



Project Summary

The Application of Pollution Prevention Techniques to Reduce Indoor Emissions from Engineered Wood Products

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The objective of this research was to investigate pollution prevention options to reduce indoor emissions from a type of finished engineered wood. Emissions were screened from four common types of finished engineered wood. An oak-veneered particleboard coated and cured with a heat-curable, acid-catalyzed alkyd-urea sealer and topcoat (PBVST) was selected for further testing based on its higher initial emission factors of summed volatile organic compounds (VOCs) and higher decay emission factors of formaldehyde relative to other products tested.

Subsequent testing identified the acid-catalyzed alkyd-urea coating and particleboard as sources of VOCs emitted from the PBVST. A study was conducted to evaluate emissions and performance properties of five potentially low-emitting substitutes for the acid-catalyzed alkyd-urea coatings. Three types of coatings were found to have significantly lower emission factors of summed VOCs and formaldehyde relative to those for the heat-curable, acid-catalyzed alkyd-urea coatings, while demonstrating comparable performance.

A fiber study was conducted to evaluate emissions of six types of potentially low-emitting engineered fiber panels compared to those of conven-

tional particleboard. Three types of engineered fiber panels were identified as having significantly lower emission factors of summed VOCs and formaldehyde relative to those for particleboard.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Engineered wood products are used throughout residential, office, and commercial settings. Engineered wood is distinct from solid wood, in that it is composed of wooden elements of various sizes held together by a synthetic resin. Particleboard (PB) and medium density fiberboard (MDF) are the most common types of engineered wood for constructing interior products. Hardboard (HB) is also used. PB is made from finely ground wood particles of various sizes, whereas MDF and HB are made from wood fibers. In the U.S., most interior-grade PB and MDF are bonded with urea-formaldehyde (UF) resins; hardboard is bonded with phenol-formaldehyde (PF) resins. Engineered wood is typically finished prior to assem-

bling it into a product. Wood veneered boards are usually coated with sealers and topcoats.

In September 1993, the Research Triangle Institute (RTI) began a collaborative research effort with the Air Pollution Prevention and Control Division/Indoor Environment Measurement Branch of the U.S. Environmental Protection Agency's National Risk Management Research Laboratory to identify and evaluate pollution prevention (P2) techniques to reduce indoor emissions from engineered wood products. The approach to the research consisted of three major phases:

- 1) conduct emission tests for volatile organic compounds (VOCs) from several types of finished engineered wood to select a type of material for P2 evaluation (i.e., emissions reduction evaluation);
- 2) collect components of the selected material at different stages of the manufacturing process and test them to identify raw materials that are sources of VOCs from the finished material; and
- 3) identify and evaluate potentially low-emitting substitutes for the raw materials identified in Phase 2.

Based on the results of Phase 2, Phase 3 examined alternative coatings and alternative engineered substrates as potential P2 opportunities.

Procedure

Multiple environmental test chambers were used to measure VOCs from materials under dynamic conditions. The 0.012 m³ chambers operated at 50% relative humidity (% RH), 23 ± 2° C, an air exchange rate of 1 air change per hour (ACH), and a loading ratio (L) of 1.0 m²/m³ [total surface area of the tested material (0.012 m²) divided by the volume of test chamber]. Air that entered the chambers was treated to remove VOCs. The test chambers were constructed of glass, Teflon, and stainless steel.

VOCs in the test chambers were collected by passing chamber air through one dinitrophenylhydrazine (DNPH)-coated silica gel cartridge and two multisorbent cartridges containing Tenax TA, charcoal, and Ambersorb. Cartridges were eluted or thermally desorbed, and samples were analyzed by high-pressure liquid chromatography, gas chromatography/mass spectrometry, or gas chromatography/flame ionization detection.

Concentrations of individual VOCs measured in chamber air samples were converted to emission factors (EFs) using the equation:

$$EF = \frac{C_m \cdot ACH}{L}$$

where

C_m = measured concentration of a VOC in a chamber air sample (µg/m³)

ACH = air exchange rate in the test chamber

L = loading ratio in the test chamber

Four types of finished engineered wood were selected for Phase 1 testing: oak-veneered particleboard coated and cured with a heat-curable, acid-catalyzed alkyd-urea sealer and topcoat (PBVST); oak-veneered hardboard coated and cured with a stain, and a heat-curable, acid-catalyzed alkyd-urea sealer and topcoat (HBVSST); particleboard overlaid with vinyl (PBVY); and particleboard overlaid with melamine (PBM). Melamine is a paper overlay saturated with melamine and UF resins. Three samples each of PBVST, HBVSST, PBM, and PBVY were collected directly from the end of the finishing line. Three coupons were cut from the center of each sample. The coupons were stored at -10 to -20° C to minimize losses of VOCs from the coupons prior to testing.

Phase 1 testing included screening and quantitative decay tests. The screening tests were conducted to estimate initial emission factors of summed VOCs from the four types of finished engineered wood. Quantitative decay tests were conducted to measure emission factors of formaldehyde over time.

For testing, the coupons were prepared in 0.0762 by 0.0762 m test squares. The edges of the test squares were sealed with sodium silicate (liquid glass) to ensure that emitted VOCs came only from the surfaces of the test squares and not the cut edges. The test squares were placed in individual test chambers. Chamber air samples for measuring VOCs were collected 6 hours after each test square was placed in a test chamber.

Quantitative decay tests were initiated approximately 10 weeks after sample collection. The purpose of collecting chamber air samples over time was to determine if emission factors decreased over time due to sample conditioning. Chamber air samples were collected 1, 3, 7, 14, 21, and 31 days after each test square was placed in a test chamber. Thirty-one days represents a typical time lag between when materials are finished and when they arrive in an indoor environment as part of an assembled product.

In Phase 2, quantitative emission tests were conducted on the different compo-

nents of PBVST: particleboard (PB); veneer (V); oak-veneered particleboard (PBV); oak-veneered particleboard with a heat-curable, acid-catalyzed alkyd-urea sealer (PBVS); and oak-veneered particleboard with a heat-curable, acid-catalyzed alkyd-urea sealer and topcoat. Three samples of each material (PB, V, PBV, PBVS, and PBVST) were collected from the finishing line. The coated samples were collected after they were cured. Three coupons were cut from the center of each sample. The coupons were prepared in test squares using the same methods as in Phase 1. The test squares were placed in individual test chambers. Chamber air samples for measuring VOCs were collected 31 days after each test square was placed in a test chamber.

Phase 3 consisted of two separate sets of emissions tests designed to evaluate potential P2 options to reduce VOC emissions from finished engineered wood. The first test focused on alternative coatings, and the second on alternative engineered fiber panels. Five alternative coatings systems were identified and evaluated as potentially low-emitting substitutes for heat-curable, acid-catalyzed alkyd-urea coatings (Table 1). The coatings were selected for evaluation because they are marketed as having low product emissions; they may have comparable performance and aesthetics to the heat-curable, acid-catalyzed alkyd-urea coatings system; they are compliant with current regulatory requirements for manufacturing emissions; they are currently available to users in the wood finishing industry; and they differ from one another in terms of their chemistry, carrier medium, and curing technique. Performance and quantitative emissions tests were conducted on the five coatings systems and the heat-curable, acid-catalyzed alkyd-urea coatings system. Performance tests included tests for hardness; adhesion; fingernail mar resistance; and chemical resistance to methyl ethyl ketone (MEK), mustard, and 11 types of stains. Gloss was also measured.

Coatings were applied to coupons using a drawdown bar. The drawdown method is a standard laboratory technique for applying a uniform thickness of coating to small substrates. Although spray systems and roll coaters are used at wood finishing plants, both methods can transfer different amounts of coatings from application to application. The coupons conditioned for 27 days, at 50 % RH, 23 ± 2° C and then were removed from the conditioning chambers and prepared in test squares using the procedures described in Phase 1. The test squares were

Table 1. Selected Coatings Systems

	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Chemistry	Acid-catalyzed alkyd-urea	Two-component polyurethane	Non-air-inhibited unsaturated polyester	Acrylate	Multi-functional acrylate-free emulsion	Polyurethane dispersion
Carrier	organic solvents	water	water	none	water	water
Cure method	heat	heat	UV ^a light	UV light	heat+UV light	heat

^a UV = ultraviolet

Table 2. Selected Engineered Panels

Panel Identification	Fiber Source	Resin Source	Interior Applications
A	Recycled newspaper	None	floors, walls, subfloors, roof decking, filler board for furniture.
B	Wheat straw	MDI ^a	PB ^b applications such as furniture, cabinetry, and shelving.
C	Recycled corrugated cardboard	None	furniture, store displays, countertops, shelving, etc.
D	Lumber and plywood residuals	MDI	MDF ^c applications such as furniture, cabinetry, and shelves.
E	Lumber and plywood residuals	UF ^d	MDF applications such as furniture, cabinetry, and shelves.
F	Lumber and plywood residuals	UF	PB applications such as furniture, cabinetry, shelves, floor underlayment, and stair treads.
N	Lumber and plywood residuals	PF ^e	PB applications such as furniture, cabinetry, shelves, floor underlayment, and stair treads.

^a MDI = Methylene diisocyanate.

^b PB = Particleboard.

^c MDF = Medium density fiberboard.

^d UF = Urea-formaldehyde.

^e PF = Phenol-formaldehyde.

placed in individual test chambers. Chamber air samples were collected 1 day after each test square was placed in a test chamber.

In the second test, six types of engineered fiber panels were identified as potentially low-emitting materials for constructing engineered products (Table 2). Screening tests were conducted on the six types of engineered panels and PB manufactured with wood fibers and UF resins. PB tested during the fiber study did not come from the same manufacturing plant used to collect samples in Phases 1 through 3. For the fiber panel evaluation, three panels of each material were collected from the last step in the manufacturing process, when the panels were ready for shipment. Several 0.006 m² coupons were cut from the center of each panel.

Screening tests were conducted on the panel materials within 7 to 11 days of sample collection. For these tests, coupons of each material were removed from their containers and prepared in test squares using the procedures described in Phase 1. The test squares were placed in individual test chambers, and chamber air samples were collected 28 days after placing each test square in a test chamber.

Results and Discussion

Results from Phase 1 screening tests showed that initial emission factors of summed VOCs were substantially higher for test squares of PBVST and HBVSST relative to those for PBVY and PBM. Emission factors for summed VOCs for PBVST and HBVSST ranged from 7000 to 19000

µg/(m²•hr) as compared with 1400 to 2400 µg/(m²•hr) for PBVY and PBM. Alcohols made up a large portion of the emission factors of summed VOCs for test squares of PBVST and HBVSST; whereas, virtually no alcohol emissions were detected from test squares of PBVY and PBM. Alcohols were listed as solvents in the material safety data sheets (MSDS) for the coatings.

Initial emission factors of formaldehyde were substantially higher for test squares of PBVST and HBVSST relative to those for test squares of PBVY and PBM. Initial emission factors of formaldehyde for PBVST and HBVSST ranged from 2000 to 5800 µg/(m²•hr) as compared with 51 to 90 µg/(m²•hr) for PBVY and PBM. The acid-catalyzed alkyd-urea sealer and topcoat were believed to be the major reason for these differences. Test squares of

PBVST and HBVSST showed a rapid decay of formaldehyde during the first week of sampling. By the fourth time point (14 days), formaldehyde emission factors for PBVST and HBVSST appeared to level out to approximately 300 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, which was substantially higher than initial emission factors of formaldehyde for PBVY and PBM. For this reason, quantitative decay tests were not conducted on PBVY and PBM.

Component results from Phase 2 tests showed that emission factors of summed VOCs for PB and PBV were 1600 and 470 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, respectively. The emission factor of summed VOCs for the veneer was 17 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, which suggests that VOCs from PBV were being emitted by the PB and possibly the glue used to adhere the veneer to the PB. (The glue is a mixture of 70% polyvinyl acetate and 30% UF resin.) Since the emission factor of summed VOCs for PBV was substan-

tially lower than the emission factor of summed VOCs for PB, this suggests that the veneer was suppressing emissions from the PB. The emission factor of summed VOCs was 470 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ for the test square of PBV compared to 1400, 1600, and 1300 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ for test squares of PBVS and 2300, 1900, and 1800 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ for test squares of PBVST. The increase in emissions from PBV to PBVS appears to be due to the addition of the sealer to PBV. The increase in emissions from PBVS to PBVST appears to be due to the addition of the topcoat to the PBVS.

Emission factors of formaldehyde for PB and PBV were 230 and 130 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, respectively. The emission factor of formaldehyde for the veneer was 9 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, which suggests that the veneer was suppressing formaldehyde emissions from the PB. The emission factor of formaldehyde for the test square of PBV was 130 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ compared to 320, 340, and 360

$\mu\text{g}/(\text{m}^2\cdot\text{hr})$ for test squares of PBVS and 530, 440, and 390 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ for test squares of PBVST; these increases suggest that the coatings were a source of formaldehyde.

Based on the results from Phase 2, we examined alternative coatings and substrates for engineered wood products. For the coatings evaluation, five coatings were compared with the conventional heat-curable, acid-catalyzed alkyd-urea coating used to coat the materials tested in Phases 1 and 2. In performance tests, all alternative coatings performed as well as or better than the heat-curable, acid-catalyzed alkyd-urea coatings system in all tests, except for the UV-curable, non-air-inhibited, unsaturated polyester, which had slightly poorer performance on the grape juice and coffee stain tests.

Table 3 presents mean emission factors of selected compounds for test squares of PBV coated and cured with

Table 3. Selected Mean Emission Factors for Uncoated and Coated Test Squares

Compounds	Emission Factors, $\mu\text{g}/(\text{m}^2 \cdot \text{hr})$						
	Uncoated Test Squares of PBV	Test Squares Coated and Cured with					
		Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Formaldehyde	140	400	20	70	18	19	33
Acetone	420	520	490	380	390	430	510
n-Hexanal	410	150	120	280	79	93	350
1-Butanol	6	800	- ^a	5	-	8	7
m,p-Xylene	-	660	-	-	110	-	-
2-Heptanone	15	550	8	13	9	7	22
o-Xylene	-	210	-	-	32	-	-
1-Methyl-2-pyrrolidone	-	11	-	20	-	5	2400
2-(2-Butoxyethoxy)ethanol	8	1700	43	610	18	6	7
C3-Benzenes	-	1100	-	-	-	-	-
Dipropylene glycol, methyl ether	-	-	-	-	-	24	240
Unknown 1	-	-	-	180	-	-	-
Unknown 2	-	-	-	260	-	-	-
TVOC ^b	1000	5200	610	1700	810	540	2800
Summed VOCs ^c	1600	7800	1100	2300	1000	900	4100

Coating 1 = heat-curable, acid-catalyzed alkyd-urea.

Coating 2 = heat-curable, two-component polyurethane.

Coating 3 = UV-curable, non-air-inhibited, unsaturated polyester.

Coating 4 = UV-curable acrylate.

Coating 5 = UV- and heat-curable, multi-functional, acrylate-free emulsion.

Coating 6 = heat-curable, polyurethane dispersion.

^a < 5 $\mu\text{g}/(\text{m}^2 \cdot \text{hr})$.

^b TVOC = total volatile organic compounds from TVOC analysis of multisorbent tubes.

^c Summed VOCs are the sum of emission factors > 5 $\mu\text{g}/(\text{m}^2 \cdot \text{hr})$, rounded to two significant figures.

each of the six coatings systems and for test squares of uncoated PBV. The emissions data were statistically analyzed to ascertain if emission factors of summed VOCs for test squares of coated and cured PBV were significantly different than those for test squares of uncoated PBV. The mean emission factors of summed VOCs for test squares coated and cured with Coating Systems 1, 3, and 6 were statistically higher than the mean emission factor of summed VOCs for test squares of uncoated PBV, indicating that these coatings systems are a significant source of emissions from finished PBV. The mean emission factors of summed VOCs for test squares coated and cured with Coatings Systems 2, 4, and 5 were statistically lower than the mean emission factor of summed VOCs for test squares of uncoated PBV, indicating that these coatings systems are not a significant source of emissions from finished PBV.

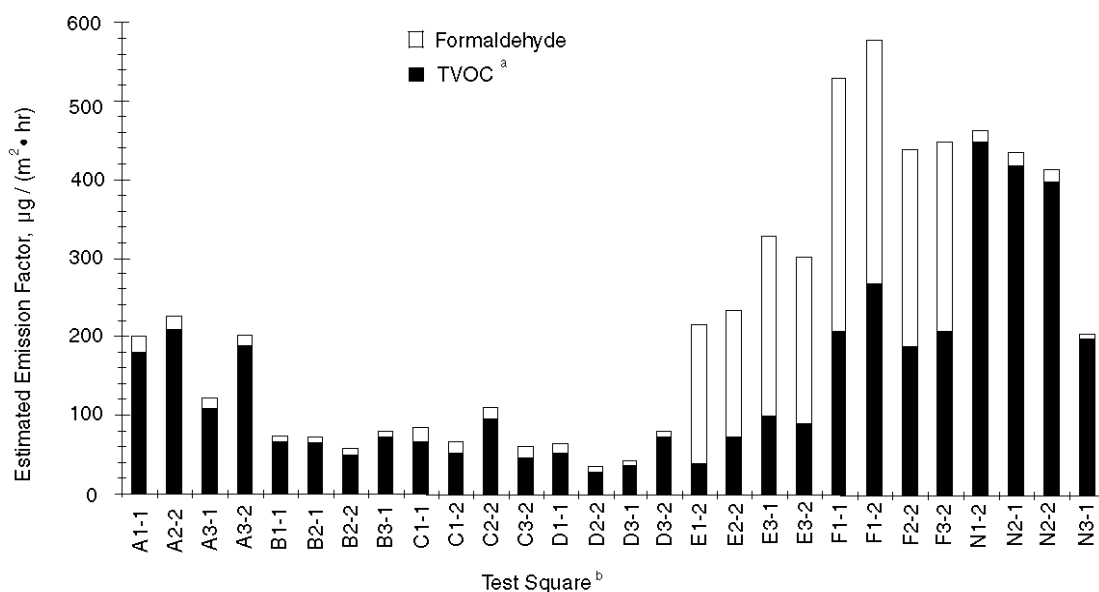
The emission data were also statistically analyzed to ascertain if emission

factors of individual and summed VOCs for test squares of PBV coated and cured with Coatings System 1 (i.e., the existing coatings system for finishing PBVST in Phases 1 and 2) were statistically different than those for test squares of PBV coated and cured with the five alternative coatings systems. The mean emission factor of summed VOCs for test squares of PBV coated and cured with Coatings System 1 was significantly higher than the mean emission factors of summed VOCs for test squares of PBV coated and cured with Coatings Systems 2 through 6. The mean emission factors of most organic solvents [such as butanol, 2-(2-butoxyethoxy)ethanol] and of formaldehyde were significantly higher for test squares of PBV coated and cured with Coatings System 1 compared to test squares with Coatings Systems 2 through 6.

In terms of individual compounds, the mean emission factor of 1-methyl-2-pyrrolidone for test squares of PBV coated

and cured with Coatings System 1 was significantly lower than the mean emission factor of 1-methyl-2-pyrrolidone for test squares of PBV coated and cured with Coatings System 6 (1-methyl-2-pyrrolidone is a type of solvent listed in the MSDS for Coatings System 6). The mean emission factors for compounds unknown 1 and unknown 2 were also significantly lower for test squares of PBV coated and cured with Coatings System 1 compared to those for test squares of PBV coated and cured with Coatings System 3.

In the fiber panel study, we examined emissions from alternative substrate materials that differed from conventional urea-formaldehyde-bonded particleboard in terms of the fiber material and/or bonding resin. Figure 1 presents emission factors of TVOC and formaldehyde for test squares of unfinished panel materials. The TVOC and formaldehyde data were statistically analyzed to ascertain which test squares differed with respect to their emis-



^a TVOC = Total volatile organic compounds.

^b Test squares are labeled by material letter (A, B, C, D, E, F, or N), followed by panel number and test square number, respectively, where

A = Panel made from recycled newspaper.

B = Panel made from wheatboard and methylene diisocyanate (MDI) resin.

C = Panel made from recycled corrugated cardboard.

D = Medium density fiberboard with MDI resin.

E = Medium density fiberboard with urea-formaldehyde (UF) resin.

F = Particleboard with UF resin.

N = Particleboard with phenol-formaldehyde resin.

Figure 1 Estimated emission factors of TVOC and formaldehyde for test squares of engineered panels conditioned 26 to 30 days.

sions of TVOC and formaldehyde. The mean emission factors of TVOC for test squares A, F, and N were significantly higher than the mean emission factors of TVOC for test squares B through E. The mean emission factors of formaldehyde for test squares E and F (the UF-bonded panels) were significantly higher than the mean emission factors of formaldehyde for test squares A through D, and N.

Conclusions and Recommendations

The objective of this research was to reduce indoor emissions from a type of finished engineered wood. Conclusions that can be drawn from this study include:

- UF-bonded PB and acid-catalyzed alkyd-urea coatings were identified as sources of emissions from PBVST, a type of finished engineered wood used to construct a variety of engineered wood products. These findings are based on emission testing of PBVST made by a single manufacturer, and may not be applicable

to PBVST made by other manufacturers.

- Within the scope of the emission tests and performance tests conducted for the coatings evaluation, the heat-curable, two-component polyurethane; the UV-curable acrylate; and the UV-curable, multi-functional, acrylate-free emulsion appear to be viable alternatives for the heat-curable, acid-catalyzed alkyd-urea.
- A variety of engineered fiber panels (i.e., those made with wheat and MDI; wood and MDI; and recycled corrugated cardboard) were found to have very low emission factors of TVOC and formaldehyde (relative to UF-bonded PB and MDF). These low-emitting engineered fiber panels can be finished with veneer, vinyl, melamine, etc, and are currently used to construct a wide variety of products for interior applications.

Recommendations for future research relating to the findings of this study include:

- The screening materials collected in Phase 1 (i.e., PBVST, HBVSST, PBVY, and PBM) should be collected from several manufacturers and tested to assess emissions variability between manufacturers.
- A broader study of the recommended coatings systems should be conducted to determine how they perform in the manufacturing environment, in terms of their ease of use, worker safety, cleanup, manufacturing emissions, etc. The cost of the coatings should be assessed in terms of equipment needs; e.g., stainless steel or plastic pipes for water-borne coatings, and UV lights for UV coatings. Performance tests should also be conducted at critical time points.
- A broader study of the low-emitting engineered fiber panels should be conducted to assess manufacturing issues (such as cost and worker safety) involved with making the panels. Performance tests should also be conducted on the panels.

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Kelly W. Leovic and Elizabeth M. Howard are the EPA Project Officers (see below).

The complete report, entitled "The Application of Pollution Prevention Techniques to Reduce Indoor Emissions from Engineered Wood Products," (Order No. PB99-118309; Cost: \$44.00, subject to change) will be available only from

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