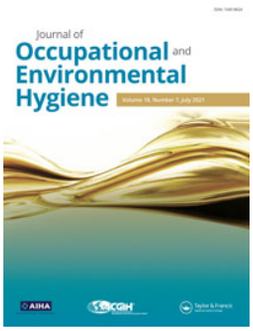

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SHORT REPORT

Investigation of particle transfer to sampler covers during the transportation of samples

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ABSTRACT

This study investigated the effects of particle transfer to the covers of aerosol samplers during transportation of wood dust and welding fume samples. Wood dust samples were collected in a sanding chamber using four sampler types: closed-face cassettes (CFC), CFC with Accu-CAP inserts, disposable inhalable samplers (DIS), and Institute of Occupational Medicine (IOM). Welding fumes were collected in a walk-in chamber using the same samplers, with Solu-Sert replacing Accu-CAP. The samples were divided into two groups, with one group transported by air and the other by land. They were returned in the same manner and analyzed gravimetrically for wood dust and chemically for welding fumes. For wood dust, IOM showed a significantly higher percentage of particles transferred to the covers compared with the other samplers regardless of the transportation mode ($p < 0.0001$; 64% by air and 15% by land), while other samplers showed less than or close to 10% (3.5–12%). When the percentages of particle transfer to the covers were compared between the air and land transportation, both IOM and CFC samples showed differences between modes of transportation, while others did not. For welding fumes, most samples (61% of samples for copper [Cu] and 76% of samples for manganese [Mn]) showed nondetectable amounts of the analyte on the covers. For all samplers, the particle transfer to the covers for both transportation modes ranged from 0.2–33% for Cu and less than 4.5% for Mn. Overall, this study confirms that particle transfer to sampler covers during transport highly depends upon the transportation mode and sampler type for wood dust, whereas particle transfer seems minimal for welding fumes. The findings of this study are based on two materials and limited sample sizes. Further investigation considering different industry types and tasks, particle size ranges, and materials might be necessary. Nevertheless, occupational professionals should account for this transfer when handling and analyzing samples in practice.

KEYWORDS

Gravimetric methods; inhalable samplers; internal wall deposit; particle transfer; sample transportation; sampler covers

Introduction

Time-weighted average mass concentrations of airborne particles are determined by sample collection using size-selective samplers, such as inhalable or respirable samplers, depending on the purpose of sampling. The collected samples are often transported to a laboratory for analysis, at a facility other than the collection site.

Several researchers have addressed the concerns of particle concentration being underestimated because of particle deposition to the sampler's internal walls during sample collection. Puskar et al. (1991), for example, found that only 22% of the pharmaceutical dust sampled was collected on the filters with 78% settling on different parts of the sampler cassette body. Other studies have reported on the proportion of metal components deposited to the internal walls when samples were collected using two commonly used samplers, the 37-mm closed-face cassette (CFC) and the Institute of Occupational Medicine (IOM) inhalable sampler. The median mass percentages of wall deposit measured from various work environments ranged from 5–53% for the CFC sampler and 3–19% for the IOM sampler for metal components including copper (Cu), lead, zinc, hexavalent chromium, iron, aluminum, tin, and beryllium (Ceballos et al. 2015; Demange et al. 1990; Harper et al. 2005, 2006; Harper and Demange 2007; Harper and Pacolay 2006; Hetland and Thomassen 1993; Lee et al. 2019; OSHA 2006). These findings indicate that sample

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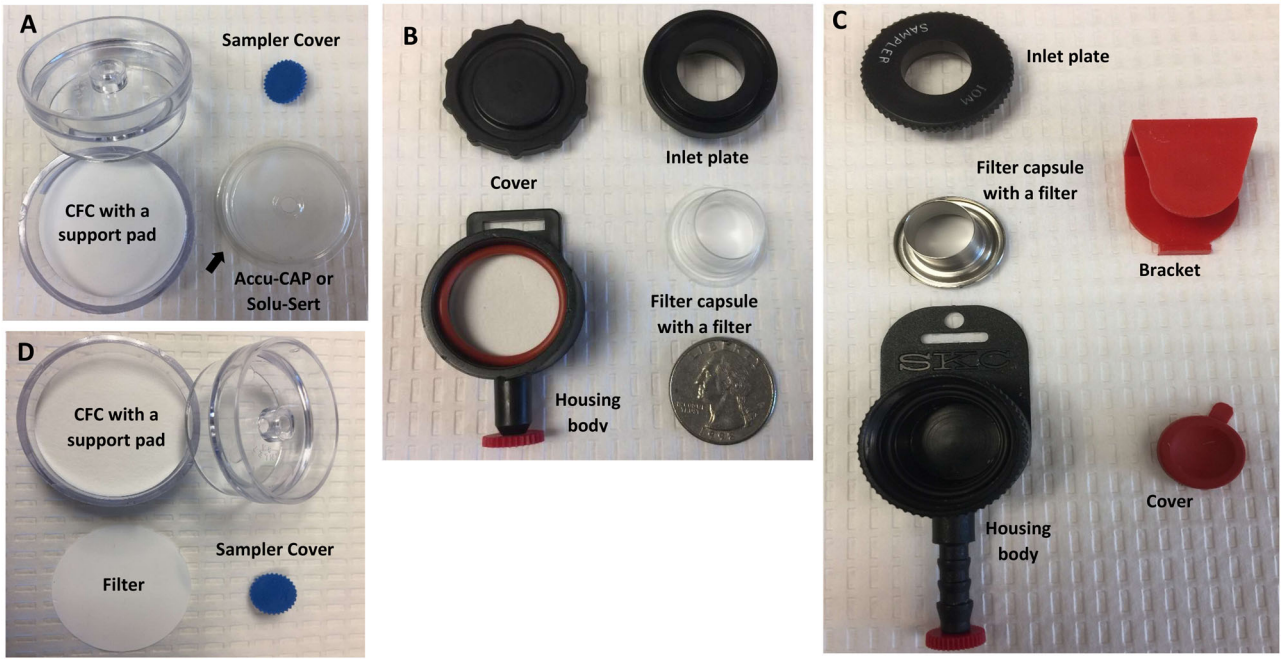

Figure 1. Tested samplers to collect wood dust and welding fumes. (A) Accu-CAP (or Solu-Sert); (B) Disposable inhalable sampler (DIS); (C) Institute of Occupational Medicine (IOM); and (D) Closed-face cassettes (CFC).

analysis of the filter only should not be considered representative for worker exposure and might substantially underestimate worker exposure.

To address these concerns, there has been a steady evolution of sampling and analytical practices. The Occupational Safety and Health Administration (OSHA), for example, requires wiping the sampler's internal walls when evaluating metal components (Hendricks et al. 2009; OSHA 2008). The National Institute for Occupational Safety and Health (NIOSH) also recommends wiping internal walls when analyzing metal components (e.g., NIOSH Method 7302) and using an internal capsule to limit wall deposits during sampling (NIOSH 2020). For example, Accu-CAP (SKC Inc., Eighty-Four, PA) or Gravi-Sert (Zefon International, Ocala, FL) can be used for gravimetric analysis by capturing the entire sample collected into the sampler. In addition, Solu-Sert (Zefon International) and Solu-CAP (SKC Inc.) can be used for the analysis of airborne metals because the filter medium, a mixed cellulose ester (MCE) filter attached to a cellulose dome, can undergo complete dissolution for wet chemistry and thus account for all particles deposited on its walls.

Nevertheless, little attention has been given to particle deposits that could potentially transfer to the covers of samplers. This is highly likely to occur during sample handling and transportation as particles could bounce and transfer to the cover. From literature search (e.g., Google, PubMed), only one study was found by Lee et al. (2019) reporting particle transfer to disposable inhalable aerosol sampler (DIAS; customized prototype and not commercially available) and IOM covers. To the best of the authors' knowledge, no other previous studies have been conducted that investigate particle transfer to sampler covers. The particle transfer to the cover, if not adequately accounted for, would create the same concerns with underestimation as do unaccounted particles on internal sampler surfaces.

This study investigated particle transfer to the covers of aerosol samplers caused by two transportation modes (air and land). Two occupational agents (wood dust and welding fumes) and four types of samplers were used, focusing on potential losses to the sampler covers, not to the internal walls. As these losses can be easily neglected in analytical procedures, the findings of this study would provide a basis to review current common practices in the industrial hygiene community.

Methods

Wood dust sample preparation

Four sampler types were used to collect airborne wood dust from an automated sanding chamber where a sander (Model 97181; Central Machinery, Camarillo, CA) equipped with zirconium aluminum oxide sandpaper (P120-grit; Norton, Saint-Gobain Abrasives, Inc., Worcester, MA) performed sanding

actions on a wooden log. Lee et al. (2020) provide a detailed description of the sanding chamber. The following samplers were used: Accu-CAP insert in a 37-mm two-piece cassette (part number [PN]: 225-8516GLA; SKC Inc., Eighty Four, PA); 25-mm disposable inhalable sampler (DIS) with a polyvinylchloride (PVC) filter capsule (PN: PVPV-DIS5010; Zefon International, Ocala, FL); 25-mm IOM sampler (stainless steel filter capsule in a plastic housing body; PN: 225-79A; SKC Inc.); and 37-mm CFC (PN: 225-2250; SKC Inc.) (Figure 1).

All samplers, except for the Accu-CAP, were loaded with a 5-µm pore sized PVC filter. The Accu-CAP insert consisted of a PVC filter (5-µm pore size) attached to a PVC capsule and placed as a whole inside a 37-mm cassette. Wood dust samples were collected at a nominal flowrate of 2 L/min using personal sampling pumps (AirChek XR5000; SKC Inc.) for all samplers. Sampling flowrates were checked before and after sampling with a mass flowmeter (Model 4143; TSI Inc., Shoreview, MN) to ensure the flowrate variation stayed within ±5%.

Based on the stipulated range of mass loadings in NIOSH Method 0501, four mass levels of wood dust (0.5 mg, 1 mg, 2 mg, and 3.5 mg) were generated by running all samplers at the same flowrate and adjusting the sample duration. For each run, one type of sampler was used, and a total of 128 samples (32 per sampler type) were collected.

Two preliminary studies were conducted to determine the optimum locations of samplers in the chamber and to measure the particle size distributions using an aerodynamic particle sizer (Model 3321; TSI Inc., Shoreview, MN) with a measurable size range of 0.5–20 µm. The preliminary runs exhibited the same shapes of particle size distributions by mass, showing two modes with peak concentrations at about 3 µm and 13.8 µm. Their magnitudes were also similar. Because the same test conditions and wooden log were used for all runs, the particle size distributions by mass were assumed to be uniform, and thus no additional particle size distributions were measured.

Prior to the sample collection, all sampling media (the filter for CFC, the insert for Accu-CAP, and the filter capsule with filters for IOM and DIS) and the corresponding sampler covers were equilibrated in an environmentally controlled weighing room (temperature at 20 ± 2 °C and relative humidity of 50 ± 5%) for 48 hrs. Laboratory personnel measured pre-weights by using a microbalance (Model AG245; Mettler-Toledo LLC, Columbus, OH) with a 0.01 mg sensitivity. For each sampler type, six field blank samples (sampling media and sampler covers) were weighed in the same manner.

Welding fume sample preparation

Welding fumes were generated through the welding action of a robotic welder built in a walk-in chamber. In this study, the welding fumes were sampled in a replicated manner using the same operating and environmental conditions as described in Cena et al. (2016). The wire feeder connected to the robotic arm was fitted with mild steel wire (ER70S-3; Lincoln Electric, Cleveland, OH) that operated at 762 cm/min with 0.17–0.22% Cu and 1.42–1.60% Mn. The welding machine was operated at 25 volts and 220 amperes with 95% argon and 2% carbon dioxide shielding gas at 1.13 m^3/hr. Cena et al. (2016) collected samples at 30 cm and 120 cm away from the fume generation source, and reported that regardless of the sampler's locations, the particle size distributions by number were similar over time, showing a single mode with a peak at about 200 nm, except when welding-in-progress at 30 cm away from the arc, which showed a secondary mode between 15 nm and 50 nm. The particle size distributions by mass were also similar, showing the mass median aerodynamic diameter at 0.3 µm at 30 cm and 0.35 µm at 200 cm away from the source over different time intervals. Because the test conditions were replicated, the particle size distributions by number and by mass were assumed to be the same as those reported by Cena et al., and no additional particle size distributions were measured.

Welding fumes were collected using the same sampler types except for replacing Accu-CAP with Solu-Sert (PN: CLCL-C3750; Zefon International, Ocala, FL). Also, instead of PVC filters, all samplers were loaded with MCE filters with a 0.8-µm pore size for analyzing metal components, according to the modified NIOSH Method 7303 (see modification below). All samplers were run at 2 L/min with flowrate variations less than 5%. For each run, three sets of the four sampler types were placed in the welding chamber, and 11 runs were conducted for a total of 132 collected samples. For each sampler type, six field blanks (sampling media and sampler covers) were prepared.

Sample transportation by air and land

All sample collections and handlings were performed by a senior industrial hygienist with good laboratory practices. Before and during the sample collections, all sampler covers were kept in the weighing room to

minimize cross-contamination. After the sample collection, the samples were taken to the weighing room for packing.

After sampling, wood dust samples (128 samples plus six field blanks per sampler type) were divided evenly into two groups for either air or land transportation. For welding fume samples, samples with an odd number of runs (72 samples = 4 samplers per set × 3 sets per run × 6 runs) were transported by land, while samples with an even number of runs (60 samples = 4 samplers per set × 3 sets per run × 5 runs) were transported by air; for each transportation method, three field blanks per sampler type were included. For the samples of CFC and CFC with Accu-CAP (or Solu-Sert) inserts, the sampler covers were placed tightly on both inlet and outlet orifices of the samplers without removing the filters or inserts. Similarly, for DIS samples, the sampler covers and the outlet plugs were secured on the samplers without removing the capsules from the housing body (Figure 1). For IOM samples, each filter capsule with its filter was removed from the housing body, covered with the corresponding sampler cover, and secured with the supplied bracket. All samples of each group were placed upright in a cardboard box. Antistatic packing peanuts were used to secure the samples during transport, and a sticker, which said "fragile," was placed on each box. Both land and air transport boxes were prepared identically.

The air transportation sample box was shipped to Ocala, Florida from Morgantown, West Virginia, using the following chain of custody: a courier service picked up the box from the Morgantown facility and drove it to the local airport (about 126 km) where it was flown about 1,500 km to Ocala. The box was then driven to the receiving facility from the Ocala airport (about 3 km). It was returned to Morgantown in the same manner. The land transportation sample box was driven in a personal vehicle for 965 km on paved interstate highway roads with minimal turns (i.e., less vibration compared with unpaved roads), and with an elevation change of approximately 245 m for the entire trip. During land transportation, the sample box was not unloaded or reloaded into the vehicle.

Wood dust sample analysis

All returned samples along with field blanks were stabilized for 48 hr in the same weighing room used for the pre-weighing of sampling media and sampler covers. Then, the same laboratory personnel who performed the pre-weighing conducted the post-weighing analysis using the same microbalance to minimize variations between users and balances. In addition, six media blanks were used to determine the limit of detection (LOD) for each sampler type. The LODs of the sampling media and covers for each sampler type were calculated at three times the standard deviation for differences between pre- and post-weighing of the six media blanks and covers. The estimated LODs for the sampling media and covers were 0.04930 mg and 0.03912 mg for Accu-CAP; 0.06481 mg and 0.05254 mg for DIS; 0.07823 mg and 0.05167 mg for IOM; and 0.05899 mg and 0.03507 mg for CFC, respectively.

Welding fume sample analysis

For the IOM and CFC samples, each sample was prepared in three steps. First, the filter medium was carefully removed from the sampler and placed in a 50-mL reaction tube. Next, the internal walls of the sampler were wiped twice with a quartered 25-mm MCE filter soaked with isopropyl alcohol and then placed in a second tube. Last, the sampler cover was wiped with a fresh wipe in the same manner and placed in a third tube. Although Hendricks et al. (2009) demonstrated that a single wipe of the internal walls was sufficient to extract most metal components, the second wipe was performed to ensure that almost all metals deposited to the internal walls and covers were removed. For the Solu-Sert and DIS samples, the first and third steps just described were performed; however, in the first step, each Solu-Sert insert and filter capsule with its filter for DIS was placed in a tube. In addition, six field blank samples were treated in the same manner as the samples.

The prepared samples were analyzed to determine the amount of Cu and Mn using inductively coupled plasma-mass spectrometry (ICP-MS; Perkin Elmer 300 D, Waltham, MA) following the NIOSH Method 7303 with some modifications. To dissolve each filter sample placed in a tube, nitric acid (3 mL), hydrochloric acid (1 mL), and water (2 mL) were added to the tube and then left for 30 min at room temperature. The tube was then placed in a water bath and warmed to 85–95 °C for 1 hr. After cooling at room temperature, water was added to bring the volume to 40 mL. The wipe samples were treated in the same manner with reduced volumes of acids (0.75 mL nitric acid and 0.25 mL hydrochloric acid) and water (0.5 mL). Water was also added later to the sample to a final volume of 10 mL. Aliquots of sample solutions were diluted with water to a nominal 1% total acid

Table 1. Summary of total mass sampled and percentage transferred to sampler cover by transportation method (wood dust).

	Land transportation				Air transportation				p-value of statistical comparison	
Sampler type	N	N < LOD (%)	Total mass range, unit in mg	Median percent transfer (SD)[A]	N	N < LOD (%)	Total mass range, unit in mg	Median percent transfer (SD)[A]	By transport-ation	By sampler type[B]
Accu-CAP	15	3 (20)	0.1–2.6	10.0 (11.9)	15	7 (47)	0.4–2.7	3.9 (8.5)	0.1224	*
DIS	16	4 (25)	0.3–2.7	11.8 (10.5)	13	7 (54)	0.5–2.9	3.5 (5.3)	0.0674	*
IOM	10	2 (20)	0.4–13.6	15.2 (37.9)	15	0 (0)	0.5–6.9	63.7 (20.6)	0.0005	**
CFC	16	11 (69)	0.2–3.8	4.0 (3.2)	15	3 (20)	0.1–3.5	11.9 (14.4)	0.0034	*

[A]Median percentage of wood dust transferred to the sampler covers.
[B]Samplers with the same number of asterisk indicate no statistical difference. LOD = Limit of detection, SD = Standard deviation

concentration and analyzed by ICP-MS. The concentration of Cu and Mn in sample solution was determined by comparison to standard solutions made by diluting concentrated standard solutions (10 ppm, Multi-element, two standards; SPEX CertiPrep Inc., Metuchen, NJ) with an acid mixture of 0.75% nitric acid and 0.25% hydrochloric acid. The LODs for these experiments were 0.076 μg for Cu and 0.144 μg for Mn.

All field blank samples (including the sampling media and wiped samples of internal walls and sampler covers) resulted in nondetectable amounts of Cu and Mn except for the sampling media for Cu. For Cu, the average mass of sampling media for Solu-Sert, DIS, IOM, and CFC was 0.45 μg, 0.34 μg, 0.42 μg, and 0.25 μg for land transportation, respectively, and 0.38 μg, 0.35 μg, 0.43 μg, and 0.27 μg for air transportation, respectively.

Data analyses

For the samples of wood dust and welding fumes, the mass (i.e., dust mass for wood dust and Cu/Mn mass for welding fumes) on a sampling medium and sampler cover were adjusted by the corresponding field blank samples. Then, the proportion of dust or metal components that transferred to the sampler cover was calculated by dividing the mass on the cover by the total mass. The total mass was determined by adding the mass of dust or metal components on the sampling medium—i.e., on the insert for Accu-CAP or Solu-Sert, the filter capsule with its filter for DIS, the filter capsule with its filter for IOM (wood dust only), the filter plus wiped sample of internal walls for IOM and CFC (metal components only), and the filter for CFC (wood dust only)—plus the mass of dust or metal components that transferred to the sampler cover.

For the wood dust samples, 11 negative values between pre- and post-weight of sampler covers were excluded. For the IOM samples, two extreme total masses (197 mg and 511 mg) were observed, while the total mass of the remaining IOM samples ranged 0.4–14 mg (Table 1). During the weighing analysis, we observed no indication of large agglomerated particles on the sampling media that could cause such extreme values. Although the sources of the errors were unclear, both data points were removed from the further data analysis. For the dust mass loaded on the sampler covers that resulted in less than LOD, the mass was replaced with the LOD divided by the square root of 2 (Hornung and Reed 1990). Statistical analyses were conducted to determine the differences of the percentage of dust loading on the sampler cover between the modes of transportation and among different sampler types using a two-way analysis of variance with JMP software (SAS Institute, Cary, NC). Data were log transformed prior to the analysis to meet the assumption of the model. Post-hoc comparisons were carried out using Fisher's least significant difference. Differences with a p-value of <0.05 were considered statistically significant.

Of the 132 welding fume samples, three samples (two land-transported and one air-transported) were excluded because of sampling pump malfunctions. In addition, two land-transported samples were excluded because of mishandling of samples during the ICP-MS sample preparation. Finally, 11 land samples and seven air samples showed negative values of Cu when the mass of sampling filter was adjusted by the mass of field blanks and thus excluded from data analysis. As shown in Tables 2 and 3, the majority of samples showed mass on the sampler covers less than LOD for Cu and Mn. Thus, no statistical analysis was done and only the masses on the covers greater than LOD were used to calculate the proportion of an analyte transferred to the cover.

Results and discussion

Wood dust

Table 1 presents a summary of the number of samples and the percentages of particle transfer to the sampler

Table 2. Summary of particle mass sampled and transferred to the sampler covers (Cu).

	Land transportation				Air transportation			
Sampler type	N	N < LOD (%)	Total mass range, unit in μg	% transfer to the cover[A]	N	N < LOD (%)	Total mass range, unit in μg	% transfer to the cover[A]
Solu-Sert	15	11 (73)	0.2–19	1.1–11.2	14	7 (50)	1.0–20	1.3–19.3
DIS	14	11 (79)	0.3–14	0.9–30.8	15	7 (47)	0.1–12	0.2–33.3
IOM	13	10 (77)	0.7–16	5.1–12.6	12	4 (33)	0.8–20	0.9–8.7
CFC	15	11 (73)	0.3–14	0.7–4.7	11	6 (55)	0.6–16	0.4–12.0

[A]Range of Mn transfer to the sampler covers for those having mass on the cover greater than LOD. LOD = Limit of detection

Table 3. Summary of particle mass sampled and transferred to the sampler covers (Mn).

	Land transportation				Air transportation			
Sampler type	N	N < LOD (%)	Total mass range, unit in μg	% transfer to the cover[A]	N	N < LOD (%)	Total mass range, unit in μg	% transfer to the cover[A]
Solu-Sert	17	12 (71)	7.4–156	0.1–1.7	15	12 (80)	0.4–165	0.3–2.4
DIS	16	15 (94)	7.2–161	1.4	15	14 (93)	6.8–153	1.6
IOM	17	13 (76)	1.9–202	0.3–4.4	14	6 (43)	1.5–109	0.2–1.3
CFC	18	15 (83)	7.5–160	0.2–3.9	15	10 (67)	4.1–153	0.2–3.5

[A]Range of Mn transfer to the sampler covers for those having mass on the cover greater than LOD. LOD = Limit of detection

covers during the sample transportation. Note that 11 negative values between pre- and post-weight of sampler covers or sampling media and two outliers were removed. As a result, the number of samples for each sampler type ranged from 10 to 16 for the land-transported samples and from 13 to 15 for the air-transported samples. Unlike other samples, CFC samples transported by land had the highest number of samples showing less than LOD on the sampler covers (11 out of 16 samples).

Regardless of the transportation mode, IOM samples showed a wider variation compared to the other sampler types. The median percentage of mass transfer to the sampler covers for IOM was considerably higher than that for the other sampler types (15% for the land- and 64% for the air-transported samples; p-value < 0.001), while no differences were observed among the other three sampler types (Table 1). Figure 2 shows a photograph of the wood dust transfer to one IOM sampler cover used for air transport during the study. The remaining samplers showed the median percentage of dust transfer to the covers less than or close to 10%.

Both IOM and CFC air samples showed higher percentages of dust transfer than the land samples (p-values $= 0.0005$ for IOM and 0.0027 for CFC). However, the Accu-CAP and DIS samples demonstrated no statistical differences between the air and land transports. As shown in Figure 3, no trend between the percentage of dust mass loadings on the sampler covers and total dust mass loadings was observed.

Several investigators have reported that wood dust mass is highly influenced by particles $> 10\,\mu m$,

Figure 2. IOM sampler cover after air transportation.

although the reported mass median aerodynamic diameters (MMAD) would be different depending on the industry types and tasks (Harper et al. 2004; Hinds 1988; Pisaniello et al. 1991; Whitehead et al. 1981). For example, Whitehead et al. (1981) collected wood dust samples using cascade impactors during sanding of various wood material types at furniture and plywood manufacturing companies. They reported that particles $> 22.5\,\mu m$ contributed to about 65%–86% of total mass concentrations for 14 of 15 samples. Pisaniello et al. (1991) reported an average MMAD of $18.7\,\mu m$ for hardwood dust and $19.6\,\mu m$ for softwood dust from sanding works. This study revealed two peaks at $3\,\mu m$ and $13.8\,\mu m$, which are smaller diameters than those reported by Whitehead et al. and Pisaniello et al. It is expected that more particles would transfer to the sampler covers during shipping if particle size larger than those in this study were collected.

The findings of this study demonstrate that the mode of transportation and sampler type can result in

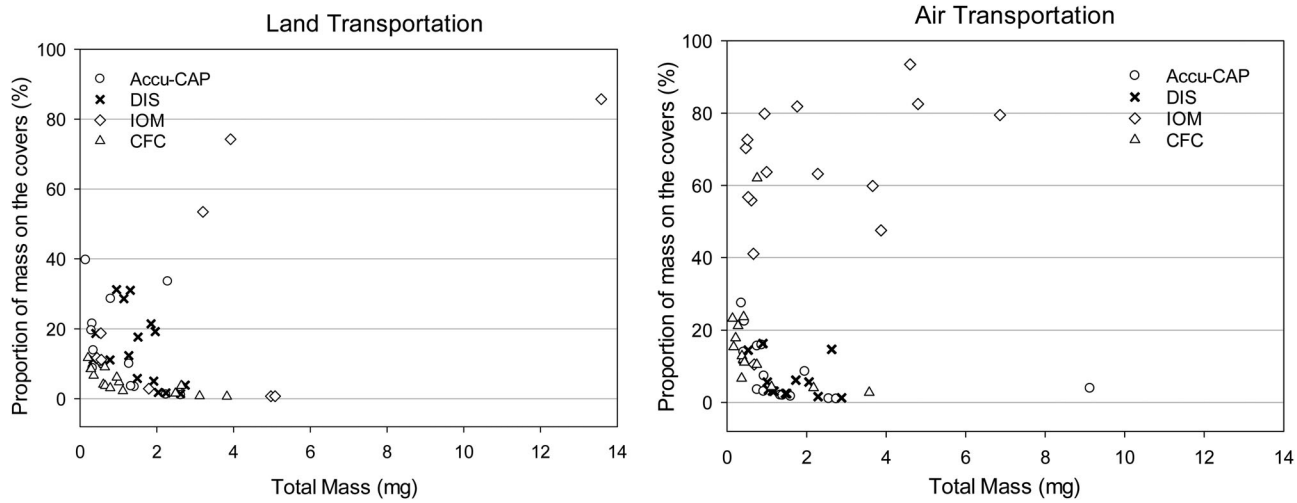

Figure 3. Percentage of mass loadings on the sampler covers with the corresponding total mass loadings (wood dust). Note that the dust mass loaded on the covers that resulted in less than LOD was replaced with the LOD divided by the square root of 2.

dust transfer to the sampler covers, affecting subsequent weighing analyses and leading to an underestimation of mass concentrations. Interestingly, as shown in Figure 1, identical sampler covers were used for Accu-CAP and CFC, and the statistical test showed no difference between these two samplers (see the comparison results by sampler type in Table 1). On the other hand, when a comparison was made between air and land transportation, CFC showed a significant difference (p-value = 0.0034), while Accu-CAP showed no difference (p-value = 0.1224). Probably, various factors such as differences in material handling, sampler packing, and travel distances were involved in causing such differences. Unfortunately, the scope of this study did not allow for investigating the impact of each factors influence.

Special caution should be given to the IOM sampler because of its wider inlet diameter. IOM samplers showed a considerably higher percentage of dust transfer to their covers compared to the other samplers. Interestingly, DIS samplers, having the same inlet diameter as the IOM sampler, did not exhibit the same pattern. The difference might be caused from the nonconductive plastic body of the 25-mm DIS sampler, which is more likely to attract dust particles that stick to its capsule, while the conductive metal body of the IOM sampler doesn't behave in the same manner. It should be noted that IOM has two versions of filter capsules—conductive stainless steel and nonconductive plastic capsules. Typically, the former is recommended for the chemical and weighing analyses, while the latter is suggested for the chemical analysis. The IOM manufacturer made weighing the sampler cover as part of the pre-weight assembly "optional" depending on the size of dust being measured. However, the findings in this study suggest that ignoring the sampler cover could potentially result in underestimation of mass concentrations.

Welding fumes

Summaries of particle mass sampled and transferred to the sampler covers are listed in Table 2 for Cu and Table 3 for Mn. As expected from the type of welding wire, greater masses were observed from Mn compared with Cu. Overall, the majority of samples had nondetectable amounts of the analyte on the sampler covers for all sampler types (33–79% of samples for Cu and 43–94% of samples for Mn). Figure 4 shows the percentage of mass loadings on the covers for those having mass greater than LOD. For the Cu samples, the DIS sampler seemed to demonstrate a higher percentage of mass on the covers compared to the other sampler types. The Mn results show the percentage of transfer to the covers at less than 4.5% regardless of the transportation modes and sampler types. Also, no trend—such as a positive or negative correlation between the total mass and the percentage of mass loadings on the covers—was observed (Figure 4).

Lee et al. (2019) reported that for samples collected at an electrorefinery worksite, 7.4% of Cu particles transferred to the sampler covers during transport for IOM samplers and 6.4% for a customized prototype of DIAS (not commercially available). In this study, given the information in Tables 2 and 3, as well as in Figure 4, the results show that the particle transfer to the covers might not be a major issue because the majority of samples showed nondetectable amounts of metals on the sampler covers. The particle size

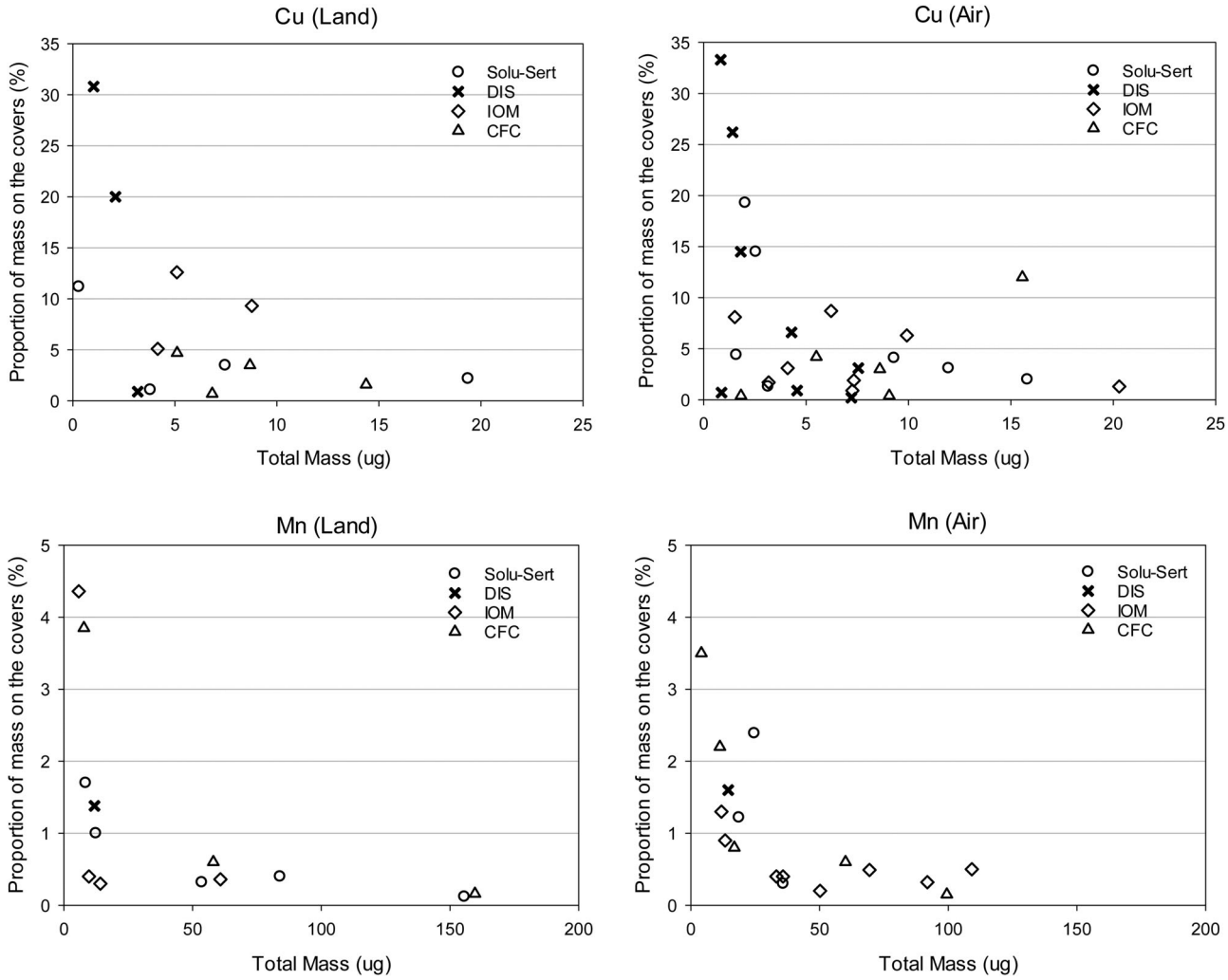

Figure 4. Percentage of mass loadings on the sampler covers with the corresponding total mass loadings. Note that only those having mass on the cover greater than LOD are presented.

distributions by mass in this study showed peak concentrations between 0.3 µm and 0.35 µm. Unfortunately, Lee et al. (2019) did not report the particle size distributions by mass or number and thus, it would be difficult to explain the differences between two studies.

Compared with the wood dust results, welding fumes resulted in smaller percentages of particle transfer to the covers during shipping. This is probably due to the different processes from which the particles are generated. The aerosolized particles from the welding process condensate and coagulate at ambient temperatures, forming agglomerates of nanoparticles and spheres ($0.5-4\,\mu m$) from the welding spatter (Cena et al. 2016). In this study, the mechanical sanding process produced larger particles than the hot wire welding process, leading to more particle transfer to the sampler covers.

Overall, no strong conclusions can be made about the effect of transportation on Cu or Mn particle transfer to the sampler covers because of the limited sample sizes above the LOD for both analytes. For a similar reason, no conclusion can be made among different sampler types.

Study limitations

This study is limited to the unique transportation conditions used. For example, the proportion of particles transferred to the sampler covers could be considerably different if collected samples were shipped on different road conditions (e.g., paved vs. unpaved), traveling distances (e.g., 2-hr driving vs. 6-hr driving), and/or environmental factors (e.g., vibration). The material handlers' characteristics could be another important factor. In practice, conditions of sample handling can be highly variable, which might lead to completely different results.

In this study, the air transportation sample box made a round trip, combining both air and ground

transport, while in practice, only a one-way trip would be utilized. Thus, the associated material handling (e.g., loading and unloading of the sample box) between transport vehicles was likely doubled. Although we placed a "fragile" sticker on the box, this doubled amount of handling might provide more opportunity for more particles to move to the covers than during a one-way trip. Unfortunately, determining all the variability in the material handling could not be done in this study because that is beyond our capacity, and thus we cannot estimate which factor is more effective between the transportation method and the material handling. Similarly, the land transportation box traveled only on paved roads. Other environmental factors (e.g., unpaved road, car vibration) could affect the particle transfer to the covers but again, these factors were not investigated in this study.

The present study is limited to only two materials and one task per material. In addition, the sample sizes, especially for welding fumes, might not be large enough to draw firm conclusions. Additional studies considering other factors such as different particle size distributions, material types (e.g., hard wood vs. soft wood), material characteristics (e.g., different static electricity properties), tasks (e.g., cutting vs. sanding), and sufficient sample sizes would be necessary.

Conclusion

This is the first study investigating particle transfer to sampler covers using different inhalable and total particle samplers and transportation methods. The findings clearly indicate that for the wood dust samples, particles initially collected on a filter and/or internal walls of a sampler can transfer to the sampler covers during shipping regardless of the mode of transportation and sampler type, while the welding fume samples require additional studies. If these particles are not accounted for during analysis, particle concentrations could be underestimated, leading to lower assessment of the overall hazard to the worker. Therefore, it is strongly recommended that in practice, occupational professionals are aware of the potential loss of particles during shipping and account for these particles in the sample analysis, such as including the sampler cover in pre- and post-weighing analysis.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH/CDC.

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