainout in clouds, and dry deposition denotes the direct collection of gaseous and particulates on land and water surfaces. Wet deposition includes both dissolved and particulate material, and the partitioning of the elements into these phases is largely dependent on the emitted form, the solubility of the element, and the pH of the rain. Particles and gases in the ambient air may deposit or absorb onto surfaces at a rate that depends on their physical and chemical characteristics, meteorological conditions and collection surface properties (Finlayson Pitts and Pitts 1986; Hoff et al. 1996; Tasdemir 1997; Tasdemir et al. 2005). In order to collect and quantify dry deposition, several different kinds of surrogate surfaces have been used, such as Teflon plates, petri dishes, different kinds of filters, greased knife edge strips, inverted Frisbees and buckets (Davidson et al. 1985; Dolske and Gatz 1985; Hall and Upton 1988; Noll et al. 1988; Tasdemir et al. 2005). Previous research indicated that the impact of atmospheric deposition of air pollutants to the surface waters is large (Hoff et al. 1996). However, there is no generally accepted method to directly measure or estimate dry deposition. The use of various types of surrogate surfaces is one approach that has been used to directly measure dry deposition. Recently, the water surface sampler (WSS) in conjunction with dry deposition plates has been successfully used to directly measure particle dry deposition and air–water

exchange of organic and inorganic air pollutants found in particulate and gas phases (Tasdemir et al. 2004, 2005; Odabasi et al. 1999, 2001; Odabasi and Bagiroz 2002; Shahin et al. 1999; Yi et al. 1997; Yi and Cindoruk 2007). A water surface sampler (WSS) was developed in order to minimize disadvantages caused by greased surfaces (Tasdemir et al. 1997; Odabasi et al. 1999; Tasdemir et al. 2005). The deposition surface is water that is continuously replenished to maintain a constant level and short residence time thereby minimizing the effects of water (Tasdemir 1997; Odabasi et al. 1999; Tasdemir et al. 2005).

The purpose of this study is to develop a methodology to estimate the difference for atmospheric pollutants by using dry depositions and water surface samplers simultaneously during daytime and nighttime at this highway traffic sampling site. In addition, meteorological data such as temperatures, relative humidity and wind speed were also monitored. Besides, a correlation coefficients analysis was applied to derive statistical relationships between air particulate pollutants during sampling period at this highway traffic sampling site.

## Experimental method

### Sampling program

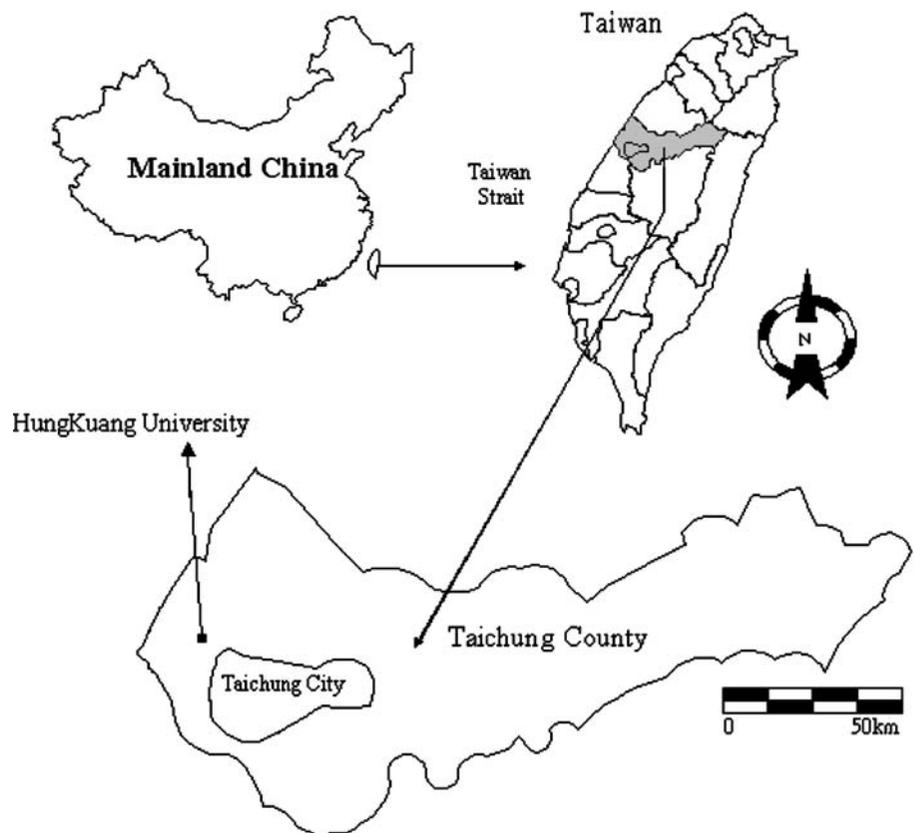
Figure 1 shows the sampling position for this study. Ambient particle concentration was taken on the roof of the Medical and Industrial Building in the campus of Hungkuang University which is an eight story building (25 m) and is the highest site of 500 m on Da Du Mountain. This sampling position was near highway and Taiwan Straits for about 100 m and 10 km, respectively.

### Sampling apparatus

#### *PS 1 sampler*

PS 1 that can collect total suspended particulate matter. So, the maximum collection particle size was appropriate 100  $\mu\text{m}$  (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

**Fig. 1** The location of this highway traffic sampling site in central Taiwan



was adjusted to 200 l/min in this study. The quartz filter (diameter 10.2 cm) is used to filter the suspended particles in the study. The filters were first conditioned for 24 h under an electric chamber at humidity  $35\pm 5\%$  and temperature  $25\pm 5^\circ\text{C}$  prior to both on and off weighing. Filters were placed in sealed CD box during transport and storage process.

#### *Water surface sampler*

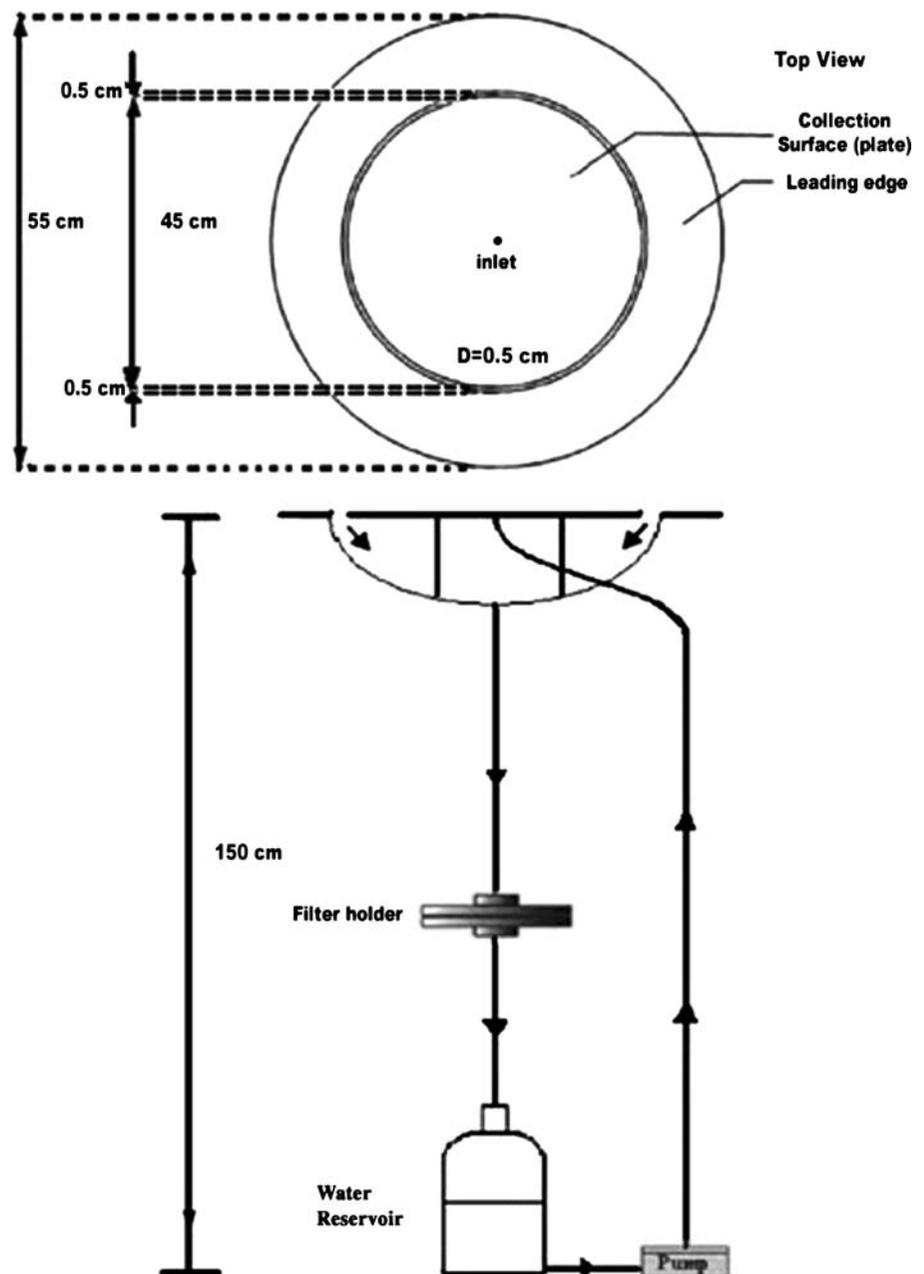
The water surface sampler (WSS) was used to measure particulate and gas phase fluxes. The deposition plate consists of an aerodynamically designed surrogate surface allowing the formation of thin and uniform laminar boundary layer on the surface (Davidson and Wu 1990; Yi and Holsen 2005).

Direct particle phase flux measurements were made using an aerodynamically designed WSS, which is assumed to capture deposited particles with 100% efficiency (Tasdemir 1997; Odabasi et al. 1999; Pryor and Barthelmie 2000; Shahin et al. 2002; Yi and Holsen 2005). A WSS has been successfully used for particle phase flux collections of sulfate, nitrate, PAHs

and PCBs (Yi et al. 1997; Yi and Holsen 2005; Tasdemir 1997; Shahin et al. 1999; Odabasi et al. 1999). A smooth surface plate was made of polyvinyl chloride (PVC) and was 21.5 cm long, 8.0 cm wide and 0.8 cm thick with a sharp leading edge that was pointed into the wind (Fig. 2). All filters were maintained in a condition of 50% RH and  $25^\circ\text{C}$  for over 48 h and then weighted before sampling. Then they were put into 15 ml bottles for each sampling group. Ion Chromatography (DIONEX DX 100) was used to analyze for the anions: sulfate, chloride and nitrate in the Universal samples. The analysis procedure is the same as the previous study (Fang et al. 1999).

The WSS was continuously replenished with water to maintain a constant water depth and to control water retention time on the surface (Tasdemir 1997; Odabasi et al. 1999; Yi and Holsen 2005). Water entered the WSS plate from its center and overflowed from the weirs located along its sides. The retention time on the WSS plate was maintained as small as possible (2–4 min) in order to prevent any evaporation loss from deposited PCBs (Tasdemir 1997; Yi and Holsen 2005).

**Fig. 2** The water surface sampler (WSS)



### *Dry deposition plate*

Dry deposition plate (DDP) was use of a smooth, horizontal, surrogate surface provides a lower bound estimate of the dry deposition flux onto a horizontal surface (Holsen et al. 1992). A smooth surface plate was made of polyvinyl chloride (PVC) and was 21.5 cm long, 8.0 cm wide and 0.8 cm thick with a sharp leading edge that was pointed into the wind. All

filters were maintained in a condition of 50% RH and  $25^{\circ}\text{C}$  for over 48 h and then weighted before sampling.

### *Honeycomb denuder/filter pack system sampler*

The particulate sampler used in this work to collect aerosols (PM<sub>2.5</sub> and PM<sub>10</sub>) was an R&P model 2300 (RP2300) Partisol Sampler that was equipped with R&P ChemComb Speciation Sampling Cartridges

(Rupprecht&Patashnick Co., Inc., NY, USA). Two channels of RP2300 were used to collect PM<sub>2.5</sub> and PM<sub>10</sub> soluble species. To analyze particulate soluble ions, the filter pack was preceded with a coated ChemComb denuder to prevent interference by precursor gases during aerosol collection. This sampler collects fine (aerodynamic diameter <2.5 µm) and coarse (aerodynamic diameter >2.5 µm) airborne particles on 2.0 µm pore size quartz filter.

#### *Meteorological analysis*

Meteorological analysis was made by a Watchdog weather station Model 525 (Spectrum Technologies, Inc, USA). The weather station can provide data of wind speed, wind direction, temperature and humidity during the sampling period.

#### *Analysis methods*

##### *Chemical analysis*

The filters were weighed after humidity equilibration (24 h) in the desiccators then exposed to the near highway traffic sampling site and the sampling time was recorded. At the end of sampling, the filter was taken back to the laboratory. After humidity equilibration (24 h), the filter was reweighed on an analytical balance with a precision of 10 mg to calculate the particulate weight and concentrations at this near highway traffic sampling site (Table 1).

After final weighing, all Quartz filters were put into 15 ml bottles for each bottle sampling group. Ultrasonic method was used to extract all filters for determination of inorganic ionic components and normally over 98% of sulfate, nitrate, and ammonium can be extracted. Within 24 hour of weighing, the filter was put in a vial and submerged into 10 ml Distilled deionizer water for extraction. The vial was then sealed and put into an ultrasonic bath for 120 min. Ion Chromatography (DIONEX DX 100) was used to analyze for the anions: sulfate, chloride and nitrate in the Universal samples. The analysis procedure is the same as the previous study (Fang et al. 1999).

##### *Blank test/Detection limit*

The blank test can be used to determine the background contamination from the analysis process.

Background contamination was routinely monitored by using operational blanks (unexposed filter) which were processed simultaneously with field samples. In this study, the background contamination is insignificant and be ignored. The concentrations of the background contaminations are 0.08, 0.07, 0.02, 0.004, 0.07, 0.05, 0.03, 0.05, and 0.07 µg m<sup>-3</sup> for Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup>, respectively. Detection limit was used to determine the lowest concentration level that can be detected to be statistically different from a blank. The detection limits of the elements in this study were, 0.003, 0.013, 0.0005, 0.0001, 0.001, 0.003, 0.003 and 0.021 mg/l for Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup>, respectively.

##### *Recovery efficiency test*

At least 10 of the samples are analyzed after spiking with a known amount of ions to calculate recovery efficiencies. The analysis procedure for the recovery test is the same as that described for the field samples. The results indicated the range of recovery efficiency varies between 95 and 107% and the relative standard deviation is smaller than 10%.

##### *Reproducibility test*

The reproducibility test can display the stability of instruments. The procedure was to repeat the analysis of the same sample seven times. The value of three standard deviations for repeat analysis should not exceed the upper control limit (+10%) and lower control limit (-10%). If the value of (3 × S.D.) exceeds the upper and lower control limit, the experiments should be paused to examine the procedures of analysis and instruments.

## **Results and discussion**

Correlation coefficients of ionic species on various deposition collectors to meteorological conditions during daytime or nighttime periods

Table 2 showed the results of correlation coefficients of various ionic species on different dry deposition collectors to meteorological conditions. The results indicated that the low correlation coefficients were obtained for these ionic species on dry deposition

**Table 1** Summary of meteorological data at near highway traffic sampling site during August to October of 2006

Sample No.	Sample date	T° (°C)	RH (%)	WS (m/s <sup>-1</sup> )	PWD	PM <sub>2.5</sub> (µg m <sup>-3</sup> )	PM <sub>10</sub> (µg m <sup>-3</sup> )
1	0823D	30.4	67.6	1.5	ESE	61.71	66.99
2	0823N	26.6	81.2	2.2	ESE	39.96	45.41
3	0824D	29.8	61.5	1.2	NNE	32.73	39.24
4	0824N	26.6	77.2	1.3	ENE	50.33	63.62
5	0826D	30.2	64.4	1.5	NNW	41.19	49.95
6	0826N	26.4	82.8	0.7	N	36.54	54.47
7	0827D	31.3	58.7	0.9	NNW	32.43	37.70
8	0827N	26.8	74.4	1.2	ESE	22.10	31.50
9	0828D	32.1	55.8	1.5	N	18.64	22.53
10	0828N	27.3	82.4	0.9	ESE	20.51	43.06
11	0829D	31.8	59.9	0.9	ESE	36.44	49.52
12	0829N	27.0	85.7	1.6	ESE	22.03	39.78
13	0830D	32.0	56.3	2.1	ESE	21.08	26.92
14	0830N	26.8	81.4	2.3	ENE	16.40	30.45
15	0831D	31.7	58.9	2.7	SSE	28.19	38.14
16	0831N	26.5	69.3	3.1	ENE	20.71	30.51
17	0901D	29.7	66.7	2.9	ESE	38.83	51.77
18	0901N	26.8	76.6	2.4	ESE	77.78	99.10
19	1024D	26.4	62.7	8.2	NNW	62.65	75.88
20	1024N	22.5	66.2	5.8	N	24.34	77.16
21	1025D	26.1	62.8	8.4	NNW	52.37	84.53
22	1025N	22.9	69.6	3.9	N	18.24	54.06
23	1026D	26.0	65.8	7.5	NNW	12.42	52.06
24	1026N	22.9	73.9	4.4	N	50.88	46.24
25	1027D	26.7	70.3	6.3	NNW	64.07	68.55
26	1027N	22.9	77.3	2.4	NNW	73.42	105.29
27	1028D	27.1	72.1	5.4	NNW	41.83	38.02
28	1028N	23.5	72.8	3.4	NNW	38.97	40.22
29	1030D	25.6	67.0	9.8	NNW	39.59	63.46
30	1030N	23.1	73.8	6.8	NNW	22.41	4.60
31	1031D	24.1	68.8	8.4	NNW	18.37	30.03
32	1031N	22.6	72.8	6.9	NNW	23.96	45.55
Average		26.94	69.88	3.70		36.28	50.20
Standard deviation		2.98	8.01	2.69		17.33	21.52

T° Temperature, WS Wind speed, PWD Prevailing wind

collectors to the meteorological conditions for either daytime or nighttime sampling period.

As for WSS sampler, the results indicated that the correlation coefficients order for WSS to wind speed of these ionic species was  $\text{NH}_4^+ > \text{SO}_4^{2-} > \text{NO}_3^-$ . And the correlation coefficients order for WSS to humidity of these ionic species was  $\text{NH}_4^+ > \text{SO}_4^{2-} > \text{NO}_3^-$ . Finally, the correlation coefficients order for WSS to temp of these ionic species was  $\text{NO}_3^- > \text{NH}_4^+ > \text{SO}_4^{2-}$  during daytime sample period.

As for DDP sample, the results indicated that the correlation coefficients order for DDP to wind speed of these ionic species was  $\text{NH}_4^+ > \text{SO}_4^{2-} > \text{NO}_3^-$ . And

the correlation coefficients order for DDP to humidity of these ionic species was  $\text{NH}_4^+ > \text{NO}_3^- > \text{SO}_4^{2-}$ . Finally, the correlation coefficients order for DDP to temp of these ionic species was  $\text{NO}_3^- > \text{SO}_4^{2-} > \text{NH}_4^+$  during daytime sample period.

In addition, the correlation coefficients order for gas deposition flux of these ionic to the wind speed of these ionic species was  $\text{NH}_4^+ > \text{NO}_3^- > \text{SO}_4^{2-}$ . And the correlation coefficients order for gas to humidity of these ionic species was  $\text{NH}_4^+ > \text{NO}_3^- > \text{SO}_4^{2-}$ . Finally, the correlation coefficients order for gas to temp of these ionic species was  $\text{NH}_4^+ > \text{NO}_3^- > \text{SO}_4^{2-}$  during daytime sample period.

**Table 2** Correlation coefficients of ionic species for various deposition collectors to meteorological conditions during daytime or nighttime periods

	Wind speed			Temp (°C)			RH (%)		
	NH <sub>4</sub> <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NH <sub>4</sub> <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	NH <sub>4</sub> <sup>+</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>
Daytime									
WSS	0.0216	0.0012	0.0045	0.1239	0.0089	0.0198	0.2985	0.3578	0.0154
DDP	0.0576	0.0523	0.027	0.1065	0.0339	0.0005	0.139	0.2277	0.0182
WSS-DDP	0.0167	0.0017	0.0002	0.109	0.0011	0.0163	0.2675	0.0045	0.0045
Nighttime									
WSS	0.0118	0.4746	0.5088	0.3882	0.2389	0.185	0.1904	0.2819	0.5606
DDP	0.0757	0.261	0.0215	0.0324	0.1194	0.3371	0.0289	0.0628	0.1065
WSS-DDP	0.0933	0.4455	0.4466	0.3567	0.226	0.4184	0.1564	0.2634	0.6795

As for WSS sampler, the results indicated that the correlation coefficients order for WSS to wind speed of these ionic species was SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup>. And the correlation coefficients order for WSS to humidity of these ionic species was NH<sub>4</sub><sup>+</sup> > NO<sub>3</sub><sup>-</sup> > SO<sub>4</sub><sup>2-</sup>. Finally, the correlation coefficients order for WSS to temp of these ionic species was SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup> during nighttime sample period.

As for DDP sampler, the results indicated that the correlation coefficients order for DDP to wind speed of these ionic species was NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup> > SO<sub>4</sub><sup>2-</sup>. And the correlation coefficients order for DDP to humidity of these ionic species was SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup>. Finally, the correlation coefficients order for DDP to temp of these ionic species was SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup> during nighttime sample period.

In addition, the correlation coefficients order for gas deposition flux of these ionic to the wind speed of these ionic species was SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup>. And the correlation coefficients order for gas to humidity of these ionic species was SO<sub>4</sub><sup>2-</sup> > NH<sub>4</sub><sup>+</sup> > NO<sub>3</sub><sup>-</sup>. Finally, the correlation coefficients order for gas to temp of these ionic species was SO<sub>4</sub><sup>2-</sup> > NO<sub>3</sub><sup>-</sup> > NH<sub>4</sub><sup>+</sup> during nighttime sample period.

Ambient airborne particle range percentage of concentrations for soluble ions

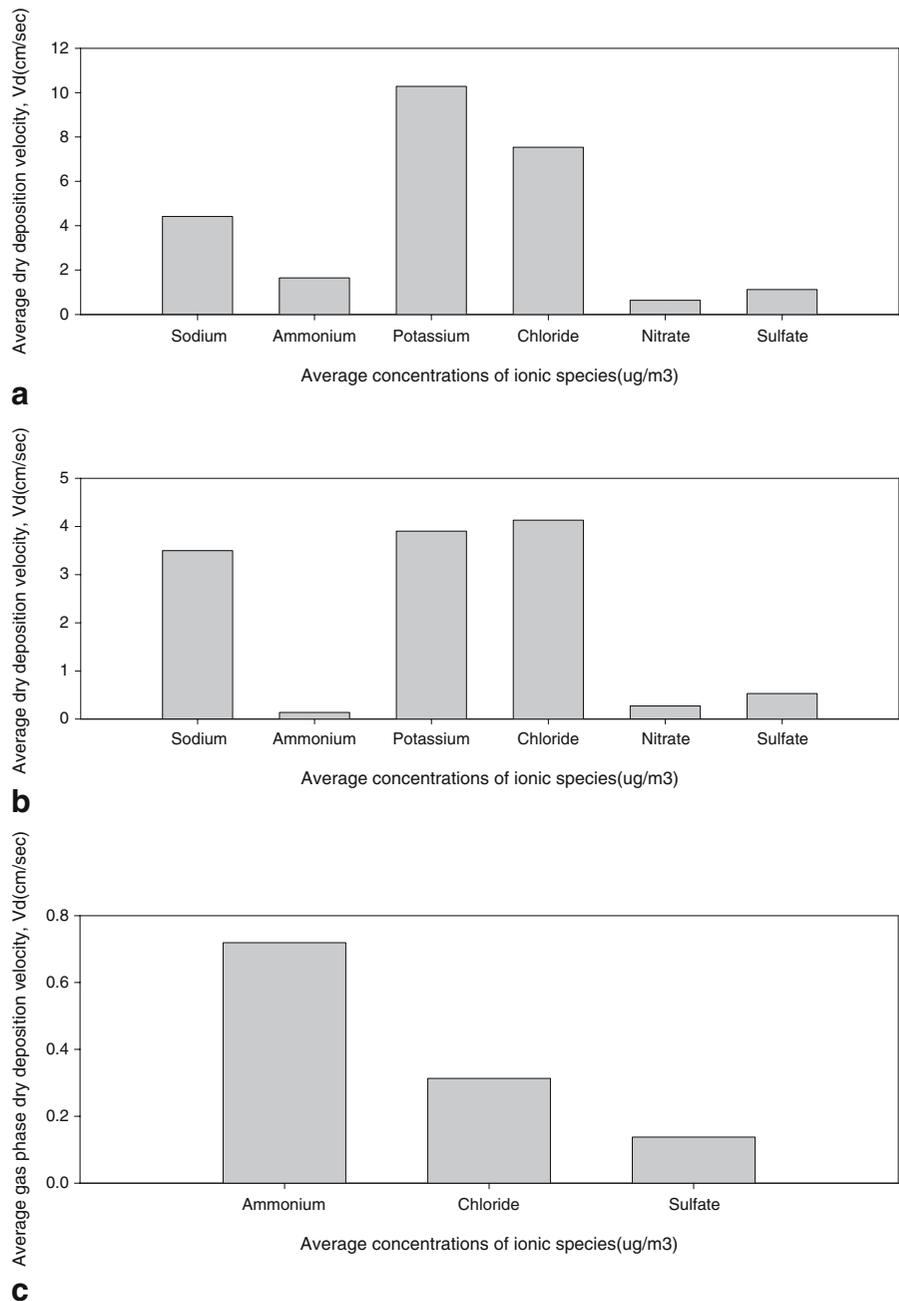
Table 3 shows the average water surface sampler fluxes of ionic species Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup>. The results indicated that the average flux for ionic species Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were 13, 11, 8, 4, 13, 17, 14 and 23%, respectively at the sampling site during August to October of 2006. As for dry deposition flux of ionic species, by using dry deposition plate the results also showed the a average percentage of dry deposition flux for ionic species Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were 21, 2, 7, 2, 13, 20, 13 and 22%, respectively at the sampling site during August to October of 2006.

Table 3 shows the average water surface sampler fluxes of ionic species Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup>. The indicated that the average flux for ionic species Na<sup>+</sup>, NH<sub>4</sub><sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> were 12, 10, 8, 1, 12, 16, 17 and 24%, respectively at the sampling site for daytime during August to October of 2006. As for water surface sampler fluxes of ionic species, the results

**Table 3** Average percentage of ionic species collected by using water surface sampler and dry deposition plate at Shalu sampling site

		Na <sup>+</sup> (%)	NH <sub>4</sub> <sup>+</sup> (%)	K <sup>+</sup> (%)	Mg <sub>2</sub> <sup>+</sup> (%)	Ca <sub>2</sub> <sup>+</sup> (%)	Cl <sup>-</sup> (%)	NO <sub>3</sub> <sup>-</sup> (%)	SO <sub>4</sub> <sup>2-</sup> (%)
All Day	WSS	13	11	8	4	13	17	14	23
	DDP	21	2	7	2	13	20	13	22
Daytime	WSS	12	10	8	1	12	16	17	24
	DDP	22	2	6	1	14	20	14	21
Nighttime	WSS	15	12	9	1	13	19	11	20
	DDP	23	2	7	2	13	19	11	23

**Fig. 3 a, b and c** which represent the average dry deposition velocity of ionic species by using dry deposition plate, water surface sampler and gas phase average dry deposition velocity, respectively



also showed the a average percentage of water surface sampler fluxes for ionic species  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 15, 12, 9, 1, 13, 19, 11 and 20%, respectively at the sampling site for nighttime during August to October of 2006.

As for dry deposition flux of ionic species, by using dry deposition plate indicated that the average flux for ionic species  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,

$\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 22, 2, 6, 1, 14, 20, 14 and 21%, respectively at the sampling site for daytime during August to October of 2006. As for dry deposition flux ionic species, by using dry deposition plate the results showed the a average percentage of dry deposition flux for ionic species  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 23, 2, 7, 2, 13, 19, 11 and 23%, respectively at the sampling site for nighttime during

August to October of 2006. Basically, the average highest fluxes for water surface sampler were  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ , the average highest fluxes for dry deposition flux were  $\text{Cl}^-$ ,  $\text{Na}^+$  and  $\text{SO}_4^{2-}$ .

The study of dry deposition (gas + particle) of ambient air pollutant by using water surface sampler

Figure 3a displayed the results average dry deposition velocity of ionic species collected by using water surface sampler. The results indicated that the average dry deposition velocity for ionic species of  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 4.42, 1.65, 10.29, 7.53, 0.64 and 1.12 cm/s, respectively. The highest three dry deposition velocities of ionic species were  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$ .

The lowest three dry deposition velocity of ionic species by using dry deposition plate were  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ . Figure 3b displayed the results of average dry deposition velocity of ionic species collected by using dry deposition plate. The results indicated that the average dry deposition velocity for ionic species of  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  by using dry deposition plate were 3.49, 0.13, 3.9, 4.1, 0.27 and 0.52 cm/s, respectively. The highest three dry deposition velocities of ionic species were  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$ . The lowest three dry deposition velocity of ionic species by using were  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ .

Figure 3c indicated the gas phase of average dry deposition velocity of these various ionic species. There results of gas phase dry deposition flux which were obtained by using the results of Fig. 3a subtract Fig. 3b. And the gas phase dry deposition velocities for these ionic species were obtained by using the results of gas phase flux divided by the gas phase conc. Of these ionic species which were measured by using R&P Partisol model 2300 Speciation Sample. The results indicated that the average gas phase of  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 0.719, 0.313 and 0.1375 cm/s, respectively.

Basically the average highest three of ionic species by using water surface sampler were  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$ . Basically the average lowest three of ionic species by using water surface sampler were  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ .

Basically the average highest three of ionic species by using dry deposition plate were  $\text{Na}^+$ ,  $\text{K}^+$  and  $\text{Cl}^-$ . Basically the average lowest three of ionic species by using dry deposition plate were  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ .

## Conclusion

The main inclusion in this study was summarized as followed:

1. The results obtained in this study indicated that the ionic species of  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  occupied about average 65~70% ionic species concentrations out of total suspended particulate for daytime during August to October of 2006 at this near highway traffic sampling site in central Taiwan. The results obtained in this study indicated that the ionic species of  $\text{Cl}^-$ ,  $\text{Na}^+$  and  $\text{SO}_4^{2-}$  occupied about average 60~70% ionic species concentrations out of total suspended particulate for nighttime during August to October of 2006 at this near highway traffic sampling site in central Taiwan.
2. The average dry deposition velocity by using water surface sampler (WSS)(gas + particle) for ionic species of  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 4.42, 1.65, 10.29, 7.53, 0.64 and 1.12 cm/s, respectively.
3. The average dry deposition velocity by using dry deposition plate(DDP)(particle) for ionic species of  $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  by using dry deposition plate were 3.49, 0.13, 3.9, 4.1, 0.27 and 0.52 cm/s, respectively.
4. Figure 3c indicated the gas phase of average dry deposition velocity of these various ionic species. There results of gas phase dry deposition flux which were obtained by using the results of Fig. 3a subtract Fig. 3b. And the gas phase dry deposition velocities for these ionic species were obtained by using the results of gas phase flux divided by the gas phase conc. Of these ionic species which were measured by using R&P Partisol model 2300 Speciation Sample. The results indicated that the average gas phase of  $\text{NH}_4^+$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$  were 0.719, 0.313 and 0.1375 cm/s, respectively.

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