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Identifying airborne metal particles sources near an optoelectronic and semiconductor industrial park

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ABSTRACT

The recently developed Central Taiwan Science Park (CTSP) in central Taiwan is home to an optoelectronic and semiconductor industrial cluster. Therefore, exploring the elemental compositions and size distributions of airborne particles emitted from the CTSP would help to prevent pollution. This study analyzed size-fractionated metal-rich particle samples collected in upwind and downwind areas of CTSP during Jan. and Oct. 2013 by using micro-orifice uniform deposited impactor (MOUDI). Correlation analysis, hierarchical cluster analysis and particle mass-size distribution analysis are performed to identify the source of metal-rich particle near the CTSP.

Analyses of elemental compositions and particle size distributions emitted from the CTSP revealed that the CTSP emits some metals (V, As, In Ga, Cd and Cu) in the ultrafine particles (<1 μm). The statistical analysis combines with the particle mass-size distribution analysis could provide useful source identification information. In airborne particles with the size of 0.32 μm, Ga could be a useful pollution index for optoelectronic and semiconductor emission in the CTSP. Meanwhile, the ratios of As/Ga concentration at the particle size of 0.32 μm demonstrates that humans near the CTSP would be potentially exposed to GaAs ultrafine particles. That is, metals such as Ga and As and other metals that are not regulated in Taiwan are potentially harmful to human health.

1. Introduction

In past decades, Taiwan has become the global leader of high-tech products, and the considerable production value of high-tech industrial parks (HTIP) is a major contributor to the Taiwanese economy. However, the large amount of pollutants emitted by HTIPs is a major concern (Wang et al., 2015). Accurate apportioning of pollutant components is an essential step for developing efficient control strategies and reducing the harmful effects of pollutants (Choi et al., 2015). Some studies used backward trajectory, element mass size distributions, positive matrix factorization, and expected theory to analyze the pattern of particle pollution and identify the pollution source (Chen et al., 2015; Hang and Kim Oanh, 2014; Liu et al., 2016; Tan et al., 2014; Tan et al., 2016). For example, principal component analysis (PCA) and logistic regression were adopted to identify volatile organic compounds and odor sources near a HTIP (Chen and Liang, 2013). Hierarchical cluster analysis (HCA) is a statistical method to extract information concerning the emission source (Đorđević and Šolević, 2008), and Wang et al. used HCA to analyze the correlation of different diameter particle fractions with related gaseous pollutants and meteorological parameters near Rome (Wang et al., 2010). is applied to extract information concerning the source.

High-tech nanometer manufacturing processes performed at the HTIP also produce metal-rich airborne particles (Huang et al., 2011) that lead to the accumulation of trace metals in the organs of animals (Suzuki et al., 2007). The size of particulate matter (PMs) emitted from HTIPs are usually fine and ultrafine particles (FPs and UFPs) (Chein et al., 2006; Suzuki et al., 2007); the harmful effects of FPs and UFPs on the lungs and the heart are well established. Lu et al. (2015) demonstrated that UFPs at low concentration could damage human alveolar basal epithelial cells (Lu et al., 2015), and the effects of UFPs with diameters of less than 1 μm are particularly serious (Mutlu et al., 2012). Meanwhile, several trace metals hidden in FPs and UFPs have only recently been identified as potentially hazardous materials, and the toxic efficiencies depends on their size (Allen et al., 2001; Ntziachristos et al., 2007) and chemical composition (Spurny, 1998). Hence, size distribution of PMs and their chemical compositions are highly related to their emission sources (Fang et al., 2006), and traffic and stationary sources are the major emission sources of ultrafine particles (Díaz-Robles et al., 2014).

The recently developed Central Taiwan Science Park (CTSP) is home to optoelectronic and semiconductor industrial complexes, with a total investment of US$15.3 billion in 2013. As the number of factories in the CTSP increases, pollutant emissions increase, and the CTSP is close to

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several complicated pollution sources, and the metal-rich airborne particles emitted from the CTSP have attracted great concern. Few studies have analyzed the metal-rich airborne particles around the CTSP. Fang et al. (2012a, 2012b, 2012c) investigated the ambient arsenic species in PMs around the CTSP but the large size (<5.6 μm) of the PMs could not match the particle characteristics of HTIP (Fang et al., 2012a). To provide useful insight into pollution prevention for the CTSP, this study characterizes metal-rich particles emitted from the CTSP and proposes a pollution index for the stationary source in the CTSP. Metal-rich particle samples were collected in the upwind and downwind areas of the CTSP. Various elemental compositions and particle mass-size distributions near the CTSP are reported in this study. Patterns of particle mass-size distributions and fingerprint metals were identified by statistical methods and particle mass-size distribution analysis in the sample.

2. Materials and methods

2.1. Environmental background around CTSP

Fig. 1 shows that the CTSP in central Taiwan has recently become home to photoelectronics, and semiconductor clusters. The CTSP is located on the mountainside; the near topography is an altitude terrain of 50–300 m above sea level and declining from northwest to southeast; such local geography may possibly lead to pollutant aggregates (Chen et al., 2015). The east and south of the study area are connected to the Taichung Metropolitan area which has a population of 2 million. Approximately 5 km to the south of the CTSP is the Taichung Industrial Park, which is a conventional machinery industrial complex that has been operating intensively for approximately 30 years. About 2 km to the east of the CTSP is a national highway. The coast on the Taiwan Strait and the Taichung coal-burning power plant are approximately 15 km to the east of the CTSP. High-traffic networks in the study area include two National Freeways and Taiwan Boulevard. Additionally, several potential sources of pollutants near the CTSP increase the difficulty of identifying the sources of particles emitted from the CTSP.

2.2. Sampling design and trace metal measurement

In the study area, most of daily prevailing winds come from the north or the south. THU and Daya sample sites are located approximately 2.5 km in the northeastern and southwestern side of the CTSP, respectively. A nine-stage micro-orifice uniform deposit impactor sampler (MOUDI, TM Model 110, MSP Corporation, Minneapolis, Minnesota, USA) was used to monitor airborne metal particle between Jan. and Oct. 2013; each campaign lasted for 24 consecutive hours in the sample sites. The sampling period in this study was designed to capture normal emissions from the CTSP and the collected sample data were sufficient for identifying metal particle sources. To minimize the interference of other pollution sources such as the power plant, the collected sampling data were not adopted to identify the source when the daily prevailing winds come from the east or the west. Therefore, this study preliminarily selected the appropriate 18-sample data to evaluate the metal particle sources. Lin et al. (2010) reported that nitrate aerosol was mainly influenced by temperature and relative humidity during high particulate days (Lin et al., 2010). By contrast, metal particles were possibly associated with wind direction (Fang et al., 2012b; Lee and Hieu, 2011), and the pattern of particle size distribution would facilitate the identification of the source category (Wan et al., 2015). Fig. 2 shows daily wind rose diagrams, temperature (Temp), and relative humidity (RH) during the experimental campaigns when the THU site is considered as the downstream sampling site. While the daily prevailing wind blows from the north/south, the Daya sample site will be an upwind/downwind site. Likewise, when the daily prevailing wind blows from the north/south, the THU sample site will be a downwind/upwind site. In addition, the variation of the Temp and RH in the two sampling sites are small and can be neglected. Based on the above sampling design, this study investigated the daily metal concentration difference between the upwind and downwind sample sites, and used statistical analysis and particle mass-size distribution analysis to identify the source of the metal particles.

The flow rate of the MOUDI sampler was set to 30 L/min, and nine staged size fractions (18, 10, 5.6, 3.2, 1.8, 1, 0.56, 0.32 and 0.18 μm)

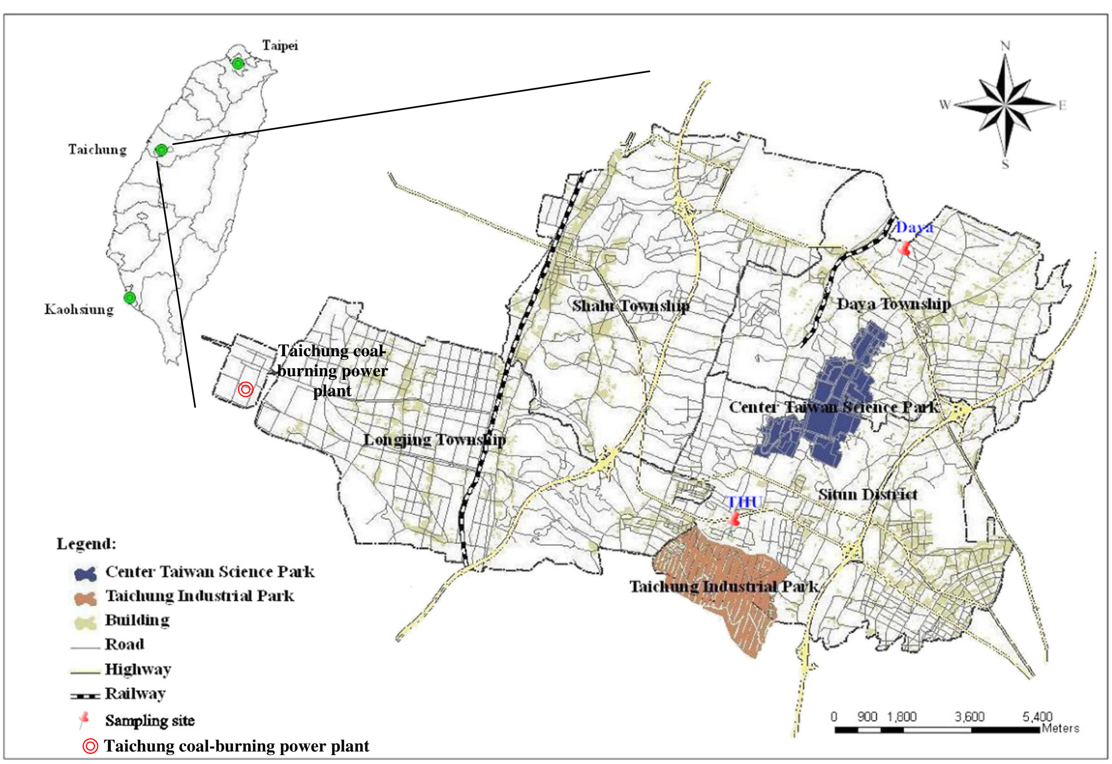

Fig. 1. Environmental characteristics of the study area and CTSP.