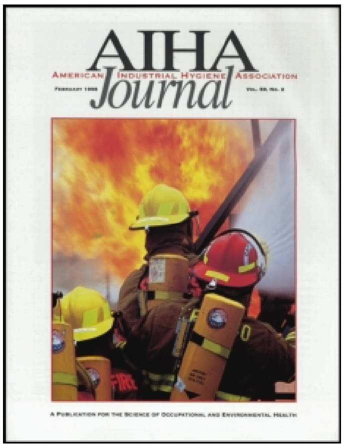

American Industrial Hygiene Association Journal
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713608243

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Jeffrey M. Stumpf [a]; Kenneth D. Blehm [b]; Roy M. Buchan [b]; Bobby J. Gunter [c]
[a] Hewlett Packard, Rancho Bernardo, CA. [b] Department of Microbiology and Environmental Health, Colorado State University, Fort Collins, CO 80523. [c] NIOSH, Region VIII, Denver, CO 80297.

To cite this Article Stumpf, Jeffrey M., Blehm, Kenneth D., Buchan, Roy M. and Gunter, Bobby J.(1986) 'Characterization of Particleboard Aerosol — Size Distribution and Formaldehyde Content', American Industrial Hygiene Association Journal, 47: 12, 725 — 730

To link to this Article: DOI: 10.1080/15298668691390575

URL: http://dx.doi.org/10.1080/15298668691390575

Am. Ind. Hyg. Assoc. J. 47(12):725-730 (1986)

Characterization of Particleboard Aerosol — Size Distribution and Formaldehyde Content

JEFFREY M. STUMPF[A], KENNETH D. BLEHM[B], ROY M. BUCHAN[B] and BOBBY J. GUNTER[C]
[A]Hewlett Packard, Rancho Bernardo, CA; [B]Department of Microbiology and Environmental Health, Colorado State University, Fort Collins, CO 80523; [C]NIOSH, Region VIII, Denver, CO 80297

Health hazards unique to particleboard include the generation of urea-formaldehyde resin bound in wood aerosol and release of formaldehyde gas that can be inhaled by the worker. A particleboard aerosol was generated by a sanding process and collected under laboratory conditions that determined the particle size distribution and formaldehyde content. Three side-by-side Marple 296 personal cascade impactors with midget impingers attached downstream collected particleboard aerosol and gaseous formaldehyde for ten sample runs. Gravimetric analysis quantified the collected aerosol mass, and chromotropic acid/spectrophotometric analytical methods were employed for formaldehyde content in particleboard aerosol and gaseous formaldehyde liberated from sanded particleboard. Significant variations ($p<.005$) were observed for the particleboard mass and gaseous formaldehyde collected between sample runs. No significant differences ($\alpha = .05$) were observed for the aerosol size distribution determined and formaldehyde content in particleboard aerosol per unit mass for sampling trials. The overall MMAD of particleboard aerosol was 8.26 μmAED with a σg of 2.01. A predictive model was derived for determining the expected formaldehyde content (μg) by particleboard aerosol mass (mg) collected and particulate size (μmAED).

Introduction

The major constituents of medium density particleboard, coniferous wood species, and urea-formaldehyde resin have been identified as potential health hazards in the work environment. Combined as particleboard, however, wood dust and formaldehyde have been overlooked in epidemiological studies.[1,2] Wood dust and formaldehyde share the ability to cause respiratory irritation with symptoms of dryness in the throat, eye irritation and rhinitis.[3,4] The strong epidemiological association of wood dust, combined with the suspected potential of formaldehyde to cause nasal cancers, illustrates a need to research particleboard.[3,4] Both wood dust and formaldehyde have a demonstrated ability to decrease mucociliary clearance in the nasal area.[5,6] This provides not only prolonged contact of wood particles in the nasal turbinates, but it also may allow hydrolyzed release of formaldehyde, providing additional physiological insult. The purpose of this research was to characterize particleboard aerosol by size distribution and formaldehyde content under laboratory conditions for preliminary assessment as to the potential health effects. Utilization of the cascade impactor as a collection device allowed direct comparison of size distribution to the fractional deposition of particulate matter in the respiratory tract.[7] Analysis of formaldehyde content in the collected particleboard aerosol determined the potential additional health hazard where the wood particles may act as carriers for formaldehyde.

Particleboard is an inexpensive building material used extensively for the manufacture of furniture and cabinets and construction of conventional, prefabricated and mobile homes.[8] Like wood, particleboard can be sized or shaped by a variety of manual or mechanical equipment. It has been reported that sawing generates the largest particulate matter, 11.5 μm mass median aerodynamic diameter (MMAD), and sanding the finest dust, 8.5 μm MMAD, with various woods;[9] however, particleboard is not solid wood, but a collection of chips, flakes, shavings and granules of various woods bound with urea-formaldehyde resin. The generation of particleboard aerosol may or may not follow the size distribution patterns of wood.

Typically, the quality of particleboard is such that surface sanding normally is not required. For cabinetmaking operations using particleboard, sanding is utilized for shaping, cutting and applying finished edges.[10] For the characterization of particleboard aerosol in this research, the design consisted of sanding the edges of particleboard and included factors such as the type of particleboard, belt sander, and grit characteristics of the abrasive belt commonly used in cabinetmaking operations.

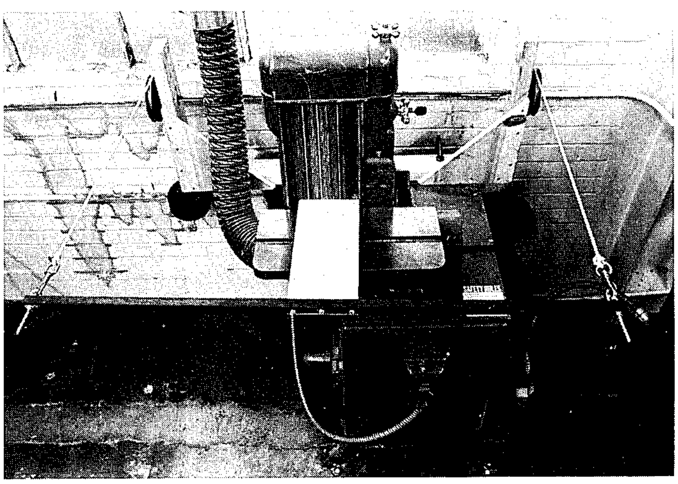

Figure 1 — Particleboard sanding assembly.

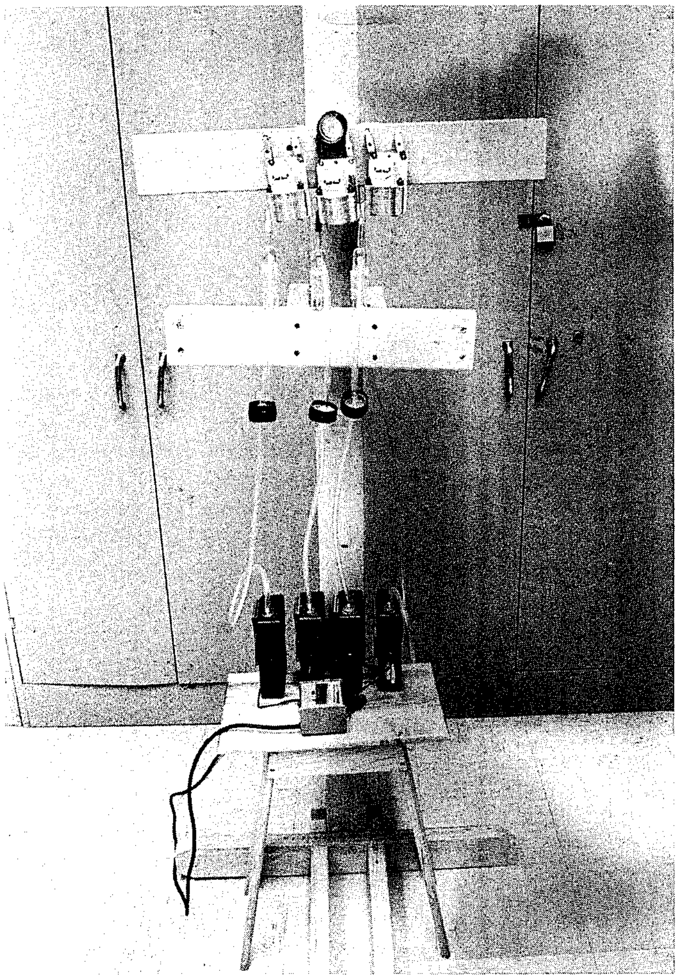

Figure 2 — Particleboard aerosol sampling stand.

Methods

This research project used a Delta Rockwell Model 66-044 stationary vertical belt sander. The abrasive belt selected for this study was a 3-M® aluminum oxide, open-faced, 80 grit, with dimensions of 6 in. by 48 in. circumference. Weyerhaeuser Company medium density urea-formaldehyde industrial grade particleboard with dimensions of 4 by 8 ft with 3/4 in. thickness was cut into 5 in. by 12 in. long slabs to fit the particleboard for automated edge sanding. To generate a consistent particleboard aerosol, a gravity-weighted pulley apparatus was constructed and attached to the vertical belt sander, as shown in Figure 1. This provided consistent applied force of the particleboard slab to the operating face of the vertical belt sander. The local exhaust ventilation system attached to the vertical belt sander was not used when generating the aerosol to prevent potential bias of collecting the larger sized particles. The mass applied to the particleboard slab (13.8 pounds) was preselected and intended as a means for generation of a consistent particleboard aerosol that allowed sample collection for analysis of particleboard size distribution and formaldehyde content and not as a model for determination of the potential total dust encountered in industrial settings.

For collecting the particleboard aerosol, the Marple 296 six-stage personal cascade impactor was used. Substrates for collecting the impacted dust were Sierra 34 mm diameter C-290-MY mylar filters for the cascade impactor stages, and Sierra 34 mm 5.0 μm pore size polyvinyl chloride (PVC) filters for the back-up stage. These filters were utilized because it was determined from preliminary trials that less than 1% weight change from ambient humidity conditions would be realized, thus eliminating the need to desiccate the filters for pre- and post-weighing procedures. This also prevented potential formaldehyde loss that may occur from desiccation of the collected particleboard aerosol. Each mylar filter was placed in a template supplied with the Marple 296 cascade impactor and sprayed with silicon grease to reduce particle bounce and reintrainment of particles on impactor stages during particulate collection.

The National Institute for Occupational Safety and Health (NIOSH) recommended sampling method for collecting gaseous formaldehyde was employed. The tip of the impinger inlet was attached immediately downstream with the tip of the cascade impactor outlet with tygon tubing. This was to prevent polymerization of gaseous formaldehyde on the inside surface of the tubing with any greater distance allowed between impinger inlet and cascade impactor outlet. Total particleboard aerosol was collected separately with the use of a 37 mm 5.0 μm pore size PVC filter assembled in a three-stage, closed filter cassette. This was for comparison of total dust collected from the cascade impactor *vs.* the commonly employed method for collecting wood dust.

Three side-by-side cascade impactor/impinger samples and one closed-face filter cassette were assembled on a 2 in. by 4 in. pine stand, shown in Figure 2. This stand simulated the location of cascade impactors/impingers and filter cassette in the breathing zone of a 5 ft, 10 in. worker at the worker's normal distance from the vertical belt sander. Dupont P-2500 constant high-flow pumps were utilized for each cascade impactor/impinger assembly and filter cassette, and operated on charger to insure constant flow rate to sampling trains. The flow rate for the filter cassette was set at 2.0 Lpm and three cascade impactor/impinger assemblies at 1.0 Lpm. The 1.0 Lpm flow rate was selected to allow downstream collection of gaseous formaldehyde that followed NIOSH guidelines, and to reduce particle bounce and reintrainment of particles at each cut size collected by the cascade impactors.

The reduced flow rate to cascade impactors from the recommended 2.0 Lpm in the Marple 296 instruction manual[11] to 1.0 Lpm used in this research increased the cut sizes for each stage. The cut sizes in Aerodynamic Equivalent Diameter (AED) for the cascade impactor at a flow rate of 1.0 Lpm were derived from the following equation supplied by the manufacturer and are shown in Table 1.

$$D_p = \sqrt{St}\ W\sqrt{\frac{9nL}{CP_pQ}}$$

St = Stokes number (for this device, $\sqrt{St} = 0.72$)

W = slot width, cm

L = slot length, cm

n = gas viscosity, gm/cm-sec

C = Cunningham slip correction, unitless

Q = volumetric flow rate in the impactor stage, cc/sec

Ten identical particleboard sanding runs were conducted for two 5-day consecutive periods, at a sampling duration of 30 min. To insure consistent results and minimize the occurrence of aerosol reintrainment for each subsequent sample run, the inside and outside surfaces of the vertical belt sander were vacuumed free of accumulated particulate matter immediately before each sample run, and a new abrasive belt was installed.

A Mettler semi-microbalance was employed for gravimetric analysis of the mass collected per stage from the cascade impactors and closed-face filter cassettes. Based upon previous studies,[12] the particulate matter generated from the abrasive belt during sanding was considered insignificant. Gaseous formaldehyde concentrations were determined with the NIOSH (P&CAM 125)[13] analytical procedure. Formaldehyde content in particleboard aerosol was analyzed with a modified NIOSH (P&CAM 125) analytical method developed by the Weyerhaeuser Analytical Laboratories Research Branch.[14] The modification in this method calls for the desorption of formaldehyde from particleboard aerosol in 1% (wt./vol.) sodium bisulfite solution, centrifuging the residual particles and then obtaining a dilution aliquot for analysis. The remainder of the method then follows the NIOSH (P&CAM 125) procedure for formaldehyde analysis.

Results

Table I summarizes the data collected and analyzed for all ten sampling runs and three background samplings. Comparison of the background sampling results indicated these values did not contribute significantly to the overall results. Therefore, no corrections were made to adjust the data for background contamination prior to statistical analysis.

Crossdraft conditions were minimal during each sampling run for "calm air" aerosol collection. The flowrates of 1.0 Lpm for the three cascade impactors/impingers and 2.0 Lpm for the closed-face filter cassettes supplied by the four Dupont P-2500 constant high flow pumps remained unchanged for all ten sample runs. The total volume of air sampled for the cascade impactors/impingers was 30 L, and for the filter cassettes, the volume of air sampled was 60 L, all at 25°C and 630 to 640 mmHg barometric pressure.

The data from the particleboard aerosol and formaldehyde samples were compiled and entered into the Colorado State University computer system for statistical analysis using the Minitab® computer program. The data recorded for the mass collected on the back-up stages of the cascade impactors were omitted since all weights represented no detectable mass based on the detection (±.02 mg) limit of the semi-microbalance.

Generation of the particleboard aerosol for the ten sample runs demonstrated a statistically significant difference between sample runs for impactor stages three through five, ($p<.005$), for stage six ($.025<p<.05$), and for gaseous formaldehyde

TABLE I
Summary of Particleboard Aerosol and Background Sampling Results

	Marple 296 Stage Cut Size (μmAED)	Total Wt. (Mass)	3 (40.0-14.14)	4 (14.14-8.48)	5 (8.48-4.95)	6 (4.95-2.83)	7 (2.83-1.27)	8 (1.27-.71)	Final (.71-0)	Back-up (0)	Impinger (μg HCHO)
						Particleboard Aerosol					
Sampling Duration	Average mg Dust/ Stage	7.58	2.28	3.37	.70	.44	.26	.08	.05	.015	12.35
30 min	Std. Dev.	4.39	1.39	2.43	.37	.18	.17	.03	.02	.02	5.12
	Average μg HCHO/ Stage	5.20	10.62	18.36	4.31	2.10	.928	.104	.004	n.d.	-
	Std. Dev.	7.82	4.28	10.9	2.71	1.36	.910	.279	.011	n.d.	-
						Background					
Sampling Duration	Average mg Dust/ Stage	.05	.02	.02	.01	n.d.	n.d.	n.d.	n.d.	n.d.	.06
240 min	Std. Dev.	.01	.01	.01	n.d.	.01	n.d.	n.d.	n.d.	n.d.	.02
	Average μg HCHO/ Stage	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
	Std. Dev.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-

Barometric Pressure: 630 to 640 mmHg
Temperature: 25°C

Flowrates: For all Cascade Impactors; 1.0 Lpm
For all Filter Cassettes; 2.0 Lpm

n.d. = not determined.

($p<.005$) liberated from sanded particleboard. The insignificant variation for cascade impactor stage seven (α = .05) between sample runs may be attributed to the small mass collected. The variation between sample runs may be due to the heterogeneous make-up of the sanded particleboard, the differences in the length of particleboard sanded per sample run, and the secondary, unplanned dispersion of accumulated particleboard aerosol from the belt sander. No statistical difference (α = .05) was observed for the mass of particleboard aerosol collected per impactor stage and formaldehyde collected per midget impinger by replicates within sample runs, however.

The distribution of particleboard aerosol collected for all runs was described by a log normal size distribution. Since no significant differences were noted for size distributions derived between runs, a composite distribution for all runs was developed and is shown in Figure 3. The best fitted linear regression equation for the plot was:

$$Y = 2.02 + 3.25X$$

where:

Y = % normal cumulative mass

X = long cut size (μmAED)

The r^2 value of the best fitted linear regression plot was 87.9%. Because particleboard is constructed with different wood species of various size and geometries, the observed variation of the aerosol generated was anticipated.

The formaldehyde content (μg) per mass (mg) of particleboard aerosol collected for all particle sizes was statistically insignificant (α = .05) across all sample runs. Therefore, an expected formaldehyde content in μg could be calculated based on mass of aerosol collected and resulted in a best fitted linear regression equation of:

$$Y = -.0956 + .429X(1) + 1.16X(2)$$

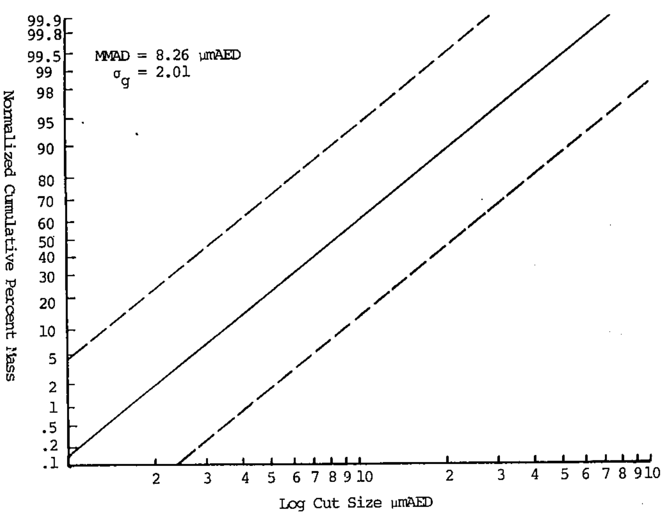

Figure 3 — Cumulative percentage size distribution *vs.* log cut size (μmAED) of particleboard aerosol with 95% confidence limits.

TABLE II
Total Airborne Concentrations of Particleboard Aerosol and Gaseous Formaldehyde Collected by Sampling Run

Run Number	Airborne Formaldehyde Concentration mg/m³	Total Airborne Concentrations of Particleboard Aerosol (mg/m³)	
		Cascade Impactors	Filter Cassettes
1	.187	110	87
2	.311	181	125
3	.568	540	435
4	.326	157	136
5	.444	290	209
6	.300	127	127
7	.783	451	369
8	.480	300	253
9	.340	261	198
10	.318	110	74

Temperature: 25°C Barometric Pressure: 630-640 mmHg

where:

Y = log μg formaldehyde content

X(1) = log cut size (μmAED)

X(2) = log mg particleboard aerosol

The observed variation of the above model (r^2 = 88.8%) for the predicted quantities of formaldehyde may be attributed to the inherent diversity of urea-formaldehyde resin distributed within particleboard based on current manufacturing methods.

Comparison of the average total airborne concentrations of particleboard aerosol collected by the cascade impactors to the total airborne concentration of particleboard aerosol collected by closed-face filter cassettes demonstrated a significant ($p<.001$) difference. This indicated that the cassette sampler may limit the collection of larger particles due to the small inlet diameter and associated high velocity through the orifice. This result was expected, based upon results of previous research with open- *vs.* closed-face filter cassettes.[15] Table II summarizes the uncorrected airborne concentrations in mg/m³ collected with cascade impactors and closed-face filter cassettes including the uncorrected gaseous formaldehyde concentrations in mg/m³.

Discussion

Based upon the International Commission for Radiological Protection (ICRP) Task Group on Lung Dynamics,[16] the fractional deposition in any respiratory tract region can be estimated with MMAD of the aerosol. The particleboard aerosol generated yielded a MMAD of 8.26 μmAED with a geometric standard deviation (σ_g = 2.01) to result in respiratory tract deposition in all three regions (nasopharyngeal, tracheobronchial, alveolar). It was observed that 40% of the aerosol cloud may be available for the deposition into the nasopharyngeal region, and significant proportions of the aerosol cloud (*e.g.*, 14% to 60%) may be available for fractional deposition in all regions of the respiratory tract.

When considering the fractional deposition of particulate matter within the three respiratory tract regions (nasopharyngeal, tracheo-bronchial, alveolar), the concept of "inspirability" should be taken into account as well as the traditional concept of respirable dust. Inspirability is defined as the fraction of ambient airborne particles capable of entering the head region of the upper respiratory tract.[17,18] European research has demonstrated the concept of inspirability using models under laboratory conditions, and Table III lists those ratios of particles for various aerodynamic particle diameters.

The important health hazard consideration associated with particleboard aerosol is the ability of the wood dust to act as a carrier for formaldehyde that may be deposited within the three regions of the respiratory tract. For the nasopharyngeal region, both wood dust and formaldehyde are known to decrease mucociliary clearance with prolonged contact.[5,6] The decrease in mucociliary clearance has been associated with the inducement of nasal cancer from wood dust.[2] Formaldehyde is highly water soluble and currently is suspected as a potential carcinogen, based on toxicological studies with rats.[4] Therefore, it is possible that the wood dust may act as a biological sink for hydrolyzed release of formaldehyde within the nasal area for increased associated risk of developing nasal cancer. Thus, for the tracheobronchial and alveolar respiratory tract regions, the associated risk of irritant or allergic reactions associated with particleboard aerosol inhalation and deposition is also possible. The concept of wood dust acting as a biological sink for formaldehyde for hydrolyzed release presents unique possibilities for adverse health reactions in the tracheobronchial and alveolar regions, even though the greater portion of the aerosol cloud on a percentage basis would be deposited in the upper respiratory tract.

Conclusions

The practical applications for utilizing the data from this research are limited because the particleboard aerosol was generated and collected under controlled laboratory conditions. Therefore, the results may or may not approximate true conditions experienced in the industrial setting. The generation of the aerosol was intended as a means to produce ample particleboard aerosol for characterization by size distribution and formaldehyde content and not for simulation of the potential airborne concentrations that may be encountered in industrial settings. Variations in sanding techniques in addition to the belt sander, type of abrasive belt and type of particleboard also may contribute to significantly different results than the observed results from this research. Field validation for the airborne concentration, size distribution, and formaldehyde content of particleboard aerosol compared with pulmonary function status may provide more definitive conclusions regarding the potential health effects. Nonetheless, it is important to note that the aerosol generated had the size characteristics and formaldehyde content to pose potential health threats to exposed workers.

TABLE III
Inspirability Ratios of Particulate Matter by Particle Aerodynamic Diameter[17]

Particle Aerodynamic Diameter (μm)	Inspirability Ratio
0	1.00
1	0.99
2	0.97
5	0.94
10	0.82
20	0.63
30	0.54
40	0.52
50	0.52
100	0.52

Acknowledgments

This project was supported partially by NIOSH Training Grant Number 5 TO3 OHO7039-10 and fellowship support from the American Industrial Hygiene Foundation (AIHF).

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