CONCENTRATION AND SIZE OF AIRBORNE PARTICLES IN MANUFACTURING ENVIRONMENTS[1]

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ABSTRACT – In furniture factories, the cutting of medium density fiberboard (MDF) generates high concentrations of particulates suspended in the air, which, depending on their dimensions, can reach the sensitive areas of the respiratory tract of workers. The aim of this study was to test a method to measure particle sizes derived from the cutting of wood paneling. The experiment was conducted in two small furniture factories located in the municipality of Lavras, Minas Gerais state, Brazil. During the cutting of MDF, airborne particles were collected and measured by means of optical microscopy. The data obtained showed a critical condition in the work environments, with high concentrations of small particles (<10 microns), which could be lodged in the workers' lungs. The particle measuring process proved to be accurate and easy to perform. In addition, it is worth noting the importance of investment in personal protective equipment (PPE) such as hoods and/ or PFF2 dust masks for the protection of workers.

Keywords: Work Safety; Occupational Hygiene; Furniture Factories.

CONCENTRAÇÃO E DIMENSÕES DE PARTICULADOS SUSPENSOS NO AR DE AMBIENTES FABRIS

RESUMO – Em fábricas de móveis, o corte de painéis de fibras de média densidade (MDF) gera altas concentrações de particulados suspensos no ar, que dependendo de suas dimensões podem atingir áreas sensíveis do aparelho respiratório dos trabalhadores. O objetivo desse trabalho foi testar um método para medir dimensões de partículas oriundas do corte de painéis de madeira. O experimento foi desenvolvido em duas fábricas de móveis, de pequeno porte, em Lavras/MG. Durante o corte de painéis MDF foram coletadas e medidas partículas suspensas no ar, por meio de microscopia óptica. Os dados obtidos mostraram uma condição crítica no ambiente de trabalho, com elevadas concentrações de partículas pequenas (< 10 μm), que podem se alojar nos pulmões dos trabalhadores. O processo de medição das partículas demonstrou-se preciso e de fácil execução. Também, observou a importância de investimentos em exaustores (EPC) e, ou respirador tipo PFF2 (EPI), para a proteção dos trabalhadores.

Palavras-Chave: Segurança do Trabalho; Higiene Ocupacional; Fábricas de Móveis.

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1. INTRODUCTION

Currently, most wood furniture factories have no control over the emission of wood particles suspended in air. Locations with high concentrations of these agents generate discomfort and can cause dermatitis, irritation, respiratory allergies and obstructions, asthma, cardiovascular conditions, and cancer (American Conference of Governmental Industrial Hygienists, 2008; Jesus et al., 2012; Oliveira et al., 2014; Saliba, 2013).

During the processing of wood, carpenters and sawmill workers are exposed to different risk agents, such as dust, fibers, particle wastes containing adhesives, and high levels of monoterpenes (Edman et al., 2003; Hagstrom et al., 2008; Nunes and Moreschi, 2009a; Svedberg et al., 2004). Workers in industries of agglomerate material, for instance, are also exposed to chemical risks, such as resin acids, which cause absenteeism, chronic health effects, and various respiratory problems (Gomes-Yepes and Cremades, 2010; Hagström et al., 2008; Keira et al., 1997; Sadhra et al., 1994).

The efficiency with which inhaled particles are deposited in the human respiratory tract depends on their size, shape, density, and hygroscopicity. Particles small enough to be suspended in air can be inhaled through the nose or mouth, and the probability of inhaling them depends on their size, the movement of air around the respiratory tract, and the respiration rate of individuals (Santos, 2005).

The path of particles in the different regions of the respiratory tract and the places they are likely to be lodged are dependent on their size, airway dimensions, and respiratory pattern. Particles deposited in the upper airways or lungs have the potential to cause various health damages (Santos, 2005).

Considering the great interest of occupational hygiene in the classification of airborne particulate dimensions, field studies have become increasingly relevant, because particle size may be associated with the site of deposition in the respiratory tract and damage to health.

In this context, the objective of this study was to test a method to measure particle size by means of optical microscopy based on the concentration of airborne dust resulting from the cutting of medium density fiberboard (MDF).

2. MATERIAL AND METHODS

The experiment was conducted in the medium density fiberboard (MDF) cutting sector of two wood furniture factories, labeled 1 and 2, located in the municipality of Lavras, Minas Gerais state, Brazil.

The procedures defined by the Occupational Hygiene Standards NHO 03 (Fundação Jorge Duprat e Figueiredo, 2001) and NHO 08 (Fundação Jorge Duprat e Figueiredo, 2009) were followed for collection of suspended dust, Test Method for Gravimetric Analysis of Solid Aerodispersoids on Membrane Filters and Technical Procedure for Collecting Solid Particle Material Suspended in Air from Working Environments, respectively. In order to complement this type of evaluation, technical parameters defined by the National Institute for Occupational Safety and Health - NIOSH were used according to the Manual of Analytical Methods no. 0500 - Particulates Not Otherwise Regulated, Total (National Institute for Occupational Safety and Health, 1994).

Optical methodology was used to assess the dimensions of the collected particles. The particulate matter retained on the PVC membrane filters was collected and deposited on glass slides. A drop of glycerin was added to the slides, which were covered with coverslips and analyzed under an optical microscope coupled to the Wincel-Pro-Plus image analysis system. The magnification used in all measurements was 400X.

Particle-size analysis was performed considering a completely randomized design with two treatments (with and without exhaustion). The number of repetitions was four and three for systems with and without exhaustion, respectively. The systems with and without exhaustion for factories 1 and 2 were compared using the Kruskal-Wallis non-parametric test with subsequent application of the Student's t-test at 5% significance level. Four replicates were used for factory 1 (system with exhaustion), whereas seven replicates were used for factory 2 (system without exhaustion). The factories were also compared considering only the system without exhaustion, with three and seven repetitions, respectively. The Kruskal-Wallis test followed by the Student's t-test were applied at 5% significance level.

3. RESULTS

The minimum, mean and maximum values of the airborne dust particles according to concentration level, as well as the standard deviations and coefficients of variation, collected at factory 1 during the cutting of medium density fiberboard (MDF), with and without exhaustion, using circular saw are presented in Table 1.

Table 2 shows the minimum, mean and maximum values of the airborne dust particles according to concentration level, as well as the standard deviations and coefficients of variation collected at factory 2 during the cutting of MDFusing sectioning machine.

The overall respirable, thoracic, inhalable and non-inhalable particulate matter of airborne dust during MDF cutting at factories 1 and 2 are shown in Table 3.

Figure 1 shows the multiple comparisons of the mean dimensions of the airborne particles collected at factory 1 with and without exhaust system.

The comparison between the concentration and dimensions of the airborne particles collected at factories 1 (circular saw) and 2 (sectioning machine) with exhaust system is presented in Figure 2.

4. DISCUSSION

At factory 1, no increasing or decreasing trend between the concentration and the particle size of airborne dust (Table 1) was observed, and great variation in particle size due to the high coefficients of variation was found. It is worth mentioning that variation in concentration is high in wood processing environments, which according to Oliveira et al. (2014), can reach up to six times the threshold limit defined by the American Conference of Governmental Industrial Hygienists (2017), and more than 130 times that in places without exhaustion, according to the results of Teixeira et al. (2017).

At factory 2,no increasing or decreasing trend between the concentration and the size of airborne dust particles (Table 2) was also observed, and great variation in particle size due to the high coefficients of variation was also found. Thus, cutting performed in sectioning machines did not change the quality of particles compared with that from circular saws. However, presence of smaller particles was observed, which increases the risk of lung diseases according to the study by Jesus et al. (2012), which demonstrates that finer particles, generally <10 μm, penetrate more deeply in the respiratory system, and are of greater risk to workers'health.

In general, the mean concentrations obtained atfactories1 and 2 were higher than those reported by Nunes and Moreschi (2009a) and Oliveira et al. (2014), who found variation from 2.0 to 16.0 mg.m^{-3}. The same was observed for the dimensions, whose means ranged from 11 to 55 μm, differing from the values obtained by Nunes and Moreschi (2009b) for agglomerate particles, with means between 3.5 and 6.5 μm, possibly because of variations in processing, machinery, and processed material.

In the analyzed factories, presence of particulate matter harmful to humans was observed even in small concentrations, below the threshold limit values established by the American Conference of Governmental Industrial Hygienists (2017), corresponding to the range of respirable particulates (Table 3).This finding is consistent with the observations of Nunes and Moreschi (2009a), who

Table 1 – Minimum, mean and maximum values, standard deviation of the mean, and coefficient of variation of the dust particles suspended in the air at factory 1, with and without exhaustion system.
Tabela 1 – *Valores mínimos, médios, máximos, desvio padrão da media, e coeficiente de variação das partículas de poeiras suspensas no ar, por nível de concentração na empresa 1, com e sem exaustão.*

Parameters	Dimensions of dust particles (ìm)						
	Samples withexhaustion			Samples without exhaustion			
	1	2	3	4	5	6	7
Concentration(mg.m^{-3})	15.24	33.95	43.65	48.90	40.65	66.69	68.59
Minimum	12.60	1.74	6.79	5.43	1.83	4.86	3.88
Mean	54.97	17.33	36.51	41.12	14.20	37.41	34.15
Maximum	237.31	187.38	137.78	195.94	64.50	158.52	160.86
Standard deviation of the mean (μm)	45.69	27.96	21.47	37.06	12.92	29.08	24.96
Coefficient of variation (%)	120	62	170	111	110	129	137

Table 2 – Minimum, mean and maximum values, standard deviation of the mean, and coefficient of variation of the dust particles suspended in the air at factory 2 with exhaustion system.
Tabela 2 – *Valores mínimos, médios, máximos, desvio padrão da média, e coeficiente de variação das partículas de poeiras suspensas no ar, por nível de concentração na empresa 2, com exaustão.*

Parameters	Dimensions of dust particles (ìm) Samples with exhaustion						
	1	2	3	4	5	6	7
Concentration ($mg.m^{-3}$)	0.00	1.72	1.77	1.77	2.66	3.55	8.87
Minimum	1.84	3.76	2.05	3.49	2.33	4.68	2.68
Mean	12.13	17.46	12.12	11.46	20.60	18.28	17.07
Maximum	38.52	49.65	62.36	28.40	40.77	70.78	49.25
Standard deviation of the mean (ìm)	9.63	10.62	11.83	7.01	9.90	11.96	11.20
Coefficient of variation (%)	126	164	102	163	208	153	152

Table 3 – Maximum and minimum values of the size of respirable, thoracic, inhalable and non-inhalable particulate matter of airborne dust during MDF cutting in factories 1 and 2.
Tabela 3 – *Valores das dimensões mínimas e máximas das partículas respirável, torácica, inalável e não inalável das poeiras suspensas no ar durante o corte do MDF nas empresas 1 e 2.*

Types and sizesof particles	Factory 1*		Factory 2**
	Withexhaustion	Without exhaustion	
Respirable <10 µm	1.74 to 9.86	1.83 to 9.92	1.84 to 9.89
Thoracic <25 µm	10.24 to 24.89	10.17 to 24.95	10.19 to 24.99
Inhalable <100 µm	25.06 to 96.85	25.00 to 99.84	25.01 to 70.78
Non-inhalable >100 µm	110.80 to 237.31	117.77 to 160.86	-

Circular saw; ** Sectioning machine with exhaustion.

consider potential occupational risk for workers exposed to respirable particulate from wood panels.

In addition, a large distribution of particle size was observed regardless of particle concentrations in the environment. These facts corroborate the findings by several authors such as Harper et al. (2004), Hinds (1988), Pisaniello et al. (1991), Tatum et al. (2001), Verma et al. (2007), and Whitehead et al. (1981), who reported that particles <10 µm are present even at small concentrations of airborne particulates. It is important to note that the smaller the particles, the greater the discomfort, insecurity, and the possibility of reaching the bronchi, putting workers at greater risk of respiratory diseases.

Fiedler et al. (2010), in a study on the work environment of carpenters using solid wood and medium density fiberboard (MDF), found that more than 60% of the workers considered the presence of excessive dust and 15% of them felt uncomfortable with dust because it causes respiratory problems.

According to Oliveira et al. (2014), particles <10 ìm remain suspended in the air even in environments with exhaust systems. Thus, they can be inhaled by workers and reduce the respiration rate, according to Mohan et al. (2013). However, the presence of an exhaust system enables improvement of comfort, safety, and cleanliness in the workplace.

Figure 1 shows that there was no statistically significant difference, by the F test at 5% significance level, between the mean dimensions of the airborne particles in environments with and without exhaustion system. This fact, once again, confirms that, regardless of concentration level, there is a wide distribution of particle size, which is evidenced by the high standard deviation values found in the different collections.

Figure 2 shows that there was statistically significant difference, by the Student's *t*-test at 5% significance level, between the mean dimensions of the airborne particles with exhaustion system at factories 1 and 2.

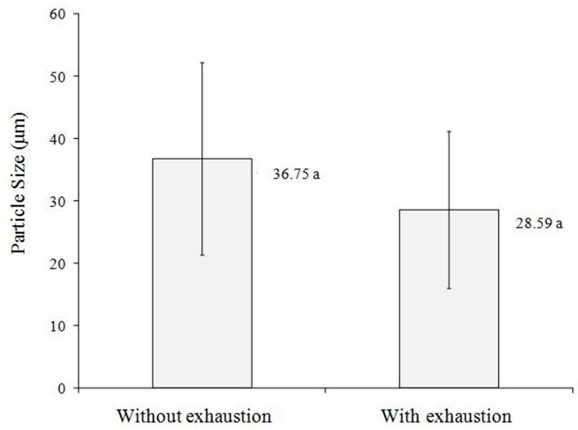

Figure 1 – Multiple comparisons of mean dimensions of the airborne particles, with and without exhaustion system, at factory 1. Means followed by the same letter do not significantly differ at 5% significance level by the F-test.
Figura 1 – *Comparação múltipla das médias das concentrações de particulados suspenso no ar, com e sem sistema de exaustão, na empresa 1. Médias seguidas pela mesma letra não diferem entre si a 5% pelo teste F.*

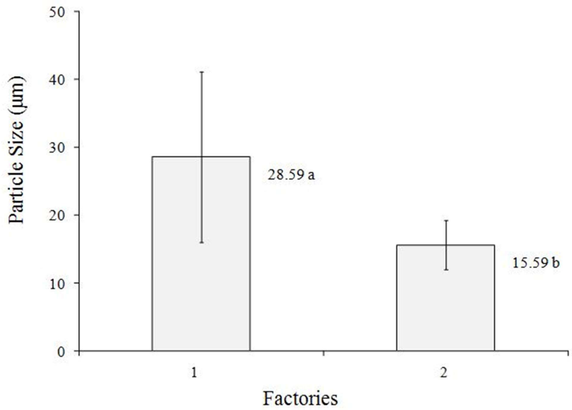

Figure 2 – Multiple comparisons of the mean dimensions of the airborne particles, with exhaustion system, at factories 1 and 2. Means followed by the same letter do not significantly differ at 5% significance level by the Student's *t*-test.
Figura 2 – *Comparação múltipla das médias das dimensões de particulados suspenso no ar, com sistema de exaustão, nas empresas 1 e 2. Médias seguidas pela mesma letra não diferem entre si a 5% pelo teste t-Student.*

The most likely explanation is that sectioning machines have exhaust systems better sized for their respective characteristics. Therefore, in this type of processing, the particle suction system removes the larger particles from the environment. However, smaller particles are easier to be dispersed in air, hindering their removal by suction. This fact can be verified in the reduced standard deviation values of the means of the particle dimensions observed in the different factories. It can be observed that, at factory 2, the standard deviation of the mean was reduced by 70%, compared with that of factory1.

The presence of particles <10 µm in these environments shows the need to establish special occupational care regulations. Even in the presence of exhaust systems, Brasil (1978), Mohan et al. (2013), and Nunes and Moreschi (2009b) reinforce the need for continuous monitoring, periodic medical examinations, eye protection, and the use of appropriate respirators with filters to protect against fine particles, fumes, and toxic mists (PFF2).

The particles sampled were sections of wood fibers of varying shapes- from long sections of wood fiber adhered to residues, probably from the adhesive used in the manufacturing of MDF panels, to rounded particulates with adhesive and crystals present on the MDF, corroborating the observations by Nunes and Moreschi (2009a). In future works, the use of special dyes applied to the residues can facilitate the identification and even the composition of particles.

5. CONCLUSION

Based on the results presented in this study, we conclude that the distribution of particles suspended in air showed a widely variable profile regardless of the concentrations present in the manufacturing environments; the process of measuring the particles by means of optical microscopy has proved to be precise as a function of the values obtained; the quality of the air in these factories during the cutting of MDF may represent a health risk to workers; even when exhaust systems are used, suitable masks or respirators with filters, both intended to protect against fine particles, smoke, and toxic mists (PFF2), must be worn by workers.

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