Reduction of Atmospheric PM$_{2.5}$ Level by Restricting the Idling Operation of Buses in a Busy Station

Yen-Yi Lee$^1$, Sheng-Lun Lin$^{2,3,*}$, Ria Aniza$^1$, Chung-Shin Yuan$^4$

$^1$ Department of Environmental Engineering, National Cheng Kung University, Tainan City 70101, Taiwan
$^2$ Department of Civil Engineering and Geomatics, Cheng Shiu University, Kaohsiung City 83347, Taiwan
$^3$ Super Micro Mass Research and Technology Center, Cheng Shiu University, Kaohsiung City 83347, Taiwan
$^4$ Institute of Environmental Engineering, National Sun Yat-sen University, Kaohsiung City 80424, Taiwan

ABSTRACT

Fine particulate matter (PM$_{2.5}$) has been found to be harmful when inhaled by people, which has caused enormous health problems. It is found at high levels at public bus stations, where many passengers and workers may be exposed to PM$_{2.5}$ emissions from idling diesel engines. This study evaluated the restriction on idling vehicles as a strategy to control PM$_{2.5}$ levels at bus stations by measuring the PM$_{2.5}$ and the chemical properties at both upwind and exposure sites for comparable data. The sampling took place on weekends and weekdays and before and after the idling restriction was applied. Originally, the exposure site showed a PM$_{2.5}$ level that was 7% higher, non-neutralized nitrate content, anthropogenic metal elements, and higher mobile source contributions, as evaluated by a chemical mass balance model (CMB8.2). After the prohibition on idling heavy-duty diesel vehicles, the PM$_{2.5}$ mass concentrations at the exposure site were reduced to levels comparable to those at the upwind site. Additionally, the nitrate content was reduced in the background. Moreover, the contributions of several anthropogenic metals (Zn, Pb, Mn, Cu, Cr, V, Ni, and Ti) in PM$_{2.5}$ were reduced while those of crustal elements (Na, Mg, Al, K, and Ca) significantly increased after the restriction. Finally, the mobile contribution decreased to only 33.7–34.5%. Consequently, these findings verify that the prohibition policy on idling vehicles works well as a control strategy to manage the PM$_{2.5}$ emissions at local hotspots such as bus stations.

Keywords: PM$_{2.5}$; Idling operation; Source apportionment; Chemical composition; CMB model.

INTRODUCTION

Bus station is basically a place where the buses starting to do both carrying- and dropping- people. Seems like a usual place, but recently it is going a big issue when bus station is listed as one of vehicular emission source, because it is provided some combustion from the engines and contributed the particle emission into the ambient air, while there are hundreds of passenger exposed to those harmful pollutants (Martins et al., 2012). Health issues of exposure particle emission have been consistently associated with air pollution (Kunzli et al., 2000; Navrot et al., 2007; Pope et al., 2013) which the issues are related on potentially increased the human respiratory problem, cancer, cellular dysfunction, high mortality and childbirth disorder (Sharma and Patil, 2016; Zhang et al., 2016; Zhu et al., 2016).

Many previous studies mentioned that the public transportations are the most important anthropogenic emission sources of those particulate and gaseous components in PM$_{2.5}$, including toxic compounds (PAHs) (Liu et al., 2016; Pongpiachan, 2016), nitro-compounds (Allen et al., 1996; da Rocha et al., 2009; Bakeas et al., 2011; Cheruiyot et al., 2015), water soluble ions and metal elements (Zheng et al., 2016), carbonyl-compounds (Rodrigues et al., 2012; Ballesteros et al., 2014; Fujii et al., 2016) and organic/elemental carbon (Ho et al., 2006) in urban areas. Nevertheless, the particle emissions generated by vehicles varied widely, depending on the human activities. Particle emission that gained during rush hour might extremely higher than normal situation, but it was also depending on vehicle operation model. Urban-related particle emission includes fine particle (PM$_{2.5}$), which well-known as particulate matter with an aerodynamic diameter less than 2.5 µm at surrounding bus station and correlation of the human health impact have been studied in several studies (Asmi et al., 2009; Shandilya and Kumar, 2010).

Additionally, the air quality modeling has been employed to investigate the association between various factors-meteorological condition, chemical reaction, and also the emission sources, which contributed to airborne...
PM$_{2.5}$ (Deutsch et al., 2008) in fixed monitoring sites. However, the fixed monitoring stations are not designed to represent micro-scale impacts and the outcome might not be precisely described the local circumstance (Dons et al., 2012). Finally, an exposure prediction models might be used to predict the exposure in certain micro-scale air quality (Long et al., 2001). To verify the prediction results, the mobile sampling system was obtained to monitor the real-time air quality by using bicycle and pedestrian monitoring instrument (Kaur et al., 2005; Hagler et al., 2010; Peters et al., 2013; Pattinson et al., 2014).

On the other hand, there were very few report focusing on the effect of idling condition of vehicle that might happen around the bus station. This is important since a lot of people potentially exposed to local air pollution in such area. A previous study was conducted to the impact of the idling vehicle in surrounding school bus stop. They found that the particle number concentration in surrounding study area was obviously increased and would put people in health-related risk (Zhang et al., 2013).

This research adds some important analyses that discuss about implementation of idling vehicle condition and the mass concentration of PM$_{2.5}$, their chemical compositions, and source apportionments at both exposure and upwind sites. There were two desired sampling periods, including rush and normal hour, to give more information for idling policy analysis that compared before and after implementation.

**METHODOLOGY**

**Research Design**

The bus station selected for monitoring site located in Chiayi City, Taiwan. The station is the main transportation both inter-area in a city and inter-city in southern Taiwan for 12 routes. The surrounding areas of bus station are urban expressway, arterial road, intersection, collector road, local road, multi-commercial buildings, and surface parking lots. The target bus station area has two platforms with outdoor waiting area for passenger. The routes of buses are noticed as the potential emission zone while the outdoor waiting room for passenger is noted as exposure place as shown in Fig. 1. The platform location was surrounded by the building of bus station, which might avoid most effects of the traffic and other emissions from this densely populated city and focus on the regional emission from buses. The configuration of the bus station has two important places, including exposure site and potential emission zone. Two sampling sites are shown in Fig. 1, which also includes the wind-rose plots of two sites measured by a meteorological recording system during sampling period.

The number of buses operated in this station were varied by weekend and weekday. There were 267 buses daily operated to transport the passenger during 6 am to 11 pm (17 hours) on weekend (Friday to Sunday). On the other hand, there were 214 buses daily operated in the station on weekday. Therefore, the effect of various amount of buses inside the station were analyzed by two different sampling conditions, weekend and weekday.

The passenger that daily expose to air pollution surrounding the bus station is unpredictable, then this is not a variable in this research. The condition of idling buses during coming-and leaving-bus station is the main point in this research. The restriction of idling vehicle in bus station before and after implemented are analyzed at exposure site in two situations during weekend and weekday. And this result would be compare with the atmospheric monitoring data parallel collected at upwind site as shown in Fig. 1. Although the fixed sites were reported with less time-spatial sensitivity for studying traffic emissions in previous research, their capability in chemical fingerprint analysis of PM$_{2.5}$ were more reliable than only mass or number concentration by continuous monitoring. For the purpose of source apportionment in such hotspot in a densely populated urban area, chemical composition was important and the fixed site samplings thus took place in the current study.

**Sampling Method for Stationary Site**

Fine particulate matter (PM$_{2.5}$) was monitored simultaneously both upwind and exposure sites at specific time, weekend and weekday, and also in identical condition before and after restriction. The method followed the standard method of NIEA A205 that certified by Environmental Analysis Laboratory (EAL) of Taiwan Environmental Protection Administration (TWEPA) applied in each site. Particulate sampler PQ200 series, BGI was used to collect the sample of PM$_{2.5}$ in two-stage compartment operated in 16.7 L min$^{-1}$ ± 5% low flow rate of ambient air at 1 atm in 24 hours. Every site was applied for parallel two filter packs in, in this sampler the ambient air would be trap on the first compartment, which completed with a very-sharp-cut-cyclones (VSCCs, BGI), to prohibit the coarse particulate matter (aerodynamic diameter > 2.5 µm) going through then other particle diameter would be trap in second stage of sampler, in here PM$_{2.5}$ is collected. To analyze the particle mass, ion and metal content the filter pack was completed with polytetrafluoroethene (PTFE, Teflon®) fiber filter (diameter: 46.25 ± 0.25 mm), and for quantifying the elemental and organic carbon within particle was used quartz fiber filter (diameter: 46.25 ± 0.25 mm).

To determine the mass that collected in the sampler pack, an electronic microbalance (METTLER TOLEDO Model XP2U) was used, with sensitivity ± 1 µg over 24 hours with calibration on 23 ± 1°C and relative humidity at 40 ± 5% in a class-100 clean room. Three times weighing was applied for filter pack before-and after-weigh to get the variance less than 10 µg for each sampler and ensure PM$_{2.5}$ concentration was calculated by subtract the initial mass of final mass then divide to sampling volume (about 24 m$^3$).

**Chemical Composition Analyses**

**Water-Soluble Ions**

All chemical solutions, standard solutions and eluents used in this research was followed EAL NIEA W415 method for water-soluble ionic contents analysis. The target ionic species included anion (Cl$^-$, F$^-$, NO$_3^-$, and SO$_4^{2–}$) and cation (Na$^+$, NH$_4^+$, K$^+$, Mg$^{2+}$, and Cr$^{3+}$). The PTFE filter was shaken with 15 mL ultrapure deionized-water for 30
minutes, then extracted for 90 minutes by using an ultrasonic basin for releasing the water-soluble ion species into the water phase. An ion chromatography (IC), Dionex ICS-1000, USA with ASRS-ULTRA suppressor and equipped with ion Pac AS4A-SC column, was used for anion analysis. The eluent was operated under a low rate of 0.38 mL min$^{-1}$. Additionally, the cations were quantified by a Dionex DX-900, USA, with Ion Pac CS12 column. An eluent of 0.1 M sulfuric acid (H$_2$SO$_4$) in isocratic mode at a flow rate of 0.35 mL min$^{-1}$ with a CSRS-ULTRA suppressor current of 43 mA were used. There are three samples, one blank, one recovery, and one replication sample are added in each sample sequences. The blank samples were set up for two times of method detection limit (MDL), when the recoveries of standard samples were ranged 85–115%, particularly in this research. Finally, the replications of samples were controlled less than 20%.

**Trace Metal Elements**

EAL A305 method was applied for quantifying the metal content in PM$_{2.5}$, including Na, K, Mg, Fe, Al, Zn, Ca, Pb, Mn, V, Cu, Cr, Ni, Ba, Sr, Ti, As, Ga, Sb, Rb, Cd, and Pt. The PTFE filter was used for acid digestion to dissolve the metal into ionic form. A certain amount of nitric acid (HNO$_3$) and hydrochloric acid (HCl) in Teflon® vessels are applied for acid digestion. To identify the sample contents, a series of high-resolution inductively coupled plasma with a mass spectrometer (ICP-MS, Jobin Yvon ULTIMA 2000) was employed. The calibration absolute error of ICP-MS was less than 10%. For the recovery check, a standard sample was added in the analytical sequence each 10-sample and resulted a stable recovery ranged 75–125%. The intensity from instrument for the blank sample were all less than 2 times MDL.

**Carbonaceous Species**

The carbonaceous species (elemental, organic, and total carbons) of PM$_{2.5}$ were measured with an elemental analyzer (EA) (Carlo Erba, Model 1108). Before sampling, the quartz fiber filters had to be pre-heated at 900°C for 1.5 h to expel the potential impurities. This preheating procedure minimized the background carbonaceous species in the quartz fiber filters and matrix, which would interfere with the analytical results, leading to an overestimation of the carbonaceous
species of PM$_{2.5}$. The elemental analyzer was operated using the procedure of oxidation at 1020°C and that of reduction at 500°C, with continuous heating for 15 min. Additionally, one eight of the quartz fiber filters was heated in advance by hot nitrogen gas (340–345°C) for 30 min to expel the organic carbon (OC) fraction, after which the amount of elemental carbon (EC) was determined. Another one eighth of the quartz fiber filters was analyzed without heating, and the carbonaceous species thus characterized as total carbon (TC). The amount of organic carbon was then estimated by subtracting the elemental carbon from total carbonaceous species. Although the most widely used method, thermal analysis, was used to determine the carbonaceous species in ambient aerosols, a charring formation error from sample preheating was not considered for correction, and this artifact might cause in the overestimation of EC and the underestimation of OC.

**Chemical Mass Balance Receptor Model (CMB)**

The contribution of numerous air pollution source in this research is employed the chemical mass balance (CMB) model, a receptor model that able to evaluate the possible sources depending on the chemical fingerprints of each atmospheric PM$_{2.5}$ sample. By using a matrix linear equation, the CMB model expressed the chemical components that might be contained in PM$_{2.5}$ by summing the product of compositions and source contributions. Previous studies claimed the possible sources and its properties might be less than the number of chemical compositions and source contributions. Previous studies claimed the possible sources and its properties might be less than the number of species (Watson et al., 1994; Schauer, 2005). The mass balance is given as following Eq. (1):

\[
C_i = \sum_{j=1}^{n} a_{ij} s_j, \quad i = 1, 2, \ldots, n
\]

(1)

where \(C_i\) is the concentration of species \((i\) measured at the receptor site in \(\mu g\ m^{-3}\)), \(a_{ij}\) is the mass fraction of species \((i\) in the profile of the source \(j\)) ; \(n\) is the number of species; \(s_j\) is the mass concentration at the receptor site of overall species assigned to the source \(j\) (\(\mu g\ m^{-3}\)).

Notably, there are several assumptions for CMB model given by Watson: (1) sampling duration is in steady rate, (2) inter-chemical reaction is negligible, (3) all of possible sources have been identified, (4) the number of source is less than the number of chemical species, (5) the sources profile are independently linear, (6) normally distributed would be occur if any ambiguities happen (Watson et al., 1994).

**RESULT AND DISCUSSION**

**Atmospheric PM$_{2.5}$ Mass Concentration Level around Bus Station**

The PM$_{2.5}$ levels at upwind and exposure sites during weekend and weekday were presented in Fig. 2 simultaneously. The 24 hour-PM$_{2.5}$ concentrations were all higher than the standard of WHO guideline (25 \(\mu g\ m^{-3}\)) no matter if the idling restriction policy was applied since there were other emission sources contribute to the background levels of PM$_{2.5}$ around this densely populated city. Before the idling restriction, the PM$_{2.5}$ concentration around bus station on weekend did not show higher value than that on weekday, even there were more buses operated on weekend. This is because of that the time variation could be strongly affected by different meteorological conditions, other emission sources, and long-term transport. Therefore, the comparison of upwind and exposure sample simultaneously collected during the sample environmental condition could illustrate the change of PM$_{2.5}$ level more clearly. The PM$_{2.5}$ concentration was 27.2 and 25.4 \(\mu g\ m^{-3}\) at the exposure and upwind sites, respectively, on weekend. The PM$_{2.5}$ increased 7% from background to the exposure area, representing the potential of bus emission on PM$_{2.5}$ level. However, it told a different story in weekday, when the exposure site had no significantly increase of PM$_{2.5}$ level (31.0 \(\mu g\ m^{-3}\)) from that of upwind site (31.4 \(\mu g\ m^{-3}\)). The less bus activity might be the reason which inhibited that local effect.

Moreover, the exposure and upwind sites reported 50.7 and 51.2 \(\mu g\ m^{-3}\) of PM$_{2.5}$, on weekend, and 32.9 and 32.7 \(\mu g\ m^{-3}\) on weekday, respectively, after the idling operation was prohibited (as shown in Fig. 2). The absolute concentrations at upwind and downwind sites after traffic restriction were much higher than those before the policy applied, which could be resulted from the lower temperature and boundary condition during later sampling period (in autumn), comparing with the sampling period in summer for unrestricted cases. The increase of PM$_{2.5}$ at the exposure site from upwind site no longer existed on weekend. This phenomenon could be resulted from the effective emission control of idling heavy-duty diesel engine and could be supported by that the carbonaceous species in the PM$_{2.5}$ did not show significant difference between two sites in weekend even with higher amount of bus operation in the station. Meanwhile, the differences between upwind and exposure site could also not be found on weekday after vehicle operation control. The variation of PM$_{2.5}$ concentrations between upwind and exposure sites in several conditions are mentioned in previous studies. There were many possibilities made local concentration of PM$_{2.5}$ unstable, including the type of bus engine, emission frequency, and convection condition. The diesel engines have been shown to emit higher level of particulate emission (Wayne et al., 2004; Bitterman and Hess, 2008).

**Ion Compositions of Atmospheric PM$_{2.5}$**

Water soluble ions which usually occupied one-third part of the particulate matter mass is also found in this research as the major components in fine particulate matter (PM$_{2.5}$) (Penner et al., 1992; Andrews et al., 2000). Ion compositions within PM$_{2.5}$ in surrounding bus station is served as graphical illustration in Fig. 3. There are nine various ions that measured in PM$_{2.5}$ and followed the mass content order as SO$_{4}^{2-}$, NH$_{4}^{+}$, NO$_{3}^{-}$, Cl$^-$, Na$^+$, Ca$^{2+}$, K$^+$, Mg$^{2+}$, and F$^-$. The high level of ions Ca$^{2+}$ and K$^+$ within fine particulate matter might be basically contributed from soil dust dispersal (Mkoma et al., 2014), when K$^+$ could and also be important tracer for biomass burning (Chow, 1995), biofuel combustion, and biomass burning (Liu et al., 2000; DeBell et al., 2004; Hsu et al., 2009). There were other
Fig. 2. Atmospheric PM$_{2.5}$ mass concentrations and major chemical compositions around bus station (A) before and (B) after the idling restriction.

Before idling restriction was applied, the fractions of SO$_4^{2-}$, NH$_4^+$, and NO$_3^-$ were stood for 54.6, 22.5%, and 15.5% of total ion contents, respectively at upwind site on weekend, while the fractions at exposure site were 54.6, 22.3, and 15.5%, respectively (as shown in Fig. 3(A)). The results shown no significant difference of major fine particle-bounded ions between background and exposure sites on rush weekend. On weekday, three major ions stood for 54.6, 22.2%, and 15.5%, respectively in upwind site, which were very similar to those on weekend. However, the NO$_3^-$ content in total ions increased about 3.1% (15.5 → 18.6%) from upwind to exposure site, while SO$_4^{2-}$ and NH$_4^+$ kept in the similar fractions (53.5 and 22.1%, respectively) to the upwind site. The trend of high concentration of nitrite ion (NO$_3^-$) within fine particulate matter PM$_{2.5}$ was similar with previous studies that claimed the heavy traffic especially diesel vehicles tend to emit NOx and further oxidized to form NO$_3^-$ in the air (Chang et al., 2013; Peters et al., 2013; Tseng et al., 2016). Moreover, the semi-close geometry of the potential emission area inside the bus station could provide a canyon effect to accumulate the NO$_3^-$, NH$_4^+$, and other pollutants for a longer time to form the NO$_3^-$ contents (Jin et al., 2017). Therefore, NO$_3^-$ might play a big role within PM$_{2.5}$ on potential emission area and needed to be inhibited by source restriction. Moreover for the high level of sulfate ion (SO$_4^{2-}$) in PM$_{2.5}$ is emission.
which coming from the fuel combustion or undergoes from conversion of gas to particle phase from SO₂ (Mkoma et al., 2014); however, the local emission inside the bus station shown no obviously increase from the upwind site.

After the idling restriction was applied, the fractions of SO₄²⁻, NH₄⁺, and NO₃⁻ were stood for 45.2, 22.7%, and 24.1% of total ion contents, respectively in upwind site on weekend, while the fractions at exposure site were 47.1, 26.3, and 16.7%, respectively (as shown in Fig. 3(B)). For weekday samples, three major ions stood for 49.4, 21.2%, and 19.6%, respectively at upwind site, when they stood for 50.9, 24.9, and 12.4%, respectively, at the exposure site. Interestingly, both SO₄²⁻ and NH₄⁺ contents increased from the upwind to exposure (+1.9 and +3.6% on weekend; +1.5 and +3.7% on weekday), when NO₃⁻ significantly reduced 7.4 and 7.2% in tow conditions. This observation might support the reductions of NOx emission from the idling buses and further reduce the nitrate formation even the NH₄⁺ was rich by canyon accumulation inside the station.

The sulfur oxidation ratio (SOR) and nitrogen oxidation ratio (NOR) are two important value in neutralizing processes towards particulate matter to ambient air (Tseng et al., 2016). The SOR and NOR are derived as following equations, respectively:

**Sulfur Oxidation Ratio (SOR)**

$$\text{SOR} = \frac{nss \cdot SO_{4}^{2-}}{nss \cdot SO_{4}^{2-} + SO_2} \quad (2)$$

When $nss \cdot SO_{4}^{2-}$ stands for the concentration for non-seasalt SO₄²⁻ in ambient air (µg m⁻³); $nss \cdot SO_{4}^{2-} = SO_{4}^{2-} - 0.251 \times Na^{+}$; SO₂ represents the concentration of SO₂ in gaseous phase (µg m⁻³).

**Nitrogen Oxidation Ratio (NOR)**

$$\text{NOR} = \frac{NO_{3}^{-}}{NO_{3}^{-} + NO_x} \quad (3)$$

When $NO_{3}^{-}$ stands the concentration for NO₃⁻ in particulate phase (µg m⁻³); NOₓ is the concentration for NO₂ in gaseous phase (µg m⁻³).
Before restriction, SOR were 0.469 and 0.451 at the upwind and exposure sites, respectively, on weekend, while NOR were 0.089 and 0.084, respectively (as shown in Table 1). Additionally, SOR value were 0.537 and 0.493 at the upwind and exposure sites, respectively, on weekday, then NOR value were 0.088 and 0.090, respectively. Moreover, after restriction applied SOR were 0.463 and 0.451 at the upwind and exposure sites, respectively, on weekend, while NOR were 0.108 and 0.071, respectively. Additionally, SOR value were 0.533 and 0.534 at the upwind and exposure sites, respectively, on weekday, then NOR value were 0.067 and 0.042, respectively. The values of SOR all reduced in from upwind to exposure site no matter on weekend/weekday or before/after idling restriction, indicating the secondary aerosol tended to reduce inside the station. The above phenomenon might be resulted from the bus station building act as a shelter to prevent the $SO_4^{2-}$ and NH$_4^+$ coming by the long-range transport. However, NOR shown no significant reduction from upwind to the exposure area, since there were local NO$_x$ emissions provided by the idling activities in southern Taiwan. However, the J values were less than 1.0 on both upwind and exposure sites before restriction, indicating that nitrates were not all balanced by NH$_4^+$. The above observation also indicated that the PM$_{2.5}$ level could be again increase if more NH$_4^+$ were provided by transport from nearby area. After the idling restriction, the NO$_3^-$ contents were reduced at exposure site and most of them were neutralized by NH$_4^+$ to increase the J values to that higher than 1.0. The reduction of NO$_3^-$ might be the more effective way to control the secondary PM$_{2.5}$ level.

**Metal Elements and Carbonaceous Species in PM$_{2.5}$ around Studying Area**

**Metal Elements**

Several metal elements in PM$_{2.5}$ were considered as the characteristic components of the emission sources, such as industrial exhaust, open burning, sea salt suspension, fuel combustion, and soil dust particle (Pipalatkar et al., 2014; Tseng et al., 2016). There were 22 of them analyzed in this study and illustrated in other order of their contributions (%) of total metal components as Figs. 5 and 6. The dominant metal contents at both site on all condition were Na, K, Mg, Fe, Al, and Ca. The dominant species within PM$_{2.5}$ before and after restriction were explained as some natural phenomenon. Previous studies mentioned element Ca and K are included of alkaline earth metal and alkali metal which usually presents in soil/ mineral dust dispersal or biomass burning (Mkombo et al., 2014), also trace metal element for Na is possible from sea salt spray (Pipalatkar et al., 2014; Tseng et al., 2016).

Several harmful metal compositions could be emitted from human activities surrounding the bus station, especially Pb, Zn, Ni, and V could be emitted from the vehicles on both weekend and weekday. Notably, the different metal distributions were observed after idling restriction was applied. The anthropogenic species, especially Zn, Pb, Mn, Cu, Cr, V, Ni, and Ti, in PM$_{2.5}$ were reduced, when the crustal element (Na, Mg, Al, K, and Ca) were much increased.

<table>
<thead>
<tr>
<th>Sampling Sites</th>
<th>Site Properties</th>
<th>Condition</th>
<th>SOR</th>
<th>NOR</th>
<th>References</th>
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<td>Before idling restriction</td>
<td>Weekend</td>
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<td>0.469</td>
<td>0.089</td>
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<tr>
<td></td>
<td></td>
<td>Exposure</td>
<td>0.451</td>
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<td>Upwind</td>
<td>0.537</td>
<td>0.088</td>
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<td>Exposure</td>
<td>0.534</td>
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Table 1. Sulfate and nitrate conversions around the bus station and other reported places.
Fig. 4. I and J values of the atmospheric PM$_{2.5}$ around bus station (A) before and (B) after the restriction of vehicle idling operation.

(as shown in Fig. 6). The reduction of PM$_{2.5}$-bounded metal anthropogenic emission sources again supported the effective control of diesel vehicle from idling operation.

**Carbonaceous Species**

Carbonaceous species concentrations in this research is shown in Table 2. One type of carbonaceous species is elemental carbon (EC), also known as Black Carbon (BC). It has a graphitic-like structure and is black in color, which is reported to be a significant contributor to radiative-heating of the atmosphere. Another one was called organic carbon (OC), which was emitted along with EC, influenced the scattering phenomenon, and had a cooling effect on the atmosphere (IPCC, 2001; Menon et al., 2002; Meehl et al., 2008; Jin et al., 2016). Most of EC was considered as a primary pollutant, which emitted directly during the incomplete combustion of fossil and biomass carbonaceous fuels. In contrast with EC, OC had both primary and secondary aerosol properties and formation pathway. Primary OC was formed during incompletely combustion or several mechanical processes, including associated with plant spores and pollen, vegetation debris, tire rubber, and soil organic matter, produced basically coarse primary organic aerosol particles (Hildemann et al., 1994; Tao et al., 2017). OC also had the secondary origin from gas-to-particle conversion of volatile organic compounds in the atmosphere, either as result of the condensation of low pressure volatile organic compounds, or from physical and chemical adsorption of gaseous species on aerosol particle surfaces. The purpose of quantify the secondary organic carbon is to understand how well the method could be reduce the aim object since reduction of direct emission only effects primary particulate carbon constituents (Ligocki and Pankow, 1989; Pandis et al., 1992; Khan et al., 2017).

Before restriction, the OC/EC were 2.14 and 2.08 at upwind and exposure site, respectively, on weekend, while those were 2.11 and 2.26, respectively, on weekday. On the other hand, the value of OC/EC ratio were 2.18 and 2.14 at upwind and exposure site, respectively, on weekend after restriction was applied. Finally, the OC/EC reported as 2.14 and 2.26, respectively, on weekday. Those ratios could be used to identified in some specific activities, such as ~0.39 for fossil fuel combustion (Wang et al., 2006) and 9.4–21.6 for biomass burning (Alves et al., 2011; Vicente et
Fig. 5. Metal element compositions of PM$_{2.5}$ around bus station on (A) weekend and (B) weekday before the restriction of vehicle idling operation.

Additionally, the previous studies reported that if the OC/EC ratio in PM$_{2.5}$ was higher than 2.2, the organic aerosol could be potentially generated from the secondary carbonaceous component (Turpin and Huntzicker, 1995). The OC/EC ratios observed in this study were all at the critical value between primary and secondary aerosol, meaning that the carbonaceous species in the station were complicated. Additionally, the minimum OC/EC ratio (2.08) in this study could be used to find the secondary organic carbon (SOC$_{min}$/OC ratio) by method published in the previous study (Zhang et al., 2012; Huang et al., 2014). The equation of the SOC fraction in total OC, which was used either in urban, rural, and coastal area, was as follows.

$$SOC = OC_{total} - \frac{OC}{EC}_{min} \times EC$$  \hspace{1cm} (6)

Before idling restriction, the SOC$_{min}$/OC were 3 and 0.2% at upwind and exposure, respectively, on weekend, while they were 1.3 and 7.8%, respectively, on weekday. Furthermore, the SOC$_{min}$/OC ratios were 4.7 and 3.0%, respectively, on weekend and 3.0 and 7.8%, respectively, on weekday after restriction. These values displayed certainly low fractions in secondary organic carbons, while these monitoring data is also corresponding with previous research that have been done in Chiayi area, which is obtained seasonal fraction SOC minimum to OC in 4–9% in spring, 1–11% in summer, 3–12% in fall, and 1–8% in winter (Tseng et al., 2016). Additionally, this phenomenon also could be contributed by the high value of EC content, that as well-known as black carbon and emitted from local traffic, such as idling buses.

**PM$_{2.5}$ Source Apportionment**

CMB model analysis have been utilized to perform the calibrating of the contribution from air pollution sources by getting analyses of three object including ions, metal and carbon fingerprints. The sources profile referred to our previous studies (Hsu et al., 2016; Lu et al., 2016; Tseng et al., 2016). There were five major sources, including mobiles (MO), petrochemical industry (PI), secondary sulfate, secondary nitrate, and soil re-suspension induced in current...
Fig. 6. Metal element compositions of PM$_{2.5}$ around bus station on (A) weekend and (B) weekday after the restriction of vehicle idling operation.

Before restriction, the MO contribution increased from 36.1% at upwind to 39.7% at exposure site on weekend, while they increased from 36.9 to 38.1% at two sites on weekday (as shown in Fig. 7). The above results showed 3.6% of MO contribution increases on weekend and 1.2% increases on weekday. This circumstance might be resulted from the local emissions of idling buses, which produced heavily primary black carbon and soot and subsequently reduced the OC contribution (Turpin and Huntzicker, 1995; Chen et al., 2017). On the contrary, the MO contribution were 33.7–34.5% at the exposure sites, representing 1.7–1.8% reduction from those at the upwind sites (35.5–36.2%) after the idling restriction around the bus station. However, the contributions of secondary sulfate, nitrate, as well as soil suspension were not affected by the traffic control. Nevertheless, the mobile contribution to the atmospheric PM$_{2.5}$ after idling restriction were still high, which could be resulted from the international or inter county transport and might hard to be completely avoided. Therefore, the restriction then became the most important and effective to both control the local PM$_{2.5}$ increases and further reduce the potential secondary PM$_{2.5}$ formation in the downwind area to provide a healthier environment for passenger and worker in the bus station.

CONCLUSION

This study focused on the local atmospheric PM characteristics around a bus station in a densely populated city. PM conditions were checked before and after a restriction on idling vehicles was applied. Before the restriction, the level of PM$_{2.5}$ was 7% higher in the exposure area than the background, representing potential bus emissions on the local scale. After the restriction, the PM$_{2.5}$ level at the exposure site was comparable to that of the upwind site, indicating that less bus activity might account for the decrease. The major components within the PM$_{2.5}$ were water soluble ions, including SO$_4^{2-}$, NH$_4^+$, and NO$_3^-$, ...
Table 2. Secondary organic carbon (SOC) around the bus station and other reported places.

<table>
<thead>
<tr>
<th>Sampling Sites</th>
<th>Site Properties</th>
<th>Condition</th>
<th>Carbonaceous Species</th>
<th>SOC$_{mi}/$OC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before idling restriction</td>
<td>Weekend Upwind</td>
<td>EC: 1.22 µg m$^{-3}$ OC: 2.61 µg m$^{-3}$ OC/EC: 2.14 Exposure EC: 1.31 µg m$^{-3}$ OC: 2.73 µg m$^{-3}$ OC/EC: 2.08</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weekday Upwind</td>
<td>EC: 1.57 µg m$^{-3}$ OC: 3.31 µg m$^{-3}$ OC/EC: 2.11 Exposure EC: 1.44 µg m$^{-3}$ OC: 3.25 µg m$^{-3}$ OC/EC: 2.26</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>After idling restriction</td>
<td>Weekend Upwind</td>
<td>EC: 2.67 µg m$^{-3}$ OC: 5.83 µg m$^{-3}$ OC/EC: 2.18 Exposure EC: 2.71 µg m$^{-3}$ OC: 5.81 µg m$^{-3}$ OC/EC: 2.14</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Weekday Upwind</td>
<td>EC: 1.66 µg m$^{-3}$ OC: 3.56 µg m$^{-3}$ OC/EC: 2.14 Exposure EC: 1.76 µg m$^{-3}$ OC: 3.97 µg m$^{-3}$ OC/EC: 2.26</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 7. Source contribution evaluated by CMB model around bus station before/after the restriction at rush and normal hour of vehicle idling operation.

and NO$_3^-$ was found to be reduced at the exposure site after idling was prohibited. Additionally, I and J indexes indicated that controlling NO$_x$ (or NO$_3^-$) was more effective in inhibiting the PM level in the local area. Moreover, the contributions of several anthropogenic metals (Zn, Pb, Mn, Cu, Cr, V, Ni, and Ti) in PM$_{2.5}$ were reduced, when the crustal element (Na, Mg, Al, K, and Ca) were much increased after restriction. Before the restriction, the contributions of mobile sources were 1.2–3.6% higher at the exposure site than the upwind site; after the restriction, they decreased by 1.7–1.8% around the bus station. Hence, idling restrictions on vehicles should be applied to prevent adverse effects from fine particulate matter, especially at high exposure sites such as bus stations.

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