# Chapter 1

## Introduction

Ambient suspended particle is a major source of environmental air quality pollution in Taiwan during the past decades. Previous air quality studies have concentrated mainly on outdoor air quality problems. Indoor air quality has raised people's attention and became an important issue in resent year (Chao and Wong, 2002; Gomzi, 1999).

Tzu Yun Yen temple has a history of three hundred years. It is the oldest temple in the Taichung area with brilliant gilded walls and ceiling. The main deity worshiped at the temple is the Bodhisattva Kuan-yin. Other Buddhist-Taoist gods are also worship at Tzu Yun Yen temple. The temple symbolizes the religious and cultural development of communities in the surrounding regions. Since its first completion in 1662, the temple has been restored and partially rebuilt several times. From 1972 to 1980, a major renovation and expansion of the temple structure was conducted. When the expansion was completed in 1980, Tzu Yun Yen became even more brilliant and grandiose.

There are many pilgrims from different areas and various beliefs, representing the eclecticism of the temple and those who come to visit it. Incense burning is the major activity for each pilgrim visiting the temple. The average number of people visiting this temple is about 3000   5000 per day. More number of pilgrims visited the temple and burning incense on Zhong Yuan Jie, and the $1^{st}$ and $15^{th}$ of nong li for each month (Period É) than non- Zhong Yuan Jie, or non-$1^{st}$ and $15^{th}$ days of each month (Period Ð).

The current suspended particles air quality standards in Taiwan is with aerodynamic diameters less than 10 μm ($PM_{10}$) are 65 μg $m^{-3}$ for an annual arithmetic average and 125 μg $m^{-3}$ for 24-hours average. But, these limitations apply only to outdoor air quality standards. There are no indoor air quality standards being enforced in Taiwan EPA. Especially its impacted to human health effect. Thus, the result obtained in this study can provide as a reference index for EPA as a health index in the future.

# Chapter 2

# Literature Review

## 2.1 Suspended particulates and size distribution

Ambient aerosol particulate matter in the air is called PM (particulate matter). The aerosol particles cover a size range from a few nanometers up to several tens of micrometers in diameter. These ultra particles coagulate rapidly at depending on their concentration and thermodynamic conditions to form larger particles with diameter of 0.1 up to 100 μm (Chen *et al.*, 1998). The particulate air pollution includes solid and liquid particles directly emitted into the air such as diesel soot, road and agricultural dust, and particles resulting from manufacturing processes (Ostro, and Chestnut, 1998). Total mass concentration of suspended particulates in the air is called TSP (total suspended particulates). Particles less than 10ì m (0.01mm) in aerodynamic diameter are called respiratory particulates or $PM_{10}$, which $PM_{2.5}$ refers to fine particles less than 2.5 ì m in aerodynamic diameter (Ohlström *et al.*, 2000). The suspended particulate is a non-chemically specific criteria standard that has been frequently modified more. The standard was initially applied to TSP and, then, revised to a diameter of less than 10 μm ($PM_{10}$). PM smaller than 2 or 3 μm, referred to as ‘fine particle size fraction’, which consists of the ‘nucleation’ range with diameters of less than 0.08 μm and the ‘accumulation’ range with diameters between 0.08 and 2 μm (Chow *et al.*, 1995). Ultra-fine particle with diameters less than 0.1 μm originate mainly from gas-to-particle conversion or combustion processes. The ultra-fine particles coagulate rapidly depending on their concentration and thermodynamic conditions forming larger particles attributed to the accumulation mode, which ranges from 0.1 up to 1.0μm (Tuch *et al.*, 2000).

Ambient PM from different related source of suspended particulates. In past decade, emissions of anthrogenic air pollutants in Asia have been increasing drastically in recent years. Air pollution caused by suspended particle pollution has become a serious problem in Taiwan (Lee *et al.*, 2001). Secondary aerosol including, sea-spray exhaust from diesel engine combustion, photochemical production, exhaust from power plants, and incomplete combustion exhaust from vehicles are the major air pollution sources in Central Taiwan (Chen *et al.*, 1998). Air pollution in traffic centers is characteritic by emissions and concentrations of primary pollutants that have extremely strong spatial and temporal variations Some particles are also produced through photochemical reactions from air pollution gases, such as sulfur and nitrogen oxides that come from fuel combustion (Ostro, and Chestnut, 1998).

## 2.2 Source of metallic elements component in suspended particulates

The study results by Marcazzan *et al.*, (2001) in Milan (Italy). The size distribution of the metals were influenced by at least four processes governing their concentrations in sub-micron, inter-mediate and coarse particles: (a) primary emissions of ultra-fine particles from combustion and/or industrial processes; (b) advection of air masses containing aged intermediate size aerosols and/or primary emissions of particles in this size range; (c) large particles arising mainly from re-suspension; and (d) frictionally generated particles (mechanical wear).

Dust on the surface of paved roads or streets consists of a complex mixture of soil dust, deposited motor vehicles exhaust particles, tire dust brake lining wear dust plants fragments, and other biological materials (Miguel *et al.*, 1999). These dust were by wind become PM in air. In addition, the $PM_{10}$ include man-made sources and natural sources. The primary man-made sources of $PM_{10}$ include fugitive dust from motor vehicles, combustion of solid fuels, agricultural activities, and construction activities. Volcanic emissions, wind blown dust, marine aerosols and fly ash from forest fires are some of the more important natural sources of $PM_{10}$ (Rajkumar and Chang, 2000). The chemical composition of the ceramic particulate emissions is very similar to the crustal end-member. High Al, Fe, and Ti levels coupled with a peculiar grain-size distribution in the major insoluble phases in the PM (Querol *et* *a*l., 2001).

The study results by Conner *et al.,* 2001 at both the indoor and outdoor sites, particle types associated with industrial activities (e.g., Al rich, Ni and/or V, fly ash) were measured their highest concentrations on the industrial air PM. These were found at much lower concentrations, or not at all, at the indoor sampling site, as expected for coarse particles of industrial origin.

Nickel compounds mainly emitted by combustion from anthropogenic sources are predominantly soluble such as nickel sulphate. A few industrial processes may also emit metallic nickel and nickel alloys. Both Ni and V are correlated in the chemical fraction of metal bound to organic matter or sulphidic metal. These metals have a strong relationship with the combustion of fuels used in the industrial activities of Seville city (Spain). Other metals are also correlated in this fraction, such as Pb with Cu and Cd. These metals have a relationship with combustion of fuels used in vehicular traffic (Espinosa *et al.*, 2002).

The ambient Cu and Pb concentrations around these temples were generally higher than those of the background site and is in agreement with the hypothesis that activities inside the temples would have adverse impacts on the surrounding. Since the joss paper stick ash contains higher levels of heavy metals than the joss stick ash, burning joss paper is the major cause of higher heavy metals found in the ambient air around the temple (Lau and Luk, 2001).

Coarse particles characterized by high concentrations of Ca, Mg, and K were similar to those found in components of sea salt. Measured concentrations on the marine air mass at the community site (Conner *et al.*, 2001). The outdoor site appeared to be less impacted by marine air on that day. The cations $Na^{+}$, $K^{+}$, $Ca^{2+}$ and $Mg^{2+}$ accounted 22.7% to the total water-soluble mass and for the ionic components of the aerosol. On a percentage basis $K^{+}$ dominated in the fine mode while $Ca^{2+}$ and $Mg^{2+}$ in the coarse mode. $Na^{+}$ was equally distributed in the two modes (Parmar *et al*., 2001). The $Na^{+}$, $K^{+}$, $Ca^{2+}$, and $Mg^{2+}$ are major components in marine air mass.

## 2.3 Epidemiological studies

### *2.2.1 Airborne particulates in epidemiological studies*

Recent epidemiological studies have shown that the suspended particulate matters cause adverse lung function parameter, respiratory symptoms and mortality (Dockery *et al.*, 1993). Additionally, there is an increasing recognition that adverse health effects due to the exposure to airborne PM than many other airborne pollutants (Hitchins *et al*., 2000). Epidemiological studies conducted in several countries show consistent associations of exposure to ambient particulates with adverse health effects, which include increased mortality, hospitalization for respiratory or cardiovascular disease, respiratory symptoms and decreased lung function. Based on epidemiological time series studies, the dose-response functions was identified between an increase in PM and adverse health effects (El-Fadel and Massoud, 2000). The PM is a different deposition in the respiratory system. A total of 18% of the 0.37 ìm particles is predicted to deposit in the respiratory tract: 3.5 % in the nasopharyngeal region, 3.5 % in the tracheobronchial region, and 11% in the pulmonary region. Since incense burning generates a large amount of particles, over an extended period of time (e.g. years of incense use) habitual incense use increases the exposure to respirable-size particles. However, the literature dose not supplies epidemiological links with respiratory disease and incense use (Mannix *et al.*, 1996).

Tuch *et al.*, (2000) and Koliadima *et al.*, (1998) found the health-related were associated with either the total mass concentration of TSP or the mass concentration of particles with aerodynamic diameters smaller than 10 μm or smaller than 2.5 μm. The concentration, composition, and particle size of suspended particulate matter at a given site are determined by such factors as meteorological properties of the atmosphere, topographical influences, emission sources, and by particle parameters such as density, shape, and hygroscopicity. Standards methods for monitoring this pollution have been established. As technology improves in measurement techniques and more information will become available on the relationship between exposure and health effects (Hitchins *et al.*, 2000). Table 2.3-1 are shows metallic elements adverse health effects (Lin, 1997).

Table 2.3-1

Metallic elements have a direct adverse health effects. (Lin, 1997)

| Metal element | Adverse health effects |
|---|---|
| Cadmium (Cd) | Emphysema, kidney disease, high blood pressure, and carcinogenic |
| Nickel (Ni) | Skin disease (dermatitis), carcinogenic, and obstacle breathe |
| Manganese (Mn) | Skin disease (dermatitis), carcinogenic, and memory decline |
| Lead (Pb) | Lead poisoning, anemic, loss of appetite, vomit, abdominal pain, and otitis media |
| Iron (Fe) | Iron poisoning and dust pulmonary disease |
| Zinc (Zn) | Arteriosclerosis, high blood pressure, and heart disease |
| Chromium (Cr) | Nostril inflammation, nostril per-formation, and emphysema, and carcinogenic |
| Copper (Cu) | Skin disease (dermatitis) and carcinogenic |

## 2.4 Indoor air pollutions

The major physical change of indoor dust caused by heating, is increased of number emitted sub-micron particles. These particles are probably dominated by condensation particles, including condensed water. Size, shape and specific surface area of the residual dust show only minor differences from non-heated dust. The emission of particles even at low temperatures, starting at 50-100℃, which is often present in an indoor environment. This should be considered when introducing new products like halogen lamps etc. into the indoor environment. The particle counters do not separate between solid combustion products and condensation particles, and do not give any information of the particle chemistry (Pedersen *et al.*, 2001).

Chao and Wong (2002) measured at 34 homes in Hong Kong. These were also caught in the polymerized cyanoacrylate, which interacted with fingermarks and to enhance cyanoacrylate developed traces. The fine mode species were probably from combustion related sources and the coarse mode species were probably from the crust and of soil nature. Morimoto *et al.,* (1998) found the average indoor/outdoor (I/O) ratio of $PM_{2.5}$ was higher than the that of $PM_{10}$ indicating these fine mode particles existed indoors, and that come from combustion related sources such cooking, smoking, and incense burning. It was poorly correlates to the indoor and outdoor particulate level. Source of sublimation was a cigarette or stick of incense in which the dyes were packed with black carbon. The sublimation in an enclosed box developed clear traces within 15 min and the sublimated particles adhered to some fatty acids in the ridges of latent fingermarks.

In the past, the conditions prevailing in homes may not have been as comfortable as those we now enjoy, and some characteristics of the indoor environment are less than acceptable. Certainly an increased reliance on wood and coal burning to provide domestic heat meant that particle pollution from these sources is generally higher than observed today. At present, we have only limited knowledge in this area. In part, this is due to the lack of gold standards that can be used to assess the quality of indoor air; whilst highly refined techniques are available for outdoors, the measurement and reporting of indoor air pollution is less advanced. These technologies must be developed (Jones, 1998).

Human indoor activity seems not to have any noticeable effect on the typical daily aerosol concentration, which seems to indicate that in the absence of combustion, indoor sources are very limited in office environment (Koponen *et al.*, 2001). The major outdoor sources of important indoor air pollutants are given in Table 2.4-1. The study have showed that reactive gasses such as ozone tend to occur at lower concentrations the indoor than outdoors because they react rapidly with indoor environment surface. Non-reactive gases may accumulate indoors and exposures there may be greater than outside (Jones, 1999).

Table 2.4-1
Outdoor sources of major indoor air pollutants (Jones, 1999).

| Pollutant | Percentage of emissions associated with industry | Percentage of emissions associated with transport |
|---|---|---|
| Benzene | 32 | 65 |
| Carbon monoxide (CO) | 3 | 90 |
| Lead (Pb) | 31 | 60 |
| Oxides of nitrogen (Nox) | 38 | 49 |
| Particulates ($PM_{10}$) | 56 | 25 |
| Sulphur dioxide ($SO_2$) | 90 | 2 |
| Volatile organic compounds (VOCs) | 52 | 34 |
| Ozone ($O_3$) | Arises from atmospheric chemical reactions | |

## *2.5* Dry deposition

### *2.5.1 Characteristic of dry deposition*

The process for removing particles or gases from the atmosphere through the delivery of mass to the surface by non-precipitation is defined as dry deposition (Dolske and Gatz 1985). Dry deposition of atmospheric contaminants is known to be an importance removal mechanism for trace metals. Understanding of the dry deposition to natural surface is far from complete. Dry deposition plate can be used to directly assess the deposited material that allows comparisons to be made between measured and modeled data (Holsen, and Noll, 1992).

Dry deposition plates have wave and flat surfaces opposite effects. Such as larger wave slopes that deposition plate is increase dry deposition flux with increasing wave slope. Total deposition to the wave surfaces was generally greater than to the flat surfaces. On average, deposition to the wave surfaces was 80 % greater than to flat surfaces. However, there was a large amount of variation among the different surface of plate (Zufall *et al.*, 1999).

### *2.5.2 Dry deposition velocities*

The definition of dry deposition velocity (Vd) is the dry deposition flux (mgm$^{-2}$day$^{-1}$) divides the TSP concentrations (ì gm$^{-3}$) and is a strong function of particle size. The dry deposition velocity of TSP mass was calculate as follows:

$$\mathbf{Vd = K \times (F)/(C_{TSP})} \text{............} \mathbf{(1)}$$

Vd: The dry deposition velocity of TSP mass (cm/sec)

K: Units conversion factor

F: The dry deposition flux of TSP mass (mgm$^{-2}$day$^{-1}$)

$C_{TSP}$: Ambient air concentration of TSP (ì gm$^{-3}$)

Metal elements are tended to associate with particle size less than 10 ì m in ambient air (Balachandran *et al.,* 2000; Querol *et al.,* 2001). Best-fit overall dry deposition velocities of metallic elements were obtained by calculating the slope of the regression line between the measured dry deposition flux and ambient concentration divided into several size ($PM_{2.5}$, $PM_{2.5-10}$, and $PM_{10}$) categories. To increase the sample size the following elements were grouped together (Yi *et al.,* 2001). The dry deposition velocity of metallic elements was calculate as follows:

$$\mathbf{Vd' = K \times (F)/(C_{SP})} \ldots\ldots\ldots\ldots (2)$$

Vd': The dry deposition velocity (cm/sec) of ambient concentration (ì $gm^{-3}$) divided into several sizes ($PM_{2.5}$, $PM_{2.5-10}$, and $PM_{10}$)

K: Units conversion factor

F: The dry deposition flux of TSP mass ($mgm^{-2}day^{-1}$)

$C_{SP}$: Ambient concentration (ì $gm^{-3}$) divided into several sizes ($PM_{2.5}$, $PM_{2.5-10}$, and $PM_{10}$)

Yi *et al.,* (2001) found while theory and experiments compare well for dry deposition to flat surfaces, it is necessary to understand the relationship between the minimum estimates and actual deposition. The deposition velocities are difficult to predict because they vary with atmospheric conditions, location and the size distribution of the depositing species. Very high deposition velocities and poor correlation coefficients for crustal elements obtained using fine particle concentrations were obtained because of the small concentration of crustal elements in the fine particle mode. The overall dry deposition velocities obtained using fine particle concentration for the primarily anthrogenic elements were better correlated with the flux. Deposition was increased at the upslope but reduced at the crest and down-slope.

# Chapter 3

# Experimental Methods

## 3.1 Sampling program

Ambient suspended particulate concentrations were taken at Tzu Yun Yen temple in this study. This is characteristic of incense burning indoor air pollution sampling sites. Universal sampler, MOUDI sampler, and dry deposition plate were used to measure particulate concentrations at Tzu Yun Yen temple. Besides, two dry deposition plates were located at indoor and outdoor environment at Tzu Yun Yen temple in this study. Table 3.1-1 showed the sampling information (sampling date, sampling time, pilgrims rate and sampling device) at Tzu Yun Yen temple. The sampling times were 9:00 AM to 9:00 PM and sampling periods were from 16/08/2001 to 02/01/2002 at Tzu Yun Yen temple in this study. The date of 8/19, 9/2, 9/17, 10/1, 10/17, 10/31, 11/15, 11/29, and 12/29 were days the 1$^{st}$ or 15$^{th}$ for each month of the Chinese lunar calendar (nong li) period in year of 2001 to 2002, respectively. The sampling date of 9/8 was day of Zhong Yuan Jie in 2001. Mean sampling time was 584 min/day at Tzu Yun Yen temple in this study. Meanwhile, pilgrims were 589 per hours at Tzu Yun Yen temple. In addition, metallic elements concentrations, compositions of $PM_{2.5}$ and $PM_{2.5-10}$ for incense burning at Tzu Yun Yen temple were also analyzed in this study. Furthermore, particle size distributions of Tzu Yun Yen temple were also described in this study.

Table 3.1-1

Sampling information at Tzu Yun Yen temple in the Taichung.

| Sampling NO. | Sampling date (m/d/y)[a] | Sampling times (min) | Pilgrims /hr | Sampling device |
|---|---|---|---|---|
| 1 | **08/16/2001** | 720 | 324 | **Universal** |
| 2 | **08/17/2001** | 550 | 552 | **Universal** |
| 3 | **08/18/2001** | 705 | 810 | **Universal, MOUDI** |
| 4 | **08/19/2001** | 612 | 840 | **Universal, DDP1**[b] |
| 5 | **08/20/2001** | 605 | 276 | **Universal, DDP1** |
| 6 | **08/22/2001** | 540 | 180 | **Universal, DDP1, DDP2**[c] |

| | | | | |
|---|---|---|---|---|
| 7 | 08/23/2001 | 670 | 216 | Universal, MOUDI, DDP1, DDP2 |
| 8 | 08/26/2001 | 575 | 552 | Universal, MOUDI, DDP1, DDP2 |
| 9 | 08/27/2001 | 565 | 156 | Universal, MOUDI, DDP1, DDP2 |
| 10 | 08/28/2001 | 615 | 108 | Universal, MOUDI, DDP1, DDP2 |
| 11 | 08/30/2001 | 580 | 180 | Universal, MOUDI, DDP1, DDP2 |
| 12 | 09/02/2001 | 605 | 744 | Universal |
| 13 | 09/03/2001 | 545 | 120 | Universal, MOUDI, DDP1, DDP2 |
| 14 | 09/04/2001 | 595 | 216 | Universal, MOUDI, DDP1, DDP2 |
| 15 | 09/05/2001 | 565 | 204 | Universal, MOUDI, DDP1 |
| 16 | 09/07/2001 | 523 | 264 | Universal, MOUDI, DDP1 |
| 17 | 09/08/2001 | 627 | 3120 | Universal, MOUDI, DDP1, DDP2 |
| 18 | 09/17/2001 | 588 | 928 | Universal |
| 19 | 09/21/2001 | 617 | 470 | Universal, MOUDI, DDP1, DDP2 |
| 20 | 09/22/2001 | 617 | 630 | Universal, DDP1, DDP2 |
| 21 | 09/23/2001 | 642 | 756 | Universal, MOUDI, DDP1, DDP2 |
| 22 | 10/01/2001 | 564 | 1460 | Universal, MOUDI, DDP1 |
| 23 | 10/06/2001 | 605 | 720 | Universal, MOUDI |
| 24 | 10/07/2001 | 635 | 444 | Universal, MOUDI, DDP1, DDP2 |
| 25 | 10/10/2001 | 613 | 504 | Universal, MOUDI, DDP1, DDP2 |
| 26 | 10/17/2001 | 603 | 1200 | Universal, MOUDI |
| 27 | 10/23/2001 | 330 | 312 | Universal, MOUDI, DDP1 |
| 28 | 10/27/2001 | 608 | 912 | Universal, MOUDI, DDP1 |
| 29 | 10/31/2001 | 418 | 684 | Universal, MOUDI, DDP1, DDP2 |
| 30 | 11/06/2001 | 635 | 312 | Universal |

Continue

a: month/day/year, b: Dry deposition plate 1 (indoor),

c: Dry deposition plate 2 (outdoor),

d: Standard deviation

| | | | | |
|---|---|---|---|---|
| 31 | 11/08/2001 | 635 | 264 | Universal |
| 32 | 11/15/2001 | 417 | 429 | Universal, MOUDI, DDP1 |
| 33 | 11/20/2001 | 635 | 366 | Universal, |
| 34 | 11/29/2001 | 660 | 1080 | Universal, MOUDI, DDP1, DDP2 |
| 35 | 12/04/2001 | 601 | 420 | Universal, MOUDI, DDP1 |
| 36 | 12/25/2001 | 525 | 220 | Universal, MOUDI |
| 37 | 12/29/2001 | 555 | 708 | Universal |
| 38 | 01/01/2002 | 459 | 756 | Universal, MOUDI, DDP1 |
| 39 | 01/02/2002 | 635 | 408 | Universal |
| | Average ± SD[d] | 584 ± 76 | 589 ± 527 | |

## 3.2 Sampling site

Ambient suspended particulate concentrations were taken at Tzu Yun Yen temple (120°, 34', 10" E; 24°, 16', 12" N) in this study. This is a representative sampling site of incense burning indoor air pollution. Tzu Yun Yen is the biggest and most famous temple in Ching Shui, Taichung, Taiwan. Ching Shui is a small city located at about 15 km in northwest of Taichung city. The population was Ching Shui city approximately 85,000 in 2001. The temple sampling site was about 250 m away from a major road. This is a typical incense burning and semi open sampling site. This temple is well ventilated and open to the outdoors either from the front door or from the ceiling. All samplers are near by the altar of the urn. The urn was the device and which all the pilgrams' incense was placed. A map of sampling site and sampler related sites were shown in Figure 3.2-1.

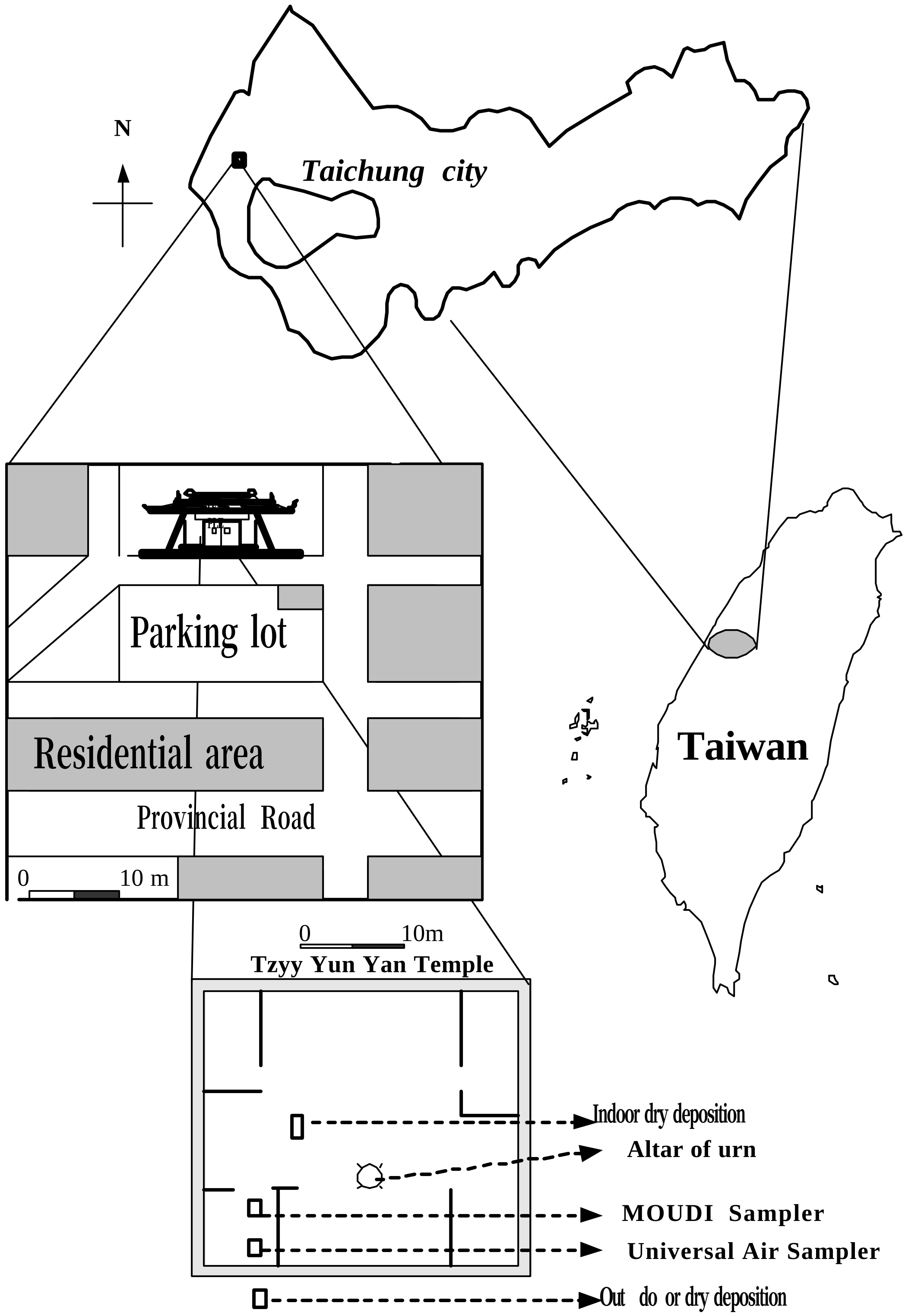


Figure 3.2-1

The sampling sites and sampler related sites at Tzu Yun Yen temple in central Taiwan.

## 3.3 Sampling device

An universal sampler, MOUDI (Micro Orifice Uniform Deposit Impactor) sampler and dry deposition plate were used to measure particulate concentrations at Tzu Yun Yen temple. Also, two dry deposition plates were located in the indoor and outdoor environment. The universal sampler, MOUDI sampler and dry deposition plate of related distance were more than 3-5 m at this temple. Universal Air Sampler and MOUDI Sampler were used to collect the ambient suspended particle concentrations during the whole sampling period. Universal Air Sampler measured the ambient suspended particles with equivalent aerodynamic diameter (E.A.D.) less than 2.5 μm and 2.5-10 μm. MOUDI Sampler was used to collect the different particle sizes ranging from 0.18 μm to 18 μm. Universal sampler, MOUDI sampler and dry deposition plate were used to measure particulate concentrations at Tzu Yun Yen temple.

### *3.3.1 Universal Air Sampler*

The Model 310 Universal Air Sampler ™ (UAS) is a general-purpose air sampler for atmospheric aerosol sampling and for mass concentration, and metal elements analysis (Figure 3.3-1). The sampler has a design inlet sampling flow rate of 300 L/min. Fully equipped, it includes two virtual impactors for size fractionation of airborne particles and a Poly-Urethane Filter (PUF) sampler for analysis of volatile organic compounds (VOCs) in the air sample. The sampler is provided with an omni-directional inlet, a $PM_{10}$ (10 μm cut) virtual impactor classifier, either a $PM_{2.5}$ or $PM_{10}$ virtual impactor classifier, or a fine particle filter and a PUF sampler. This allows operation as a high volume dichotomous sampler for size fractionation of airborne particle in the 0-2.5 μm and 2.5-10 μm aerodynamic size ranges. Air is sampled at 300 L/min from the ambient atmosphere through an omni-directional, cylindrical inlet. Particles greater than 10μm aerodynamic equivalent diameter are removed from the sampled air stream by the $PM_{10}$ classifier and discarded. Particle less than 10 μm flowed to the $PM_{2.5}$ classifier located downstream. Particles in the 2.5-10 μm range are collected on a 62 mm × 165 mm quartz fiber filter and those smaller than 2.5 μm are collected on a 200 mm × 250 mm final quartz fiber filter (Universal Air Sampler, 1996).

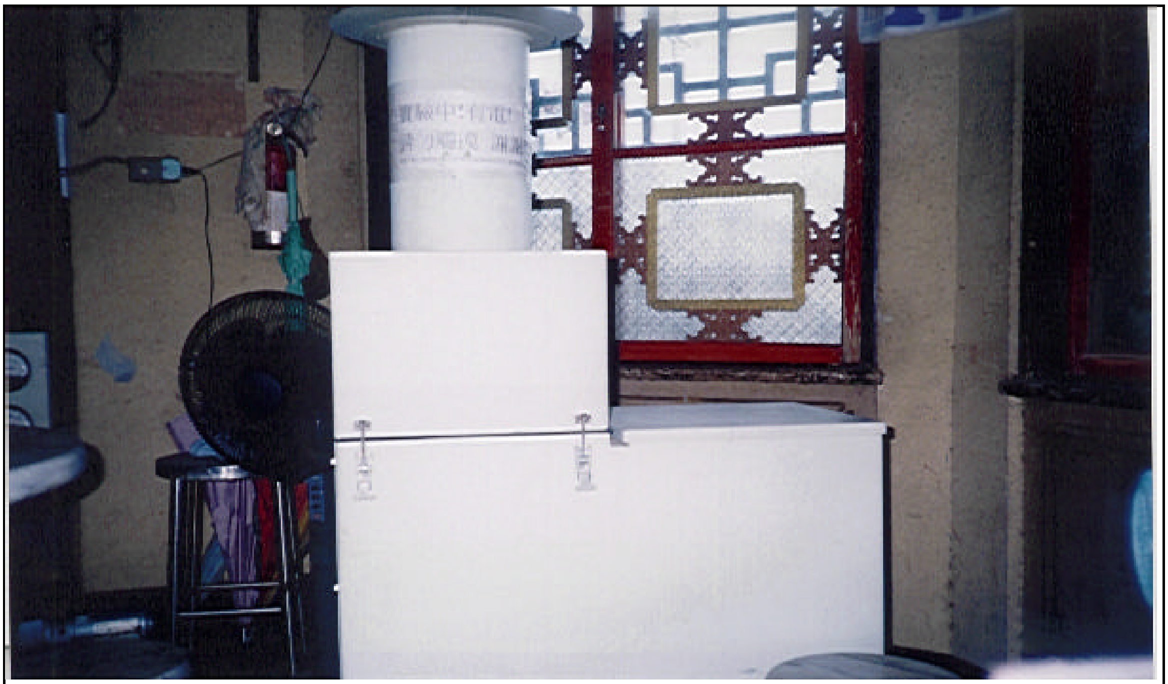

Figure 3.3-1

The Model 310 Universal Air Sampler collecting particulates at Tzu Yun Yen temple.

### *3.3.2 MOUDI Sampler*

MOUDI (Micro-Orifice Uniform Deposit Impactor, Model 100, MSP) Sampler is a cascade impactor intended for general-purpose aerosol sampling (Figure 3.3-2). The MOUDI Sampler is an 8-stages cascade impactor and consists of five basic assemblies, rotator impactor, magnehelic gage, rotator unit, shelter and blower motor. Each stage on the MOUDI Sampler consists of an impaction plate for the nozzle plate above and a nozzle plate for the impaction plate below. The use of micro-orifice nozzles can extend the cut sizes of the lower stage to 0.056

μm without creating an excessive pressure drop across the impactor stages. The principle of operation of the MOUDI is the same as any inertial cascade impactor with multiple nozzles. At each stage jets of particles laden air impinge upon an impaction plate and particles larger than the cut off size of the stage cross the air streamlines and are collected upon the impaction plate. The smaller particles with less inertia do not cross the streamlines and proceed on to the next stage at which the nozzles are smaller, the air velocity through the nozzles is higher and finer particles are collected. This continues on through the cascade impactor until the smallest particles are collected at the after-filter. The eight stages MOUDI includes cut off points of 18, 10, 5.6, 3.2, 1.8, 1.0, 0.56, 0.32, 0.18 and 0.056 μm, respectively (choice of eight) (Table 3.3-1). The flow rate was adjusted to 30 l/min. 47 mm diameter of aluminum filter paper with Silicone grease was used to collect particles. The final stage was used 37 mm diameter of quartz fiber filter to filter the particles.

The 47 mm aluminum filter was for 24 hours in a Soxhlet extractor. Silicone grease was then applied to the surface and allowed to equilibrate in a dry box (Temperature: 20 ±0.5℃, humidity: 35 ±5%) for at least 24 hours. Aluminum filter coated with silicone grease (ITW Fluid Products Group) was used as the surrogate surface and absorbent grease in this study. The sample substrates were held to the impaction plate by removable clamping rings, and the entire impaction plate assemblies were held in place by magnets for easy removal. The base of the MOUDI

Sampler held an after-filter in a removable filter holder similar to the impaction plates. Interchangeable impaction plates and filter holders were provided so that the impaction plate substrates and filter could be loaded and unloaded in the laboratory and decreased the chance of damaging the particle deposits during in-the-field substrate removal. Sealed transport covers for impaction plates and filter holders were provided so that the impaction plates and after-filter could be transported to and from the test site without contamination (Model 100 Micro-Orifice Uniform Deposit Impactor, MOUDI™, Instruction Manual, 1989).

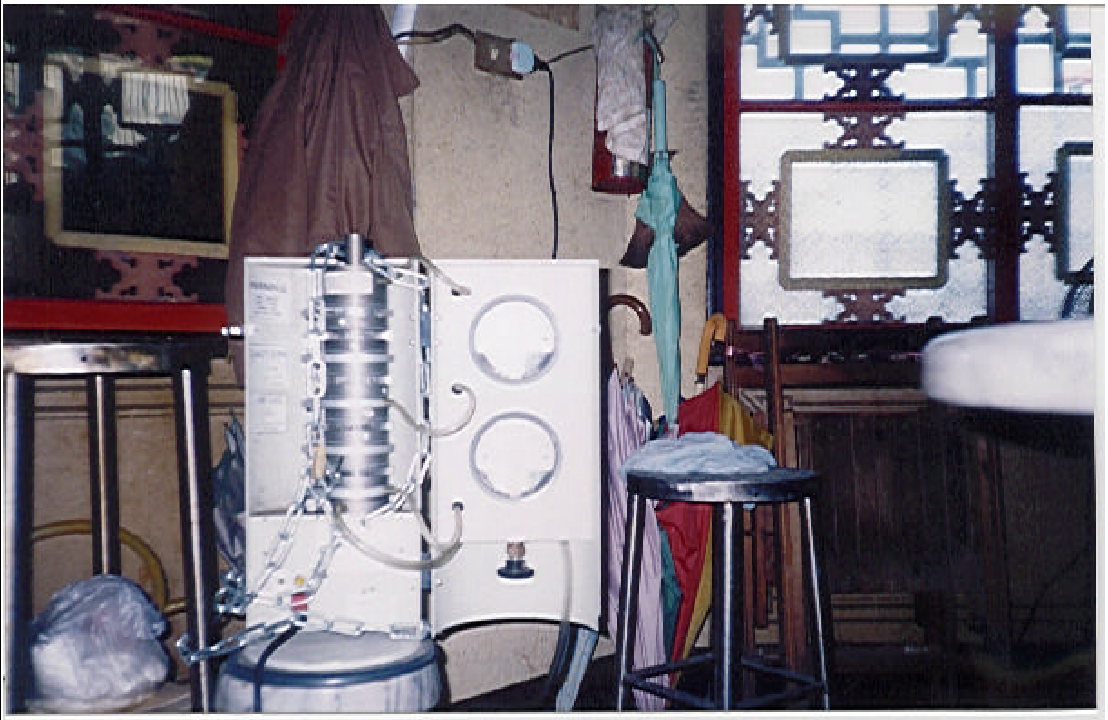

Figure 3.3-2

MOUDI Sampler collecting particulates at Tzu Yun Yen temple.

Table 3.3-1

The cut size and numbers of nuzzles of MOUDI Sampler.

| Stage | Nominal cut-point* (μm) | As calibrated cut-point* (μm) |
|---|---|---|
| Inlet (0) | 18 | 18 |
| 1 | 10 | 9.9 |
| 2 | 5.6 | 6.2 |
| 3 | 3.2 | 3.1 |
| 4 | 1.8 | 1.8 |
| 5 | 1.0 | 1.0 |
| 6 | 0.56 | 0.56 |
| 7 | 0.32 | 0.32 |
| 8 | 0.18 | 0.18 |
| Backup filter | < 0.056 | < 0.057 |

*Based on flow rate of 30 $lmin^{-1}$ at standard atmospheric temperature and pressure.

### *3.3.3 Dry Deposition Plate*

The dry deposition plate (Figure 3.3-3 and Figure 3.3-4) was similar and slightly modified to those used in wind tunnel studies, was made from polyvinyl chloride (PVC). It is 21.5 cm long, 7.6 cm wide, and 0.65 cm thick with a sharp leading edge (less than 10 degree angle) that is pointed into the wind by a wind vane. Each plate was covered on top with a thick projection film coated with approximated 20 mg of silicone grease to collected impacted particles. The thick projection film is 8 cm long, 5.5 cm wide, and 8 mm thick. The film was placed on the plate and held down on the edges with a thick plastic template, which was secured at each end by acrylic slats screwed into the plate. The plate were cut to slide onto two 0.7 cm diameter rods, two screws were fastened through the plate to a wind vane, allowing the plate to swing freely into the wind. The wind vane was made of aluminum and is 21.5 cm long, 17.5 cm wide. The plate was fitted with a galvanized iron stand. The stand can adjust its height between 130 cm and 200 cm. The distance between each stand can be regulated to prevent sample interactions. The two dry deposition plates were located at indoor and outdoor environment at Tzu Yun Yen temple in this study. The filters were weighed before and after exposure to determine the total mass and metal of particles collected. The analysis procedure is the same as the previous study by Fang *et al.*, (1997).

Figure 3.3-3

The dry deposition plate measured in indoor environment at Tzu Yun Yen temple.

Figure 3.3-4

The dry deposition plate measured in outdoor environment at Tzu Yun Yen temple.

## 3.4 Sample analysis

### *3.4.1 Suspended particle mass concentration measurement*

The quartz fiber filter used for collecting total suspended particles was quartz fiber filter (2500QAT-UP, Geleman Science. It produced by Pallflex Company (Putram, CT, U.S.A.). Its collection efficiency was 99.999% for the particle size greater than 0.5 μm. For the particle size less than 0.3 μm, its collection efficiency was 99.99%. Two dry deposition plates both measured dry deposition flux using the 70 mm × 90 mm quartz fiber filter. In addition, universal air sampler measured $PM_{2.5}$ and $PM_{2.5-10}$ using the same filter with 200 mm × 250 mm and 62 mm × 165 mm quartz fiber filter, respectively. Moreover, aluminum filter coated with silicon grease (ITW Fluid Products Group) was used as the surrogate surface and absorbent grease for MOUDI Sampler in this study. The aluminum filter paper was coated with the silicon grease to reduce particle bounce. The method for applying silicon grease to the surface of the aluminum filter paper is to spray the silicon grease from an aerosol causing a mask to protect the edges of the surface of filter paper. The mask is a thin plastic sheet with 3.71 cm diameter hole; it is placed over the filter paper that the hole is concentric with the center of the aluminum filter. The silicon grease was sprayed onto the surface of the aluminum filter paper.

Ordinarily, all filters were conditioned in a desiccator with constant temperature (20 ± 0.5°C) and relative humidity (35 ± 5%) to remove the unwanted moisture for at least 24 hours. Prior to sampling, the filter was taken from the desiccator and was weighted for the initial mass. Then, the filter was placed onto the dust-free and was brought to the sampling site. After sampling, the filter was also put into the dust-free box then taking it back to the laboratory. The filter was put into the desiccator for another 48 hours until the humidity equilibrium and then weighted the final mass. Finally, all the quartz fiber filters were divided to two parts for metallic element analysis.

### *3.4.2 Analysis for metal species*

The filter were weighted after humidity equilibrium (>24 hrs) in the desiccator, then exposure to the other half of the 70 mm ×90 mm filter, 62 mm ×165 mm filter and one-eighth of the 200 mm ×250 mm filter were digested in 20 ml concentrated nitric acid (65 %) at 150 ~ 200℃ for 2 hours, and then diluted to 30 ml with distilled-deionized water. After digestion, the AA-680/G flame atomic absorption spectro photometer was used to measure all samples. The samples were analysis Cadmium (Cd), Nickel (Ni), Manganese (Mn), Lead (Pb), Iron (Fe), Zinc (Zn), Chromium (Cr), and Copper (Cu) concentration, respectively. Background contamination was routinely monitored by using unexposed filters which are processed simultaneously with field samples.

## 3.5 Quality control

### *3.5.1 Blank test*

In Table 3.5-1, the results of the blank test are shown for this study. The blank test can be used to determine the background contamination from the analysis processes. Background contamination was determined by using operational blanks (unexposed filter) and the treatment for blank filters was the same as the field samples. The averaged operational blanks (unexposed filter) were not higher than 7 ì g/g for all elements.

Table 3.5-1

The results of the blank test for Quartz filter in this study.

| **Elements** (**Unit= ì g/g**) | Quartz filter 1 (62 ×165 mm) | Quartz filter 2 (200 ×250 mm) | Quartz filter 3 (70 ×90 mm) | Average |
|---|---|---|---|---|
| Cadmium (Cd) | **1.07** | **0.63** | **1.23** | **0.98** |
| Nickel (Ni) | **0.48** | **0.37** | **0.48** | **0.44** |
| Manganese (Mn) | **0.95** | **0.69** | **0.82** | **0.82** |
| Lead (Pb) | **2.08** | **1.21** | **2.40** | **1.90** |
| Iron (Fe) | **8.81** | **4.48** | **7.67** | **6.99** |
| Zinc (Zn) | **3.81** | **2.53** | **2.33** | **2.89** |
| Chromium (Cr) | **0.30** | **0.23** | **0.34** | **0.29** |
| Copper (Cu) | **1.67** | **0.95** | **1.64** | **1.42** |

*Quartz filter 1 and Quartz filter 2 used in universal air sampler. And quartz filter 3 used in dry deposition plate.

### *3.5.2 Method detection limit*

Detection limit was used to determine the lowest concentration level that can be detected to be statistically different from a blank. Method detection limit (MDL) was determined from selected the concentration slightly higher than the low concentration of the standard line. Repeat this blank concentration for seven times to estimate the standard deviation (S). Then, the MDL was based on three times the standard deviation of the blank concentration. The MDL of the chemical species in this study are showed in Table 3.5-2. Method detection limit (MDL) for metallic elements were 0.022, 0.027, 0.020, 0.127, 0.454, 0.019, 0.015, and 0.019 for Cadmium (Cd), Nickel (Ni), Manganese (Mn), Lead (Pb), Iron (Fe), Zinc (Zn), Chromium (Cr), and Copper (Cu), respectively.

Table 3.5-2

The results of the detection limit for this study. (N=12)

| Chemical species | Detection limit (ppm) |
|---|---|
| Cadmium (Cd) | 0.022 |
| Nickel (Ni) | 0.027 |
| Manganese (Mn) | 0.020 |
| Lead (Pb) | 0.127 |
| Iron (Fe) | 0.454 |
| Zinc (Zn) | 0.019 |
| Chromium (Cr) | 0.015 |
| Copper (Cu) | 0.019 |

### *3.5.3 Recovery efficiency test*

At least 10% of the samples are analyzed in spiking with a known amount of metal to calculate recovery efficiencies. The analysis procedure for the Cadmium (Cd), Nickel (Ni), Manganese (Mn), Lead (Pb), Iron (Fe), Zinc

(Zn), Chromium (Cr), and Copper (Cu) recovery test is the same as described for the field samples. The results of recovery efficiency test are shown in Table 3.5-3, which indicated the range of recovery efficiency test varies between 90 ~ 110 % and the relative standard deviation is less than 10 %. For example: Added same sample concentrations (1 mg/L) in AA-680/G flame atomic absorption spectro- photometer to determine for the levels of Iron (Fe) in this study. Finally, found levels of Fe has 2.02 mg/L and calculate recovery efficiencies. Recovery of Fe (%)= (2.02-1)/1×100%=102%.

Table 3.5-3

Recovery tests for some metal elements.

| Elements | Amount added (mg/L) | Amount found (mg/L) | Recovery (%) |
|---|---|---|---|
| Cadmium (Cd) | 0.20 | 0.41 | **105** |
| Nickel (Ni) | 0.10 | 0.19 | **90** |
| Manganese (Mn) | 0.20 | 0.38 | **90** |
| Lead (Pb) | 0.30 | 0.62 | **107** |
| Iron (Fe) | 1.00 | 2.02 | **102** |
| Zinc (Zn) | 0.40 | 0.84 | **110** |
| Chromium (Cr) | 0.20 | 0.41 | **105** |
| Copper (Cu) | 0.10 | 0.19 | **90** |

Recovery (%)

= (Amount found－Sampler concentration)/Amount added×100%

### *3.5.4 Sample storage*

For the best situation, samples should be analyzed as soon as possible after sampling. If samples could not be analyzed right after sampling, all of the samples should stored at 4 ± 0.5℃ in a refrigerator. In order to avoiding the occurrence of unexpectedly chemical reactions, the storage time should not exceed one month. The samples were analyzed not over one month in this study.

# Chapter 4

## Results and Discussion

### 4.1 Suspended particulate variations

### 4.1.1 *Suspended particulate during the incense period*

Suspended particulate concentrations and size distributions at Tzu Yun Yen temple were also measured during Chinese lunar calendar days in this study. Figure 4.1-1 showed the suspended particulate variations at Tzu Yun Yen temple. Table 4.1-1 shows the indoor suspended particulate ($PM_{2.5}$, $PM_{2.5-10}$, $PM_{10}$ and $PM_{2.5}/PM_{10}$) at Tzu Yun Yen temple. The concentrations for $PM_{2.5}$, $PM_{2.5-10}$ and $PM_{10}$ increased during the pilgrims incense burning period. 23 % of the average $PM_{10}$ concentrations were higher than 125 ì gm$^{-3}$ during the sampling period (Tzu Yun Yen temple).

The $PM_{2.5}$/ $PM_{10}$ ratios ranged between 31 to 87 % and averaged 71 ± 11 % during the incense burning period. $PM_{2.5}$ concentrations ranges were from 18.7 to 180.8 (ì gm$^{-3}$). $PM_{2.5-10}$ concentrations ranges were from 9.8 to 76.4 (ì gm$^{-3}$). Generally speaking, fine particulates ($PM_{2.5}$) are dominant in the indoor environment in this study. In general, the average percentages of $PM_{2.5}$ /$PM_{10}$ were about 71 percent. This ratio is higher than that for suspended particulates in the outdoor environment of a previous study (averaged 60%) in Taiwan, Taichung (Fang *et al.*, 2002) and other study (Salma *et al.*, 2002). The results also demonstrated that the fine particulates ($PM_{2.5}$) constitute the majority of indoor suspended particulates at Tzu Yun Yen temple.

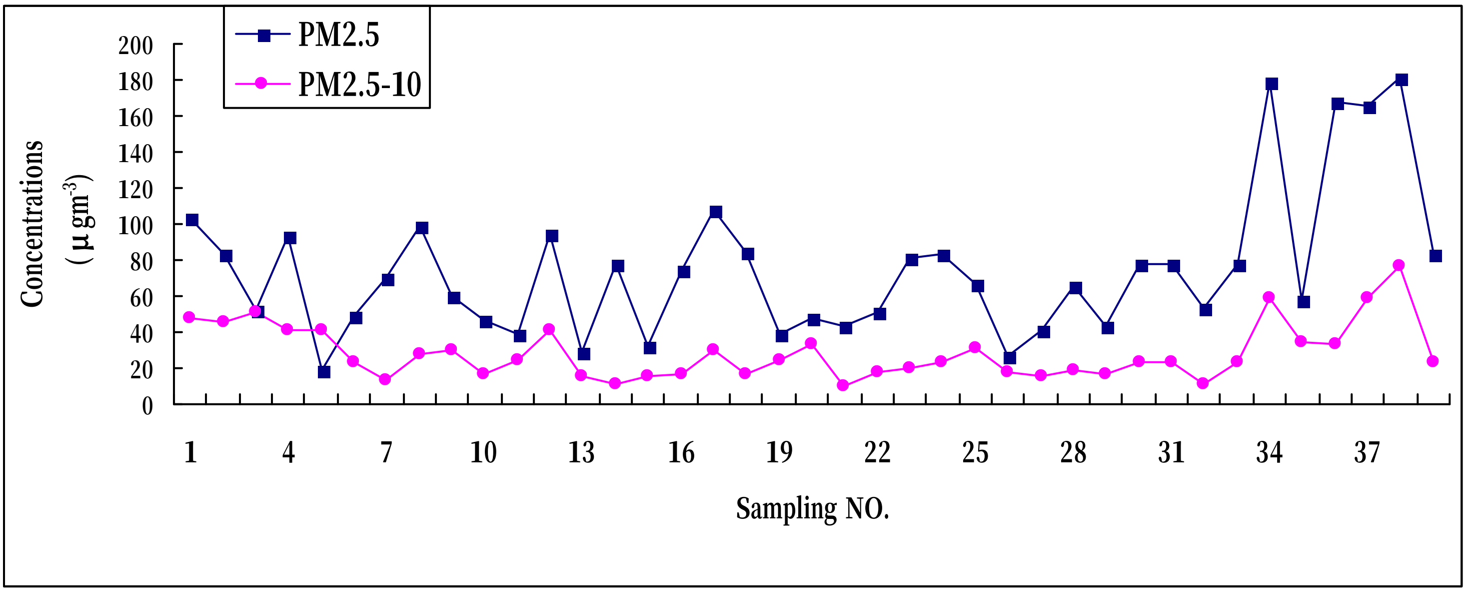


Figure 4.1-1

The suspended particulate ($PM_{2.5}$ and $PM_{2.5-10}$) variations at Tzu Yun Yen temple sampling site.

Table 4.1-1

The indoor suspended particulate ($PM_{2.5}$, $PM_{2.5-10}$ and $PM_{10}$) at Tzu Yun Yen temple.

| Sampling NO. | $PM_{2.5}$ (ì $gm^{-3}$) | $PM_{2.5-10}$ (ì $gm^{-3}$) | $PM_{10}$ (ì $gm^{-3}$) | $PM_{2.5}$/ $PM_{10}$ Ratio |
|---|---|---|---|---|
| 1 | 103.2 | 47.8 | 151.0 | 0.68 |
| 2 | 83.6 | 45.9 | 129.5 | 0.65 |
| 3 | 52.5 | 51.3 | 103.8 | 0.51 |

| | | | | |
|---|---|---|---|---|
| 4 | 93.1 | 40.7 | 133.8 | 0.70 |
| 5 | 18.7 | 41.2 | 59.9 | 0.31 |
| 6 | 48.8 | 23.4 | 72.2 | 0.68 |
| 7 | 69.7 | 13.6 | 83.3 | 0.84 |
| 8 | 99.1 | 28.1 | 127.2 | 0.78 |
| 9 | 59.6 | 29.8 | 89.4 | 0.67 |
| 10 | 47.2 | 17.1 | 64.3 | 0.73 |
| 11 | 39.1 | 24.2 | 63.3 | 0.62 |
| 12 | 94.2 | 41.2 | 135.4 | 0.70 |
| 13 | 28.7 | 16.1 | 44.8 | 0.64 |
| 14 | 77.9 | 11.2 | 89.1 | 0.87 |
| 15 | 32.4 | 15.5 | 47.9 | 0.68 |
| **16** | 74.6 | 16.8 | 91.4 | 0.82 |
| **17** | 107.9 | 29.7 | 137.6 | 0.78 |
| **18** | 83.9 | 16.7 | 100.6 | 0.83 |
| **19** | 38.4 | 24.5 | 62.9 | 0.61 |
| **20** | 48.1 | 33.0 | 81.1 | 0.59 |
| **21** | 43.6 | 9.8 | 53.4 | 0.82 |
| **22** | 51.4 | 17.4 | 68.8 | 0.75 |
| **23** | 81.5 | 20.3 | 101.8 | 0.80 |
| **24** | 83.5 | 23.8 | 107.3 | 0.78 |
| **25** | 66.9 | 30.9 | 97.8 | 0.68 |
| **26** | 27.1 | 18.0 | 45.1 | 0.60 |
| **27** | 41.4 | 15.9 | 57.3 | 0.72 |
| **28** | 65.8 | 18.5 | 84.3 | 0.78 |
| **29** | 43.1 | 16.8 | 59.9 | 0.72 |
| **30** | 77.7 | 23.8 | 101.5 | 0.77 |

Continue

| | | | | |
|---|---|---|---|---|
| 31 | 77.7 | 23.8 | 101.5 | 0.77 |
| 32 | 53.6 | 10.9 | 64.5 | 0.83 |
| 33 | 77.7 | 23.8 | 101.5 | 0.77 |
| 34 | 179.3 | 59.0 | 238.3 | 0.75 |
| 35 | 58.2 | 35.0 | 93.2 | 0.62 |
| 36 | 168.3 | 33.4 | 201.7 | 0.83 |
| 37 | 165.8 | 59.4 | 225.2 | 0.74 |
| 38 | 180.8 | 76.4 | 257.2 | 0.70 |
| 39 | 83.5 | 23.8 | 107.3 | 0.78 |
| Mean± SD* | 75.1± 40.4 | 28.4± 15.2 | 103.5± 51.8 | 0.71± 0.11 |

*: Standard deviation

### *4.1.2 Compares two periods of incense burning at Tzu Yun Yen temple*

Table 4.1-2 compares Period Ⅰ (Zhong Yuan Jie, and the $1^{st}$ and $15^{th}$ of nong li for each month ) and Period Ⅱ (non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days at Tzu Yun Yen temple during the incense burning period. The results show the $PM_{10}$ concentrations averaged 121 ì gm$^{-3}$ for Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar), which were higher than non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days average 96 ì gm$^{-3}$. Also, $PM_{2.5}$ concentrations for Period Ⅰ (average 90 ì gm$^{-3}$) were higher than Period Ⅱ (average 70 ì gm$^{-3}$). As for average $PM_{2.5-10}$ concentrations, the results display equal concentration distributions in Period Ⅰ and Period Ⅱ at Tzu Yun Yen temple, respectively.

And average ratios of $PM_{2.5}$/ $PM_{10}$ were higher in Period I (74 %) than Period II (71 %) during incense burning at Tzu Yun Yen temple. However, the results obtain here also reflected that the increased number of pilgrims leads to increased concentrations of suspended particulates ($PM_{10}$) and fine particulates ($PM_{2.5}$) in Period I at Tzu Yun Yen temple.

Statistical analysis of the suspended particulate ($PM_{10}$) concentrations for Zhong Yuan Jie, and the $1^{st}$ and $15^{th}$ of nong li for each month (Chinese lunar calendar), and non- Zhong Yuan Jie, or non-$1^{st}$ and $15^{th}$ days of each month (Chinese lunar calendar) at the Tzu Yun Yen temple yielded a T statistic of –0.291, which is greater than $-t_{á, 8}$ = –1.412, suggesting that the sample concentration means are different. However, the results obtain here also show that the wire pilgrims incense burning then were suspended particulate at Tzu Yun Yen temple. The average stay period of visitors (pilgrims) in the temple was about 30 minutes. Thus, we suggest that decreased incense burning and period of stay at Tzu Yun Yen temple during Zhong Yuan Jie, and the $1^{st}$ and $15^{th}$ of nong li for each month (Chinese lunar calendar) is an effective way to decrease the suspended particulate influence on pilgrims' health.

Table 4.1-2

Comparison at Period I and Period II at Tzu Yun Yen temple during the incense burning period.

| | Sampling time (min) | Pilgrims /hr | $PM_{2.5}$ (ì $gm^{-3}$) | $PM_{2.5-10}$ (ì $gm^{-3}$) | $PM_{10}$ (ì $gm^{-3}$) | $PM_{2.5}$/ $PM_{10}$ (%) |
|---|---|---|---|---|---|---|
| **Period É*** | **564** | **1119** | **90** | **31** | **121** | **74** |
| **N=10** | **± 83** | **± 761** | **± 51** | **± 18** | **± 68** | **± 7** |
| **Period Đ**** | **591** | **402** | **70** | **28** | **98** | **71** |
| **N=29** | **± 74** | **± 227** | **± 36** | **± 14** | **± 45** | **± 12** |

*: Zhong Yuan Jie and the 1st or 15th of nong li for each month (Chinese lunar calendar)

**: Non-Zhong Yuan Jie and non-1st or 15th days

### *4.1.3 Mass size distribution during incense burning at Tzu Yun Yen*

***temple***

Figure 4.1-2 and 4.1-3 displays the mass size distribution during incense burning at Tzu Yun Yen temple. Comparing mass size distribution during incense burning of two periods shows that those for Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar), were higher than non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days, respectively. It found that the average mass size distributions are bimodal with the major peaks within 0.56-1 ìm and 5.6-10ìm, respectively during non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days. It also found that the average mass size distributions are bimodal with the major peaks within 0.18-0.32 ìm and 5.6-10ìm, respectively during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar) at Tzu Yun Yen temple. The results how that fine suspended particulate concentrations increase at Tzu Yun Yen temple during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar).

Figure 4.1-4 displayed average mass size distribution during incense burning at Tzu Yun Yen temple. It showed that the average mass size distributions are bimodal and with the major peak within 0.32-0.56 ìm and 5.6-10 ìm, respectively during incense burning period at Tzu Yun Yen temple. The results yield here indicated that fine ($PM_{2.5}$) suspended particulate concentrations were major particle type at Tzu Yun Yen temple incense burning period in this study.

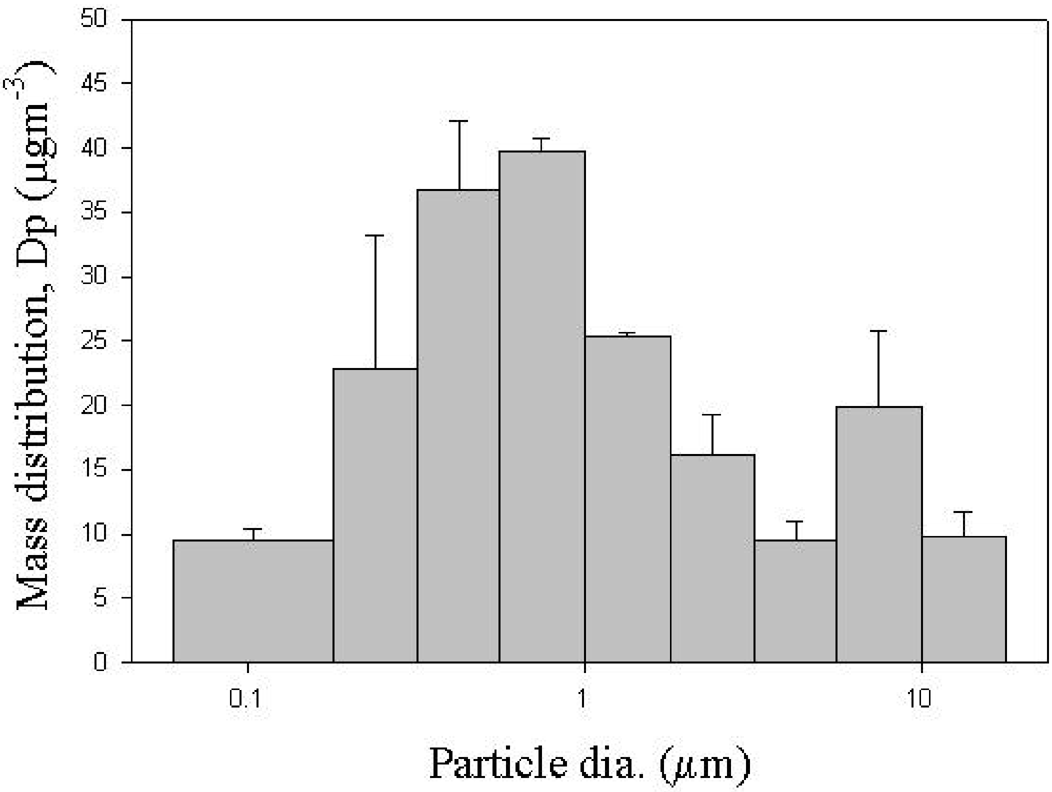


Figure 4.1-2

The mass distribution during non-Zhong Yuan Jie and non-1st or 15th for each month of the Chinese lunar calendar (nong li) period (n=20) at Tzu Yun Yen temple.

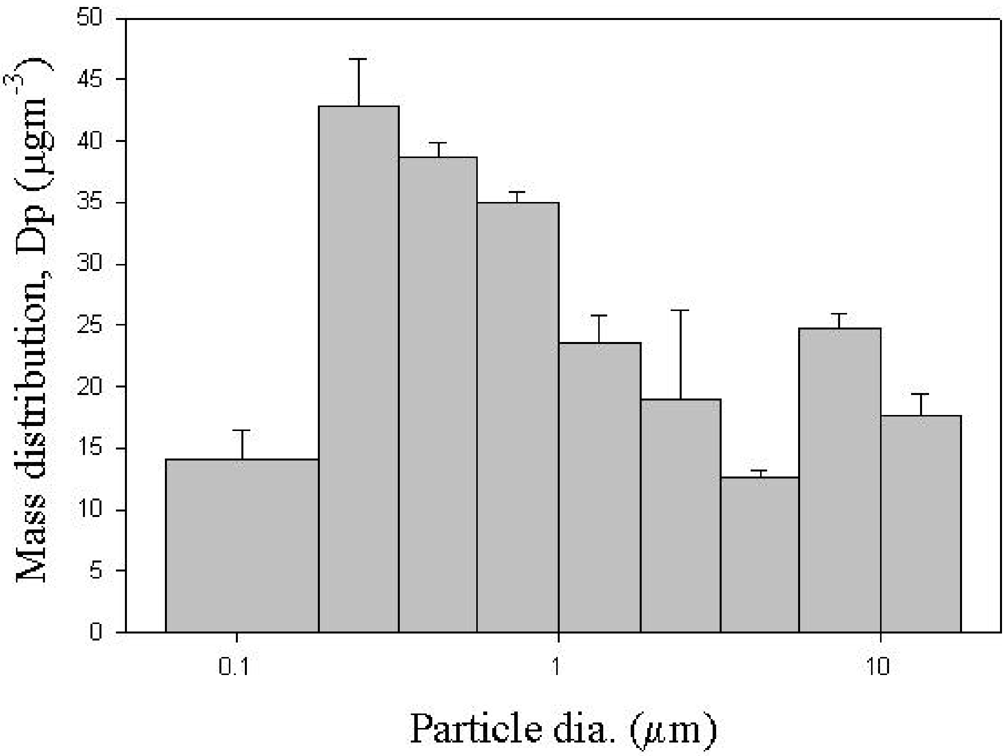


Figure 4.1-3

The mass distribution during Zhong Yuan Jie and the 1st or 15th for each month of the Chinese lunar calendar (nong li) period (n=6) at Tzu Yun Yen temple.

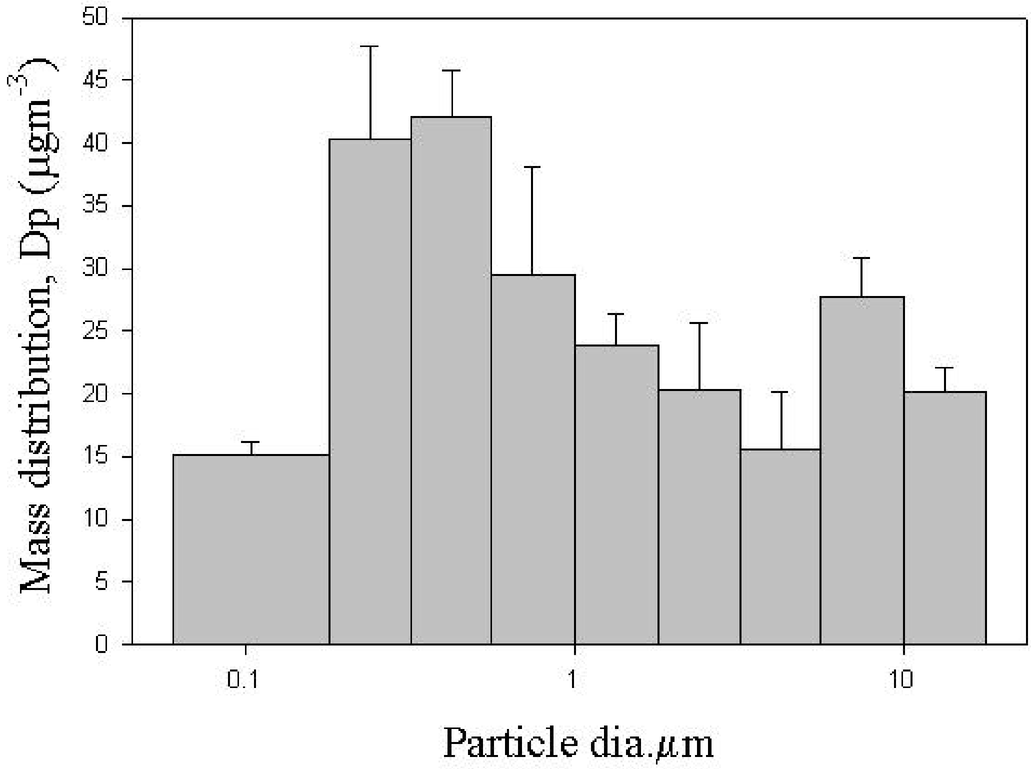


Figure 4.1-4

Average cumulative particle size distribution of total aerosols during incense burning period (n=26) at Tzu Yun Yen temple.

### *4.1.4 Mass median aerodynamic diameter (MMAD) and geometric standard deviation (óg)*

Figure 4.1-5 and 4.1-6 exhibits average cumulative particle size distributions of total aerosols in two periods (Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month and non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days at Tzu Yun Yen temple. The results clearly show average mass median aerodynamic diameter (MMAD) and geometric standard deviation (óg) for the two periods in this study. The average mass median aerodynamic diameter (MMAD) of suspended particles is 0.94 ì m during non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ of nong li days. The average mass median aerodynamic diameter (MMAD) of suspended particles is 0.68 ì m during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar) at Tzu Yun Yen temple. In addition, the average geometric standard deviation (óg) is 6.32 during non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days. The average geometric standard deviation (óg) is 7.75 during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar). The average geometric standard deviation (óg) 7.75 at Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each mouth (Chinese lunar calendar) which is greater than 6.32 during non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days.

Figure 4.3-7 exhibited average cumulative particle size distribution of total aerosols during the incense burning at Tzu Yun Yen temple. The results were clearly shown average mass median aerodynamic diameter (MMAD) and geometric standard deviation (óg) for this study. The average mass median aerodynamic diameter (MMAD) of suspended particles is 0.32 ìm during the incense burning at Tzu Yun Yen temple in this study. In addition, average geometric standard deviation (óg) were 7.14 during the incense burning at Tzu Yun Yen temple.

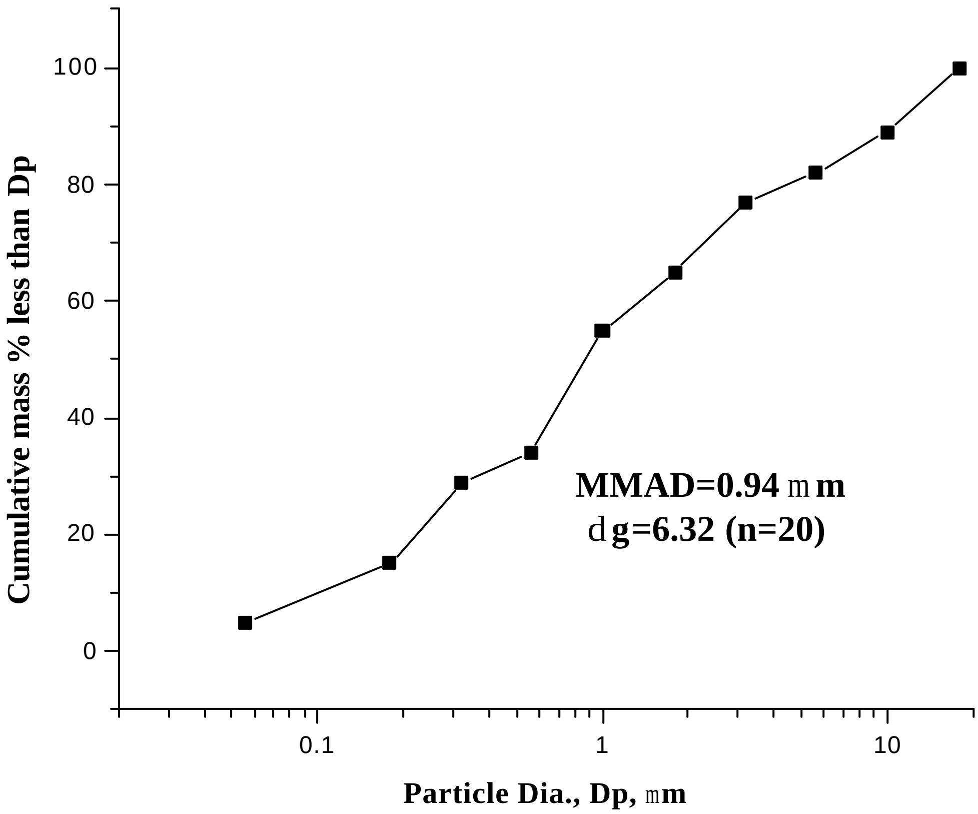


Figure 4.1-5

Average cumulative particle size distribution of total aerosols during non-Zhong Yuan Jie and non-1st or 15th days for each month of Chinese lunar calendar (nong li) period (n=20) at Tzu Yun Yen temple.

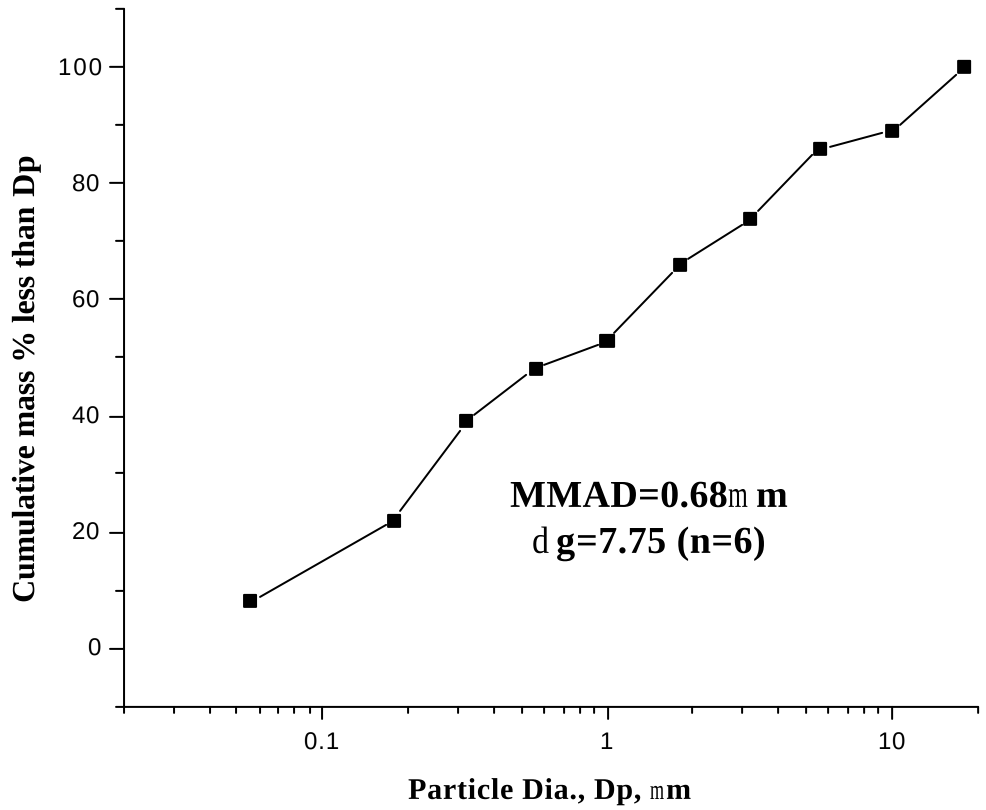


Figure 4.1-6

Average cumulative particle size distribution of total aerosols during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ for each month of the Chinese lunar calendar (nong li) period (n=6) at Tzu Yun Yen temple.

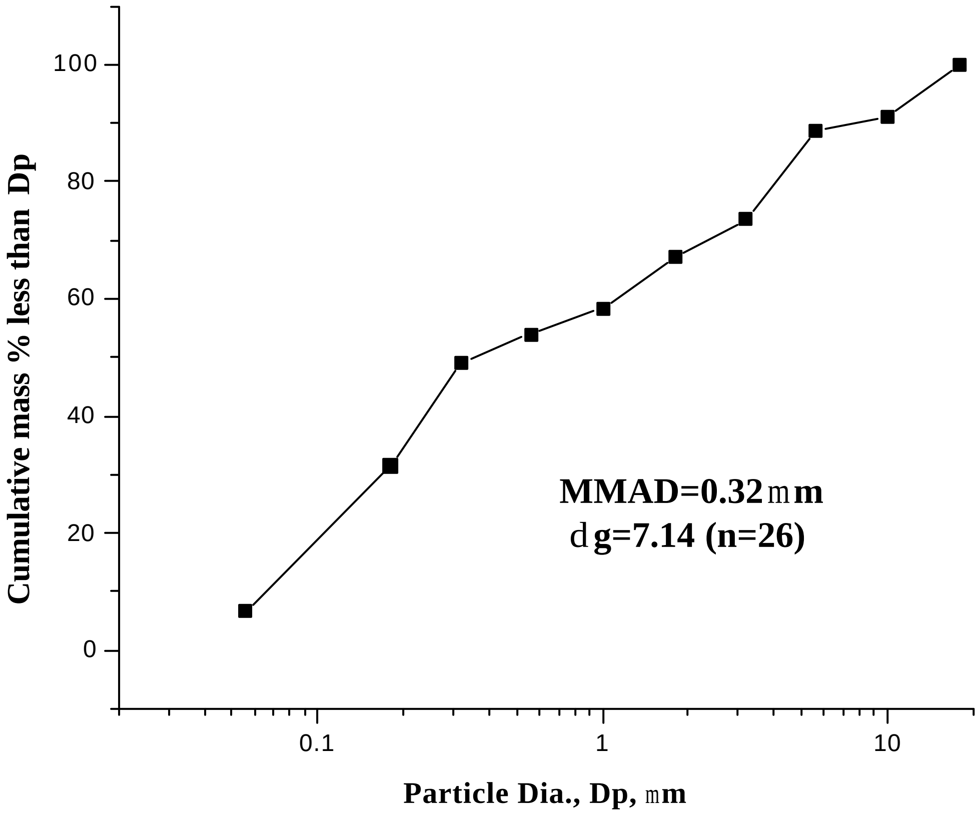


Figure 4.1-7

Average cumulative particle size distribution of total aerosols during incense burning period (n=26) at Tzu Yun Yen temple.

### *4.1.5 Compares the dry deposition flux for the indoor and outdoor environment at Tzu Yun Yen temple*

Table 4.1-3 compares the dry deposition flux for the indoor and outdoor environment at Tzu Yun Yen temple during the burning incense period. The results also indicate that almost the average dry deposition flux in the indoor environment is lower than in the outdoor environment at Tzu Yun Yen temple. The dry deposition flux ranged from 18 to 88 $mg\ m^{-2}day^{-1}$ and from 56 to 731 $mg\ m^{-2}day^{-1}$ in the indoor and outdoor environment, respectively. In general, the average dry deposition flux (59 $mg\ m^{-2}day^{-1}$) in the indoor environment was lower than in the outdoor environment (averaged 207 $mg\ m^{-2}day^{-1}$) in this study. The mean dry deposition indoor/outdoor flux ratios were 28 %.

Table 4.1-3

One day mass dry deposition flux indoors and outdoors at Tzu Yun Yen temple in central Taiwan.

| Sampling date (2001 to 2002) | Dry deposition flux ($mg\ m^{-2}\ day^{-1}$) | | Indoor/ Outdoor (%) |
|---|---|---|---|
| | Indoor (n=26) | Outdoor (n=16) | |
| Minimum | 18.1 | 55.6 | 33.6 |
| Maximum | 88.4 | 730.8 | 12.0 |
| Mean | 58.5 | 206.7 | 28.3 |
| SD | 25.4 | 156.5 | 35.1 |

## 4.2 Suspended particulates and metallic elements at Tzu Yun Yen temple

### *4.1.1 Metallic elements concentrations in fine particle ($PM_{2.5}$) and coarse particle ($PM_{2.5-10}$) for incense burning at Tzu Yun Yen temple*

Metallic elements concentrations in fine particle ($PM_{2.5}$) and coarse particle ($PM_{2.5-10}$) for incense burning at Tzu Yun Yen temple were shown in Figure 4.2-1 and Figure 4.2-2. The box plots indicated the median concentrations and the minimum value, $25^{th}$ percentile, $75^{th}$ percentile and maximum value (n=39). The median metallic elements concentrations order for these elements are Fe > Zn > Cr > Cd > Pb > Mn > Ni > Cu in fine particle ($PM_{2.5}$) at Tzu Yun Yen temple sampling site. And the median metallic elements concentrations order for these elements are Fe > Zn > Cr > Pb > Cd > Ni > Mn > Cu in coarse particle ($PM_{2.5-10}$) at Tzu Yun Yen temple sampling site. From the point of view of $PM_{10}$, these data reflect that elements of Fe, Zn, and Cr were the major elements distributed at Tzu Yun Yen temple in this study. However, element Cu has the lowest concentrations in $PM_{2.5}$ and $PM_{2.5-10}$ at Tzu Yun Yen temple.

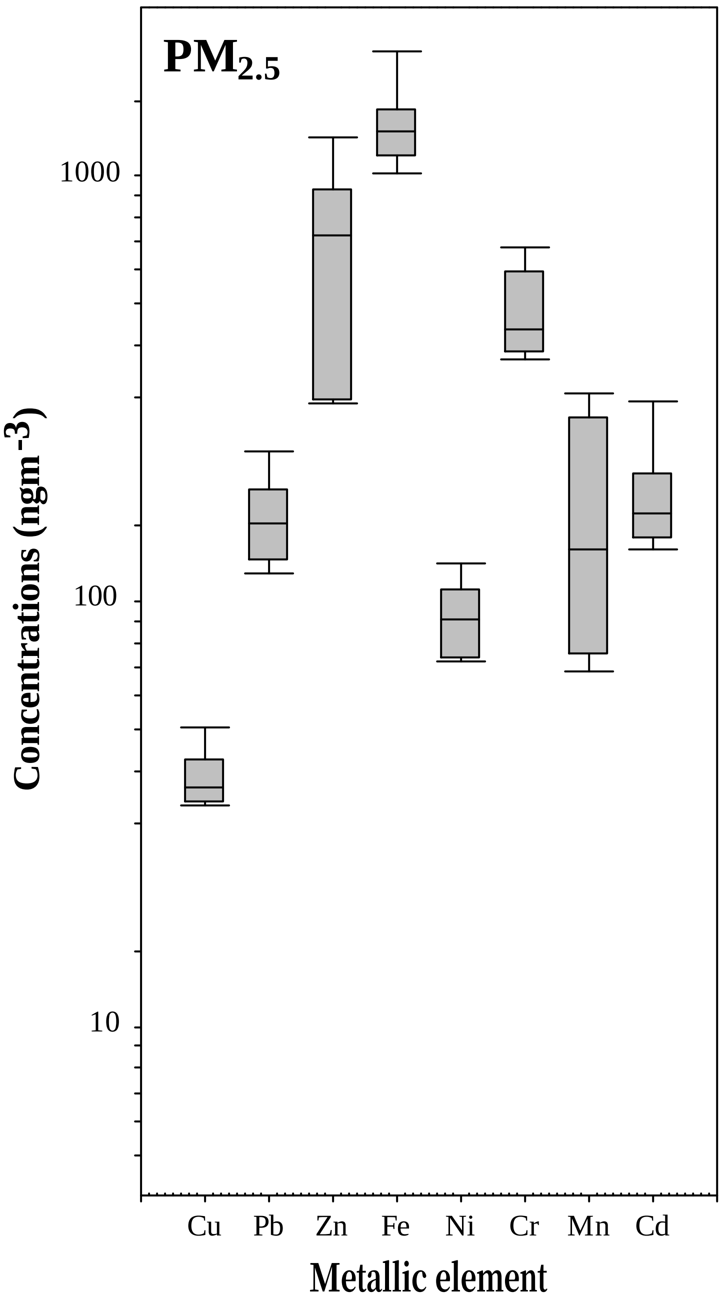
PM2.5
Concentrations (ngm-3)
1000
100
10
Cu
Pb
Zn
Fe
Ni
Cr
Mn
Cd
Metallic element

Figure 4.2-1.

Metallic elements concentrations in $PM_{2.5}$ for incense burning at Tzu Yun Yen temple. The box plots indicate the median concentrations, 25[th] percentile and 75[th] percentile value (n=39).

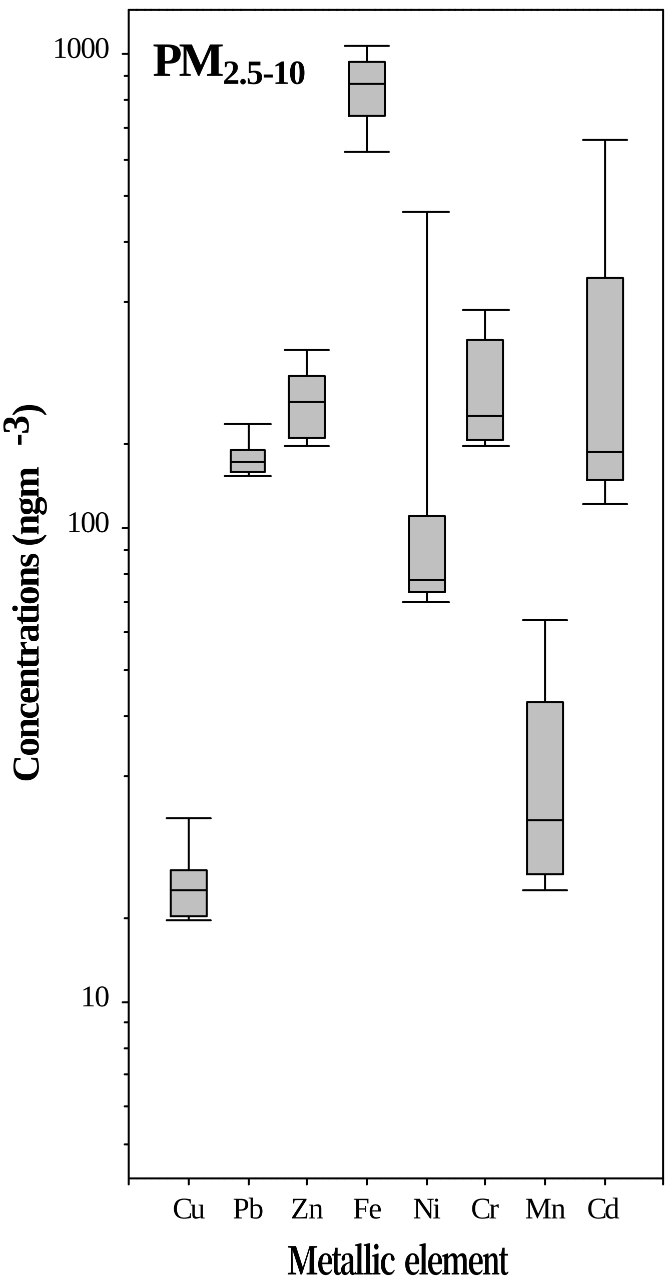

Figure 4.2-2

Metallic elements concentrations in $PM_{2.5-10}$ for incense burning at Tzu Yun Yen temple. The box plots indicate the median concentrations, $25^{th}$ percentile and $75^{th}$ percentile value (n=39).

### *4.1.2 Composition of metallic elements in fine particle ($PM_{2.5}$) and coarse particle ($PM_{2.5-10}$) at Tzu Yun Yen temple*

The average metallic elements fine particle ($PM_{2.5}$) and coarse particle ($PM_{2.5-10}$) composition at Tzu Yun Yen temple were shown in Figure 4.2-3 This figure indicated that the composition (mg/g) for metallic elements Cu, Pb, Zn, Fe, Ni, Cr, Mn, and Cd were 0.49, 1.17, 5.22, 11.91, 0.72, 4.80, 1.08, and 1.56 mg/g in fine particle ($PM_{2.5}$), respectively. And metallic elements compositions in coarse particle ($PM_{2.5-10}$) were 0.49, 4.23, 4.18, 19.99, 2.57, 5.16, 0.59, and 4.91 mg/g, respectively. The mean metallic elements composition order for these elements are Fe > Zn > Cr > Cd > Pb > Mn > Ni > Cu in fine particle ($PM_{2.5}$) at Tzu Yun Yen temple sampling site while the mean metallic elements composition order for these elements are Fe > Cr > Cd > Pb > Zn > Ni > Mn > Cu in coarse particle ($PM_{2.5-10}$) at Tzu Yun Yen temple sampling site. The results indicated that the Fe, Zn, and Cr have the higher average composition in fine particle ($PM_{2.5}$) at Tzu Yun Yen temple while Fe, Cr, Cd, and Pb have the higher average composition in coarse particle ($PM_{2.5-10}$) at Tzu Yun Yen temple.

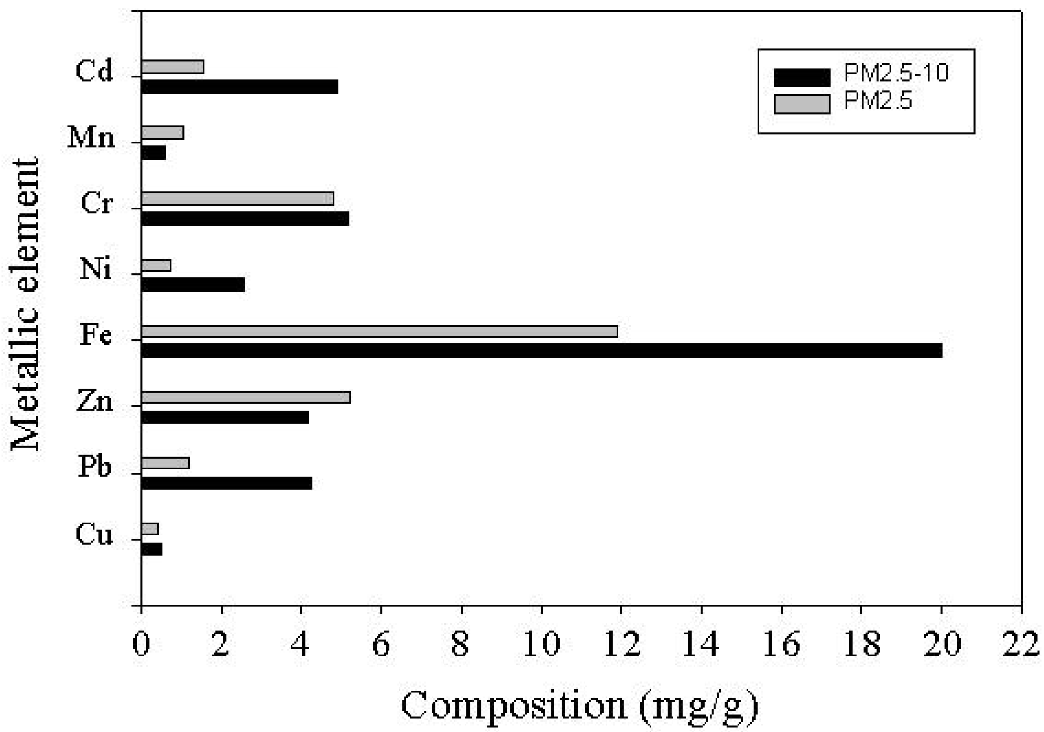


Figure 4.2-3

Averaged metallic element ($PM_{2..5}$ and $PM_{2.5\text{-}10}$) composition at Tzu Yun Yen temple sampling site.

### *4.1.3 Compared suspended particulates and metallic elements collected in different areas*

Table 4.2-1 indicated bulk metal element samples of suspended particulates and metallic elements collected in different areas around world. In general, $PM_{2.5}$ particulates concentrations collected at this study were about 3.4 times as the $PM_{2.5}$ concentrations collected at rural site during nighttime period (Fang *et al.*, 1999) and were about 4.6 times as the concentrations collected at rural site during daytime period (Fang *et al.,* 1999). As for $PM_{10}$ particulates concentrations the data obtained in this study reflected that the $PM_{10}$ particulates concentrations were about 1.2 times as the data collected at traffic site (Fang *et al.,* 2000) and were about 3.8 times as the data collected at Kuopio sampling site and were about 2.1 times as the data collected at Ho Chi Minh City sampling site. However, the $PM_{10}$ concentrations were slightly lower than Milan (Marcazzan *et al.,* 2001) during winter season. As for element Cu, the results obtained here indicated that the $PM_{10}$ concentrations were higher than rural data collected at Taiwan area (Fang *et al.,* 1999). And were about 2.5, 1.4 times the data collected at rural sampling site during daytime and nighttime period, respectively. As for element Pb, the results obtained here indicated that the $PM_{10}$ concentrations were higher than rural data collected at Taiwan area (Fang *et al.,* 1999). And were about 6.1, 16 times the data collected at rural sampling site during daytime and nighttime period, respectively. There data also were about 4.2, 1.4 times as the data collected at Chicago (Yi *et al.,* 2001) and Ho Chi Minh City (Hien *et al.,* 2001) sampling site, respectively.

The Pb in $PM_{10}$ concentrations was slightly lower than Milan (Marcazzan *et al.,* 2001) and Madrid (Gómez *et al.,* 2001) sampling site, respectively. As for element Zn, the results obtained here indicated that the $PM_{10}$ concentrations were higher than previous rural data collected at Taiwan area (Fang *et al.,* 1999). And were about 5.6, 3.8 times as the data collected at rural sampling site during daytime and nighttime period, respectively. And were about 3.8 times the data collected at Chicago (Yi *et al.,* 2001) sampling site. The Zn in $PM_{10}$ concentrations collected at this temple was slightly lower than Ho Chi Minh City (Hien *et al.,* 2001) sampling site. As for element Fe, the results obtained here showed that the $PM_{10}$ concentrations were higher than Antarctica area (Mazzera *et al.,* 2001). And were about 11.2, 1.7 times the data collected at Hut Point Sit and Kuopio sampling site (Hosiokangas *et al.,* 1999), respectively. However, the Fe in $PM_{10}$ concentrations which obtained at temple were lower than Central Taiwan (Fang *et al.,* 1999), Milan (Marcazzan *et al.,* 2001), Tehran (Sohrabpour *et al.,* 1999) and Ho Chi Minh City (Hien *et al.,* 2001) sampling site, respectively. As for element Cr, the results obtained here displayed that the $PM_{10}$ concentrations were higher than rural data collected at Taiwan area (Fang *et al.,* 1999). And were about 6.4, 11.5 times the data collected at rural sampling site during daytime and nighttime period, respectively. And the data were about 36.3 times as the data collected at Milan (Marcazzan *et al.,* 2001) sampling site during winter season. When considered element Mn, the results obtained here reflected that the $PM_{10}$ concentrations were higher than rural data collected at Taiwan area (Fang *et al.,* 1999). And were about 2.5, 3.3 times the data collected at rural sampling site during daytime and nighttime period, respectively. And were about 2.2, 1.1 times the data collected at Milan (Marcazzan *et al.,* 2001) and Ho Chi Minh City (Hien *et al.,* 2001) sampling site, respectively.

In general, the $PM_{10}$ particulate mass concentrations collected at Tzu Yun Yen temple sampling site were ranked as the second highest data (103 ì $gm^{-3}$) compared with result obtained from the other regions of the world. The mean metallic elements (Cu, Pb, and Fe) concentrations were resembled as the median value at different areas around the world. However, the mean metallic elements concentrations (Zn and Mn) results in fine particle ($PM_{2.5}$) were ranked as the compared with the other areas around the world. And the mean metallic elements (Ni, Cr, and Cd) concentrations were ranked as the highest in either fine particle ($PM_{2.5}$) or coarse particle ($PM_{2.5-10}$) concentrations compared with the other data collected from the other world regions.

Table 4.2-1. Bulk metal element samples of suspended particulate collected in different areas around world.

| Locations | Reference | Sampling denotes | Size (ì m) | Mass (ì gm$^{-3}$) | Cu (ngm$^{-3}$) | Pb (ngm$^{-3}$) | Zn (ngm$^{-3}$) | Fe (ngm$^{-3}$) | Ni (ngm$^{-3}$) | Cr (ngm$^{-3}$) | Mn (ngm$^{-3}$) | Cd (ngm$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Central Taiwan | Fang *et al.*, 1999 | Daytime, Rural | < 2.5 | 22 | 13 | 27 | 60 | 260 | - | 70 | 30 | - |
| | | Daytime, Rural | 2.5-10 | 11 | 5 | 7 | 30 | 4120 | - | 10 | 10 | - |
| | | Nighttime, Rural | < 2.5 | 30 | 30 | 10 | 110 | 400 | - | 30 | 20 | - |
| | | Nighttime, Rural | 2.5-10 | 14 | 2 | 3 | 25 | 1160 | - | 14 | 10 | - |
| Kuopio | Hosiokangas *et al.*, 1999 | Lake region | < 10 | 27 | 30 | 10 | 18 | 840 | 3 | 2 | - | - |
| Milan | Marcazzan *et al.*, 2001 | Winter | < 10 | 110 | 90 | 310 | 285 | 2440 | 10 | 14 | 45 | - |
| Madrid | Gómez *et al.*, 2001 | Airborne | < 10 | - | 150 | 304 | - | - | - | - | - | - |
| Tehran | Sohrabpour *et al.*, 1999 | Urban | TSP | - | - | 1040 | 288 | 2720 | 46 | 56 | 98 | - |
| Chicago | Yi *et al.*, 2001 | Airborne | < 2.5 | - | 9 | 29 | 84 | - | - | 1 | 8 | - |
| | | Airborne | 2.5-10 | - | 10 | 20 | 52 | - | - | 3 | 23 | - |
| Hong Kong | Lau and Luk, 2001 | Airborne | TSP | - | 110 | 89 | 130 | 3057 | - | - | - | - |
| Ho Chi Minh City | Hien *et al.*, 2001 | Urban | < 2 | 32 | 3 | 73 | 326 | 1222 | - | - | 52 | - |
| | | Urban | 2-10 | 16 | 2 | 79 | 245 | 261 | - | - | 14 | - |
| Antarctica | Mazzera *et al.*, 2001 | Hut Point Site | < 10 | 3 | 0.2 | 1 | 2 | 130 | - | 0.3 | 2.5 | - |
| Southwest Spain | Querol *et al.*, 2000 | Aznalcazar | TSP | 191 | 215 | 462 | 421 | 18300 | 11 | 10 | 94 | 2 |
| Taichung, Taiwan | This study | Temple | < 2.5 | 75 | 32 | 88 | 392 | 894 | 54 | 360 | 81 | 117 |
| | | | 2.5-10 | 28 | 14 | 120 | 119 | 568 | 73 | 147 | 17 | 139 |

"-": Mean not measured

### *4.1.4 Compared suspended particulates and elements variations in the two periods*

Averaged metallic elements concentrations for suspended particulate ($PM_{10}$) during non-Zhong Yuan Jie and non-1$^{st}$ or 15$^{th}$ for each month of the Chinese lunar calendar (nong li) period (n=29) and Zhong Yuan Jie and the 1$^{st}$ or 15$^{th}$ for each month of the Chinese lunar calendar (nong li) period (n=10) were showed in Figure 4.2-4. The date of 8/19, 9/2, 9/8, 9/17, 10/1, 10/17, 10/31, 11/15, 11/29, and 12/29 were days of Zhong Yuan Jie and the 1$^{st}$ or 15$^{th}$ for each month of the Chinese lunar calendar (nong li) period in year of 2001, respectively. The results also demonstrated that the suspended particulate ($PM_{10}$) elements concentrations during the Zhong Yuan Jie, and the 1$^{st}$ and 15$^{th}$ of nong li for each month (Chinese lunar calendar) were all higher than non-Zhong Yuan Jie and non-1$^{st}$ or 15$^{th}$ days at Tzu Yun Yen temple. Statistical analysis of the suspended particulate ($PM_{10}$) concentrations for Zhong Yuan Jie, and the 1$^{st}$ and 15$^{th}$ of nong li for each month (Chinese lunar calendar), and non- Zhong Yuan Jie, or non-1$^{st}$ and 15$^{th}$ days of each month (Chinese lunar calendar) at the Tzu Yun Yen temple yielded a T statistic of – 0.152, – 1.172, – 0.824, – 0.564, – 0.625, – 0.672, – 0.672, and – 2.172 for Fe, Cr, Cd, Pb, Zn, Ni, Mn, and Cu, respectively. These values are greater than $-t_{á,10} = -2.262$, suggesting that the sample concentration means are different. However, the results obtain here also show that the wire pilgrims incense burning then were suspended particulate at Tzu Yun Yen temple.

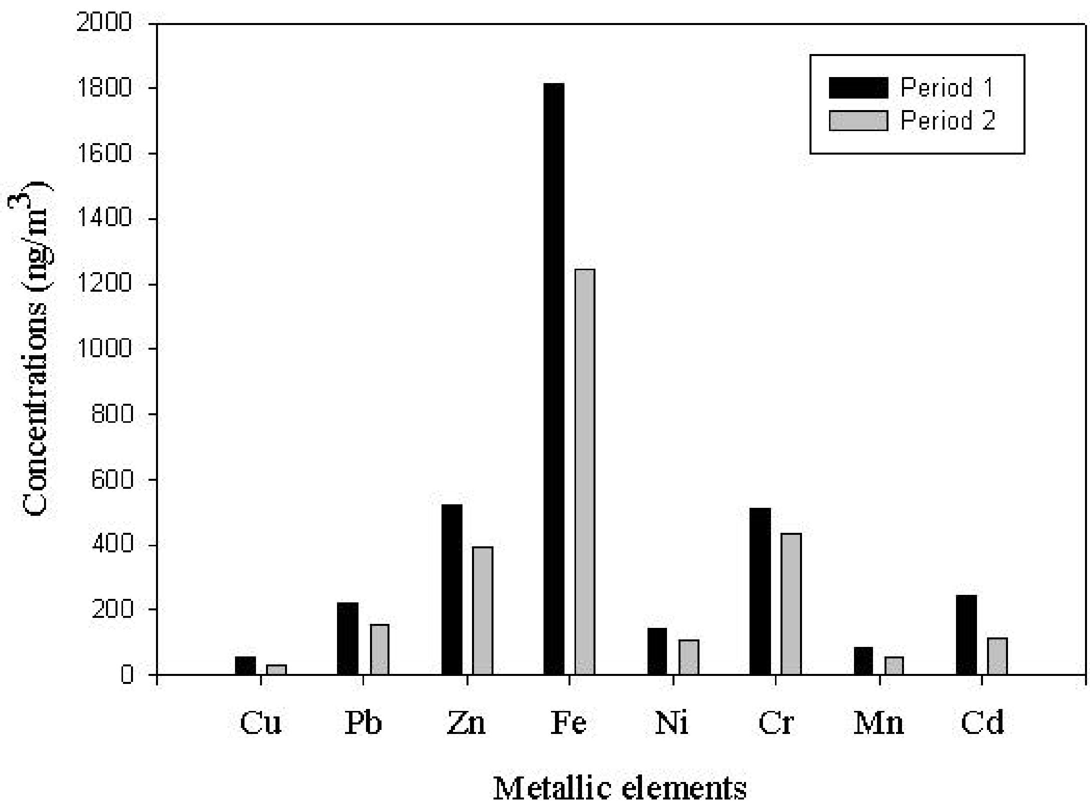


Figure 4.2-4

Averaged metallic elements for suspended particulate ($PM_{10}$) concentrations during non-Zhong Yuan Jie and non-1st or 15th for each month of the Chinese lunar calendar (nong li) period (Period 2, n=29) and Zhong Yuan Jie and the 1st or 15th for each month of the Chinese lunar calendar (nong li) period (Period 1, n=10) at Tzu Yun Yen temple.

### *4.1.5 Metallic elements of $PM_{10}$ concentrations compares another study*

The average metallic elements of $PM_{10}$ particulates concentrations at Tzu Yun Yen temple compares another study (Chao and Wong, 2002) were shown in Table 4.2-2 This table indicated that the concentrations ($ngm^{-3}$) for metallic elements Cu, Cd, Ni, Mn, Pb, Fe, Zn, and Cr were 46, 256, 127, 98, 208, 1463, 511, and 508 $ngm^{-3}$ in $PM_{10}$ particulates, respectively. The mean metallic elements composition order for these elements are Fe > Zn > Cr > Cd > Pb > Ni > Mn > Cu in $PM_{10}$ particulates at Tzu Yun Yen temple sampling site. The (Chao and Wong, 2002) study not measured chromium (Cr) and cadmium (Cd) at 34 homes in Hong Kong. This case indicated 10 homes had smokers and 13 homes had other combustion related activities such incense burning. And the concentrations ($ngm^{-3}$) for metallic elements Cu, Ni, Mn, Pb, Fe, and Zn were 19, 2, 17, 105, 408, and 172 $ngm^{-3}$ in $PM_{10}$ particulates, respectively.

These metallic elements Cu, Ni, Mn, Pb, Fe, and Zn were all higher than (Chao and Wong, 2002) at Tzu Yun Yen temple in this study. In general, the indoor environment of semi open temple particles sources by combustion related processes such as vehicle-exhaust in outdoor environment or smoking and incense burning in indoor environment.

Table 4.2-2
Compares another study metallic elements for the indoor environment at sampling site.

| Elements | Tzu Yun Yen temple | | Home in Hong Kong (Chao and Wong, 2002) | |
|---|---|---|---|---|
| | Mean | SD* | Mean | SD* |
| Copper (Cu) | 46.2 | 33.4 | 19.3 | 25.0 |
| Cadmium (Cd) | 256.1 | 158.9 | NA** | - |
| Nickel (Ni) | 127.3 | 89.4 | 2.1 | 1.9 |
| Manganese (Mn) | 98.2 | 74.8 | 16.5 | 10.1 |
| Lead (Pb) | 208.3 | 176.5 | 104.8 | 69.1 |
| Iron (Fe) | 1462.8 | 688.7 | 408.2 | 160.2 |
| Zinc (Zn) | 511.3 | 354.1 | 171.8 | 81.1 |
| Chromium (Cr) | 507.5 | 267.5 | NA** | - |

*: Standard deviation; **: Not analyzed

## 4.3 Dry deposition velocities for suspended particulate

### *4.1.1 Metallic correlation of dry deposition flux and suspend particulates at Tzu Yun Yen temple*

Best-fit overall dry deposition velocities were obtained by calculating the slope of the regression line between the measured dry deposition flux (y-axis) and ambient concentration divided into several size categories (x-axis). To increase sample sizes the following elements (Mg, Al, V, Cr, Cu, Cd, Ni, Mn, Pb, Mo, Ba, and Zn) were grouped together (Yi *et al.*, 2001). Figure 4.3-1 indicated metallic correlation of dry deposition flux and fine particulates ($PM_{2.5}$) at Tzu Yun Yen temple. Metallic correlation (Cd, Ni, Mn, Pb, Fe, and Zn) was 0.70, 0.51, 0.70, 0.68, 0.54, and 0.72 for dry deposition flux and fine particulates ($PM_{2.5}$), respectively. Figure 4.3-2 showed metallic correlation of dry deposition flux and coarse particulates ($PM_{2.5-10}$) at Tzu Yun Yen temple. Metallic correlation (Cd, Ni, Mn, Pb, Fe, and Zn) was 0.69, 0.41, 0.02, 0.01, 0.72, and 0.47 for dry deposition flux and coarse particulates ($PM_{2.5-10}$), respectively. Metallic correlation of dry deposition flux and suspended particulates ($PM_{10}$) were indicated in Figure 4.3-3. Metallic correlation (Cd, Ni, Mn, Pb, Fe, and Zn) was 0.74, 0.37, 0.76, 0.64, 0.59, and 0.70 for dry deposition flux and suspended particulates ($PM_{10}$), respectively. Meanwhile, calculating dry deposition velocities of metallic elements for different particulates sizes were also studied.

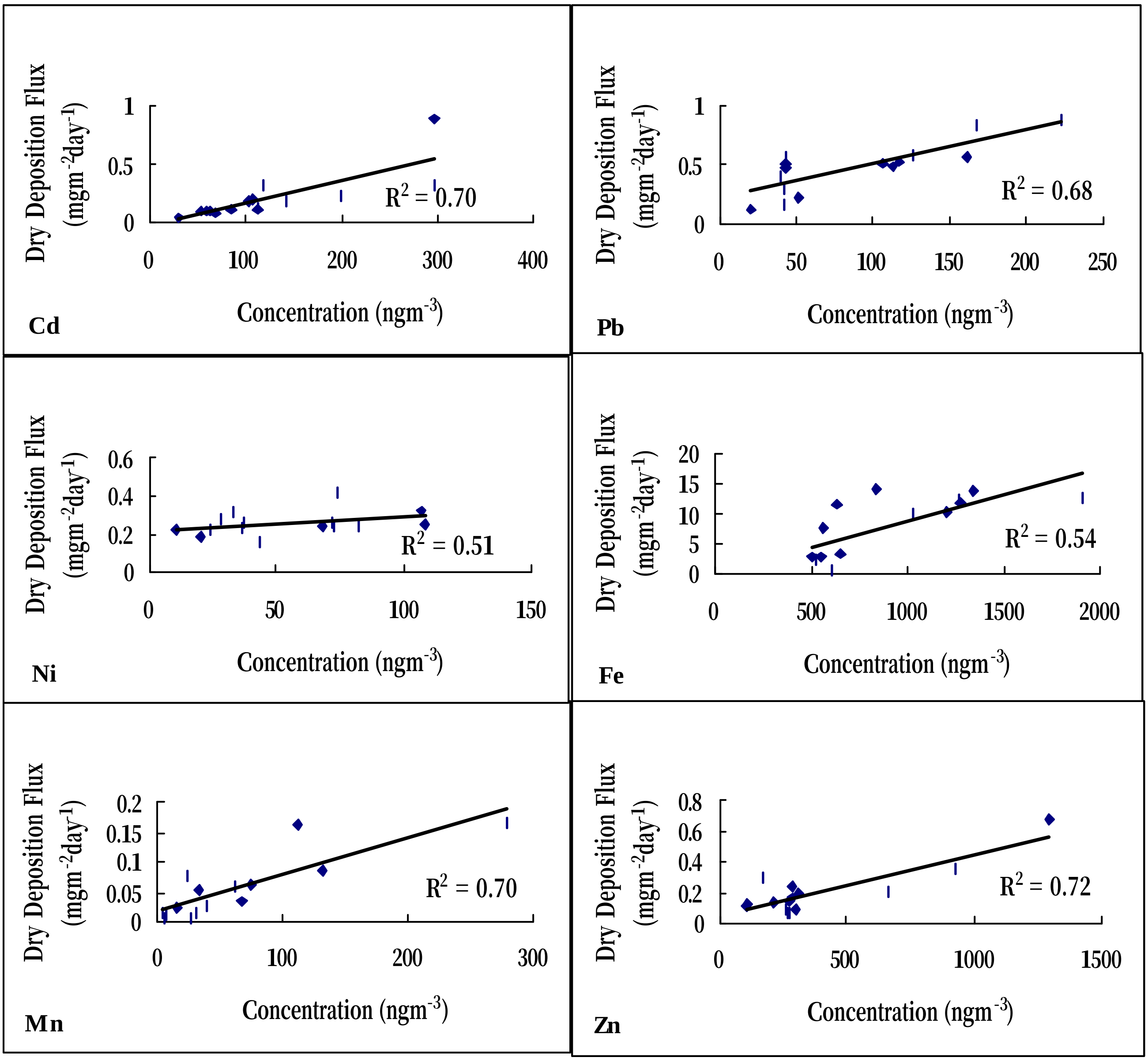


**Figure 4.3-1**

Metallic correlation of dry deposition flux and fine particulates ($PM_{2.5}$) at Tzu Yun Yen temple (n=15). The regression line is the best-fit overall dry deposition velocity.

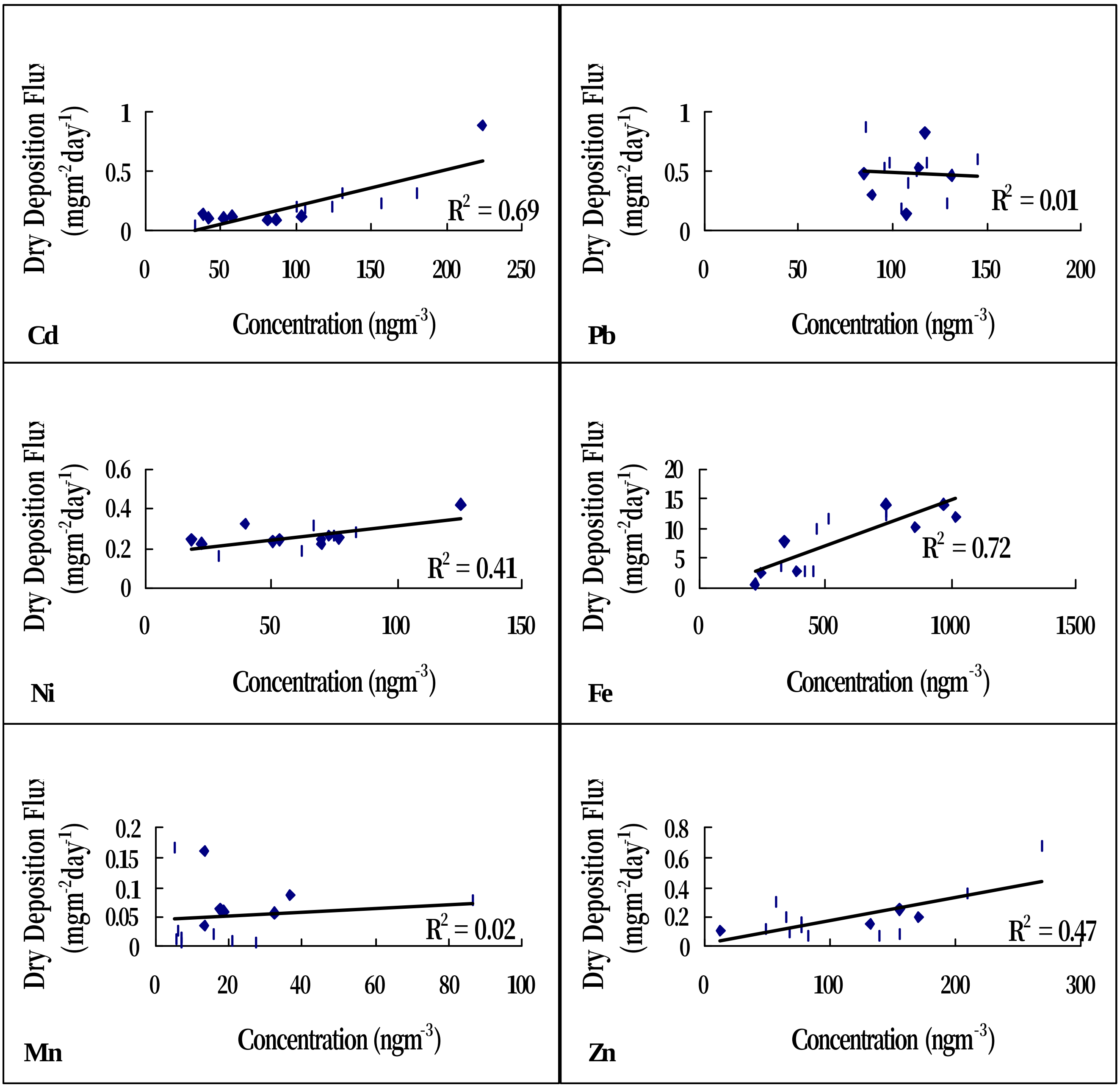


Figure 4.3-2

Metallic correlation of dry deposition flux and coarse particulates ($PM_{2.5-10}$) at Tzu Yun Yen temple (n=15). The regression line is the best-fit overall dry deposition velocity.

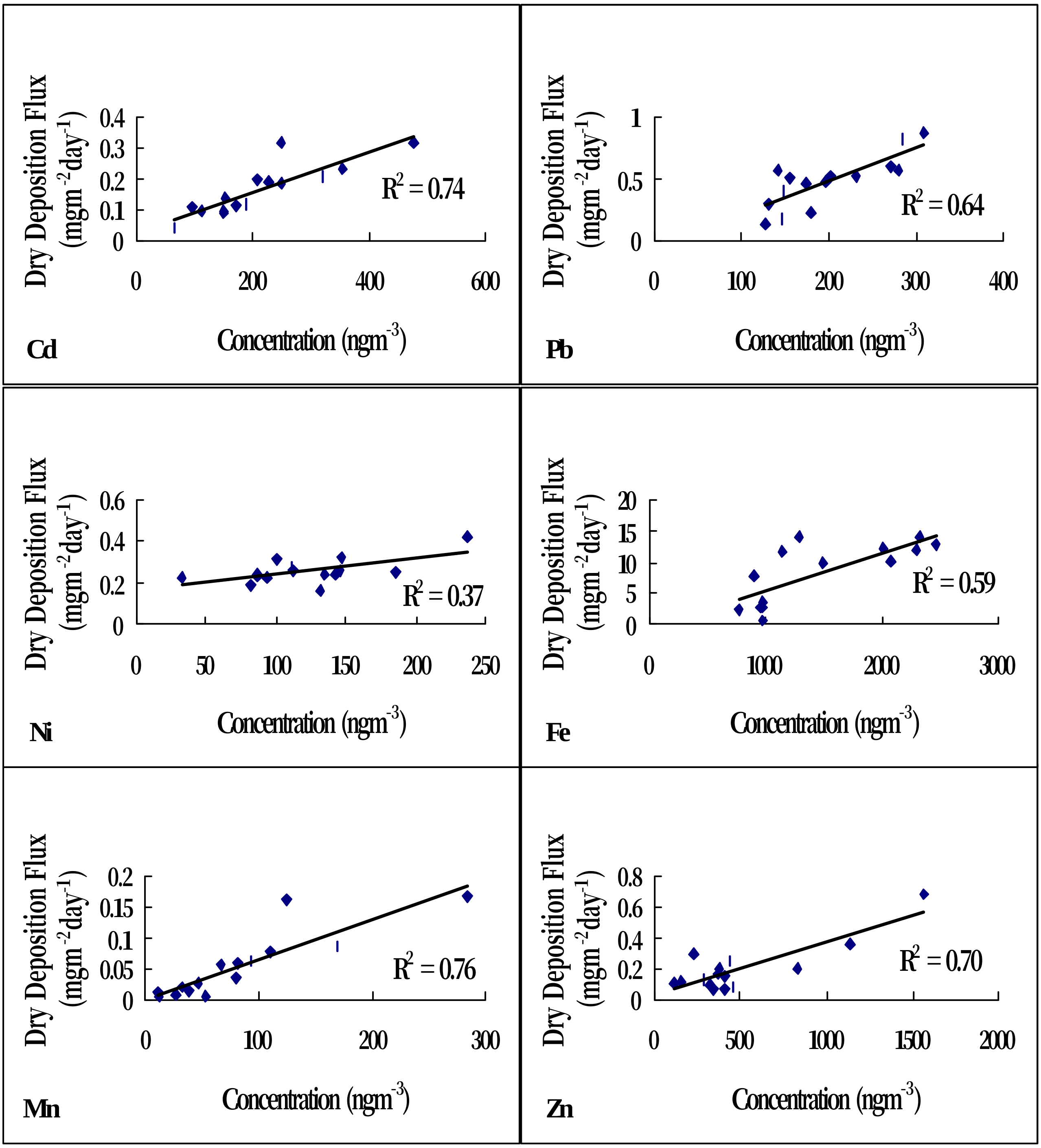


Figure 4.3-3

Metallic correlation of dry deposition flux and suspended particulates ($PM_{10}$) at Tzu Yun Yen temple (n=15). The regression line is the best-fit overall dry deposition velocity.

### *4.1.2 Average dry deposition velocities at Tzu Yun Yen temple*

Average dry deposition velocities for suspended particulate ($PM_{2.5}$, $PM_{2.5-10}$ and $PM_{10}$) at Tzu Yun Yen temple were displayed in Table 4-3-1. With high correlation coefficients obtained for element Zn between dry deposition flux and $PM_{2.5}$, $PM_{10}$, the results also indicated that dry deposition collected of Zn between dry deposition flux and $PM_{2.5}$, $PM_{10}$ were 0.74 and 0.56 $cms^{-1}$ in this study, respectively. By the same method mentioned about, the dry deposition velocities of Fe in coarse particulates ($PM_{2.5-10}$) mode were 15.49 $cms^{-1}$ at Tzu Yun Yen temple. Furthermore, dry deposition velocities of Mn in fine particulates ($PM_{2.5}$) and suspended particulate ($PM_{10}$) mode were 1.43 and 0.75 $cms^{-1}$ in this study, respectively. Finally, dry deposition velocities of Cd used fine particulates ($PM_{2.5}$) and suspended particulate ($PM_{10}$) mode were 1.86 and 0.99 $cms^{-1}$ in this study, respectively. These results were some in other study.

The average overall dry deposition velocities obtained using coarse particle concentrations for primarily elements were only slightly larger than the ones obtained using the total particle concentrations at all sampling sites. This result indicates that the primarily crustal elements are mostly associated with coarse particles (i.e. coarse and total concentrations were very similar). Very high deposition velocities and poor correlation coefficients for crustal elements obtained using fine particle concentration were obtained because of the small concentration of crustal elements in the fine particle mode. The overall dry deposition velocities obtained using fine particle concentration for the primarily anthropogenic elements were better correlated with the flux (Yi *et al.*, 2001).

Table 4.3-1
Average dry deposition velocities for suspended particulate ($PM_{2.5}$, $PM_{2.5-10}$ and $PM_{10}$) at Tzu Yun Yen temple. (n=15)

| | <2.5ì m ($cms^{-1}$) | | 2.5ì m 10ì m ($cms^{-1}$) | | <10ì m ($cms^{-1}$) | |
|---|---|---|---|---|---|---|
| **Species** | **Average** | **SD** | **Average** | **SD** | **Average** | **SD** |
| **Zn** | **0.74*** | **0.49** | **2.70** | **2.53** | **0.56*** | **0.37** |
| **Fe** | **10.01** | **5.51** | **15.49*** | **7.45** | **5.98** | **3.04** |
| **Pb** | **7.62** | **3.74** | **5.19** | **2.61** | **2.75** | **0.92** |
| **Mn** | **1.43*** | **1.05** | **5.34** | **4.13** | **0.75*** | **0.37** |
| **Ni** | **7.49** | **6.13** | **4.89** | **2.69** | **2.56** | **1.74** |
| **Cd** | **1.86*** | **0.64** | **2.27** | **0.96** | **0.99*** | **0.34** |

*: Correlation values are higher 0.7 between dry deposition flux and suspended particulates.

### *4.1.3 Dry deposition and metallic elements flux for the indoor /outdoor environment at Tzu Yun Yen temple*

Table 4.3-2 showed averaged mass dry deposition flux, metallic elements flux, and indoors/outdoors ratio (%) for the indoor and outdoor environment at Tzu Yun Yen temple during the incense burning periods. The results also indicate that almost the average dry deposition flux in the indoor environment is lower than in the outdoor environment at Tzu Yun Yen temple. The average dry deposition flux was 80.2 mg $m^{-2}day^{-1}$ and 202.7 mg $m^{-2}day^{-1}$ in the indoor and outdoor environment, respectively. The mean dry deposition flux indoor/outdoor ratios were 39.6% at Tzu Yun Yen temple in this study. Averaged elements fluxes were 0.03, 0.15, 5.35, 0.15, 0.08, 0.05, and 0.08 $mgm^{-2}day^{-1}$ for Cr, Zn, Fe, Pb, Mn, Ni, and Cd at the indoor environment, respectively. And Averaged elements fluxes were 0.01, 0.03, 0.11, 5.75, 0.07, 0.08, 0.06, and 0.04 $mgm^{-2}day^{-1}$ for Cu, Cr, Zn, Fe, Pb, Mn, Ni, and Cd at the outdoor environment, respectively. The data provided here also indicated that element Fe were higher than anthropogenic elements (Zn, Pb, Mn, Ni, and Cd) in the dry deposition flux mode at Tzu Yun Yen temple in this study. In general, mean indoor/outdoor ratios for dry deposition flux of metallic elements were 91%, 138%, 93%, 222%, 101%, 95%, and 208% for Cr, Zn, Fe, Pb, Mn, Ni, and Cd at this temple, respectively. Results also indicated that the major metallic elements dry deposition at Tzu Yun Yen temple indoor environment were Zn, Pb, and Cd.

Table 4.3-2

Compares averaged dry deposition metallic elements flux ($mg\ m^{-2} day^{-1}$), and indoors/outdoors ratio (%) for the indoor and outdoor environment at Tzu Yun Yen temple sampling site.

| | Indoors environment (n=20) | | Outdoors environment (n=15) | | Indoors/ Outdoors |
|---|---|---|---|---|---|
| | Mean | SD* | Mean | SD* | Average ratio |
| Cadmium (Cd) | 0.077 | 0.066 | 0.037 | 0.022 | 208.1% |
| Nickel (Ni) | 0.053 | 0.046 | 0.056 | 0.042 | 94.6% |
| Manganese (Mn) | 0.076 | 0.056 | 0.075 | 0.056 | 101.3% |
| Lead (Pb) | 0.153 | 0.145 | 0.069 | 0.052 | 221.7% |
| Iron (Fe) | 5.349 | 2.982 | 5.747 | 3.137 | 93.1% |
| Zinc (Zn) | 0.152 | 0.134 | 0.110 | 0.058 | 138.2% |
| Chromium (Cr) | 0.031 | 0.024 | 0.034 | 0.018 | 91.2% |
| Copper (Cu) | - | - | 0.012 | 0.005 | - |

*: Standard deviation

# Chapter 5

## Conclusions and Suggestions

### 4.4 Conclusions

The major conclusions for this study are as follows:

1. The average percentages of $PM_{2.5}$ /$PM_{10}$ were about 71 percent. The results also demonstrated that the fine particulates ($PM_{2.5}$) constituted the majority of indoor suspended particulates at Tzu Yun Yen temple. In general, the average $PM_{10}$ concentrations collected at Tzu Yun Yen temple were 23 % higher than 125 ì gm$^{-3}$ (EPA standard) during sampling period.

2. The $PM_{10}$ concentrations were 121 ì gm$^{-3}$ for Zhong Yuan Jie and the 1$^{st}$ or 15$^{th}$ of nong li for each month (Chinese lunar calendar), which were higher than non-Zhong Yuan Jie and non-1$^{st}$ or 15$^{th}$ days averaged 96 ì gm$^{-3}$. It is suggest that decreased incense burning and period of stay at Tzu Yun Yen temple during Zhong Yuan Jie, and the 1$^{st}$ and 15$^{th}$ of nong li for each month (Chinese lunar calendar) is an effective way to decrease the suspended particulate influence to pilgrims' health. Besides, It is also suggested that exposure to PM could reduced by decreasing the amount of incense burned or by decreasing the time for visitors stay at this temple.

3. The average dry deposition flux (58.5 $mg\ m^{-2}day^{-1}$) in the indoor environment is lower than that measured in the outdoor environment (averaged 206.7 $mg\ m^{-2}day^{-1}$). The mean mass dry deposition indoor/outdoor flux ratio was 28.3 % in this study. The mean indoor/outdoor ratios for dry deposition flux of metallic elements were 91%, 138%, 93%, 222%, 101%, 95%, and 208% for Cr, Zn, Fe, Pb, Mn, Ni, and Cd at this temple, respectively. Results also indicated that the major metallic elements dry deposition at Tzu Yun Yen temple indoor environment were Zn, Pb, and Cd.

4. The average mass size distributions are bimodal with the major peaks within 0.18-0.32 ì m and 5.6-10ì m, respectively during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar) at Tzu Yun Yen temple. The results also showed that fine suspended particulate concentrations increase at Tzu Yun Yen temple during Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar).

5. The average particle mass size distribution of total aerosols at Tzu Yun Yen temple during the incense burning period was also characterized. The average geometric standard deviation (óg) is 7.75 at Zhong Yuan Jie and the $1^{st}$ or $15^{th}$ of nong li for each month (Chinese lunar calendar), is greater than 6.32 during non-Zhong Yuan Jie and non-$1^{st}$ or $15^{th}$ days.

6. From the point of view of $PM_{10}$ concentrations, these data reflect that elements of Fe, Zn, and Cr were the major elements distributed at Tzu Yun Yen temple in this study. However, element Cu has the lowest concentrations in either $PM_{2.5}$ or $PM_{2.5-10}$ at Tzu Yun Yen temple. The results indicated that the Fe, Zn, and Cr have the higher average composition in fine particle ($PM_{2.5}$) at Tzu Yun Yen temple while Fe, Cr, Cd, and Pb have the higher average composition in coarse particle ($PM_{2.5-10}$) at Tzu Yun Yen temple.

7. The mean metallic elements concentrations for Zn and Mn in fine particle ($PM_{2.5}$) at Tzu Yun Yen temple were ranked as the highest compared with the other world areas (outdoor environment). And the mean metallic elements (Ni, Cr, and Cd) concentrations were ranked as the highest in either fine particle ($PM_{2.5}$) or coarse particle ($PM_{2.5-10}$) concentrations compared with the other world regions (outdoor environment) data.

8. With high correlation coefficients obtained for element Zn between dry deposition flux and $PM_{2.5}$, $PM_{10}$, the results also indicated that dry deposition collected of Zn between dry deposition flux and $PM_{2.5}$, $PM_{10}$ were 0.74 and 0.56 $cms^{-1}$ in this study, respectively. By the same method mentioned about, the dry deposition velocities of Fe in coarse particulates ($PM_{2.5-10}$) mode were 15.49 $cms^{-1}$ at Tzu Yun Yen temple. Furthermore, dry deposition velocities of Mn in fine

particulates ($PM_{2.5}$) and suspended particulate ($PM_{10}$) mode were 1.43 and 0.75 $cms^{-1}$ in this study, respectively. Finally, dry deposition velocities of Cd obtained by best fitted method in fine particulates ($PM_{2.5}$) and suspended particulate ($PM_{10}$) mode were 1.86 and 0.99 $cms^{-1}$ in this study, respectively.

9. Average mass size distribution during incense burning at Tzu Yun Yen temple was also studied. It showed that the average mass size distributions are bimodal and with the major peak within 0.32-0.56 ì m and 5.6-10ì m, respectively during incense burning period at Tzu Yun Yen temple. And the average mass median aerodynamic diameter (MMAD) and geometric standard deviation (óg) of suspended particles are 0.32 ì m, 7.14 during the incense burning at Tzu Yun Yen temple in this study.

## 4.5 Suggestions

The major suggestions for this study are as follows:

i. In order to collect indoor/outdoor ambient air particulates need to Universal Air Sampler and MOUDI sampler implemented simultaneously at Tzu Yun Yen temple in the future. In addition, mass size distributions for suspended particulate and metallic elements concentrations variation characterize for the indoor/outdoor environment at Tzu Yun Yen temple for future study.

ii. Pilgrims' health risk assessment and other hazard toxic pollutants such as PAHs at Tzu Yun Yen temple during incense burning period need to be further discussed in the future.

# References

Balachandran, S., Meean, B.R., Khillare, P.S., 2000. Particle size distribution and its elemental composition in the ambient air of Delhi. Environment Internation 26, 49-54.

Chao, C.W., and Wong, K.K., 2002. Residential indoor PM10 and PM2.5 in Hong Kong and the elemental composition. Atmospheric Environment 36, 265-277.

Chow, J. C., 1995. Measurement methods to determine compliance with ambient air quality standards for suspended particles. Journal Air Waste Manage Assoc 45, 320-382.

Chen, C.Y., Cheng, M.T., Zuang, P.C., 1998. The Total Quantity Control in Taichung Park. EPA, Taiwan, Taichung.

Conner, T.L., Norris, G.A., Landis, M.S., and Williams, R.O.,2001. Individual particle analysis of indoor, outdoor, and community samples from the 1998 Baltimore particulate matter study. Atmospheric Environment 35, 3935-3946.

Dockery DW, Pope CA, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG, Speizer GE, 1993. An association between air pollution and mortality in six US cities. NewW Engl J Med 329, 1753-1759.

Dolske, D. A. and Gatz, D. F., 1985. ”A Field Intercomparison of Methods for The Measurement of Particle and Gas Deposition”, Journal. *of Geophysical Research*, 90, 2076-2084.

El-Fadel, M. and Massoud, M., 2000. Particulate matter in urban areas: health-based economic assessment, Journal of the Science of the Total Environment 257, 133-146.

Espinosa, A.J.F., Rodriguez, M.T., Rosa, F. J.B., and Sánchez, J.C.J., 2002. A chemical speciation of trace metals for fine urban particles. Atmospheric Environment 36, 773-780.

Fang, G.C., Cheng, M.T.,Chang, C.N.,1997. Monitoring and modeling the mass, heavy metal and ion species dry deposition in central Taiwan. Journal of Environmental Science and Health. A32, 2183-2199.

Fang, G.C., Chang, C.N., Wang, N.P., Wu, Y.S., Wang, v., Fu, P.C.P., Cheng, C.D., Chen, S.C., Lin, D.Y., 2000. The study of TSP, $PM_{2.5}$ and $PM_{2.5-10}$ during Taiwan Chu-Chi Earthquake in the traffic site of central Taiwan, Taichung. Chemosphere 41, 1727-1731.

Fang, G.C., Chang, C.N., Wu, Y.S., Fu, P.C.P., Chang, K.F., Yang, D.G., Chu, C.C., 1999. Characterization of chemical species in $PM_{2.5}$ and $PM_{10}$ aerosol in the suburban and rural sites of central Taiwan. Journal of the

Science of the Total Environment 234, 203-212.

Fang, G.C., Chang, C.N., Wu, Y.S., Fu, P.C.P., Chang, Chang, S.C., Cheng, C.D., Yuen, W.H., 2002. Concentration variations study of atmospheric particulate during dust storm period in central Taiwan. Journal of the Science of the Total Environment 287,141-145.

Gomzi, M., 1999. Indoor air and respiratory health in preadolescent childen. Atmospheric Environment 33, 4081-4086.

Gómez, B., Gómez, M., Sanchez, J.L., Fernández, R., and Palacios, M.A., 2001. Platinum and rhodium distribution in airborne particulate matter and road dust. Journal of the Science of the Total Environment 269, 131-144.

Hien, P.D., Binh, N.T., Truong, Y., Ngo, N.T., and Sieu, L.N., 2001. Comparative receptor modeling study of TSP, $PM_2$ and $PM_{2-10}$ in **Ho Chi Minh City.** Atmospheric Environment 35, 2699-2678.

Hitchins, J., Morawska, L., Wolff, R., Gilbert, D., 2000. Concentrations of submicrometer particles from vehicle emissions near a major road. Atmospheric Environment *34*, 51-59.

Holsen, T. M., and Noll, K. E., 1992. Dry deposition of atmospheric particles: application of current models to ambient data. Environmental Science and Technology 26 1802-1814.

Hosiokangas, J., Ruuskanen, J., and Pekkanen, J., 1999. Effects of soil dust episodes and mixed fuel sources on source apportionment of PM10 paticles in Kuopio, Finland. Atmospheric Environment 33, 3821-3829.

Jones, A.P., 1999. Indoor air quality and health. Atmospheric Environment 33, 4535-4564.

Jones, A.P., 1998. Asthma and domestic air quality. Soc. Sci. Med. 47, 755-764.

Koliadima, A., Athanasopoulou, A. and Karaiskakis, G., 1998. Particulate matter in air of the cities of Athens and Patras (Greece): particle-size distribution and elemental concentrations, Aerosol Science Technology 28 292-300.

Koponen, I.K., Asmi, A., Keronen, P., and Kulmala, M., 2001. Indoor air measurement campaign in Helsinki, Finland 1999 the effect of outdoor air pollution on indoor air. Atmospheric Environment 35, 1465-1477.

Lau, O.W., and Luk, S.F., 2001. Leaves of *Bauhina blakeana* as indicators of atmospheric pollution in Hong Kong. Atmospheric Environment 35, 3113-3120. Li, C.S., and Ro, Y.S., 2000. Indoor characteristics of polycyclic aromatic hydrocarbons in the urban atmosphere of Taipei. Atmospheric Environment 34, 611-620.

Lee, J. H., Kim, Y. P., Moon, K. C., Kim, H. K. and Lee, C. B., 2001. fine particle measurements at two background sites in Korea between 1996 and 1997. Atmospheric Environment 35 635-643.

Mannix, R.C., Nguyen, K.P., Tan, W.E., Ho, E.E., Phalen, R.F., 1996. Physical characterization of incense aerosols. Journal of the Science of the Total Environment 193, 149-158.

Marcazzan, G.M., Vaccaro, S., Valli, G., and Vecchi, R., 2001. Characterisation of PM10 and PM2.5 particulate matter in the ambient air of Milan (Italy). Atmospheric Environment 35, 4639-4650.

Mazzera, D.M., Lowenthal, D.H., Chow, J.C., Watson, J.G., and Grubísíc, V., 2001. PM10 measurements at McMurdo Station, Antarctica. Atmospheric Environment 35, 1891-1902.

Miguel, A.G., Cass, G.R., Glovsky, M. M., Weiss, J., 1999, Allergens paved road dust and airborne particles. Environ, Sci, Technol., 33, 4159-4168.

Morimoto, S.I., Kaminogo, A., Hirano, T., 1998. A new method to enhance visualization of latent fingermarks by sublimating dyes, and its practical use with a combination of cyanoacrylate fuming, Forensic science International 97, 101-108.

Model 100 Micro-Orifice Uniform Deposit Impactor (MOUDI™) Instruction Manual, 1989. MSP Corporation, 1313 Fifth Street, S.E. Suite 206, Minneapolis, MN, U.S.A. 55414.

Ohlström, M.O., Lehtinen, K.E.J., Moisio, M., Jokiniemi, J.K., 2000. Fine-particle emissions of energy production in Finland. Atmospheric Environment 34, 3701-3711.

Ostro, B., and Chestnut, L., 1998. Assessing the health benefits of reduction particulate matter air pollution in the United States. Environ Research 76 94-106.

Parmar, R.S., Satsangi, G.S., Kumari, M., Lakhani, A., 2001, Study of size distribution of atmospheric aerosol at Agra. Atmospheric Environment 35, 693-702.

Pedersen, E.K., BjØrseth, O., Syversen, T., and Mathiesen, M., 2001. Physical change of indoor dust caused by hot surface contact Atmospheric Environment 35, 4149-4157.

Querol, X., Alastuey, A., Rodriguez, S., Plana, F., Mantilla, E and Ruiz, C.,

2001. Monitoring of PM10 and PM2.5 around primary particulate anthropogenic emission sources. Atmospheric Environment 35, 845-858.

Rajkumar, W.S. and Chang A.S., 2000. Suspended particulate matter concentrations along the East-West Corridor, Trinidad, West Indies. Atmospheric Environment 34, 1181-1187.

Salma, I., Maenhaut, W., Papp, E.Z., and Záray, G., 2001. Comprehensive characterization of atmospheric aerosols in Budapest, Hungary: physicochemical properties of inorganic species. Atmospheric Environment 35, 4367-4378.

Sohrabpour, M., Mirzaee, H., Rostami, S., and Athari, M. 1999. Elemental concentration of the suspended particulate matter in the air of Tehran. Environment International 25, 75-81.

Tuch, T.A., Mirme, E., Tamm, J., Heinrich, J., Hyder, P., Brand, Ch. Roth, H.E. Wichmann, J. Pekkanen, W.G.Kreuling. 2000. Comparison of two particle-size spectrometers for ambient aerosol measurements. Atmospheric Environment 34, 139-149.

Universal Air Sampler. Model 310 Universal Air Sampler$^{TM}$ Instruction Manual (USA$^{TM}$), MSP Corporation, I313 Fifth Street, S.E. Sulte206 Minncapolis, MN55414, USA, 1996.

Yi, S. M., Shahin, U., Sivadechathep, J., Sofuoglu, S.C., Holsen, T.M., 2001. Overall elemental dry deposition velocities measured around Lake Michigan. Atmospheric Environment 35, 1133-1140.

Zufall, M.J., Dai, W., and Davidson, C.I., 1999. Dry deposition of particles to wave surfaces: Π Wind tunnel experiments. Atmospheric Environment 33, 4283-4290.

**林志忠，大氣中陰離子及重金屬之粒徑分布及乾沈降研究，碩士論文，國立屏東科技大學工程技術研究所，**1997.