Emission and Dry Deposition Characteristics of Metal Elements from the Engineering Construction Sites

Hsi-Hsien Yang*, Ching-Min Yang, Chih-Ho Wong, Chu-Chin Hsieh, Hsiao-Hsuan Mi and Tze-Wen Chi

1Department of Environmental Management, Chaoyang University of Technology, Wufeng, Taichung 413, Taiwan
2Department of Environmental Engineering, National Cheng Kung University, Taiwan 70101, Taiwan
3Department of Environmental and Safety Engineering, National Yunlin University of Technology, Touliu, Yunlin 640, Taiwan
4Department of Environmental Engineering and Health, Chia-Nan University of Pharmacy and Science, Tainan County 717, Taiwan

Abstract

In order to explore the emission characteristics of particulate and its particle-bound metal elements, eight construction sites in southern Taiwan were investigated during the period between Dec. 1996 and May 1997. Total suspended particulate (TSP) samples were collected with PS-1 samplers, and the dry deposition particles were sampled by dry deposition plates with smooth surface. The emission factors of particulate matter from construction sites were estimated using a dispersion model. Twenty elements, including Al, Ca, Fe, Mg, Na, Pb, Zn, Ni, V, Ba, Mn, Cr, Cu, Cd, Sr, Ag, Mo, Sb, As, and Ti, were analyzed in this study. The results indicated that dry deposition fluxes of TSP ranged between 762 and 3760 mg/m²-day with an average of 2230 mg/m²-day. The dry deposition velocities (V_d) of TSP varied in a narrow range between 2.63 to 5.55 cm/s with an average of 4.31 cm/s and a standard deviation of 1.21 cm/s. The major elemental components of particulate matter in the ambient air at construction sites were found to be crustal elements including Al, Ca, Fe, Mg and Na. These compositions were similar to those of road dust. Dry deposition fluxes

*Corresponding author. Tel: 886-4-23323000 Ext. 4451; Fax: 886-4-23742365; E-mail: hhyang@mail.cyut.edu.tw
of crustal metals were much higher than those measured at urban and suburban sites.

Keywords: Particulate, Construction, Metal elements, Dry deposition, and Emission factor

1. Introduction

Recently, considerable attention has been focused on the air quality degradation caused by the particulate matter. Many studies have shown that fugitive dust is the major source of TSP and/or PM$_{10}$ [Chow et al., 1992; Watson et al., 1994]. Unpaved road, agricultural tilling operation, aggregate storage piles, and heavy constructions contribute to fugitive dusts that are loaded with crustal elements [USEAPA, 1996]. The ambient air concentration of particulate matter is universally high in developing areas because of higher road dust loading attributed from on-going construction activities.

PM$_{10}$ can be easily transported through the upper respiratory tract into the bronchioles and alveoli of the lungs and cause direct health hazard. Most recent researchers focus their attentions on finer particulates such as PM$_{2.5}$ for its ability to penetrate deep into the respiratory system. The effects of dust and deposits with large particles are both visible and tangible and are one of the main causes of complaint to air pollution [Hall et al., 1993]. The influences of coarse particles to environment have been studied over the past decades [Steen, 1986; Noll et al, 1989; Noll et al., 1990]. Dry deposition is an important mechanism by which coarse particles dispersed in the atmosphere to reach land surface. Some natural pollutants are also transported to the environment via the dry deposition process [Biddleman, 1988]. Particulate emission during construction is associated with land clearing, drilling and blasting, ground excavation, cut and fill operations, and building the facility itself. The particulate emission factors of these dust-generating activities are summarized in the USEPA's AP-42 manual. Application of numerical value suggested by the manual can yield uncertain emission estimates. There are recommendations for the reexamination of the manual
The particulate matters emitted from the construction sites are characterized by large particle sizes. Thus, dry deposition phenomenon is significant. The particulates on the road and construction area are resuspended into the air by wind blow and mechanical disturbance. Johnson (1992) investigated the resuspension mechanisms of particulate matters from the unpaved road and found that one third of resuspended particulate matters (aerodynamic diameter greater than 10 µm) remained in the air after 40 seconds. That is, two thirds of particulate matters were deposited to the ground nearby. Nicholson (1992) investigated the relationship between resuspension and some parameters including time, wind speed, particle size, and particle shape by wind tunnel experiment. However, study on the characteristics of particulate and metal dry deposition at construction sites remains to be conducted. Many metals are hazardous to human by damaging the nerve center, causing mental deficiency, inducing heart diseases and even promoting cancers [Nriagu and Pacyna, 1988; Paasivirta, 1991]. Metal pollution comes from industrial discharges and non-point sources of various kinds. Metals emitted from fugitive sources were under-investigated. Fugitive sources emitted large amount of metal elements, especially crustal elements. In this study, twenty metal elements emitted from construction sites were measured. Particulate size distribution, particle-bound metal concentration, dry deposition flux and dry deposition velocity were evaluated.

2. Experiment

2.1. Sampling Programs

Eight large building construction sites (symbol as A-H) in Tainan city, Taiwan were selected for this investigation. In Taiwan, construction activities are classified into building construction, road construction, zone development construction, bridge construction, pipe
excavation construction and miscellanea for levying air pollution fee. Site E is a zone
development construction and the other seven sites are all building construction. The area of
zone development construction site E is 1,350,000 m$^2$ and the building construction sites are
between 600 and 40,000 m$^2$ in area (Fig 1). The construction sites were selected with the
following considerations: (1) The construction site is located in the open area without tall
buildings nearby. (2) No other significant air pollution sources (especially particulate matter)
are identified near the sites. (3) The electricity supply, support from the site owner, and
management security during the sampling are available. To enable comparison of upwind/
downwind measure data, multiple sampling spots were strategically situated around a
construction site. One high volume sampler (General Metal Work Co., GPS1 PUF sampler)
and one set of dry deposition plate were set up at each sampling spot. The sampling
campaigns were performed starting on Dec. 1996 through May 1997. The sampling
durations were 6 hrs for PS-1 high volume sampler and dry deposition plate in order to collect
enough particulate and metal elements for further elemental analysis. The sampling
programs were performed at daytime (from 8:00 a.m. to 6:00 p.m.) when the construction
works were active. A total of 100 particulate data and 100 dry deposition data for the whole
sampling program were collected for analysis. All the sampling campaigns were performed
from the beginning of the construction projects. The number of samples at each construction
site is listed in the second column of Table 1.

2.2. Sampling Methods

*Total Suspended Particulate (TSP)*

TSP and metal elements were collected by using a high volume sampler (General Metal
Works PS-1) equipped with a quartz filter (Whatman International Ltd., 2500QAT-uce). The
diameter of the filter is 10.2 cm and the pore size is 0.8 μm. A quartz filter was weighed
before and after sampling, the difference was accrued to the suspended particulate matter
collected. The filter was then digested by acid for chemical analysis of metal elements.

**Dry deposition plate**

Dry deposition of particulates and metal elements were measured by a smooth surface plate with a sharp leading edge and the plate was mounted on a wind vane [Holsen et al., 1993]. The plate used in this study was similar to those used in wind tunnel studies [McCready, 1986]. It was made of polyvinyl chloride (PVC) and was 21.5 cm long, 8.0 cm wide, and 0.8 cm thick with a sharp leading edge (< 10-degree angle) pointing toward the wind direction. In order to minimize system errors during the experiments, 3 duplicate plate samples on a side-by-side basis were taken during each sampling period for averaging.

Each plate was covered with quartz strips (10 cm x 8 cm) coated with silicon grease (NO. 11025 silicon spray, Cling-surface CO., Inc., Angola, NY) to collect impacted particles (132 cm$^2$ of total exposed surface). The coating is hydrophobic and has a high molecular weight and low vapor pressure suitable for capturing the particulate and metal flux. The strips were placed on the plate and held down at the edge with a 0.03 cm thick stainless steel template, which was secured at each end by acrylic slats screwed into the plate. The plate was cut out so that it would slide onto a 3-cm diameter rod. Two screws were fastened through the plate to a wind vane, allowing the plate to swing freely into the wind direction. Each plate was separated by 55 cm (horizontally), which was shown experimentally to be sufficient to prevent sampling interference. The strips were weighed before and after sampling to determine the total mass of the particles collected. The strips were then digested and the solution was, then, analyzed for metal elements.

**Wind direction and wind speed**

Wind direction and wind speed at ground level height was measured for each sampling campaign. An anemometer (Davis company, Model: Weather Monitor II) was used for this
investigation.

**Analysis of Elemental Composition**

Twenty metal elements (Al, Ca, Fe, Mg, Na, Pb, Zn, Ni, V, Ba, Mn, Cr, Cu, Cd, Sr, Ag, Mo, Sb, As, and Ti) were analyzed in this study. Silicon (Si) was not resolved in this experiment due to its abundance in the quartz filter. The total suspended particulate and dry deposition particulate samples were first treated with pressurized digestion [Wang et al., 1989]. Polytetrafluoroethylene (PTFE), polyethylene and polypropylene containers were used. All chemicals used were supplied by Merck (pro analysis grade) and high-purity water (resistance $>10 \, \text{M} \Omega$) produced by reverse osmosis and de-mineralization was used. All stock solutions of the elements of interest (2000 $\mu$g/mL) were prepared from Titrisol concentrates (Merck) by diluting to volume with de-ionized water.

One fourth of Whatman 2500QAT-ype quartz filter loaded with airborne particulate matter was placed in a 25-mL PTFE container and a 5-mL mixture of HNO$_3$-HClO$_4$ (3 + 7 V/V) was added. The sealed container was then transferred into a pressure bomb (supplied by Berghof) and heated on a heating block at 170 $^\circ$C for 5 hours to facilitate complete dissolution. After cooling to room temperature, the solution was transferred into a 25-mL calibrated flask and diluted to volume with distilled water. The digested samples were then measured for the metal elements by using an inductively coupled plasma/atomic emission spectrometry (ICP/AES, Jobin-Yvon JY38 Plus).

Blank tests were performed. Quartz filters with no particulate matter were placed in PTFE containers and the digestion procedures were followed. The actual metal concentration was gained by subtracting the blank concentration. The content of metal elements in blank quartz filter were listed at Table 2. Spectral interferences due to the matrix effect and background shift were studied qualitatively by examining the standard additions and calibration graphs. The calibration graphs were constructed by measuring multi-element
standards prepared in the laboratory.

3. Results and Discussion

3.1 TSP concentration

TSP concentrations at the eight building construction sites are listed in Table 1. Except at sites E and H, TSP concentrations higher than 500 µg/m$^3$ were observed in other sites. The concentration of 500 µg/m$^3$ is the regulation standard of TSP concentration at construction sites in Taiwan. Among these 100 samples, 34 samples did not satisfy the regulation standard. It showed that particulate matter emission from construction sites was serious. Levying air pollution fee on construction projects has started in Taiwan since 1997/7/1 (after our sampling campaign), the particulate matter emission is expected to decrease. In this study, TSP concentrations were between 107 and 3990, and averaged 625 µg/m$^3$. The relative standard deviation (RSD) of these eight construction sites was between 3.30 and 112 %. The high variation of particulate matter emission is one of the most important characters of construction sites. Particulate emissions at construction sites often vary substantially from day to day, depending on the wind speed, level of construction activity and the specificity of operations.

The factors affecting particle reentrainment include wind speed, particle size, humidity, and surface roughness [Matsusaka and Masuda, 1996]. Of these parameters, wind speed was proposed as an important factor that affects the emission of particulate matter from fugitive sources [USEPA, 1996]. The other previous studies showed reentrainment may occur at all wind speeds [Matsusaka and Masuda, 1996]. In this study, a ratio of TSP concentration at upwind divided by that at downwind was used to estimate the effect of wind speed on TSP concentration. The ratio less than 1.0 means that TSP concentration is higher at downwind side, which is probably caused by reentrainment of particulate. In this field experiment of construction sites, however, TSP concentration was not significantly higher at downwind side
of wind speed between 1.7 and 5.0 m/s (Table 3). Among the 26 sampling campaigns, only 15 sampling campaigns had higher TSP concentration at downwind. The anemometer installed in this study was not right at downwind side therefore it is not sure whether the wind was parallel to the axis of upwind and downwind sites during TSP collection.

Some construction activities play more important role on particulate emission than the others. In this study, the effect of ground excavation and watering on TSP emission was investigated. TSP average concentrations before, during, and after ground excavation were 457, 668, and 670 µg/m³, respectively (Fig. 2). It showed that before ground excavation, TSP concentration was significantly lower. During ground excavation, a lot of dirt was suspended into the air, which was enhanced by frequent truck flow. After ground excavation, various construction activities still caused high TSP emission. The influence of watering on TSP emission was shown in Fig. 3. Average TSP concentrations were 476 and 1070 µg/m³ for watering and no watering respectively. Watering reduced 55.5% TSP concentration in this study.

3.2. Emission factors of TSP

At present, three methods have been used to infer emissions from the paved road. These methods may be applicable to estimate the emission from construction sites [Venkatram, 2000]. The first is a mass balance calculation using the profiles of particulate concentrations [Cowherd and Englehart, 1984]; the second is a dispersion modeling using the concentration measurements [Claiborn et al., 1995]; the third is the tracer methods [Kantamaeni et al., 1996]. An ISCST dispersion model was utilized to estimate particulate emission factor in this study. Wind speed, wind direction, construction dimension, ambient temperature and stability conditions were the input parameters (Table 4). Particulate emission from these eight building construction sites was determined to be between 0.163 and 0.916 kg/m²-month, and averaged 0.549 ± 0.303 kg/m²-month. These values are very near the emission rates

3.3 Dry deposition of TSP

Particulate dry deposition fluxes and dry deposition velocities at construction sites are listed in Table 5. Particulate dry deposition fluxes for these eight construction sites were between 678 and 3760 mg/m$^2$-day. Noll et al. (1990) measured the particulate dry deposition flux of urban environment (Chicago) by using the same type of dry deposition sample device. The mean dry deposition flux in Chicago is 175 mg/m$^2$-day. Lee (1991) and Lin et al. (1993) also investigated the dry deposition characteristics in Chicago and found the mean dry deposition fluxes are 172 and 163 mg/m$^2$-day, respectively. Sheu et al. (1996) found that the particulate dry deposition fluxes are 134 mg/m$^2$-day for urban and 361 mg/m$^2$-day for petrochemical-industry area, respectively. Fang et al. (1997) found that the particulate dry deposition flux at slip road in Taiwan is 323 mg/m$^2$-day. These studies above showed that the particulate dry deposition fluxes at non-construction environments (urban environments, slip roads, and traffic interactions) are significantly lower than those at the construction sites of this study.

The particulate dry deposition velocity has been estimated by the following equation [Noll et al., 1990]:

$$V_d = F / C$$  \hspace{1cm} (1)

Where

- $V_d$: dry deposition velocity of particulate matter (cm/sec).
- $F$: dry deposition flux of particulate matter (mg/m$^2$-day);
- $C$: measured ambient concentration of particulate matter (µg/m$^3$);

The estimated particulate dry deposition velocities of these eight construction sites are also listed in Table 5. The mean particulate dry deposition velocities for these eight construction
sites are between 2.63 and 5.55 cm/sec. These values are higher than the values measured at urban environments, slip roads, traffic interactions, and the ambient air [Noll et al., 1990; Lee, 1991; Lin et al., 1993; Fang et al., 1997]. The particulate generated from the construction sites were probably caused by wind blowing of road dust and sand pile, and mechanical disturbance of construction materials. These types of generating mechanisms act on relatively large particles in size. Larger particles exhibit high gravitational settling velocity that is tantamount to high dry deposition velocity at construction sites [Sheu et al., 1996].

The influence of wind on particulate dry deposition flux is also investigated. The ratio in Table 6 is the quotient of particulate dry deposition flux at upwind divided by at downwind. Similar to TSP concentration, among the 26 sampling campaigns, only 11 sampling campaigns had the ratio lower than 1.0. Wind is not showing as a significant factor for particulate dry deposition flux at building construction sites. The effects of ground excavation and watering on particulate dry deposition flux are also investigated. As Fig. 4 shows, particulate dry deposition fluxes before, during, and after ground excavation were 1720, 2300, and 2510 mg/m$^2$-day, respectively. And as Fig. 5 shows, particulate dry deposition fluxes with and without watering were 2030 and 2710 mg/m$^2$-day, respectively. Similar to the effect on TSP concentration reduction, watering also reduced TSP dry deposition fluxes.

3.4 Emission of metallic elements at construction sites.

Twenty metal elements embedded in the particulates from construction sites were analyzed chemically. In terms of concentrations (ng/m$^3$) and contents (µg/g), the five top elements are Al, Ca, Fe, Mg, and Na. Fig. 6 shows the concentrations and contents of the major five while Fig. 7 shows the other elements. The mean concentrations of Al, Ca, Fe, and Mg at eight building construction sites are 5720, 12900, 8210, and 2860 ng/m$^3$, respectively. The mean contents of Al, Ca, Fe, and Mg are 8930, 23700, 14200, and 4870 µg/g, respectively.
Na is also a major component, the content of Na in the particulate is 2770 μg/g. Yang (1998) analyzed 16 ambient air metal element concentrations at southern Taiwan. The first five major metal elements are also Al, Ca, Fe, Mg, and Na. The fact that these metals are crustal elements shows that fugitive dust is a significant source of particulate in the ambient air. Of the other 15 metal elements, the variations of sampled concentrations among these eight building construction sites are small. These metal elements are not generated from mineral dust, and samplers at construction sites are far away from anthropogenic pollution source, the concentrations of these metals are quite stable.

The concentrations of these 20 elements were further analyzed by performing linear regression analysis on the TSP concentrations. The $R^2$ values are 0.90, 0.80, 0.86, and 0.90 for Al, Ca, Fe, and Mg at the eight construction sites, respectively (Fig. 8). Except for Na ($R^2 = 0.80$), the $R^2$ values for the other metals are below 0.6. The results show that the concentrations of crustal elements are linear to the TSP concentrations.

3.5 Dry deposition of metallic elements

Dry deposition flux and dry deposition velocity of the metal elements at construction sites were seldom investigated. This study measured and evaluated the twenty metal dry deposition fluxes, and dry deposition velocities at eight building construction sites. Mean values of dry deposition fluxes and dry deposition velocities of Al, Ca, Fe, Mg, and Na are shown in Fig. 9 and Table 7. Similar to their showing the importance in concentrations, these five metals are also the major elements of dry deposition. The mean dry deposition fluxes of Al and Fe are 9.32 and 14.4 mg/m$^2$-day. These are higher than those observed in the Chicago urban environment of 3.25 and 5.14 mg/m$^2$-day [Noll et al., 1990] (Table 7). In comparison with the studies at coastal areas, crustal elements dry deposition flux at construction sites is 1-10 order higher [Golomb et al., 1997; Rojas et al., 1993; Ottley and Harrison, 1993]. Except the polluted city Chicago, the metal dry deposition fluxes were
higher than coastal sites, but not significant higher as major element (Table 7).

Similar to the particulate dry deposition velocity, metal dry deposition velocities were calculated from equation (1) and shown in Figs. 9 and 10. Most previous studies focused on metal deposition to the sea and lakes. Ottley and Harrison (1993) found that the dry deposition velocities of Al, Fe, Pb, and Zn at North Sea were 0.46, 0.45, 0.17, and 0.52 cm/sec, respectively. Rojas et al. (1993) found that the dry deposition velocities of Pb and Zn at North Sea were 0.25 and 0.35 cm/sec. The dry deposition velocities of Pb and Ni at Ligurian Sea were 0.22 and 1.2 cm/sec [Migon et al., 1997]. In our study, the dry deposition velocities of crustal metal elements (Al, Ca and Fe) are 2.6, 4.9 and 2.8 cm/s, these are higher than the findings of the previous studies. For other anthropogenic elements, dry deposition velocities were not higher at construction sites than at urban environment and coastal areas. Crustal metals are nonvolatile and most metals are bound with particulate. Thus, the higher particulate dry deposition velocity would result in higher crustal metal dry deposition velocity.

4. Conclusions

Emission characteristics of twenty metal elements and particulate matter at eight construction sites were investigated for a period of 6 months from Dec. 1996 to May 1997. Ambient air TSP concentrations at the eight construction sites were between 107 and 3990 \( \mu g/m^3 \) with an average of 625 \( \mu g/m^3 \). The relative standard deviations were between 3.30 and 112 %, which covered a wide range of variation. TSP concentrations before, during, and after ground excavation were averaged 457, 668, and 670 \( \mu g/m^3 \), respectively. During ground excavation, a lot of dirts was scoured into the air. The intensity of pollution was enhanced by frequent truck flow. After ground excavation, various construction activities still caused high TSP emission. TSP concentrations were averaged 476 and 1070 \( \mu g/m^3 \) for watering and no watering. Watering reduced 55.5% TSP concentration in this study.
Particulate dry deposition fluxes for these eight construction sites were between 678 and 3760 mg/m$^2$-day. The average of the particulate dry deposition fluxes before, during, and after ground excavation were 1720, 2300, and 2510 mg/m$^2$-day, respectively. The averages of the particulate dry deposition fluxes with watering and without watering were 2030 and 2710 mg/m$^2$-day, respectively. Crustal elements (Al, Ca, Fe, and Mg) were found to be the major metal components in the atmospheric particulate at construction sites. The mean concentrations of Al, Ca, Fe, and Mg at these construction sites were 5720, 12900, 8210, and 2860 ng/m$^3$, respectively. Regression analysis showed that the concentrations of crustal elements and the TSP concentrations were linearly correlated ($R^2 \geq 0.8$). Finally, a dispersion model was employed to estimate particulate emission factor at construction sites. Particulate emissions from these eight building construction sites were between 0.163 and 0.916 kg/m$^2$-month with an average of 0.549 kg/m$^2$-month and a standard deviation of 0.303 kg/m$^2$-month.
References


Paasivirta J. (1991) Chemical Ecotoxicology, Lewis Publisher Inc.


