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Source apportionment and potential source locations of $PM_{2.5}$ and $PM_{2.5–10}$ at residential sites in metropolitan Bangkok

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ABSTRACT

Fine and coarse fractions of PM_{10} ($PM_{2.5}$ and $PM_{2.5–10}$, respectively) were collected from January 2003 to December 2007 at an urban Bangkok site (Chatuchak district) and a suburban site (Klongha district, Pathumthani) in Thailand. The filter samples were analyzed for mass, black carbon, and up to 28 elements were determined using instrumental neutron activation analysis and Particle–Induced X–ray Emission (PIXE). The long–term database shows that PM mass at the urban area had higher mass, black carbon, and some elements than the one at the suburban area. Furthermore, it is found that mass and elemental concentrations were generally elevated in the coarse fractions whereas black carbon was the major content in fine fractions. Positive Matrix Factorization (PMF) and multiple linear regression were applied to investigate for PM source fingerprints and apportionment. Source contributions and wind direction influence were also examined by use of conditional probability function (CPF) and potential source contribution function (PSCF). The PMF results indicated that major sources contributed to coarse fractions were soil, construction, whereas traffic and biomass burning were the major sources for fine fractions. CPF and PSCF models assisted in determining of the potential locations and/or the preferred pathways of these possible sources.

Keywords:
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1. Introduction

Over the past two decades, it has been recognized that particulate matter is a major urban air pollutant, particularly in most of the world's mega cities. It is because airborne particulate matter (APM) causes not only the adverse impacts on human health but also on visibility. A large number of studies related to APM have been conducted worldwide to understand the nature of APM and their association with adverse impacts such as cardiovascular– and respiratory– disease, as specific causes of mortality (e.g., Castillejos et al., 2000; Kwon et al., 2001; Health Effects Institute, 2004; Anderson et al., 2005; Lipsett et al., 2006; Kumar et al., 2007; Sarnat et al., 2008).

Unlike other key air pollutants, i.e., ozone (O_3), sulfur dioxide (SO_2), nitrogen oxides (NO_x) or carbon monoxide (CO) that are known single compounds, APM is a mixture of solid and liquid particles suspended in the air. Generally, the size frequency of the air particles has a distribution, with two main peaks at about 0.2 µm and at about 10 µm (Whitby and Cantrell, 1975). They are commonly classified as fine and coarse mode particles. Coarse particles (particles with aerodynamic diameter 2.5–10 µm or $PM_{2.5–10}$) mostly derive from mechanical processes (e.g. soil erosion) or incomplete combustion. Fine particles (particles with aerodynamic diameter less than 2.5 µm or $PM_{2.5}$) can be attributed mainly to combustion processes (anthropogenic activities) or from gas–to–particle conversion processes. Therefore, monitoring of both fine and coarse mode particles is useful in defying risk to human and also for developing efficient PM control strategies. A long–term database could result to more precise interpreted information. Furthermore, identification of major sources and the apportionment (assessment) of their relative contribution can provide valuable information for epidemiologists and regulatory agencies.

In Thailand, ambient air quality has been monitored for more than 25 years. The air pollutants being measured include NO_x, ground–level O_3, CO, SO_2, Pb and PM_{10}. Although the ambient levels of most key air pollutants are steadily declining, ambient PM_{10} is still the most serious problem in many locations. The Thailand PM_{10} standard for 24 hours, 120 µg/m^3, has been exceeded on occasion, particularly near roadsides in urban areas such as Bangkok (Pollution Control Department, 2007). Many research and monitoring studies have been conducted in Thailand primarily for PM_{10} levels and their adverse effects on human health and the environment (e.g., Ostro et al., 1999; Vajanapoom et al., 2001; Cheevaporn et al., 2004; Vichit–Vadakan et al., 2008). A Thai national $PM_{2.5}$ standard has been established since January 2010. However, the number of monitoring stations for $PM_{2.5}$ is limited only in specific areas where particulate air pollution is of concern. At present, only three $PM_{2.5}$ monitoring stations are being operated by the Pollution Control Department (PCD) of Thailand. In addition to $PM_{2.5}$, a concern regarding $PM_{2.5–10}$ has also increased. Fine and coarse fractions can be different in their chemical nature and sources. Thus, source information can be useful for air quality management in Thailand. Nevertheless, there are very few studies of both size fractions.

Vichit–Vadakan et al. (2001) conducted three panel studies in Bangkok to determine statistical relation between $PM_{2.5}$ levels and respiratory symptoms. Tsai et al. (2000) researched on indoor and outdoor PM_{10} and $PM_{2.5}$ in Bangkok, while Jinsart et al. (2002) examined the roadside $PM_{2.5}$ and $PM_{2.5-10}$ levels. More informative studies emphasized on different sized–fractions in order to understand their sources of origin. Chueinta et al. (2000) reported the characterization and source identification of fine and coarse particles collected in urban and suburban residential areas in Thailand and an extended study at Bangkok metropolitan curbside was later performed (Chueinta and Bunprapob, 2003). Leenanupan et al. (2002) carried out similar work for characterization of fine particulate pollution at Mae Hong Son province in the north of Thailand. A few collaborative studies on fine and coarse particulate air pollution in the Asia Pacific regional scale were reported, e.g., Oanh et al. (2006); Ebihara et al. (2006; 2008); Hopke et al. (2008). Besides, only few long–term $PM_{2.5}$ and $PM_{2.5-10}$ monitoring data are available elsewhere in this region.

This report presents a 5–year study of ambient air quality in the Bangkok Metropolitan Region (BMR) covering the period of 2003 to 2007. Sampling of fine and coarse fractions, $PM_{2.5}$ and $PM_{2.5-10}$, at two sites representing an urban residential area, i.e., Chatuchak district (Bangkok) and a suburban residential area, Klongha district (Pathumthani). All of the PM samples were analyzed for their chemical composition. Positive matrix factorization (PMF) was applied for source identification and apportionment aided by conditional probability function (CPF) and potential source contribution function (PSCF) analyses. This work presents the longest continuous study of fine and coarse PM in Thailand.

2. Sampling and Analysis

2.1. PM sampling

Two Gent Stacked Filter Units (Hopke et al., 1997) were continuously operated from 2003 to 2007 at the two monitoring sites (See Figure 1). These sites were chosen to represent urban and suburban residential areas where there would be population exposures to the ambient aerosol and be characteristic of typical regions within the Bangkok metropolitan area. The first site at Chatuchak is an urban residential district of Bangkok located about 10 km from city center and about 40 km from the Gulf of Thailand. There is a toll highway and railway aligned from SW to NW of the sampling site. The sampler was placed on the roof–top of the one floor building, which was about 3 meters from the ground.

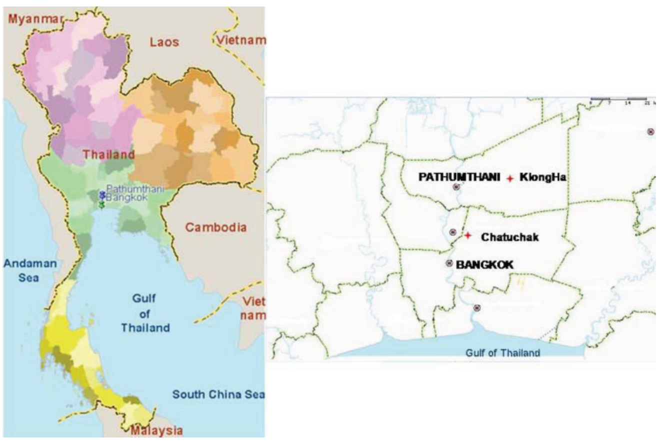

***Figure 1.** Map of Thailand (left) and expanded view of sampled area (right) showing the sites at Chatuchak, Bangkok and Klogha, Pathumthani.*

The second site is located at Klongha, a district of Pathumthani (suburb 40 km north east of Bangkok). The sampler was set up in an open field. It is a residential area surrounded by houses (wooden and brick), a canal, trees and grassy fields. A major road is situated about 5 km in the south. The samplers were operated at a flow rate of about 16 L/min for 24 hours to collect both fine and coarse particles ($PM_{2.5}$ and $PM_{2.5-10}$) on two sequential 47 mm diameter Nuclepore polycarbonate filters of 0.4 µm and 8 µm pore size, respectively (Maenhaut et al., 1994; Hopke et al., 1997). The sampling frequency was twice a week on Wednesday and Sunday. The total number of $PM_{2.5}$ and $PM_{2.5-10}$ pairs collected at Bangkok and Pathumthani sites were 508 and 425, respectively.

2.2. Mass measurements

PM mass was determined by gravimetry using a microbalance (Mettler MT5). The filters were weighed before and after PM loading in order to determine PM mass collected and then divided by the volume of total air sampling (m^3) to get the particulate mass concentration in $\mu g/m^3$. The weighing was done in a clean room under controlled atmosphere, i.e., 25 °C and 30–40% relative humidity, and with the use of Po–210 as a static eliminator. Both blank and loaded filters were kept in an auto–desiccator under the same controlled condition at least 24 prior to weighing.

2.3. Black carbon measurement

The Smoke Stain Reflectometer (Diffusion Systems Ltd Model 43D) was used for the measurement of reflectance of fine fraction filters and calculated for black carbon (BC) content using the following equation (Fuller et al., 1999):

$$BC\ (\mu g/m^3) = [\{1000 \log(R_0/R) + 2.39398\}/45.7985] \times (A/V) \qquad (1)$$

where R_o is the reflectance from blank filter, R is the reflectance from loaded filter, A is the area of collected particulate (cm^2), V is the volume of air (m^3).

2.4. Elemental analysis

Instrumental Neutron Activation Analysis (INAA) and Particle–Induced X–ray Emission (PIXE) were used for the determination of multiple elemental concentrations in the PM samples.

For INAA, the air filter samples including standards and filter blanks were packed in polyethylene vials and irradiated in 1.2 MW TRIGA MARK III Research Reactor at the thermal neutron flux in the order of 10^{12} n/cm^2 sec. All irradiated samples were transferred to new vials and counted for gamma ray activities using a high purity germanium (HPGe) detector (EG&G ORTEC detector). In summary, two different irradiations and four gamma ray counts after appropriate decay times were conducted in order to determine short–, medium–, and long–lived radionuclides. Up to 25 elemental concentrations, their uncertainties and detection limits were obtained.

For PIXE, the filter samples were exposed to a beam of protons accelerated with typically 2.5 million volts from a van–de–Graaff accelerator. The X–rays emitted were detected by means of a Si(Li) detector. The analyses of 25 to 30 elements in PM including uncertainties and detection limits were obtained.

2.5. Data analysis and PM source identification

Four PM data set (fine and coarse fractions each of the two sampling sites) consisted of mass, BC, and elemental compositions were obtained.

Positive Matrix Factorization. Positive Matrix Factorization (PMF) is a commonly used receptor model. It solves the factor analysis problem using a least squares analysis with data point weighting