Dry deposition of sulfate-containing particulate at the highway intersection, coastal and suburban areas

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Abstract

Sulfate-containing aerosol (SCA) dry deposition at the highway intersection, coastal location, and suburban area in Taiwan were analyzed and compared. Sampling was accomplished with a surrogate surface technique. Samples particles were coated with barium chloride (BaCl\textsubscript{2}) in a vacuum evaporator and then exposed to a relative humidity of 85\% for 2 hours to form distinctive products of SCAs. Treated samples were examined by a scanning electron microscopy. SCA dry deposition fluxes were 10.2, 4.1, 3.4 \(\mu\text{g}/(\text{m}^2/\text{s})\) and nonsulfate-containing aerosol (NSCA) dry deposition fluxes were 23.3, 8.2, 13.5 \(\mu\text{g}/(\text{m}^2/\text{s})\) at the highway intersection, coastal, and suburban areas. At the highway intersection, both SCA and NSCA dry deposition fluxes were much higher than those at the other two sites. The dry deposition of particles was also analyzed with a traditional technique. The number median diameters (NMDs) of SCA were 0.41, 0.82, and 1.2 \(\mu\text{m}\) at the highway intersection, coastal, and suburban sites, respectively. The highway intersection site had a small NMD, which showed that most sulfate-containing deposited aerosols existed in fine diameter range. The mass median diameters (MMDs) of SCA were 8.8, 19.5, and 14.9 \(\mu\text{m}\) at the highway intersection, coastal, and suburban sites, which were much higher than NMDs. Average numbers of SCAs in total particulate were 32.8\%, 33.2\%, and 21.8\% at the highway intersection,
coastal and suburban areas. Most deposited particulates were nonsulfate-containing at the three sampling sites. SCAs less than 10 µm contributed 28.6%, 7.6%, and 7.18% to the total dry deposition at the highway intersection, coastal, and suburban areas, respectively. The contribution of fine particulate was significantly higher at the highway intersection site.

**Keywords:** Sulfate; Dry deposition; Size distribution; Single particle

1. Introduction

Atmospheric deposition occurs in three forms: wet deposition, dry deposition, and cloud/fog impaction (Kim and Allen, 1997; Peters et al., 2002). Dry acid deposition has received increasing attention in recent years because it is believed to be as important as wet acid deposition in acidifying ecosystems (US EPA, 1991; Geigert et al., 1994; Kim and Allen, 1997). Dry deposition is the process by which atmospheric trace chemicals are transferred by air motions and the gravitational force to the surface of the earth. It can account for a large portion of the removal of trace chemicals from the troposphere (Wesely and Hicks, 2000). Many studies have investigated particulate dry deposition in the past decades (McCready, 1986; Allen et al., 1991; Holsen and Noll, 1992; Biryukov, 1998; Zufall et al., 1998; Tai et al., 1999).

Continuous rises in emission of air pollutants have necessitated the development of reliable methods for quantifying atmospheric deposition. Techniques used to estimate dry deposition fluxes include leaf washing techniques, direct micrometeorological methods, throughfall method, and watershed mass balance method. Another method is the application of mathematical modeling to the ambient concentration measurement data to predict dry deposition velocities for various measured particulate concentrations or particulate size distributions to calculate dry deposition flux (Davidson and Wu, 1990; Holsen and Noll, 1992; Pirrone et al., 1995a, b; Kim and Allen, 1997; Saxena et al., 1997). Particulate dry deposition velocity calculation introduces the parameter of “shape factor” (Lin et al., 1994). Goldenberg and Brook (1997) elaborate the effect of particle shape on deposition velocity and define the “shape effect
ratio”. Shape factor and shape effect estimation must be based on the observation of deposited particles for the characterization of atmospheric particulate dry deposition (Tai et al., 1999). However, this analytical approach is limited to the particulates and cannot be used to analyze the trace chemical dry deposition until now.

Thin-film chemical tests have been developed to determine sulfates in individual particulates (Bigg et al., 1974; Ayers, 1976, 1977; Mamane and De Pena, 1978; Mamane and Pueschel, 1980). The application of these techniques has been shown to be useful for obtaining detailed information about individual particulates and their origins (Bigg, 1980; Zhang and Iwasaka, 1999; Zhang et al., 2000). In this study, the approach by vacuum-deposited thin film reaction method is developed to characterize the dry deposition of sulfate-containing aerosol (SCA) at the highway intersection, in coastal zone, and suburban area.

2. Methods

2.1. Sampling device and method

Several techniques of measuring deposited material have been reported in literature. Surrogate surface technique is advantageous to sampling time control, sample extraction and for parameters estimation. It is widely used for air pollution investigation (Davidson et al., 1985). However, there are some limitations for the smooth surface plates. Particles with diameter less than 10 μm do not settle well under the influence of gravity and bounce off and resuspension might occur. The technique employs a smooth surface plate with a sharp leading edge and the plate was mounted on a wind vane (Holsen et al., 1991; Tai et al., 1999). The plate used in this study was similar to those used in wind tunnel studies (McCready, 1986). It was made of polyvinyl chloride (PVC) and was 21.5 cm long, 8 cm wide, and 0.8 cm thick with a sharp leading edge (< 10-degree angle) pointing toward the wind direction. The sharp leading edge and smooth horizontal surface was supposed to cause the minimum airflow disruption and thus provide an estimation of the lower limit estimation of deposition (Davidson et al., 1985; Holsen et al., 1991).
To prevent the bouncing-off and resuspension of particles, a plain surface was further treated as follows: first, a double-sided adhesive tape were affixed to the Mylar strip which was then placed on the plate and held down at the edge with a 0.03 cm thick stainless steel template, which was secured at each end by acrylic slats screwed into the plate (Fig. 1). The size of Mylar strip is 6 cm × 8 cm and an adhesive tape is 4 cm × 8 cm. The strip was cleaned before use with high-purity water (resistance > 10 MΩ) produced by osmosis and demineralization process. The plate was cut out so that it would slide onto a 3-cm diameter rod. Two screws were fastened through the plate to a wind vane, allowing the plate to swing freely into the wind direction. The tapes were conditioned under temperature of 25 ± 3 °C and humidity of 40 ± 5 % for over 24 hours and then weighed before use. They were weighed again after sampling to determine the total mass of the particulates collected. The tapes were then vacuum coated and analyzed by scanning electron microscopy. Duplicate plates were exposed to the atmosphere at suburban site side by side and showed to collect the same mass of total particulate at 95% confidence level statistically. No particulates were observed on the blank tapes.

2.2. Sampling program

Atmospheric particulate dry deposition samples were taken at the highway intersection, in coastal zone, and suburban area in Taichung, Taiwan (Fig. 2). The sampling site representing the highway intersection was the intersection of Guoguang Road and Guochung Road. Guoguang Road is the main motor road connecting Taichung city and Dali city with very heavy traffic. The dry deposition plate was installed on the roof of the underground passage (2 m in height above ground) about 1 m from the road. The sampling site for coastal zone was located inside Gaomei wetland in the western part of Taiwan. It was far from traffics and industrial and commercial activities. The sampler was installed on the roof of a building, which is about 10 m above the ground. The last sampling site was located at Chaoyang University (suburban area). The dry deposition plate was installed on the roof of a building (15 m in height). The
only road leading to school was more than over 500 m from the sampling site. There were little air movement obstructions caused by tall structures around these three sites. At a measurement height of 2 to 10 m above the ground, the plate is much more aerodynamically exposed to atmospheric particulates than surface elements. Therefore aerodynamic and boundary layer resistance are likely to be much smaller than for the surface and the deposition to the plate may in fact be larger than to very smooth surface, such as tarmac. Dry deposition samples were collected on non-raining days from October to December 2001. The major wind direction during sampling period was northerly. Ten sets of data were analyzed for every sampling site. The sampling time (exposure time) for each sample was 24 hours.

2.3. Analysis of particulates on the deposition plate

Collected particulate samples were coated with barium chloride (BaCl₂) in a vacuum evaporator. The pressure of vacuum evaporator was controlled below 10⁻⁶ mmHg. The coated samples were then exposed in a desiccator cabinet to a relative humidity of 85% for 2 hours to allow the sulfate present to react with BaCl₂ to form distinctive products (BaSO₄): a central spherical cap surrounded by one or more rings of small satellite droplets (Liesegang ring) (Bigg et al., 1974; Ayers, 1976, 1977; Mamane and De Pena, 1978; Mamane and Pueschel, 1980). According to the laboratory experiment of Qian et al. (1991), the detection limit of the reagent film for sulfate contained in individual particulates was 10⁻¹⁷ g. The SCAs were identified by scanning electron microscopy (Topcon Model-C50s).

To compare dry deposition velocities calculated from ambient measurements and predicted with a velocity model, Lin et al. (1994) define a volume shape factor \( S_v \) :

\[
S_v = \frac{d_{PA}}{d_e}
\]  

(1)

where \( d_{PA} \) is the projected area and \( d_e \) is the equivalent volume diameter.

The volume shape factor is determined from the count data as follows (Tai et al., 1999):
\[ S_V^3 = \frac{\sum d_{PA}^3}{\sum d_e^3} \]  \hspace{1cm} (2a)

= \frac{\sum \rho_p \left( \frac{\pi}{6} \right) d_{PA}^3}{\sum \rho_p \left( \frac{\pi}{6} \right) d_e^3} \hspace{1cm} (2b)

\[ \sum \rho_p \left( \frac{\pi}{6} \right) d_{PA}^3 \] is the total particulate mass converted from number count data and \[ \sum \rho_p \left( \frac{\pi}{6} \right) d_e^3 \] is the total particulate mass by weighing. Here \[ S_V \] is the average for all particulates deposited on the plate. In this study, a particulate density (\( \rho_p \)) of 1.77 g/cm\(^3\) for fine particulates (diameter \( \leq 2.5 \mu m \)) and 2.64 g/cm\(^3\) for coarse particulates (diameter > 2.5 \mu m) was used (Lewis, 1981; Tai et al., 1999). To relate \( d_e \) to the aerodynamic diameter, \( d_a \), a dynamic shape factor, \( S_D \), is used (Davies, 1979).

\[ d_a = d_e \left( \frac{\rho_p}{\rho_0 S_D} \right)^{1/2} \]  \hspace{1cm} (3)

where \( \rho_0 \) is the unit particulate density in g/cm\(^3\). By substituting \( d_{PA} = S_V d_e \), equation (3) becomes

\[ d_{PA} = S_V \left( \frac{\rho_0 S_D}{\rho_p} \right)^{1/2} d_a \]  \hspace{1cm} (4)

For irregular shape particulates, \( S_D \) can only be obtained by experimental measurement. Adopting the experimental measured \( S_D \) value of 1.41 for dust particles by Davies (1979) and \( S_V \) from the plate data in this study, the relationship between \( d_{PA} \) and \( d_a \) is derived. This relation allows the particulate number count data to be converted to the particulate mass equivalent to the total mass to particulates deposited on the deposition plate.

The deposited particulates were evaluated by an image analysis processing system (SigmaScan\textsuperscript{®} Pro 5.0). Particulates were grouped into 11 successive size ranges of less than 0.17, 0.17-0.31, 0.31-0.52, 0.52-1.0, 1.0-1.8, 1.8-3.2, 3.2-5.6, 5.6-10, 10-24.7, 24.7-36.5, and greater than 36.5 \mu m (Groups 1-11) based on the projected area diameter. The image analysis processing system defined and isolated discrete...
particulates from the background and determined the projected area diameters of the particulate images. At least ten particulates were counted in each size range. The SCA and nonsulfate-containing aerosols (NSCAs) on the collection plate were isolated and their dry deposition fluxes were calculated. For SCA calculation, the Liesegang ring was not included. To ascertain the reproducibility, three samples were randomly selected for recounting. The results showed that the estimated fluxes were the same at 95% confidence level statistically.

3. Results and discussion

3-1 Shape factors of deposited particulates

The shape factor values for the deposited particulates at three different sites are listed in Table 1. For total particulates, the $\bar{S}_V$ values for the highway intersection were 1.82. The result agrees well with the values of 1.89 (Noll et al., 1988) and 1.61 (Lin et al., 1994; Tai et al., 1999) determined in Chicago urban area. The $\bar{S}_V$ values are 1.39, and 1.42 for coastal and suburban areas, respectively. The results also agree well with those determined at nonurban sites (1.18 at Claremond, 1.18 at LA proper, and 1.38 at Argonne by Fang (1989), 1.20 at Wisconsin, 1.14 at Michigan by Tai et al., (1999)). For SCAs, the average $\bar{S}_V$ values are 1.87, 1.25, and 1.24 for the highway intersection, coastal area, and suburban area, respectively. Higher $\bar{S}_V$ values are an indication of greater particulate shape irregularity. The average $\bar{S}_V$ value of SCAs at the highway intersection is significantly higher than those at coastal and suburban areas. This suggests that SCAs at the highway intersections are more irregular than those at coastal and suburban areas. For NSCAs, the $\bar{S}_V$ values were 1.70, 1.45, and 1.55 for the highway intersection, coastal and suburban areas. The similar observation as SCAs, the highway intersection site has the highest $\bar{S}_V$ value. However, the discrepancies in $\bar{S}_V$ values were less than those estimated for the SCAs.
3.2. Dry deposition fluxes

Dry deposition fluxes at three sites are presented in Table 2. SCA dry deposition fluxes are 10.2, 4.1, 3.4 μg/(m²/s) and NSCA dry deposition fluxes are 23.3, 8.2, 13.5 μg/(m²/s) at the highway intersection, coastal, and suburban areas. For the three sampling sites, NSCA dry deposition fluxes are higher than those of SCA statistically at 5% level. At the highway intersection, both SCA and NSCA dry deposition fluxes were much higher than the values at the other two sites.

Traditionally, particulate dry deposition fluxes are calculated from the particulate mass collected divided by the collecting surface area and time. Dry deposition fluxes estimated by this approach are 31.5, 10.9, and 13.5 μg/(m²/s) at the highway intersection, coastal, and suburban areas, which are not different from the values estimated by our method statistically at 5% level (33.5, 12.2, 16.8 μg/(m²/s) at the highway intersection, coastal, and suburban areas). The result shows that particulate dry deposition flux estimated by observing the deposited particulates is comparable to the traditional approach. Noll et al (1998) measured the particulate dry deposition fluxes by the similar technique to what we used here. The result was 3.0 μg/(m²/s) in Chicago urban area. At the same area, the particulate dry deposition flux was 5.28 μg/(m²/s) measured by Lin et al (1994). Two non-urban areas in Wisconsin and Michigan were measured by Tai et al. (1999). The particulate dry deposition fluxes were 1.20 and 1.14 μg/(m²/s), respectively. The dry deposition fluxes were lower than those measured in this study.

3.3. Number and mass size distributions at different sites

Typical number and mass size distributions of deposited particulate at the three sampling sites are shown in Fig. 3. At the highway intersection site, SCA deposition number size distributions have a peak between 0.17 and 0.31 μm in diameter. Based on the SEM detection limit, the smallest size range could peak at smaller sizes. Total particulate deposition number size distribution has a peak between 0.52 and 1.0 μm in diameter. For mass size distributions, SCA and total particulate have peaks at 10.0-24.7 μm and
24.7-36.5µm in diameter, respectively. Number size distribution of deposited particulate has a peak at fine diameter. However, mass size distribution of deposited particulate has a peak at coarse diameter. This is the same for coastal and suburban areas.

The average number and mass median diameters (NMD and MMD) of SCA and total particulate at different sites are presented in Table 3. The NMDs of SCA are 0.41, 0.82, and 1.2 µm at the highway intersection, coastal, and suburban sites. Highway intersection site had small NMD, which shows that most SCAs existed in fine mode. These fine particulates might be the secondary particulate formed from photochemical reactions and/or the particulate emitted from diesel-powered vehicles. The MMDs of SCA were 8.8, 19.5, and 14.9 µm at the highway intersection, coastal, and suburban sites. Coastal area has the highest MMD. Sulfur dioxide may react on the surface of sea-salt particulate and form coarse SCA (Chow, 1992). Sievering et al. (1995) found that heterogeneous oxidation of SO$_2$ by O$_3$ proceeds rapidly in freshly formed coarse sea-salt particulate. Formation of non-sea-salt sulfate by droplet-phase oxidation of SO$_2$ in cloud was also suggested to be a major mechanism of coarse mode non-sea-salt sulfate (Kerminen and Wexler, 1995). The sea salt mode typically peaks between 1 and 10 µm. Although the MMD is the largest at the coastal site, the absolute concentration of SO$_4^{2-}$ in the coarse mode is actually lower than at the highway intersection. A more likely explanation for the large MMD at the coastal site is the much lower concentration combustion-derived SCA < 10 µm at this site.

The NMDs of total particulate were 0.51, 0.73, 1.7 µm, and MMDs are 15.0, 18.7, 17.9 µm at the highway intersection, coastal, and suburban sites (Table 3). The same as SCA, the highway intersection site had the smallest NMD and coastal area had the highest MMD. The geometric standard deviations ($\sigma_g$) were also listed in Table 3. All number size distributions had much higher $\sigma_g$ than mass size distributions at the three sampling sites. The result shows that the number size distributions disperse wider than mass size distribution.
3.4. Cumulative dry deposition fluxes

Typical mass cumulative particulate dry deposition fluxes at various sites are shown in Fig. 4. SCAs less than 10 µm contributed 28.6% (18.2 - 35.1%), 7.6% (4.5 - 10.3%), and 7.1% (4.2 - 9.9%) to total dry deposition of SCA at the highway intersection, coastal, and suburban areas, respectively (Fig 4a). The contribution of fine particulate (here defined as diameter less than 10 µm) was significantly higher at the highway intersection site. One possible reason may be due to the fact that particulate exhausted from diesel-powered vehicles dispersed mainly in submicron range (Panne et al., 1995; Kerminen et al., 1997). Total particulates (sum of SCA and NSCA) less than 10 µm contributed 7.4% (4.4 - 9.3%), 8.6% (5.9 - 10.8%), and 6.3% (4.1 - 9.0%) to total dry deposition at the highway intersection, coastal, and suburban areas, respectively (Fig 4b). The contribution is less for total particulate than for the SCA. The results show that over 90% of dry deposition is in the particulates larger than 10 µm in diameter. The finding compares well with the conclusions of previous studies (Holsen and Noll, 1992; Lin et al., 1994; Tai et al., 1999).

3.5. Percentage of SCA in total particulate

Percentages of SCA in total particulate at various size ranges are shown in Fig. 5. At the highway intersection site, the percentages were 12.5, 18.2, 20.2, 17.9, 7.6, 6.5, 7.8, 5.4, 3.7, 0.13, and 0.13 % for groups 1-11. The size range of 0.31-0.52 µm had most SCAs. At coastal and suburban areas, the highest percentage of SCA appeared at the size ranges of 1.0-1.8 µm (20.2%) and 0.52-1.0 µm (17.6%), respectively. The results show that most SCAs appeared in fine size ranges. Average ratios of SCA to total particles were 32.8%, 33.2%, and 21.8% at the highway intersection, coastal and suburban areas. Most deposited particulates were NSCA at the three sampling sites. The percentage of SCA is lowest at suburban area.
4. Conclusions

This study presents the first investigation of sulfate-containing aerosol (SCA) dry deposition by observing the deposited particulates. The results showed that average shape factor (\( \bar{\overline{S}}_v \)) value of total particulate at the highway intersection is significantly higher than those at coastal and suburban areas, which suggests that SCAs at the highway intersections are more irregular. Dry deposition fluxes estimated by mass of collected particulate divided by the collecting surface area and time are 31.5, 10.9, and 12.5 \( \mu g/(m^2/s) \) at the highway intersection, coastal, and suburban areas, which are comparable to the values estimated by observing the deposited particulate (33.5, 12.2, 16.8 \( \mu g/(m^2/s) \)) at the highway intersection, coastal, and suburban areas. SCA dry deposition fluxes were 10.2, 4.1, 3.4 \( \mu g/(m^2/s) \) and non-sulfate-containing aerosol (NSCA) dry deposition fluxes were 23.3, 8.2, 13.5 \( \mu g/(m^2/s) \) at the highway intersection, coastal, and suburban areas. At the highway intersection, both SCA and NSCA dry deposition fluxes were much higher than the other two sites. The number median diameters (NMDs) of SCA were 0.41, 0.82, and 1.2 \( \mu m \) at the highway intersection, coastal, and suburban sites. Highway intersection site had small NMD, which shows that most SCAs existed in fine diameter range. The mass median diameters (MMDs) of SCA were 8.8, 19.5, and 14.9 \( \mu m \) at the highway intersection, coastal, and suburban sites. Total particulates (sum of SCA and NSCA) less than 10 \( \mu m \) contributed 7.4%, 8.6%, and 6.3% to total dry deposition at the highway intersection, coastal, and suburban areas, respectively. The results show that over 90% of dry deposition was contributed by the particulates larger than 10 \( \mu m \) in diameter. SCAs less than 10 \( \mu m \) contributed 28.6%, 7.6%, and 7.1% to total dry deposition at the highway intersection, coastal, and suburban areas, respectively. The contribution of fine particulate was significantly higher at the highway intersection site. Average number of SCA in total particulate was 32.8%, 33.2%, and 21.8% at the highway intersection, coastal and suburban areas. Most deposited particulates were NSCA at the three sampling sites. The percentage of SCA was lowest at suburban area. This study developed an innovative technique to sample, analyze and characterize the dry deposition.
technique is useful for obtaining detailed information about individual particulates. In addition, the samples for SEM analysis could be collected for less time compared to integrative techniques like filter collection.

References


Table 1  
Average shape factors of deposited particulates ($\bar{S}_V$) (Mean ± standard deviation) (n=10)  

<table>
<thead>
<tr>
<th>Sites</th>
<th>SCAs</th>
<th>NSCAs</th>
<th>Total particulates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highway intersection</td>
<td>1.87 ± 0.22</td>
<td>1.70 ± 0.14</td>
<td>1.82 ± 0.20</td>
</tr>
<tr>
<td>Coastal area</td>
<td>1.25 ± 0.19</td>
<td>1.45 ± 0.25</td>
<td>1.39 ± 0.22</td>
</tr>
<tr>
<td>Suburban area</td>
<td>1.24 ± 0.19</td>
<td>1.55 ± 0.32</td>
<td>1.42 ± 0.25</td>
</tr>
</tbody>
</table>
Table 2

Average dry deposition fluxes at different sites (μg/(m²/s)) (Mean ± standard deviation) (n=10)

<table>
<thead>
<tr>
<th>Sites</th>
<th>Highway intersection</th>
<th>Coastal area</th>
<th>Suburban area</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCA</td>
<td>10.2 ± 1.0</td>
<td>4.1 ± 1.1</td>
<td>3.4 ± 1.0</td>
</tr>
<tr>
<td>NSCA</td>
<td>23.3 ± 4.9</td>
<td>8.2 ± 3.0</td>
<td>13.5 ± 2.8</td>
</tr>
<tr>
<td>Total particulate&lt;sup&gt;a&lt;/sup&gt;</td>
<td>33.5 ± 5.9</td>
<td>12.2 ± 2.5</td>
<td>16.8 ± 3.7</td>
</tr>
<tr>
<td>Total particulate by weighing&lt;sup&gt;b&lt;/sup&gt;</td>
<td>31.5 ± 4.9</td>
<td>10.9 ± 2.1</td>
<td>13.5 ± 3.8</td>
</tr>
</tbody>
</table>

<sup>a</sup> Sum of SCA and NSCA dry deposition.

<sup>b</sup> Deposition fluxes estimated by particulate mass weighted divided by the collecting surface area and time.
Table 3
Average number median diameters (NMDs), mass median diameters (MMDs) and geometric standard deviations of the size distributions ($\sigma_g$) at different sites

<table>
<thead>
<tr>
<th>Sites</th>
<th>SCA</th>
<th>Total particulate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NMD (µm)</td>
<td>$\sigma_g$</td>
</tr>
<tr>
<td>Highway intersection</td>
<td>0.41±0.24</td>
<td>14.6±3.88</td>
</tr>
<tr>
<td>Coastal area</td>
<td>0.82±0.31</td>
<td>12.2±4.04</td>
</tr>
<tr>
<td>Suburban area</td>
<td>1.2±0.42</td>
<td>15.6±4.02</td>
</tr>
</tbody>
</table>
Projected area diameter (µm)

(a) Cumulative deposition flux (%)

(b) Cumulative deposition flux (%)

- Suburban area
- Highway intersection
- Coastal area
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Fig. 1. Deposition plate in this study.

Fig. 2. Location of the sampling sites.

Fig. 3. Number and mass size distributions of deposited particulate. (a) Highway intersection (b) Coastal area (c) Suburban area.

Fig. 4. Cumulative particulate dry deposition fluxes (a) SCA (b) Total particulate.

Fig. 5. Percentage of SCA in total particulate at various size ranges (a) Highway intersection (b) Coastal area (c) Suburban area