DOI: 10.2478/10004-1254-64-2013-2316

Scientific Paper

SIDE-BY-SIDE DETERMINATION OF WORKERS' EXPOSURE TO WOOD DUST WITH IOM AND OPEN-FACED SAMPLERS

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Received in September 2012
CrossChecked in October 2012
Accepted in July 2013

Woodworkers' exposure to airborne particles is measured with different sampling techniques throughout the world. Due to a great number of exposure data obtained with different samplers, European countries have aimed over the last ten years to find a conversion factor for mass concentrations that would render these measurements comparable. Following the accepted EU standards and regulations, we replaced a 25 mm open-faced (OF) filter holder with an IOM head to determine woodworkers' exposure to inhalable dust and establish an IOM/OF sampler ratio that might serve as a reliable factor for converting the existing OF data to IOM dust mass concentration in the industrial environment. For this side-by-side sampling we used personal 25 mm OF (N=29) and IOM (N=29) sampling heads over eight working hours. The obtained IOM/OF ratios ranged between 0.7 and 2.3. However, mass concentrations obtained by IOM and OF samplers did not significantly differ. Our findings suggest that there is no need for conversion of the existing OF data for workers exposed to wood dust, provided that dust mass concentrations in the working environment range between 1 mg m^{-3} and 7 mg m^{-3}. Future side-by-side measurements should also involve environments with low wood dust mass concentrations.

KEY WORDS: *carcinogenic substances, hardwood dust, IOM/OF conversion factor, inhalable fraction, European Directive 2004/37/EC*

Hardwood dust, such as the dust of ebony, oak, and beech wood involves the highest occupational risk of developing sinonasal adenocarcinomas (1, 2). Intestinal-type sinonasal adenocarcinomas are epithelial tumours of the nasal cavities and paranasal sinuses that are strongly related to occupational exposure to wood dust and are almost exclusive to carpenters and furniture makers. Between 1986 and 2002, in just one hospital in Spain sixty-two patients with exposure to wood dust from three to 50 years were diagnosed with sinonasal adenocarcinomas (1). A study in the United Kingdom came up with a similar, strong correlation between adenocarcinoma and furniture industry (3). Because the frequency of this particular type of tumour is low in the general population, it can be assumed that all such tumours in workers in the furniture industry are occupational in origin.

Between 2002 and 2003, about 3.6 million workers were occupationally exposed to inhalable wood dust in 25 member states of the European Union (EU). Around 563,000 workers (16 % of the exposed) may have been exposed to a level exceeding the EU occupational exposure limit (OEL) of 5 mg m^{-3} (2). In Croatia, about 40,000 woodworkers and 2,000 forest cutters are exposed to wood dust (4). Wood industry in Croatia dominantly uses the most harmful hardwood species - oak and beech wood - for processing, which account for 70 % of the whole production.

The International Agency for Research on Cancer (IARC) has classified wood dust as a carcinogenic substance (5). The EU Directive 2004/37/EC has also classified hardwood dust as carcinogenic and has set the OEL for inhalable hardwood dust to 5 mg m^{-3} (6). Moreover, the Scientific Committee for Occupational Exposure Limits (SCOEL) of the EU has stated that exposure to wood dust above 0.5 mg m^{-3} induces pulmonary effects and should be avoided (7). The American Conference of Governmental Industrial Hygienists (ACGIH) has adopted the 0.5 mg m^{-3} as the new lowest inhalable OEL for wood dust exposure (8). However, this limit is within the concentration range giving the highest inter-method variability (9).

Devices for measuring woodworkers' exposure to airborne particles differ all over the world. One of the differences is the design of filter holders, which defines how efficiently certain airborne particle fractions are collected.

European standards (EN 13205:2001 and CEN/TR 15230:2005) (10, 11) have attempted to address this issue by harmonising measurement methods to ensure the comparability of results obtained by different filter holders. In addition, European studies of 25 EU member states have established that all measured concentrations of dust should be converted to concentrations of inhalable dust, using conversion factor if necessary. However, these factors vary by the particle size distribution of dust. Only German and British measurements have been carried out using the sampling methods that correspond to the concentration of inhalable dust. The Dutch sampling method is approximately comparable, whereas the concentrations obtained by French and Danish sampling methods are to be converted into inhalable dust by multiplying them by 1.59. The conversion factor for Finnish dust mass concentrations is 2 (2).

Many authors have compared the results of side-by-side personal sampling in an industrial environment, mostly between the Institute of Occupational Medicine (IOM) sampler and samplers such as Gesamtstaub-Probenahmesystem (GSP), 7-hole sampler (7HS), CIP10-I, or 37 mm open and close-faced filter cassette (plastic) (9, 12-14).

Croatia adopted the European Directive 2004/37/EC, with the OEL of 5 mg m^{-3} for inhalable fraction of hardwood dust, in 2007 (15). Previously, the limit value for the concentration of respirable fraction was 1 mg m^{-3} and for inhalable dust 3 mg m^{-3} (16). The preferred dust sampling method for exposure to wood dust has been the 25 mm open-faced (OF) filter holder (metal) manufactured by Casella. However, since 2007, Croatia has fully adopted a new technical report CEN/TR 15230:2005 (11) that no longer includes the 25 mm OF sampling head but has replaced it with the IOM inhalable dust sampler (SKC, Dorset, UK).

The aim of this study was to determine the IOM/OF sampler ratio based on side-by-side measurements in a woodworking environment in order to establish the conversion factor for OF dust mass concentration to IOM dust mass concentration.

MATERIALS AND METHODS

In order to determine IOM/OF sampler ratio, we sampled wood dust in the air next to a wide-belt sander and a four-sided planer during oak wood floor processing (moisture content between 8 % and 10 %) using a 25 mm OF filter holder (metal) manufactured by Casella (Bedford, UK, Part No. B8255/Z) side by side with the IOM head manufactured by SKC (Dorset, UK, Part No. 225-70A) (Figure 1). Recommendations for wood dust sampling include the convention for measuring inhalable particles given in HRN EN 481:2007 (EN 481:1993) (17).

During the sampling, ambient air temperature ranged between 18 °C and 20 °C and relative air humidity between 55 % and 58 %.

Dust was sampled for eight working hours over eight days. Every day, three to four participants carried both an IOM and a 25 mm OF sampler, each on the opposite shoulder. Over the 8 days, 29 pairs of samples

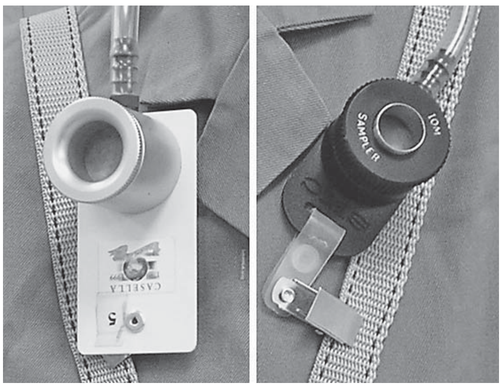

Figure 1 *Samplers a) 25 mm open-faced (Casella), b) IOM (SKC)*

were collected. The mean sampling time was 7 h 49 min (SD±39 min). Suction flow rate on the Casella personal sampling pump was set at 2 L min^{-1}. 25 mm quartz filters (Whatman QM-A) were conditioned in the desiccator on (20±1) °C and (50±5) % relative humidity 24 h before weighting and before and after the sampling. Weighting was performed using a micro scale METTLER-TOLEDO MX-5 (Greifensee, Switzerland) with 10^{-6} g scale sensitivity. Mass concentration of dust was determined using the gravimetric method according to the standard ZH 1/120.41 (18).

The conversion factor (IOM/OF ratio) was calculated as the ratio between mass concentration obtained with the IOM and OF samplers [equation 1], as follows:

$$k_f = \frac{c_{IOM}}{c_{OF}} \qquad [1]$$

where: k_f is the conversion factor; c_{IOM} is the mass concentration determined with the IOM sampler, mg m^{-3}; and c_{OF} is the mass concentration determined with the OF sampler, mg m^{-3}.

Variables were analysed using descriptive statistics (mean, geometric mean, median, standard deviation). Differences in mass concentrations between the samplers were tested using Student's t-test. Mann-Whitney U-test was used when the condition of homogeneity of variance was not fulfilled (19). The 5 % error type I (a) was considered statistically significant. All statistical analyses and graphs were made using STATISTICA 7.0 (StatSoft Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

Figure 2 shows the distribution of mean mass concentrations (and data dissipation) measured with the IOM and 25 mm OF samplers. Greater data dissipation was observed with IOM than with OF measurements, perhaps due to a higher sensitivity of the IOM sampler for a wide range of particle sizes.

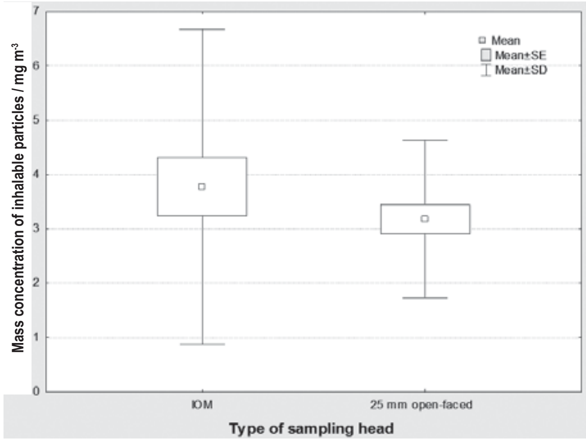

Figure 2 *Distribution of mean mass concentrations and standard errors (SE)/standard deviations (SD) obtained with IOM and OF sampling heads*

Table 1 compares the arithmetic means and ranges of measured mass concentrations obtained with IOM and OF. IOM/OF ratios ranged between 0.7 and 2.3. However, as the differences between mass concentrations obtained with the two samplers were not statistically significant, there is no need for the conversion of the OF data to IOM. As the condition of homogeneity of variance for the two groups of results was not fulfilled (F=4.01, p=0), we ran the Mann-Whitney U-test (p=0.59, N=29), which has confirmed that there is no need for the conversion of OF data if within the mass concentration range between 1 mg m^{-3} and 7 mg m^{-3}, because OF dust mass concentrations were higher than 1.21 mg m^{-3} and lower than 6.85 mg m^{-3} (Table 1).

Because of the small number of samples and great variability of IOM/OF ratios when OF dust mass concentration was higher than 6 mg m^{-3} (Figure 3), we subdivided OF measurements into groups of (1 to 2) mg m^{-3}; (2 to 3) mg m^{-3}; (3 to 4) mg m^{-3}, and (4 to 7) mg m^{-3} (Table 2) to test differences between the samplers in those ranges. The only significant

Table 1 *Means and ranges of dust mass concentrations obtained with the IOM and OF samplers and samples exceeding OEL*

Type of mass concentration	N	Mean	Min	Max	Share of samples exceeding OEL (n) in total number of samples (N)		
			mg m^{-3}		OEL	n/N	%
c_{IOM}	29	3.78	1.00	15.45	5	5/29	17
c_{OF}	29	3.17	1.21	6.85		4/29	14

OEL – occupational exposure limit (5 mg m^{-3}) adopted in Croatia since

Table 2 *Comparison of mass concentrations obtained with IOM and OF samplers by concentration subgroups*

Subdivisions to c_{OF}/mg m^{-3}	*N*	Mean, c_{OF}	Mean, c_{IOM}	Mean, k_f	Student's t-test	Mann-Whitney U- test
		mg m^{-3}		-	-	-
1 to 2	4	1.583	1.511	0.949	*p*=0.78	-
2 to 3	11	2.338	2.382	1.017	-	*p*=0.79
3 to 4	8	3.310	3.732	1.140	*p*=0.03*	-
4 to 7	6	5.580	7.903	1.366	-	*p*=0.22

statistically significant (p<0.05)

difference was in the subdivision (3 to 4) mg m^{-3} (Student's *t*-test, *p*=0.03) for which the mean conversion factor was 1.14 (*N*=8, SD±0.19).

As no comparative measurements for IOM and 25 mm OF samplers have been published so far, we can only refer to data for similar 37 mm open- and close-faced samplers. The SCOEL (7) found similar sampling efficiencies between open- and close-faced filter cassettes, which dropped substantially with particle sizes larger than 45 µm. Kenny et al. (12) have shown that the IOM sampler collects two to three times the amount of dust 37 mm open- and close-faced samplers do, depending on aerosol size distribution. Based on side-by-side personal sampling for large particles with a (plastic) OF filter cassette and IOM head, Liden et al. (20) concluded that IOM mass concentration corresponded to approximately double the OF mass concentration. In contrast, Predicala and Maghirang (21) found no significant difference between paired IOM and OF or IOM and close-faced mass concentration.

The existing studies are contradictor, and some of the findings are limited to sampling for large particles, which limits comparability with our results. Even our finding that there is no need for conversion of the OF data to IOM is limited to a mass concentration range between 1 mg m^{-3} and 7 mg m^{-3}.

Investigations of the IOM/OF ratio (7, 21), including ours, have not answered the question why the 25 mm OF sampler is not on the CEN's list of standardised samplers for inhalable, thoracic, and respirable aerosol fractions (11) and the Button sampler is, even though Harper and Muller (14) have shown that it measured significantly different concentrations (*p*=0.02, *N*=12) than IOM, and that IOM/Button ratios ranged from 0.49 to 163 (median 3.15). Even though SCOEL (7) has shown that the IOM and GSP samplers best follow the sampling convention for inhalable dust, measuring ratios evidently depend on mass concentration and other measurement conditions. Kenny et al. (12) reported median IOM/7HS and IOM/CIP10-I ratios of 1.17 and 1.5, respectively. Vaughan et al. (13) reported a mean IOM/7HS ratio of 1.3 in side-by-side measurements. Davis et al. (9), in turn, proposed a 1.7 ratio for GSP/7HS (for inhalable dust particles), but concluded that it varied significantly between devices and particle sizes, and was the highest at low ambient dust mass concentrations.

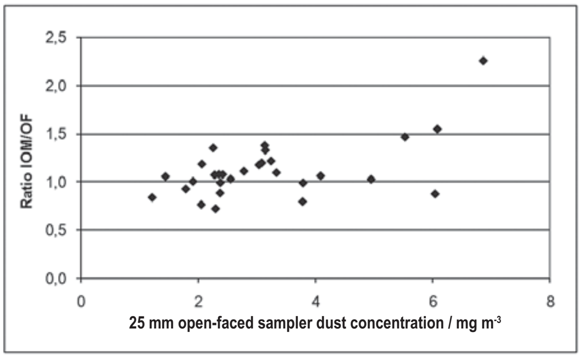

Figure 3 *IOM/OF ratio for dust concentrations (mg m^{-3}) measured with the 25-mm open-faced sampler*

CONCLUSION

Croatia has replaced the 25 mm OF sampling head with the IOM sampler to accommodate the EU requirements. Clearly, this is the best in a choice of possible replacements. Yet our study, like some others (7, 9, 12-14, 21), indicates that, under well-defined conditions, different sampling instruments could reliably be used for inhalable particle monitoring, and several countries would not have to change current sampling methods even if not included in the CEN Technical Reports (11).

Variability in sampling results may be due to differences in sampling conditions, such as particle size distribution, local aerosol sources, and external winds (although much less than 0.5 m s^{-1}). This variability involves a high degree of uncertainty in terms of OEL and exposure-related health risks and calls for further research into the sources of variability the industrial environment.

The conversion factors determined in our study could be valid for an environment with a higher dust mass concentration, between 1 mg m^{-3} and 7 mg m^{-3}. It would also be interesting to see side-by-side measurement variability at lower wood dust concentrations (<1 mg m^{-3}) in woodworking environments and to determine the share of small respirable particles during these measurements. It would also be useful to determine a work-specific IOM/OF ratio for a wider range of mass concentrations to obtain reliable estimates of exposure in Croatian workers monitored with 25 mm OF between 1996 and 2005 (22).

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Sažetak

USPOREDNO ODREĐIVANJE IZLOŽENOSTI RADNIKA DRVNOJ PRAŠINI UPORABOM "IOM" I "*OPEN FACE*" SAKUPLJAČA

U svrhu određivanja izloženosti radnika drvnoj prašini na radnome mjestu, diljem svijeta korišteni su različiti mjerni uređaji koji se razlikuju izvedbom držača filtra i učinkovitošću prikupljanja inhalabilne frakcije lebdećih čestica. U proteklih deset godina cilj je istraživanja u europskim zemljama odrediti konverzijski faktor za masene koncentracije dobivene različitim sakupljačima. Prema prihvaćenim europskim standardima i propisima, 25 mm Open Face (OF) sakupljač zamijenjen je IOM sakupljačem u uređaju za određivanje izloženosti radnika inhalabilnoj prašini. Cilj ovog istraživanja bio je utvrditi IOM/OF omjer za ta dva tipa sakupljača u industrijskim uvjetima za dobivanje faktora konverzije iz postojećih OF masenih koncentracija u IOM masene koncentracije. Usporedno uzorkovanje provedeno je tijekom osam radnih sati osobnom metodom sakupljanja koristeći se 25 mm Open Face (N=29) i IOM (N=29) držačima filtra. Dobiveni IOM/OF omjer raspona iznosio je 0,7 do 2,3. Masene koncentracije dobivene IOM i OF sakupljačima statistički se značajno ne razlikuju, iz čega proizlazi da nema potrebe pretvarati postojeće OF masene koncentracije u IOM koncentracije. Dobivena postavka vrijedi samo za radni okoliš s višom masenom koncentracijom, otprilike između 1 mg m^{-3} i 7 mg m^{-3}. Usporedno određivanje izloženosti radnika inhalabilnoj frakciji lebdećih čestica treba provesti i u radnim uvjetima s niskom masenom koncentracijom drvne prašine.

KLJUČNE RIJEČI: *karcinogena tvar, prašina tvrdih vrsta drva, IOM/OF faktor konverzije, inhalabilna frakcija, Europska direktiva 2004/37/EC*

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