J. of Ag. Eng. - Riv. di Ing. Agr. (2010), **1**, 25-31

THE MEASUREMENT AND DISTRIBUTION OF WOOD DUST

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1. Introduction

The production and diffusion of dust in the woodwork industry is a function of the work organization, the presence and efficiency of ventilation systems, the skill of the individual worker and the kind of wood products that are manufactured. Wood dust is an accumulation of any wood particulate that is generated during the processing or handling of wood. When this dust becomes airborne it may be inhaled by workers, leading to mucosal irritation, allergies and respiratory system cancer [Mandryk 2000; Pellegrini 2002]. The average diameter of wood dust is usually between 10 and 30 µm; however, in thin processing, even smaller dust can be produced with a diameter lower than 5 µm. Machines emit wood particles at an average speed of 10 m s^{-1}. Although big particles cannot be inhaled, they carry smaller particles which can be [Alwis 1999; Cavallo 2008]. The distribution of wood dust and particle size has been reviewed and discussed in different studies [IARC 1995].

The current maximum concentration of hardwood dust allowed in Italy is 5 mg/m^3 [Law 66/2002] for each 8 hour work period. This evaluation refers to a personal sample of the percentage of dust which can be inhaled. The inhalable fraction (I.F), as defined by the UNI EN 481, represents the mass fraction of total airborne particles which are inhaled through the nose and mouth. The specification of the level of exposure in the workplace in relation to the fraction that can be inhaled gives little information about the real quantity of dust which can reach the bronchi. In order to carry out a detailed study on the correlation between wood dust and pulmonary pathology, it is necessary to monitor the respirable fraction (R.F), which can reach the deepest respiratory tracts. The norm UNI EN 481 defines the respirable fraction as "the mass fraction of inhaled particles penetrating the unciliated airways" (Table 1 - Fig. 1).

Several studies have emphasised breathing problems with the lungs and their functions, such as negative respiratory symptoms and chronic obstructive pathologies related to exposure to airborne particles. These particles have size characteristics which are typical of the respirable fraction and have a mass which infiltrates the respiratory tracts [Whitehead 1981; ICRP 1994; Edman 2003]. The accumulation of particles begins in the respiratory tract, in particular, the bronchial region, but also in the windpipe and extra-thorax regions. The infiltration of wood dust into human organisms depends upon two factors: mass and dimension [Proto 2009]. Studies carried out on the size distribution of wood particles stress that only 25-30% of dust mass has an aerodynamic diameter <5 µm, with a distribution of particle mass between 5 and 20 µm. Numerical measures, instead, show that most particles are under 5 µm. There is therefore a problem regarding mass size (the larger particles) and the level of penetration (the smaller particles < 5µm). In actual fact, a particle with a diameter of 1 µm weighs 125 times less than a 5 µm particle and 1000 times less than a 10 µm particle [Hounam 1974; Whitehead 1981, McCammon 1985, Pisaniello 1999, Innocenti 2008].

Thanks to modern scientific apparatus available nowadays, it is possible to acquire precise information on the number of particles dispersed into the air and their dimensions. These scientific instruments are based upon the "light scattering" principle. The air sample goes through a laser beam and the quantity of light intercepted by the sensor is relative to the number and size of the particles. The use of these instruments, based upon the laser scansion, allows an analysis of several concentrations and in addition, each sample of dust can be combined with a real number of particles which have a well defined diameter and dimension.

In this study, the results of a cross research methodology were considered first. This methodology

Paper received 21.12.2009; accepted 22.02.2010

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Terms	Definition
Total airborne particles	"all particles surrounded by air in a given volume of air"
Inhalable fraction	"the mass fraction of total airborne particles which are inhaled through the nose and the mouth"
Thoracic Fraction	"the mass fraction of inhaled particles penetrating the larynx and beyond"
Respirable Fraction	"the mass fraction of inhaled particles penetrating the unciliated airways"

TABLE 1 - Size fraction definitions for the measurement of airborne particles (UNI EN 481).

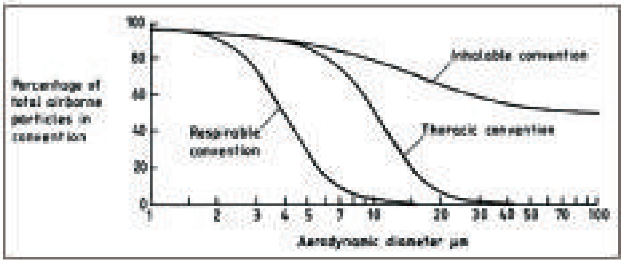

Fig. 1 - The inhalable, thoracic and respirable conventions (UNI EN 481)

was carried out using qualitative and quantitative analysis on the concentration of wood dust and in particular dust particles which were produced by several transformation processes and had different diameters.

A number of phases of wood processing in the first and second transformation mills were studied in order to monitor (in real time) the dimension of the wood dust produced and compare it to the traditional gravimetric analysis.

2. Materials and methods

2.1 *Wood dust measurements*

The sampling methodology used two different survey strategies; the first was carried out using the gravimetric analysis which applies proper selectors according to the directions of the relevant technical norms [UNI EN 481/1993 - 482/2006 - 689/1997]. The second methodology was based upon the optical measurement of the dimensions of particles dispersed into the air. For the first survey strategy, personal inhalable dust sampling was performed using 25-mm diameter sampling cassettes containing 5.0 µm pore size polyvinylchloride (PVC) filters for the collection of wood dust and gravimetric analysis in accordance with EN 481. Samples were collected using the Institute of Occupational Medicine (IOM) sampling head. The IOM sampling head samples the inhalable dust fraction, which includes all particles that could enter the nose and mouth. The respirable fraction was monitored by a GS-3 centrifugal separator using 25-mm diameter sampling cassettes containing 5.0 µm pore size PVC filters. Cassettes and filters were weighed before and after sampling using a Mettler microbalance (0.001 mg). Prior to pre-weighing, filters were set to a stable temperature (20±5°C) and relative humidity (50±5%) for 48 hours. For every 10 samples, two field blanks were analysed to allow correction of humidity or other background effects on the filters. Prior to post-weighing, filters were set to a stable temperature (20±5°C) and relative humidity (50±5%) for 48 hours. In further testing, the mean of the two measurements was used. The weight of the sample filters was corrected by the average weight change of the field blanks. The filters were placed in line with AirChek XR 5000 air sampling pumps which were pre-set to a flow rate of 2.0 l/min for inhalable dust fraction and of 2.75 l/min for respirable dust fraction using a precision rotameter that had been standardized. Post standardization was also performed with the same rotameter to check if the wood dust inhaled had changed the initial flow rates. Each sample filter cassette was placed in the breathing zone of the worker, approximately 30 cm from the worker's mouth. The sampling methodology predicted the analysis of dust emissions for each one of the machines used throughout the study and the various processing cycles [Alwis 1999; Cecchini 2005; Cavallo 2008].

For the second survey strategy, particle number and size measurements were conducted using the ParticleScan Pro-aerodynamic particle sizer, which measures particle size distribution and number concentration in real time. This instrument sucked the air at a flow of 0.8 l/min through an isokinetic probe linked to the instrument using a PVC connection pipe. This instrument, thanks to its small dimensions (20x10x5 cm), allows one to count particles dispersed into the air. It represents both the fraction that can be inhaled and the fraction that can be respired. Thanks to its high level of precision and sensitivity in the optical scansion, it allows one to monitor particles which are even smaller than a micron, up to a reading limit of 0.3 µm. In order to monitor this, the concentrations of the ultra-thin fraction (particles with aerodynamic diameter smaller than a micron; UT.P.), the thin fraction (particles with a diameter between 1 and 5 µm; T.P.), and big fraction (all particles bigger than 5 µm; B.P.) were collected. The laser source is constituted by a diode and the sampling time is adjustable to four different time intervals (6 - 60 - 600 - 3.600 seconds). In view of the high cutting speed and the power of different tools, a scansion time of six seconds was adopted for this research and for this reason, for each hour of sampling, 600 data were collected for each particle size class dispersed. At the end of each sampling the counter suction pipe was cleaned from residues of particles still present in the instrument, by means of a purification filter. The data (collected in real time) was sent to a PC via a serial cable and thanks to ParticleTrack™ software that was supplied with the instrument, it was possible to record continuously.

2.2 *Sawmills examined*

The first sawmill examined in this study contains two production lines. The first one, called line A, starts with de-barking and is used for processing conifers (silver fir and corsican pine). The second, called line B, processes beech and chestnut. The building in which the two production lines of the sawmill are housed is completely closed, while de-barking is carried out at the building near the round wood log yard. Six members of staff work continuously with the same machinery (8 hours per day) while another operator alternates between the de-barker (4 hours per day) and the pit saw (4 hours per day). The mill has a working surface of about 450 m^2 and an annual timber production of about 1.400 m^3. The dust extraction system flows through sheet steel pipes and outside into a general duct that ends inside a number of collection sacks. These sacks are then changed when full.

In the second mill, the second wood processing was carried out. The building is located in a single room with an active area of 280 m^2. It produces chairs, stools and other wooden goods. Three employees work continuously with the same machines (8 hours per day) while two operators alternate evenly between the tenoning machine and the mortising machine (operator B2) and the toupie and the planer machine (operator B4). The production cycle transforms saw logs of beech, chestnut and walnut purchased at the sawmill into finished ones. The firm has localized dust extraction devices which converge into a general duct, terminating in an external silo.

Finally, the third mill makes kitchen modules. The productive process begins with a series of longitudinal and transverse cuts of the wood particle panels. The complete final assembly is obtained from these components. The processing plant is equipped with vacuum systems located at each machine with a single pipeline which transports the particles that are sucked into a storage room outside the plant itself. The engine room has an area of approximately 400 m^2 and has a work force of 5 employees.

Four of the five operators work standing up, using the same machines all day, while a single operator splits his shift evenly between two machines (a panel sizing saw and a boring machine).

At the end of the day a questionnaire is completed by each worker providing information on the type of machine operated, type of wood used, use of personal protective equipment, general ventilation, and cleaning methods.

3. Results and Discussion

3.1 *Dust emission*

The results of the concentration measures of wood dust that can be inhaled and respired in each working activity are shown in tables 2, 3 and 4. In the tables the average number of particles monitored during the research are conveyed; they are assembled in accordance with the three class sizes (UT.P.- T.P.- B.P.), followed by standard deviation values. The concentration values

Work place	Concentration					Operator				
	Standard method		Number of Particles			A1	A2-A3	A4-A5	A6	A7
	mg/m³		n° · 10⁶/m³ (ds)			Time of permanence in the work place (hours)				
	I.F	R.F.	UT.P.	T.P.	B.P.					
Debarker	2.1 0.15	0.5 0.06	170 (±21)	18 (±6)	8 (±0,5)	4,00				
Head band saw	1.9 0.11	0.4 0.03	135 (±16)	13 (±5)	4 (±0,3)		8,00			
Trimmer	1.8 0.13	0.4 0.05	117 (12)	10 (±4)	6 (±0,3)			8,00		
Edger	1.3 0.11	0.3 0.04	125 (±14)	12 (±5)	9 (±0,1)				8,00	
Multiblade saw	2.8 0.18	0.7 0.06	232 (±16)	33 (±3)	22 (±1,1)					8,00
Pit saw	1.3 0.09	0.3 0.05	90 (±10)	12 (±5)	4 (±0,4)	4,00				

TABLE 2 - Concentration and distribution of wood dust in the first sawmill, factory A.

Work place	Concentration					Operator				
	Standard method		Number of Particles			B1	B2	B4	B4	B5
	mg/m³		n° · 10⁶/m³ (ds)			Time of permanence in the work place (hours)				
	I.F.	R.F.	UT.P.	T.P.	B.P.					
Band saw	2.4 0.16	0.5 0.05	119 (±15)	10 (±8)	6 (±0,5)	8,00				
Toupie	2.6 0.17	0.6 0.05	140 (±14)	16 (±6)	9 (±0,4)				4,00	
Planer	2.5 0.14	0.5 0.02	300 (±11)	13 (±5)	8 (±0,5)				4,00	
Sander I	4.2 0.21	1.2 0.05	457 (±12)	23 (±3)	11 (±0,5)			8,00		
Tenoning machine	1.4 0.15	0.3 0.06	285 (±15)	15 (±7)	7 (±0,4)		4,00			
Mortising machine	1.5 0.14	0.3 0.04	173 (±16)	18 (±8)	10 (±0,9)		4,00			
Sander II	4.8 0.19	1.0 0.05	497 (±18)	38 (±9)	18 (±0,5)					8,00

TABLE 3 - Concentration and distribution of wood dust in the second sawmill, factory B.

Work place	Concentration					Operator		
	Standard method		Number of particles			C1-C2	C3-C4	C5
	mg/m³		n° · 10⁶/m³ (ds)			Time of permanence in the work place (hours)		
	I.F.	R.F.	UT.P.	T.P.	B.P.			
Cut-to-size saw I	5.1 0.23	1.0 0.04	130 (±20)	18 (±9)	4 (±0,5)	8,00		
Cut-to-size saw II	3.0 0.19	0.6 0.02	126 (±18)	15 (±8)	4 (±0,7)		8,00	
Panel sizing saw	2.4 0.15	0.5 0.05	120 (±17)	10 (±6)	3 (±0,8)			4,00
Boring machine	3.3 0.16	0.7 0.06	176 (±10)	16 (±2)	4 (±0,4)			4,00

TABLE 4 - Concentration and distribution of wood dust in furniture factory C.

represent the operators' level of exposure during the eight working hours, as required by law 66/2000. The sample distribution shows that in some work places, the exposure to hard wood dust exceeds the limit value (fraction which can be inhaled $\leq$ 5.00 mg/m^3). In the second factory, all workers were considered to be potentially exposed due to the duties that they both directly and indirectly performed. They operate in a single work environment that does not absorb the processed flows of wood in a suitable manner.

In almost all studies, the concentration of the respirable fraction is lower than 1 mg/m^3. On the one hand these values can be considered low but on the other hand the fraction that can be inhaled is high regarding some work processes [Mandryk 2000; Innocenti 2008]. In fact, the percentage of the respirable fraction varies between 15 and 20%; the danger of these high values is confirmed by many studies carried out on this subject [Hounam 1974; Whitehead 1981, McCammon 1985, Pisaniello 1999].

3.2 *Particle size analysis*

The results obtained from the differential sampling show a higher concentration of ultra-thin dust. These are particles smaller than 1 µm and they make up 88% of the total particles dispersed in the air (Fig. 2). The distribution of the numerous diameter classes is diversified. It follows the typical trend of the conventional curve of total particles dispersed in the air [UNI EN 481/1993]. Figure 3 shows the trends of the concentrations (n°/m^3) in the three productive processes.

For each cycle, the data linked to the machines with a higher dust production were analyzed very carefully: a multi-blade saw for cutting, an orbital sander for the carpenter's factory and a boring machine for the furniture factory. The peaks in each curve show that the highest concentrations of dust are produced during the cutting operations; the distance between two peak values depends on the cutting speed. In particular, the figures show that in the curve trend of the multi-blade saw there is a bigger difference between the highest and the lowest peak values when compared to those of the two other operating machines. This is due to the fact that the feed of these machines is manual and when boards are moved for cutting, feed time is further reduced. The wood dust produced by a multi-blade saw has more time to disperse into the air before new dust is then produced again by following cuts to the boards. The boring machine, however, has an automatic feed which is much quicker. For this reason, there is less difference between the highest and the lowest concentration values. The production of ultrathin dust during the sanding process exceeds the values of the other operations studied. This is due not only to the type and precision of the cut but also to the speed upon which the tool produces dust dispersion. This dust is not sufficiently caught by the dust extraction system. The temporal trend of thin dust (Fig. 3) is similar to that of ultra-thin dust. When comparing this data to the results of other studies conducted in similar working factories many important similarities on the size distribution of wood dust can be highlighted [Belosi 2007; Proto 2009]. It is therefore, possible to

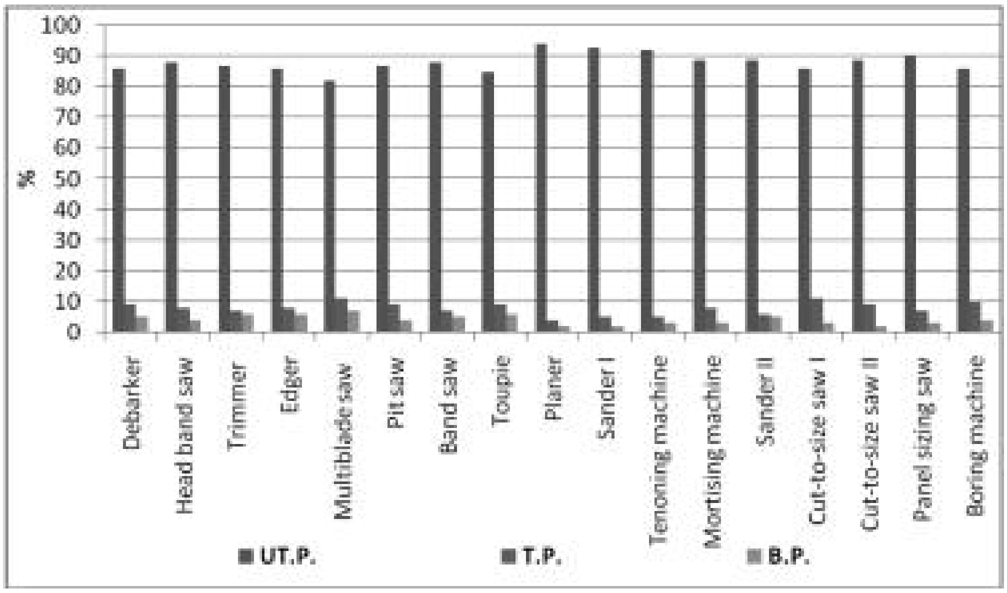

Fig. 2 - Distribution (%) of dust in the different work places

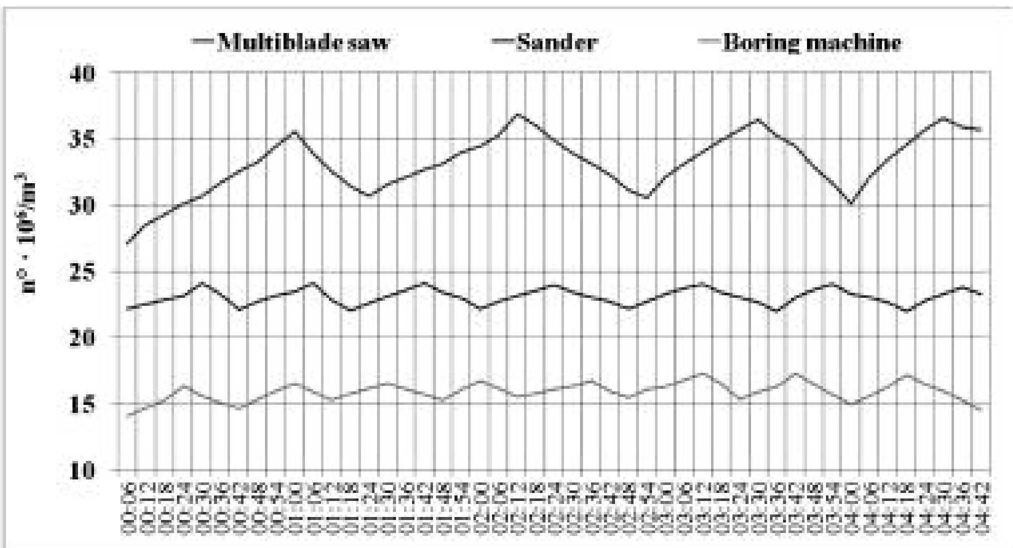

Fig. 3 - Temporal trend – Thin Dust

assert that the various trends of distribution curves, plotted in each graphic, depend upon several important parameters: the type of machine, speed of cut and feed, type of tools used for cutting (number of blade, depth and precision of cut), and the size of the semi-manufactured products. All these factors exert a powerful influence on the different class sizes and on the concentrations of wood dust produced during the process of woodwork. This knowledge of the temporal trend of dust should encourage workers to take suitable measures of protection and in addition, a review of the factory floor layout should be undertaken, distancing the machines that produce the most dust.

3.3 *Impact on operators*

The detailed study on airborne dust particles confirms the high concentration of wood dust which can be very harmful to humans.

Considering the dimensions of particulate matter, its distribution in the working environment and the data reported by IARC [1995], we can assert that the level of penetration inside the human organism of this class size varies between the larynx and bronchi. Moreover, considering the time spent in different work phases by the operators listed in the right columns of Tables 1, 2 and 3, it is noted that some operators are exposed to critical levels and sometimes higher than legal limits. It is necessary to take into consideration the evaluation of the level of risk therefore, not on the basis of the performance of individual locations but based on a thorough knowledge of work processes and actual exposure of individual operators.

4. Conclusions

The experimental results obtained throughout this study have allowed an assessment of the temporal trend of the number of particles through the productive processes, the single work phases and the organization of work and work duties. Thanks to a dimensional classification, the particle counter highlighted important differences in the size of wood dust (qualitative information), obtaining several results that were consistent with traditional measures.

This study technique, if conducted in a comprehensive manner, may be used for filing and classification. Taking into consideration the distribution of the dust produced, the different types of wood and its numerous transformation processes would result in an exhaustive outline of elements which can be contained in specific technical files. These findings, based upon the different size fractions of wood dust, establish a real correlation between the dust produced during processing and the health of the operators. Prevention, however, remains the primary form of intervention and the possibility of confinement of the machines is one of the most effective means of protection.

Effective ventilation methods should be guaranteed at all woodworking machines and the ventilation (general or local) should always be balanced with intervals of fresh air. Machines and equipment should not be cleaned by compressed air but by a vacuum and pieces of work should eventually be cleaned using a brush. Operations which produce dust should be done in separate places in order to limit the number of people exposed. The diffusion of wood dust can be properly controlled using effective ventilation systems, regulated in accordance to the different processing methods, the levels of dust produced and the dimension of wood dust.

Taking into consideration the results obtained during this study it seems evident that research and personnel training efforts are essential to improve the safety conditions within wood processing businesses.

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Summary

In Italy, the woodworking industry presents many issues in terms of occupational health and safety. This study on exposure to wood dust could contribute to the realization of a prevention model in order to limit exposure to carcinogenic agents to the worker. The sampling methodology illustrated the analysis of dust emissions from the woodworking machinery in operation throughout the various processing cycles. The quantitative and qualitative assessment of exposure was performed using two different methodologies. The levels of wood dust were determined according to EN indications and sampling was conducted using IOM and Cyclon personal samplers. The qualitative research of wood dust was performed using an advanced laser air particle counter. This allowed the number of particles present to be counted in real time. The results obtained allowed for an accurate assessment of the quality of the dust emitted inside the workplace during the various processing phases. The study highlighted the distribution of air particles within the different size classes, the exact number of both thin and ultra-thin dusts, and confirmed the high concentration of thin dust particles which can be very harmful to humans.

Keywords: Wood dust, occupational exposure, particle size distribution.