ALDEHYDE EMISSIONS FROM PARTICLEBOARD AND MEDIUM DENSITY FIBERBOARD PRODUCTS

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ABSTRACT

Indoor air quality problems resulting from the emission of volatile organic compounds (VOCs) have become an issue of increasing concern. Emissions from building and furnishing materials, which are frequently constructed from particleboard and medium density fiberboard (MDF), are a potentially important contributor of indoor VOCs. In this research, VOC emissions from particleboard and MDF were measured in small (53-L) stainless steel chambers for 4 days. Samples were collected from 53 of the 61 U.S. mills that produce particleboard and MDF. Each mill identified the predominant tree species used to manufacture the panels. Laboratory tests were conducted at room temperature and 45 percent relative humidity. Gas chromatographic/mass spectrometric analysis was used to identify and quantify VOC compounds. The predominant compounds identified in the emissions from particleboard and MDF samples were terpenes and aldehydes, although small straight-chain alcohols and ketones were also found. This study describes the aldehyde emission data, excluding formaldehyde. Emissions of small straight-chain aldehydes, such as hexanal, pentanal, heptanal, octanal, and nonanal, generally exceeded emissions of other compounds and accounted for more than 50 percent of total VOC emissions. All 53 particleboard and 16 of 18 MDF samples emitted hexanal, the most prevalent aldehyde found (excluding formaldehyde). The tests showed differences in VOC composition and emission factors by product and tree type. On average, aldehyde emissions from southern pine MDF samples considerably exceeded the aldehyde emissions from southern pine particleboard. Emissions from all other MDF samples, however, were lower than those from particleboard samples in the same species group. With the exception of formaldehyde, aldehydes are not added to the adhesives used to bond wood, and they have not previously been reported as extractable compounds in wood. Degradation of the wood or its secondary metabolites is probably responsible for the presence of the aldehydes.

As homeowners and builders have worked to increase the energy efficiency of buildings, air exchange rates in buildings have decreased, which allows volatile organic compounds (VOCs) emitted from building materials and furnishings to accumulate. Adverse health effects associated with moderate and high VOC concentrations include eye and respiratory irritation, irritability, inability to concentrate, and sleepiness. Because of increased emphasis on indoor air quality, accurate information is needed regarding the amounts and types of VOCs emitted from building materials, furnishings, cleaning products, and other materials found or used in the indoor environment. Such information will allow building occupants, product manufacturers, building designers and contractors, and regulatory and public health agencies to make informed decisions about the products they use and recommend.

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Composite wood products such as particleboard, hardwood plywood, and MDF are widely used in indoor products such as subflooring, door cores, cabinets, paneling, and furniture. In 1997, combined shipments of particleboard and MDF in the United States totaled almost 5.4×10^8 m^2 (19-mm basis) (10). The majority of these wood products are bonded with urea-formaldehyde (UF) adhesive. Emissions of VOCs potentially can arise from any of the materials that compose a panel, but attention until recently has been on emissions of formaldehyde from UF adhesive. Voluntary standards (1,2) have helped decrease formaldehyde emissions from these products. Attention has now shifted to a variety of VOCs that are associated with wood and other consumer products.

In recent evaluations of chemicals found in the indoor air of new homes, the most prevalent compounds in the air were hexanal, acetone, toluene, α-pinene, long-chain alkanes, limonene, 2,2,4-trimethyl-1,3-pentanediol monoisobutyrate (Texanol, Eastman Chemical Co., Kingsport, Tenn.), and pentanal (19,20). Significant sources other than wood products were identified only for toluene, alkanes, and Texanol. It was concluded that the wood products were responsible for the elevated levels of terpenes, aldehydes, and acetic acid. Investigation of the emissions from one of the wood products used in home construction found significant levels of aldehydes and acetone.

To determine the prevalence of different compounds in the VOC emissions from wood composite products, we undertook a study of emissions from unfinished particleboard and MDF produced in the United States. Small, stainless-steel chambers were used to house small samples of wood products under controlled environmental conditions. Wood samples were collected directly from the mills using a sampling protocol developed by the USDA Forest Service, Forest Products Laboratory (FPL), in consultation with staff at the Composite Panel Association (CPA). This sampling protocol decreased the possibility of postmanufacture contamination and provided consistency and quality control. Samples were collected and evaluated from 53 of the 61 mills in the United States that manufacture particleboard and MDF. This represented more than 85 percent of the particleboard and MDF produced in the United States. Most mills not included in this study either produce specialized products or use materials that are atypical of the particleboard and MDF industries. This study evaluates aldehyde emissions from these particleboard and MDF products. A previously published report evaluates the terpene emissions from these samples (5).

TABLE 1. - Summary of chamber conditions during testing.

Parameter	Value
Chamber volume	0.053 m^3
Chamber air flow	0.001 m^3/min. (1.13 air changes/hr.)
Temperature	23±1°C(73±1°F)
Chamber humidity	45% ± 5%
Sample area	0.021 m^2
Loading ratio	0.40 m^2/m^3
GC sample volume	315 mL

EXPERIMENTAL PROCEDURE

SAMPLE COLLECTION FROM MILLS

Samples of particleboard and MDF panels were collected by three CPA employees during routine visits to mills. Sample collection kits were provided by FPL, and explicit sample handling instructions were given to each of the sampling personnel. Panels were chosen at the mill from the center of a bundle of product that had been designated "ready for shipment." To prevent exposure to or loss of VOCs during shipping, 300- by 300-mm (12- by 12-in.) panel samples were sandwiched between two pieces of the same panel, wrapped in aluminum foil, double-bagged in polyethylene zipper bags, and placed inside a mailing envelope prior to shipping. Information about the product type, predominant wood species, additives used, and manufacturing conditions was recorded at the time of panel sample collection. General information about each panel, including adhesive resin type and wood species, was provided to FPL along with the panel samples. Sampling was blind in that FPL researchers were not given information that would identify the individual mill or manufacturer of each sample.

Panel samples were collected from the mills between March and June of 1997. Upon receipt at FPL, the samples were logged and placed in storage at 2°C (35.6°F) for 8 to 10 weeks until testing commenced. A total of 57 particleboard and MDF panel samples were collected, including duplicates from four mills, All panels were bonded with the UF resin that was being used at the mill at the time of sampling. The samples were divided into nine product-species groupings based on manufacturer reports of predominant species groups used at the mills: southern pine particleboard (22 samples), other pine particleboard (8 samples), Douglas-fir particleboard (4 samples), hardwood particleboard (4 samples), other particleboard (1 sample), southern pine MDF (6 samples), other pine MDF (5 samples), hardwood MDF (5 samples), and other MDF (2 samples). Duplicate panel samples, included in the numbers above, were provided for southern pine particleboard, hardwood particleboard, southern pine MDF, and other pine MDF. The species designation was based on predominant species, and other species of wood may be present in the panels.

CHAMBER SYSTEM

The experimental chamber system (5,6,7) was constructed in accordance with ASTM D 5116-90 (3). The 10 electropolished stainless-steel test chambers had a nominal volume of 53 L and were located within a conditioned room maintained at 23°C (73°F). Clean, humidified air was metered into each chamber at 1.0 L/min., providing 1.13 air exchanges per hour to each chamber. The inlet and outlet ports consisted of tubes that extended to within 2 cm (0.8 in.) of the bottom of the chamber. Holes were distributed along the length of the tubes to assure adequate mixing of the inlet air with chamber air and to assure that air samples collected at the chamber outlet were representative of the chamber air.

A clean air supply to the chambers was generated by passing house-compressed air through a zero-air generator (Peak Scientific, Scotland). A portion of the dry, purified air was humidified using a temperature-controlled impinger

containing hydrocarbon-free water and blended with dry air to produce 45 ± 5 percent relative humidity. The humidified airstream was then distributed to the chambers.

Chamber outlets led to a rotary switching valve that allowed sequential sampling of air in the chambers without having to connect or disconnect tubing. All materials in contact with the sample air were constructed of stainless steel, glass, or Teflon. Chamber conditions during testing are summarized in **Table 1.**

LABORATORY CHAMBER TESTS

The testing schedule for each sample consisted of a 5-day cycle: 1 day of sampling air in the empty chambers, 1 day of conditioning samples in the chambers, and 3 days of collecting and analyzing emissions from the wood specimens. On the first day, prior to putting specimens into the chambers, blank runs were performed for each of the empty chambers while clean, humidified air was flowing through the chamber at a rate of 1 L/min. With the exception of toluene, none of the target compounds were present at detectable levels in the blanks. Wood panel samples were removed from the cold room, and a 102- by 102-mm test specimen was cut from each of the center panels; the outer 25.4 mm from each sample panel and the outer panels used during shipping were discarded. To minimize edge emissions, the specimens were edge-sealed by brushing the edges with two coats of a saturated solution of sodium silicate (22) and left to dry overnight in a room maintained at 23°C (73°F) and 43 percent relative humidity.

Nine samples were then placed into separate chambers, and one chamber was left empty to serve as **a** control. The chambers were closed, and clean humidified air flowed through the chambers for the next 4 days. Air samples were drawn from each chamber after approximately 24, 48, and 72 hours and analyzed for VOCs, as described in the following section.

VOC COLLECTION AND ANALYSIS

When a particular chamber was selected using the sampling valve, 315 mL of air from that chamber was passed through a cryoconcentrator (CDS Analytical, Peakmaster EV, Oxford, Pa.) at -100°C where VOCs condensed out of the air sample. Subsequently, the cryoconcentrator trap was heated to 150°C for 5 minutes to transfer the VOCs to the gas chromatograph (GC) (Hewlett Packard 5890 II, Palo Alto, Calif., with electronic pressure control). The VOCs were cryofocussed at the head of the GC column at -100°C. The column head was then heated to 150°C within ~ 15 seconds and held at that temperature for 3 minutes to inject the VOCs into the GC.

During separation of the VOCs, the GC column (EC-5, 30 m by 0.25 mm, 25-µm film thickness, Alltech Associates, Inc., Deerfield, Ill.) was held at -20°C for 5 minutes, then heated to 120°C at a rate of 10°C/min., and finally held at 120°C for 5 minutes. This program achieved adequate separation of the compounds expected from wood products. A mass selective detector (MSD) (Hewlett Packard 5972) at the GC column outlet was used to detect and quantify VOCs.

The following target compounds were based on a review of the literature (8,11,22,25,28,30) and include the major terpenes, aldehydes, and alcohols that have been associated with wood products: benzaldehyde, benzene, borneol, camphene, 3-carene, *p*-cymene, heptanal, heptane, 2-heptanone, 3-heptanone, hexanal, limonene, nonanal, octanal, octane, *t*-2-octenal, pentanal, pentane, 1-pentanol, α-pinene, β-pinene, toluene, xylenes.

The VOCs were identified and quantified using retention time and a spectral library developed using authentic standards for each target compound. Nontarget compounds were tentatively identified by comparison with a standard mass spectral library (18), but concentrations were not quantified. Formaldehyde was not included in the target compounds because it is not readily detected using the gas chromatographic-mass spectrometric (GC-MS) method that was used to detect the other target compounds.

GC-MSD CALIBRATION

Calibration curves for the target compounds were constructed using standards prepared from neat VOCs in pentane solutions, direct injections into the GC injection port of the CDS Peakmaster, and cryofocussing on the GC column. Quantitation was based on the concentrations of particular ions representative of the compounds being analyzed. Careful selection of the ions allowed compounds with close GC elution times to be quantified without interfering with one another. Limits of detection for all aldehydes were between 0.10 and 0.70 µg/m^3. Based on replicate samples, reproducibility of VOC measurements was typically 10 to 25 percent. Target compounds were not detected in blanks.

ESTIMATION OF TOTAL VOCS

The total VOC (TVOC) emission factor was derived by summing emission factors of the target compounds with an estimate of the emission factors for nontarget compounds. The latter was determined by summing the total ion counts for the nontarget compounds above baseline with retention times between 10 and 24 minutes and using a calibration curve based on toluene. This procedure, which is similar to that used in both indoor and ambient air quality research, provides an approximate but useful estimate of TVOC concentrations.

RESULTS AND DISCUSSION

Among target compounds, the predominant VOCs emitted from the particleboard and MDF specimens were straightchain aldehydes, including pentanal, hexanal, and *t*-2-octenal, and the terpenoid compounds. Nontarget compounds, including heptanol, 2-pentylfuran, camphor, fenchone, and fenchol, were identified in numerous air samples. We have previously reported on levels of terpene and nontarget compounds (5). Only aldehyde emissions from the particleboard and MDF specimens are discussed here.

The emission factors for aldehydes emitted from the particleboard and MDF samples after approximately 48 hours in the chamber are shown in **Tables 2** and **3,** respectively. Emissions at 48 hours were chosen for presentation here, but results for other times showed similar differences between the species groupings and product types **(Table 4).**

PREVALENCE OF ALDEHYDES

Aldehydes were present in all samples except one. Total aldehydes accounted for 49 to 68 percent of TVOC levels measured in the particleboard samples and 40 to 81 percent in the MDF samples, using averages for the species groupings. The most prevalent aldehydes in both particleboard and MDF were hexanal, pentanal, benzaldehyde, and heptanal. (Species and product differences are discussed later.)

In most samples, aldehydes accounted for more than 50 percent of the VOC

TABLE 2. - Emission factors for aldehyde emissions from particleboard samples after 48 hours in the test chamber. Emissions data for a-pinene are given for comparison

Sample type and no.	Emissions									% of TVOC[a]
	a-pinene	Pentanal	Hexanal	Heptanal	Benxaldehyde	0ctanal	*t*-2-Octenal	Nonanal	TVOC	
	(µg/m2hr.)									
S. pine particleboard (PB)										
12	60	29	395	0	20	29	14	35	1,002	52
14	26	98	850	52	104	92	23	60	1,944	66
15	63	121	1,117	29	104	81	58	72	2,362	67
16	14	92	948	43	60	84	43	72	1,935	69
18	14	46	582	14	14	29	32	32	1,097	68
19	49	207	1,812	46	98	98	49	81	3,122	77
21	20	35	446	12	37	26	29	32	1,020	60
22	12	101	916	52	84	101	20	63	1,532	87
23	78	66	729	23	35	58	37	60	1,668	60
31	12	144	950	43	101	109	32	86	2,111	69
33	55	84	1,123	35	132	49	46	40	2,506	60
36[b]	26	121	899	43	98	69	26	46	2,595	50
37	43	109	1,146	49	84	84	40	66	2,388	66
38	17	179	1,175	49	135	75	23	69	2,062	83
47	37	184	948	52	141	81	20	55	2,042	72
40	20	78	1,040	29	37	46	20	40	1,748	74
43	153	207	1,299	81	225	132	37	109	2,874	73
45	12	40	671	26	69	43	23	37	1,817	50
49	75	135	1,238	37	40	78	40	69	2,036	80
50	49	118	1,022	49	135	69	46	60	2,405	62
51	52	181	1,331	92	199	153	46	127	3,211	66
55	26	104	936	60	115	81	23	63	1,979	70
S. pine PB avg.	41	113	981	42	94	76	33	63	2,066	68
S. pine PB SD[c]	33	54	314	21	55	32	12	24	604	10
Other pine PB										
7	26	66	766	23	52	29	23	35	1,679	59
9	23	92	924	17	60	29	29	23	1,993	59
10	9	29	219	14	20	29	12	23	962	36
11	29	43	446	23	26	23	32	32	1,302	48
24	210	253	2,678	17	121	32	138	37	5,184	63
25	23	101	1,103	20	46	40	63	35	2,701	52
28	6	46	395	20	52	52	23	40	1,054	60
44	12	29	274	29	66	40	12	32	636	76
Other pine PB avg.	42	82	851	21	55	34	41	32	1,939	58
Other pine PB SD	68	74	804	4	32	9	42	6	1,465	12
Hardwood PB										
2	12	32	478	0	0	6	12	9	567	94
4	6	184	2,722	20	6	29	78	17	3,419	89
5	12	52	536	0	3	6	20	9	714	88
Hardwood PB avg.	10	89	1,245	7	3	13	36	12	1,567	90
Hardwood PB SD	3	83	1,279	12	3	13	36	5	1,605	4
Douglas-fir PB										
1	9	0	135	0	0	0	0	0	173	78
30	3	23	170	0	23	17	9	14	360	71
35	35	0	46	0	0	0	9	0	412	13
54	0	0	12	0	0	0	0	0	104	69
D. fir PB avg.	12	6	106	0	6	4	4	4	262	49
D. fir PB SD	16	12	57	0	12	9	5	7	147	30

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TABLE 2 .– Continue from previous page.

Sample type and no.	Emissions									% of TVOC[a]
	a-pinene	Pentanal	Hexanal	Heptanal	Benxaldehyde	Octanal	*t*-2-Octenal	Nonanal	TVOC	
	($\mu g/m^2$ hr.)									
Other PB										
3	98	158	2,123	23	23	37	86	35	2,894	86
39	6	0	55	0	9	6	12	12	331	28
Other PB avg.	52	79	1,089	12	16	22	49	23	1,613	80
Other PB SD	65	112	1,462	16	10	22	53	16	1,812	41

[a] % of TVOC is the percentage of the total VOCs that are aldehydes.
[b] The 48-hour data for this sample was lost. Data shown here are the 72-hour data.
[c] SD = standard deviation for the values within a particular product-species group.

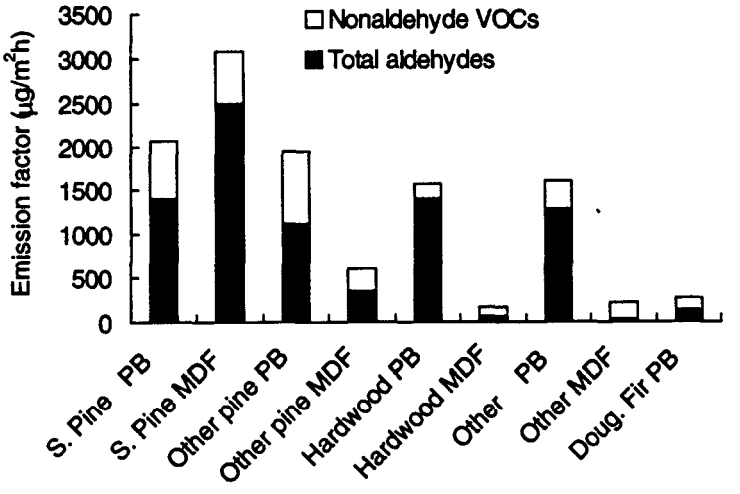

Figure 1. – Average emission factors for aldehydes and nonaldehyde VOC emissions for each manufacture-designated product-species grouping. The sum of these two values gives the total VOC emissions from the samples. Measurements were made after samples had been in the chamber for approximately 48 hours (PB = particleboard; MDF = medium-density fiberboard).

emissions. The emissions of aldehydes routinely surpassed the emissions of terpenes, even in southern pine panels, which is surprising because these aldehydes are not known to be present in natural wood and they are not added to the adhesives used to bond wood products.

Effect of species and product type

As reported previously (5), the types and amounts of terpenes varied with species, and MDF samples consistently had lower terpene emissions than particleboard samples. However, the variation in the aldehyde emissions with species and product type is not as straightforward as that for terpenes. Southern pine particleboard samples emitted considerably less aldehydes (and total VOCs) than southern pine MDF **(Fig. 1).** For all other species groups, the MDF samples had much lower average emission factors than the particleboard.

The variation in the observed emissions for the samples within all species groups except southern pine may be due to the variety of wood species included in each species grouping **(Table 5).** Within several product-species groups, some samples appeared to differ significantly from other samples. Specifically, other pine particleboard samples 24 and 25, other pine MDF sample 6, and hardwood particleboard sample 4 emitted significantly more of all compounds tested than did the other members of their groups. These results were confirmed by sampling results obtained after 24 and 72 hours in the chamber and are most likely not associated with a sampling error. Further information about the source of these materials, the manufacturing conditions, and wood species is needed to determine whether these samples are representative of the mill from which they were sampled. Further information about the wood species from which the panels are made is necessary to determine whether manufacturing differences between the two product types account for the differences seen within the other pine and hardwood groups.

Source of aldehydes

There are several reports of straight-chain aldehyde emissions associated with wood products. Emissions of straight-chain aldehydes have been detected from composite wood products (19,20,21,28), lumber (12,13,23,28), and during the manufacture of composite panels (4,9,29).

The occurrence of aldehydes in emissions from both lumber, which has no adhesive, and composite products indicates that the source of the aldehydes probably lies in some component of the wood or its secondary metabolites. However, extractable compounds from wood have been studied for decades (26), and simple straight-chain aldehydes have not been reported in this body of literature. Only recently, Wang and Gardner (29) reported the presence of the homologous series of straight-chain aldehydes with four through nine carbons in methylene chloride extracts from commercial southern pine particleboard furnish. The extraction yielded equal amounts of hexanal and cl-pinene, the predominant extractive previously reported for southern pine. Because Wang and Gardner's data were collected

TABLE 3. - Emission factors for aldehyde emissions from MDF samples after 48 hours in the test chamber: Emissions of a-pinene were not detected from any of the MDF samples.

Sample type	Emissions								% of TVOC[a]
	Pentanal	Hexanal	Heptanal	Benzaldehyde	Octanal	*t*-2-Octenal	Nonanal	TVOC	
	($\mu g/m^2 hr.$)								
Southern pine MDF									
17	55	559	20	55	55	43	58	1,117	16
29	409	2,454	156	161	233	46	161	4,706	77
34	132	1,457	23	20	46	132	60	2,180	86
41	297	2,419	138	144	228	40	156	4,496	76
42	334	2,788	52	325	109	63	89	4,473	84
59	141	1,008	32	104	55	32	55	1,549	92
S. pine MDF avg.	228	1,781	70	135	121	60	96	3,087	81
S. pine MDF SD[b]	138	902	61	107	88	37	50	1,649	7
Other pine MDF									
6	132	1,256	35	32	32	9	23	1,797	84
21	0	81	0	12	9	12	14	435	29
32	0	20	0	12	6	0	12	236	21
56	0	66	0	17	0	0	12	317	30
51	0	0	0	12	0	0	0	228	5
Other pine MDF avg.	26	285	7	17	9	4	12	602	60
Other pine MDF SD	59	544	15	9	13	6	8	673	30
Hardwood MDF									
46	0	98	0	9	9	17	9	323	44
48	0	20	0	9	0	0	0	107	27
52	0	17	0	0	0	0	0	98	18
53	0	52	0	0	0	0	0	60	86
58	0	81	0	0	0	0	0	222	36
Hardwood MDF avg.	0	54	0	3	2	3	2	162	40
Hardwood MDF SD	0	36	0	5	4	8	4	108	26
Other MDF									
8	0	60	0	6	0	0	0	259	26
13	0	0	0	0	0	0	0	167	0
Other MDF avg.	0	30	0	3	0	0	0	213	16
Other MDF SD	0	43	0	4	0	0	0	65	18

[a] % of TVOC is the percentage of the total VOCs that are aldehydes.
[b] SD = standard deviation for the values within a particular product-species group.

TABLE 4. -Average emission factors for &anal, nonanal, and total aldehydes at all sampling times.

Sample type	Hexanal			Nonanal			Total aldehyde		
	24 hr.	48 hr.	72 hr.	24 hr.	48 hr.	72 hr.	24 hr.	48 hr.	72 hr.
	($\mu g/m^2 hr.$)								
S. pine PB	1,291	984	830	62	63	55	1,728	1,404	1,187
Other pine PB	1,044	851	470	37	32	29	1,346	1,116	650
Hardwood PB	1,762	1,245	916	15	11	11	1,960	1,420	1,090
Douglas-fir PB	94	105	57	6	3	3	116	128	71
Other PB	1,176	1,089	913	29	23	22	1,430	1,288	1,103
S. pine MDF	2,192	1,446	1,533	90	83	92	2,934	2,026	2,168
Other pine MDF	334	284	258	15	11	15	421	360	340
Hardwood MDF	52	58	35	6	4	4	80	81	48
Other MDF	48	30	22	0	0	0	51	32	24

TABLE 5. - Wood species included in each of the manufacture-designated species groupings that had more than one individual species.

Southern pine	Other pine	Hardwood	Other
Longleaf pine *(Pinus palustris)*	Lodgepole pine *(Pinus contorta)*	Oak *(Quercus* spp.)	True firs *(Abies* spp.)
Shortleaf pine *(P. echinata)*	Ponderosa pine *(P. ponderosa)*	Maple *(Acer* spp.)	Redwood *(Sequoia sempervirens)*
Loblolly pine *(P. taeda)*	Western white pine *(P. monticola)*	Aspen *(Populus* spp.)	Softwood-hardwood mixes
Slash pine *(P. elliottii)*		Alder *(Alnus rubra)*	
		Basswood *(Tilia* spp.)	

on commercial particleboard furnish, which was dried, and previous extractives research generally used freshly felled lumber that had not been dried or otherwise treated, the aldehydes may be degradation products of some portion of the wood or the secondary metabolites.

Mechanisms that may form aldehydes and ketones in extractives and wood products include thermal, enzymatic, and microbial degradation. Research conducted on the oxidative degradation of plant material has yielded some information about how certain types of aldehydes and ketones are formed. However, these mechanisms do not account for the variety of aldehydes and ketones observed in the wood product emissions, and in some cases, the mechanisms occur under conditions that are distinctly different from wood products manufacturing conditions. The presence of formaldehyde in emissions from wood that does not contain adhesive resin has been explained by thermal degradation of polysaccharides in the wood (27), but this does not explain findings that show formaldehyde emissions from wood that had never been heated (24). In the work of Faix et al. (14,15), pyrolysis of milled wood lignin at 450°C yielded benzaldehyde, and pyrolysis of spruce and pine wood at 450°C generated formaldehyde, acetaldehyde, 2-propenal, butanal, and butanone (methylethyl ketone MEK), which were attributed to the breakdown of the polysaccharide fraction of the wood. Conditions of pyrolysis are extreme and not oxidative, and during manufacture of wood products, only wood particles for particleboard are likely to be exposed to such extreme conditions and then only for a very brief time. Enzymatic pathways for the oxidation of fatty acids to form hexanal and nonanal have been described for nonwoody plants (16,17), but no such pathway has been described for other aldehydes. In short, although pathways exist for some of the aldehydes and ketones that are observed in wood product emissions, there are no mechanisms for other aldehydes (for example, pentanal, heptanal, and octanal). With the exception of hexanal and nonanal, there is no explanation of how the aldehydes and ketones could be formed at room temperature or under the relatively mild conditions that are encountered in wood products manufacturing.

CONCLUSIONS

Samples of particleboard and MDF products were obtained from mills that produce more than 85 percent of U.S. capacity. These samples were used in well-controlled chamber tests to estimate aldehyde and total VOC emissions. The sampling and analysis protocols were designed to provide representative emission factors for new particleboard and MDF panels.

A wide variation in the types and quantities of VOCs was observed among the wood species groupings and the two product types. Small, straight-chain aldehydes were consistently present in the VOC emissions from the wood products tested, and these aldehydes often made up the majority of emissions from the panels. No clear source of the aldehydes has been identified, although it is likely that they are degradation products of the secondary components of the wood. The wide range of emission factors for individual and total VOCs from these products indicates that general statements about VOCs from particleboard and MDF cannot be made.

Emissions from particleboard and MDF products in typical applications will vary from results of short-term chamber tests. For example, coatings or laminates, which typically cover composite wood products, will alter emission characteristics. Effects of temperature, humidity, and loading ratios were not investigated. Finally, emission factors of aldehydes and other VOCs are expected to decrease as the product ages and volatile components are lost. Results reported in this study apply to freshly manufactured materials.

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