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Size Characteristics of Lead Particles Generated in Four Industries

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Abstract : Workers' exposure to lead particles with diverse characteristics was assessed using personal cascade impactors in four different industries. Correlation analyses found that total airborne lead (PbA) concentrations could not explain the variation on MMAD of lead particles. From regression analysis, the concentrations of lead particles smaller than 1 um in AD were found to rise very slowly with increases in total PbA. They rarely contributed more than 50 ug/m^3 of total PbA over the range of 5.6-7,740 ug/m^3 although there are a few high values greater than 100 ug/m^3, while respirable lead concentrations significantly increased with increasing total PbA concentrations. In the secondary smelting and radiator manufacturing industries requiring high temperatures, the average fraction of respirable concentration in total PbA was 43.3% and 48.9%, respectively, which indicated an important contribution to the total PbA. In lead powder and battery manufacturing, it was less than 27%. Our study results concluded that workers' exposure to lead particles with diverse characteristics might not be effectively monitored by the current total PbA sampling alone. To protect workers exposed to different sizes of lead particles generated in many operations, an occupational standard for respirable lead particles should be added to the current total lead standard.

Keywords : MMAD, lead, RPM, lead particle

Introduction

The lead standard of the U.S. Occupational Safety and Health Administration (OSHA) was promulgated in 1978. The permissible exposure limits (PEL) of 50 ug/m^3 was based on the assumption that the first 12.5 ug/m^3 of lead in the air is composed of lead particles smaller than 1 um in aerodynamic diameter (AD) and all additional air lead is present in particles larger than 1 um. This assumption made it difficult to assess the magnitude of effect caused by lead particle size distribution. There are many industries, operation and works using lead. Size characteristics of lead generated from different industry would be diverse.

There has been general agreement that the particle size distribution would affect the absorption of aerosols with particle size. To consider the effect on absorption of aerosol with diverse size characteristics, most aerosols have dual Occupational Exposure Limits (OEL) such as total and respirable particulate matter.[1)]

Although the OSHA PEL has contributed to reductions of airborne lead concentrations since its adoption, workers' exposure to lead in the workplace still remains a major occupational problem. The scope and severity of lead exposure are greater than OSHA envisaged when the lead standard was promulgated in 1978.[2)]

Park *et al.* (2002) studied effect on blood lead of lead particles characterized by size and concluded that the contribution of respirable lead particles to lead absorption was greater than that of PbA and respirable leas particle as well as PbA be measured.[3)] This recommendation was from the relationship between blood lead and lead particles taken from four different lead industries.

The secondary smelting, lead powder, and battery

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manufacturing industries were chosen for this study because workers' exposure is relatively high compared to other industries. In addition, the radiator manufacturing industry was chosen because it includes operations generating fine lead particles such as fume.

The specific objectives of this study were : 1) to evaluate workers exposure to lead particles; 2) to examine the variation in MMAD as a function of total PbA.

Methods

Sampling and Analysis

A total of 117 personal airborne lead samples were taken using Marple personal cascade impactor (model 298, Anderson Sampler, Inc., U.S.A.) with air drawn by personal pumps (model MSA 87004, MSA, U.S.A.). Operations of 4 industries whole airborne lead samples were taken, were described in Park *et al*'s former study.[3)]

The cascade impactor had cut-points (particles size for 50% collection) of 21.3 μm, 14.8 μm, 9.8 μm, 6.0 μm, 3.5 μm, 1.55 μm, 0.93 μm, and 0.52 μm plus backup filter. The pump and sampling train were calibrated to 2 *l*/min before and after sampling. The lead particle by stage was corrected for internal particle losses and inlet sampling efficiency as determined by Rubow *et al.*[4)] Mylar substrate (Anderson stock #C-290-MY, Anderson sampler, Inc., USA) was thinly coated with silicone grease (Dow corning 316 silicone release spray, Dow Chemicals, USA) to prevent the bounce of lead particles collected. The substrate and polyvinyl chloride (PVC) backup filter (5 um pore size, Anderson stock # F-290-p5, Anderson sampler, inc., USA) for each stage were pretreated by a microwave digestion system (model MDS-2000, CEM Corp, USA. The lead mass was quantified by atomic absorption spectroscopy (model Spectra 300 plus, Varian Corp, Australia).

Lead Particle Size and Mass Characteristics

The lead particles collected on each cascade impactor were used to estimate the MMAD by plotting cumulative percentage vs. AD on log-probability paper.

Using the methods suggested by Hinds (1986), respirable mass fraction (RPM) for each impactor stage size interval was estimated from the regression equation of respective mass collection efficiencies and AD defined by ACGIH using a trapezoidal rule.[5)] The proportion of lead particles smaller than 1 um was computed using the regression equation for the relationship between the cut-point diameter and the cumulative percentage of lead particles collected on each stage of the impactor.

Statistical Analysis

Statistical testing was carried out using the standard version of SPSS. Regression analysis or correlation analysis was used to determine the relationship between MMAD and three respective mass concentrations. The t-test was used to compare respirable and small lead particles smaler than 1 um concentrations by industry.

Results and Discussion

Lead Concentration by Size Characteristics

Workers' exposure to total PbA exceeded the Korean PEL (50 ug/m^3) in all operations except in radiator manufacturing (Table 1). Workers in secondary smelting were exposed to 575 ug/m^3, over 10 times greater than Korean PEL. Because this industry was run on a small scale with 10 workers or less in Korea, control measures such as installation and maintenance of local ventilation, plus education on proper work practices and cleaning of the workplace were not properly performed.[3)] Secondary smelting industry has been regarded as one of the worst lead industry. Park *et al.* (2002) and Papenek *et al.* (1992) reported that the compliance with OSHA's PEL was particularly poor in small workplaces with 20 workers or less.[3,6)]

In the battery manufacturing industry, workers who grind lead plates were exposed to the highest level, 5,011 ug/m^3 of total PbA and 398.1 ug/m^3 of RPM.

Because the lead plate formed by casting molten lead metal pasted is pasted with a micture composed of lead, lead oxide and sulfuric acid, almost of particle grinded would be lead. In addition, the type of local exhasut ventilation installed in grinding operation was evalated to be

Table 1. The Fractions of Small and Respirable Lead Concentration in Total PbA

Industry	Operation	No. of samples	Total PbA	a)Average fraction±SD, %	
			GM(ug/m³)±GSD	small lead particles ≤1 μm in AD	b)respirable lead particles
Secondary Smelting	Furnace	3	758.6±1.6	44.0±16.5	61.3±18.0
	Scrap	3	436.5±1.8	5.1±3.5	25.3±17.0
	Subtotal	6	575.4±1.7	24.5±23.8	43.3±25.6
Radiator	Dipping	10	12.9±1.9	37.4±15.0	42.4±18.8
	Soldering	32	20.4±2.1	40.2±19.6	48.6±23.8
	Subtotal	42	19.1±2.1	41.3±19.4	48.9±22.5
Battery	Casting	6	138.0±2.8	5.5±3.8	12.5±6.2
	Plate Production	7	85.1±2.0	6.3±4.1	11.9±7.1
	Paste	12	257±4.1	4.9±3.0	11.9±6.8
	Encapsulation	6	776.3±2.4	2.4±1.5	8.8±6.7
	Caste on Strap	6	537.0±5.5	3.1±2.8	8.6±4.3
	Grinding	7	5,011.9±1.4	0.9±0.3	8.4±3.1
	Subtotal	44	354.8±4.7	5.3±6.4	10.9±5.7
Lead powder	Reaction(furnace)	7	36.3±3.6	6.6±3.8	26.9±13.5
	Packing	18	389.1±4.4	2.4±1.7	9.9±7.6
	Subtotal	25	354.8±4.7	5.3±6.4	16.5±10.7
Total		117	117.5±7.1	19.1±21.8	27.5±23.5

a)The fractions of lead particles by size were expressed as a proportion of the total PbA.
b)Respirable lead particles means Respirable Particulate Matter (RPM) defined by ACGIH.

inefficient.

In the lead powder manufacturing industry, the range of total PbA exposure concentrations was 36.3-389.1 ug/m³ (GM : 389.1 ug/m³). During the process of loading lead powder into a bag by gravity and weighing it automatically, local exhaust ventilation was used but was not efficient to control the dispersion of lead powder.

The total PbA exposure in the radiator plants ranged from 12.9 to 25.1 ug/m³, lower than the Korean PEL. Because lead particles to which workers were exposed were fine like fume, the total PbA concentration was not high. Due to this characteristic, workers who repair or manufacture radiators are among the least monitored of lead-exposed workers : fewer than one percent received routine PbB testing. In Korea, inspections on these plants were often ignored because the workers are exposed to airborne lead concentration lower than PEL.[3] The nature and size of the lead particles workers are exposed to will have significant implications for the distribution of blood lead values.[7] Because lead fumes generated from high temperature operations can be easily absorbed into the body as compared to coarse lead particles, they may lead to an elevated PbB level.

Variation of the MMAD of the lead particle samples with total PbA concentration is shown in

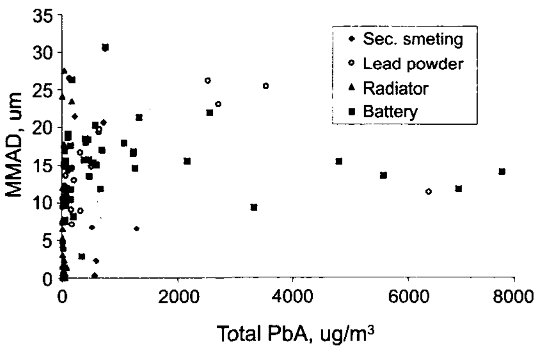

Fig. 1. Variation of MMAD as a function of the total PbA concentration.

Fig. 1. Regression analysis found that MMAD of lead particle generated in 4 industries is nearly independent of the total PbA concentration ($p = 0.18$, $R^2 = 0.027$, $p>0.05$). Thus, because total PbA concentration is not associated with the variation in AD, worker exposure to lead might not be effectively monitored by total PbA sampling alone.

Characteristics of Lead Particles Smaller than 1.0 um in and RPM

The fraction of lead particles smaller than 1.0 um ranged from 37.6 to 63.0% in the high temperature operations, such as furnace, soldering and dipping. The fraction of respirable lead particles in total PbA concentration ranged from 8.4% to 63% . It was found to be 61.3% in the furnace operation of secondary smelting and 41.3% in the radiator manufacturing industry (Table 1).

The percentage of lead particles smaller than 1 um in AD varies inversely with the total PbA concentration, particulary in total PbA less than 50 ug/m^3, where the proportion decreases dramatically as total PbA concentration increases (Fig. 2).

T-test analysis found that the respirable concentrations were significantly greater than small lead particle concentrations in the battery and lead powder manufacturing industries generating a coarse lead particles ($p = 0.0001$). However, it was not significantly different from small particle concentrations in both secondary smelting ($p = 0.2720$) and radiator manufacturing industries requiring high temperatures ($p = 0.2394$).

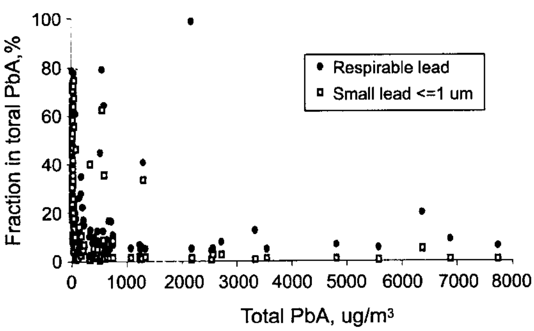

Fig. 2. Fraction of respirable and small lead particles in total PbA versus total PbA concentration.

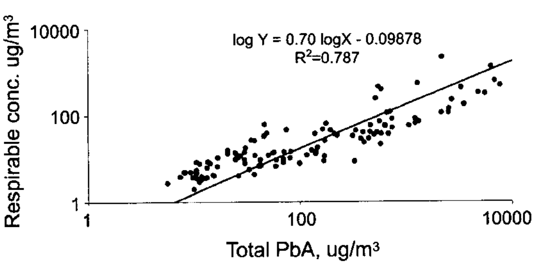

Fig. 3. The relationship between total PbA and respirable lead concentration.

Respirable lead particle concen-trations increase along with increases in total PbA concentrations (Fig. 3).

After respirable and total PbA concentration were log-transformed, significant relationships were detected in all industries except secondary smelting ($p = 0.065$). In battery and lead powder manufacturing industries that generated coarse lead size (14.1 and 15.1 um), adjusted R squares were 0.89 and 0.80, respectively. Respirable lead concentration was shown to be well correlated with the total PbA concentration using all data points ($R^2 = 0.789$, $p = 0.000$).

As discussed earier, the respirable fraction contribute a significant proportion of total PbA concentration in high temperature operations, and in particular, varies inversely with the total PbA concentration, especially those below 50 ug/m^3 (Fig. 2).

These findings suggested that current total lead sampling might not have effectively monitored the workers' exposure to fine lead particles of less than 50 ug/m^3 where their PbB level may remain high.

CPA assumed that there was no deposition in the alveolar region of particles greater than 1 um in AD.[8] It is generally accepted, however, that there is a deposition of particles with AD in the range of 1-10 um.[1,2,9] Based on this assumption, occupational standards for airborne particles such as silica, coal dust, graphite and paraquat, etc. are based on the measurement of respirable mass as well as total dust concentration.[1]

It is likely that an occupational standard for lead should not be based only on an assessment of total lead but should also incorporate measurement of the respirable lead fraction.

Conclusion

Correlation analysis found that total PbA concentration by current total mass sampling could not explain the variation of the MMADs of the lead particle ($r = 0.18$, $p>0.05$).

Our study results suggested that workers' exposure to lead particles with diverse size characteristics might not be effectively monitored by the current total PbA sampling alone.

In order to monitor the workers' exposure to lead particles with different characteristics in many operations, the measurement of respirable fractions as well as the total PbA measurement may be needed.

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