APPLICABILITY OF PHOTOMETRIC METHOD FOR DETERMINATION OF WOOD DUST MASS CONCENTRATION IN WOODWORKING ENVIRONMENT

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Abstract
The aim of research presented in this paper was to evaluate reliability and applicability of photometric methods in determining mass concentration of wood dust in the woodworking environment in comparison to gravimetric method. The samples of inhalable wood dust was collected in several plants of mechanical processing during machining of wet oak-wood (N=18), dry oak-wood (N=15), wet beech-wood (N=14), dry beech-wood (N=23) wet fir-wood (N=10) and particleboard (N=10). Relationship between the results obtained by the photometric method and values obtained by the gravimetric method is significant (Spearman's rho=0.8, 88 d.f., P=0.000) and this is the base for using the photometric method in determining mass concentration of airborne wood dust. The obtained correction factors of photometric method has high dispersion among and within sample groups. The mean values of correction factors for different groups of samples are significantly different. Such results present the usage complexity of photometric method for determination of wood dust mass concentration.

Key words: *exposure to wood dust, inhalable particles, photometric method, gravimetric methods, correction factor*

INTRODUCTION

The problem of wood dust or airborne wood particles, as cause of contamination of work environment are present in most wood-technological processes (mechanical processing of wood, drying, transport, wood combustion). Within the research of personal exposure to particles from the work environment, apart from the application of gravimetric method, in determining mass concentration of wood dust, the possibility of application of photometric method is being increasingly investigated (Thomas et al., 1994; Koch et al., 2002; Lanki et al., 2002; Čavlović et al., 2009). The reason lies in the fact that, when using a gravimetric method, measurements that take place during a whole 8-hour shift are time consuming. Consequently, the need arose for instantaneous and yet continuous determination of mass concentration of wood dust in the workplace. In research of applicability of photometric method for determination of workers' exposure to wood dust it should be taken into consideration that the Council Directive 2004/37/EC prescribes the limit value of mass concentration of inhalable fraction of hardwood species, provided that the sample is collected for 8 hours and mass concentration of particles determined gravimetrically.

The problem of airborne particles is very significant for the wood sector in Croatia, because beech and oak are the two most largely represented species with a share 73 % in wood processing. A long-term exposure to these two species of wood causes the risk of developing adenocancer of nose cavity (Hausen, 1981; Kubel et al., 1988; Kohler et al., 1995; Bleich et al., 1998; Klein et al., 2001).

In 1999 the European Community classified wood dust as carcinogenic based on IARC classification (International Agency for Cancer Research) (Klein et al., 2001). The Council Directive 2004/37/EC prescribes the limit value of inhalable fraction of hardwood species of 5 mg/m^3.

Data obtained by gravimetric method were not only used for comparison with the prescribed limit values, but also as referential values for the assessment of results obtained by photometry. Photometric method is considered a promising method applicable for the determination of short personal exposures in the working environment (Lanki et al., 2002). Photometric method is more easily applicable than gravimetric method for making exposure time profile at workplace. Numerous authors (Koch et al., 1999; Koch et al., 2002; Tatum, 2002; Rando et al., 2005a; Rando et al., 2005b) presented the development and application of the optical unit RespiCon with selective fraction collector - inhalable, tracheal and respirable fraction of airborne particles. They determined the correction factor for individual fractions comparing the measuring results of mass concentration with the application of the optical unit RespiCon and the results of determination of mass concentration by gravimetric method of samples collected by referential IOM (Institute of Occupational Medicine) collector of inhalable fraction. This research showed the impact of particle size and individual particle fractions on the efficiency of used samplers. Some authors investigated the influence of other physical characteristics of particles – particle form and reflection coefficient (O'Shaughnessy et al., 2002) and impact of relative ambient air humidity on results of photometry (Thomas et al., 1994; Lanki et al., 2002).

The aim of research presented in this paper was to evaluate reliability and applicability of photometric methods in determining mass concentration of dust of different wood species with different moisture content in comparison to gravimetric method.

MATERIAL AND METHODS

The samples of inhalable wood dust was collected in several plants of mechanical processing at working places during machining of wet oak-wood (N=18), dry oak-wood (N=15), wet beech-wood (N=14), dry beech-wood (N=23) wet fir-wood (N=10) and particleboard (N=10).

Average time of sampling was 40 minutes for samples of dry wood and 110 minutes for samples of wet wood. During the sampling there are not large differences in temperature and relative moisture of environment air.

The unit for continuous measurement of mass concentration of airborne particles, model Split II manufactured by SKC (Dorset, UK, 2006) consists of the unit for processing and presentation of data, inlet part of photometric lens holder (optical part of the unit) and outlet part of IOM (Institute of Occupational Medicine) filter holder for gravimetric analysis. The housing is connected to the suction pipe manufactured by Casella (Bedford, UK, 2001) with air flow adjusted to 2 l/min (HRN CEN/TR 15230:2005). After entering the housing, the air sample passes through the optical detector, and then through the filter.

IOM filter holder is shaped in accordance with the standard for sampling the inhalable fraction (0.1 – 100 μm). According to the standard HRN EN 481:2007, the inhalable fraction is the mass fraction of total airborne particles inhaled through the nose and mouth.
Weighing for gravimetric analysis was performed by microscale METTLER-TOLEDO MX-5 (Greifensee, Switzerland, 2000). Quartz filters (Whatman QM-A), 25 mm in diameter, were used as the media for collecting samples of wood dust. Mass concentration of wood dust was determined by the following equation:

$$c_g = \frac{m_2 - m_1}{V} \quad (1)$$

where:
c_g – mass concentration of wood dust, mg/m^3
m_1 – filter mass before sampling, mg
m_2 – filter mass with sample, mg
V – total air volume from which the sample was obtained, m^3

The instructions of the NMAM Method 0600 were used for working with the unit for photometry of airborne particles. In accordance with the recommendations of the unit manufacturer, an individual correction factor should be determined for each type of particles (metal, stone, wood dust) because, even at the same mass concentration, different types of particles do not have the same characteristic of light dispersion. The correction factor of the unit for continuous determination of mass concentration is established by comparison between values of mass concentration obtained gravimetrically and by photometric method (equation 2):

$$K = \frac{c_g}{c_f} \quad (2)$$

where:
K – correction factor for continuous determination of mass concentration,
c_g – mass concentration determined by gravimetric method, mg/m^3,
c_f – mean value of mass concentration determined by photometry, mg/m^3.

The correction factor should be calculated from the mean value obtained on the basis of at least 10 repetitions. The unit for continuous determination of mass concentration should be reset to zero before each sampling. The highest mass concentration that can be determined by this unit is 200 mg/m^3.
The unit was adjusted so as to continuously record the mass concentration every 10 seconds. At the end of the measurement, the following data are available: all recorded values of mass concentrations (graphically and numerically), total number of data and measurements, minimum and maximum mass concentration, mean value of all data and short-term 15-minute exposure. Implementation of a continuous measurement of not less than 30 minutes is the condition for the determination of short-term exposure. An adequate programme is used for drawing the diagram which presents all values during the period of continuous determination of mass concentration by photometric method (Figure 1).

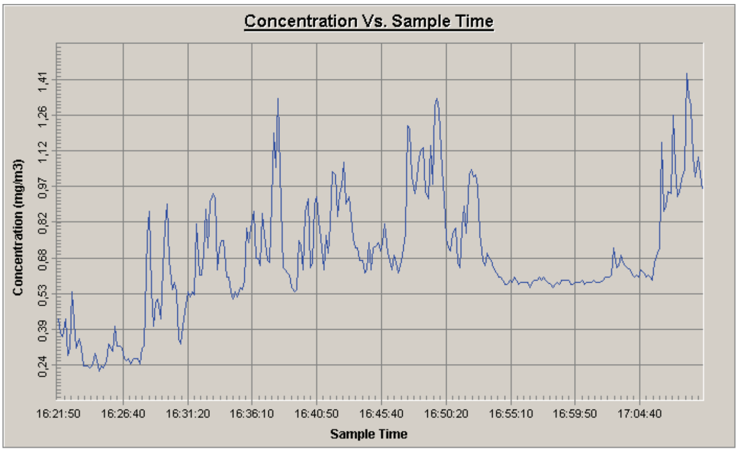

Figure 1 Diagram of continuous determination of mass concentration by photometry

All statistical analyses and statistical tests have been made by use of the statistics software - STATISTICA 6.0.

RESULTS AND DISCUSSION

Table 1 presents the average mass concentration of inhalable particles of wood dust determined by gravimetric and photometric method, calculated correction factors, short term exposure level and standard deviations for presented average values.

Table 1: Average mass concentration of inhalable particles of different wood dust determined by gravimetric and photometric method and calculated correction factors

Group of samples	N	c_g	SDV (c_g)	c_f	SDV (c_g)	STEL	K_{ave}	SDV (K_{ave})
		mg/m^3						
WFW	10	0.39	0.34	0.40	0.34	0.75	1.0	0.35
WBW	14	0.81	0.39	0.49	0.25	0.72	2.1	1.47
WOW	18	1.07	0.51	0.33	0.14	0.54	3.4	1.59
DBW	23	1.74	2.02	0.58	0.63	0.75	3.8	2.70
DOW	15	1.93	2.24	0.49	0.49	0.75	4.4	3.92
PB	10	12.38	5.78	2.87	1.50	4.32	4.5	1.00

N – number of samples in group, c_g – mean value of mass concentration determined by gravimetric method, c_f – mean value of mass concentration determined by photometric method, K_{ave} – mean value of correction factors, SDV – standard deviation, STEL – Short Term Exposure Level, WFW – wet fir-wood, WBW – wet beech-wood, WOW – wet oak-wood, DBW – dry beech-wood, DOW – dry oak-wood, PB – particleboard

The relationship between results obtained by the photometric method and values obtained by the gravimetric method is significant for all groups of samples except for samples of wet beechwood (Table 2).

Also, the relationship between all results obtained by the photometric method and values obtained by the gravimetric method is significant and positive (Spearman's rho=0.8, 88 d.f., P=0.000) and this is the base for using the photometric method in determining mass concentration of airborne wood dust. The best correlation of the gravimetrically determined mass concentrations is obtained with the results of short term exposure level – STEL (Spearman's rho=0.85, 88 d.f., P=0.000)

Table 2: Results of Spearman rank corellation between wood dust mass concentration obtained by the photometric and gravimetric method for different samples groups

Group of samples	ρ	d.f.	*P*
WFW	0.79	21	0.0000
WBW	0.28	12	0.34
WOW	0.77	13	0.0007
DBW	0.55	16	0.018
DOW	0.76	8	0.0118
PB	0.90	8	0.0003

ρ - Spearman's rho, d.f. – degrees of freedom, P – probability

The means of correction factors of sample groups were significantly heterogeneous (Kruskal–Wallis test, *P*=0.000268). According to this we can conclude that correction factors must be determined and used for measuring mass concentration of inhalable wood dust during the machining of different wood species and wood with different moisture content.

The best corresponding results of photometric and gravimetric methods are obtained for the samples collected during machining of wet fir-wood (K_{ave}=1). The largest correction factor should be used in determining workers exposure to wood dust during machining of dry oak-wood (K_{ave} =4.4) and particleboard (K_{ave} =4.5).

In Table 3 are presented results of statistical comparison of correction factors for pairs of sample groups. Because of considerable variance of correction factors within the groups of samples significant difference between correction factors is statistically approved for samples of wet fir-wood and other groups and for particleboards and samples of wet wood.

Table 3: Results of statistical comparison of correction factors for pairs of sample groups (Mann–Whitney U-test)

Significance level *P*	PB	WFW	WOW	DOW	WBW
DBW	0.14	0.012	0.48	0.58	0.08
WBW	0.0002	0.02	0.03	0.09	-
DOW	0.27	0.004	0.91	-	-
WOW	0.05	0.0002	-	-	-
WFW	0.0002	-	-	-	-

The results of similar researches of other authors (Koch et al., 1999; Koch et al., 2002; Tatum et al., 2002; Rando et al., 2005a; Rando et al., 2005b), who compared these two methods, showed that the efficiency of photometry (of wood particles) was nearly the same as the efficiency of the referential IOM sampler (correction factor is approximately 1) for particles up to 10 μm, and that the correction factor for the particles of extratoracic fraction (from 10 to 30 μm) would range between 1.5 and 2. The efficiency of samplers with photometry decreases with the increase of aerodynamic diameter of the observed particle, which results in higher correction factor. Generally, lower exposure to airborne particles from the same sample is determined by continuous photometry unit, than by gravimetric method with IOM sampler of inhalable particle fraction (Koch et al., 2002; Rando et al., 2005a), that is showed also in the presented results.

CONCLUSION

According to the results of this research, the application of photometric method for the determination of mass concentration of wood particles is possible with the use of correction factor. Unfortunately, the results of correction factors have shown large variations within and among groups of samples. The means of correction factors of sample groups were significantly heterogeneous. According to this we can conclude that correction factors must be determined and used for measuring mass concentration of inhalable wood dust during the machining of different wood species and wood with different moisture content. Results have shown that applicability of photometric method in determination of wood dust mass concentration of inhalable particles is very complex.

Photometric method could not be a replacement for gravimetric method in determining mass concentration of airborne particles of wood dust and the results of photometry can not be compared to the prescribed limit values of workers' exposure to wood dust. However, the determination of mass concentration of wood dust by photometric method may be applied for short-term exposure measurements and for additional measurements within the analysis of exposure time profile at workplaces during the working day. Additionally, photometric method is very useful for simultaneous collection of samples of the respirable, thoracic and inhalable fractions of airborne particulate matter.

Workers' exposure to wood dust at workplaces in woodworking plants varies considerably so that further research should investigate the impact of mass concentration and type of working operation on the size of correction factor. The important influence on correction factor could have also the time of sampling.

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