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# Diurnal ambient air particles, metallic elements dry deposition, concentrations study during year of 2012–2013 at a traffic site

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ABSTRACT

The main purpose of this study was to monitor ambient air particulates and metallic pollutants (Cu, Cd, Cr, Pb and Zn) concentrations, dry deposition during day and nighttime sampling periods at a traffic sampling site during 2012 March to 2013 February, In addition, four ambient air dry deposition models (Wood's, Petroff & Zhang, Baklanov and Noll & Fang) were also used to evaluate the ambient air dry deposition pollutants differences between monitored and modeling results. The result indicated that: 1) Petroff & Zhang's model exhibited better performances for the ambient air particles dry deposition predictions at the particles sizes of 10 μm, 20 μm, 23 μm than those of the other dry deposition models for both day and nighttime sampling periods: 2) Noll & Fang, Woods, and Petroff & Zhang's models exhibited best dry deposition prediction results for both day and nighttime sampling periods for metallic element Zn at the particles sizes of 10 μm, 20 μm at this traffic sampling site. However, metallic elements Cu and Cr have the least dry deposition predictions results for all the models mentioned in this study at the particles size of 23 μm for both day and nighttime sampling periods.



## 1. Introduction

In Taiwan, many investigations on heavy metals such as Pb, Cd, and Cr discuss the combustion of waste and fuel and the generation of particulate matter consisting of inorganic elements (Chan and Kwok, 2000). However, Ca, Mg and Mn are associated with construction materials as sources, while Al, K, Ti and Mn may indicate with wind-blown soils as sources. Higher concentrations of Pb reflect the impact from vehicle emissions (Shu et al., 2001). Mn is also generated from multiple industrial, combustion and resuspension sources (Allen et al., 2001). The atmosphere in urban areas has been the subject of many studies that show greater contribution of atmospheric pollution from vehicular emissions (Chiaradia et al., 1997; Özsoy and Örnektekin, 2009; Vuai and Tokuyana, 2011).

The application of Principal Component Analysis and Multiple Linear Regression Analysis helped to identify the emission sources for 82% of the total PM10 mass inside the tunnel. Identified sources include resuspension (27%), diesel exhaust emissions (21%), petrol exhaust emissions (12%), brake wear emissions (11%) and road surface wear (11%). This study shows that major health related chemical species of PM10 originate from non-exhaust sources, further signifying the need for legislations to reduce these emissions (Lawrence et al., 2013). Industrial emissions of aerosols have a strong influence on the levels of air pollution (Nriagu and Pacyna, 1988; Pacyna and Pacyna, 2001; Serbula et al., 2012; Wilson et al., 2005). Industrial emissions of trace elements include nickel, chromium, lead, zinc, copper, mercury, and arsenic, among many others. These elements well exceed natural levels (Boyd, 2004; Krachler et al., 2003; Nriagu, 1989). And anthropogenic emissions have a major impact on regional and global cycles of heavy metals (De Vleeschouwer et al., 2007; Nriagu and Pacyna, 1988). In addition, heavy metals contribute to the toxicity of atmospheric particulate matter (PM) (Lü et al., 2009; Lighty et al., 2000; Oberdorster et al., 2005; Seaton et al., 2010); the deposition of atmospheric heavy metals in soil and water has a negative impact on plant growth and productivity (Clemens, 2006; Peralta-Videa et al., 2009; Seth et al., 2012; Shparyk and Parpan, 2004).

Exposure to individual metallic elements can cause various conditions in humans. For example, prolonged exposure to Zn can cause arteriosclerosis, hypertension and heart disease, while exposure to Cr is carcinogenic and can lead to nasal septum perforation, asthma. Notably, Cu can cause nasal septum perforation, pulmonary granuloma, pulmonary interstitial fibrosis and lung cancer, while exposure to Pb can poisoning and anemia (Shu et al., 2001). Exposure to Ni, Cr, As, or Cd can produce cancer, lung cell damage, and/or breathing problems. Furthermore, HM

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health risk assessment showed that average daily dose (ADD) and hazard quotient (HQ) were found in the order of Cr > Fe > Ni > Cu > Mn > Zn > Co > Pb > Cd and Ni > Cd > Cu > Mn > Pb > Zn > Cr, respectively. Water contamination was the main source of diseases like, viral hepatitis, Complaints by most of the respondents during a field visit and reported in basic health unit (BHU) suggested links between water contamination and other health problems such as diarrhea, headaches, hypertension, abdominal pain, liver and kidney problems. Fatal cardiac arrest as In order to reduce the health risk, posed by contaminated drinking water, it is necessary that governments immediately close the contaminated sites used for drinking water and should supply clean potable water to the inhabitants (Shah et al., 2012). Therefore, the main goals of this study were to: 1) Discuss the differences between measured and modeled dry deposition results for ambient air particles and metallic elements during day and nighttime sampling periods: 2) Discuss and compare the differences between particles and metallic elements during day and nighttime sampling periods: 3) Compare the seasonal concentrations, dry deposition variations for particles and metallic elements during day and nighttime sampling periods.

## 2. Dry deposition model

The dry deposition model applied in this study is described below:

### 2.1. Empirical equations, deposition model by Wood (1981a,b)

The deposition across the entire range of particle sizes may be predicted by simple empirical equations and applied to vertical surfaces across all deposition regimes when configured in the following manner (Sippola and Nazaroff, 2002):

$$V_D^+ = k_1 Sc^{-2/3} + k_2 \pi^{+2} \quad \text{if} \quad k_1 Sc^{-2/3} + k_2 \tau^{+2} \le k_3 \tag{1}$$

1. $V_D^+$ = dimensionless particle deposition velocity
2. $Sc$ = particle Schmidt number
3. $k_1$, $k_2$, $k_3$ = constants in equations.
4. Table 1 summarizes different values for $k_1$, $k_2$, and $k_3$ found by different investigators for (Jonsson et al., 2008).

$$V_d^+ = k_3 \quad \text{if} \quad k_1 Sc^{-2/3} + k_2 \tau^{+2} > k_3 \tag{2}$$

To apply empirical equations of this type to horizontal surfaces, a simple modification was made to account for the effect of gravitational settling on the particle deposition velocity (Kvasnak and Ahmadi, 1996). The result becomes:

$$V_d^+ = k_1 Sc^{-2/3} + k_2 \tau^{+2} + g^+ \tau^+ \tag{3}$$

**Table 1**
Summarizes different values for $k_1$, $k_2$, and $k_3$ found by different investigators for (Jonsson et al., 2008).

| Investigator | $k_1$ | $k_2$ | $k_3$ |
|---|---|---|---|
| Cleaver and Yates | 0.084 | | |
| Friedlander | 0.059 | | |
| Wood | 0.045 | $4.5 \times 10^{-4}$ | 0.13 |
| Davies | 0.075 | | 0.3 |
| Papavergos and Hedley | 0.07 | $3.5 \times 10^{-4}$ | 0.18 |
| Kneen and Strauss | | $3.79 \times 10^{-4}$ | |
| Liu and Agarwal | | $6 \times 10^{-4}$ | |
| Fan and Ahmadi | | | 0.14 |

1. $g^+$ = dimensionless gravitational acceleration.
2. $\tau^+$ = dimensionless particle relaxation time, equation.

where $g+$ is the dimensionless gravitational acceleration defined by

$$g^+ = \frac{g\nu}{u_\tau^3} \tag{4}$$

and $g$ is positive for a floor and negative for a ceiling surface. In Eq (3) the first term on the right hand side accounts for Brownian diffusion, the second term accounts for interactions between particle inertia and turbulent eddies and the final term accounts for gravitational settling. However, Eq (3) does not account for surface roughness. The following Eq (3) is referred to as Wood's model.

As in Wood's model, 20 μm and 23 μm which represent an average particle size (Ghose and Majee, 2007; Hoffmann et al., 2008) in TSP, were selected in this study to model the ambient air particles and particle-bound mercury dry deposition fluxes (Fang and Huang, 2012). Previous studies have used Zhang's model in the prediction of ambient air particulate and particulate bound mercury Hg(p) in central Taiwan. As for the Bei-Shi suburban/coast sampling site, the ranges of calculated/measured ratios for ambient air particle and particle bound mercury Hg(p) dry deposition fluxes at particle sizes of 20 μm were 1.63–40.68 and 1.88–12.98, for the 37 sampling groups, respectively. The calculated/measured ratios for particle and particle-bound mercury Hg(p) dry deposition fluxes for particles sizes of 23 μm ranged from 1.65 to 41.26 and 1.91–13.17, respectively, for the 37 sampling groups (Fang et al., 2011a).

### 2.2. Baklanov and Sorensen's model

Baklanov and Sorensen (Baklanov and Sorensen, 2001) have proposed improved deposition models for long-range deposition computation, by defining the dry deposition velocity as the inverse of a sum of resistances $r_a$, $r_b$, $r_c$ in three sequential layers (Wesely, 1989; Ghose and Majee, 2007; Basu et al., 2009; Fang et al., 2006; Calvert and Lidberg, 2005; Lin et al., 1995; Poissant, 1999), in the following form for gaseous pollutants:

$$V_d = (r_a + r_b + r_c)^{-1}, \tag{5}$$

where $r_a$ is the aerodynamic resistance, $r_b$ is the resistance to penetration across the atmospheric laminar sublayer, and $r_c$ is the resistance associated with direct pollutant–surface interaction.

For particles, Baklanov and Sorensen (Baklanov and Sorensen, 2001) suggest that the transfer resistance, $r_c$, is negligible, since once the particle encounters the surface, it is considered to be deposited. For particles, Seinfeld suggested another term, $r_a\, r_b\, v_g$, instead of $r_c$.

Additionally, this formula for the dry deposition velocity of particles has a term, defined by the sedimentation/gravitational settling of particles:

$$V_d = \left(r_a + r_b + r_a r_b v_g\right)^{-1} + v_g, \tag{6}$$

where $v_g$ is the gravitational settling velocity.

The aerodynamic resistance $r_a$ depends on meteorological parameters, such as wind speed, atmospheric stability and surface roughness, and can be derived:

$$r_a = [\ln(Z_s/Z_o) - \Psi_c]/ku^*, \tag{7}$$

where $\Psi_c$ is the stability function,