Chapter 1

Introduction

The emission of anthropogenic air pollutants in north-eastern Asia was increasing drastically in the past decade (Lee *et al.*, 2001). Concentrations of air pollutants varied with meteorological conditions and pollutant emission level (Lu, 2002). Ambient weather conditions such as air temperature, relative humidity and short wave radiation can also influence chemical reactions leading to secondary aerosol formation (Marcazzan *et al.*, 2001). Larger particles are greatly affected by gravity and fine particles are more affected by diffusion (Chan and Kwok, 2000).

Secondary sulfate, wood combustion, diesel exhaust, secondary ammonium, secondary nitrate, meat cooking, gasoline-powered motor vehicle exhaust, and road dust were responsible for the main components of fine particulate ($PM_{2.5}$) concentrations (Kleeman and Cass, 2001; Schauer *et al.*, 2002; Zheng *et al.*, 2002). From viewpoint of source chemical composition of the pollutants, compounds should be considered as tracers only if they occur for all reasonable atmospheric conditions (Fine *et al.*, 2002). The potential $PM_{2.5}$ sources involve large economic and social consequences when emission controls are considered (Kleeman and Cass, 2001).

In addition to traffic source, more vehicles are on the main traffic roads in recent decades. Motor vehicle exhaust has been ranked as one of the most important sources of fine airborne particulates (Nolte *et al.*, 2002). These fine and ultrafine aerosol particles are often transported for long distances, and can reach and penetrate into the lung. Airborne particles are important carriers of metals, certain of which possess toxic properties and commonly are present in excess of natural levels (Sternbeck *et al.*, 2002; Cincinelli *et al.*, 2003). Various types and different operating modes such as idling, stopping, accelerating, and decelerating of vehicles along with a higher density of vehicles at traffic junctions lead to a pollution source problem at traffic junctions (Kumar *et al.*, 2001).

Since traffic exhaust is the main contributor of finer particulates around traffic areas, the influence of ambient particulate and chemical concentration variations of the daytime and nighttime period are of great concern. In order to understand the concentration variations of fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particulates during daytime and nighttime at the traffic junctions in front of Hungkuang University in Taichung, a versatile air pollutant system (VAPS) was used to collected samples for analyses of the above pollutants and their chemical components in this study.

Chapter 2

Literature Review

2.1 Particle Matter

PM_{10} are associated with fine particle ($PM_{2.5}$) and coarse particle ($PM_{2.5-10}$). Epidemiological studies conducted in several countries have shown consistent associations of exposure to ambient particulates with adverse health effects including increased mortality, hospitalization for respiratory or cardiovascular disease, and respiratory symptoms and decreased lung function (El-Fadel and Massoud, 2000; Wang *et al.*, 2002). Besides, PM_{10} has been widely studied to assess and regulate air quality in many countries (Cincinelli *et al.*, 2003; Salvador *et al.*, 2004). The sources, characteristics and potential health effects of coarse particulates were different from those for fine or ultrafine particulates. In Taiwan, PM_{10} is one of major pollutant indexes to estimate the air quality (ROC EPA, 2003). Particulate matter has been noted for its potential adverse health impact in recent decades. Certain toxic compounds which in excess of natural levels were carried by airborne particles (Sternbeck *et al.*, 2002). Motor vehicle emissions, fuel combustion from industrial facilities and construction are major sources of particle pollution such as PM_{10} in Taiwan (Chen *et al.*, 1999). Geological material such as construction, road and soil dusts are predominantly sources of coarse particulates that contributed to constitute about 50% of PM_{10} (Quiterio *et al.*, 2004).

In recent years, Asian dust (AD) or yellow sand which occurs in

Inner Mongolia plateau reduce visibility and harm the respiratory system of many Asian people. Spring and April have been the most abundant occurrence season and months of AD events in Korea (Lee *et al.*, 2004). Funasaka *et al.* (2003) indicated that fine particulate may spread over a wide ranging area while coarse particulates might affect by local situation. Chan and Kwok (2000) indicated the larger sized particles are greatly affected by gravity and fine particles are more affected by diffusion. The transportation mechanism for long-range transport of accumulation mode material, sources are likely to have included (a) road transport, (b) industrial emissions, (c) biogenic particles, and (d) marine aerosols containing trace metals (Allen *et al.*, 2001). In Europe, people also experience a nuisance called dust plumes originated in the Sahara desert (Salvador *et al.*, 2004).

2.2 Metallic Elements

Many researchers were interested in the distributions of particle matters and their chemical properties at different regions like urban, suburban, rural and industrial zones. The concentrations and size distributions of trace metals are governed by the nature of emissions to the atmosphere, as well as by rates of wet and dry deposition, cloud processing, exchange of air between the boundary layer and the free troposphere and chemical transformations (Allen *et al.*, 2001). Table A-1 shows the basic characteristics of selective metallic elements.

Most air pollution/source apportionment studies determine total elemental concentrations in airborne particulate matter (Voutsa and

Samara, 2002). Urban populations are exposed to metals in suspended particles and these are often well above natural background levels owing to anthropogenic processes (Espinosa *et al*., 2001). In Taipei aerosol, fossil fuel utilization, such as vehicular exhaust and lubricant residues, is an important contributor (Yang and Wang, 2002). The increase of atmospheric anthropogenic emissions of heavy metals is particularly damaging in rural areas (Ragosta *et al*., 2002). When this results in elevated metal concentrations, it can pose a serious risk to human health (Espinosa *et al*., 2002). Many investigations on heavy metals that were regulated by law, such as Pb, Cd and Cr, have been made, regarding with their formation, enrichment in different size particles, removal by absorption and adsorption, reaction and so on. Combustion of waste and fuel generates particle matter which consists of inorganic matter including metal and unburned carbon mainly as soot (Yoo *et al*., 2002). Average total suspended particulates (TSP) concentrations decrease from the urban and industrial zone to the residential area. The same behavior is observed for Pb, Zn, and Cd, but not for Cu, which has a relatively short residential time (Morawska *et al*., 2001).

2.3 Metallic Profiles for Emission Source

Metallic element profiles for sources of relevance in other studies were listed in Table 2.3-1. The following metallic elements have been identified as markers for various sources in atmosphere: soil and resuspended dust – Ca, Mg, Al, Si, Fe and Mn; vehicular emission – Cr, Pb, Cu, Zn, Cd, Sb, Br, Fe and Ba; Industrial process – Mn, Zn and K;

Incinerator – K, Zn and Pb; sea salt – Na, Ca, Mg and K; coal combustion – Cr; Metal industry – Fe, Mn and Pb; oil combustion – Ni and V; Construction – Al, Fe, Si, Mn and Ti. The metallic element profiles for stationary sources including soil and resuspended dust, vehicular emission, industrial process, incinerator, sea salt, coal combustion, metal industry, oil combustion and construction sites (Allen *et al*., 2001; Conner *et al*., 2001; Espinosa *et al*., 2001; Kumar *et al*., 2001; Marcazzn *et al*., 2001; Chao and Wong, 2002; Gao *et al*., 2002; De Miranda *et al*., 2002; Sternbeck *et al*., 2002; Funasaka *et al*., 2003; Lee and Hills, 2003; Salvador *et al*., 2004; Shu *et al*., 2001).

Table 2.3-1

Indicatory metallic elements for various major sources

Source	Predominant species	Reference
Soil and Resuspended Dust	Ca, Mg, Al, Si, Fe and Mn	Allen *et al.*, 2001 Kumar *et al.*, 2001 Marcazzan *et al.*, 2001 Chao and Wong, 2002 Sternbeck *et al.*, 2002 Lee and Hills, 2003 Salvador *et al.*, 2004
Vehicular Emission	Cr, Pb, Cu, Zn, Cd, Sb, Br, Fe and Ba	Kumar *et al.*, 2001 Marcazzan *et al.*, 2001 Shu *et al.*, 2001 Chao and Wong, 2002 Sternbeck *et al.*, 2002 Funasaka *et al.*, 2003 Salvador *et al.*, 2004
Industrial Process	Mn, Zn and K	Allen *et al.*, 2001 Marcazzan *et al.*, 2001
Incinerator	K, Zn and Pb	De Miranda *et al.*, 2002 Funasaka *et al.*, 2003
Sea Salt	Na, Ca, Mg, and K	Conner *et al.*, 2001 Salvador *et al.*, 2004
Coal Combustion	Cr	Gao *et al.*, 2002
Metal Industry	Fe, Mn and Pb	De Miranda *et al.*, 2002 Funasaka *et al.*, 2003
Oil Combustion	Ni and V	Espinosa *et al.*, 2001 Chao and Wong, 2002
Construction site	Al, Fe, Si, Mn and Ti	Chao and Wong, 2002

2.4 Enrichment Factor

Enrichment Factor (EF) which is widely used to identify the anthropogenic source of metallic elements is defined as followed: $EF_i = (i/j)_{air}/(i/j)_{crust}$; where EF_i is the enrichment factor of species i; j is a reference element for the crustal material, $(i/j)_{air}$ is the ratio of species i to species j in the aerosol sample, and $(i/j)_{crust}$ is the ratio of species i to species j in the crust (Chao and Wong, 2002; Quiterio *et al.*, 2004).

The crustal compositions of selective metallic elements were listed in Table A-1. After analysis of metallic element concentrations of air samples, enrichment factor equation was used to confirm the anthropogenic and natural contributions. If the EF values are in the range of 1 to 10, the major pollutant sources were major come from natural input. On the other hand, the higher EF values, the more anthropogenic contributions were occurred.

2.5 Principal Component Analysis

Principal component analysis (PCA) is the oldest and most widely used multivariate statistical technique in the atmospheric sciences. The principle of PCA is to transform the original set of variables into a smaller set of linear combinations that account for most of the variance of the original set. The primary function of this analysis is the reduction of the number of variables while retaining the original information as much as possible, and thus variables with similar characteristics can be grouped into factors (Ho and Lee, 2002).

The basic assumption for receptor models is that the concentration of a pollutant at the receptor (X*i*) for a given sample is the linear sum of the products of the emission profile (A*i*) and contribution (Si) of *n*-sources, see eq. 2.1.

$$\mathrm{X}i = \sum_{i=1}^{n} AiSi \quad \ldots\ldots\ldots\ldots \quad (2.1)$$

Note that A*i* remains constant and S*i* varies with time. Using the Z-score matrix described above, the correlation matrix C (*nxn*) is calculated. Factor analysis proceeds through the determination of the eigenvector (factor) matrix which is a matrix of weights each applicable to the variables, B (*nxn*), and the corresponding transposition, B^{-1} (*nxn*), matrix, which are used to calculate a diagonal table Λ (*nxn*) using the following equation 2.2:

$$\mathrm{B\ (nxm)} \times \mathrm{C\ (nxn)} \times \mathrm{B}^{-1}\ \mathrm{(nxn)} = \Lambda\ \mathrm{(nxn)} \ldots\ldots \ldots\ldots \ldots\ldots \quad (2.2)$$

The matrix Λ (*nxn*) contains the eigenvalues of the corresponding eigenvectors, which are equal to the sum of the squares of the corresponding factor loadings. The number of extracted factors is equal to the number of variables. However, typically a smaller number *p*, of eigenvectors (factors) can explain a large fraction of the total variance. Therefore, the dimensionality of the system can be reduced from *n* to *p*. The virtually infinite number of mathematically equivalent solutions introduces an important limitation to the use of factor analysis. The orthogonal rotation of eigenvectors, where the right angle between the factors is equal to 90°, has been applied to overcome this problem. Oblique rotation was also used to split up correlated factors because the right angle between the factors can be varied and therefore they can take up any position. Because the initial conclusions from factor loadings are not easily interpretable, these factors are orthogonally transformed using the VARIMAX method. This transformation (rotation) results in high loadings of certain variables on a given factor and relatively low loadings of the others. Therefore, this rotation produces a better correlation of factors with the measured species, allowing them to be attributed to specific sources of metal. The factor scores (FS) are the product of the component score coefficient matrix (W(pxn)) and the Z-score matrix (Z(nxm)). Since the Z-score is calculated using the mean concentrations, these initially calculated FS values do not correspond to the "real" factor scores.

To determine the "real" factor scores (source contributions), the "absolute zero factor score" must be calculated. This was achieved by separately scoring an extra day where ambient concentrations of elements are set at zero. The difference between the FS and the "absolute zero" FS is the actual factor score (AFS). Finally, by regressing daily concentrations of metal on these AFS values, the source contributions are estimated as follows: where Mj is the concentration of particle mass or element (in ng m^{-3}) for the j-sample; AFSkj* is the rotated absolute factor score for k-source on sample j; a_k is the regression coefficient of the AFS to metal concentrations; and a^o is the intercept. The contribution of each factor-source to the total concentration of metallic elements can be determined by multiplying the regression coefficients by the corresponding absolute factor score. This method was previously applied to apportion the sources of heavy metal, volatile organic compounds and PAH in other studies (Yang *et al.*, 1998; Dickhut *et al.*, 2000; Li and Ro, 2000; Ho *et al*., 2002; Park *et al*., 2002; Fang *et al*., 2003).

$$\mathrm{Mj} = \mathrm{a}^{\mathrm{o}} \times \sum_{k=1}^{p} a_k (AFS)_{kj} \quad (2.3)$$

2.6 Objectives of This Study

The major objectives of this study are shown as follows:

(a) Understand the concentration variations of particulate matters and metallic elements in fine and coarse particulates during daytime- and nighttime-period.

(b) Find the possible emission sources by using statistical methods at the traffic junction in central Taiwan.

Chapter 3

Experimental and Methods

3.1 Sampling Site

The sampling site is located at Chung-Chi Road in front of Hungkuang University (CCRU) in central Taiwan (Figure 3.1-1). Chung-Chi Road which changes to Taijunggang Road is a main traffic road with a traffic flow of about 3,000 during daytime (09:00-21:00) and 800 vehicles hr^{-1} during nighttime (21:00-09:00). The CCRU sampling site is also close to another main highway (Taiwan 2nd Highway) and about 30 km east of Taiwan Strait.

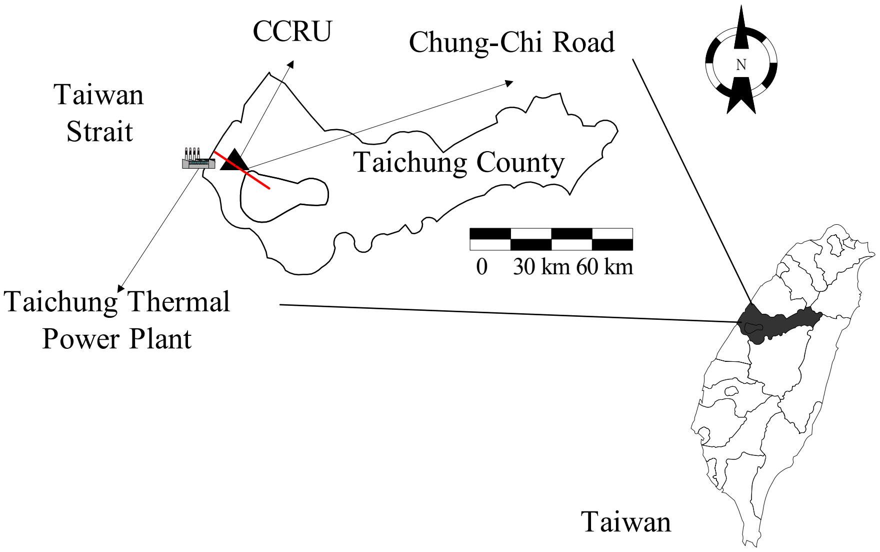

Fig. 3.1-1 Location of the sampling site at the safety island of Chung-Chi Road in front of Hungkuang University (CCRU) in central Taiwan.

3.2 Sampling and Analyze

The versatile air pollutant sampler (VAPS, URG-3000K, URG Corp., Chapel Hill, NC)(Figure 3.2-1) was used to collect the $PM_{2.5}$ (fine) and $PM_{2.5-10}$ (coarse) particulates simultaneously. Twelve hours consecutive sampling for fine and coarse particles during daytime (09:00-21:00) and nighttime (21:00-09:00) was performed six to eight times per month between August 2003 and March 2004 at the CCRU sampling site.

Fig. 3.2-1 The structure of versatile air pollutant system used for fine and coarse particulates collection.

In this study, Teflon filters with a diameter of 47 mm (Zeflour^{TM} Supported PTFE, Pall) were used to collect the ambient particulate. The Teflon filters were first conditioned for 24 hrs in the desiccators at humidity 50±5% and temperature 25±5°C prior to both on and off weighing. After daytime and nighttime sampling, the Teflon filters were weighted after reaching humidity equilibrium (> 24 hrs) in the desiccators after sampling. An analytical balance (AND GR-202) with a reading precision of 0.01 mg was used to calculate the fine and coarse particulate concentrations (Fig. 3.2-2).

Fig. 3.2-2 The illustration of analytical balance (AND GR-202) used for particle mass measurement.

After sampling processes, the Teflon filters (Zeflour^{TM} Supported PTFE, Pall, dimension 47 mm) were first digested in 30 mL 65% nitric acid at 150-200°C for 2 hrs, and then diluted to 50 mL with distilled-deionized water. In order to measure the concentration of chemical species from the atmospheric particles, a Hitachi Z-5000 series polarized zeeman atomic absorption spectrophotometer (Fig. 3.2-3) and Hollow Cathode Lamps were used (Fang *et al.*, 2000; 2003). The weighed process of Teflon filter obtained in this study is described in Fig. 3.2-4.

Fig. 3.2-3 The structure of Z-5000 flame atomic absorption spectrophotometer used to measure the metallic element concentrations.

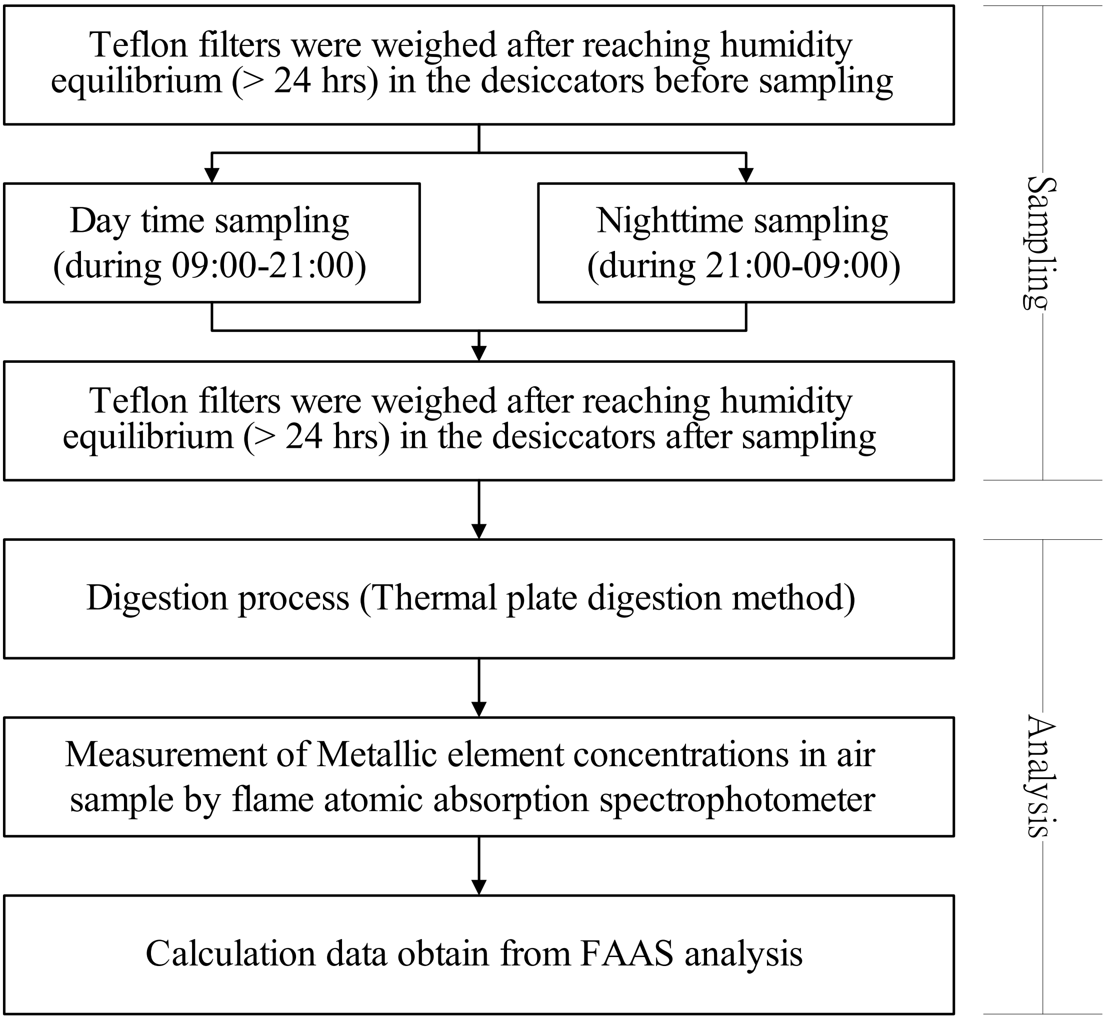

Fig. 3.2-4 The experimental procedures for versatile air pollutant system during daytime and nighttime sampling period at the CCRU sampling site.

3.3 Sampling Device and Analysis Instrument

3.3.1 Versatile Air Pollutant System

The VAPS sampler has a single inlet assembly (PM_{10}) and is designed to remove particle with aerodynamic diameter larger than 10 μm at a flow rate of 32 L min^{-1}. Aerosols exiting the inlet are separated with a Teflon coated virtual impactor into fine and coarse particles and collected on filters. Fig. 3.3-1 shows the inner structures of VAPS and virtual impactor. Coarse particles are collected on one filter, while the fine particles are divided equally and collected on two filters. Different filter materials, e.g. Teflon and quartz may be used or different objectives, so the mass, XRF, SEM light transmission and elemental composition data can be obtained.

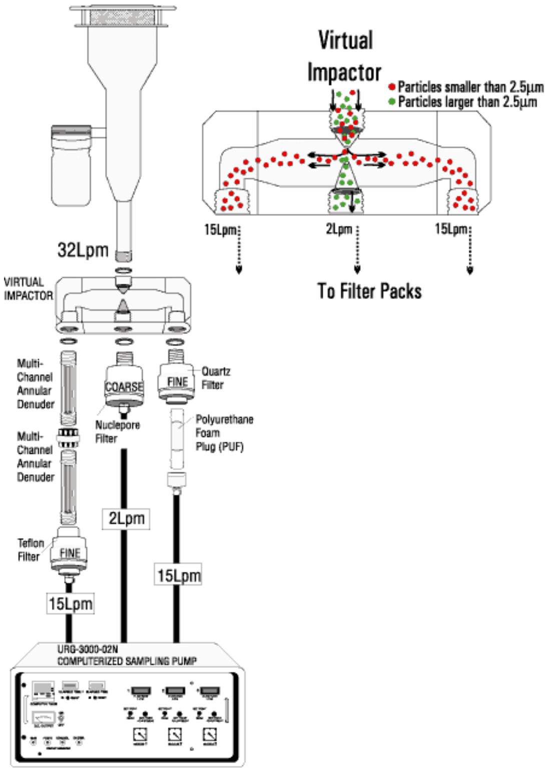

Fig. 3.3-1 The inner structures and virtual impactor of versatile air pollutant system

3.3.2 Portable Weather Station

When sampling, the environment conditions are monitor with a portable weather station (Watchdog model 525)(Fig. 3.3-2) that consists of a wind speed sensor and wind direction sensor. It is for fast, on-demand deployment in pesticide application and civil emergency situations. The set-up procedure takes less 3 minutes. The wind speed sensor uses a three-cup anemometer to produce a series of contact closures in a magnet-red switch. The wind direction sensor uses a balanced anodized aluminum vane assembly that changes the value of a linear conductive potentiometer as wind direction changes. All measurement data is stored in a fail-safe memory until it was download to computer.

Fig. 3.3-2 The illustration of portable weather station (Watchdog model 525) used for record wind speed and wind direction.

3.4 Quality Control

3.4.1 Method Detection Limit

The detection limit is used to determine the lowest concentration level that can be detected to be statistically different from a blank. The Method Detection Limit (MDL) is selected as the concentration slightly higher than the lowest concentration of the standard line. The procedure of repeating the lowest concentration of standard solution twelve times is also used to estimate the standard deviation (S). The MDL for chemical species analyzed in this study are showed in Table 3.4-1. They vary from 0.008 to 0.024 mg L^{-1}.

Table 3.4-1

Method detection limit of each metallic element by using flame atomic absorption spectrophotometer (N=12)

Chemical Species	Method Detection Limit (mg L^{-1})
Iron (Fe)	0.024
Magnesium (Mg)	0.008
Chromium (Cr)	0.024
Copper (Cu)	0.013
Zinc (Zn)	0.016
Manganese (Mn)	0.011
Lead (Pb)	0.017

3.4.2 Recovery Efficiency Test

In this study, the background contamination is insignificant and can be ignored. Recovery efficiencies were calculated and analyzed with at least 10% of the samples spiked with a known amount of metal. Blank samples are spiked with know quality of standard solution and the samples are subject to the thermal plate digestion process. The results showed in Table 3.4-2, indicate a good recovery efficiency (97-103%)(Fang *et al.*, 2000; 2003).

Table 3.4-2

Recovery test for selective metal elements

Chemical Species	Amount spike (mg L^{-1})	Amount found (mg L^{-1})	Recovery (%)
Iron (Fe)	2.0	1.98	99
Magnesium (Mg)	1.0	1.01	101
Chromium (Cr)	2.0	2.04	102
Copper (Cu)	1.0	1.03	103
Zinc (Zn)	1.0	0.98	98
Manganese (Mn)	1.0	0.97	97
Lead (Pb)	2.0	2.01	101

Chapter 4

Results and Discussion

4.1 Meteorological Parameters and Particulate Mass

The sampling information at the CCRU sampling site during period of August 2003 to March 2004 was show in appendix B. The average temperatures for daytime and nighttime sampling periods were 22.4 and 21.5ºC, respectively, and the average wind speed was ranged from 3.6 to 5.2 km hr^{-1} during the sampling periods. The prevailing wind direction was south. After regression analysis, no obvious correlation coefficients were found among atmospheric temperature and wind speed in either daytime or nighttime periods for fine particulates and coarse particulates.

The average fine, coarse, and PM_{10} concentrations during daytime and nighttime sampling periods at this traffic sampling site were also showed in Appendix B. The average PM_{10} concentrations were 74.7 and 68.2 μg m^{-3} for daytime and nighttime, respectively. Fang *et al*. (2000) indicated the average PM_{10} concentrations were 38.9 μg m^{-3} at suburban sampling site. The higher concentrations of PM_{10} were observed in this study.

The average ratios of fine to coarse particulates (Table 4.1-1) are 1.11 and 1.06 during daytime and nighttime sampling periods, respectively. Compared with the previous study, the average ratios of fine and coarse particulates were 2.01 and 2.21 at suburban and farm sampling sites, respectively (Fang *et al*., 2000; 2003). The average ratios of fine to coarse particulates obtained in this study were lower compared with the above studies. Compared with coarse particulates concentrations, higher values were observed in this study. A possible reason for these phenomena was re-suspended soil especially in this busy traffic region. The CCRU sampling site was located in the safety island in Chung-Chi Road; diesel trucks were the main vehicle flow in this traffic lane. Thus, soil might be re-suspended in the ambient air at the CCRU sampling site (Gehrig and Buchmann, 2003).

Table 4.1-1

$PM_{2.5}$, $PM_{2.5\text{-}10}$, and PM_{10} concentrations ($\mu g\ m^{-3}$); $PM_{2.5}/PM_{2.5\text{-}10}$ concentrations ratios during daytime (09:00-21:00) and nighttime (21:00-09:00) during August 2003 to March 2004

Type	$PM_{2.5}$	$PM_{2.5\text{-}10}$	PM_{10}	$PM_{2.5}/PM_{2.5\text{-}10}$
Daytime	39.3	35.4	74.7	1.11
Nighttime	35.1	33.1	68.2	1.06
Suburban[a]	25.9	12.9	38.8	2.01
Farm[b]	42.8	19.4	62.2	2.21

a Fang *et al.*, 2000

b Fang *et al.*, 2003

Fig. 4.1-1, Fig. 4.1-2, Fig. 4.1-3 and Fig. 4.1-4 showed the daily variations for fine and coarse particulate concentrations measured at the CCRU sampling site during daytime and nighttime sampling periods, respectively. From Fig. 4.1-1 and Fig. 4.1-2, the results indicated that the fine particulates were higher at daytime than nighttime sampling period. But this phenomenon was different for coarse particulates during August 2003 to January 2004 at the CCRU sampling site. As for coarse particulate, the concentrations were higher than fine particulate concentrations during February to March 2004. In fact, February 15-17 and March 16 were suffered from dust storm event. Hence, dust storm might be responsible for these results. In Taiwan, dust storm usually occurred every spring especially in February to April (Fang *et al.*, 2002). Lee *et al.* (2004) indicated that dust origin, transport path, duration time, inland meteorology, local source pattern might affect the results of dust storm. Besides, fine particulates can be transported to long-distance area; coarse particulate can be affected by local pollutant sources. The range of fine particulate concentrations of non-dust storm and dust storm period were 11.3 to 75.5 and 44.2 to 63.1 μg m^{-3}, respectively. It revealed that no obvious variations occurred for fine particulates during dust storm event. On the other hand, the range of coarse particulate concentrations of non-dust storm and dust storm period were 5.3 to 53.3 and 60.6 to 72.2 μg m^{-3}, respectively. Higher concentrations of coarse particulate were found during dust storm event. Those phenomena were consisted with other studies (Fang *et al.*, 2002; Funasaka *et al.*, 2003; Lee *et al.*, 2004).

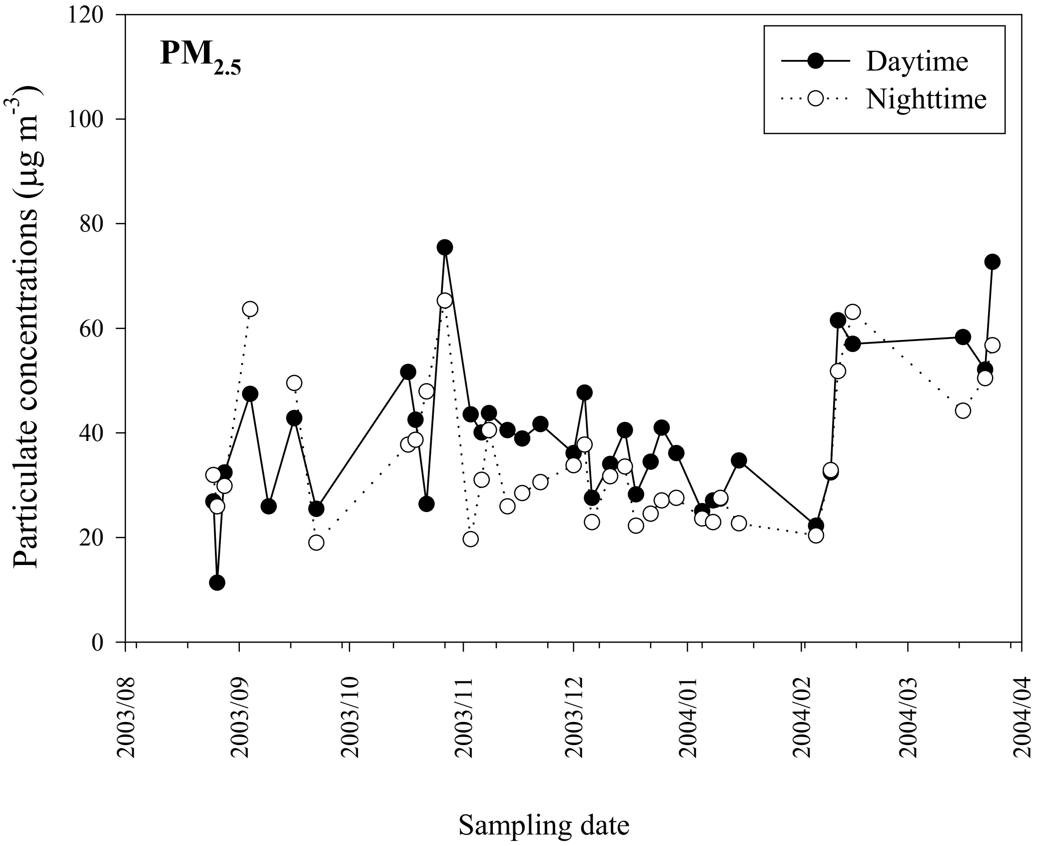

Fig. 4.1-1 Daily variations for fine particulate concentrations measured during daytime and nighttime sampling periods at the CCRU sampling site.

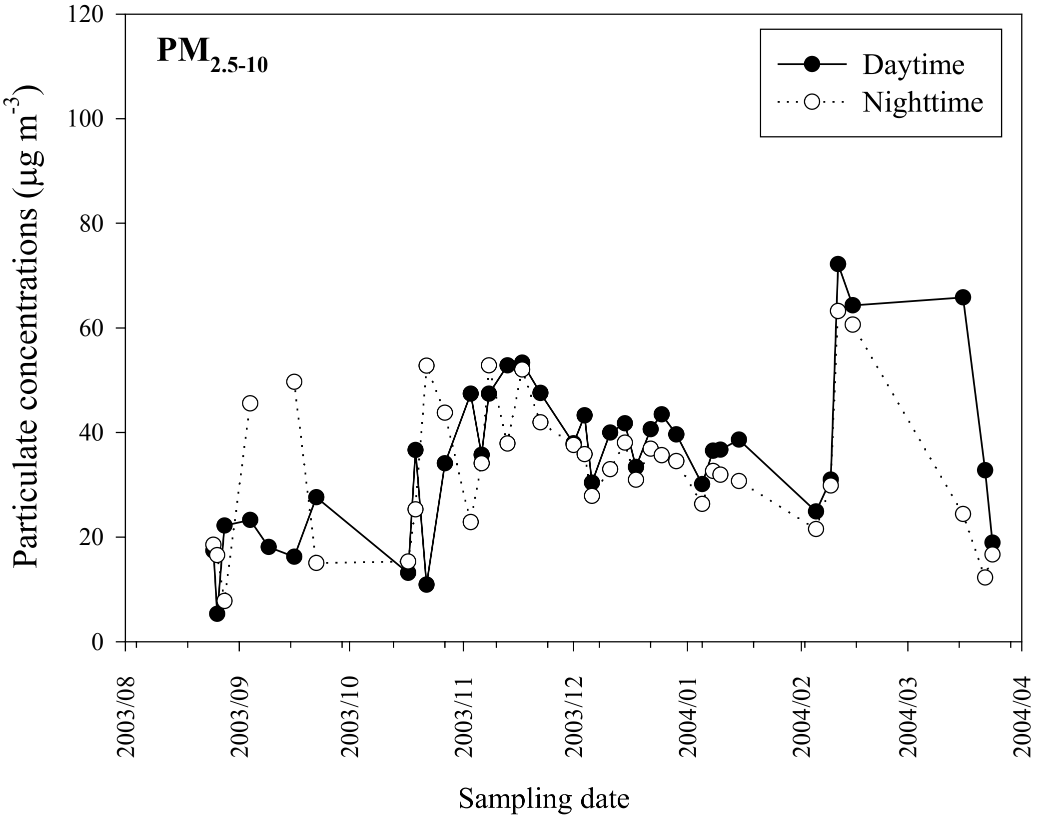

Fig. 4.1-2 Daily variations for coarse particulate concentrations measured during daytime and nighttime sampling periods at the CCRU sampling site.

From Fig. 4.1-3 and Fig. 4.1-4, the differences of fine and coarse particulate concentrations during daytime and nighttime sampling periods were observed. In general, fine particulate concentrations were higher or close to coarse particulate concentrations during daytime sampling period and lower than coarse particulate during nighttime. It suggested the major pollutant sources of fine particulates were almost disappeared during nighttime. Because the finer particulates were major come from anthropogenic activities.

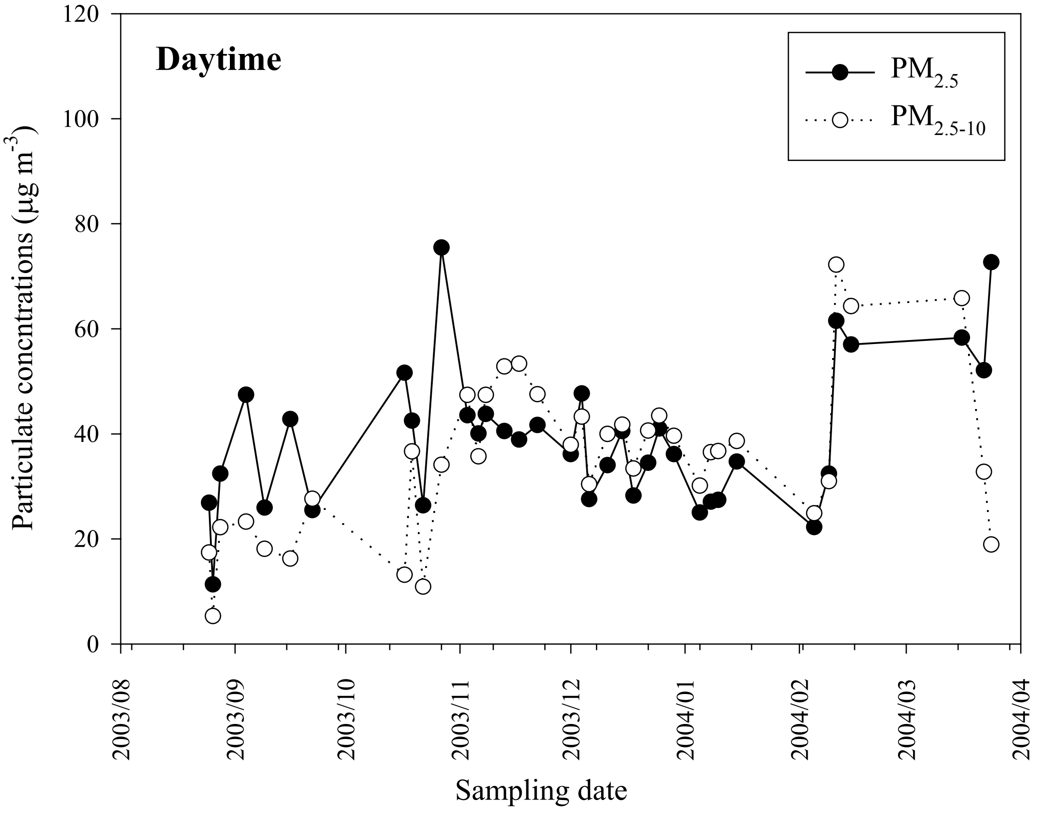

Fig. 4.1-3 Daily variations for fine and coarse particulate concentrations measured during daytime sampling periods at the CCRU sampling site.

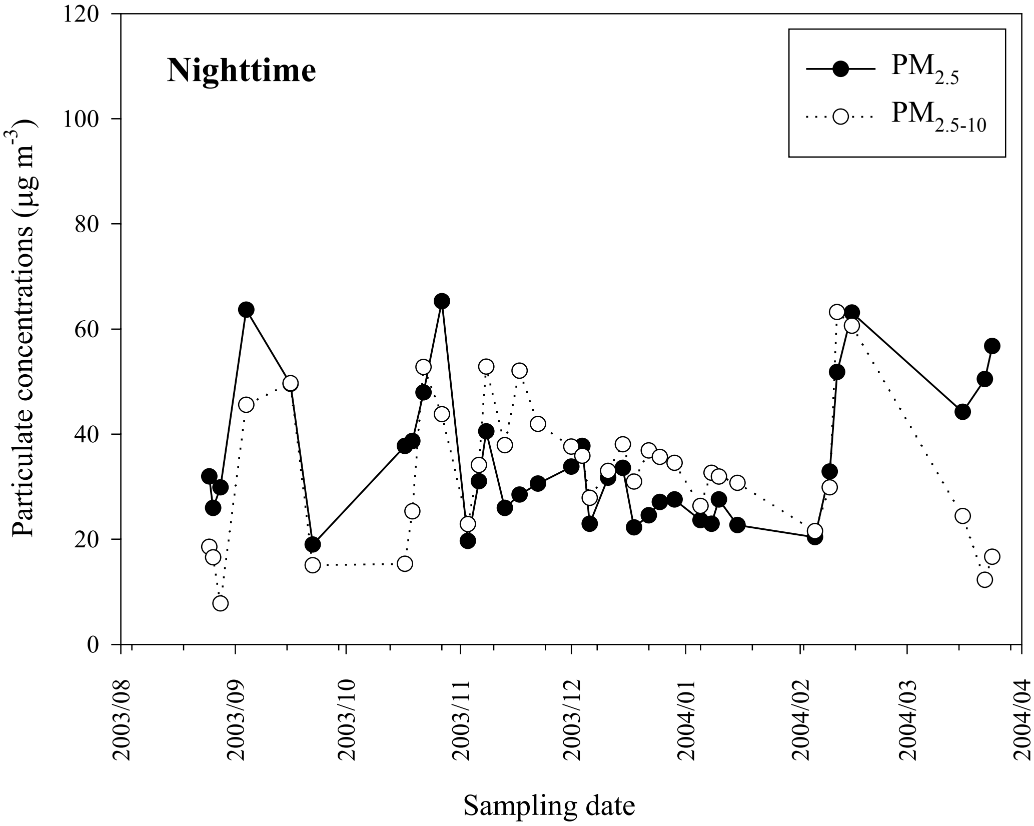

Fig. 4.1-4 Daily variations for fine and coarse particulate concentrations measured during nighttime sampling periods at the CCRU sampling site.

Fig. 4.1-5 showed the variations of fine/coarse particulates ratios during daytime and nighttime periods at the CCRU sampling site. The ratios of fine and coarse particulates were closed to one during November 2003 to February 2004. These phenomena were consisted with the contributions of resuspension of dust.

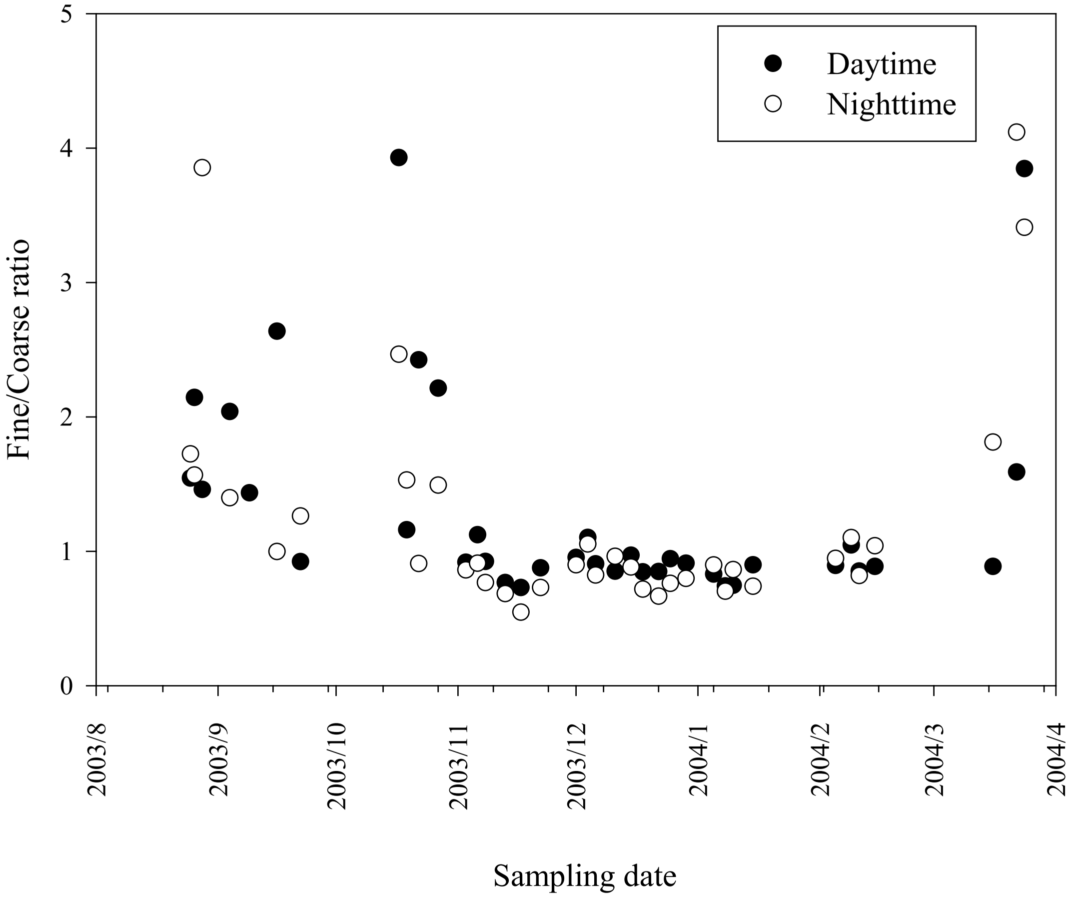

Fig. 4.1-5 The variations of fine/coarse particulates ratios during daytime and nighttime periods at the CCRU sampling site.

4.2 Metallic Element Concentrations

The average metallic element concentrations of fine and coarse particulates during daytime and nighttime during August 2003 to March 2004 were shown in Fig. 4.2-1. In general, metallic element concentrations in fine particulates were higher than coarse particulates except for the crustal elements Fe and Mg. With regard to the variations of daytime and nighttime sampling periods, the mean metallic concentrations of fine particulates were in the following order: Fe (732.4) > Zn (576.7) > Cu (266.4) > Cr (239.7) > Mg (233.5) > Pb (36.4) > Mn (33.6) and Fe (783.4) > Zn (532.2) > Mg (274.3) > Cu (255.6) > Cr (238.9) > Mn (53.4) > Pb (20.9) in ng m^{-3}, respectively.

In the daytime sampling period, the metallic element Fe and Zn were the predominant constituents on the fine particulates. Fe is one of the indicatory metallic elements of crustal, re-suspended dust and metal industry (Allen *et al.*, 2001; Kumar *et al.*, 2001). In this study, it suggested the major source of Fe might be soil and re-suspended. In previous studies, Pb was considered to be a traffic pollutant index (Kumar *et al.*, 2001; Shu *et al.*, 2001). Zheng *et al.* (2004) indicated that Pb can not consider a traffic emission index after the phase-out of leaded gasoline by comparing with lead isotope ratios. Though, Zn has been suggested as a good marker for unleaded fuel vehicular emissions (Salvador *et al.*, 2004). Hence, gasoline engine vehicles should responsible for these results in fine particulates.

The average metallic concentrations on coarse particulates during daytime and nighttime sampling periods were in the following order: Fe

(741.6) > Mg (413.9) > Zn (248.1) > Cu (139.0) > Cr (118.3) > Mn (24.2) > Pb (4.2) and Fe (651.5) > Mg (230.6) > Zn (221.9) > Cu (126.9) > Cr (111.8) > Mn (13.8) > Pb (4.9) in ng m^{-3}, respectively. The predominant constituents on the coarse particulates are Fe and Mg during daytime and nighttime sampling periods. Funasaka *et al.* (2003) indicated coarse particulates were the major local contaminants. Hence, the distribution trends of metallic elements concentrations for coarse particulates at this traffic sampling site were similar as the previous study. In general, the metallic elements concentrations were higher in daytime than nighttime sampling periods. Magnesium is the pollutant index of marine salt, construction materials and resuspended dust. Although the predominant metallic elements were found after chemical analysis by flame atomic absorption spectrophotometer, the real pollutant sources were not yet confirmed at present.

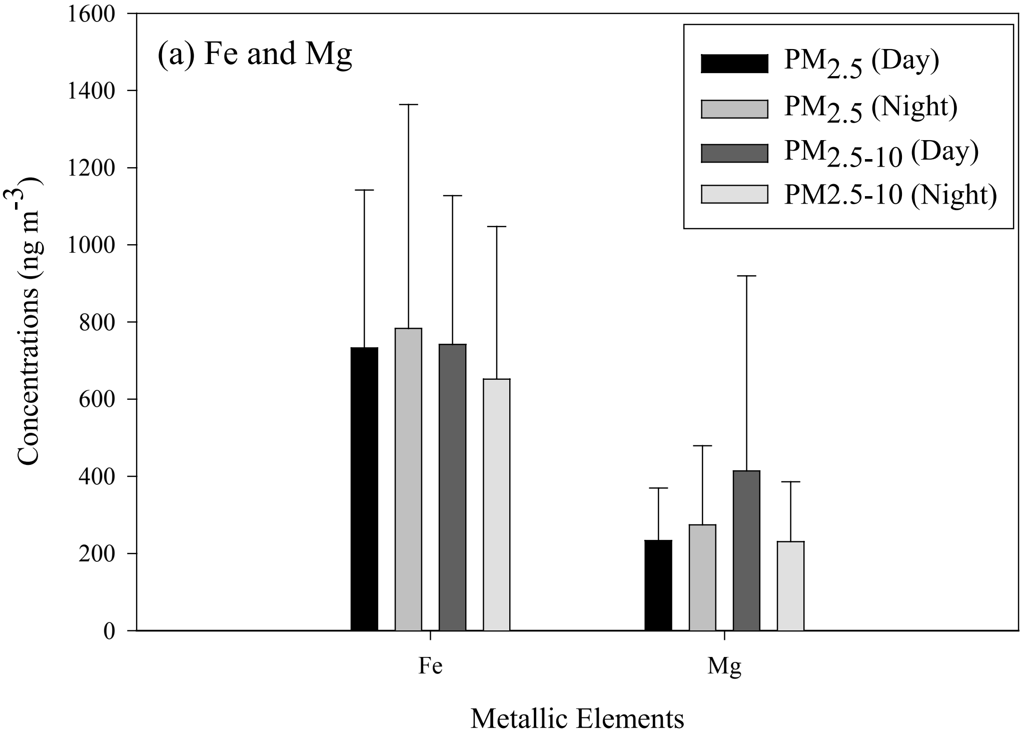

Fig. 4.2-1 (a) Average metallic element concentrations of Fe and Mg on fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) particulates during daytime (09:00-21:00) and nighttime (21:00-09:00) by using VAPS at the CCRU sampling site.

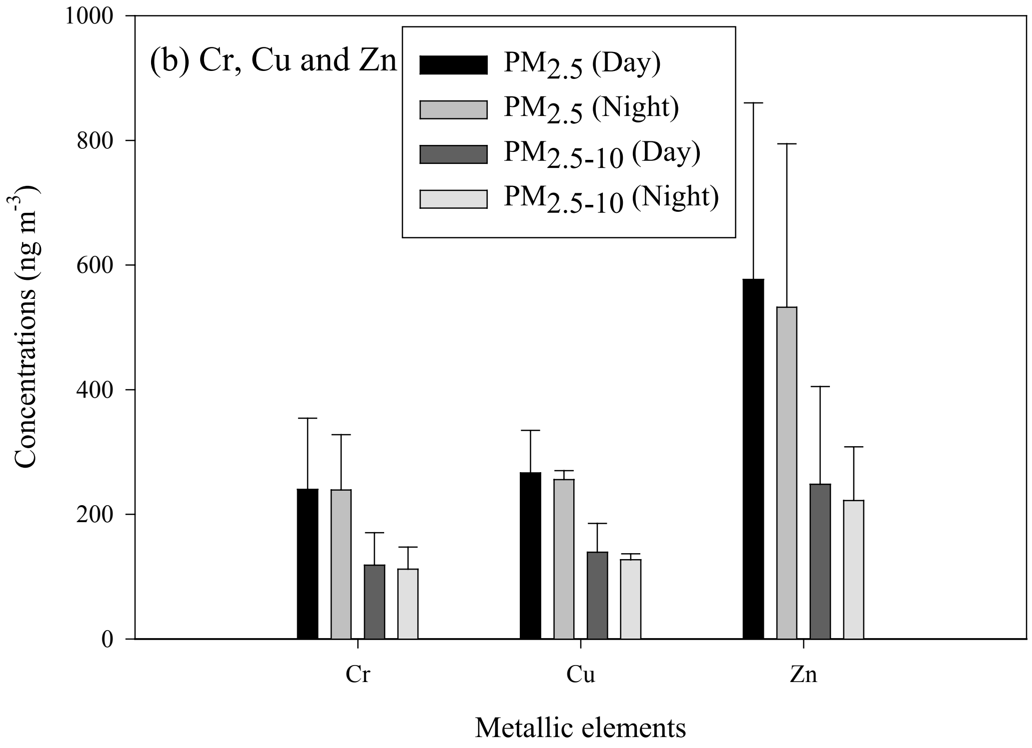

Fig. 4.2-1 (b) Average metallic element concentrations of Cr, Cu and Zn on fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) particulates during daytime (09:00-21:00) and nighttime (21:00-09:00) by using VAPS at the CCRU sampling site.

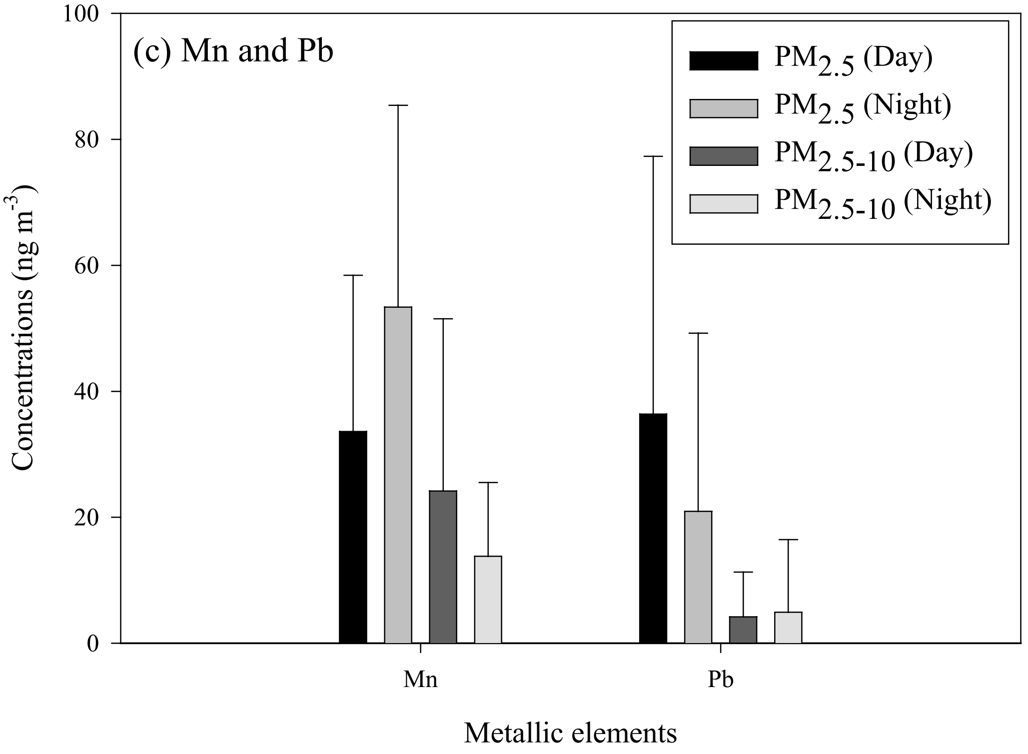

Fig. 4.2-1 (c) Average metallic element concentrations of Mn and Pb on fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) particulates during daytime (09:00-21:00) and nighttime (21:00-09:00) by using VAPS at the CCRU sampling site.

4.3 Correlation Coefficient Analysis

Table 4.3-1 and Table 4.3-2 showed the correlation coefficients matrix of seven selected metallic elements during daytime and nighttime sampling periods at CCRU sampling site. From Table 4.3-1, high correlation coefficients of metallic elements were observed on fine particulates during daytime sampling period except for elements Mn and Pb. On coarse particulates, higher correlation coefficients were observed among Mg, Cr, Cu and Zn during daytime period. These results indicated that the metallic elements of Mg, Cr, Cu and Zn might come from the similar pollutant sources during daytime sampling period.

Table 4.3-2 showed the correlation coefficients matrix on fine and coarse particulates during nighttime sampling period. The same results were not occurred during nighttime sampling period. Higher correlation coefficients were also observed only on Fe, Mg and Cu. These results indicated that the major pollutant sources might disappear during nighttime period. Compared with coarse particulates, the same correlation coefficients were only occurred between Cr and Zn. Higher correlation coefficients among Mg, Cr and Cu during daytime sampling period were become moderate during nighttime sampling period. Besides, Fe and Mn had higher correlation coefficients with other metallic elements on coarse particulates during nighttime sampling period. This result indicated that coarse particulates pollutant sources might be varied significant during daytime and nighttime sampling periods.

Table 4.3-1

Correlation coefficients of fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particulates during daytime (09:00-21:00) sampling period at the CCRU sampling site

$PM_{2.5}$	Metal	Fe	Mg	Cr	Cu	Zn	Mn	Pb
(Day)	Fe	1.00						
	Mg	**0.85***	1.00					
	Cr	0.68	0.53	1.00				
	Cu	0.68	**0.80***	0.65	1.00			
	Zn	0.63	**0.78***	0.54	0.66	1.00		
	Mn	0.11	0.22	0.42	0.12	0.31	1.00	
	Pb	-0.06	0.13	-0.58	-0.18	0.12	0.04	1.00
$PM_{2.5-10}$	Metal	Fe	Mg	Cr	Cu	Zn	Mn	Pb
(Day)	Fe	1.00						
	Mg	0.14	1.00					
	Cr	0.49	0.66	1.00				
	Cu	0.15	**0.98***	**0.70***	1.00			
	Zn	0.21	0.52	0.65	0.61	1.00		
	Mn	0.43	0.30	0.40	0.25	0.01	1.00	
	Pb	-0.41	0.68	0.14	0.67	0.37	-0.16	1.00

*: P value < 0.01

Table 4.3-2

Correlation coefficients of fine (PM$_{2.5}$) and coarse (PM$_{2.5\text{-}10}$) particulates during nighttime (21:00-09:00) sampling period at the CCRU sampling site

PM$_{2.5}$	Metal	Fe	Mg	Cr	Cu	Zn	Mn	Pb
(Night)	Fe	1.00						
	Mg	**0.81***	1.00					
	Cr	0.46	0.32	1.00				
	Cu	0.61	0.62	0.40	1.00			
	Zn	0.52	0.17	0.33	0.27	1.00		
	Mn	0.55	0.61	0.62	0.51	0.14	1.00	
	Pb	-0.40	-0.23	-0.61	-0.24	-0.14	-0.20	1.00
PM$_{2.5\text{-}10}$	Metal	Fe	Mg	Cr	Cu	Zn	Mn	Pb
(Night)	Fe	1.00						
	Mg	**0.87***	1.00					
	Cr	0.58	0.37	1.00				
	Cu	**0.86***	0.58	0.52	1.00			
	Zn	0.52	0.42	0.69	0.31	1.00		
	Mn	**0.82***	**0.75***	0.60	0.63	0.58	1.00	
	Pb	-0.22	-0.23	0.17	-0.17	0.15	-0.36	1.00

*: P value < 0.01

4.4 Enrichment Factor Analysis

As mentioned in previous section, the enrichment factor analysis is used to confirm anthropogenic contributions of metallic element concentrations. The elements that often used as reference for crustal abundance are Al, Fe, Mg and Ca (Quiterio *et al.*, 2004). In this study, Fe and Mg was chose to be the reference metal for enrichment factor calculation. Table 4.4-1 and Table 4.4-2 showed the results of enrichment factor analysis of fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) particulate element concentrations data base on crustal elements (Fe and Mg) at the CCRU sampling site. Enrichment factor calculated for the mean concentrations of Cu, Zn and Pb are in the ranges of 8.1-822.0. Such high EF values were suggested come from anthropogenic input. It is worth to pay attention to the results of Cu and Zn. The enrichment factor values of Cu and Zn are higher than 60 confirming that for these elements anthropogenic sources prevail over natural input. As for Mg and Mn, the mean concentrations are in the ranges of 0.6-4.0. It suggested the natural pollutant sources such as soil and marine salt might be responsible for these results. Besides, some enrichment factor values of anthropogenic sources are higher than one. Thus, anthropogenic sources can not be ignored in this study.

Table 4.4-1

Enrichment factor analysis which use Fe as reference metal of fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particulate element concentrations data at the CCRU sampling site

Metal	$PM_{2.5}$ Day	$PM_{2.5}$ Night	$PM_{2.5-10}$ Day	$PM_{2.5-10}$ Night
Fe	-	-	-	-
Mg	0.7	0.8	1.4	0.8
Cr	10.3	9.6	5.4	5.9
Cu	347.6	321.6	199.6	215.0
Zn	547.9	502.9	243.7	312.7
Mn	2.3	4.0	3.2	1.1
Pb	132.2	88.9	22.9	43.2

Table 4.4-2

Enrichment factor analysis which use Mg as reference metal of fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particulate element concentrations data at the CCRU sampling site

Compound	$PM_{2.5}$ Day	$PM_{2.5}$ Night	$PM_{2.5-10}$ Day	$PM_{2.5-10}$ Night
Fe	1.3	0.5	0.3	0.5
Mg	-	-	-	-
Cr	13.3	4.8	1.6	2.7
Cu	483.3	169.4	61.1	100.0
Zn	822.0	277.2	85.6	137.4
Mn	1.5	2.0	0.6	0.6
Pb	124.5	61.0	8.1	17.1

4.5 Principal Component Analysis

Principal component analysis (PCA) with Varimax rotation and retention of principal components having eigenvalues > 1 (SPSS 10.0) was used to identify the possible pollutant sources (Winner and Cass, 2001). Table 4.5-1 and Table 4.5-2 show the factor analysis on fine and coarse particulate metallic element concentrations during daytime and nighttime sampling periods. During the daytime sampling period, factor 1 explained 54.9% of the total variance of the data and had high loadings for Fe (0.891), Mg (0.958), Cu (0.863), and Zn (0.832), which were identified as re-suspended dust and traffic emission sources on fine particulates (Sternbeck *et al.*, 2002). Higher factor loading of Pb (0.981) and Mn (0.985) were observed on factor 2 and factor 3 for fine particulates during daytime sampling period. After check the enrichment factor values, the contributors of Pb were come from anthropogenic activities but not for traffic emission (Espinosa *et al.*, 2001; De Miranda *et al.*, 2002; Zheng *et al.*, 2004). As for Mn, low enrichment factor and high factor loading values were observed simultaneously. Besides, the major contributors of Mn are anthropogenic and natural sources (Marcazzan *et al.*, 2001; Chao and Wong, 2002). According to the above reasons, crustal source was the third major pollutant source affects the fine particulates concentrations during daytime sampling period.

As for coarse particulates, high factor loadings of Mg (0.942), Cu (0.966) and Zn (0.713) were observed in the daytime sampling period. This suggested that the traffic vehicle emissions and marine salt were the major contributors (Kumar *et al.*, 2001; Sternbeck *et al.*, 2002). Factor 2 showed high factor loadings of Fe (0.882) and Mn (0.709) on fine particulates during the daytime sampling period. In addition, the enrichment factor value of Mn was 3.2, re-suspended dust was responsible for these results (Funasaka *et al.*, 2003).

Table 4.5-1

Factor analysis of fine ($PM_{2.5}$) and coarse ($PM_{2.5\text{-}10}$) particulate element concentrations data in daytime (09:00-21:00) at the CCRU sampling site

Metal	$PM_{2.5}$ (Day)			$PM_{2.5\text{-}10}$ (Day)	
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2
Fe	**0.891**	-0.151	0.007	0.027	**0.882**
Mg	**0.958**	0.085	0.107	**0.942**	0.124
Cr	0.602	-0.681	0.361	0.679	0.605
Cu	**0.863**	-0.245	0.005	**0.966**	0.130
Zn	**0.832**	0.098	0.293	**0.713**	0.181
Mn	0.098	-0.025	**0.985**	0.142	**0.709**
Pb	0.061	**0.981**	0.059	**0.776**	-0.537
Eigenvalues	3.844	1.392	1.018	3.566	1.848
Variance (%)	54.908	19.889	14.543	50.939	26.396
Cumulative (%)	54.908	74.797	89.340	50.939	77.334
Origin	Dust Traffic	Anthropogenic	Crustal	Marine Salt Traffic	Dust

Compared with daytime sampling data, differences were also found between fine and coarse particulates during daytime and nighttime periods. From Table 4.5-2, factor 1 showed 51.6 % of the total variance of the data and high factor loading of Fe (0.831) and Mg (0.907) were found on fine particulates during the nighttime sampling period. Thus, soil was inevitably became the major pollutant source. Besides, higher factor of Cu (0.787) and Mn (0.717) were also observed in factor 1 during nighttime sampling period. Salvador *et al*. (2004) indicated Cu and Zn were associated with tyre wearing. In addition, Zn has been suggested as a good marker of gasoline engine emissions. Based on above reasons, it suggested anthropogenic activities such as industrial process and traffic emission were the major pollutant sources in fine particulates during nighttime sampling period (Ragosta *et al*., 2002). Chromium had high factor loading in fine particulate during nighttime sampling period. After check the enrichment factor values, no obvious contributor was observed according to the limit information.

The same phenomena were occurred on coarse particulate values during nighttime sampling period. The descriptions of coarse particulates were the same to fine particulates at CCRU sampling site.

High factor loading of Cr (0.720), Zn (0.710) and Pb (0.742) were observed on factor 2 in coarse particulates during nighttime sampling period. Chromium and zinc were enriched from anthropogenic activities such as coal combustion and incinerator emissions (Gao *et al*., 2002; De Miranda *et al*., 2002). In addition, the CCRU sampling site is close to Taiwan Strait, the land-sea wind transfer can also affect the results obtained in this study. The distance of Taichung Thermal Power Plant which located at the west side of the CCRU sampling site is about 20 km. Hence, the influence of Taichung Thermal Power Plant seems important on coarse particulate during nighttime sampling period at CCRU sampling site.

Table 4.5-2

Factor analysis of fine ($PM_{2.5}$) and coarse ($PM_{2.5-10}$) particulate element concentrations data in nighttime (21:00-09:00) at the CCRU sampling site

Metal	$PM_{2.5}$ (Night)		$PM_{2.5-10}$ (Night)	
	Factor 1	Factor 2	Factor 1	Factor 2
Fe	**0.831**	0.353	**0.950**	0.183
Mg	**0.907**	0.078	**0.861**	0.050
Cr	0.324	**0.840**	0.521	**0.720**
Cu	**0.787**	0.177	**0.805**	0.132
Zn	0.307	0.379	0.471	**0.710**
Mn	**0.717**	0.298	**0.905**	0.156
Pb	-0.054	-0.879	-0.471	**0.742**
Eigenvalues	3.613	1.109	4.104	1.373
Variance (%)	51.616	15.837	58.629	19.617
Cumulative (%)	51.616	67.453	58.629	78.246
Origin	Dust Anthropogenic	-	Dust Anthropogenic	Coal Combustion Incinerator

4.6 Comparison with Other Studies

Table 4.6-1 showed the regulations of seven metallic elements in ng m^{-3}. No standard regulations were found among Fe, Mg, Cu and Zn. After compared the data, only Cr concentrations (111.8-239.7 ng m^{-3}) were higher than ATSDR (Agency for Toxic Substances and Disease Registry) standard. Other metallic element concentrations were under the regulations of ATSDR, WHO (World Health Organization) and ROC EPA (Environmental Protection Agency, Republic of China).

Table 4.6-1

The regulations of selective metallic elements (ng m^{-3})

Fe	Mg	Cr	Cu	Zn	Mn	Pb	Reference
Nd*	Nd	100	Nd	Nd	500	1500	ATSDR
Nd	Nd	1100	Nd	Nd	150	500	WHO (2000)
Nd	Nd	Nd	Nd	Nd	Nd	1000	ROC EPA

Nd: No data available

Table 4.6-2 summarizes the atmospheric studies at different sites around the world. The relative discussions of those metallic elements were showed as follows.

4.6.1 Metallic Element of Fe

Iron is the most abundant metallic elements among all selective elements. The average concentrations of Fe on fine particulates during daytime and nighttime sampling periods were 732.4 and 783.4 ng m^{-3}, respectively. The results were similar to previous study (729-959 ng m^{-3}, Fang *et al.*, 2002) and Beijing (800 ng m^{-3}, Mori *et al.*, 2003). Compared with other studies, higher metallic elements Fe concentrations were observed on fine particulates in this study. The average concentrations of Fe on coarse particulates during daytime and nighttime sampling periods were 741.6 and 651.5 ng m^{-3}, respectively. These values were close to Los Angeles riverside site (737.55 ng m^{-3}, Singh *et al.*, 2002) but lower than Dhaka (1,306 ng m^{-3}, Begum *et al.*, 2004), Rajshahi (1,119 ng m^{-3}, Begum *et al.*, 2004), Beijing (25,400 ng m^{-3}, Mori *et al.*, 2003), Yamaguchi (3,900 ng m^{-3}, Begum *et al.*, 2004) and Osaka (830-1,110 ng m^{-3}, Funasaka *et al.*, 2003).

4.6.2 Metallic Element of Mg

The metallic Mg concentrations on fine and coarse particulates were ranged between 233.5-274.3 and 230.6-413.9 ng m^{-3}, respectively. The values are lower than Dhaka (207-1,306 ng m^{-3}, Begum *et al.*, 2004), Rajshahi (314-812 ng m^{-3}, Begum *et al.*, 2004), Beijing (11,900 ng m^{-3}, Mori *et al.*, 2003) and Yamaguchi (2,000 ng m^{-3}, Mori *et al.*, 2003).

4.6.3 Metallic Element of Cr

Chromium is a naturally occurring element found in rocks, animals, plants, soil, and in volcanic dust and gases. The metallic Cr concentrations on fine and coarse particulates ranged between 238.9-239.7 and 111.8-118.3 ng m^{-3}, respectively. Compared with other studies in Table 4.6-2, metallic elements Cr concentrations were ranked as the highest concentration around the world.

4.6.4 Metallic Element of Cu

Copper is a reddish metal that occurs naturally in rock, soil, water, sediment, and, at low levels, air. The metallic Cu concentrations on fine and coarse particulates ranged between 255.6-266.4 and 221.9-248.1 ng m^{-3}, respectively. After compared with other studies (Table 4.6-2), the same results were observed with Cr. The highest concentrations of Cu were also found in this study.

4.6.5 Metallic Element of Zn

Zinc is one of the most common elements on earth crust. It is found in the air, soil, and water and is also present in all foods. The concentrations of metallic Zn on fine particulates during daytime and nighttime sampling periods were 576.7 and 532.2 ng m^{-3}, respectively. Compared with other studies, no higher values of Zn concentrations in fine particulates were found. The concentrations of metallic Zn on coarse particulates were 248.1 and 221.9 ng m^{-3}, respectively. The metallic Zn values obtained on coarse particulates were similar to Osaka (250 ng m^{-3}, Funasaka *et al.*, 2003) but lower than Dhaka (375 ng m^{-3}, Begum *et al.*, 2004).

4.6.6 Metallic Element of Mn

Manganese is a naturally occurring substance found in many types of rock. The concentrations of metallic Mn on fine and coarse particulates ranged between 33.6-53.4 and 13.8-24.2 ng m^{-3}, respectively.

The values of metallic Mn measured in this study were quite lower than Beijing (67-588 ng m^{-3}, Mori *et al.*, 2003) and Yamaguchi (88 ng m^{-3}, Mori *et al.*, 2003). Besides, the values of metallic Mn obtained in this study were similar to Dhaka (8.87-30.7 ng m^{-3}, Begum *et al.*, 2004), Rajshahi (5.12-28.7 ng m^{-3}, Begum *et al.*, 2004) and Osaka (12-34 ng m^{-3}, Funasaka *et al.*, 2003).

4.6.7 Metallic Element of Pb

Lead occurs naturally in the environment. However, most of the lead found throughout the environment comes from human activities. The values of metallic Pb on fine particulates during daytime and nighttime sampling periods were 36.4 and 20.9 ng m^{-3}, respectively. These values were quite lower than Milan (85-190 ng m^{-3}, Marcazzan *et al.*, 2001), Dhaka (164 ng m^{-3}, Begum *et al.*, 2004), Hong Kong (60.13-91.62 ng m^{-3}, Ho *et al.*, 2003) and previous study at farm sampling site (283.1 ng m^{-3}, Fang *et al.*, 2003) on fine particulates. In addition, the values of metallic Pb measured on fine particulate were similar to another previous study at traffic site (34-44 ng m^{-3}, Fang *et al.*, 2002).

The concentrations of metallic Pb on coarse particulates during daytime and nighttime sampling periods were 4.2 and 4.9 ng m^{-3}, respectively. These values were similar to Los Angeles (0.16-2.97 ng m^{-3}, Singh *et al.*, 2002) and Auckland (6 ng m^{-3}, Senaratne and Shooter, 2004). In addition, the concentrations of metallic Pb measured on coarse particulates were lower than Dhaka (124 ng m^{-3}, Begum *et al.*, 2004), Osaka (14-40 ng m^{-3}, Funasaka *et al.*, 2003) and Taichung farm sampling site (90.6 ng m^{-3}, Fang *et al.*, 2003).

Table 4.6-2

Comparisons of atmospheric metallic element concentrations at different sites around the world (ng m^{-3})

Country	Sampling site	Character	Survey year	Particle Size	Fe	Mg	Cr	Cu	Zn	Mn	Pb
USA	Los Angeles[a]	Industrial/ Traffic	2000-2001	$PM_{2.5}$	295.68	-	5.04	13.07	35.17	10.55	1.34
				$PM_{2.5-10}$	150.89	-	1.05	3.46	4.39	2.26	0.16
		Riverside		$PM_{2.5}$	169.72	-	0.9	0.74	12.54	3.77	4.09
				$PM_{2.5-10}$	737.55	-	1.15	8.72	11.72	12.77	2.97
New Zealand	Auckland[b]	Campus	2000-2001	$PM_{2.5}$	63 ± 60	86 ± 16	-	3 ± 2	23 ± 20	2 ± 3	9 ± 10
				$PM_{2.5-10}$	332 ± 330	147 ± 57	-	4 ± 3	17 ± 16	7 ± 8	6 ± 7
Spain	Catalonia[c]	Urban	1999-2000	$PM_{2.5}$	260	80	6	23	178	14	130
Italy	Milan[d]	Campus	1997-1998								
		winter	1997-1998	$PM_{2.5}$	210 ± 100	-	5 ± 1	21 ± 9	145 ± 70	15 ± 9	190 ± 110
		summer	1997-1998	$PM_{2.5}$	170 ± 80	-	< 10	14 ± 6	75 ± 30	11 ± 5	85 ± 40
Bangladesh	Dhaka[e]	Semi-urban	2001-2002	$PM_{2.5}$	207 ± 132	433 ± 228	7.99 ± 7.76	5.05 ± 4.07	272 ± 247	8.87 ± 5.57	164 ± 557
				$PM_{2.5-10}$	1306 ± 766	919 ± 412	25.2 ± 127	13.2 ± 43.4	375 ± 367	30.7 ± 18.8	124 ± 350
	Rajshahi	urban		$PM_{2.5}$	114 ± 70.6	314 ± 112	4.55 ± 3.35	1.67 ± 0.5	16.7 ± 9.43	5.12 ± 3.89	14.7 ± 4.59
				$PM_{2.5-10}$	1119 ± 675	812 ± 306	9.34 ± 5.44	2.58 ± 1.86	27.4 ± 16.1	28.7 ± 15.6	16.2 ± 8.48

Table 4.6-2 (continue)

Country	Sampling site	Character	Survey year	Particle Size	Fe	Mg	Cr	Cu	Zn	Mn	Pb
China	Hong Kong[f]	Traffic	2000-2001	$PM_{2.5}$	250 ± 120	110 ± 70	2.43 ± 1.65	17.32 ± 7.80	290 ± 20	9.96 ± 4.93	76.86 ± 33.90
		Industrial	2000-2001	$PM_{2.5}$	480 ± 50	200 ± 250	4.51 ± 3.67	36.78 ± 20.64	380 ± 410	19.72 ± 22.08	91.62 ± 50.11
		Urban	2000-2001	$PM_{2.5}$	190 ± 190	160 ± 120	4.19 ± 1.17	9.71 ± 1.61	120 ± 10	9.41 ± 5.61	60.13 ± 17.67
China	Nanjing[g]	Urban	2001	$PM_{2.5}$	2.71-58.42	0-535	0.71-5.41	3.59-41.93	-	6.51-91.15	0-59.53
	Beijing[h]	Urban	2001	Fine (≦ 2.1 μm)	800	-	-	-	240	67	150
				Coarse (≧ 2.1 μm)	25400	11900	-	-	170	588	-
Japan	Yamaguchi[h]	Urban	2001	Fine (≦ 2.1 μm)	400	-	-	-	100	-	-
				Coarse (≧ 2.1 μm)	3900	2000	-	-	-	88	-
	Osaka[i]	Traffic	1999-2002	Fine (≦ 2.1 μm)	220 ± 40	-	-	13 ± 3.5	140 ± 42	17 ± 4.3	37 ± 11
			1999-2002	Coarse (≧ 2.1 μm)	1100 ± 290	-	-	21 ± 4.1	250 ± 74	34 ± 10	40 ± 14
		Residential	1999-2002	Fine (≦ 2.1 μm)	190 ± 51	-	-	12 ± 3.0	130 ± 31	12 ± 3.1	30 ± 10
			1999-2002	Coarse (≧ 2.1 μm)	830 ± 240	-	-	18 ± 5.1	92 ± 40	17 ± 6.2	14 ± 6.9
Taiwan	Taichung	Traffic[j]	2000	$PM_{2.5}$	729-959	-	-	-	137-235	-	34-44
		Farm[k]	2002	$PM_{2.5}$	162.8 ± 163.3	37.9 ± 50.8	33.5 ± 48	11.5 ± 19.9	177.8 ± 103	19.1 ± 20.5	283.1 ± 252.2
				$PM_{2.5-10}$	360.6 ± 115.8	92.1 ± 54.7	9.0 ± 13	12.8 ± 11.8	40.3 ± 33.9	7.5 ± 3.4	90.6 ± 54.9
	This study	Traffic	2003	$PM_{2.5}$ (Daytime)	732.4 ± 409.4	233.5 ± 136.0	239.7 ± 114.4	266.4 ± 68.4	576.7 ± 283.4	33.6 ± 24.8	36.4 ± 40.9
				$PM_{2.5}$ (Nighttime)	783.4 ± 580.0	274.3 ± 204.9	238.9 ± 88.6	255.6 ± 14.4	532.2 ± 262.3	53.4 ± 32.0	20.9 ± 28.3
				$PM_{2.5-10}$ (Daytime)	741.6 ± 386.1	413.9 ± 505.5	118.3 ± 52.1	139.0 ± 46.3	248.1 ± 157.1	24.2 ± 27.3	4.2 ± 7.1
				$PM_{2.5-10}$ (Nighttime)	651.5 ± 395.6	230.6 ± 154.8	111.8 ± 35.4	126.9 ± 9.6	221.9 ± 86.2	13.8 ± 11.7	4.9 ± 11.5

a Singh *et al*., 2002
b Senaratne and Shooter, 2004
c Querol *et al*., 2001
d Marcazzan *et al*., 2001
e Begum *et al*., 2004
f Ho *et al*., 2003
g Wang *et al*., 2002
h Mori *et al*., 2003
i Funasaka *et al*., 2003
j Fang *et al*., 2002
k Fang *et al*., 2003

Chapter 5

Conclusions and Suggestions

5.1 Conclusions

The major conclusions for this study are as follows:

(1) The average concentrations of fine particulates during daytime and nighttime sampling periods at traffic sampling site were 39.3 and 35.1 μg m^{-3}, respectively. As for average concentrations of coarse particulates during daytime and nighttime sampling periods were 35.4 and 33.1 μg m^{-3}, respectively. In general, the fine particulates concentrations were high than coarse particulate concentrations except during dust storm period.

(2) The major metallic elements of fine particulates during daytime and nighttime sampling periods were Fe and Zn. In addition to coarse particulates, Fe and Mg were the predominant species during daytime and nighttime sampling periods.

(3) After correlation coefficients analysis, different results were observed between daytime and nighttime sampling periods. The metallic elements of Mg, Cr, Cu and Zn might come from the same pollutant sources during daytime sampling period. As for nighttime sampling periods, higher correlation coefficients were observed on Fe, Mg and Cu. This phenomenon indicated the major pollutant sources or anthropogenic activities might disappear during nighttime.

(4) The results of enrichment factor analysis indicated that the mean concentrations of Cr, Cu, Zn and Pb are in the range of 5.4-547.9, suggesting an anthropogenic input. As for Mg and Mn, the mean concentrations are in the range of 0.7-4.0. It suggested the natural pollutant sources such as soil dust and marine salt might be responsible for these results.

(5) With regarding to source identification by PCA, marine salt, traffic exhaust and re-suspended dust were the major possible emission sources during daytime sampling period at the CCRU sampling site of central Taiwan. During nighttime sampling period, soil dust and some anthropogenic activities were responsible for these results.

5.2 Suggestions

The major suggestions for this study are as follows:

(1) VAPS can collect particulate phase, gas phase pollutants and atmospheric pollutants that associated with them. Hence, more sampling devices such as PUF and Annular Denuder can also use to monitor those pollutants for future study.

(2) The difference and sampling error of two sampling devices such as universal air sampler and versatile air pollutant system can be further discusses for future work.

(3) Different sampling sites such as coastal areas can choose to compare the variations of air pollutants between traffic and continental shelf areas to observe and monitor the atmospheric pollutant transport pathway in the future.

Reference

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Appendix A

Selective Metallic Element Characteristics

Table A-1

Crustal compositions of selective metallic elements*

Compound	Crustal Composition (%)
Fe	5.63
Mg	2.33
Cr	1.80×10^{-1}
Cu	5.50×10^{-3}
Zn	7.00×10^{-3}
Mn	9.50×10^{-2}
Pb	1.25×10^{-3}

*The information comes from "World wide distribution and abundance of metals, 2004. (http://mac01.eps.pitt.edu/harbbook/c_xi/c_xic.htm)"

Table A-2

Basic characteristics of selective metallic elements*

Metal	Atomic Number	Atomic Weight	Melting Point (K)	Boiling Point (K)	Density ($g\ m^{-3}$)	Phase at Room Temperature
Fe	26	55.85	1811	3134	7.87	Solid
Mg	12	24.31	923	1363	1.74	Solid
Cr	24	52.00	2180	2944	7.15	Solid
Cu	29	63.55	1358	2835	8.93	Solid
Zn	30	65.41	693	1180	7.13	Solid
Mn	25	54.94	1519	2334	7.30	Solid
Pb	82	207.2	601	2022	11.34	Solid

*The information comes from "The Periodic Table of Elements, Jefferson Lab, 2004. (http://education.jlab.org/itselemental/index.html)"

Appendix B

Raw Data

Table B-1

Meteorological parameters of ambient air at the CCRU sampling site during August 2003 to March 2004

Date	Temperature (ºC)		Maximum Wind Speed (km hr^{-1})		Average Wind Speed (km hr^{-1})		Prevailing wind (deg)	
	Day	Night	Day	Night	Day	Night	Day	Night
08/25-26	30.4	26.9	12.4	5.4	4.1	0.7	174.1	158.4
08/26-28	31.5	27.3	12.0	5.2	3.4	0.7	225.4	190.5
08/28-30	31.5	27.5	11.7	3.1	3.5	0.3	209.9	161.8
09/04-05	30.3	27.2	10.5	5.2	3.5	0.8	138.1	187.2
09/09-10	29.9	27.0	22.5	15.1	9.1	5.8	57.5	68.3
09/16-18	29.9	27.0	10.8	2.5	3.6	0.1	97.1	162.4
09/22-24	27.6	25.0	14.4	4.0	4.9	0.3	98.8	120.0
10/17-19	25.0	20.6	24.3	12.8	10.3	4.3	62.5	108.0
10/19-21	26.0	20.5	21.9	5.7	8.9	1.1	65.3	132.4
10/22-24	23.7	19.8	32.7	19.2	13.6	7.8	59.2	60.8
10/27-28	25.4	21.2	14.4	4.3	5.6	0.3	142.0	159.9
11/03-04	24.4	21.8	26.3	12.4	11.0	4.7	94.7	95.9
11/06-07	26.9	23.2	14.4	3.1	6.0	0.1	117.5	202.0
11/08-09	25.8	22.8	17.2	8.0	7.1	2.4	119.3	75.4
11/13-14	23.4	20.0	13.8	4.0	5.8	0.4	158.8	203.2
11/17-18	24.5	22.1	17.0	3.4	6.8	0.7	89.4	25.0
11/22-23	21.5	19.1	17.2	5.4	6.4	1.4	333.1	332.9
12/01-02	20.9	19.8	25.4	3.8	10.4	0.0	333.2	223.0
12/04-05	25.1	21.3	18.4	6.1	7.3	1.3	108.5	96.5
12/06-07	26.0	22.2	15.5	9.3	5.9	3.1	145.7	148.0
12/11-12	25.0	22.9	22.5	5.7	8.9	1.6	82.0	111.2
12/15-16	29.0	26.7	19.5	14.7	7.3	5.4	86.7	67.0
12/18-19	30.3	23.1	11.8	14.7	4.1	5.4	142.3	205.8
12/22-23	14.4	18.7	6.6	11.7	1.7	4.3	268.0	287.2

Table B-1 (continue)

Date	Temperature (ºC)		Maximum Wind Speed (km hr^{-1})		Average Wind Speed (km hr^{-1})		Prevailing wind (deg)	
	Day	Night	Day	Night	Day	Night	Day	Night
12/25-26	15.1	19.2	10.7	16.5	3.2	6.2	282.1	278.0
12/29-30	17.6	21.3	7.5	16.3	1.7	6.8	246.7	296.6
1/05-06	13.5	14.2	21.1	29.0	8.2	11.4	298.0	288.1
1/08-09	15.5	19.5	4.5	12.5	0.6	4.5	221.3	255.3
1/10-11	14.2	17.3	15.3	21.8	4.1	9.0	265.1	288.7
1/15-16	8.9	11.0	6.1	22.4	1.8	8.4	296.2	284.1
2/05-06	13.4	16.9	2.3	12.5	0.1	5.0	299.2	297.4
2/09-10	15.8	19.0	3.0	10.5	0.2	4.1	209.4	275.2
2/11-13	15.3	19.6	4.1	9.3	0.5	3.1	200.6	256.1
2/15-16	18.6	22.4	13.3	18.5	4.4	7.9	219.2	276.6
3/16-18	15.9	19.6	7.9	18.4	2.5	7.4	306.8	287.4
3/22-23	18.0	21.1	7.7	10.9	1.7	3.7	247.0	257.5
3/24-25	18.3	20.3	10.6	10.1	2.7	2.9	242.0	209.2
Ave.	22.4	21.5	14.3	10.6	5.2	3.6	182.2	192.8
S.D.	6.3	3.7	7.1	6.5	3.3	3.0	87.1	84.8

Table B-2

Fine, coarse, and PM_{10} concentrations ($\mu g\ m^{-3}$) during daytime (09:00-21:00, N=37) and nighttime (21:00-09:00, N=36) periods during August 2003 to March 2004

Date	$PM_{2.5}$ ($\mu g\ m^{-3}$)		$PM_{2.5\text{-}10}$ ($\mu g\ m^{-3}$)		PM_{10} ($\mu g\ m^{-3}$)	
	Day	Night	Day	Night	Day	Night
08/25-26	26.9	31.9	17.4	18.5	44.2	50.5
08/26-28	11.3	25.9	5.3	16.6	16.6	42.5
08/28-30	32.4	29.9	22.2	7.8	54.6	37.6
09/04-05	47.5	63.7	23.3	45.5	70.7	109.2
09/09-10	25.9	-	18.1	-	44.0	-
09/16-18	42.8	49.5	16.2	49.7	59.1	99.2
09/22-24	25.5	19.0	27.6	15.0	53.1	34.0
10/17-19	51.6	37.7	13.1	15.3	64.8	53.0
10/19-21	42.5	38.7	36.7	25.3	79.2	63.9
10/22-24	26.4	47.9	10.9	52.8	37.3	100.7
10/27-28	75.5	65.3	34.1	43.8	109.6	109.0
11/03-04	43.5	19.7	47.4	22.9	90.9	42.5
11/06-07	40.0	31.0	35.7	34.1	75.7	65.1
11/08-09	43.8	40.5	47.4	52.8	91.1	93.3
11/13-14	40.5	25.9	52.8	37.9	93.3	63.8
11/17-18	38.9	28.5	53.3	52.0	92.2	80.5
11/22-23	41.7	30.6	47.5	41.9	89.2	72.5
12/01-02	36.1	33.8	37.9	37.6	74.0	71.4
12/04-05	47.7	37.7	43.2	35.8	90.9	73.6
12/06-07	27.5	22.9	30.4	27.9	57.9	50.8
12/11-12	34.0	31.7	40.0	33.0	74.0	64.7
12/15-16	40.5	33.6	41.7	38.0	82.2	71.6
12/18-19	28.2	22.2	33.4	30.9	61.6	53.2
12/22-23	34.5	24.5	40.6	36.9	75.1	61.4

Table B-2 (continue)

Date	$PM_{2.5}$ (μg m^{-3})		$PM_{2.5-10}$ (μg m^{-3})		PM_{10} (μg m^{-3})	
	Day	Night	Day	Night	Day	Night
12/25-26	41.0	27.1	43.4	35.6	84.4	62.7
12/29-30	36.1	27.5	39.6	34.5	75.7	62.1
1/05-06	25.0	23.6	30.1	26.3	55.1	49.9
1/08-09	27.1	22.9	36.5	32.6	63.6	55.6
1/10-11	27.4	27.5	36.7	31.9	64.1	59.5
1/15-16	34.7	22.7	38.6	30.7	73.4	53.4
2/05-06	22.2	20.4	24.9	21.5	47.1	41.9
2/09-10	32.4	32.9	31.0	29.8	63.4	62.7
2/11-13	61.5	51.8	72.2	63.2	133.7	115.0
2/15-16	57.0	63.1	64.3	60.6	121.3	123.7
3/16-18	58.3	44.2	65.8	24.4	124.1	68.6
3/22-23	52.1	50.5	32.8	12.3	84.9	62.7
3/24-25	72.7	56.7	18.9	16.6	91.6	73.4
Ave.	39.3	35.1	35.4	33.1	74.7	68.2
S.D.	13.8	13.2	15.2	13.6	24.4	22.5

Table B-3

The concentrations (ng m^{-3}) of metallic species for PM$_{2.5}$ during daytime sampling period

Date	PM$_{2.5}$	Day	ng m^{-3}				
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
08/25-26	1666.7	601.9	509.3	509.3	1225.2	46.3	0.0
08/26-28	856.5	162.0	254.6	254.6	218.8	23.1	5.6
08/28-30	879.6	208.3	185.2	231.5	788.5	23.1	43.1
09/04-05	1273.1	347.2	254.6	254.6	733.1	46.3	99.2
09/09-10	810.2	300.9	254.6	254.6	562.4	23.1	0.0
09/16-18	925.9	208.3	324.1	254.6	686.7	23.1	5.6
09/22-24	833.3	208.3	254.6	277.8	615.6	0.0	43.1
10/19-21	416.7	115.7	324.1	231.5	582.6	46.3	0.0
10/22-24	416.7	92.6	324.1	231.5	348.3	69.4	0.0
10/27-28	562.7	203.2	218.8	241.2	592.9	43.2	3.8
11/03-04	1125.4	406.4	243.8	463.4	914.9	42.1	66.3
11/06-07	578.3	109.4	171.9	231.7	147.7	21.1	5.1
11/08-09	800.5	140.7	125.0	210.7	717.6	21.1	39.2
11/13-14	1158.6	316.0	141.2	222.5	667.2	42.1	90.3
11/17-18	737.3	273.9	171.9	371.9	511.8	21.1	59.3
11/22-23	842.6	189.6	294.9	231.7	624.9	20.8	5.1
12/01-02	758.4	189.6	231.7	252.8	560.2	17.3	29.1
12/04-05	579.2	195.3	291.7	215.7	524.4	45.2	22.9
12/06-07	422.3	184.3	294.9	259.3	317.0	43.2	39.2
12/11-12	758.4	273.9	261.4	237.7	592.9	62.5	47.1
12/15-16	1315.0	541.7	358.3	463.4	827.3	42.1	48.0
12/18-19	770.9	163.8	231.7	279.4	699.1	27.2	35.1
12/22-23	821.7	187.5	166.7	238.3	717.6	21.1	37.0
12/25-26	1002.4	314.5	202.1	229.2	667.2	41.7	33.6
12/29-30	739.2	203.2	229.2	267.3	521.8	20.8	22.9
1/05-06	625.2	173.7	224.2	234.7	624.9	24.7	25.1
1/08-09	562.7	142.7	231.7	262.0	554.0	0.0	29.1
1/10-11	281.3	178.2	266.9	256.3	524.4	42.1	27.2

1/15-16	281.3	154.3	218.8	192.6	313.5	43.2	22.8
2/05-06	562.7	273.9	233.2	231.9	651.5	23.4	35.1
2/09-10	281.3	154.3	294.8	225.7	348.3	46.5	39.2
2/11-13	313.9	187.7	148.3	260.0	670.3	76.8	97.2
2/15-16	388.6	277.9	96.6	252.8	833.3	21.9	97.2
3/16-18	924.3	330.5	148.3	252.8	385.1	30.5	97.2
3/22-23	95.8	76.5	96.6	238.3	164.8	0.0	25.8
3/24-25	351.2	84.2	96.6	238.3	184.6	4.5	25.8

Table B-4

The concentrations (ng m^{-3}) of metallic species for $PM_{2.5}$ during nighttime sampling period

Date	$PM_{2.5}$	Night	ng m^{-3}				
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
08/25-26	509.3	208.3	254.6	231.5	465.8	23.1	0.0
08/26-28	463.0	324.1	185.2	231.5	60.1	92.6	43.1
08/28-30	902.8	185.2	254.6	254.6	600.6	46.3	0.0
09/04-05	1527.8	231.5	254.6	254.6	821.5	46.3	5.6
09/16-18	1088.0	300.9	324.1	277.8	578.9	92.6	5.6
09/22-24	763.9	138.9	324.1	254.6	500.3	46.3	0.0
10/17-19	2245.4	856.5	254.6	277.8	616.3	69.4	0.0
10/19-21	810.2	532.4	324.1	277.8	271.9	92.6	0.0
10/22-24	648.1	254.6	324.1	254.6	585.6	46.3	0.0
10/27-28	787.0	208.3	393.5	254.6	823.7	92.6	5.6
11/03-04	688.1	158.8	130.5	276.4	655.0	17.6	22.5
11/06-07	652.8	246.9	142.9	276.4	413.7	72.8	32.5
11/08-09	687.9	189.4	130.5	194.0	614.4	47.4	27.5
11/13-14	1164.2	236.8	254.7	239.0	840.3	47.4	15.6
11/17-18	829.0	307.8	324.1	242.4	496.7	86.4	25.6
11/22-23	781.5	142.1	324.1	230.5	456.4	47.4	15.2
12/01-02	1999.0	876.2	254.6	214.4	315.9	71.0	19.3
12/04-05	828.8	272.9	324.1	211.7	539.4	88.7	18.2

12/06-07	663.1	130.5	299.1	194.0	495.2	35.3	24.6
12/11-12	805.1	226.8	299.9	260.5	422.2	47.5	15.6
12/15-16	261.0	241.8	194.0	236.8	465.8	25.3	20.3
12/18-19	237.3	166.1	141.1	236.8	459.2	47.5	19.5
12/22-23	762.8	294.9	194.0	260.5	457.7	35.3	25.6
12/25-26	788.1	231.5	194.0	330.5	625.9	46.3	25.6
12/29-30	857.7	301.0	224.1	242.4	441.1	33.5	17.2
1/05-06	691.6	142.1	324.1	226.5	511.8	47.4	17.9
1/08-09	1022.0	439.0	260.5	342.4	696.3	35.6	13.4
1/10-11	810.4	272.9	301.5	267.8	471.9	89.5	23.6
1/15-16	651.3	270.5	331.5	254.7	585.6	35.3	17.2
2/05-06	787.2	286.8	201.7	254.7	823.9	70.6	18.6
2/09-10	483.1	324.1	165.9	376.4	389.1	94.7	22.4
2/11-13	369.9	157.8	148.3	260.0	345.4	56.6	43.6
2/15-16	257.8	154.1	148.3	252.8	361.9	24.8	97.2
3/16-18	1254.5	433.7	148.3	260.0	989.7	71.0	43.6
3/22-23	27.3	61.8	96.6	245.5	161.5	0.0	25.8
3/24-25	95.8	66.1	148.3	245.5	799.2	0.0	43.6

Table B-5

The concentrations (ng m^{-3}) of metallic species for $PM_{2.5-10}$ during daytime sampling period

Date	$PM_{2.5-10}$	Day	ng m^{-3}				
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
08/25-26	759.5	2191.8	238.7	303.8	567.3	43.4	22.8
08/26-28	803.0	444.9	119.4	130.2	79.4	108.5	0.0
08/28-30	1117.6	260.4	119.4	130.2	288.2	43.4	0.0
09/04-05	1215.3	379.8	151.9	141.1	245.7	21.7	0.0
09/09-10	889.8	282.1	119.4	119.4	293.1	21.7	0.0
09/16-18	878.9	227.9	119.4	130.2	278.4	21.7	0.0
09/22-24	1204.4	314.7	151.9	141.1	264.7	32.6	0.0
10/19-21	813.8	314.7	151.9	130.2	445.8	21.7	0.0
10/22-24	282.1	162.8	151.9	119.4	242.6	10.9	0.0
10/27-28	1269.5	368.9	151.9	130.2	211.3	21.7	0.0
11/03-04	762.7	723.8	122.3	112.3	192.4	39.2	11.3
11/06-07	806.3	446.8	119.9	130.8	125.2	42.5	3.3
11/08-09	870.0	261.5	119.9	173.2	289.4	43.4	0.0
11/13-14	751.3	936.1	116.6	140.1	241.7	21.7	7.2
11/17-18	893.5	251.8	118.6	118.6	288.3	21.7	0.0
11/22-23	873.0	203.3	118.6	128.1	273.8	21.7	0.0
12/01-02	622.4	372.2	149.4	138.8	260.4	32.6	5.3
12/04-05	808.3	312.6	112.2	128.1	337.2	21.7	7.8
12/06-07	280.2	423.6	132.3	181.5	240.9	10.9	6.3
12/11-12	650.0	362.9	149.4	129.3	209.9	21.7	0.0
12/15-16	747.2	528.1	102.1	129.2	201.1	26.3	12.7
12/18-19	789.9	726.1	122.4	184.3	122.4	22.5	6.2
12/22-23	692.3	258.7	118.6	129.3	247.2	20.1	3.4
12/25-26	835.6	377.2	72.5	140.1	244.1	21.7	3.4
12/29-30	794.0	449.4	118.6	115.3	221.7	21.7	4.7
1/05-06	784.3	433.6	117.4	132.6	270.0	21.7	5.3
1/08-09	775.8	354.0	116.8	125.9	265.8	20.2	2.4
1/10-11	808.3	316.0	129.3	141.2	442.8	21.7	10.1

1/15-16	280.2	362.8	149.4	151.2	243.6	10.9	0.0
2/05-06	885.2	366.4	69.3	116.2	212.2	21.7	0.0
2/09-10	864.6	226.3	106.5	172.3	279.5	21.7	0.0
2/11-13	139.0	360.5	69.5	121.9	117.0	0.0	12.1
2/15-16	842.1	503.2	45.3	128.7	90.7	11.6	3.7
3/16-18	342.8	159.9	69.5	115.1	71.1	3.5	12.1
3/22-23	366.1	162.2	69.5	128.7	482.0	0.0	12.1
3/24-25	199.7	75.0	45.3	115.1	43.7	0.0	0.0

Table B-6

The concentrations (ng m^{-3}) of metallic species for $PM_{2.5-10}$ during nighttime sampling period

Date	$PM_{2.5-10}$	Night	ng m^{-3}				
	Fe	Mg	Cr	Cu	Zn	Mn	Pb
08/25-26	596.8	282.1	86.8	130.2	183.3	10.9	0.0
08/26-28	553.4	206.2	86.8	119.4	265.7	21.7	0.0
08/28-30	835.5	173.6	119.4	130.2	241.5	10.9	0.0
09/04-05	1345.5	336.4	151.9	151.9	228.2	21.7	2.6
09/16-18	803.0	271.3	119.4	130.2	282.2	21.7	2.6
09/22-24	553.4	130.2	151.9	130.2	246.1	21.7	0.0
10/17-19	293.0	76.0	151.9	119.4	289.3	0.0	46.5
10/19-21	878.9	347.2	151.9	130.2	259.1	21.7	0.0
10/22-24	1356.3	651.0	151.9	130.2	314.5	32.6	0.0
10/27-28	900.6	260.4	151.9	130.2	322.2	32.6	0.0
11/03-04	623.8	278.5	86.8	130.2	190.3	11.3	18.2
11/06-07	578.7	203.5	86.8	119.4	275.9	22.5	2.3
11/08-09	867.6	171.4	119.4	130.2	250.8	11.3	3.6
11/13-14	693.2	332.0	132.3	151.9	237.0	21.4	2.6
11/17-18	833.8	267.8	119.4	105.2	182.2	22.5	2.6
11/22-23	574.6	130.2	150.0	130.2	242.9	22.5	4.4
12/01-02	304.2	227.1	106.2	119.4	285.5	0.0	1.2
12/04-05	912.7	347.2	125.3	130.2	255.7	22.5	7.2

12/06-07	772.4	332.2	122.4	114.2	190.0	15.3	4.2
12/11-12	889.0	270.4	117.2	115.4	199.3	17.2	5.2
12/15-16	589.1	293.0	90.1	131.4	180.9	10.9	5.3
12/18-19	546.2	214.1	85.7	119.4	253.2	11.3	3.8
12/22-23	824.7	173.6	117.8	130.2	250.8	10.9	5.3
12/25-26	749.4	336.4	115.4	151.9	237.0	17.2	2.6
12/29-30	803.0	271.3	122.3	115.2	278.6	11.4	1.5
1/05-06	504.4	130.2	122.0	135.2	233.2	14.5	3.2
1/08-09	282.0	95.2	107.2	119.4	265.2	0.0	1.1
1/10-11	795.1	347.2	114.5	130.2	203.8	11.2	0.0
1/15-16	859.8	227.4	104.8	122.2	170.2	12.3	22.2
2/05-06	706.1	260.4	102.5	130.2	178.0	22.4	2.1
2/09-10	597.1	282.1	79.1	130.2	167.1	10.9	0.0
2/11-13	561.8	164.6	93.8	128.7	123.7	7.5	3.7
2/15-16	991.0	404.4	69.5	135.5	202.2	18.4	12.1
3/16-18	299.0	152.5	69.5	115.1	95.3	0.0	3.7
3/22-23	336.9	130.5	93.8	118.5	334.3	0.0	3.7
3/24-25	62.4	59.6	69.5	115.1	95.3	0.0	3.7

Appendix C

Selective Metallic Element Analysis Conditions and Calibration Curves

Table C-1

Operation conditions of each metallic elements of flame atomic absorption spectrophotometer

Metal	Wavelength (nm)	Slit Width (nm)	Time (sec)	Operation Current (mA)	Maximum Current (mA)
Fe	248.3	0.2	1.0	10	15
Mg	285.2	1.3	1.0	10	18
Cr	359.3	1.3	1.0	10	15
Cu	324.8	1.3	1.0	5	15
Zn	213.9	1.3	1.0	10	15
Mn	279.6	1.3	1.0	7.5	15
Pb	283.3	1.3	1.0	7.5	15

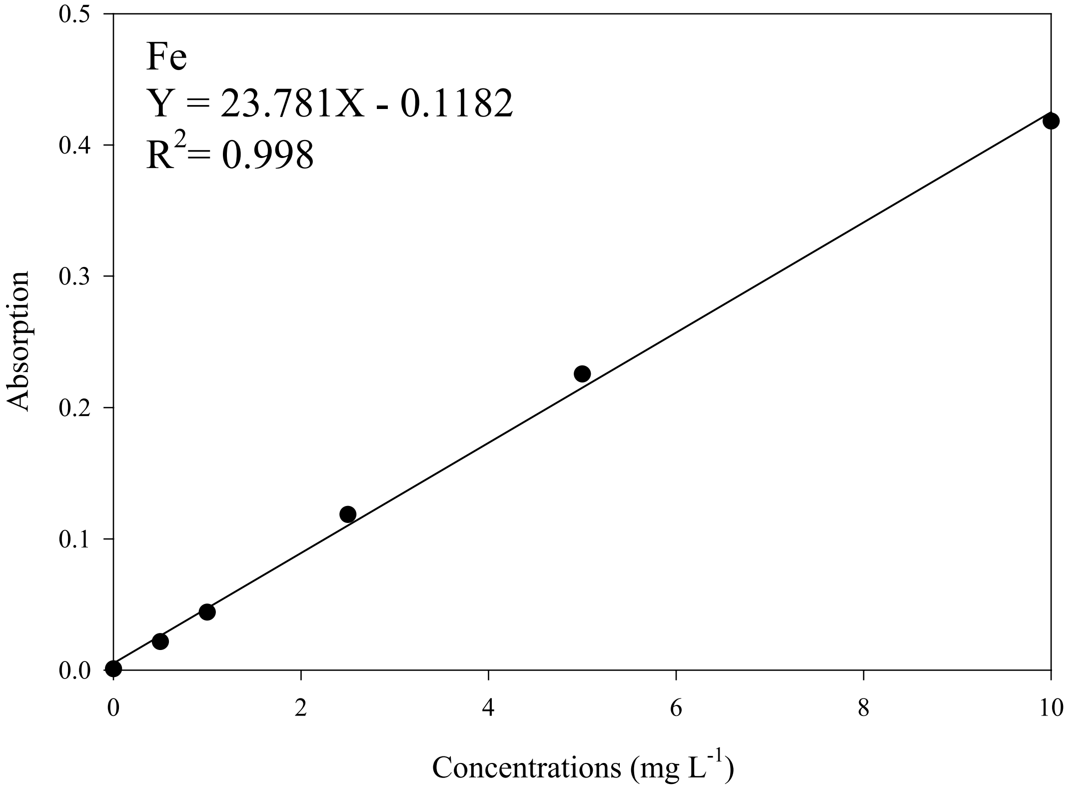

Fig. C-1 Fe of the calibration curve

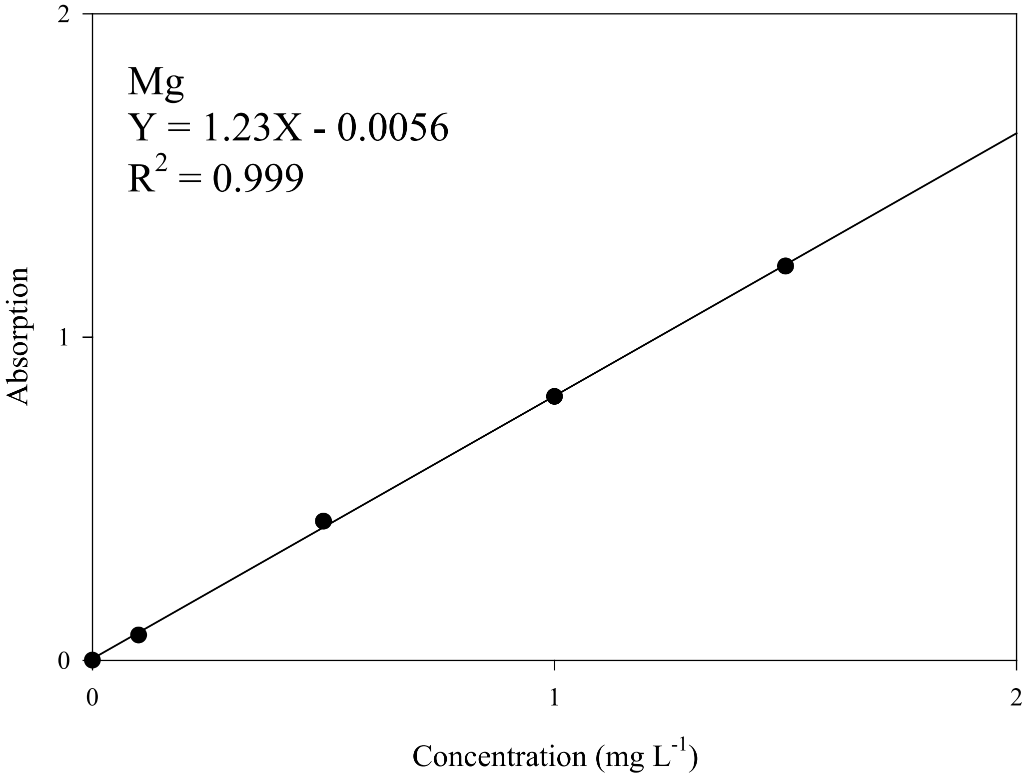

Fig. C-2 Mg of the calibration curve

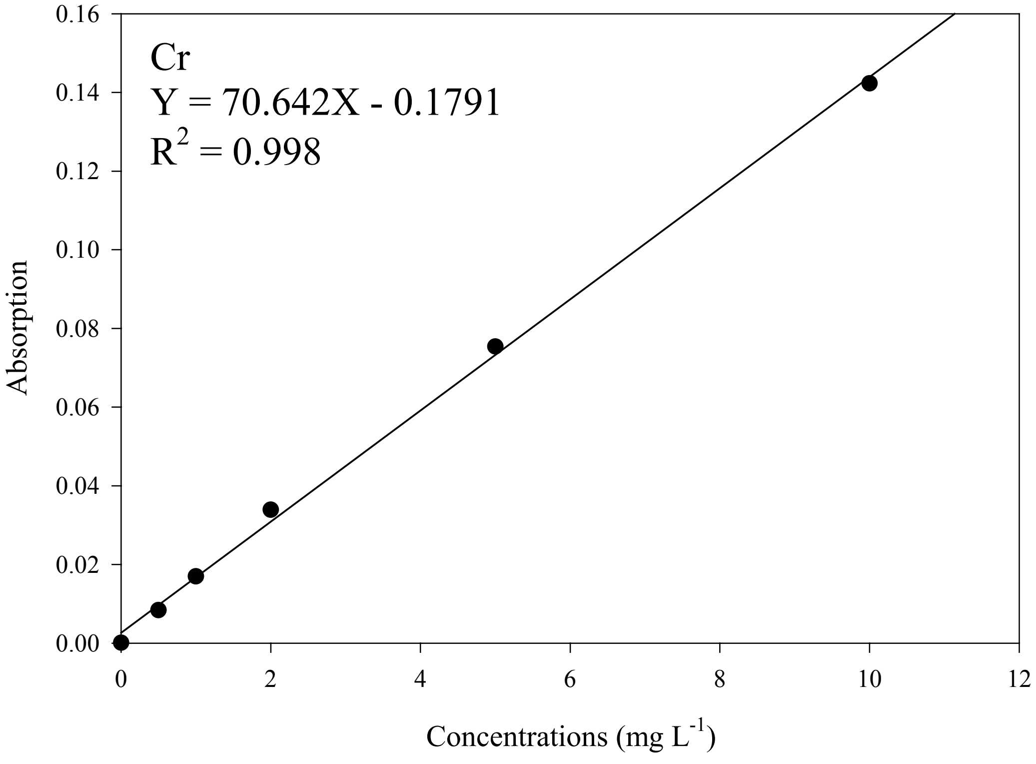

Fig. C-3 Cr of the calibration curve

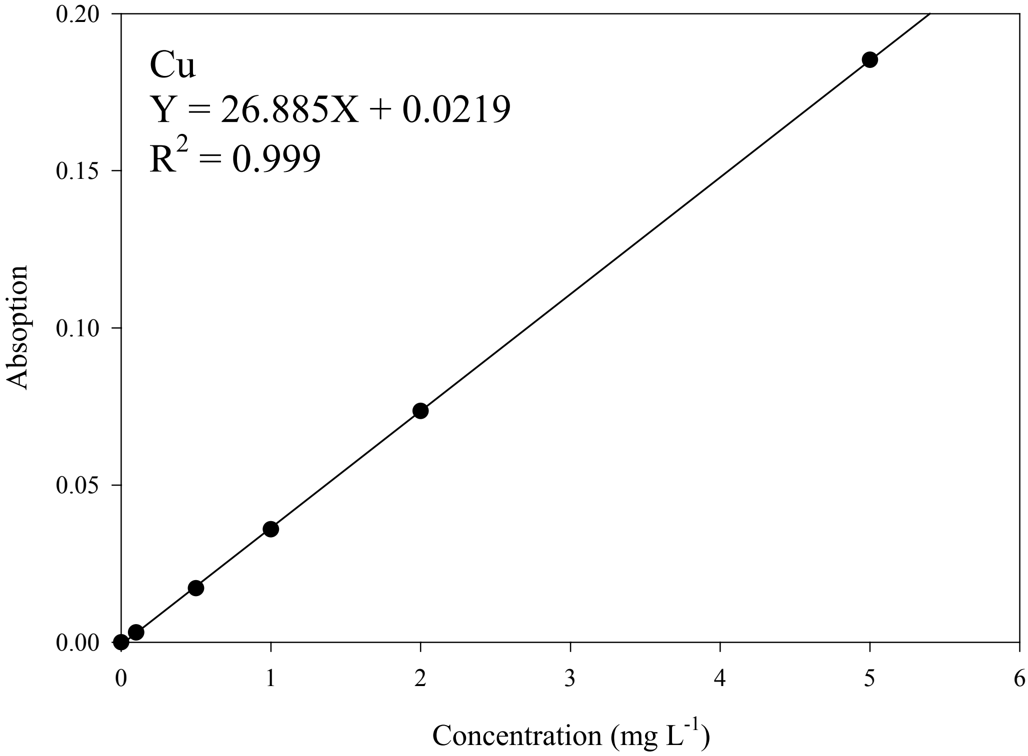

Fig. C-4 Cu of the calibration curve

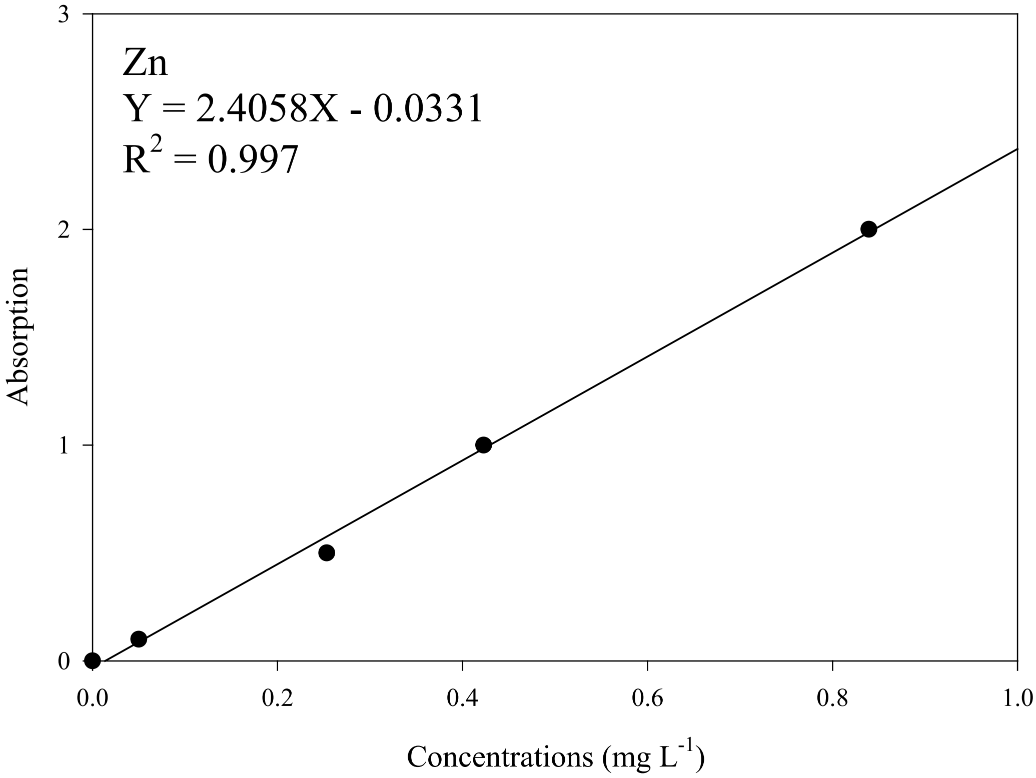

Fig. C-5 Zn of the calibration curve

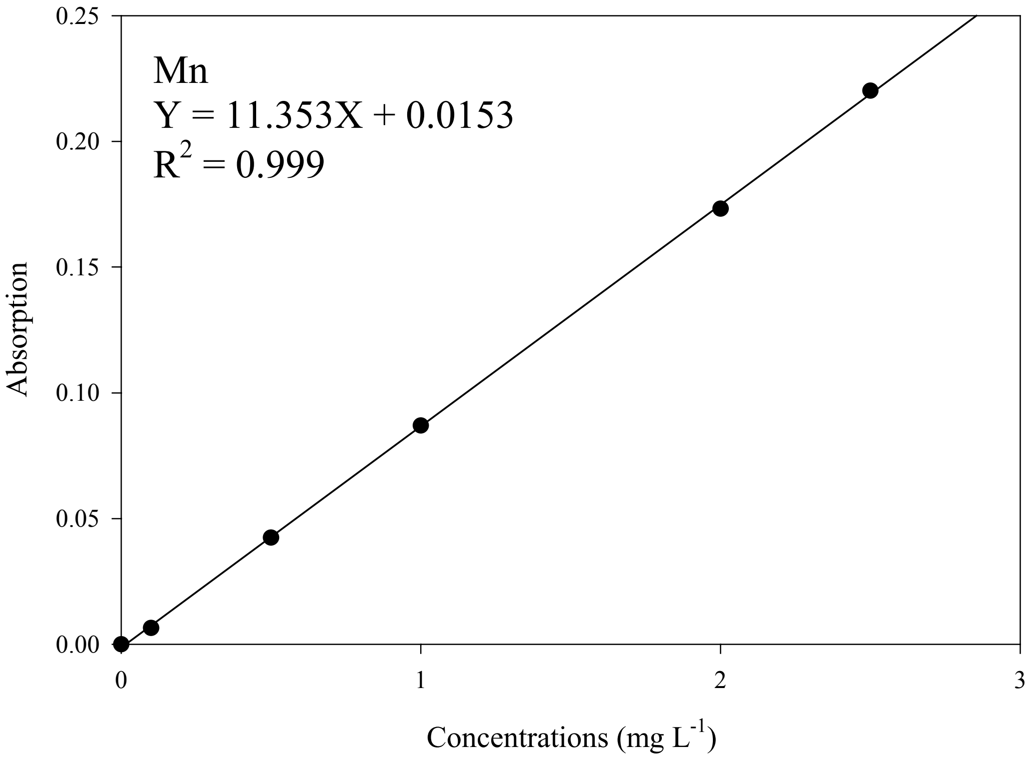

Fig. C-6 Mn of the calibration curve

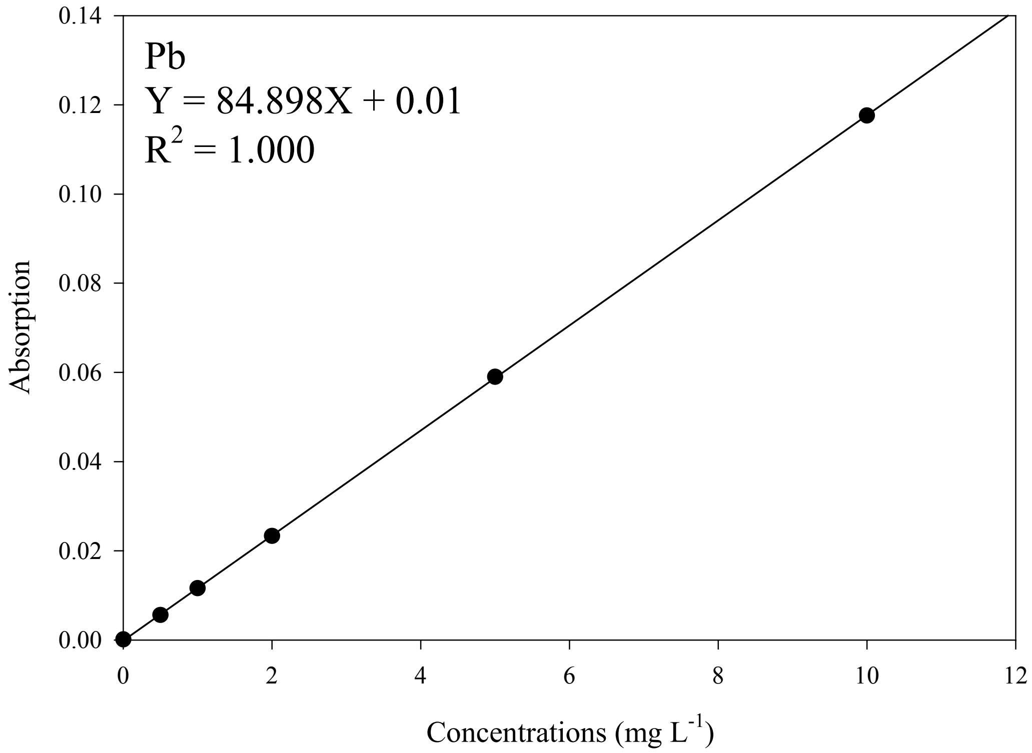

Fig. C-7 Pb of the calibration curve