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THE APPLICATION OF POLLUTION PREVENTION TECHNIQUES TO REDUCE INDOOR AIR EMISSIONS FROM ENGINEERED WOOD PRODUCTS

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FOREWORD

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

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 types of finished engineered wood: 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). The PBVST and HBVSST had substantially higher initial emission factors of summed volatile organic compounds (VOCs) relative to those for PBVY and PBM. The PBVST and HBVSST also had higher decay emission factors of formaldehyde relative to the initial emission factors of formaldehyde for PBVY and PBM.

The acid catalyzed alkyd-urea coatings and particleboard were identified as sources of VOCs from the PBVST. A coatings study was conducted to evaluate emissions and performance properties of potentially low-emitting substitutes for the acid catalyzed alkyd-urea coatings. Within the scope of the emissions and performance tests of the study, 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; these included a two component waterborne polyurethane; a UV curable acrylate; and a UV and heat curable multi-functional acrylate-free emulsion. These coatings also had comparable performance characteristics to the heat curable acid catalyzed alkyd-urea coatings. All three wood coatings are currently available in the market place.

A fiber study was conducted to evaluate emissions of potentially low-emitting engineered fiber panels. Three types of engineered fiber panels were identified as having significantly lower emission factors of summed VOCs and formaldehyde relative to those for particleboard; these included medium density fiberboard made with methylene diisocyanate resin (MDI); a wheatboard panel made with MDI resin; and a panel made from recycled corrugated cardboard. All three fiber panels are in the market place and are used to construct a wide variety of interior products.

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Acronyms

A _{QS}	peak area of the quantitation standard (ng/cartridge)
A _{Tol}	peak area of toluene (ng/cartridge)
A _{TVOC}	peak area of TVOC (ng/cartridge)
A _{VOC}	peak area of VOC (ng/cartridge)
ACH	air exchange rate (air changes per hour)
ACH/L	air exchange rate per loading
ANSI/KCMA	American National Standards Institute/Kitchen Cabinet Manufacturers Association
APPCD	Air Pollution Prevention and Control Division
BFB	bromopentafluorobenzene
C _{a/k}	concentration of the target aldehyde or ketone in the chamber air sample (µg/m ³)
C _{VOC or TVOC}	concentration of VOC or TVOC
C _y	concentration of DNPH/analyte derivative in the sample extract (ng/µL)
D _f	molecular weight of the aldehyde or ketone ÷ molecular weight of the aldehyde or ketone/DNPH derivative
DNPH	dinitrophenylhydrazine
DR	double rub
EPA	Environmental Protection Agency
ETAC	Electrotechnology Application Center
GC	gas chromatography
GC/FID	gas chromatography/flame ionization detection
GC/MS	gas chromatography/mass spectrometry
HB	hardboard
HBVSST	oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat
HPLC	high pressure liquid chromatography
IAQ	indoor air quality
IEMB	Indoor Environment Measurement Branch
LEMs	low-emitting materials
M _{QS}	mass of quantitation standard (ng/cartridge)
M _{Tol}	mass of toluene (ng/cartridge)
M _{TVOC}	mass of TVOC (ng/cartridge)
M _{VOC}	mass of VOC (ng/cartridge)
MACT	maximum achievable control technology
MDF	medium density fiberboard
MDI	methylene diisocyanate
MEK	methyl ethyl ketone
mL/min	milliliter per min
MSDC	Mass Spectral Data Centre
MSDS	material safety data sheet
NBS	National Bureau of Standards
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NRMRL	National Risk Management Research Laboratory
P2	pollution prevention
PB	particleboard
PBM	particleboard overlaid with melamine
PBV	oak-veneered particleboard

Acronyms (continued)

PBVS	oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer
PBVST	oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
PBYY	particleboard overlaid with vinyl
PF	phenol-formaldehyde
PFT	perfluorotoluene
RH	relative humidity
RIC	reconstructed ion chromatogram
RRF _{Tol}	relative response factor for toluene
RRF _{VOC}	relative response factor for VOC
RSD	relative standard deviation
RTI	Research Triangle Institute
TVOCs	total volatile organic compounds
UF	urea-formaldehyde
UV	ultraviolet light
V _s	sample volume of chamber air (L)
V _y	total volume of sample extract (i.e., 5000 µL)
V	veneer
VOC	volatile organic compound
VOCs	volatile organic compounds

Chapter One Introduction

1.1 Background

A 1987 report by the U.S. Environmental Protection Agency (EPA) ranked indoor air pollutants as the fourth highest risk in a list of nearly 30 environmental problems.¹ A 1990 follow-up study by EPA's Science Advisory Board also identified indoor air pollution as a prime candidate for more aggressive risk reduction strategies.² The primary risk from indoor air pollutants is to human health. The high human health risk from pollutants in indoor air is a result of the following factors: 1) pollutant concentrations are higher indoors than outdoors; this occurs because indoor air includes outdoor air pollutants in addition to those pollutants generated indoors; and, 2) people spend more time indoors. On average, people spend an estimated 90 percent of their time indoors where they are exposed to the higher levels of pollutants than outdoors. Particularly sensitive populations (such as the sick, elderly, and young) often spend more time indoors than outdoors, resulting in even greater than average exposure.

Health effects from exposure to indoor air pollution range from eye, nose, or throat irritation to cancer. The high relative risk from exposure to indoor air pollution is supported by a series of long-term EPA studies of human exposure to indoor air pollutants.³ Major findings from these studies are: 1) for many pollutants, indoor levels are 2-5 times higher than outdoor levels; 2) in both rural and heavily industrialized areas, personal exposures and concentrations indoors exceed those outdoors for essentially all of the prevalent volatile organic compounds (VOCs); 3) after some activities (e.g., hobbies, painting), indoor air pollutant levels can be up to 1,000 times higher than outdoor levels; and, 4) in new non-residential buildings, levels of VOCs can be as much as 100 times higher than outdoor levels.

Sources of indoor air pollutants include both gases (organic and inorganic) and particles. The indoor environment is affected by numerous emission sources and activities that can impact indoor air quality (IAQ). The major sources of indoor air pollution can be categorized into: outdoor air, soil gas, building materials, building systems, consumer products, and human activities.

Three general approaches exist to reduce exposures to indoor air pollutants: 1) source management, i.e., controlling the source of emissions or preventing emissions indoors through use of less toxic or lower risk materials; 2) ventilation, i.e., providing general or task-specific local ventilation to reduce human exposure to pollutants in the indoor environment; and, 3) air cleaning, i.e., removing pollutants from the indoor air through filtration, adsorption, or chemical destruction.

In many cases, the most effective and efficient strategy for reducing exposure to indoor air pollution is at the source of the pollution through source management. According to the definition in the Pollution Prevention Act of 1990⁴ section (5)(A and B) the term "source reduction" means any practice which: 1) reduces the amount of any hazardous substance,

pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and 2) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. The term includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control. The term "source reduction" does not include any practice which alters the physical, chemical, or biological characteristics or the volume of a hazardous substance, pollutant, or contaminant through a process or activity which itself is not integral to and necessary for the production of a product or the providing of a service.

Source reduction or pollution prevention (P2) can be the best way to reduce risks from indoor air pollution, because it minimizes the potential for exposure to indoor air pollutants by minimizing the amount released into the indoor environment, while simultaneously reducing the environmental impacts of products used indoors throughout their life cycle. One way to reduce emissions is through the use of lower-emitting materials (LEMs). LEMs are products that have lower emissions to the indoor air than other alternatives for the same use. This encompasses the "reformulation or redesign of products, substitution of raw materials" activities listed in the definition of source reduction.

The Air Pollution Prevention and Control Division (APPCD)/Indoor Environment Measurement Branch (IEMB) of EPA's National Risk Management Research Laboratory (NRMRL) is responsible for much of EPA's IAQ research and seeks to integrate IAQ and P2 into a strategic approach to indoor source management. Strategies for improving IAQ and preventing pollution include evaluating existing data to identify LEMs; encouraging the development of LEMs, products, and equipment; and developing appropriate test methods for use by industry to promote P2. P2 projects currently underway within IEMB focus on the many sources of indoor air pollution, including office equipment, aerosol consumer products, textile products, conversion varnishes, biocontaminants, and engineered wood products.

1.2 Engineered Wood Products

Engineered wood products are used throughout residential, office, and commercial settings. Examples of products using engineered wood include computer stations, desks, entertainment units, book cases, kitchen and bathroom cabinets, counter tops, etc. Most of these products are assembled from one or more types of finished engineered wood.

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 wood particles of various sizes, whereas MDF and HB are made from wood fibers. In the US, most interior-grade PB and MDF are bonded with urea-formaldehyde (UF) resins; hardboard is bonded with phenol-formaldehyde (PF) resins.

Engineered wood is often finished prior to assembling it into a product. Panels are printed or overlaid with materials to give them a solid color, a wood grain pattern, or other decorative look. Common types of overlays include vinyl, wood veneer, and paper. Paper overlays usually contain resins to give the paper strength and durability. A protective coating

may also be applied to the paper after it is overlaid to the board. Wood veneered panels are usually coated with sealers and topcoats.

Most engineered wood products consist of three or four types of finished engineered wood. For example, a cabinet may have sides and shelves made from PB printed with a wood grain pattern; a back made from HB overlaid with a vinyl film; and a door made from MDF overlaid with wood veneer and then coated with a sealer and topcoat.

Indoor emissions from engineered wood products can arise from the engineered wood (both the wood and resin); finishing materials applied to the engineered wood; and glues used to assemble pieces of finished engineered wood together. Emissions from specific products will vary with the amount and type of materials used to construct them. For example, emissions from a cabinet made with vinyl and paper overlaid PB will differ from emissions from a cabinet made with printed PB and wood veneered MDF.

1.3 Research

In September 1993, the Research Triangle Institute (RTI) began a collaborative research effort with EPA's NRMRL/APPCD/IEMB to identify and evaluate P2 techniques to reduce indoor emissions from engineered wood products.

To begin the research, RTI reviewed the literature to characterize the engineered wood industry and to identify existing information regarding emissions from engineered wood products. Emissions from engineered wood were well characterized then, however, few studies were available on the contribution of finishing materials. RTI published these findings in the report *Sources and Factors Affecting Indoor Emissions from Engineered Wood Products: Summary and Evaluation of Current Literature*.⁵

RTI and EPA established a group of technical advisors to provide input to the research. The technical advisors included representatives from the engineered wood and wood products industries and their trade associations. These advisors played an integral role in the research by providing feedback regarding research plans, providing materials for emissions testing, and peer reviewing papers and reports of the research.

In May of 1994, RTI and EPA convened an initial research planning meeting with the technical advisors to discuss the focus and approach of the research. Since emissions from engineered wood products vary with the amount and type of materials used to construct them, the group decided that the research should focus on reducing indoor emissions from specific types of materials rather than from specific products. The objective was to reduce indoor emissions from one or two types of materials used in large quantities in a wide variety of engineered wood products. The approach to the research consisted of three major phases.

In Phase 1, emission tests were conducted to screen (i.e., estimate) emission factors of VOCs from several types of finished engineered wood. The purpose of the screening was to select a type of finished engineered wood for P2 evaluation (i.e., source reduction evaluation). In Phase 2, emission tests were conducted to determine emission factors of VOCs from components of the selected type of finished engineered wood. The purpose of the component study was to identify the source(s) of VOCs from the finished engineered wood. In Phase 3, potential LEMs were identified and evaluated as alternatives for the emission sources identified

in Phase 2.

This report presents research of Phases 1 through 3. Chapter two provides an overview of the results from each phase of the research. Chapter three presents the conclusions of the research. Chapters four through seven discuss each phase of the research in terms of their objectives, experimental design, methods, and results.

Chapter Two Results

2.1 Overview

Sections 2.2 through 2.4 present the key results from each phase of the research. In each phase of the research, emission tests were conducted to estimate or quantitate VOCs from selected materials. Multiple environmental test chambers, like the one shown in Figure 2-1, 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 (ACH) of 1/h, 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 sorbent cartridges. The mass of each VOC collected on a sorbent cartridge was either estimated (using a response factor for toluene) or quantitated (using calibration standards), depending on the objective of the emission tests. The mass of total volatile organic compounds (TVOC) collected on a sorbent cartridge was estimated using a response factor for toluene. (Chapters 4 through 7 provide detailed descriptions of how individual VOCs and TVOC were extracted and analyzed from sorbent cartridges). The estimated or quantitated masses of individual VOCs and TVOC collected on a sorbent cartridge were converted to chamber air concentrations based on the volume of chamber air that passed through the cartridge. The chamber air concentrations of individual VOCs and TVOC were then converted to emission factors (EFs) using the following equation

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

where

- C_m = measured concentration of a VOC or TVOC in a chamber air sample (µg /m³)
- ACH = air exchange rate in the test chamber
- L = loading ratio in the test chamber

An emission factor of summed VOCs for a tested material was calculated by summing the individual emission factors of VOCs for the tested material.

Throughout Chapter 2 and the remainder of the report, emission factors derived by estimating the masses of individual VOCs and TVOC on sorbent cartridges are labeled in Figures as estimated emission factors; emission factors derived by quantitating the masses of individual VOCs on sorbent cartridges are labeled in Figures as quantitated emission factors.

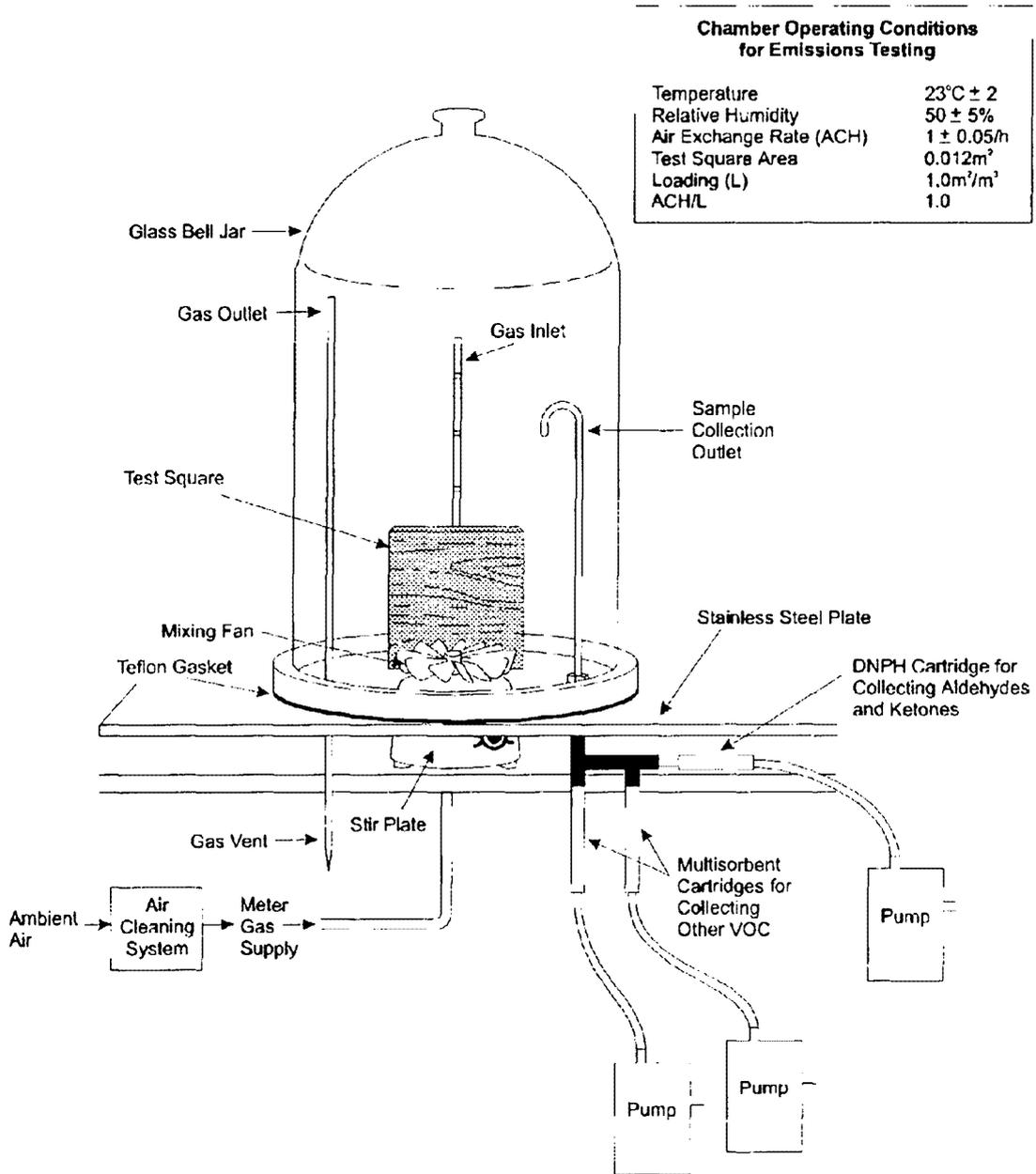


Figure 2-1. Emissions test chamber.

2.2 Phase 1

The objective of Phase 1 was to conduct emission tests to identify a type of finished engineered wood for P2 evaluation. Phase 1 testing included screening tests and quantitative decay tests.

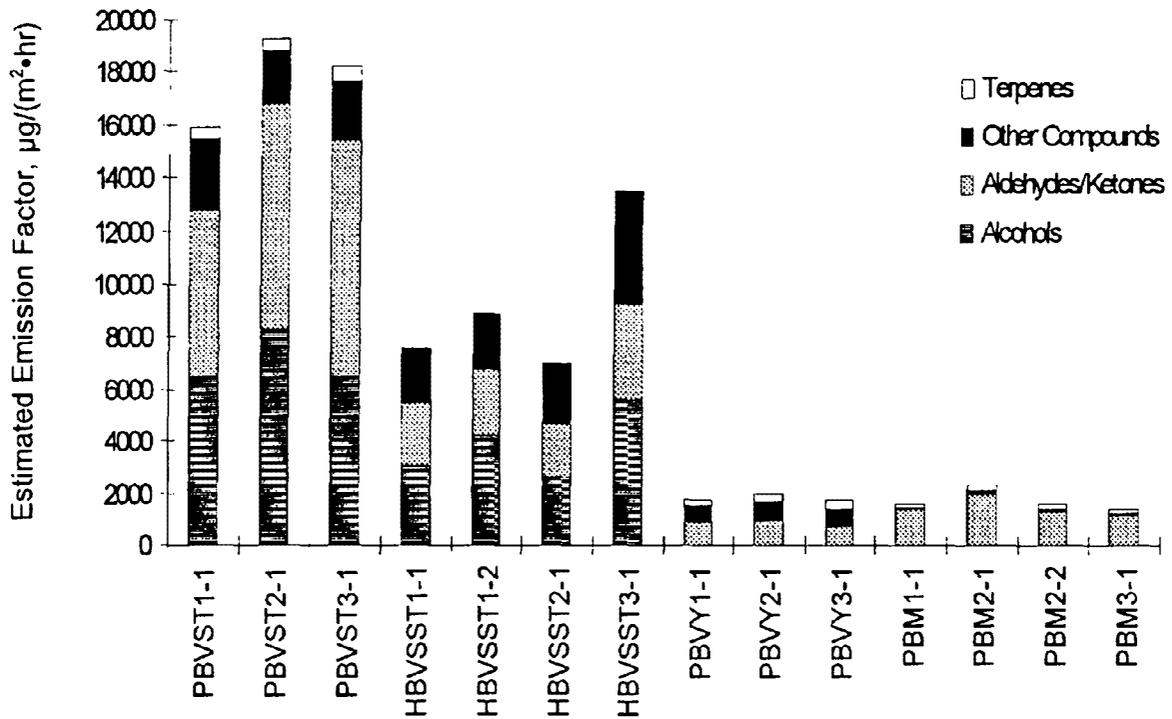
2.2.1 Screening Tests

Emission tests were conducted to screen (i.e., estimate) initial emission factors of summed VOCs for four types of finished engineered wood; these included oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat (PBVST); oak-veneered hardboard coated and cured with a stain, and an 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. These materials were selected for screening because they were identified by focus group members as materials used to construct a high volume of engineered wood products (MDF was also identified as a type of material used to construct a high volume of engineered wood products, however, it could not be acquired for the screening). Samples of the engineered wood were collected from a single manufacturer of finished engineered wood; the samples were collected from the end of the manufacturing line.

Figures 2-2 and 2-3 present estimated emission factors of summed VOCs and aldehydes and ketones, respectively, for test squares of PBVST, HBVSST, PBVY, and PBM conditioned under typical indoor conditions (23 °C, 50% relative humidity [RH], and one air exchange [ACH]). (Tables A-1 through A-4 in Appendix A list emission factors of individual VOCs, aldehydes and ketones for each of the test squares). Figure 2-2 shows that initial emission factors of summed VOCs were substantially higher for test squares of PBVST and HBVSST relative to those 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 (i.e., the sealer and topcoat). Terpenes were only detected from test squares made with PB. Terpenes are volatile constituents of certain wood species such as pine (used to make the PB). Terpenes are not major constituents of hardwood species, which are used to manufacture HB. The presence of terpenes in emissions from the PB test squares suggests that they may permeate through all three types of finishes, (i.e., veneer with coatings, melamine, and vinyl).

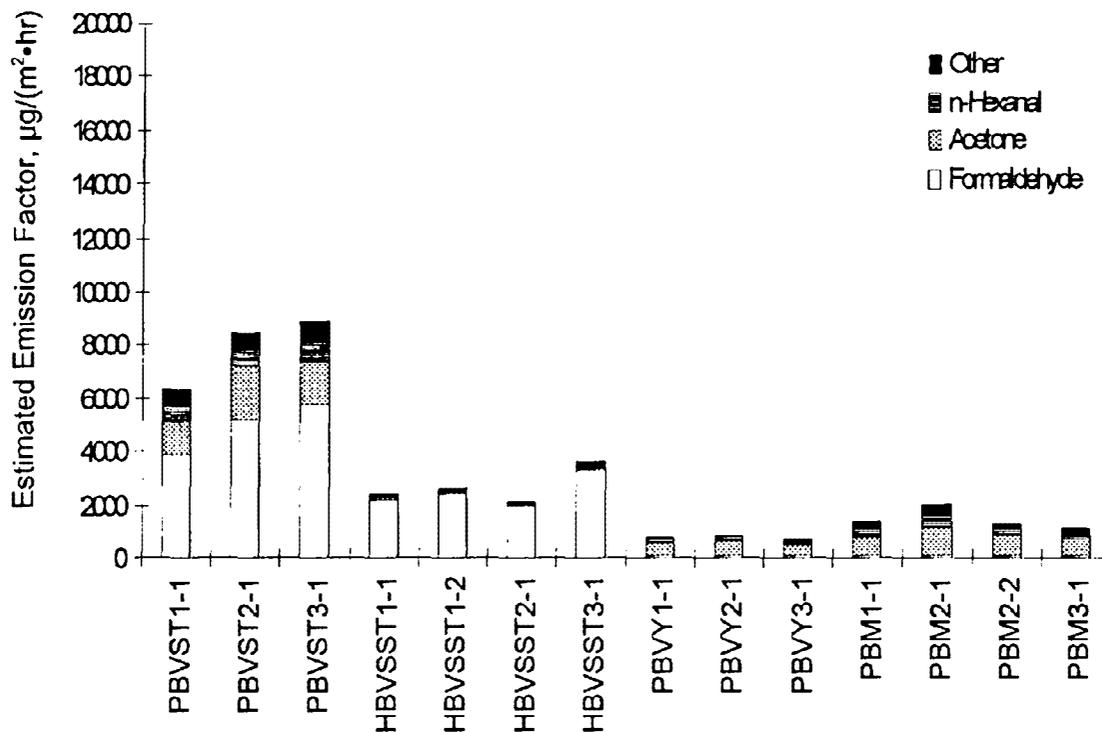
In Figure 2-3, *n*-hexanal was unique to test squares made with PB. Acetone was emitted primarily from test squares made from PB, although small amounts were measured from test squares of HBVSST. Acetone and *n*-hexanal have been associated with wood fibers in certain types of engineered wood panels.⁶ The fact that these compounds were not detected in the emissions from the HB test squares suggests that these compounds may be specific to certain wood species or specific types of engineered wood.

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. The acid catalyzed alkyd-urea sealer and topcoat were believed to be the major reason for these differences.



Test squares are labeled by material acronym (PBVST, HBVSST, PBVY, or PBM), followed by sample number (1, 2, or 3), followed by test square number (1 or 2), where
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
 HBVSST = oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat
 PBVY = particleboard overlaid with vinyl
 PBM = particleboard overlaid with melamine
 Emissions variability between samples is shown by test squares with the same material acronym, but different sample numbers. Emissions variability within samples is shown by test squares with the same material acronym and sample number, but different test square numbers.

Figure 2-2. Estimated emission factors of summed VOCs for test squares of finished engineered wood conditioned for six hours.



Test squares are labeled by material acronym (PBVST, HBVSST, PBVY, or PBM), followed by sample number (1, 2, or 3), followed by test square number (1 or 2), where
 PBVST = oak-veneered particleboard coated and cured with a acid catalyzed alkyd-urea sealer and topcoat
 HBVSST = oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat
 PBVY = particleboard overlaid with vinyl
 PBM = particleboard overlaid with melamine
 Emissions variability between samples is shown by test squares with the same material acronym, but different sample numbers. Emissions variability within samples is shown by test squares with the same material acronym and sample number, but different test square numbers.

Figure 2-3. Estimated emission factors of aldehydes and ketones for test squares of finished engineered wood conditioned for six hours.

Research has shown that catalyzed alkyd-urea coatings release formaldehyde over time as part of their curing process.⁷

2.2.2 Quantitative Decay Tests

As a final step in the selection of a type of finished engineered wood for P2 evaluation, emission tests were conducted to quantitate emission factors over time for PBVST and HBVSST. The purpose of the quantitative decay tests was to evaluate potential emissions from PBVST and HBVSST at a time when they might be installed in an indoor environment as part of an assembled product.

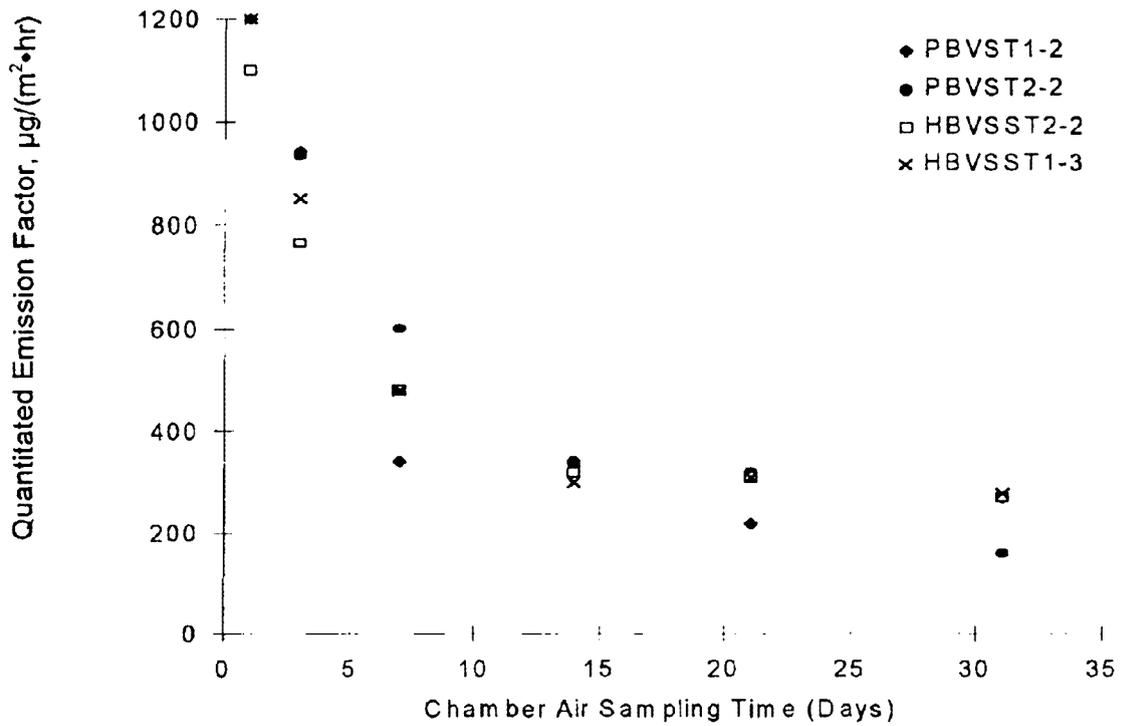
Figure 2-4 shows quantitated emission factors of formaldehyde over time for test squares of PBVST and HBVSST. All test squares showed a rapid decay of formaldehyde during the first week of sampling. By the fourth time point (14 days), formaldehyde emission factors for PBVST and HBVSST appeared to level out to approximately 300 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, which was substantially higher than initial emission factors of formaldehyde from PBVY and PBM [initial emission factors ranged from 51 to 90 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$]. Based on these results and those from the screening tests, PBVST was selected for P2 evaluation.

2.3 Phase 2

The objective of Phase 2 testing was to identify the source(s) of emissions from PBVST. Emission tests were conducted to quantitate emission factors for various components of PBVST; these included particleboard (PB); veneer (V); oak-veneered particleboard (PBV); oak-veneered particleboard coated and cured with an catalyzed alkyd-urea sealer (PBVS); and oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat (PBVST). Samples of the components were collected directly from a manufacturing line (the same manufacturing line from which samples of PBVST were collected in Phase 1).

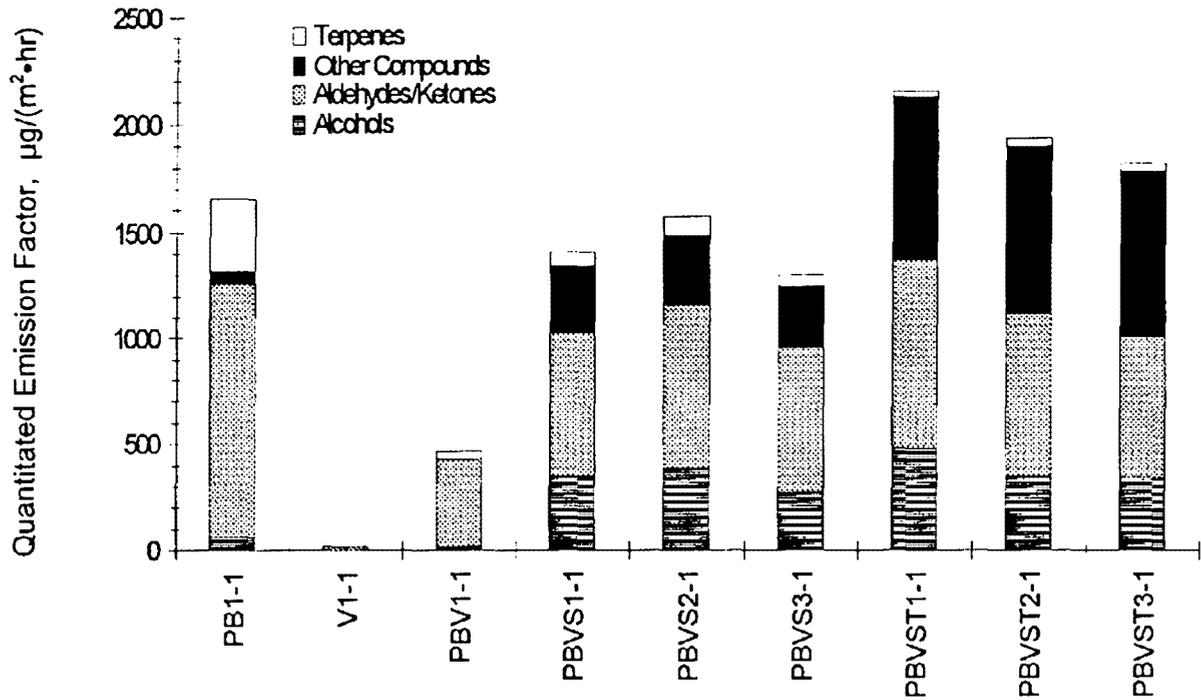
Figures 2-5 and 2-6 present quantitated emission factors of summed VOCs and aldehydes and ketones, respectively, for test squares of PB, V, PBV, PBVS, and PBVST conditioned/aged under typical indoor conditions for 31 days. (Table B-1 in Appendix B lists emission factors of individual VOCs, aldehydes and ketones for each of the test squares.) As shown in Figure 2-5, emission factors of summed VOCs for PB and PBV were 1600 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ 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 polyvinyl acetate (a white glue) and an UF resin; the mixture contains less than 0.6% formaldehyde.) Since the emission factor of summed VOCs for PBV was substantially 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.



Test squares are labeled by material acronym (PBVST or HBVSST), followed by sample number (1 or 2), followed by test square number (2 or 3), where
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
 HBVSST = oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat
 Emissions variability between samples is shown by test squares with the same material acronym, but different sample numbers.

Figure 2-4. Quantitated emission factors of formaldehyde for test squares of finished engineered wood conditioned for 31-days.



Test squares are labeled by material acronym (PB, V, PBV, PBVS, or PBVST), followed by sample number (1, 2, or 3), followed by test square number (1), where

PB = particleboard

V = veneer

PBV = oak-veneered particleboard

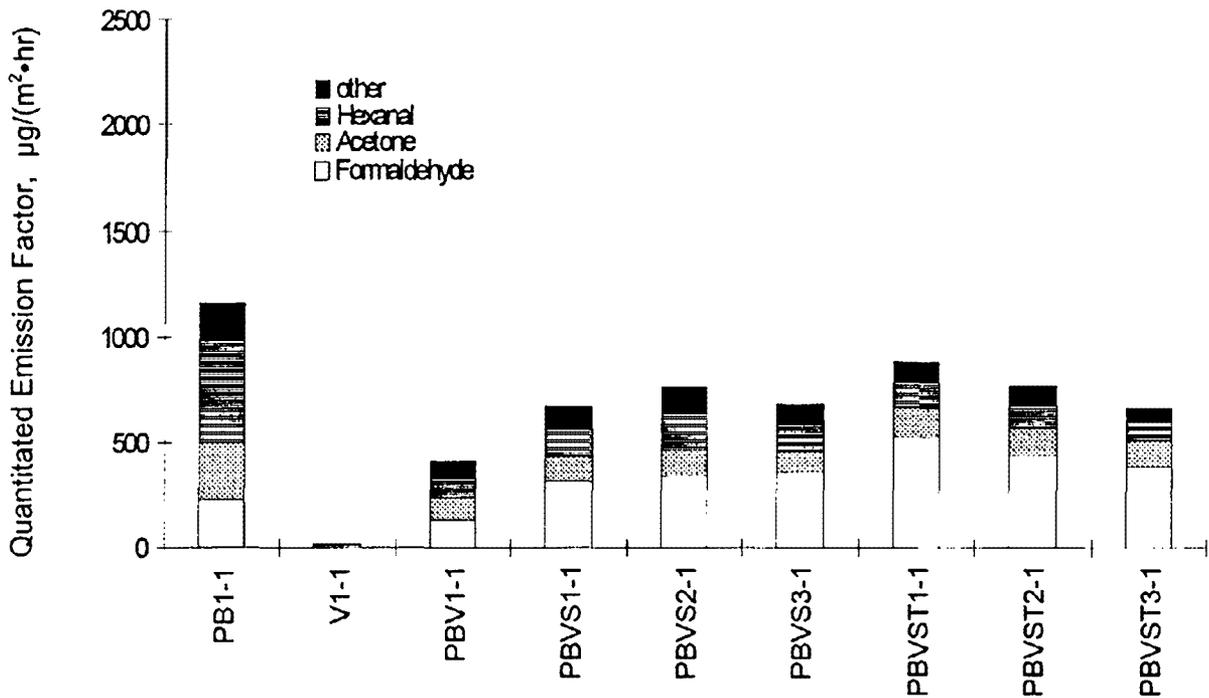
PBVS = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer

PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat

PB, V, PBV, PBVS, and PBVST all came from the same manufacturer.

Emissions variability between samples is shown by test squares with the same material acronym, but different sample numbers.

Figure 2-5. Quantitated emission factors of summed VOCs for test squares of components of finished engineered wood conditioned for 31-days.



Test squares are labeled by material acronym (PB, V, PBV, PBVS, or PBVST), followed by sample number (1, 2, or 3), followed by test square number (1), where
 PB = particleboard
 V = veneer
 PBV = veneered particleboard
 PBVS = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
 PB, V, PBV, PBVS, and PBVST all came from the same manufacturer.
 Emissions variability between samples is shown by test squares with the same material acronym, but different sample numbers.

Figure 2-6. Quantitated emission factors of aldehydes and ketones for test squares of components of finished engineered wood conditioned for 31-days.

As shown in Figure 2-6, emission factors of *n*-hexanal for PB and PBV were 490 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ and 97 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, respectively. Emission factors of acetone for PB and PBV were 270 and 110 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, respectively. The presence of *n*-hexanal and acetone in emissions from the test square of PB supports the hypothesis from Phase 1 that these compounds are associated with the wood in the PB. The lower emission factors of acetone and *n*-hexanal for the PBV test square relative to those for the PB test square suggests that the veneer suppressed emissions of these compounds from the PB. PBV, PBVS, and PBVST all had similar emission factors of *n*-hexanal and acetone, which also supports the hypothesis from Phase 1 that these compounds are emitted from the wood in the PB rather than the coatings.

Emission factors of formaldehyde for PB and PBV were 230 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ 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.

2.4 Phase 3

Phase 2 testing identified acid catalyzed alkyd-urea coatings and UF bonded PB as potential sources of emissions from PBVST. The objective of Phase 3 was to identify and evaluate potentially low-emitting substitutes for these materials.

2.4.1 Coatings Evaluation

Five alternative coatings systems (where coatings system = sealer and topcoat) were identified as potentially low-emitting substitutes for the acid catalyzed alkyd-urea coatings system (Table 2-1). Standard industry tests for performance of wood coatings and quantitative emission tests were conducted on test squares of PBV coated and cured with the six coatings systems.

Table 2-1. 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 2-2 presents the results of the performance tests. In this table, Coating 1 refers to test squares of PBV finished with an acid catalyzed alkyd-urea sealer and topcoat (the type of coatings system identified as a potential source of emissions from PBVST in Phases 1 and 2). Coatings 2 through 6 refer to test squares of PBV finished with five alternative coatings systems. Comparing the performance ratings of the alternative coatings systems to the ratings of Coating

1 (the benchmark coating) provides an indication of the ability of the alternative coatings systems to achieve the performance of Coating 1. Coatings 3, 4, and 5 outperformed Coating 1 in the methyl ethyl ketone (MEK) test. Coatings 4 and 5 outperformed Coating 1 in the mustard test. For the stain tests, Coatings 2, 4, 5, and 6 performed the same as Coating 1; Coating 3 performed fairly well in the stain tests except for its performance with grape juice and coffee. All coatings performed equally well in the adhesion and fingernail mar resistance tests. Coatings 4 and 5 had gloss ratings that differed substantially from that of Coating 1.

One caveat to the performance data is that measurements of hardness and chemical resistance depend on how much time has elapsed since a coating is cured. Some coatings gradually develop their hardness and chemical resistance over a period of one to two weeks. Standard industry practice is to wait two weeks after cure before running chemical resistance tests; hardness tests are usually measured at 1, 3, 7, 14, 31, and 93 days after cure. For this evaluation, mustard and stain tests were performed one to two weeks after the coatings were cured; MEK tests were performed on the same day the coatings were cured; and hardness tests were measured one to two days after the coatings were cured. The coatings in Table 2-2 differ mainly in how they performed in the MEK and mustard tests; since time is a critical factor in developing chemical resistance, some of the coatings that performed poorly, may have improved with time.

Table 2-3 presents mean emission factors for test squares of PBV coated and cured with each of the six coatings systems and for test squares of uncoated PBV (all of the test squares were conditioned for 28 days prior to measuring their emissions). (Tables C2 through C9 in Appendix C present emission factors for individual test squares finished with each of the coatings systems and emission factors for individual test squares of lab and field coupons; these tables also show emissions variability among test squares with the same coatings system.) 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 and that these coatings systems suppressed emissions from the veneered particleboard.

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

Table 2-2. Performance Tests of Coatings Systems

Performance Tests	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Chemical Resistance						
1) MEK Test ¹	20	10	100	100	100	10
2) Mustard Test (1 hr/24 hr) ²	4/8	2/6	2/3	10	8/9	4/6
3) Stain Test (24 hr) ³						
Vinegar	10	10	10	10	10	10
Lemon	10	10	10	10	10	10
Orange Juice	10	10	10	10	10	10
Grape Juice	10	10	8	10	10	10
Tomato Catsup	10	10	10	10	10	10
Coffee	10	10	8	10	10	10
Olive Oil	10	10	10	10	10	10
100-proof Alcohol	10	10	10	10	10	10
Detergent and Water	10	10	10	10	10	10
Water	10	10	10	10	10	10
Adhesion ⁴	5B	5B	5B	5B	5B	5B
Gloss ⁵	46	40	51	61	65	48
Hardness ⁶	74	77	74	72	77	71
Fingernail Mar Resistance ⁷	VG	VG	VG	VG	VG	VG

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

¹ The MEK Test is a test where a cloth saturated with methyl ethyl ketone (MEK) is rubbed in a back and forth motion or double rub (DR) on the surface of a coated substrate. The ratings for the MEK Test are the number of DR's until the first sign of substrate or to a maximum of 100 DR.

² Mustard tests were performed according to the procedures of the covered spot test in ASTM D1308⁸. For the test, a few drops of mustard were applied to the horizontal surface of a coated substrate; the drops were covered with a watch glass to prevent them from evaporating. The watch glass was removed after one hour and the mustard washed off with water. The coated substrate was examined for damages to the coating such as discoloration, changes in gloss, blistering, softening, swelling, and loss of adhesion. If no damages were seen, the coating was given a rating of 10 and the test stopped. If the mustard damaged the coating, the spot was evaluated 23 hours later (24 hours after the mustard was washed off) to determine if the coating improved over the interval; the coating was rated from 0 to 10.

³ The individual stains were performed according to the procedures of the covered spot test in ASTM D1308 and using stains outlined by ANSI/KCMA A161.1-1990, 9.3.⁹ The stains were applied in the same manner as the mustard, except that the stains were left on the coated substrate for 24 hours, at which point the stain was rinsed off, and the coating rated from 0 to 10 depending on its damage (a score of 10 indicated no damage to the coating).

⁴ Adhesion was tested according to ASTM D3359;¹⁰ a rating of 5B is the highest adhesion.

⁵ Gloss was measured according to ASTM D523¹¹ using a Gloss Checker (1G-310 manufactured by Horiba); gloss ratings ranged from 0 to 120, with the latter being the highest value.

⁶ Hardness was measured according to ASTM D2240¹² using a Durometer (Model 307L manufactured by PTC Instruments); the ratings are 0 to 100, with 100 being the highest value.

⁷ Fingernail mar resistance was measured subjectively; VG = very good.

Table 2-3. Quantitated Mean Emission Factors for Uncoated and Coated Test Squares Conditioned for 28 Days

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
Acetaldehyde	61	53	41	65	68	41	68
Acetone	420	520	490	380	390	430	510
Propionaldehyde	21	16	15	16	16	12	17
2-Butanone	*	-	-	-	-	-	-
Butyraldehyde	15	-	-	18	-	-	12
Benzaldehyde	23	-	-	30	14	18	23
Valeraldehyde	65	37	26	54	28	19	57
m-Toluakdehyde	-	-	-	-	-	-	-
n-Hexanal	410	150	120	280	79	93	350
1-Pentanol	62	150	16	38	13	14	49
Limonene	79	68	54	74	38	37	83
Junipene	89	61	24	54	16	13	67
Terpenes	170	320	220	170	110	100	120
1-Butanol	6	800	-	5	-	8	7
Toluene	-	16	-	5	22	-	6
2-Methyl-1-butanol	-	55	-	-	-	-	-
Butyl acetate	-	38	-	-	-	-	-
1,2-Propanediol	-	15	-	33	-	-	-
Ethylbenzene	-	270	-	-	33	-	-
m,p-Xylene	-	660	-	-	110	-	-
2-Heptanone	15	550	8	13	9	7	22
o-Xylene	-	210	-	-	32	-	-
Propylbenzene	-	91	-	-	-	-	-
Ethyl 3-ethoxypropionate	-	110	-	-	-	-	-
1-Methyl-2-pyrrolidone	-	11	-	20	-	5	2400
2-(2-Butoxyethoxy)ethanol	8	1700	43	610	18	6	7
Naphthalene	-	24	-	-	-	-	-
Hexyl acetate	-	400	-	-	-	-	-
Indan	-	13	-	-	-	-	-
C3-Benzenes	-	1100	-	-	-	-	-
C4-Benzenes	34	190	25	33	17	16	33
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

* < 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

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, C₄- benzenes, 2-(2-butoxyethoxy)ethanol] 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.

A few caveats exist regarding the emissions tests. Certain nonvolatile compounds that were listed in the MSDS for some of the coatings systems were not analyzed for in the emission tests; these included nitrocellulose, p-toluene sulfonic acid, hexamethylene diisocyanate, polyisocyanates, acrylate oligomers, and acrylic polymers. These compounds were not analyzed for in the emission tests for the following reasons: (1) they were not expected to be emitted into the air during testing (because of their low volatility); (2) they were not expected to recover efficiently from the emission test chambers and, (3) they were not expected to be amenable to the analytical methods used for this study. Certain volatile compounds that were listed in the MSDS for some of the coatings systems were also not analyzed for in the emission tests; these included acrylate monomers, N,N-dimethylethanolamine, and ammonia. Acrylate monomers and N,N-dimethylethanolamine were not analyzed for in the emission tests because they were not amenable to the analytical methods in the study and because they were not expected to recover efficiently during the chamber tests (due to their polar nature). Ammonia was not tested for in the emission tests because it was not amenable to the analytical methods in the study.

2.4.2 Fiber Panel Study

Six types of engineered fiber panels were identified as potentially low-emitting materials for constructing engineered products for interior applications (Table 2-4). Emissions were screened from the six types of engineered fiber panels and PB manufactured with wood fibers and UF resins. (The UF bonded PB tested during the fiber study did not come from the same source as the UF bonded PB tested in Phases 1 and 2.) Emissions were also screened from a few finished engineered fiber panels (Table 2-5). Due to limited resources, only a few types of finished engineered panels could be screened.

Samples of unfinished engineered fiber panels were collected from the end of the manufacturing line. For Product E, panels were collected from the manufacturing line after they were treated with ammonia (a treatment used to reduce formaldehyde emissions from the unfinished panels). Except for Product O, samples of finished panels H, I, J, and M were also collected from the end of the manufacturing line. For Product O, samples of unfinished oak-veneered wheatboard were collected from the end of the manufacturing line. The samples were sent to a coatings facility where they were coated and cured with the two component polyurethane that was evaluated in the Phase 3 (Coating 2). The finished coupons were sent back to RTI for emissions testing.

Table 2-4. Selected Engineered Panels

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

^a MDI = Methylene diisocyanate

^b PB = particleboard

^c MDF = medium density fiberboard

^d UF = Urea-formaldehyde

^e PF = Phenol-formaldehyde

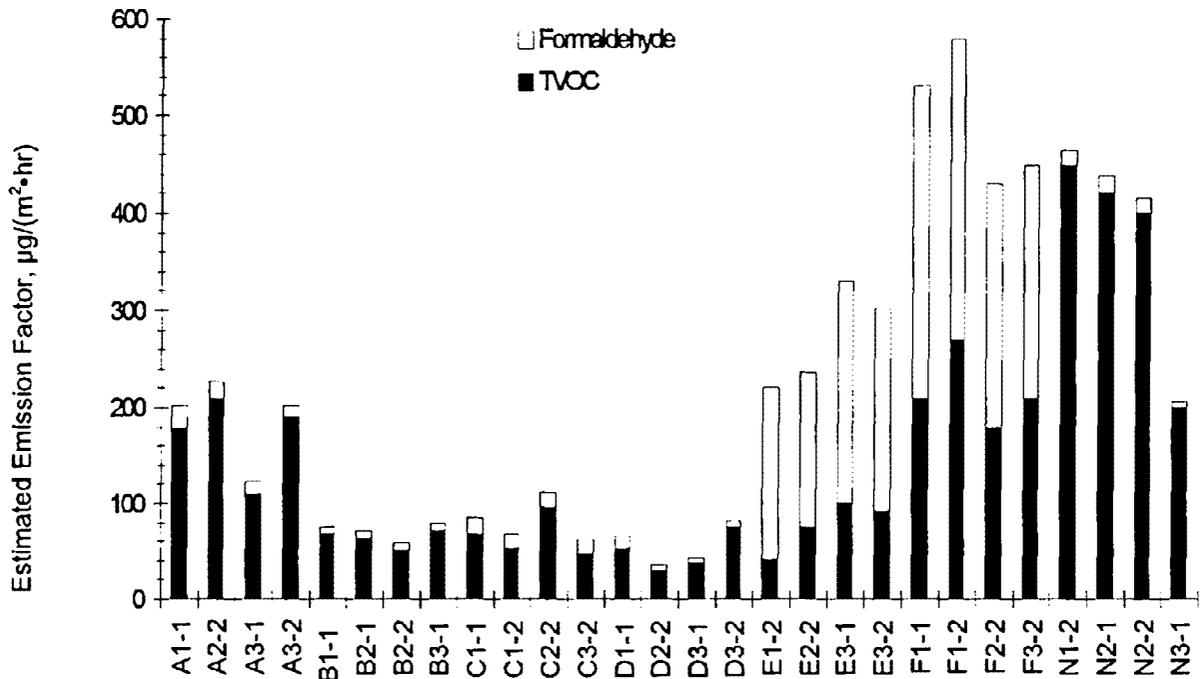
^f The manufacturing process does not require adhesive or resin to form the fibers into a panel; once the panels are manufactured, they are glued together (in sets of two) using a white, polyvinyl acetate glue.

Table 2-5. Finished Engineered Fiber Panels Selected for Screening

Panel Identification	Description
H	Product B (wheatboard) with veneer
I	Product B overlaid with vinyl
J	Product B overlaid with melamine
M	Product C (recycled corrugated cardboard) painted
O	Product B coated and cured with two component polyurethane coating

2.4.2.1 Emission Tests

Figure 2-7 presents emission factors of total volatile organic compounds (TVOC) and formaldehyde for test squares of unfinished engineered fiber panels (TVOC does not include formaldehyde). (Appendix D presents emission factors of individual VOCs for the test squares.) The TVOC and formaldehyde data were statistically analyzed to ascertain which test squares differed with respect to their emissions 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.



Test squares are labeled by material letter (A, B, C, D, E, F, or N), followed by sample 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 = ammonia treated medium density fiberboard with urea-formaldehyde (UF) resin

F = particleboard with UF resin

N = particleboard with phenol-formaldehyde resin

Emissions variability between samples is shown by test squares with the same material letter, but different sample numbers. Emissions variability within samples is shown by test squares with the same material letter and sample number, but different test square numbers.

TVOC = total volatile organic compounds

Figure 2-7. Estimated emission factors of TVOC and formaldehyde for test squares of engineered panels conditioned 26 to 30 days.

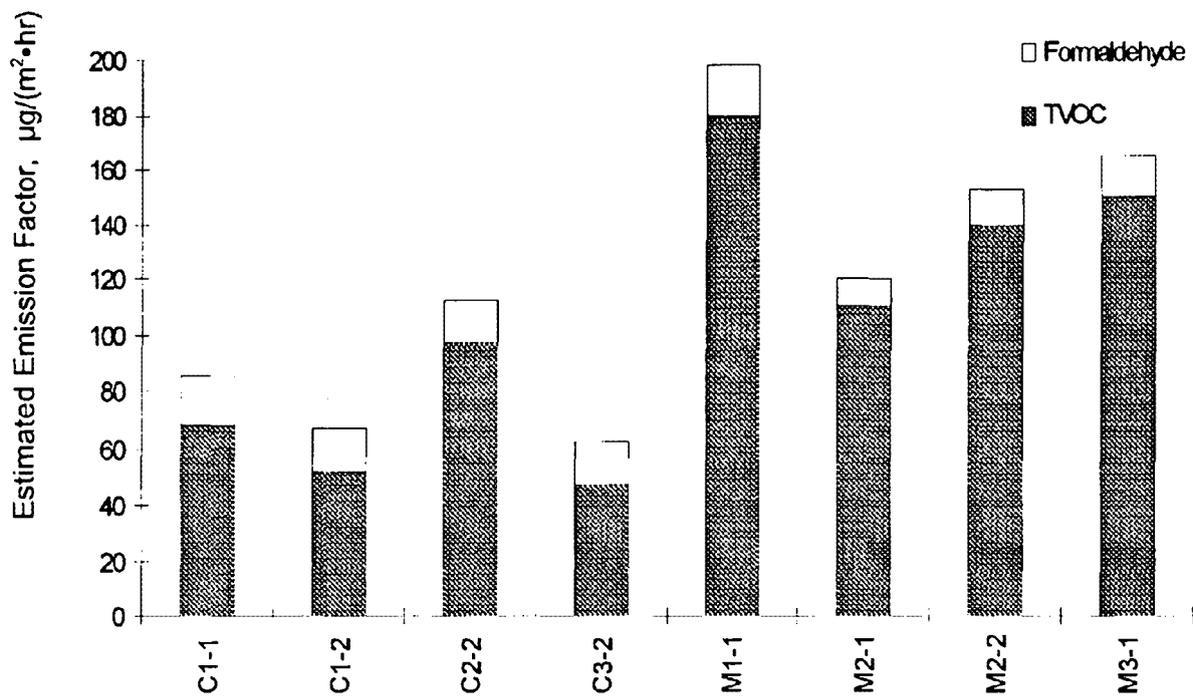
Figures 2-8 and 2-9 present emission factors of TVOC and formaldehyde for test squares of finished recycled corrugated cardboard and wheatboard, respectively; test squares of unfinished recycled corrugated cardboard and wheatboard are also shown for reference. Test squares of recycled corrugated cardboard finished with paint (Product M) had slightly higher emission factors of TVOC than the unfinished test squares of recycled corrugated cardboard (Product C). Emission factors of formaldehyde were fairly consistent between the unfinished and finished test squares.

As shown in Figure 2-9, emission factors of formaldehyde for test squares of oak-veneered wheatboard (Product H) were substantially higher compared to emission factors of formaldehyde for test squares of unfinished wheatboard (Product B). In the Phase 2 component study, formaldehyde emissions were not detected from the veneer. The elevated formaldehyde emissions from the oak-veneered wheatboard are likely due to the UF glue used to adhere the veneer to the wheatboard. Emission factors of formaldehyde for test squares of oak-veneered wheatboard coated and cured with the two component polyurethane were lower than those for test squares of unfinished oak-veneered wheatboard. The coatings evaluation showed that the mean emission factor of formaldehyde for test squares of PBV coated and cured with the two component polyurethane was very low [approximately 21 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$]. The coating appears to be suppressing formaldehyde emissions from the UF glue.

2.4.2.2 Performance Characteristics

Due to limited resources, the fiber study did not measure physical properties of the engineered fiber panels such as density, modulus of rupture, modulus of elasticity, etc. Instead, these properties were provided by the panel manufacturers (see Table D-1 of Appendix D).

According to the manufacturer of the wheat panel made with MDI resin, this panel can be used in the same manner as PB to construct finished engineered wood products; it is currently being manufactured with a variety of finishes such as wood veneer, melamine, vinyl, and paper for the construction of kitchen cabinets. The manufacturer of the panel made from recycled corrugated cardboard states that the panel can be used to construct store displays, countertops, shelving, furniture and cabinets, etc; it is currently being manufactured with finishes such as wood veneer and paint. The MDF panel made with MDI resin can be used in the same manner as UF bonded MDF in the construction of engineered wood products. Product literature for the engineered panel made from recycled newspaper lists the following applications for the panel: a construction material for office partitions, a filler material for furniture (such as bed boards), hobby boards (such as train boards), carpet underlayment, sidewall sheathing, ceiling panels, etc; it can be covered with a fabric for decorative purposes.



Test squares are labeled by material letter (C or M), followed by sample number, followed by test square number, respectively, where

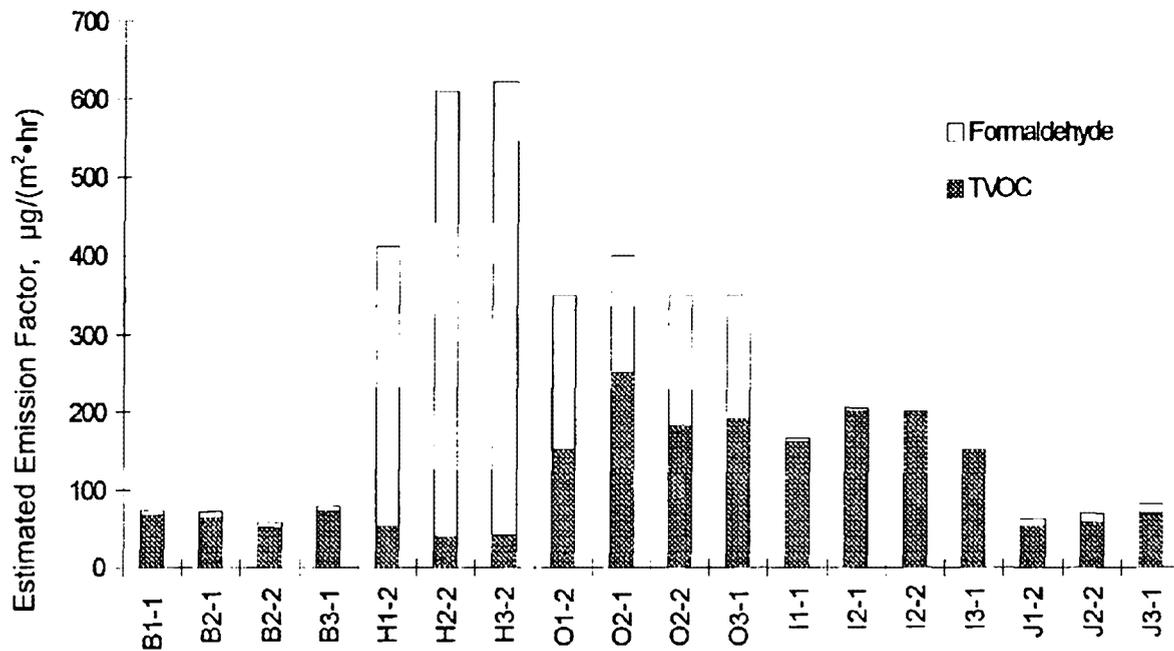
C = unfinished panel made from recycled corrugated cardboard

M = panel made from painted recycled corrugated cardboard

Emissions variability between samples is shown by test squares with the same material letter, but different sample numbers. Emissions variability within samples is shown by test squares with the same material letter and sample number, but different test square numbers.

TVOC = total volatile organic compounds

Figure 2-8. Estimated emission factors of TVOC and formaldehyde for unfinished and finished test squares of recycled corrugated cardboard conditioned 26 to 28 days.



Test squares are labeled by material letter (B, H, O, I, or J), followed by sample number, followed by test square number, respectively, where

B = unfinished wheatboard

H = veneered wheat board

O = veneered wheat board with heat curable two component polyurethane coating

I = wheatboard with vinyl

J = wheatboard with melamine

Emissions variability between samples is shown by test squares with the same material letter, but different sample numbers. Emissions variability within samples is shown by test squares with the same material letter and sample number, but different test square numbers.

TVOC = total volatile organic compounds

Figure 2-9. Estimated emission factors of TVOC and formaldehyde for unfinished and finished wheatboard conditioned approximately 28 days.

Chapter Three 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.
- The screening materials collected in Phase 1 were collected at a single time point from the manufacturing line. These samples should be collected several weeks or months apart from the same manufacturing line and tested to assess emissions variability within samples from the same manufacturing line. Engineered fiber panels tested in Phase 3 should also be collected and tested at various intervals from the same manufacturing line, particularly, panels made from recycled materials; for the latter, emissions may vary if the composition of the recycling material varies.
- 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, clean up, manufacturing emissions, etc. The cost of the coatings should be assessed in terms of equipment needs, e.g., stainless steel or plastic pipes for waterborne coatings, UV lights for UV coatings. Performance tests should also be conducted at critical time points.

- Standard air sampling methods and recovery techniques should be developed for compounds that could not be analyzed during the coatings evaluation, such as hexamethylene diisocyanate, polyisocyanates, acrylate oligomers, and acrylic polymers.
- A broader study of the low-emitting engineered fiber panels should be conducted to assess manufacturing issues (such as cost, worker safety) involved with making the panels. Performance tests should also be conducted on the panels.

Chapter Four Phase 1 Screening Study

4.1 Overview

As discussed in the overview of the report, the objective of the research was to investigate P2 options for reducing indoor emissions from a specific type of finished engineered wood rather than a whole product. A screening study was conducted to select a type of finished engineered wood for P2 evaluation.

The following materials were selected for screening:

- PBVST (oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat)
- HBVSST (oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat)
- PBM (particleboard overlaid with melamine)
- PBVY (particleboard overlaid with vinyl)

These materials were selected for screening because they were identified by focus group members as materials used to construct a high volume of engineered wood products.

4.2 Objectives

The objective of the screening study was to select a type of finished engineered wood for P2 evaluation. 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 determine if emission factors decreased over time due to sample conditioning. As explained in the Section 4.4, these tests were only conducted on PBVST and HBVSST.

4.3 Experimental Design

4.3.1 *Sample Collection*

Samples of PBVST, HBVSST, PBVY, and PBM were collected from a large manufacturer of finished engineered wood products. The manufacturer purchases PB and HB, finishes the PB and HB, and then assembles the finished boards into engineered wood products. The PB is purchased from a single supplier and is made from wood particles (made from pine) and UF resins. The HB is made with wood fibers (made from hardwood species) and PF resins. Three samples of each of PBVST, HBVSST, PBM, and PBVY were collected directly from the finishing line (Figure 4-1). Three coupons were cut from the center of each sample. All coupons cut from the same sample were placed in a steel container with an airtight lid. The containers were transported to RTI within one to four days of manufacture. Upon

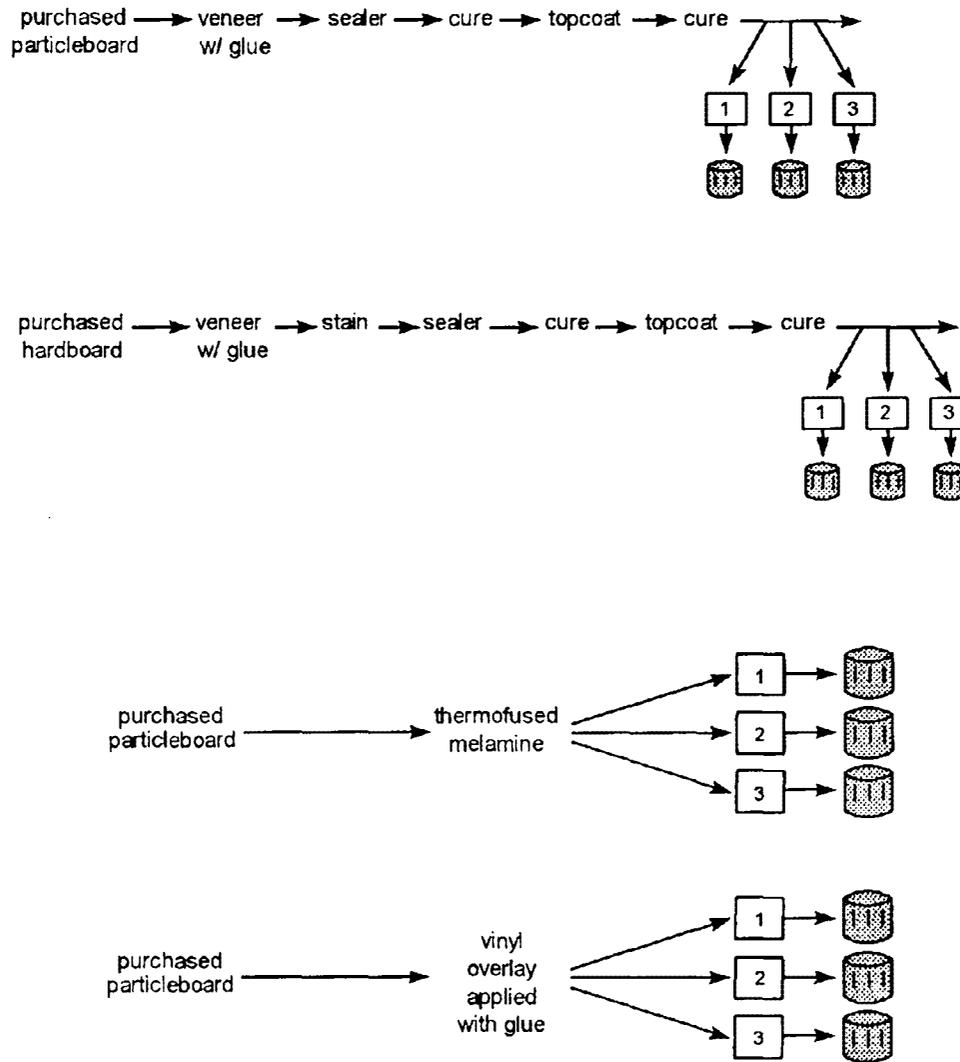


Figure 4-1. Sample collection for Phase 1.

arrival at RTI, the coupons were removed from their containers and visually inspected to ensure that the coupons remained intact during transportation. The coupons were resealed in their containers and then placed in a freezer operating at -10 to -20 °C to minimize losses of VOCs from the coupons prior to testing.

4.3.2 Chamber Air Collection

Screening tests were conducted within three weeks of sample collection. For these tests, containers of each material were removed from the freezer and allowed to warm to room temperature. A select number of coupons of each material were removed from the containers and visually inspected to determine that the finishes on the coupons remained intact during storage. The coupons were prepared into 0.0762 by 0.0762 m (~0.006 m²) test squares (containers with unused coupons were returned to the freezer). 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 (Figure 4-2). Table 4-1 lists the operating conditions of the test chambers. Chamber air samples for measuring VOCs were collected six hours after each test square was placed in a test chamber.

Table 4-1. Conditions For Chamber Testing for Screening and Decay Tests

Test Parameters	Conditions
Chamber Size	0.012 m ³
Temperature	23°C
Relative Humidity	50%
Air Exchange Rate (ACH)	1/h
Source Area (A)	~0.012 m ²
Loading (L)	1.0 m ² /m ³

Quantitative decay tests were conducted approximately ten weeks after sample collection. For these tests, containers of PBVST and HBVSST were removed from the freezer and allowed to warm to room temperature. Remaining coupons of PBVST and HBVSST were removed from the containers and visually inspected to determine that the finishes on the coupons remained intact during storage. The coupons were prepared into test squares as described above. The test squares were placed in individual test chambers that operated at the conditions shown in Table 4-1. Chamber air samples for measuring VOCs were collected 1, 3, 7, 14, 21, and 31-days after each test square was placed in a test chamber. The decay tests were carried out for 31-days to estimate potential indoor emissions from PBVST and HBVSST. According to the manufacturer of PBVST and HBVSST, 31-days represents the typical time lag between when these materials are manufactured and when they arrive in an indoor environment as part of an assembled product.

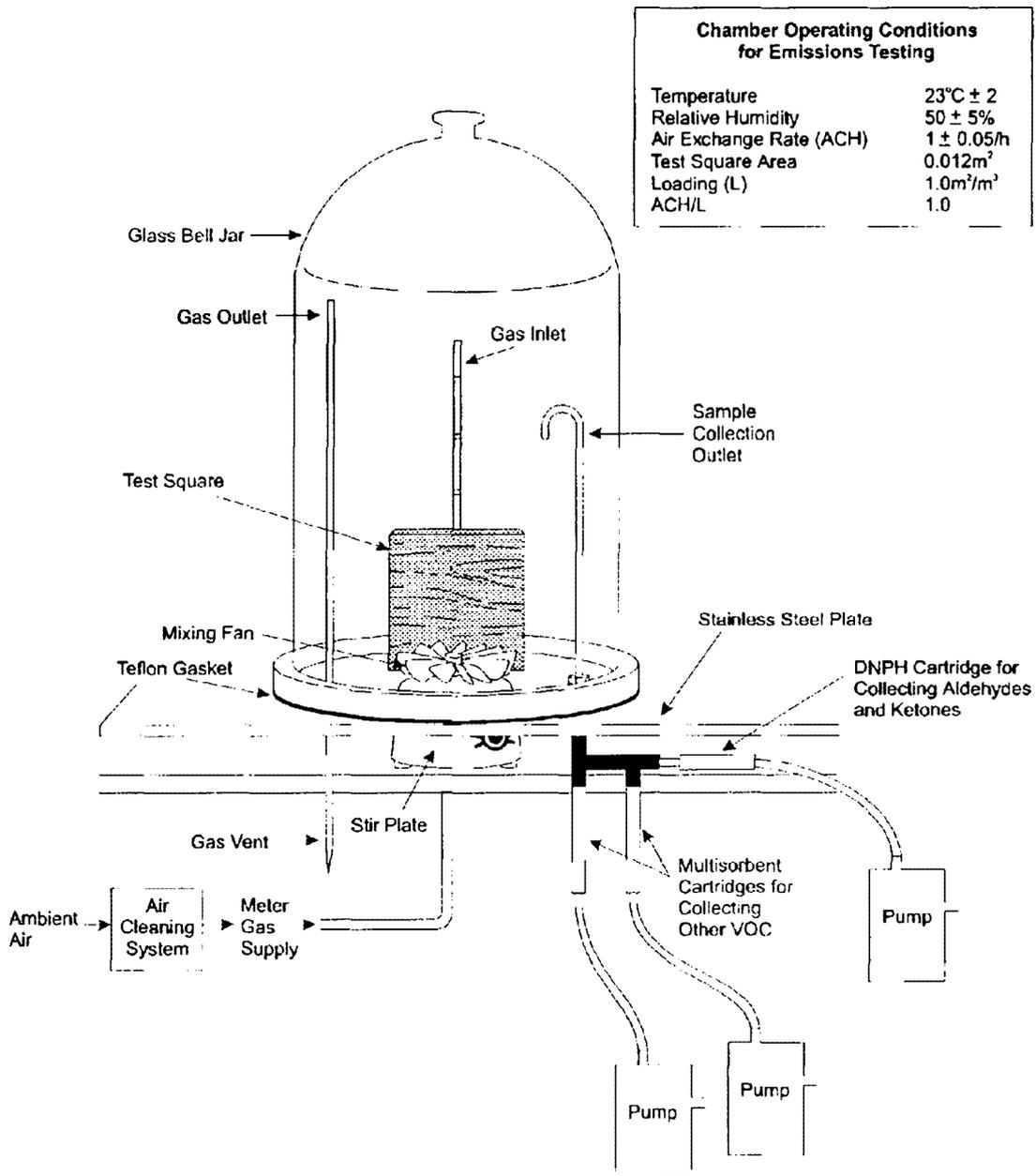


Figure 4-2. Emissions test chamber.

4.3.3 VOCs Collection

VOCs in the chamber air samples were collected by passing chamber air through one dinitrophenylhydrazine (DNPH)-coated silica gel cartridge and two multisorbent cartridges containing Tenax TA, charcoal, and Ambersorb (Figure 4-1 shows the arrangement of the cartridges for collecting VOCs). DNPH cartridges are designed to collect aldehydes and ketones. Multisorbent cartridges are designed to collect other types of VOCs.

Chamber air was passed through the DNPH cartridge at a flow rate of approximately 80 to 85 mL/min for 45 minutes to collect a sample volume of approximately 3.8 L. Chamber air was passed through each multisorbent cartridge at a flow rate of approximately 35 mL/min for 45 minutes to collect a sample volume of approximately 1 L.

4.3.4 Analysis of VOCs

4.3.4.1 Analysis of VOCs on Multisorbent Cartridges

For screening tests, VOCs on multisorbent cartridges were thermally desorbed and then analyzed by gas chromatography/mass spectrometry (GC/MS) using the conditions shown in Table 4-2. Identification of unknown sample constituents was performed using an electronic search of the NIH/EPA/MSDC Mass Spectral Data Base (NIST library) and the Registry of Mass Spectral Library (Wiley library). Manual review of the data was also performed to verify computer identifications and to identify compounds not found using the computer library search.

Prior to analysis, a set of standard cartridges were analyzed to show proper mass calibration for the GC/MS system, to establish GC retention time windows for selected VOCs, and to generate total ion response factors for VOCs quantitation estimates. Two external standards, [i.e., perfluorotoluene (PFT) and bromopentafluorobenzene (BFB)], were also added to each standard cartridge. PFT was used to monitor instrumental tune (mass resolution and ion abundance) and BFB was used as an external quantitation standard. Each day during sample analysis, an additional standard cartridge was analyzed to demonstrate ongoing instrumental performance.

Quantitative estimates of identified VOCs were based on total ion reconstructed chromatographic peak areas and a total ion relative response factor generated for toluene (RRF_{Tol}). Standard cartridges were prepared and analyzed as described above. Each of these cartridges contained a known mass of toluene and the external quantitation standard. The RRF_{Tol} was calculated from the resulting data as

$$RRF_{Tol} = \frac{A_{Tol} \cdot M_{QS}}{A_{QS} \cdot M_{Tol}}$$

where M_{Tol} is the mass of toluene (ng/cartridge), M_{QS} is the mass of quantitation standard (ng/cartridge), A_{Tol} is the peak area of toluene, and A_{QS} is the peak area of the quantitation standard (ng/cartridge).

Table 4-2. GC/MS Operating Conditions For Analysis of VOCs

Parameter	Setting
THERMAL DESORPTION	
Trap Type	1 = Multisorbent, 2 = Multisorbent
Tube Raised Ambient	Off
Initial Carrier Flow	1 min
Tube Chamber Heat Time	6 min
Tube Chamber Temperature (Max)	320°C
Secondary Carrier Flow	2 min
Trap 1 Heat (Max)	270°C
Trap 2 Heat (Max)	310°C
Trap-to-Trip Transfer Time	2 min
Trap-to-Column Transfer Time	20 min
GAS CHROMATOGRAPH	
Instrument	Hewlett-Packard 5890
Column	DB-624 widebore fused silica capillary column
Temperature Program	35°C (5 min) to 200°C (1 min) at 5°C/min
Carrier gas flow rate	1.8 mL/min
MASS SPECTROMETER	
Instrument	Hewlett Packard, Model 5988A
Ionization Mode	Electron Ionization Scan 35-350 m/z
Emission Current	0.3 mA
Source Temperature	200°C
Electron Multiplier	2000 volts ^a

^a Typical value

During each day of the screening analysis, an additional standard cartridge was analyzed. If the RRF_{Tot} was within $\pm 25\%$ of the RRF_{Tot} obtained during the instrument calibration, the GC/MS system was considered "in control", and the RRF_{Tot} from the calibration was used to estimate VOC amounts on sample cartridges as

$$M_{VOC} = \frac{A_{VOC} \cdot M_{QS}}{A_{QS} \cdot RRF_{Tot}}$$

where M_{VOC} is the estimated mass of a VOC (ng/cartridge), M_{QS} is the mass of quantitation standard (ng/cartridge), A_{VOC} is the peak area of the VOC, and A_{QS} is the peak area of the quantitation standard (ng/cartridge).

TVOC were calculated from the total ion chromatogram (TIC). The total area of the TIC was integrated for the retention time window from n-hexane through n-tetradecane. The mass of

TVOC (M_{TVOC}) was calculated as

$$M_{TVOC} = \frac{A_{TVOC} \cdot M_{QS}}{A_{QS} \cdot RRF_{Tot}}$$

The concentration of each VOC and TVOC in a chamber air sample was calculated as:

$$C_{VOC \text{ or } TVOC} = \frac{M_{VOC \text{ or } TVOC}}{V_s}$$

where $C_{VOC \text{ or } TVOC}$ = Concentration of the VOC or TVOC in the chamber air sample ($\mu\text{g}/\text{m}^3$)
 $M_{VOC \text{ or } TVOC}$ = Mass of VOC or TVOC on multisorbent cartridge
 V_s = Sample volume of chamber air, L

4.3.4.2 Analysis of VOCs on DNPH Cartridges

For both the screening and quantitative decay tests, DNPH cartridges were analyzed for the target aldehydes and ketones listed in Table 4-3. DNPH/aldehyde derivatives on sample cartridges were extracted by eluting each cartridge with 5 mL of HPLC grade acetonitrile into a 5 mL volumetric flask. The final volume was adjusted to 5.0 mL and the samples aliquoted for analysis. Blank cartridges were eluted with each sample set to identify background contaminants. Additional blank cartridges were spiked with known amounts of DNPH/aldehyde standards as a method of assessing recovery.

Table 4-3. Target Aldehydes and Ketones

Formaldehyde
Acetaldehyde
Acetone
Propionaldehyde
2-Butanone
Butyraldehyde
Benzaldehyde
Valeraldehyde
<i>m</i> -Tolualdehyde
<i>n</i> -Hexanal

DNPH/aldehyde derivatives in sample extracts were analyzed by HPLC with UV detection using the conditions shown in Table 4-4. Purified and certified DNPH derivatives of the target aldehydes were used for the preparation of calibration solutions. Target aldehydes were identified by comparison of their chromatographic retention times with those of the purified standards. Quantitation of the target compounds was accomplished by the external standard method using calibration standards prepared in the range 0.02 to 15 ng/ μL of the

DNPH/aldehyde derivatives. Standards were analyzed singly for the aldehyde DNPH derivatives and a calibration curve calculated by linear regression of the concentration and chromatographic response data. Calibration curves for all target compounds were considered acceptable if $r^2 \geq 0.998$.

Table 4-4. HPLC Operating Conditions for the Analysis of Aldehyde Emission Factors

Parameter	Setting
Instrument	Waters Series 510
Column	NOVA-PAK C18, 3.9 x 150 mm
Solvent System	A: Water/Acetonitrile/Tetrahydrofuran 60/30/10 v/v B: Acetonitrile/Water 40/60 v/v
Gradient	100% A for 3 min; then a linear gradient to 100% B in 10 min. Hold 15 min at 100% B
Mobile Phase Flow Rate	1.5 mL/min
Injection Size	20 μ L
UV Wavelength	360 nm

To demonstrate on-going instrumental performance, a calibration standard was analyzed each day prior to the analysis of any samples. The calibration was considered "in control" if the measured concentration of the aldehyde/DNPH derivatives in the standard was 85 to 115% of the prepared concentration.

The concentration of each target aldehyde and ketone in the chamber air samples was calculated as:

$$C_{a/k} = \frac{C_y \times V_y \times D_f}{V_s}$$

where $C_{a/k}$ = Concentration of the target aldehyde or ketone in the chamber air sample ($\mu\text{g}/\text{m}^3$)
 C_y = Concentration of DNPH/analyte derivative in the sample extract ($\text{ng}/\mu\text{L}$)
 V_y = Total volume of sample extract (i.e., 5000 μL)
 V_s = Sample volume of chamber air (L)
 D_f = Molecular weight of the aldehyde or ketone \div molecular weight of the aldehyde or ketone/DNPH derivative

4.3.4.3 Conversion of Concentrations to Emission Factors

Concentrations of individual VOCs and TVOC measured in chamber air samples were converted to emission factors using the following equation

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

where

- C_m = measured concentration of a VOC or TVOC in a chamber air sample ($\mu\text{g}/\text{m}^3$)
- ACH = air exchange rate in the test chamber
- L = loading ratio in the test chamber

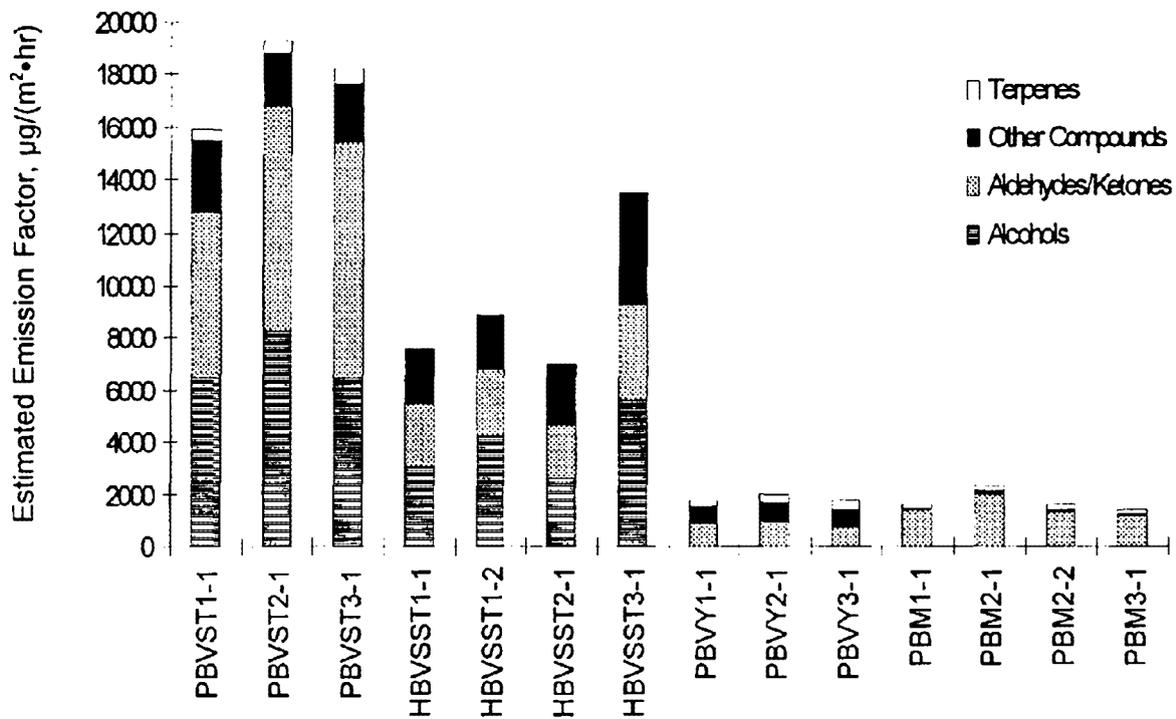
An emission factor of summed VOCs for a tested material was calculated by summing the individual emission factors of VOCs for a tested material.

4.4 Results

Results from the screening tests are presented in Tables A-1 through A-4 in Appendix A. Figures 4-3 and 4-4 are graphs of the data in these tables. Emission factors for test squares 1-1, 2-1, and 3-1 compare emissions variability between samples 1, 2, and 3. Emission factors for test squares 1-1 and 1-2, and 2-1 and 2-2 compare emissions variability within samples 1 and 2, respectively. For test squares of PBVST, PBM, and PBVY, emission factors of summed VOCs were fairly consistent between and within samples. For test squares of HBVSST, emission factors of summed VOCs were fairly consistent between samples 1 and 2; sample 3, however, had a much higher emission factor of summed VOCs than those for samples 1 and 2.

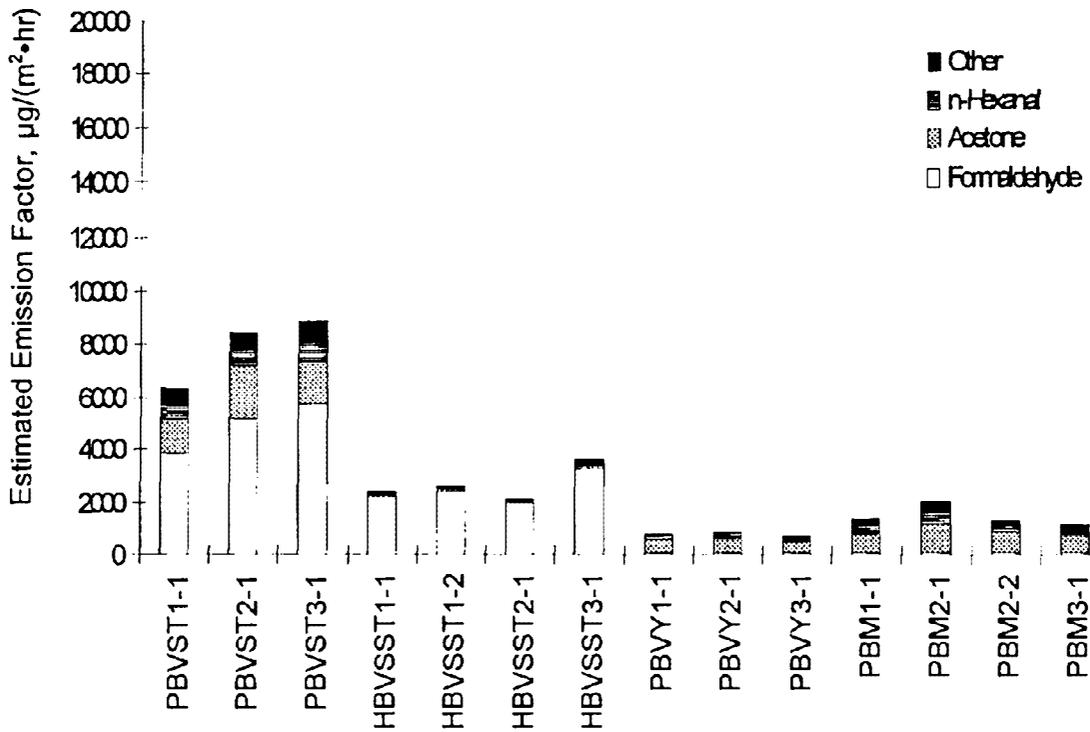
Figure 4-3 shows that initial emission factors of summed VOCs were substantially higher for test squares of PBVST and HBVSST relative to those for PBVY and PBM. Alcohols made up a large portion of the emission factors of summed VOCs for test squares of PBVST and HBVSST, whereas, virtually no alcohol emissions were detected from test squares of PBVY and PBM. Alcohols were listed as solvents in the MSDS for the coatings. Terpenes were only detected from test squares made with PB. Terpenes are volatile constituents of certain wood species such as pine (used to make the PB). Terpenes are not major constituents of hardwood species, which are used to manufacture HB. The presence of terpenes in emissions from the PB test squares suggests that they may permeate through all three types of finishes, (i.e., veneer with coatings, melamine, and vinyl).

In Figure 4-4, *n*-hexanal was unique to test squares made with PB. Acetone was emitted primarily from test squares made from PB, although small amounts were measured from test squares of HBVSST. Acetone and *n*-hexanal have been associated with wood fibers in certain types of engineered wood samples.⁶ The fact that these compounds were not detected in the emissions from the HB test squares suggests that these compounds may be specific to certain wood species or specific types of engineered wood.



Test squares are labeled by material acronym (PBVST, HBVSST, PBVY, or PBM), followed by sample number, followed by test square number, respectively, where
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
 HBVSST = oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat
 PBVY = particleboard overlaid with vinyl
 PBM = particleboard overlaid with melamine

Figure 4-3. Estimated emission factors of summed VOCs for test squares of finished engineered wood conditioned for six hours.



Test squares are labeled by material acronym (PBVST, HBVSST, PBVY, or PBM), followed by sample number, followed by test square number, respectively, where
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
 HBVSST = oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat
 PBVY = particleboard overlaid with vinyl
 PBM = particleboard overlaid with melamine

Figure 4-4. Estimated emission factors of aldehydes and ketones for test squares of finished engineered wood conditioned for six hours.

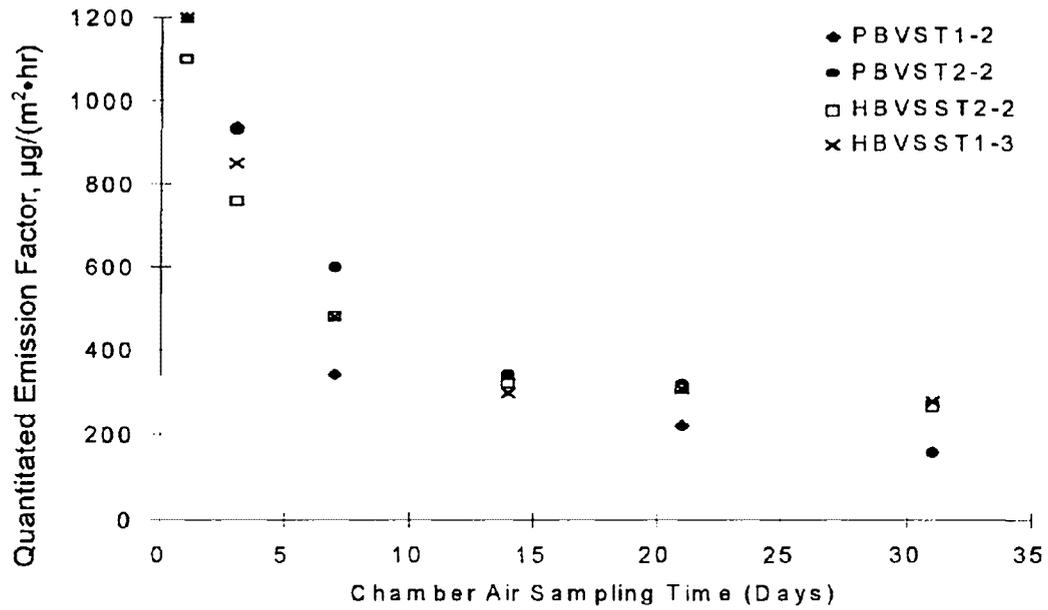
Initial emission factors of formaldehyde were substantially higher for test squares of PBVST and HBVSST relative to those for test squares of PBVY and PBM. The acid catalyzed alkyd-urea sealer and topcoat were believed to be the major reason for these differences. Research has shown that catalyzed alkyd-urea coatings release formaldehyde over time as part of their curing process.⁶

Results from the quantitative decay tests are shown in Figure 4-5. 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 from PBVY and PBM [initial emission factors ranged from 51 to 90 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$]. For this reason, quantitative decay tests were not conducted on PBVY and PBM.

Test squares in the decay study had lower, initial emission factors of formaldehyde than test squares in the screening study; the former were prepared from coupons stored in a freezer for 3 weeks, whereas the latter were prepared from coupons stored in a freezer for 10 weeks. One possible explanation for this difference is that storing the coupons at -10 to -20 °C was not completely effective in suppressing their emissions, thus, the 10 week old coupons had lower emissions than the 3 week old coupons.

4.5 Conclusions

- Initial emission factors of summed VOCs and formaldehyde were substantially higher for PBVST and HBVSST relative to those for PBVY and PBM.
- Initial emission factors of summed VOCs and formaldehyde were substantially higher for PBVST relative to those for HBVSST.
- Emission factors of formaldehyde for test squares of PBVST and HBVSST decayed over time as the test squares conditioned/aged under typical indoor conditions (e.g., 23 °C, 50% RH, and 1 ACH) . Emission factors of formaldehyde appeared to reach a steady-state level after the test squares aged for two weeks; this steady-state level was approximately a fourth of the initial emission factors of formaldehyde for the test squares aged less than six hours. This steady-state level was also substantially higher than initial emission factors of formaldehyde for test squares of PBVY and PBM.
- The acid catalyzed alkyd-urea sealer and topcoat were suspected sources of VOC emissions from PBVST and HBVSST. Most of the emitted VOCs, except formaldehyde, were listed on the MSDS for the coatings. Formaldehyde is a by-product of the curing mechanism of these coatings.



Test squares are labeled by material acronym (PBVST or HBVSST), followed by sample number (1 or 2), followed by test square number (2 or 3), where
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat
 HBVSST = oak-veneered hardboard coated and cured with a stain, and an acid catalyzed alkyd-urea sealer and topcoat

Figure 4-5. Quantitated emission factors of formaldehyde for test squares of finished engineered wood conditioned for 31-days.

- Based on the screening and quantitative decay tests, PBVST was selected for P2 evaluation. Although HBVSST could have also been selected for further evaluation (since it was finished with the same sealer and topcoat as PBVST), PBVST was selected because it had higher initial emission factors of summed VOCs than HBVSST; the higher initial emission factors suggested that both the PB and the coatings might be contributing to emissions from PBVST.
- Since emission factors of formaldehyde for test squares of PBVST decayed with time and appeared to level out after two weeks, future emissions testing was conducted on aged samples versus newly manufactured samples. Samples were conditioned/aged around 31-days, since this is the typical time lag between when PBVST is manufactured at the particular plant in Phase 1 and when it arrives in an indoor environment as part of an assembled product.
- Because freezing the coupons may not have been completely effective in suppressing their emissions, storage time was shortened for future testing.

Chapter Five Phase 2 Component Study

5.1 Overview

Based on the results from the Phase 1 Screening Study, PBVST was selected for P2 evaluation. A component study was conducted to assess the source(s) of emissions from PBVST.

5.2 Objectives

The objective of the component study was to quantitate emission factors from various components of PBVST to identify the sources of emissions from PBVST. Components tested included: particleboard (PB); veneer (V); oak-veneered particleboard (PBV); oak-veneered particleboard with an acid catalyzed alkyd-urea sealer (PBVS); and oak-veneered particleboard with an acid catalyzed alkyd-urea sealer and topcoat (PBVST).

5.3 Experimental Design

5.3.1 Sample Collection

Three samples of each material (PB, V, PBV, PBVS, and PBVST) were collected from various stages of the manufacturing process (Figure 5-1). The coated samples were collected after they were cured. Three coupons were cut from the center of each sample. All coupons cut from the same sample were placed in a steel container with an airtight lid. The containers were transported to RTI within one day of manufacture. Upon arrival at RTI, the coupons were removed from their containers and visually inspected to ensure that the coupons remained intact during transportation. The coupons were resealed in their containers and then placed in a freezer operating at -10 to -20 °C to minimize losses of VOCs from the coupons prior to testing.

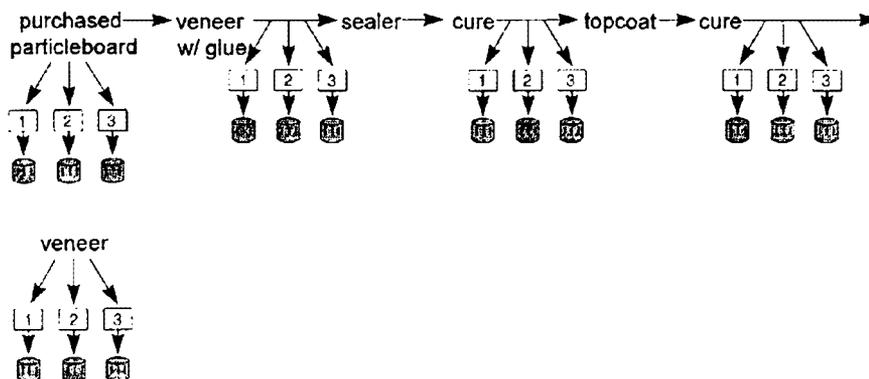


Figure 5-1. Sample collection of components.

5.3.2 Chamber Air Sampling

Approximately two weeks after sample collection, containers of PB, V, PBV, PBVS, and PBVST were removed from the freezer and allowed to warm to room temperature. A select number of coupons of each component were removed from the containers and visually inspected to determine that the coupons remained intact during storage. The coupons were prepared into 0.006 m by 0.006 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 which operated at the conditions shown in Table 5-1. Chamber air samples for measuring VOCs were collected 31-days after each test square was placed in a test chamber; 31-days was selected as the testing time since it is the typical time lag between when PBVST is manufactured (at the plant participating in the study) and when it arrives in an indoor environment as part of an assembled product.

Table 5-1. Conditions For Chamber Testing

Test Parameters	Conditions
Chamber Size	0.012 m ³
Temperature	23°C
Relative Humidity	50%
Air Exchange Rate (ACH)	1/h
Source Area (A)	~0.012 m ²
Loading (L)	1.0 m ² /m ³

5.3.3 VOCs Collection

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 Amborsorb (Figure 4-2 in Section 4.3.3 shows the arrangement of the cartridges for collecting VOCs). DNPH cartridges are designed to collect aldehydes and ketones. Multisorbent cartridges are designed to collect other types of VOCs.

Chamber air was passed through the DNPH cartridge at a flow rate of approximately 50 mL/min for a 1- to 2- hour period to give nominal sample volume of approximately 2 L. Chamber air was passed through each multisorbent cartridge at a flow rate of approximately 25 mL/min over a 2-hour period to give a nominal sampling volume of 3 L.

5.3.4 Analysis of VOCs

5.3.4.1 Analysis of VOCs on Multisorbent Cartridges

VOCs on multisorbent cartridges were thermally desorbed and then analyzed by gas chromatography with flame ionization detection (GC/FID) using the conditions shown in Table 5-2. Target VOCs were identified by comparison of their chromatographic retention times with those analyzed on standard cartridges. GC/MS confirmation was performed for selected samples.

Quantitation of target VOCs was performed using calibration curves generated from the analysis of standard cartridges prepared at five different levels. Standard cartridges contained all of the target VOCs plus the internal quantitation standard, m-dichlorobenzene. One calibration cartridge was analyzed at each level. For each target VOC, the ratio of the area of the target to the area of the internal standard was calculated. A calibration curve was generated for cartridge amount versus area ratio using second order regressions. Calibration curves for all target analytes were considered acceptable if r^2 values were greater than 0.995.

To demonstrate on-going instrumental performance, a mid-level calibration standard was analyzed each day prior to the analysis of samples. The calibration was considered "in control" if the measured concentration of each target was 70 to 130% of the prepared concentration. For 2-(2-butoxyethoxy) ethanol a window of 50 to 130% was used.

The concentration of each target analyte in chamber air samples was calculated by dividing the mass of analyte on the cartridge by the volume of air sample collected.

5.3.4.2 Analysis of Aldehydes and Ketones on DNPH Cartridges

DNPH cartridges were analyzed for the target aldehydes and ketones listed in Table 5-3. DNPH/aldehyde derivatives on sample cartridges were extracted by eluting each cartridge with 5 mL of HPLC grade acetonitrile into a 5 mL volumetric flask. The final volume was adjusted to 5.0 mL and the samples aliquoted for analysis. Blank cartridges were eluted with each sample set to identify background contaminants. Additional blank cartridges were spiked with known amounts of DNPH/aldehyde standards as a method of assessing recovery.

DNPH/aldehyde derivatives in sample extracts were analyzed by HPLC with UV detection using the conditions shown in Table 5-4. Purified and certified DNPH derivatives of the target aldehydes were used for the preparation of calibration solutions. Target aldehydes were identified by comparison of their chromatographic retention times with those of the purified standards. Quantitation of the target compounds was accomplished by the external standard method using calibration standards prepared in the range 0.02 to 15 ng/ μ L of the DNPH/aldehyde derivatives. Standards were analyzed singly for the aldehyde DNPH

Table 5-2. GC/FID Operating Conditions For Analysis of VOCs

Parameter	Setting
THERMAL DESORPTION	
Trap Type	1 = Multisorbent, 2 = Multisorbent
Tube Raised Ambient	Off
Initial Carrier Flow	1 min
Tube Chamber Heat Time	6 min
Tube Chamber Temperature (Max)	320°C
Secondary Carrier Flow	2 min
Trap 1 Heat (Max)	270°C
Trap 2 Heat (Max)	310°C
Trap-to-Trap Transfer Time	2 min
Trap-to-Column Transfer Time	20 min
GAS CHROMATOGRAPH	
Instrument	Varar 3700
Column	DB-624 widebore fused silica capillary column
Temperature Program	35°C (5 min) to 200°C (1 min) at 5°C/min
Carrier gas flow rate	1.8 mL/min
Detector	flame inonizer

^a Typical value

Table 5-3. Target Aldehydes and Ketones

Formaldehyde
Acetaldehyde
Acetone
Propionaldehyde
2-Butanone
Butyraldehyde
Benzaldehyde
Valeraldehyde
<i>m</i> -Tolualdehyde
<i>n</i> -Hexanal

Table 5-4. HPLC Operating Conditions for the Analysis of Aldehyde Emission Factors

Parameter	Setting
Instrument	Waters Series 510
Column	NOVA-PAK C18, 3.9 x 150 mm
Solvent System	A: Water/Acetonitrile/Tetrahydrofuran 60/30/10 v/v B: Acetonitrile/Water 40/60 v/v
Gradient	100% A for 3 min; then a linear gradient to 100% B in 10 min. Hold 15 min at 100% B
Mobile Phase Flow Rate	1.5 mL/min
Injection Size	20 µL
UV Wavelength	360 nm

derivatives and a calibration curve calculated by linear regression of the concentration and chromatographic response data. Calibration curves for all target analytes had $r^2 \geq 0.998$.

To demonstrate on-going instrumental performance, a calibration standard was analyzed each day prior to the analysis of any samples. The calibration was considered "in control" if the measured concentration of the aldehyde/DNPH derivatives in the standard was 85 to 115% of the prepared concentration.

The concentration of each target aldehyde and ketone in the chamber air samples was calculated as:

$$C_{a/k} = \frac{C_y \times V_y \times D_f}{V_s}$$

where $C_{a/k}$ = Concentration of the target aldehyde or ketone in the chamber air sample ($\mu\text{g}/\text{m}^3$)
 C_y = Concentration of DNPH/analyte derivative in the sample extract ($\text{ng}/\mu\text{L}$)
 V_y = Total volume of sample extract (i.e., 5000 μL)
 V_s = Sample volume of chamber air, L
 D_f = Molecular weight of the aldehyde or ketone \div molecular weight of the aldehyde or ketone/DNPH derivative

5.3.4.3 Conversion of Concentrations to Emission Factors

Concentrations of individual VOCs measured in chamber air samples were converted to emission factors using the following equation

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

where

C_m = measured concentration of a VOC in a chamber air sample ($\mu\text{g}/\text{m}^3$)
ACH = air exchange rate in the test chamber
L = loading ratio in the test chamber

An emission factor of summed VOCs for a tested material was calculated by summing the individual emission factors of VOCs for the tested material.

5.4 Results

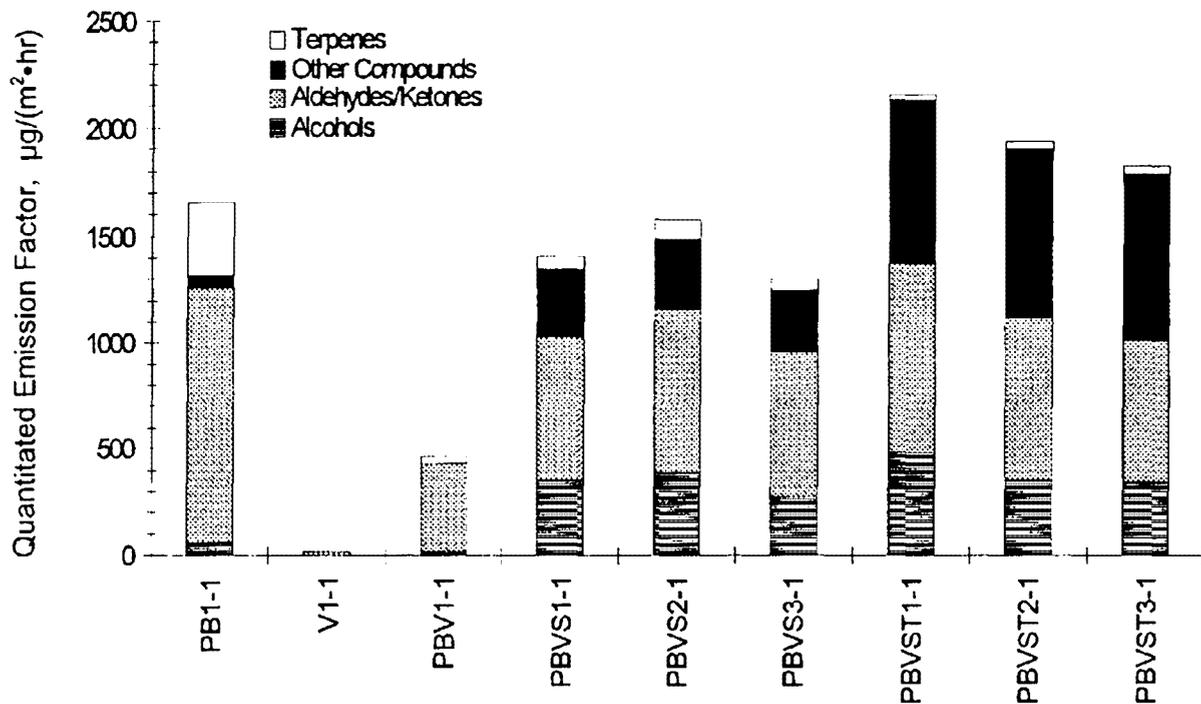
Results from the component tests are shown in Table B-1 of Appendix B. Figures 5-2 and 5-3 are graphs of the data in this table. For test squares of PBVS and PBVST, emission factors were fairly consistent between samples (i.e., test squares 1-1, 2-1, and 3-1). Only one sample each of PB and PBV was analyzed for VOCs.

Figures 5-2 and 5-3 present emission factors of summed VOCs and aldehydes and ketones, respectively, for test squares of PB, V, PBV, PBVS, and PBVST. As shown in Figure 5-2, emission factors of summed VOCs for PB and PBV were $1600 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ 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 polyvinyl acetate (a white glue) and an UF resin; the mixture contains less than 0.6% formaldehyde.) Since the emission factor of summed VOCs for PBV was substantially 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.

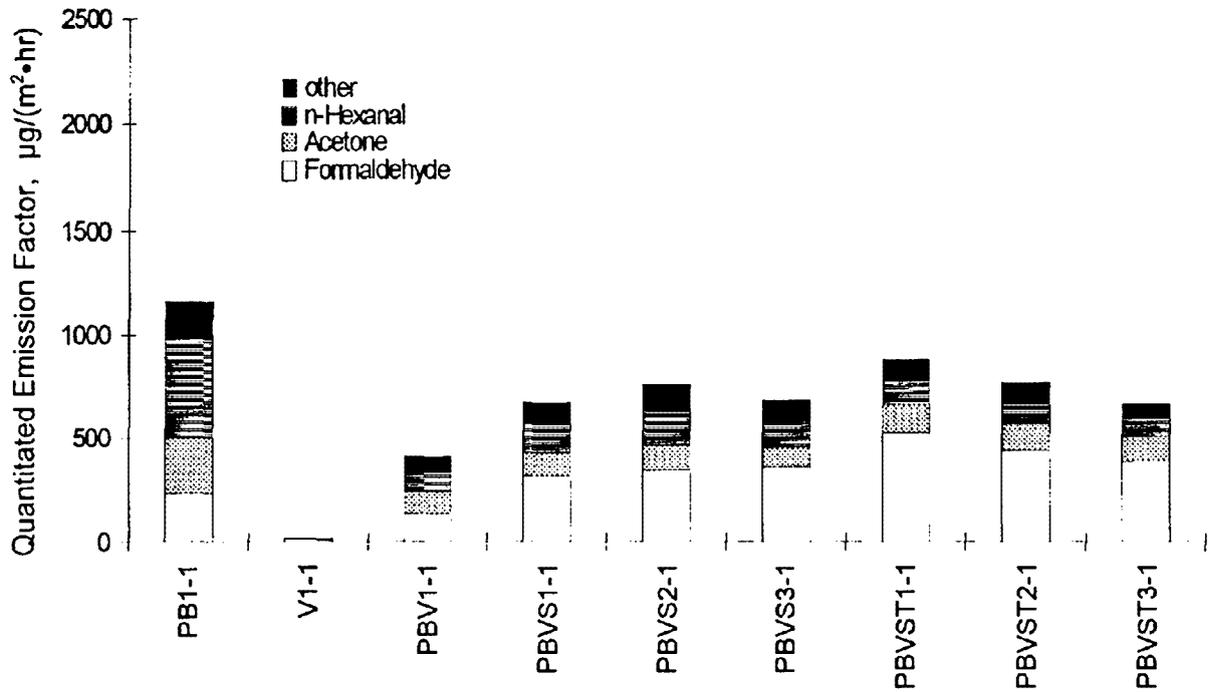
As shown in Figure 5-3, emission factors of *n*-hexanal for PB and PBV were $490 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ and $97 \mu\text{g}/(\text{m}^2\cdot\text{hr})$, respectively. Emission factors of acetone for PB and PBV were 270 and 110 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$, respectively. The presence of *n*-hexanal and acetone in emissions from the test square of PB supports the hypothesis from Phase 1 that these compounds are associated with the wood in the PB. The lower emission factors of acetone and *n*-hexanal for the PBV test square relative to those for the PB test square suggests that the veneer suppressed emissions of these compounds from the PB. PBV, PBVS, and PBVST all had similar emission factors of *n*-hexanal and acetone, which also supports the hypothesis from Phase 1 that these compounds are emitted from the wood in the PB rather than the coatings.

Emission factors of formaldehyde for PB and PBV were $230 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ 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.



Test squares are labeled by material acronym (PB, V, PBV, PBVS, or PBVST), followed by sample number, followed by test square number, respectively, where
 PB = particleboard
 V = veneer
 PBV = oak-veneered particleboard
 PBVS = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat

Figure 5-2. Quantitated emission factors of summed VOCs for test squares of components of finished engineered wood conditioned for 31-days.



Test squares are labeled by material acronym (PB, V, PBV, PBVS, or PBVST), followed by sample number, followed by test square number, respectively, where
 PB = particleboard
 V = veneer
 PBV = oak-veneered particleboard
 PBVS = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer
 PBVST = oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat

Figure 5-3. Quantitated emission factors of aldehydes and ketones for test squares of components of finished engineered wood conditioned for 31-days.

5.5 Conclusions

- PB had substantially higher emission factors of summed VOCs and formaldehyde compared to PBV. The veneer had very low emission factors of summed VOCs and formaldehyde (relative to the other components). The veneer likely suppressed emissions from the PB.
- PBVS and PBVST had substantially higher emission factors of summed VOCs and formaldehyde compared to those for PBV; these increases in emission factors were likely due to the coatings.
- Based on the results of Phase 2, potentially low-emitting coatings and engineered fiber samples were identified and evaluated for reducing VOC emissions from PBVST.

Chapter Six Phase 3 Coatings Study

6.1 Overview

In Phase 2, an acid catalyzed alkyd-urea sealer and topcoat were identified as likely sources of VOCs and formaldehyde from PBVST (oak-veneered particleboard coated and cured with the acid-catalyzed alkyd-urea sealer and topcoat). In Phase 3, a coatings study was conducted to evaluate emission factors for PBV (oak-veneered particleboard) coated and cured with five alternative coatings systems (system = sealer and topcoat) and the acid catalyzed alkyd-urea coatings system from Phase 2. Selection criteria for the alternative coatings systems included coatings that were:

- claimed as low-emitting by the manufacturer
- expected to have comparable performance and aesthetics to the acid-catalyzed alkyd-urea coatings system
- compliant with existing regulations (i.e., MACT and VOC)
- currently on the market
- representative of different chemistries and cure technologies.

Table 6-1 lists the types of coatings systems evaluated.

Table 6-1. Coatings Systems Evaluated

	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 solvent	water	water	none	water	water
Cure	heat	heat	UV ^a light	UV light	heat + UV light	heat

^a UV = ultraviolet

6.2 Objectives

The principal objectives of the coatings study were:

- (1) To ascertain if coatings systems contribute significantly to 35-day emissions of coated and cured PBV relative to uncoated PBV.
- (2) To ascertain if emission factors for test squares of PBV coated and cured with the five alternative coatings systems are significantly different than emission factors for test squares of PBV coated and cured with the heat curable acid catalyzed alkyd-urea coatings system.
- (3) To evaluate and compare the performance characteristics of the five alternative coatings systems and the heat curable acid catalyzed alkyd-urea coatings

system.

To meet these objectives, samples of uncoated PBV were collected from the manufacturing plant that supplied samples in Phases 1 and 2. The samples were cut into coupons and then coated and cured with the six different coatings systems. Quantitative emission tests were conducted to characterize individual and summed VOC emissions for the coated and uncoated coupons. Since the focus of the research was on indoor air emissions, the tests characterized emissions from the finished coupons 35-days after they were coated and cured instead of emissions from newly cured coupons; emissions were also characterized from the uncoated coupons after they had aged 35-days. A 35-day testing time was selected because it is close to the 31-day time lag between the manufacture of PBVST from the manufacturing plant in Phases 1 and 2, and the installation of PBVST as an assembled product in an indoor environment. Although a 31-day testing time was used in Phase 2, a 35-day testing time was selected for this study to avoid the possibility of having to test on weekends; i.e., a 35-day testing time ensured that emissions tests would take place on the same day of the week as the coating/cure application.

For the first objective, a statistical analysis was performed on the 35-day emission factor data to determine if the coatings systems were a significant source of individual and summed VOC emissions from the finished coupons. For the second objective, a statistical analysis was conducted on the 35-day emission factor data to ascertain if emission factors of individual and summed VOCs for PBV coated and cured with the five alternative coatings systems were significantly different than emission factors of individual and summed VOCs for PBV coated and cured with the heat curable acid catalyzed alkyd-urea coatings system. For the third objective, the performance of the coated coupons was evaluated using standard tests for performance of wood coatings.

6.3 Experimental Design

The experimental design included the following steps:

- (1) Collect boards of unfinished PBV for coatings applications trials and performance testing.
- (2) Prepare coupons from unfinished boards for coatings applications trials and performance testing.
- (3) Conduct trials of coatings applications.
- (4) Conduct performance tests.
- (5) Collect three boards of unfinished PBV for coatings applications.
- (6) Cut and prepare coupons from unfinished boards for emissions testing.
- (7) Apply and cure coatings systems to predesignated unfinished coupons.
- (8) Hold finished and unfinished coupons in sealed containers for seven days; afterwards, cut and prepare test squares from coated and uncoated coupons for emissions testing.
- (9) Allow coated and uncoated test squares to condition at ambient conditions (23°C, 50% RH, and 1 ACH) for 28 days.
- (10) Conduct chamber emissions tests on coated and uncoated test squares.
- (11) Characterize emission factors from chamber emissions test data.
- (12) Assess the statistical significance of the emission factors in terms of design objectives.

Figures 6-1 and 6-2 are flow diagrams of Steps 1 through 4 and Steps 5 through 10, respectively.

Coatings applications and performance tests (Steps 3, 4, and 7) were conducted at the Electrotechnology Application Center (ETAC) in Bethlehem, Pennsylvania. The ETAC facility is a coatings laboratory that houses an electric convection oven, an UV curing chamber, and various equipment for evaluating finish characteristics of coated wood. The staff at ETAC were selected to carry out the coatings applications and performance tests because they have widespread experience in formulating, applying, and evaluating various types of wood coatings.

Several resin manufacturers and coatings formulators for the engineered wood finishing industry provided the coatings systems for the evaluation. RTI provided these suppliers with samples of PBVST collected from the manufacturing plant in Phases 1 and 2. RTI asked the coatings suppliers to formulate their coatings to give similar gloss, thickness, and performance characteristics to the samples of PBVST. The coatings supplier to the PBVST manufacturer in Phases 1 and 2 provided a heat curable acid catalyzed alkyd-urea system that was similar to the one used by the manufacturer.

6.3.1 *Collection and Preparation of Coupons for Coatings Optimization Trials and Performance Tests (Steps 1 and 2)*

In Steps 1 and 2, several boards of unfinished PBV were collected from a manufacturing plant and cut into 15.24 cm by 20.32 cm coupons. The coupons were sent to ETAC for coatings optimization trials and performance tests.

6.3.2 *Coatings Optimization Trials (Step 3)*

In Step 3, ETAC conducted coating application and curing trials on coupons from Step 2 to optimize these procedures for Step 7 (in Step 7 coupons were coated and cured for emission factors testing). Coatings were applied using a drawdown bar (Figures 6-3 and 6-4). A drawdown bar is a round stainless steel bar tightly wound with stainless steel wire; it is standard lab apparatus for applying uniform amounts of coatings to small substrates such as coupons. The amount of coating transferred to a substrate is governed by the area of the groove between the coils of wire (Figure 6-5). This groove allows an exact amount of coating to pass through the coils, leaving a smooth, uniform thickness of coating on a substrate. Although a drawdown bar is not used to apply coatings in the manufacturing environment, it was selected to minimize variations in application thickness for a given coatings system. As will be discussed further in the text, each coatings system was applied to multiple coupons. The applied thickness of each coatings system varied depending on the recommendation of the coatings supplier (see Table C-1 in Appendix C for the applied thickness of each coatings systems). Having consistent thicknesses within a given coatings system was important to minimize variations in emission factors for each test square.

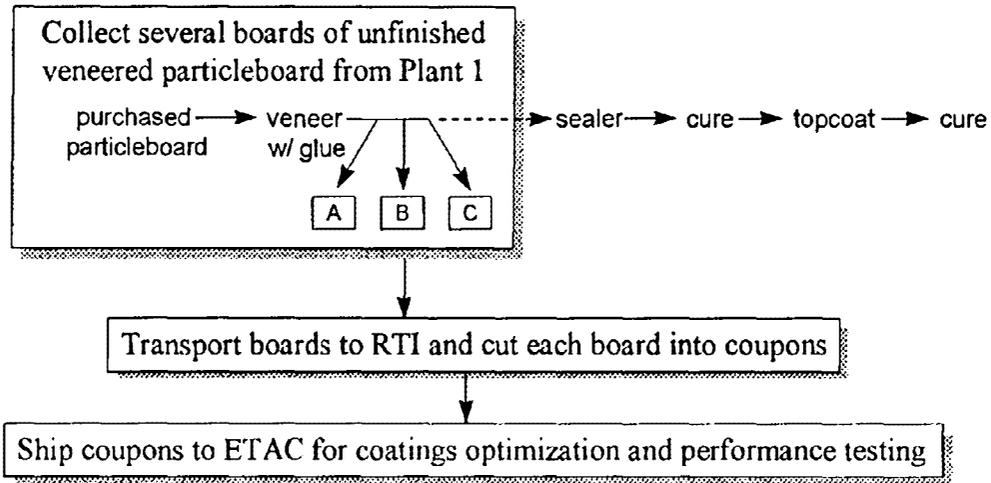


Figure 6-1. Steps one through four of experimental design.

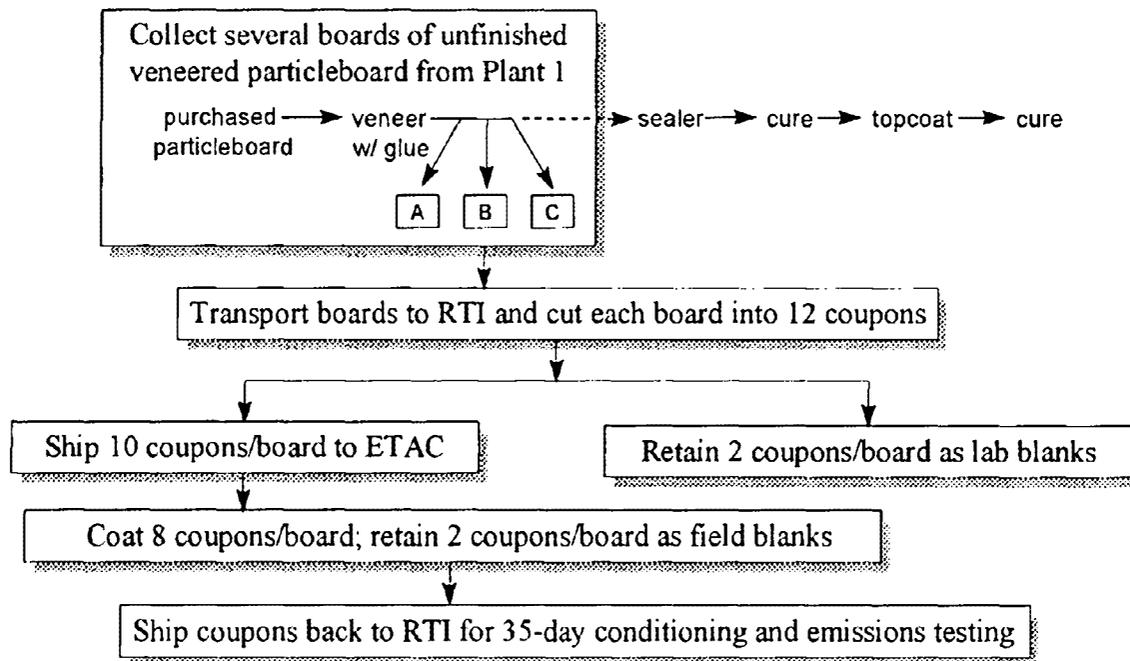


Figure 6-2. Steps five through ten of experimental design.

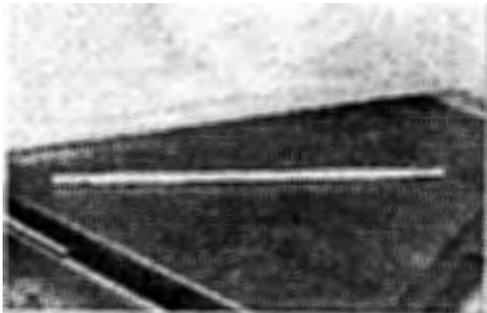


Figure 6-3. Drawdown bar.



Figure 6-4. Application of coating with drawdown bar.

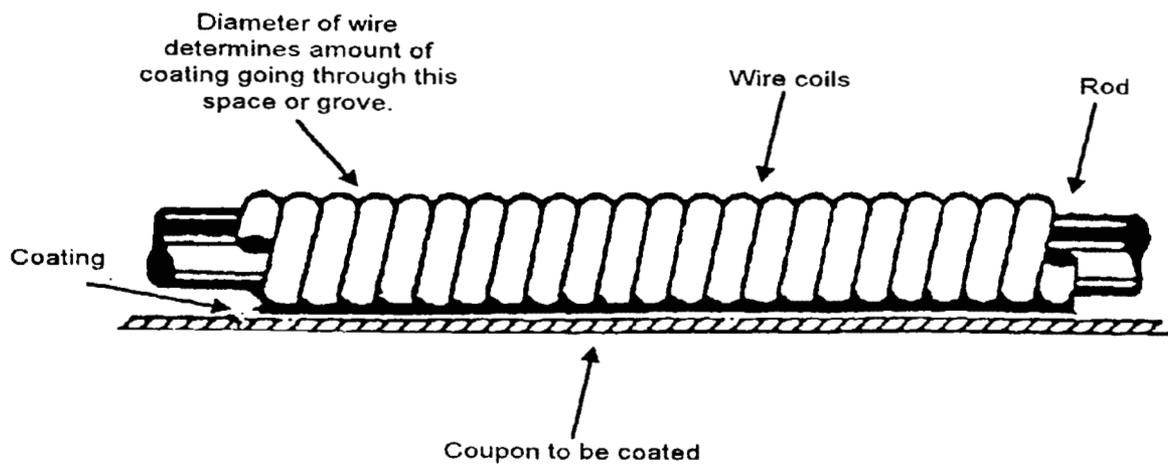


Figure 6-5. Close-up of drawdown bar.

Coatings suppliers provided instructions for applying and curing their coatings to coupons of PBV to produce a similar finish to the PBVST manufactured in Phases 1 and 2. The instructions specified coatings thicknesses (for both the sealer and topcoat), flash time, oven cure cycle, etc. ETAC made some modifications to dry and cure cycles to ensure optimal drying conditions. For example, if a coating did not dry to a visually acceptable film during the ambient flash step, then additional time was allotted to that cycle. Also, if a coupon could not be handled due to incomplete curing, the oven cure cycle was extended. Table C-1 in Appendix C lists the coating and curing procedures established during the optimization trials; these conditions were followed during applications for both the performance and emission tests.

6.3.3 Performance Tests (Step 4)

After optimizing the coating application and curing techniques, ETAC coated coupons for performance evaluations. The coated coupons were evaluated using standard industry tests of performance of wood coatings (Step 4). Properties tested included: adhesion; fingernail mar resistance; and chemical resistance to the solvent methyl ethyl ketone (MEK), mustard, and 10 types of stains. Gloss was also measured. These properties were selected for testing because they are of interest to manufacturers of engineered wood products.

For the MEK test, a rag was soaked in MEK, and then repeatedly rubbed over the same spot of a coated coupon in a back and forth motion. Each back and forth motion was counted as one double rub (DR). Each test was a maximum of 100 DRs. Coatings were rated according to the number of DRs required to rub off the coating or to a maximum of 100 DRs.

Mustard and stain tests were performed according to the procedures of the covered spot test in ASTM D1308-79⁸ using stains outlined by ANSI/KCMA A161.1-1990, 9.3.⁹ For the mustard test, a few drops of mustard were applied to the horizontal surface of a coated coupon; the drops were covered with a watch glass to prevent them from evaporating (Figure 6-6). The watch glass was removed after one hour and the mustard washed off with water. The coated coupon was examined for damages to the coating such as discoloration, changes in gloss, blistering, softening, swelling, and loss of adhesion. If no damages were seen, the coating was given a rating of 10 and the test stopped. If the mustard damaged the coating, the spot was evaluated 23 hours later (24 hours after the mustard was washed off) to determine if the coating improved over the interval; the coating was rated from 0 to 10, where 0 indicated no improvement and 10 indicated complete recovery of the coating.

Individual stains were applied in the same manner as the mustard, except that each stain was left on the coated coupon for 24 hours, at which point the stain was rinsed off, and the coating rated from 0 to 10 depending on the resulting damage (a score of 10 indicated no damage to the coating).

Adhesion was tested according to ASTM D3359.¹⁰ For this test, a crosshatch tool was used to scribe a lattice pattern on the surface of a coated coupon. A wide piece of semi-transparent, pressure sensitive tape was pressed firmly across the scribe marks and then jerked off with one quick motion (Figure 6-7). Adhesion was rated on a scale of 0B to 5B, depending on how much coating came up with the tape. A rating of 0B indicated that 65% or more of the coating was removed; a rating of 5B indicated that no coating was removed.

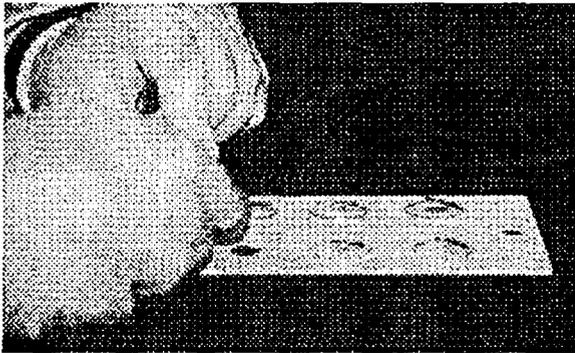


Figure 6-6. Mustard and stain tests.

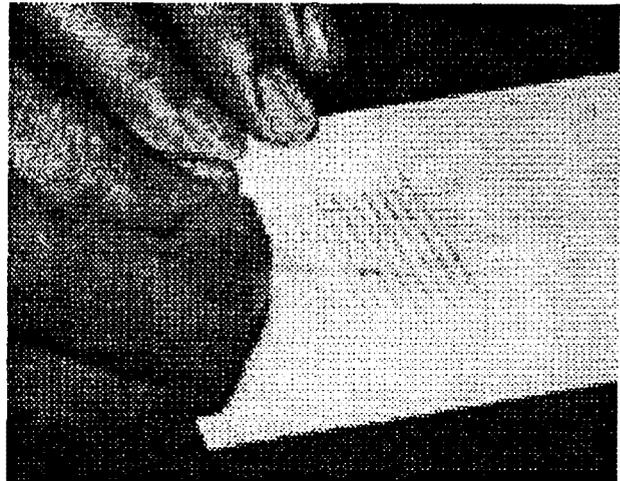


Figure 6-7. Adhesion test.

Gloss was measured according to ASTM D523¹¹ using a Gloss Checker manufactured by Horiba (model 1G-310) (Figure 6-8). Gloss ratings ranged from 0 to 120, with the latter being the highest gloss rating. Hardness was measured according to ASTM D2240¹² using a Durometer manufactured by PTC instruments (model 307L) (Figure 6-9). Hardness was rated on a scale of 0 to 100, with 100 being the highest hardness rating. Fingernail mar resistance was measured subjectively.

6.3.4 Collection and Preparation of Coupons for Coatings Applications (Steps 5 and 6)

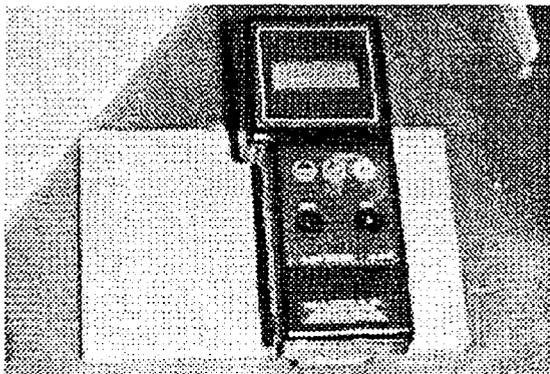


Figure 6-8. Gloss checker.

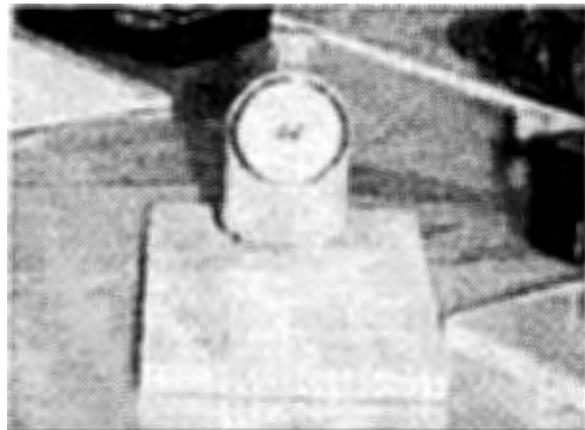


Figure 6-9. Durometer for measuring hardness.

In Step 5, three 39.37 cm by 85.09 cm boards of unfinished PBV were collected by RTI directly from the manufacturing line prior to finishing; the boards were pulled from the line one after the other and placed into a single prepurged Tedlar bag. The boards were transported to RTI within four hours of collection.

Upon arrival at RTI, each board was cut into eight 15.24 cm by 20.32 cm coupons and four 8.26 cm by 20.32 cm coupons (Step 6). Each coupon was labeled on an exposed edge with

a sample code that included a board letter designation (A to C) and a coupon number (1 to 12) as shown in Figure 6-10. After labeling, the exposed edges of the coupons were sealed with two applications of sodium silicate to ensure that emitted VOCs came only from the surfaces of the test squares and not the cut edges. Each prepared coupon was placed in a 1 gallon, uncoated steel container with a compression sealed lid. Eight 15.24 cm by 20.32 cm coupons, and two 8.26 cm by 20.32 cm coupons from each board were sent to ETAC for the coatings study.

6.3.5 Coatings Applications (Step 7)

For each board, six different coatings systems were applied to eight, 15.24 cm by 20.32 cm coupons over the course of two days; two coupons per board were left uncoated (the latter were referred to as field coupons) (Step 7). As shown in Table 6-2, the six different coatings systems were applied to coupons from the same board over the course of two days. Ideally, all eight coupons from the same board should have been coated in a single day, however, only six test chambers were available for emission factors testing at one time. For the statistical design, chamber air samples had to be collected from coated coupons that were the same age as their corresponding field and lab coupons. Since only six test chambers were available for testing at one time, only four coupons were coated per day.

6.3.6 Receipt, Storage, and Chamber Air Sampling (Steps 8 through 10)

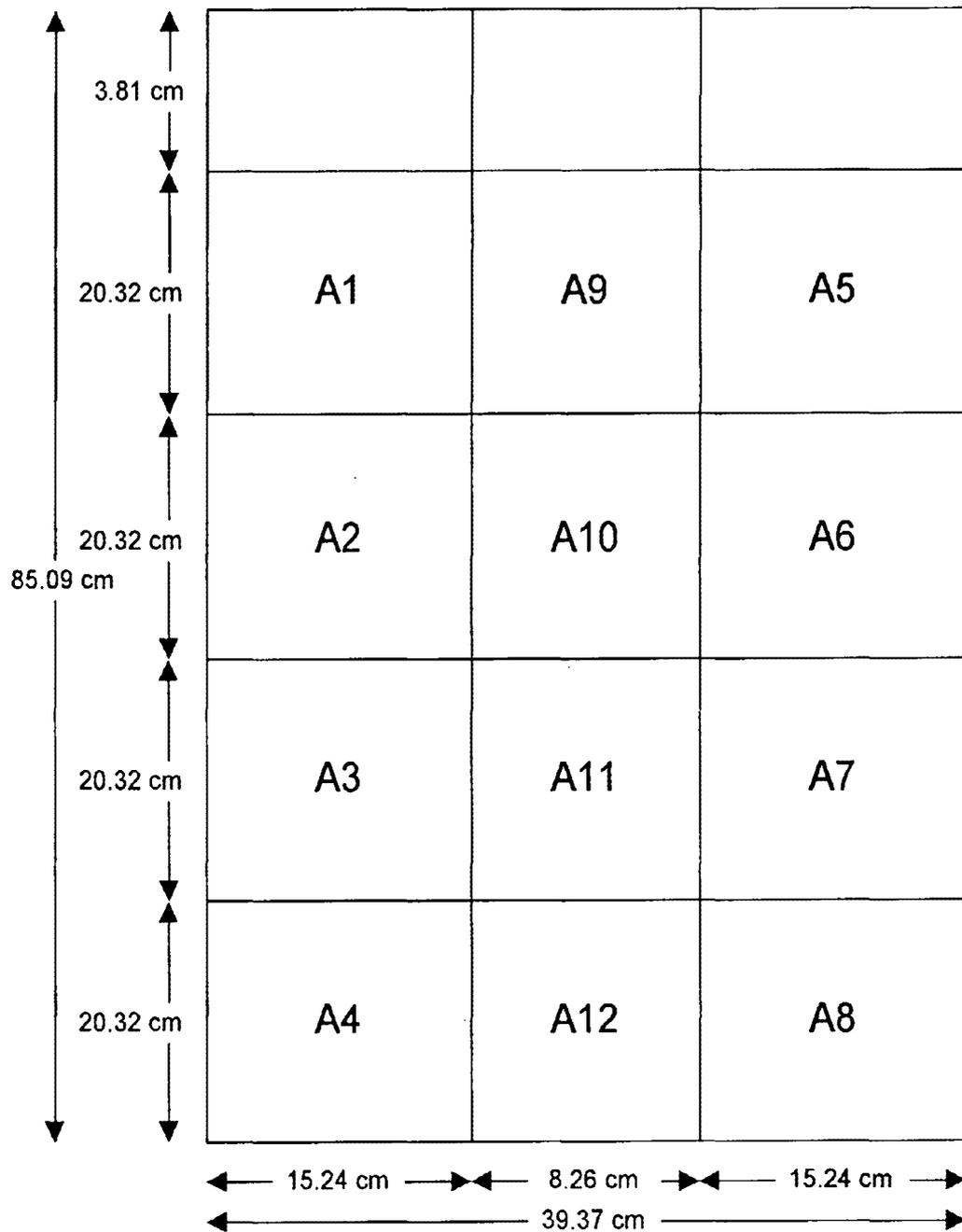
For each board, four coupons were coated and cured per day; that same day, the finished coupons and their corresponding field coupon were shipped overnight to RTI. The finished coupons and field coupon arrived at RTI in separate containers. Upon receipt at RTI, the four finished coupons and field coupon were held in their shipping containers until seven days had elapsed since the coupons were finished.

Table 6-2. Number of Coupons Coated and Reserved as Field Coupons

Coatings Day	Board	Coatings Systems						FC ^a	Total
		1	2	3	4	5	6		
1	A	1	1	1	1			1	5
2	A			1 ^b	1	1	1	1	5
3	B	1	1		1	1		1	5
4	B	1	1	1			1	1	5
5	C		1	1		1	1	1	5
6	C	1			1	1	1	1	5

^a FC=field coupon; field coupons were not coated.

^b Shaded blocks indicate duplicate applications; duplicate coatings applications were part of the statistical design.



Note:
 Coupons A1 through A8 were coated.
 Coupons A9 through A12 served as lab or field coupons.
 Direction of wood grain was parallel to 85.09 cm side.

Figure 6-10. Example of how Board A was labeled and divided into coupons (drawing not to scale).

Seven days after the coatings applications, the coupons were removed from the containers and a 0.0762 by 0.0762 m test square was cut from the center of each finished coupon (Step 8). A test square was also cut from the lab coupon corresponding to the coated coupons and field coupon (the lab coupon was the same age as the latter). Each test square was labeled on an exposed edge with its board code and coupon number using a graphite pencil. The edges of the test squares were sealed with two coats of sodium silicate to ensure that emitted VOCs came from the surfaces of the test squares and not the cut edges. Each test square was placed in an individual conditioning chamber maintained at 23°C, 50% RH, and 1 air exchange rate per hour (Figure 6-11). The 6 test squares were conditioned for 27 days (Step 9).

On the evening of the 27th day, the test squares were removed from the conditioning chambers and transferred to individual test chambers (Figures 6-12). Test conditions in the chambers are shown in Table 6-3. The test squares resided in the test chambers overnight which allowed them to equilibrate with the chamber air. The following morning, chamber air sampling was initiated. Table 6-4 shows the number of air samples collected during each chamber run. For each run, chamber air samples were collected from finished coupons that were the same age as their corresponding field and lab coupons. Chamber blanks were collected prior to each chamber run to demonstrate acceptably low chamber background concentrations. One chamber control was collected after each run to demonstrate acceptable recovery from chambers during emission testing. Upon completion of each chamber run, the test squares were removed and the chambers cleaned.

6.3.7 Collection of VOCs

In Step 10, 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 Amborsorb (Figure 4-2 in Section 4.3.3 shows the arrangement of the cartridges for collecting VOCs). DNPH cartridges are designed to collect aldehydes and ketones. Multisorbent cartridges are designed to collect other types of VOCs.

Chamber air was passed through the DNPH cartridge at a flow rate of approximately 70 to 80 mL/min for 120 minutes to collect a sample volume of approximately 9 L. Chamber air was passed through each multisorbent cartridge at a flow rate of approximately 30 to 35 mL/min for 60 minutes to collect a sample volume of approximately 1.7 to 2 L.

6.3.7.1 Analysis of VOCs on Multisorbent Cartridges (Step 11)

VOC on multisorbent cartridges were thermally desorbed then analyzed by GC/MS using the conditions shown in Table 6-5. Identification of unknown sample constituents was performed using an electronic search of the NIH/EPA/MSDC Mass Spectral Data Base (NIST library) and the Registry of Mass Spectral Library (Wiley library). Manual review of the data was also performed to verify computer identifications and to identify compounds not found using the computer library search. Results of these analyses were used to select target VOCs for quantitative analysis.

Prior to analysis, a set of standard cartridges was analyzed to show proper mass calibration for the GC/MS system, to establish GC retention time windows for selected VOCs,

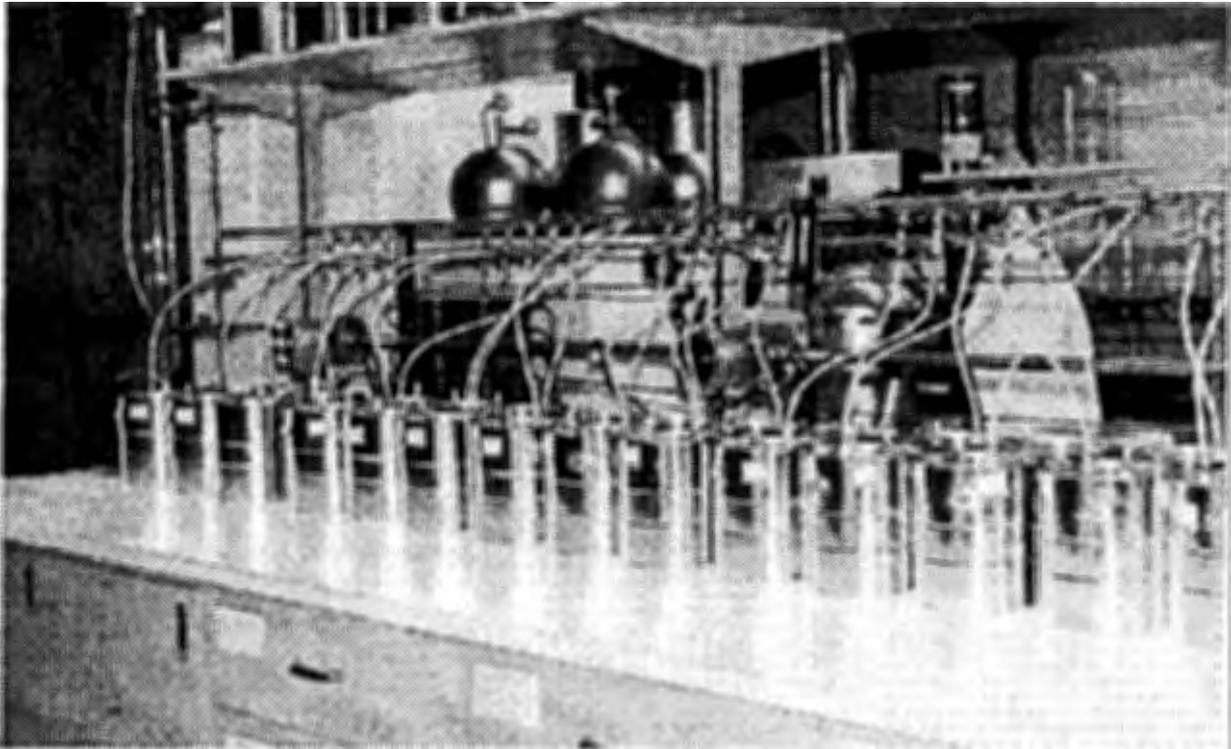


Figure 6-11. Conditioning chambers.

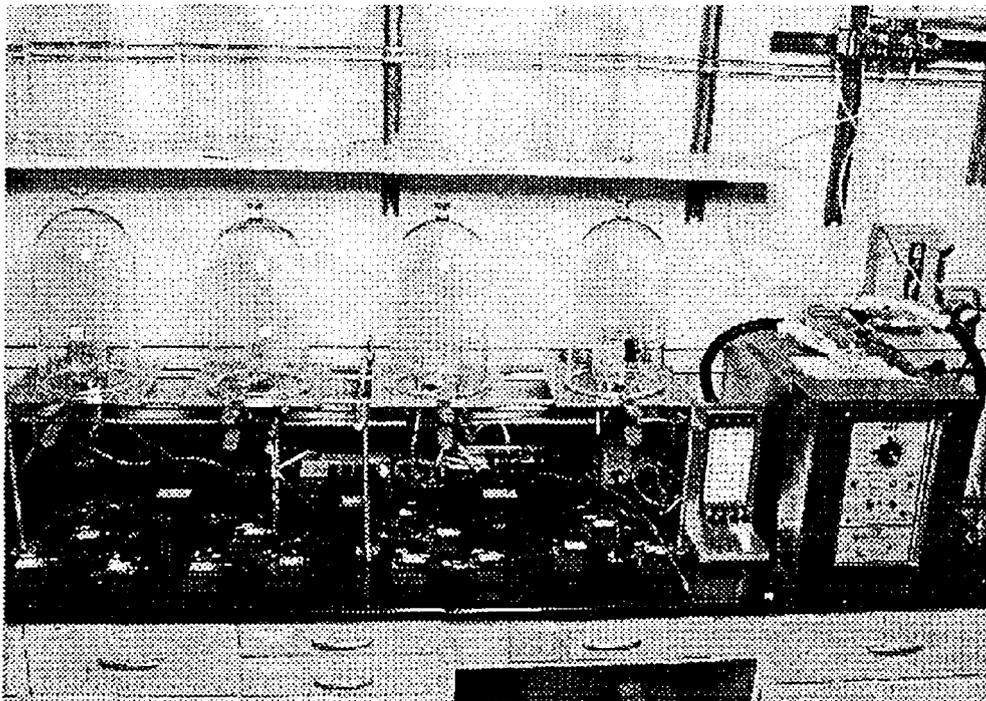


Figure 6-12. Four of six emission factors test chambers.

Table 6-3. Conditions For Chamber Testing

Test Parameters	Conditions
Chamber Size	0.012 m ³
Temperature	23°C
Relative Humidity	50%
Air Exchange Rate (ACH)	1/h
Source Area (A)	~0.012 m ²
Loading (L)	1.0 m ² /m ³

Table 6-4. Number of Chamber Air Samples Collected

Chamber Run ^c	Board	Coatings Systems						FC ^a	LC ^b	Total ^c
		1	2	3	4	5	6			
1	A	1	1	1	1			1	1	6
2	A			1	1	1	1	1	1	6
3	B	1	1		1	1		1	1	6
4	B	1	1	1			1	1	1	6
5	C		1	1		1	1	1	1	6
6	C	1			1	1	1	1	1	6

^a FC=uncoated field coupon.

^b LC=uncoated lab coupon.

^c Each chamber run occurred 35-days after each coatings day shown in Table 6-3. Coupons were randomly assigned to the test chambers.

and to generate instrumental response factors for TVOC quantitation. Standard cartridges were spiked with known amounts of toluene and aliphatic hydrocarbons ranging in volatility from n-hexane to n-tetradecane. Two external standards, perfluorotoluene (PFT) and bromopentafluorobenzene (BFB), were added to each standard cartridge. PFT was used to monitor instrumental tune (mass resolution and ion abundance) and BFB was used as an external quantitation standard. Each day during sample analysis, an additional standard cartridge was analyzed to demonstrate ongoing instrumental performance.

Table 6-5. GC/MS Operating Conditions For Analysis of VOC

Parameter	Setting
THERMAL DESORPTION	
Trap Type	1 = Multisorbent, 2 = Multisorbent
Tube Raised Ambient	Off
Initial Carrier Flow	1 min
Tube Chamber Heat Time	6 min
Tube Chamber Temperature (Max)	320°C
Secondary Carrier Flow	2 min
Trap 1 Heat (Max)	270°C
Trap 2 Heat (Max)	310°C
Trap-to-Trap Transfer Time	2 min
Trap-to-Column Transfer Time	20 min
GAS CHROMATOGRAPH	
Instrument	Hewlett-Packard 5890
Column	DB-624 widebore fused silica capillary column
Temperature Program	35°C (5 min) to 200°C (1 min) at 5°C/min
Carrier gas flow rate	1.8 mL/min
MASS SPECTROMETER	
Instrument	Hewlett Packard, Model 5988A
Ionization Mode	Electron Ionization Scan 35-350 m/z
Emission Current	0.3 mA
Source Temperature	200°C
Electron Multiplier	2000 volts ^a

^a Typical value

During quantitative analysis, identification of target analytes was based on chromatographic retention times relative to standards and the relative abundances of extracted ion fragments selected for quantitation. Quantitation was accomplished using chromatographic peak areas derived from extracted ion profiles. Calibration standards containing the target analytes were prepared on Tenax TA cartridges at masses ranging from 10 to 500 ng/cartridge. Each calibration standard and sample contained a known mass of the quantitation standard, bromopentafluorobenzene. Relative response factors (RRFs) for individual VOCs were calculated as

$$RRF_{VOC} = \frac{A_T \cdot M_{QS}}{A_{QS} \cdot M_{VOC}}$$

where M_{VOC} is the mass of the target VOC (ng/cartridge), M_{QS} is the mass of quantitation standard (ng/cartridge), A_{VOC} is the peak area of the target VOC, and A_{QS} is the peak area of the quantitation standard (ng/cartridge). Mean values and standard deviations of the RRFs were calculated for each target VOC. The calibration curve was considered acceptable if the standard deviation for each response factor was less than 30%.

During each day of analysis, an additional standard was analyzed. If the RRF values for this standard were within $\pm 25\%$ of the RRFs obtained during the instrument calibration, the GC/MS system was considered "in control", and the RRF from the calibration was used to calculate the mass of the target VOCs as

$$M_{VOC} = \frac{A_{VOC} \cdot M_{QS}}{A_{QS} \cdot RRF_{VOC}}$$

where M_{VOC} is the mass of the target VOC (ng/cartridge), M_{QS} is the mass of quantitation standard (ng/cartridge), A_{VOC} is the peak area of the target VOC, A_{QS} is the peak area of the quantitation standard (ng/cartridge), and RRF_{VOC} is the relative response factor of the target VOC.

TVOC were calculated from the total ion chromatogram (TIC). The total area of the TIC was integrated for the retention time window from n -hexane through n -tetradecane. The mass of TVOC (M_{TVOC}) was calculated as

$$M_{TVOC} = \frac{A_{TVOC} \cdot M_{QS}}{A_{QS} \cdot RRF_{Tot}}$$

where A_{TVOC} is the peak area of the TVOC and RRF_{Tot} is the average relative response factor for toluene.

The concentration of each VOC and TVOC in a chamber air sample was calculated as:

$$C_{VOC\ or\ TVOC} = \frac{M_{VOC\ or\ TVOC}}{V_s}$$

where $C_{VOC\ or\ TVOC}$ = Concentration of the VOC or TVOC in the chamber air sample ($\mu\text{g}/\text{m}^3$)
 $M_{VOC\ or\ TVOC}$ = Mass of VOC or TVOC on multisorbent cartridge
 V_s = Sample volume of chamber air, L

6.3.7.2 Analysis of Aldehydes and Ketones on DNPH Cartridges

DNPH cartridges were analyzed for the target aldehydes and ketones listed in Table 6-6. DNPH/aldehyde derivatives on sample cartridges were extracted by eluting each cartridge with 5 mL of HPLC grade acetonitrile into a 5 mL volumetric flask. The final volume was adjusted to 5.0 mL and the samples aliquoted for analysis. Blank cartridges were eluted with each sample set to identify background contaminants. Additional blank cartridges were spiked with known amounts of DNPH/aldehyde standards as a method of assessing recovery.

Table 6-6. Target Aldehydes and Ketones

Formaldehyde
Acetaldehyde
Acetone
Propionaldehyde
2-Butanone
Butyraldehyde
Benzaldehyde
Valeraldehyde
m-Tolualdehyde
n-Hexanal

DNPH/aldehyde derivatives in sample extracts were analyzed by HPLC with UV detection using the conditions shown in Table 6-7. Purified and certified DNPH derivatives of the target aldehydes were used for the preparation of calibration solutions. Target aldehydes were identified by comparison of their chromatographic retention times with those of the purified standards. Quantitation of the target compounds was accomplished by the external standard method using calibration standards prepared in the range 0.02 to 15 ng/ μL of the DNPH/aldehyde derivatives. Standards were analyzed singly for the aldehyde DNPH derivatives and a calibration curve calculated by linear regression of the concentration and chromatographic response data. Calibration curves for all target analytes were considered acceptable if $r^2 \geq 0.998$.

Table 6-7. HPLC Operating Conditions for the Analysis of Aldehyde Emission Factors

Parameter	Setting
Instrument	Waters Series 510
Column	NOVA-PAK C18, 3.9 x 150 mm
Solvent System	A: Water/Acetonitrile/Tetrahydrofuran 60/30/10 v/v B: Acetonitrile/Water 40/60 v/v
Gradient	100% A for 3 min; then a linear gradient to 100% B in 10 min. Hold 15 min at 100% B
Mobile Phase Flow Rate	1.5 mL/min
Injection Size	20 µL
UV Wavelength	360 nm

To demonstrate on-going instrumental performance, a calibration standard was analyzed each day prior to the analysis of any samples. The calibration was considered “in control” if the measured concentration of the aldehyde/DNPH derivatives in the standard was 85 to 115% of the prepared concentration.

The concentration of each target aldehyde and ketone in the chamber air samples was calculated as:

$$C_{a/k} = \frac{C_y \times V_y \times D_f}{V_s}$$

where $C_{a/k}$ = Concentration of the target aldehyde or ketone in chamber the air sample ($\mu\text{g}/\text{m}^3$)
 C_y = Concentration of DNPH/analyte derivative in the sample extract ($\text{ng}/\mu\text{L}$)
 V_y = Total volume of sample extract (i.e., 5000 μL)
 V_s = Sample volume of chamber air, L
 D_f = Molecular weight of the aldehyde or ketone \div molecular weight of the aldehyde or ketone/DNPH derivative

6.3.7.3 Conversion of Concentrations to Emission Factors

Concentrations of individual VOCs and TVOC measured in chamber air samples were converted to emission factors using the following equation

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

where C_m = measured concentration of a VOC or TVOC in a chamber air sample ($\mu\text{g} / \text{m}^3$)

ACH = air exchange rate in the test chamber
L = loading ratio in the test chamber

An emission factor of summed VOCs for a tested material was calculated by summing the individual emission factors of VOCs for a tested material.

6.3.8 Statistical Analysis of Emission Factors Data (Step 12)

The emission factors generated in Step 11 were statistically analyzed to ascertain (1) if coatings systems contribute significantly to 35-day emissions from test squares of finished PBV relative to test squares of uncoated lab coupons, i.e., unfinished PBV, and (2) if emission factors for test squares of PBV finished with the five alternative coatings systems are significantly different than those for test squares of PBV finished with the heat curable acid catalyzed alkyd-urea coatings system. To address the first objective, t-tests were conducted to assess differences in the mean emission factors of individual and summed VOCs between test squares finished with Coatings System 1 versus test squares of unfinished PBV, test squares finished with Coatings System 2 versus test squares of unfinished PBV, test squares finished with Coatings System 3 versus test squares of unfinished PBV, test squares finished with Coatings System 4 versus test squares of unfinished PBV, test squares finished with Coatings System 5 versus test squares of unfinished PBV, and test squares finished with Coatings System 6 versus test squares of unfinished PBV. To address the second objective, t-tests were conducted to assess potential differences in the mean emission factors of individual and summed VOCs for test squares finished with Coatings System 1 versus test squares finished with Coatings System 2, test squares finished with Coatings System 1 versus test squares finished with Coatings System 3, test squares finished with Coatings System 1 versus test squares finished with Coatings System 4, test squares finished with Coatings System 1 versus test squares finished with Coatings System 5, and test squares finished with Coatings System 1 versus test squares finished with Coatings System 6.

To meet the first objective, an analysis of variance (ANOVA) model of the following form was employed:

$$\log(y+1) = \text{overall mean} + \text{board effect} + \text{coating effect} + \text{error}$$

where y denotes the mean emission factor of a specific compound. The logarithmic scale was used to account for possible measurement error variance heterogeneity, which typically is approximately proportional to the magnitude of the emission factor. The addition of one to the log value was necessary to avoid taking logs of zero, which occurred for some compounds. Table 6-8 shows the ANOVA for objective one.

Table 6-8. ANOVA for Objective One

Source of Variation	Degrees of Freedom
Coatings (including lab blanks as one level)	6
Boards	2
Residual	20

For the first objective, the t value for testing coating i was determined as where \bar{L}_i and \bar{L}_{lab} denote the means of $\log(y+1)$ for test squares finished with coating i and test

$$t(i) = \frac{\bar{L}_i - \bar{L}_{lab}}{\sqrt{[s.e.(\bar{L}_i)]^2 + [s.e.(\bar{L}_{lab})]^2}}$$

squares of unfinished PBV, respectively, adjusted for board effects, and s.e. denotes the standard error of the indicated mean. The standard errors were based on the residual mean square from the ANOVA; hence p values were computed as the probability of observing a random variable T with magnitude greater than the calculated t value, when T follows a t distribution with 20 degrees of freedom. The following equation was used to calculate p-values:

$$p\text{-value}(i) = 2Pr\{T > |t(i)|\}$$

P values below some threshold level (e.g., 0.05 or 0.01) are typically used to declare that a statistically significant difference exists.

For the second objective, a similar ANOVA model was employed; however, the emissions data for the test squares of unfinished PBV were not used. Table 6-9 presents the ANOVA for objective two.

Table 6-9. ANOVA for Objective Two

Source of Variation	Degrees of Freedom
Coatings (including lab blanks as one level)	5
Boards	2
Residual	15

The test of no difference between the true average log emission factors for the pair of coating systems (i and j) was carried out by calculating the p value associated with the test statistic $t(i,j)$:

$$t(i,j) = \frac{\bar{L}_i - \bar{L}_j}{\sqrt{[s.e.(\bar{L}_i)]^2 + [s.e.(\bar{L}_j)]^2}}$$

where \bar{L}_i and \bar{L}_j denote the means of $\log(y+1)$ for test squares finished with coatings i and j , respectively, adjusted for board effects, and s.e. denotes the standard error of the indicated mean. The standard errors were based on the residual mean square from the ANOVA; hence p values were computed (using the same p -equation for Objective 1) as the probability of observing a random variable T with magnitude greater than the calculated t value, when T follows a t distribution with 15 degrees of freedom.

6.4 Results

6.4.1 Performance Tests

Table 6-10 presents the results of the performance tests. In this table, Coating 1 refers to test squares of PBV finished with an acid catalyzed alkyd-urea sealer and topcoat (the type of coatings system identified as a potential source of emissions from PBVST in Phases 1 and 2). Coatings 2 through 6 refer to test squares of PBV finished with five alternative coatings systems. Comparing the performance ratings of the alternative coatings systems to the ratings of Coating 1 (the benchmark coating) provides an indication of the ability of the alternative coatings systems to achieve the performance of Coating 1. Coatings 3, 4, and 5 outperformed Coating 1 in the MEK test. Coatings 4 and 5 outperformed Coating 1 in the mustard test. For the 11 stain tests, Coatings 2, 4, 5, and 6 performed the same as 1; Coating 3 performed fairly well in the stain tests except for its performance with grape juice and coffee. All coatings performed equally well in the adhesion and fingernail mar resistance tests. Coatings 4 and 5 had gloss ratings that differed substantially from that of Coating 1. Note, gloss can usually be varied quite easily by a coatings formulator without affecting other parameters such as hardness; therefore, a difference in gloss is not nearly as significant as a difference in a performance property such as chemical resistance.

Table 6-10. Performance Tests Results

Performance Tests	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Chemical Resistance						
1) MEK Test	20	10	100	100	100	10
2) Mustard Test (1h/24)	4/8	2/6	2/3	10	8/9	4/6
3) Stain Test (24)						
Vinegar	10	10	10	10	10	10
Lemon	10	10	10	10	10	10
Orange Juice	10	10	10	10	10	10
Grape Juice	10	10	8	10	10	10
Tomato Catsup	10	10	10	10	10	10
Coffee	10	10	8	10	10	10
Olive Oil	10	10	10	10	10	10
100-proof Alcohol	10	10	10	10	10	10
Detergent and Water	10	10	10	10	10	10
Water	10	10	10	10	10	10
Adhesion	5B	5B	5B	5B	5B	5B
Gloss	46	40	51	61	65	48
Hardness	74	77	74	72	77	71
Fingernail Mar Resistance	VG	VG	VG	VG	VG	VG

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

One caveat to the performance data is that measurements of hardness and chemical resistance depend on how much time has elapsed since a coating is cured. Some coatings gradually develop their hardness and chemical resistance over a period of one to two weeks. Standard industry practice is to wait 14 days after cure before running chemical resistance tests; hardness tests are usually measured at 1, 3, 7, 14, 31, and 93 days after cure. For this study, mustard and stain tests were performed 1 to 2 weeks after the coatings were cured; MEK tests were performed on the same day the coatings were cured; and hardness tests were measured 1 to 2 days after the coatings were cured. The coatings in Table 6-10 differ mainly in how they performed in the MEK and mustard tests; since time is critical factor in developing chemical resistance, some of the coatings that performed poorly, may have improved with time.

6.4.2 Emission Tests

Table 6-11 presents mean emission factors for test squares of PBV finished with each of the coatings systems and test squares of the lab and field coupons. Tables C2 through C9 in Appendix C present emission factors for individual test squares finished with each of the coatings systems and emission factors for individual test squares of lab and field coupons; these tables also show emissions variability among test squares with the same coatings system. As shown earlier in Table 6-2, each coatings system was applied and cured to four test squares; three of the test squares were from separate boards (i.e., one each from Boards A, B, and C). An additional test square was from one of the three boards. For each coatings system, the mean emission factors in Table 6-11 were calculated by first averaging emission factors of test squares

within boards, and then averaging emission factors across boards.

Table 6-12 presents partial results of the statistical analysis of the mean emission factors of individual and summed VOCs for test squares of PBV finished with each of the coatings systems and test squares of the lab coupons (i.e., unfinished PBV); Table C-11 in Appendix C presents the complete analysis of the mean emission factors of all compounds. As discussed in Section 6.3.8, the statistical analysis was performed on adjusted mean emission factors converted to a log scale basis.

For the comparison of the mean emission factors for test squares of unfinished PBV with the mean emission factors for test squares of PBV finished with Coatings Systems 1, 2, 3, 4, 5, and 6, statistically significant p-values (i.e., those less than 0.05) were marked with either a plus or minus sign in Table 6-12. The plus sign indicates that the mean emission factor of test squares of PBV finished with Coatings System j ($j = 1, 2, 3, 4, 5,$ and 6) was statistically higher than the mean emission factor for test squares of unfinished PBV; this is equivalent to saying that the mean emission factor for test squares of unfinished PBV was statistically lower than the mean emission factor for test squares of PBV finished with Coating System j .¹ The minus sign indicates that the mean emission factor for test squares of PBV finished with Coatings System j was statistically lower than the mean emission factor for test squares of unfinished PBV; this is equivalent to saying that the mean emission factor for test squares of unfinished PBV was statistically higher than the mean emission factor for test squares of PBV finished with Coatings System j .

In terms of answering Objective One (do coatings systems contribute significantly to 35-day emissions from finished PBV relative to unfinished PBV?), the mean emission factors of summed VOCs for test squares finished with Coatings Systems 1, 3, and 6 were statistically higher than the mean emission factor of summed VOCs for test squares of unfinished PBV. The mean emission factors of summed VOCs for Coatings Systems 2, 4, and 5 were statistically lower than the mean emission factor of summed VOCs for the test squares of unfinished PBV, indicating that these coatings systems suppressed emissions from PBV.

Some of the coatings systems suppressed wood compounds such as *n*-hexanal and limonene. For example, the mean emission factors of *n*-hexanal for test squares finished with Coatings Systems 1, 2, 4, and 5 were significantly lower than the mean emission factor of *n*-hexanal for test squares of unfinished PBV. The mean emission factors of limonene for test squares finished with Coatings Systems 2, 4, and 5 were statistically lower than the mean emission factor of limonene for test squares of unfinished PBV. None of the finished test squares had significantly different mean emission factors of acetone compared to the mean emission factor of acetone for the test squares of unfinished PBV, indicating that none of the coatings systems suppressed acetone emissions from PBV.

¹For discussions of the statistical analysis of the data, the term "mean" refers to the mean of $\log(y+1)$, where y = emission factor.

Table 6-11. Quantitated Mean Emission Factors from Uncoated and Coated Test Squares Conditioned for 28 Days

Compounds	Emission Factors, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$						
	Uncoated test squares of PBV	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
Formaldehyde	140	400	20	70	18	19	33
Acetaldehyde	61	53	41	65	68	41	68
Acetone	420	520	490	380	390	430	510
Propionaldehyde	21	16	15	16	16	12	17
2-Butanone	*	-	-	-	-	-	-
Butyraldehyde	15	-	-	18	-	-	12
Benzaldehyde	23	-	-	30	14	18	23
Valeraldehyde	65	37	26	54	28	19	57
m-Tolualdehyde	-	-	-	-	-	-	-
n-Hexanal	410	150	120	280	79	93	350
1-Pentanol	62	150	16	38	13	14	49
Limonene	79	68	54	74	38	37	83
Junipene	89	61	24	54	16	13	67
Terpenes	170	320	220	170	110	100	120
1-Butanol	6	800	-	5	-	8	7
Toluene	-	16	-	5	22	-	6
2-Methyl-1-butanol	-	55	-	-	-	-	-
Butyl acetate	-	38	-	-	-	-	-
1,2-Propanediol	-	15	-	33	-	-	-
Ethylbenzene	-	270	-	-	33	-	-
m,p-Xylene	-	660	-	-	110	-	-
2-Heptanone	15	550	8	13	9	7	22
o-Xylene	-	210	-	-	32	-	-
Propylbenzene	-	91	-	-	-	-	-
Ethyl 3-ethoxypropionate	-	110	-	-	-	-	-
1-Methyl-2-pyrrolidone	-	11	-	20	-	5	2400
2-(2-Butoxyethoxy)ethanol	8	1700	43	610	18	6	7
Naphthalene	-	24	-	-	-	-	-
Hexyl acetate	-	400	-	-	-	-	-
Indan	-	13	-	-	-	-	-
C3-Benzenes	-	1100	-	-	-	-	-
C4-Benzenes	34	190	25	33	17	16	33
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

* < 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

Table 6-12. P- Values of Mean Emission Factors of Select Compounds

1-Butanol	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.0023(-)	0.2337	0.0002(-)	0.0780	0.1039
C4-Benzenes	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.0546	0.8464	0.0011(-)	0.0048(-)	0.6644
2-(2-Butoxyethoxy)ethanol	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0307(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.0002(+)	0.0001(+)	0.2157	0.3125	0.2146
Formaldehyde	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.0001(-)	0.0001(-)	0.0001(-)	0.0001(-)	0.0001(-)
Acetone	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.7215					
	Coating 3	0.0777					
	Coating 4	0.0944					
	Coating 5	0.2792					
	Coating 6	0.8982					
	Unfinished PBV	0.1943	0.3543	0.4872	0.5594	0.9099	0.2443
n-Hexanal	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.6757					
	Coating 3	0.0048(-)					
	Coating 4	0.2359					
	Coating 5	0.2347					
	Coating 6	0.0003(-)					
	unfinished PBV	0.0001(-)	0.0001(-)	0.0979	0.0001(-)	0.0001(-)	0.6304
Limonene	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.6228					
	Coating 3	0.1184					
	Coating 4	0.0547					
	Coating 5	0.1483					
	Coating 6	0.1538					
	unfinished PBV	0.1225	0.0433(-)	0.8525	0.0010(-)	0.0055(-)	0.9806

(continued)

Table 6-12. Continued

1-Methyl-2-pyrrolidone	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.1949					
	Coating 3	0.0518					
	Coating 4	0.1088					
	Coating 5	0.1483					
	Coating 6	0.0001(-)					
	unfinished PBV	0.0135(+)	0.2267	0.0001(+)	0.4022	0.4024	0.0001(+)
Unknown 1	P(i/j)	Coating 1					
	Coating 2	1.0000					
	Coating 3	0.0001(-)					
	Coating 4	0.7874					
	Coating 5	0.8780					
	Coating 6	0.8246					
Unknown 2	P(i/j)	Coating 1					
	Coating 2	1.0000					
	Coating 3	0.0001 (-)					
	Coating 4	0.7609					
	Coating 5	0.9141					
	Coating 6	0.9676					
Sum of Emission factors	P(row/column)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0034(+)					
	unfinished PBV	0.0001(+)	0.0231(-)	0.0473(+)	0.0075(-)	0.0049(-)	0.0001(+)

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

For the comparison of mean emission factors for test squares finished with Coatings System 1 with the mean emission factors for test squares finished with Coatings Systems 2, 3, 4, 5, and 6, statistically significant p-values (i.e., those less than 0.05) were marked with either a plus or minus sign in Table 6-12. The plus sign indicates that the mean emission factor for test squares finished with Coatings System 1 was statistically higher than the mean emission factor for test squares finished with Coatings System i (i = 2, 3, 4, 5, and 6); this is equivalent to saying that the mean emission factors for test squares finished with Coatings System i were statistically lower than the mean emission factor of test squares finished with Coatings System 1. The minus sign indicates that the mean emission factor for test squares finished with Coatings System 1 were statistically lower than the mean emission factor for test squares finished with Coatings System i; this is equivalent to saying that the mean emission factor of test squares finished with Coatings System i was statistically higher than the mean emission factor of test squares finished with Coatings System 1.

In terms of answering Objective Two (are emission factors for test squares of PBV finished with the five alternative coatings systems significantly different than those for test squares of PBV finished with the heat curable acid catalyzed alkyd-urea coatings system?), the mean emission factor of summed VOCs for Coatings System 1 was significantly higher than the mean emission factors of summed VOCs for test squares finished with all five alternative coatings systems. Mean emission factors of most organic solvents [such as butanol, C4-benzenes, 2-(2-butoxyethoxy)ethanol] were significantly higher for test square finished with Coatings System 1 compared to those for test squares finished with the alternative coatings systems. This observation is consistent with the fact that Coatings System 1 is formulated with organic solvents, whereas Coatings Systems 2 through 6 are formulated with low-VOCs.

In terms of individual compounds, the mean emission factor of 1-methyl-2-pyrrolidone for test squares of PBV finished with Coatings System 1 was significantly lower than the mean emission factor of 1-methyl-2-pyrrolidone for test squares of PBV finished 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 finished with Coatings System 1 compared to those for test squares of PBV finished with Coatings System 3.

A few caveats exist regarding the emissions tests. Certain nonvolatile compounds that were listed in the MSDS for some of the coatings systems were not analyzed for in the emission tests; these included nitrocellulose, p-toluene sulfonic acid, hexamethylene diisocyanate, polyisocyanates, acrylate oligomers, and acrylic polymers (see Table 6-13). These compounds were not analyzed for in the emission tests for the following reasons: (1) they were not expected to be emitted into the air during testing (because of their low volatility); (2) they were not expected to recover efficiently from the emission test chambers; and (3) they were not expected to be amenable to the analytical methods used for this study.

Certain volatile compounds that were listed in the MSDS for some of the coatings systems were also not analyzed for in the emission tests; these included acrylate monomers, N,N-dimethylethanolamine, and ammonia (see Table 6-13). Acrylate monomers and N,N-dimethylethanolamine were not analyzed for in the emission tests because they were not amenable to the analytical methods in the study and because they were not expected to recover efficiently during the chamber tests (due to their polar nature). Ammonia was not tested for in the emission tests because it was not amenable to the analytical methods in the study.

6.5 Conclusions

- The mean emission factors of summed VOCs for test squares of PBV finished with Coatings Systems 1, 3, and 6 were statistically higher than the mean emission factor of summed VOCs for test squares of unfinished PBV, indicating that these coatings systems are a significant source of emissions from PBVST.

Table 6-13. Organic Compounds Listed on MSDS vs. Compounds Detected During Emissions Tests

<u>Coating #</u>	<u>Organic Compounds Listed on MSDS of Coatings</u>	<u>Detected in Emission (yes/no)</u>
1 (Sealer)	Aromatic solvent	yes (aromatic solvents are the C ₃ and C ₄ benzenes)
	C ₆ -branched alcohol acetate	yes (C ₆ -branched alcohol acetate is hexyl acetate)
	Xylene, mixed isomers	yes
	Butanol (Butyl alcohol)	yes
	2-Heptanone	yes
	1,2,4-Trimethylbenzene	yes (part of the C ₃ and C ₄ benzenes)
	Ethyl benzene	yes
	Nitrocellulose (gun cotton) ¹	see footnote
	Butoxyethoxyethanol	yes
1,1,3,3-Tetramethoxypropane	yes (identified but not quantified - standard unavailable)	
1 (Topcoat)	Ethyl-3-ethoxypropionate	yes
	Xylene, mixed isomers	yes
	Aromatic solvent	yes
	Butanol (Butyl alcohol)	yes
	1-Pentanol	yes
	Ethyl benzene	yes
	1,2,4-Trimethylbenzene	yes (part of the C ₃ and C ₄ benzenes)
	Butoxyethoxyethanol	yes
	Nitrocellulose (gun cotton) ¹	see footnote
1,1,3,3-Tetramethoxypropane	yes (identified but not quantified)	
1 (Catalyst)	p-Toluene sulfonic acid ³	see footnote
	Isopropanol (Isopropyl alcohol)	yes (identified but not quantified)
	Methyl alcohol (Methanol) ¹	see footnote

Continued

Table 6-13. (Continued)

<u>Coating #</u>	<u>Organic Compounds Listed on MSDS of Coatings</u>	<u>Detected in Emission (yes/no)</u>
2	Aliphatic polyisocyanates ²	see footnote
	Hexamethylene diisocyanate (HDI) ²	see footnote
	HDI based polyisocyanate ²	see footnote
3	Acrolein	no
	Acetaldehyde	yes
4 (Sealer)	Acrylate monomers ³	see footnote
	Acrylate oligomers ³	see footnote
	Naphtha	yes (naphtha is a mixture of hydrocarbon solvents, e.g., C ₃ and C ₄ benzenes)
	1-Methoxy-2-propanol	no
75 4 (Topcoat)	Acrylate monomers ³	see footnote
	Acrylate oligomers ³	see footnote
5	Acrylic polymer ³	see footnote
	2-Hydroxy-2-methyl-1-phenylpropan-1-one	no ⁴
	2,3-Dihydroxypropyl methacrylate	no ⁴
	Residual monomers ³	see footnote
	Ammonia ¹	see footnote
6	N-N-Dimethylethanolamine ¹	see footnote
	Dipropylene glycol methyl ether	yes
	N-Methyl pyrrolidone	yes

Continued

Table 6-13. (Continued)

Coating # Organic Compounds Listed on MSDS of Coatings Detected in Emission (yes/no)

¹Compound not suited for air sampling and or analysis techniques used in study.

²Recovery of compounds from test chambers was poor.

³Standard air sampling methods do not exist and chamber recovery is expected to be poor.

⁴Standard not available to confirm performance.

MSDS = Material safety data sheet

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

- The mean emission factors of summed VOCs for test squares of PBV finished with Coatings Systems 2, 4, and 5 were statistically lower than the mean emission factor of summed VOCs for test squares of unfinished PBV, indicating that these coatings systems are not a significant source of emissions from PBVST.
- Within the scope of the emissions tests and performance tests conducted for the evaluation, Coatings Systems 2, 4, and 5 (the heat curable two component polyurethane, the UV curable acrylate, and the UV curable multi-functional acrylate-free emulsion, respectively) appear to be viable alternatives for Coatings System 1.

Chapter Seven Phase 3 Fiber Panel Study

7.1 Overview

Engineered fiber panels are made from a variety of fiber sources such as lumber and plywood residuals, wheat straw, recycled newspaper, and recycled corrugated cardboard. Some panels require an adhesive to bind the fibrous materials together. Others contain additives such as wax (to retard water absorption) and flame retardents.

In Phase 2, UF bonded PB was identified as a potential source of VOCs and formaldehyde from PBVST (oak-veneered particleboard coated and cured with an acid catalyzed alkyd-urea sealer and topcoat). A fiber panel study was conducted to screen (i.e., estimate) emissions from a variety of unfinished engineered panels that can be veneered and finished with coatings, similar to PBVST. Table 7-1 lists the types of unfinished engineered fiber panels selected for screening. All of the panels, except for Panel A, can be veneered and finished with coatings. Panel A is typically used as an unfinished panel or covered with fabric; it was included in the study because it can be used in a variety of indoor applications.

Table 7-1. Selected Engineered Panels

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

^a MDI = Methylene diisocyanate

^b PB = particleboard

^c MDF = medium density fiberboard

^d UF = Urea-formaldehyde

^e PF = Phenol-formaldehyde

^f The manufacturing process does not require adhesive or resin to form the fibers into a panel; once the panels are manufactured, they are glued together (in sets of two) using a white, polyvinyl acetate glue.

Emissions were also screened from a few finished engineered fiber panels. Table 7-2 is a list of the types of finished panels screened. Project resources limited the types of finished panels screened and the extent of the emissions testing.

Table 7-2. Finished Engineered Fiber Panels Selected for Screening

Panel Identification	Description
H	Product B (wheatboard) with veneer
I	Product B overlaid with vinyl
J	Product B overlaid with melamine
M	Product C (recycled corrugated cardboard) painted
O	Product B coated and cured with heat curable two component polyurethane coating

7.2 Objective

The principal objective of the fiber panel study was to screen emissions of TVOC and formaldehyde from different types of unfinished engineered fiber panels. A secondary objective was to screen emissions of TVOC and formaldehyde from finished engineered fiber panels. Physical properties of the panels such as density, modulus of rupture, modulus of elasticity, etc., were not measured in the study, but instead were provided by the panel manufacturers (see Table D-1 of Appendix D).

Emissions were screened from test squares of unfinished panels within 24 hours of conditioning the test squares at typical indoor conditions (23°C, 50% RH, and 1 ACH), and 26 to 30 days after conditioning the test squares. Emissions from finished panels were screened 26 to 28 days after conditioning the test squares. Emissions were screened within 24 hours of conditioning to estimate emissions from newly manufactured panels. Emissions were screened after 26 to 30 days of conditioning to estimate emissions from panels at a time when they might be present in a consumer's home as part of an assembled product.

7.3 Experimental Design

7.3.1 Collection of Products

Products A through F, H, I, J, M, and N were collected after the last stage of their manufacturing process (for Product E, the last stage in the manufacturing process involved treating the panels with ammonia to reduce formaldehyde emissions from the unfinished panels). For each product type, three panels were collected from the manufacturing line (all of the unfinished panels were 1.90 cm thick). Several 23 cm by 15 cm coupons were cut from the center of each panel. All coupons cut from the same panel were placed in a steel container with an airtight lid. The containers were transported to RTI within two to five days of manufacture. Upon arrival at RTI, the coupons were stored in their containers at room temperature until testing.

For Product O, three panels of unfinished oak-veneered wheatboard were collected from the end of the manufacturing line. Several 23 cm by 15 cm coupons were cut from the center of each panel. All coupons cut from the same panel were placed in a steel container with an airtight lid. The containers were transported to a coatings facility where the coupons were coated and cured with a two component polyurethane (the same type of two component polyurethane evaluated in the Phase 3 Coatings Study). After the coatings cured, the coupons were resealed in their containers and shipped to RTI. Upon arrival at RTI, the coupons were stored in their containers at room temperature until testing.

7.3.2 Preparation of Test Squares

Within 7 to 11 days of sample collection, coupons from each product were removed from storage and cut into test squares. Test squares were labeled on each exposed edge with a product code (A through F, N, H, I, J, and M), a panel number (1 through 3), and test square number (1 through 2). A graphite pencil was used to label the test squares. After they were labeled, the edges of each test square were sealed with sodium silicate (liquid glass) to ensure that emitted VOCs came from the surfaces of the test squares and not the cut edges.

7.3.3 Chamber Air Collection

Prepared test squares of each product were transferred to individual test chambers for emissions testing. The test chambers operated at the conditions shown in Table 7-3. The test squares resided in the test chambers overnight which allowed them to equilibrate with the chamber air. Air samples for measuring VOCs were collected from the test chambers the following morning.

Table 7-3. Conditions For Chamber Testing

Test Parameters	Conditions
Chamber Size	0.012 m ³
Temperature	23°C
Relative Humidity	50%
Air Exchange Rate (ACH)	1/h
Source Area (A)	~0.012 m ²
Loading (L)	1.0 m ² /m ³

Upon completion of chamber air sampling, the test squares were removed from the test chambers and transferred to individual conditioning chambers. The conditioning chambers consisted of 1 gallon steel chambers which operated at 23°C, 50% RH, and one air exchange rate.

The test squares were kept in the conditioning chambers for 26 to 30 days; afterwards, the test squares were removed from the conditioning chambers and transferred to individual test chambers. The test squares resided in the test chambers overnight which allowed them to equilibrate with the chamber air. The following morning, air samples were collected from each test chamber.

7.3.3.1 VOCs Collection

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 Amborsorb (Figure 4-2 in Section 4.3.3 shows the arrangement of the cartridges for collecting VOCs). DNPH cartridges are designed to collect aldehydes and ketones. Multisorbent cartridges are designed to collect other types of VOCs.

Chamber air was passed through the DNPH cartridge at a flow rate of approximately 100 mL/min for 180 minutes to collect a sample volume of approximately 18 L. Chamber air was passed through each multisorbent cartridge at a flow rate of approximately 25 to 30 mL/min for approximately 180 minutes to collect a sample volume of approximately 5 L.

7.3.4 Analysis of VOCs

7.3.4.1 Analysis of VOCs on Multisorbent Cartridges

VOCs on multisorbent cartridges were thermally desorbed and then analyzed by GC/MS using the conditions shown in Table 7-4. Identification of unknown sample constituents was performed using an electronic search of the NIH/EPA/MSDC Mass Spectral Data Base (NIST library) and the Registry of Mass Spectral Library (Wiley library). Manual review of the data was also performed to verify computer identifications and to identify compounds not found using the computer library search.

Prior to analysis, a set of standard cartridges were analyzed to show proper mass calibration for the GC/MS system, to establish GC retention time windows for selected VOCs, and to generate total ion response factors for VOCs quantitation estimates. Standard cartridges were spiked with known amounts of toluene and aliphatic hydrocarbons ranging in volatility from n-hexane to n-tetradecane. Two external standards [i.e., perfluorotoluene (PFT) and bromopentafluorobenzene (BFB)], were also added to each standard cartridge. PFT was used to monitor instrumental tune (mass resolution and ion abundance) and BFB was used as an external quantitation standard. Each day during sample analysis, an additional standard cartridge was analyzed to demonstrate ongoing instrumental performance.

Quantitative estimates of the identified VOCs were based on total ion reconstructed chromatographic peak areas and a total ion relative response factor generated for toluene (RRF_{Tol}). Standard cartridges were prepared and analyzed as described above. Each of these cartridges contained a known mass of toluene and the external quantitation standard. The RRF_{Tol} was calculated from the resulting data as

$$RRF_{Tol} = \frac{A_{Tol} \cdot M_{QS}}{A_{QS} \cdot M_{Tol}}$$

where M_{Tol} is the mass of toluene (ng/cartridge)
 M_{QS} is the mass of quantitation standard (ng/cartridge)
 A_{Tol} is the peak area of toluene
 A_{QS} is the peak area of the quantitation standard (ng/cartridge).

Table 7-4. GC/MS Operating Conditions For Analysis of VOCs

Parameter	Setting
THERMAL DESORPTION	
Trap Type	1 = Glass beads, 2 = Tenax TKI, 3 = Open
CARTRIDGE DESORPTION	
Temperature	240°C
Carrier Gas Flow Rate	25 mL/min
Time	8 min
TRAP 1	
Initial Temperature	~150°C
Desorption Temperature	20°C
Desorption Carrier Gas Flow Rate	10 mL/min
Desorption Time	4 min
TRAP 2	
Initial Temperature	~10°C
Desorption Temperature	180°C
Desorption Carrier Gas Flow Rate	10 mL/min
Desorption Time	35 min
TRAP 3	
Initial Temperature	~150°C
Desorption Temperature	100°C
Inject Time	5 min
GAS CHROMATOGRAPH	
Instrument	Hewlett-Packard 5890
Column	DB-624 widebore fused silica capillary column
Temperature Program	35°C (5 min) to 200°C (1 min) at 5°C/min
Carrier Gas Flow Rate	1.8 mL/min
MASS SPECTROMETER	
Instrument	Hewlett Packard, Model 5988A
Ionization Mode	Electron Ionization Scan 35-350 m/z
Emission Current	0.3 mA
Source Temperature	200°C
Electron Multiplier	2000 volts ^a

^a Typical value

During each day of the screening analysis, an additional standard cartridge was analyzed. If the RRF_{Tot} was within $\pm 25\%$ of the RRF_{Tot} obtained during the instrument calibration, the GC/MS system was considered "in control", and the RRF_{Tot} from the calibration was used to estimate VOC amounts on sample cartridges as

$$M_{VOC} = \frac{A_{VOC} \cdot M_{QS}}{A_{QS} \cdot RRF_{Tot}}$$

where M_{VOC} is the estimated mass of a VOC (ng/cartridge)
 M_{QS} is the mass of quantitation standard (ng/cartridge)
 A_{VOC} is the peak area of the VOC
 A_{QS} is the peak area of the quantitation standard (ng/cartridge).

TVOC were calculated from the total ion chromatogram (TIC). The total area of the TIC was integrated for the retention time window from n-pentane through n-tetradecane. The mass of TVOC was calculated as

$$M_{TVOC} = \frac{A_{TVOC} \cdot M_{QS}}{A_{QS} \cdot RRF_{Tot}}$$

The concentration of each VOC and TVOC in a chamber air sample was calculated as:

$$C_{VOC \text{ or } TVOC} = \frac{M_{VOC \text{ or } TVOC}}{V_s}$$

where $C_{VOC \text{ or } TVOC}$ = Concentration of the VOC or TVOC in the chamber air sample ($\mu\text{g}/\text{m}^3$)
 $M_{VOC \text{ or } TVOC}$ = Mass of VOC on multisorbent cartridge
 V_s = Sample volume of chamber air, L.

7.3.4.2 Analysis of VOCs on DNPH Cartridges

DNPH cartridges were analyzed for the target aldehydes and ketones listed in Table 7-5. DNPH/aldehyde derivatives on sample cartridges were extracted by eluting each cartridge with 5 mL of HPLC grade acetonitrile into a 5 mL volumetric flask. The final volume was adjusted to 5.0 mL and the samples aliquoted for analysis. Blank cartridges were eluted with each sample set to identify background contaminants. Additional blank cartridges were spiked with known amounts of DNPH/aldehyde standards as a method of assessing recovery.

DNPH/aldehyde derivatives in sample extracts were analyzed by HPLC with UV detection using the conditions shown in Table 7-6. Purified and certified DNPH derivatives of the target aldehydes were used for the preparation of calibration solutions. Target aldehydes were identified by comparison of their chromatographic retention times with those of the purified standards. Quantitation of the target compounds was accomplished by the external standard method using calibration standards prepared in the range 0.02 to 15 $\text{ng}/\mu\text{L}$ of the DNPH/aldehyde derivatives. Standards were analyzed singly for the aldehyde DNPH derivatives and a calibration curve calculated by linear regression of the concentration and chromatographic response data. Calibration curves for all target compounds were considered acceptable if $r^2 \geq 0.998$.

Table 7-5. Target Aldehydes and Ketones

Formaldehyde
Acetaldehyde
Acetone
Propionaldehyde
2-Butanone
Butyraldehyde
Benzaldehyde
Valeraldehyde
<i>m</i> -Tolualdehyde
<i>n</i> -Hexanal

Table 7-6. HPLC Operating Conditions for the Analysis of Aldehyde Emission Factors

Parameter	Setting
Instrument	Waters Series 510
Column	NOVA-PAK C18, 3.9 x 150 mm
Solvent System	A: Water/Acetonitrile/Tetrahydrofuran 60/30/10 v/v B: Acetonitrile/Water 40/60 v/v
Gradient	100% A for 3 min; then a linear gradient to 100% B in 10 min. Hold 15 min at 100% B
Mobile Phase Flow Rate	1.5 mL/min
Injection Size	20 µL
UV Wavelength	360 nm

To demonstrate on-going instrumental performance, a calibration standard was analyzed each day prior to the analysis of any samples. The calibration was considered "in control" if the measured concentration of the aldehyde/DNPH derivatives in the standard was 85 to 115% of the prepared concentration.

The concentration of each target aldehyde and ketone in the chamber air samples were calculated as:

$$C_{alk} = \frac{C_y \times V_y \times D_F}{V_s}$$

where C_{alk} = Concentration of the target aldehyde or ketone in chamber the air sample ($\mu\text{g}/\text{m}^3$)
 C_y = Concentration of DNPH/analyte derivative in the sample extract ($\text{ng}/\mu\text{L}$)
 V_y = Total volume of sample extract (i.e., 5000 μL)
 V_s = Sample volume of chamber air, L
 D_f = Molecular weight of the aldehyde or ketone \div molecular weight of the aldehyde or ketone/DNPH derivative

7.3.4.3 Conversion of Concentrations to Emission Factors

Concentrations of individual VOCs and TVOC measured in chamber air samples were converted to emission factors using the following equation

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

where

C_m = measured concentration of a VOC or TVOC in a chamber air sample ($\mu\text{g}/\text{m}^3$)
 ACH = air exchange rate in the test chamber
 L = loading ratio in the test chamber

An emission factor of summed VOCs for a tested material was calculated by summing the individual emission factors of VOCs for a tested material.

7.3.5 Statistical Analysis of Emission Factors Data

A statistical analysis was conducted on the fiber data to ascertain which panel materials differ with respect to their mean, estimated emission factors of TVOC and formaldehyde. To meet this objective, an ANOVA model of the following form was employed:

$$\log(y) = \text{overall mean} + \text{panel effect} + \text{product effect} + \text{error}$$

where y denotes the mean emission factor of TVOC or formaldehyde. The logarithmic scale was used to account for possible measurement error variance heterogeneity, which typically is approximately proportional to the magnitude of the concentration. Table 7-7 presents the ANOVA for the for the statistical analysis.

Table 7-7. ANOVA for Statistical Analysis

Source of Variation	Degrees of Freedom
Products	6
Residual (Panels within Products)	14

T-tests were performed for each possible pair of panels (21 in total) to determine if emission factors differed for TVOC and formaldehyde. The t statistic for comparing products i and j was determined as

$$t(i,j) = \frac{\bar{L}_i - \bar{L}_j}{\sqrt{[s.e.(\bar{L}_i)]^2 + [s.e.(\bar{L}_j)]^2}}$$

where \bar{L}_i and \bar{L}_j denote the log-scale mean emission factors for panel i and panel j, respectively. The standard errors (s.e.) appearing in the denominator were based on the residual mean square from the ANOVA. The test of no difference between the true average log emission factors for a pair of products was carried out by calculating the p value associated with the test statistic t(i,j):

$$p\text{-value}(i,j) = 2 \Pr\{T > |t(i,j)|\}$$

where T is a random variable having a t distribution with 14 degrees of freedom, which is the (approximate) distribution of the test statistic if the null hypothesis of no difference in emission factors is true.

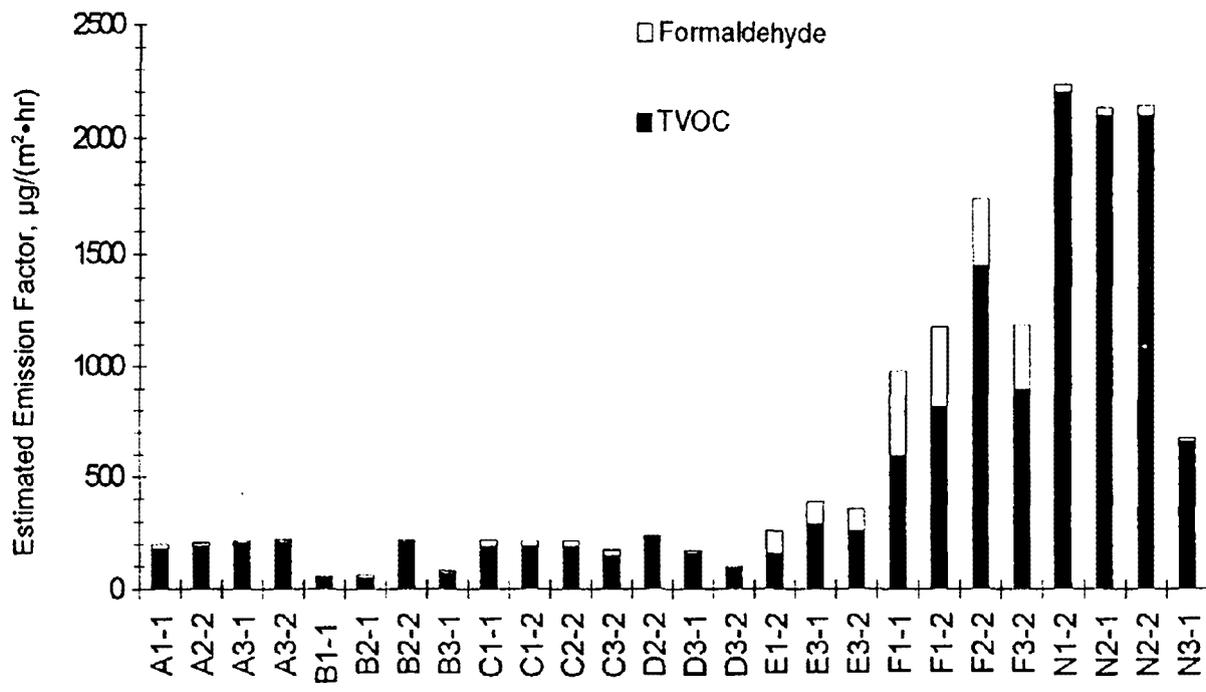
7.4 Results

7.4.1 Emission Data

7.4.1.1 Emission Data of Unfinished Test Squares

Tables D2 through D7 of Appendix D contain screening data for unfinished test squares of Panels A through F, and N. The tables list individual VOCs with emission factors greater than 5 µg/(m²•hr) for each of the test squares. The following is a discussion of the TVOC and formaldehyde emission factors for each of the test squares.

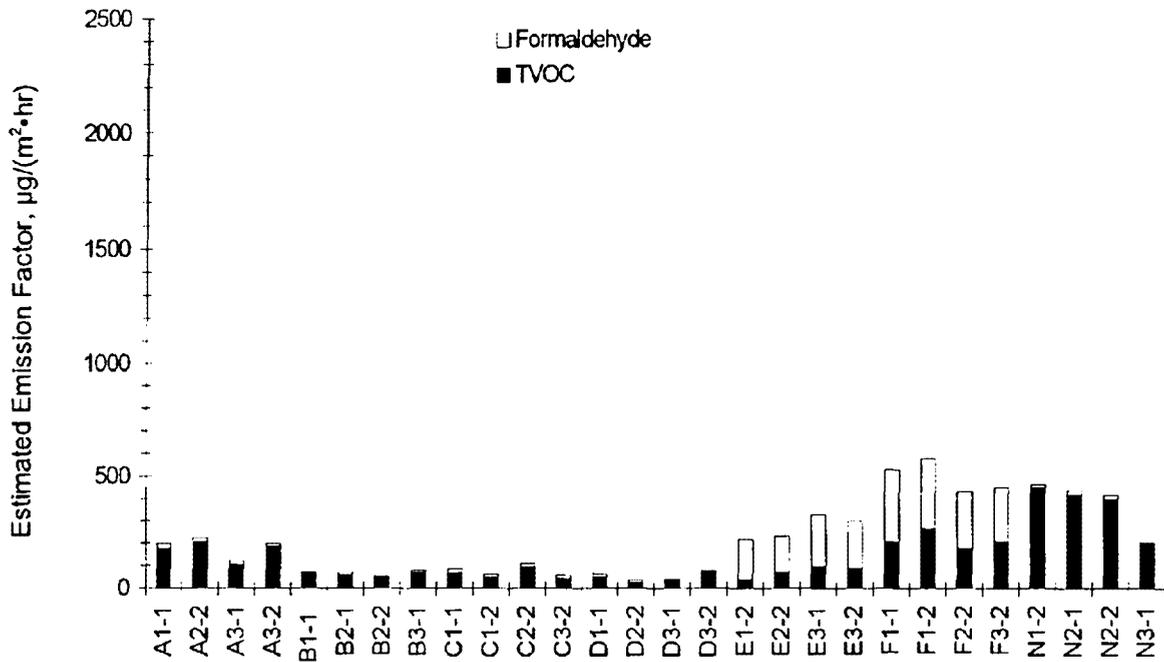
Figure 7-1 presents TVOC and formaldehyde emission factors for test squares conditioned less than 24 hours. Figure 7-2 presents TVOC and formaldehyde emission factors for test squares conditioned 26 to 30 days. Test squares F and N showed a substantial decay in TVOC emission factors due to conditioning/aging (Figure 7-2). Test square N3-1 had lower emission factors than test squares N1-2, N2-1, and N2-2 less than 24 hours after conditioning;



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 = ammonia treated medium density fiberboard with urea-formaldehyde (UF) resin
- F = particleboard with UF resin
- N = particleboard with phenol-formaldehyde resin

Figure 7-1. Estimated emission factors of TVOC and formaldehyde for test squares of engineered panels conditioned less than 24 hours.



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 = ammonia treated medium density fiberboard with urea-formaldehyde (UF) resin

F = particleboard with UF resin

N = particleboard with phenol-formaldehyde resin

Figure 7-2. Estimated emission factors of TVOC and formaldehyde for test squares of engineered panels conditioned 26 to 30 days.

however, all of the N test squares had similar emission factors after the longer conditioning period (Figure 7-2) and after 26 to 30 days conditioning. Formaldehyde emission factors remained fairly constant from test squares F and N over time.

Most of test squares A and B showed little decay over time in emission factors of TVOC and formaldehyde. Test square B2-2 had somewhat higher initial emission factors of TVOC than test squares B1-1, B 2-1, and B3-1; however, over time, the emission factor of TVOC for test square B2-2 decayed to the same level of those for test squares of B.

TVOC emission factors for test squares C through E all decayed over time. Formaldehyde emission factors for test squares C and D remained fairly constant over time. Formaldehyde emission factors unexplainably increased from test squares of E over time.

Tables 7-8 and 7-9 present results of the statistical analysis of the TVOC and formaldehyde emission factors for test squares conditioned 26 to 30 days (Figure 7-2). As shown in Figure 7-2, TVOC emission factors for test squares A, F, and N were relatively high compared to TVOC emission factors for test squares B, C, D, and E. As shown in Table 7-8, the mean emission factors of TVOC for test squares A, F, and N were significantly higher than those for test squares B through E. Formaldehyde emission factors for test squares E and F (the UF bonded products) were substantially higher than formaldehyde emission factors for test squares A through D, and N (Figure 7-2). As shown in Table 7-9, the mean emission factors of formaldehyde for test squares E and F were significantly higher than those for test squares A through D, and N.

7.4.1.2 Emission Data of Finished Test Squares

Tables D8 through D12 of Appendix D contain screening data for finished test squares of Panels H, I, J, M, and O. The tables list individual VOCs with emission factors greater than 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ for each of the test squares. The following is a discussion of the TVOC and formaldehyde results for each of the test squares.

Figures 7-3 and 7-4 present emission factors of TVOC and formaldehyde for test squares of finished recycled corrugated cardboard and wheatboard, respectively; test squares of unfinished recycled corrugated cardboard and wheatboard are also shown for reference. Test squares of recycled corrugated cardboard finished with paint (Product M) had slightly higher emission factors of TVOC than the unfinished test squares of recycled corrugated cardboard (Product C). Emission factors of formaldehyde were fairly consistent between the two products.

As shown in Figure 7-4, emission factors of formaldehyde for test squares of oak-veneered wheatboard (Product H) were substantially higher compared to emission factors of formaldehyde for test squares of unfinished wheatboard (Product B). In the Phase 2 component study, formaldehyde emissions were not detected from oak-veneer. The elevated formaldehyde emissions from the oak-veneered wheatboard are likely due to the UF glue used to adhere the veneer to the wheatboard. Emission factors of formaldehyde for test squares of oak-veneered wheatboard finished with the heat curable two component polyurethane were lower than those for test squares of unfinished oak-veneered wheatboard. The coatings evaluation showed that

Table 7-8. P-values for Mean Emission Factors of TVOC from Test Squares Conditioned 26 to 30 Days

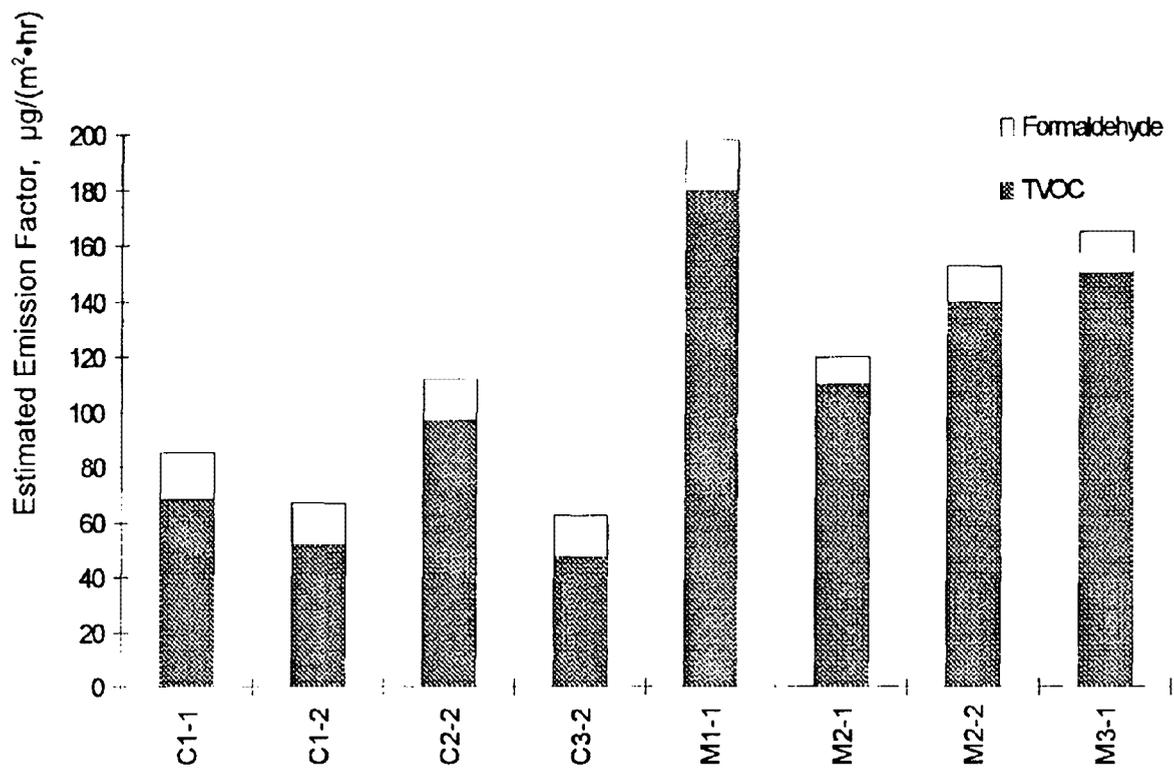
P-value for (row/column _j)	Panel A	Panel B	Panel C	Panel D	Panel E	Panel F
Panel B	0.0018 (+) ^a					
Panel C	0.0016 (+)	0.9604				
Panel D	0.0001 (+)	0.1424	0.1549			
Panel E	0.0021 (+)	0.9342	0.8949	0.1236		
Panel F	0.4527	0.0004 (-) ^b	0.0004 (-)	0.0001 (-)	0.0005 (-)	
Panel N	0.0262 (-)	0.0001 (-)	0.0001 (-)	0.0001 (-)	0.0001 (-)	0.1087

^a For p-values less than 0.05 (which indicate statistical significance at the 95 percent confidence level), a plus sign indicates that the mean emission factors of TVOC from panel j (j = A through F) were significantly higher than the mean emission factors of TVOC from panel i (i = B through N); this is equivalent to saying that the mean emission factors of TVOC from panel i were significantly lower than the mean emission factors of TVOC from panel j.

^b For p-values less than 0.05, a minus sign by the p-value indicates that the mean emission factors of TVOC from panel j were significantly lower than the mean emission factors of TVOC from panel i; this is equivalent to saying that the mean emission factors of TVOC from panel i were significantly higher than the mean emission factors of TVOC from panel j.

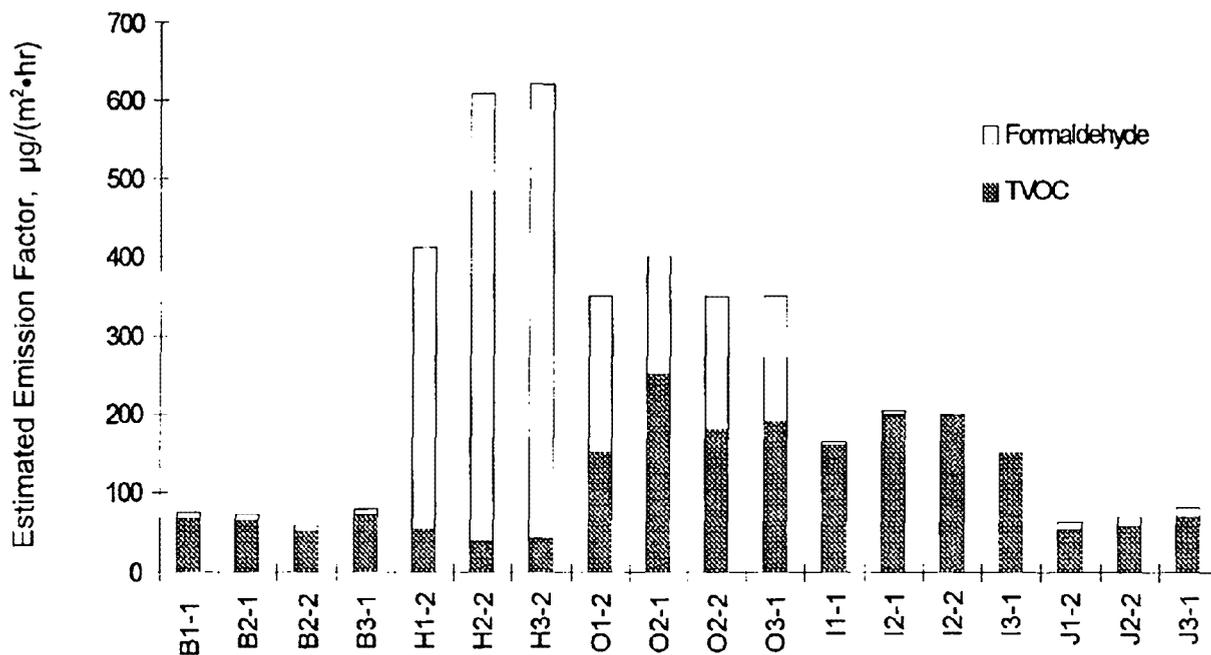
Table 7-9. P-values For Mean Emission Factors of Formaldehyde from Test Squares Conditioned 26 to 30 Days

P-value for (row/column _j)	Panel A	Panel B	Panel C	Panel D	Panel E	Panel F
Panel B	0.0021 (+)					
Panel C	0.7972	0.0036 (-)				
Panel D	0.0062 (+)	0.6043	0.0104 (+)			
Panel E	0.0001 (-)	0.0001 (-)	0.0001 (-)	0.0001 (-)		
Panel F	0.0001 (-)	0.0001 (-)	0.0001 (-)	0.0001 (-)	0.1362	
Panel N	0.1261	0.0519	0.1939	0.1332	0.0001 (+)	0.0001 (+)



Test squares are labeled by material acronym (C or M), followed by sample number, followed by test square number, respectively, where
 C = unfinished panel made from recycled corrugated cardboard
 M = panel made from painted recycled corrugated cardboard
 TVOC = total volatile organic compounds

Figure 7-3. Estimated emission factors of TVOC and formaldehyde for unfinished and finished test squares of recycled corrugated cardboard conditioned 26 to 28 days.



Test squares are labeled by material acronym (B, H, O, I, or J), followed by sample number, followed by test square number, respectively, where
 B = unfinished wheatboard
 H = veneered wheat board
 O = veneered wheat board with heat curable two component polyurethane coating
 I = wheatboard with vinyl
 J = wheatboard with melamine
 TVOC = total volatile organic compounds

Figure 7-4. Estimated emission factors of TVOC and formaldehyde for unfinished and finished wheatboard conditioned approximately 28 days.

the mean emission factor of formaldehyde for test squares of PBV coated and cured with the heat curable two component polyurethane was very low - 20 µg/(m²·hr) (see Table 6-11 in Section 6.4.2). The coating appears to suppress formaldehyde emissions from test squares of oak-veneered wheatboard.

7.5 Conclusions and Recommendations

- 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.
- A broader study of the low-emitting engineered fiber panels should be conducted to

assess manufacturing issues (such as cost, worker safety) involved with making the panels. Performance tests should also be conducted on the panels.

Chapter 8 Data Quality

8.1 Overview

Quality assurance (QA) activities were an integral part of this research program. QA activities that were conducted in support of this study included:

- Preparing quality assurance project plans (QAPPs),
- Developing data quality indicator goals for study data,
- Monitoring quality control procedures and results, and
- Conducting inspections, audits, and data reviews

8.2 QAPPs

RTI prepared three, category III QAPPs for carrying out sample collection, handling and storage, and emissions testing for each phase of the research. Each QAPP was approved by EPA prior to testing.

8.3 Data Quality Indicator Goals

Chamber air concentrations were the critical measurements in this study. Data quality indicator goals for these measurements are listed in Table 8-1.

Table 8-1. Data Quality Indicator Goals for Chamber Air Concentrations

Chamber Air Concentrations	Data Quality Indicator Goals	
	Precision, % RSD ^a	Accuracy, % REC ^b
VOCs	±20	≥75 (for quantitative emissions tests only) ^c
Aldehydes and Ketones	±20	≥75

^a % RSD = percent relative standard deviation

^b % REC = percent recovery

^c accuracy of VOCs not evaluated for semi-quantitative emissions tests

8.3.1 Precision

Precision of chamber air concentrations was evaluated by determining the percent relative standard deviation (%RSD) between duplicate chamber air samples as follows:

$$\%RSD = \frac{S}{Y} \times 100$$

where,

$\frac{S}{Y}$ = the standard deviation between duplicate air samples
= the mean of duplicate air samples

Precision calculations are reported in Tables E-1 through E-3 in Appendix E. As seen in these tables, most duplicate air samples were within the precision goal of ≤ 20 %RSD.

8.3.2 Accuracy

Accuracy of chamber air concentrations was evaluated by determining the percent recovery (%REC) of VOCs, aldehydes, and ketones from spiked sample cartridges as follows:

$$\%REC = (A_m/A_s) \times 100\%$$

where,

A_m = the amount of compound measured during chemical analysis
 A_s = the amount of compound spiked onto a sampling cartridge.

Accuracy calculations are reported in Tables F-1 through F-3 in Appendix F.

8.4 Quality Control

Chamber air samples collected from empty test chambers and blank cartridges were analyzed to monitor background and accidental contamination. Calibration curves were prepared prior to analysis of chamber air samples, and check standards were analyzed at regular intervals to ensure that the calibration remained valid. All data were generated when the analytical systems were operating within the control criteria.

8.5 Inspections, Audits, and Data Reviews

Throughout the research, several inspections, audits, and data reviews were conducted by QA officers at RTI to ascertain that standard operating procedures (SOPs) for instrumentation were being implemented; procedures in the QAPPs were being followed; data were being recorded properly; and that records and controls conformed to good laboratory practice. Table 8-2 lists the inspections, audits, and data reviews conducted in support of this research, all of which were in compliance with QA requirements.

Table 8-2. Inspections, Audits, and Data Reviews

	Conducted
Inspections	
Instrument Log Notebook Inspection (ACS-SOP-815-003) ^a	June 1995 March/April 1996 December 1996
Laboratory Inspection (ACS-SOP-815-001)	Nov. 1995/Jan. 1996 Aug./Oct. 1996
SOP Review (ACS-SOP-110-001)	Aug./Sept. 1995 Aug./Nov. 1996
Training Files Inspection (ACS-SOP-110-002)	Sept. 1995 October 25, 1996
Audits	
Operation of test chambers	May 11, 1995
Operation of analytical measurement systems	June 13-14, 1995
Laboratory activities: preparing coupons into test squares; chamber air sampling; chamber cleaning, etc.	April 30, 1996
Laboratory activities: GC/MS and HPLC analysis of VOCs	May 28, 1996
Data Reviews (ACS-PDM-180-002)	
Results, January 1996	Jan. 10-15, 1996
Preliminary Results, June 1996	June 10-12, 1996
Preliminary Results, April 1997	
Data Review, VOCs (7 day)	April 2-3, 1997
Data Review, VOCs (35 day)	April 4, 1997
Data Review, aldehydes	April 7-8, 1997

^a Refers to RTI's Analytical and Chemical Sciences Standard Operating Procedures which are followed by QA personnel at RTI.

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Appendix A
Phase One Screening Study

Table A-1. Estimated Emission Factors of Test Squares of PBVST^a

	Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$			Mean and %RSD of Emission Factors	
	PBVST1-1	PBVST2-1	PBVST3-1	Mean of PBVST1-1, 2-1, and 3-1	%RSD of PBVST1-1, 2-1, and 3-1
6 hour conditioning					
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH ^b cartridges					
Aldehydes and Ketones					
n-Hexanal	610	600	730	650	11
Acetone	1200	2000	1600	1600	25
Benzaldehyde	65	70	64	66	5
n-Pentanal	160	170	180	170	6
Formaldehyde	3900	5200	5800	5000	19
Acetaldehyde	190	220	260	220	16
n-Butanal	44	39	78	54	40
Propionaldehyde	41	58	86	62	37
2-Butanone	12	9	7	9	27
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges					
Alcohols ^c					
1-Butanol	4000	7000	5000	5300	29
2-Methyl butanol	1500	1000	1000	1200	24
1-Pentanol	1000	250	500	580	66
Total	6500	8300	6500	7100	15
Aldehydes and Ketones					
n-Heptanone	100	100	100	100	0
n-Nonanal	20	10	10	13	43
Aliphatic Hydrocarbons					
n-Tetradecane	9	5	- ^d	7	40
Alkyl Ethers					
Ethyl ethoxy propionate	400	200	200	270	43
(5.29) ^e Ethoxyether	8	9	10	9	11
(12.94) Ethoxyether	300	in ^f	400	350	20
Tetramethoxypropanes	100	60	100	87	27
(32.45) Dibutoxymethanol	50	40	40	43	13
(37.42) Dibutoxymethanol	70	40	50	53	29
(29.8) Butoxyether	10	7	9	9	18
(34.94) Butoxyether	10	-	7	9	25
(41.94) Butoxyether	90	-	50	70	40
Total	1000	360	870	740	46
Aromatic Hydrocarbons					
C3-alkyl benzenes	600	500	600	570	10

Continued

Table A-1. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>			<u>Mean and %RSD of Emission Factors</u>	
	PBVST1-1	PBVST2-1	PBVST3-1	Mean of PBVST1-1, 2-1, and 3-1	%RSD of PBVST1-1, 2-1, and 3-1
C4-alkyl benzenes	300	300	300	300	0
Naphthalene	200	300	200	230	25
C5-alkyl benzenes	200	200	100	170	34
Xylenes	100	70	80	83	18
Ethyl benzene	25	15	15	18	31
Methyl naphthalene	20	10	10	13	43
Toluene	-	6	8	7	20
Total	1400	1400	1300	1400	4
Esters					
Hexyl acetate isomers	90	130	in	110	26
Methyl dodecanonate	30	20	20	23	25
Butyl acetate	in	in	in		
Indenes					
Dihydromethyl indenenes	100	100	90	97	6
Dihydrodimethyl indenenes	10	10	9	10	6
Monoterpenes					
Limonene	80	90	100	90	11
b-Pinene	60	20	70	50	53
a-Terpene	60	-	60	60	0
a-Pinene	24	40	70	45	52
a-Carene	100	100	100	100	0
Total	320	250	400	320	23
Sesquiterpenes					
Junipene	100	200	150	150	33
Endoborneal acetate	10	10	10	10	0
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	9800	11000	9500	10000	8
TVOC ^g analysis of multisorbent cartridges ^h	3000	3000	3000	3000	0

Continued

Table A-1. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>			<u>Mean and %RSD of Emission Factors</u>	
	PBVST1-1	PBVST2-1	PBVST3-1	Mean of PBVST1-1, 2-1, and 3-1	%RSD of PBVST1-1, 2-1, and 3-1
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent and DNPH cartridges	16000	19000	18000	17700	9

^a PBVST = veneered particleboard with heat curable acid catalyzed alkyd-urea sealer and topcoat.

^b DNPH = dinitrophenylhydrazine.

^c Alcohols were large, poorly defined peaks at high concentration; interferences and overloading prevented accurate quantitation.

^d "-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

^e Number in parentheses is retention time; exact compound identification not possible from mass spectra.

^f Interference with high concentrations of alcohols prevented accurate quantitation.

^g TVOC = total volatile organic compounds.

^h The TVOC analyses were much lower than the "sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbents" because they did not include alcohols.

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Table A-2. Estimated Emission Factors of Test Squares of PBVY^a

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>			<u>Mean and %RSD of Emission Factors</u>	
	PBVY1-1	PBVY2-1	PBVY3-1	Mean of PBVY1-1, 2-1, and 3-1	%RSD of PBVY1-1, 2-1, and 3-1
6 hour conditioning					
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH ^b cartridges					
Aldehydes and Ketones					
Acetone	530	600	450	530	14
n-Hexanal	130	150	100	130	19
Acetaldehyde	67	71	56	65	12
Formaldehyde	51	52	57	53	6
n-Pentanal	35	43	33	37	14
Propionaldehyde	15	16	13	15	10
Benzaldehyde	10	11	10	10	6
2-Butanone	8	6	5	6	24
n-Butanal	7	8	7	7	8
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges					
Aliphatic Hydrocarbons					
n-Octane	5	5	7	6	20
n-Pentane	- ^c	10	-	10	0
Aromatic Hydrocarbons					
C4-alkyl benzenes	40	50	50	47	12
Toluene	20	15	13	16	23
Esters					
Isopropyl acetate	600	600	600	600	0
Butyl acetate	16	20	15	17	16
Monoterpenes					
Limonene	40	60	50	50	20
b-Pinene	30	30	40	33	17
a-Pinene	20	40	30	30	33
Total	90	130	120	110	19
Sesquiterpenes					
Junipene	30	50	40	40	25
Other Terpenes					
d-Carene	80	100	100	93	12
Camphene	17	30	30	26	29
Tricyclene	10	20	20	17	35
a-Fenchene	-	6	5	6	13

Continued

Table A-2. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>			<u>Mean and %RSD of Emission Factors</u>	
	PBVY1-1	PBVY2-1	PBVY3-1	Mean of PBVY1-1, 2-1, and 3-1	%RSD of PBVY1-1, 2-1, and 3-1
Total	110	160	160	140	21
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	910	1000	1000	970	5
TVOC ^d analysis of multisorbent cartridges	1200	1400	1200	1300	9
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent and DNPH cartridges	1800	2000	1700	1800	8

^a PBVY = particleboard overlaid with vinyl.

^b DNPH = dinitrophenylhydrazine.

^c "-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

^d TVOC = total volatile organic compounds.

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Table A-3. Estimated Emission Factors of Test Squares of HBVSST^a

	Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$				Mean and %RSD of Emission Factors			
	HBVSST 2-1	HBVSST 3-1	HBVSST 1-1	HBVSST 1-2	Mean of HBVST1-1 and HBVST1-2	%RSD of HBVST1-1 and HBVST1-2	Mean of "Mean of HBVST1-1 and HBVST1-2", HBVST2-1, and HBVST3-1	%RSD of "Mean of HBVST1-1 and HBVST1-2", HBVST2-1, and HBVST3-1
6 hour conditioning								
Identification of target compounds $>5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH ^b cartridges								
Aldehydes and Ketones								
Formaldehyde	2000	3300	2200	2400	2300	6	2500	27
Acetone	50	33	64	70	67	6	50	34
n-Hexanal	7	-	6	7	7	11	7	5
Acetaldehyde	32	60	41	43	42	3	45	32
n-Pentanal	-	9	- ^c	MD ^d			9	0
n-Butanal	-	35	9	MD	9	0	22	84
Propionaldehyde	-	19	9	-	9	0	14	51
Identification of compounds $>5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
Alcohols ^e								
1-Butanol	2000	4000	2000	3000	2500	28	2800	37
2-Methyl butanol	300	1000	800	800	800	0	700	52
1-Pentanol	300	600	300	400	350	20	420	38
Total	2600	5600	3100	4200	3700	21	4000	38
Aldehydes and Ketones								
n-Heptanone	40	200	100	100	100	0	110	73
Aliphatic Hydrocarbons								
n-Tetradecane	-	9	-	-			9	0
n-Nonane	6	8	10	10	10	0	8	25
n-Dodecane	-	7	-	-			7	0
n-Decane	8	10	10	12	11	13	10	16
Alkyl Ethers								
Ethyl ethoxy propionate	100	400	100	100	100	0	200	87
(12.94) Ethoxyether	200	500	300	100	200	71	300	58
Tetramethoxypropanes	20	100	70	70	70	0	63	64
(41.94) Butoxyether	30	40	40	40	40	0	37	16
(37.42) Dibutoxymethanol	40	40	30	25	28	13	36	20
(32.45) Dibutoxymethanol	30	80	30	30	30	0	47	62
(29.8) Butoxyether	10	40	10	10	10	0	20	87
(34.94) Butoxyether	8	10	8	10	9	16	9	11

Continued

Table A-3. (Continued)

	Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$				Mean and %RSD of Emission Factors			
	HBVSST 2-1	HBVSST 3-1	HBVSST 1-1	HBVSST 1-2	Mean of HBVST1-1 and HBVST1-2	%RSD of HBVST1-1 and HBVST1-2	Mean of "Mean of HBVST1-1 and HBVST1-2", HBVST2-1, and HBVST3-1	%RSD of "Mean of HBVST1-1 and HBVST1-2", HBVST2-1, and HBVST3-1
(5.29) Ethoxyether	-	20	10	7	9	25	14	57
Total	440	1200	600	390	495	30	710	60
Aromatic Hydrocarbons								
C3-alkyl benzenes	500	1000	300	300	300	0	600	60
C4-alkyl benzenes	400	700	400	600	500	28	530	29
Naphthalene	200	300	200	200	200	0	230	25
C5-alkyl benzenes	400	400	200	200	200	0	330	35
Xylenes	40	60	50	50	50	0	50	20
Ethyl benzene	8	10	10	10	10	0	9	12
Methyl naphthalene	10	20	10	10	10	0	13	43
Total	1600	2500	1200	1400	1300	11	1800	35
Esters								
Hexyl acetate isomers	70	100	60	80	70	20	80	22
Methyl dodecanonate	10	20	10	10	10	0	13	43
Butyl acetate	in ⁶	in	in	in				
Indenes								
Dihydromethyl indenenes	200	300	200	200	200	0	230	25
Dihydrodimethyl indenenes	10	30	10	10	10	0	17	69
Dihydroindenenes	12	40	12	15	14	16	22	72
Total	220	370	220	230	225	3	270	32
Sum of compounds ≥ 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridge	5000	10000	5300	6400	5900	13	7000	38
TVOC ^b analysis of multisorbent cartridges ⁱ	2000	4000	2000	2000	2000	0	2700	43

Continued

Table A-3. (Continued)

Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$				Mean and %RSD of Emission Factors			
HBVSST 2-1	HBVSST 3-1	HBVSST 1-1	HBVSST 1-2	Mean of HBVST1-1 and HBVST1-2	%RSD of HBVST1-1 and HBVST1-2	Mean of "Mean of HBVST1-1 and HBVST1-2", HBVST2-1, and HBVST3-1	%RSD of "Mean of HBVST1-1 and HBVST1-2", HBVST2-1, and HBVST3-1
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent and DNPH cartridges							
7000	13000	7600	8900	8300	11	9400	34

^a HBVSST = veneered hardboard with stain, and heat curable acid catalyzed alkyd-urea sealer and topcoat.

^b DNPH = dinitrophenylhydrazine.

^c "-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

^d "MI" = missing data.

^e Alcohols were large, poorly defined peaks at high concentration; interferences and overloading prevented accurate quantitation.

^f Number in parentheses is retention time; exact compound identification not possible from mass spectra.

^g Interference with high concentrations of alcohols prevented accurate quantitation.

^h TVOC = total volatile organic compounds.

ⁱ The TVOC analyses were much lower than the "sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges" because they did not include alcohols.

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Table A-4. Estimated Emission Factors of Test Squares of PBM*

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	PBM 1-1	PBM 3-1	PBM 2-1	PBM 2-2	Mean of PBM2-1 and PBM2-2	%RSD of PBM2-1 and PBM2-2	Mean of "Mean of PBM2-1 and PBM2-2", PBM1-1, and PBM3-1	%RSD of "Mean of PBM2-1 and PBM2-2", PBM1-1 and PBM3-1
6 hour conditioning								
Identification of target compounds $>5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH ^b cartridges								
Aldehydes and Ketones								
Acetone	760	660	1100	790	950	23	790	19
n-Hexanal	260	190	390	250	320	31	260	25
Acetaldehyde	140	120	200	140	170	25	140	18
Formaldehyde	70	60	90	83	87	6	72	19
n-Pentanal	100	80	150	MD ^c	150	0	110	33
Propionaldehyde	24	22	34	22	28	30	25	12
Benzaldehyde	11	8	12	8	10	28	10	16
2-Butanone	10	8	14	10	12	24	10	20
n-Butanal	20	17	28	MD	28	0	22	26
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
Alcohols ^d								
Octanol	- ^e	-	5	5	5	0	5	0
Aldehydes and Ketones								
n-Heptanone	5	6	8	MD	8	0	6	24
n-Heptanal	-	-	-	MD				
Aliphatic Hydrocarbons								
n-Octane	16	14	20	20	20	0	17	18
n-Heptane	7	6	7	12	10	37	8	23
Aromatic Hydrocarbons								
C4-alkyl benzenes	40	36	60	50	55	13	44	23
Toluene	20	7	20	15	18	20	15	46
Total	60	43	80	65	73	15	59	25
Esters								
Pentyl formate	5	5	7	MD	7	0	6	19
Monoterpenes								
Limonene	20	20	40	30	35	20	25	35
b-Pinene	15	14	23	20	22	10	17	24
a-Pinene	16	20	30	20	25	28	20	23

Continued

Table A-4. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	PBM 1-1	PBM 3-1	PBM 2-1	PBM 2-2	Mean of PBM2-1 and PBM2-2	%RSD of PBM2-1 and PBM2-2	Mean of "Mean of PBM2-1 and PBM2-2", PBM1-1, and PBM3-1	%RSD of "Mean of PBM2-1 and PBM2-2", PBM1-1 and PBM3-1
Total	51	54	93	70	82	20	62	27
Sesquiterpenes								
Junipene	20	15	30	20	25	28	20	25
Other Sesquiterpenes	-	-	5	-	5	0	5	0
Other Terpenes								
d-Carene	30	20	40	30	35	20	28	27
Camphene	12	20	30	30	30	0	21	43
Tricyclene	15	10	20	16	18	16	14	29
a-Fenchene	-	-	5	5	5	0	5	0
Total	57	50	95	81	88	11	65	31
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	220	190	350	270	310	18	240	26
TVOC ^f analysis of multisorbent cartridges	550	420	900	MD	900	0	620	40
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent and DNPH cartridges	1600	1400	2400	1600	2000	28	1700	18

^a PBM = particleboard overlaid with melamine.

^b DNPH = dinitrophenylhydrazine.

^c "MD" = missing data.

^d Alcohols were large, poorly defined peaks at high concentration; interferences and overloading prevented accurate quantitation.

^e "-" value $< 5 \mu\text{g}/(\text{m}^2 \text{ hr})$.

^f TVOC = total volatile organic compounds.

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Appendix B
Phase Two Component Study

Table B-1. Quantitated Emission Factors of Test Squares of Components of PBVST

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>						<u>Mean and %RSD of Emission Factors</u>		<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>			<u>Mean and %RSD of Emission Factors</u>	
	PB1-1	V1-1	PBV1-1	PBVS1-1	PBVS2-1	PBVS3-1	Mean of PBVS1-1, 2-1, and 3-1	%RSD of PBVS1-1, 2-1, and 3-1	PBVST1-1	PBVST2-1	PBVST3-1	Mean of PBVST1-1, 2-1, and 3-1	%RSD of PBVST1-1, 2-1, and 3-1
31 day conditioning													
Identification of target compounds $>5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges													
Aldehydes and Ketones													
formaldehyde	230	9	130	320	340	360	340	6	530	440	390	450	16
hexanal	490	-	97	140	170	130	150	14	120	110	87	110	15
acetaldehyde	48	8	30	36	48	30	38	24	18	28	25	24	21
valeraldehyde	70	-	24	34	30	30	31	7	30	26	13	23	39
2-butanone	9	-	-	-	8	-	8	0	7	6	0	4	95
butyraldehyde	-	-	7	7	10	7	8	22	7	7	6	7	8
propionaldehyde	9	-	6	5	6	5	5	11	4	5	6	5	20
benzaldehyde	33	-	10	14	11	9	11	22	11	9	7	9	22
Total	1200	17	410	680	770	690	710	7	890	770	670	780	14
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges													
Alcohols													
1-Butanol	7	-	6	320	360	250	310	18	360	260	260	290	20
1-Pentanol	54	-	14	31	29	18	26	27	89	64	51	68	28
2-Methyl-1-Butanol	-	-	-	-	-	-	-	-	35	25	25	28	21
Total	61	0	20	350	390	270	340	18	480	350	340	390	20
Aldehydes and Ketones													
Acetone	270	-	110	110	130	100	110	14	140	130	120	130	8
2-Heptanone	5	-	-	17	19	22	19	13	23	12	14	16	37
Ester													
Hexyl Acetate	-	-	-	7	5	8	7	23	7	-	-	7	0

Continued

Table B-1. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>						<u>Mean and %RSD of Emission Factors</u>		<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>			<u>Mean and %RSD of Emission Factors</u>	
	PB1-1	V1-1	PBV1-1	PBVS1-1	PBVS2-1	PBVS3-1	Mean of PBVS1-1, 2-1, and 3-1	%RSD of PBVS1-1, 2-1, and 3-1	PBVST1-1	PBVST2-1	PBVST3-1	Mean of PBVST1-1, 2-1, and 3-1	%RSD of PBVST1-1, 2-1, and 3-1
Aromatic hydrocarbons													
o-Xylene	-	-	-	-	-	-	-	-	-	-	-	-	-
Ethylbenzene	-	-	-	-	-	-	-	-	-	-	-	-	-
Naphthalene	34	-	-	-	-	-	-	-	-	-	-	-	-
Total	34												
Sesquiterpenes													
Junipene	330	-	35	61	86	52	66	27	31	34	30	32	7
Alkyl Ethers													
2-(2-Butoxyethoxy)ethanol	29	-	-	310	320	280	300	7	730	760	760	750	2
Ethyl-3-Ethoxy-Propionate	-	-	-	-	-	-	-	-	23	11	12	15	44
Total	29			310	320	280	300	7	750	770	770	760	2
Sum of compounds > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent and DNPH cartridges	1700	17	470	1400	1600	1300	1400	11	2200	1900	1800	2000	10

PB = particleboard

V = veneer

PBV = veneered particleboard

PBVS = veneered particleboard coated and cured with acid catalyzed alkyd-urea sealer

PBVS - veneered particleboard coated and cured with acid catalyzed alkyd-urea sealer and topcoat

DNPH = dinitrophenylhydrazine

"-" = value < 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$

Mean = arithmetic mean of values > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Appendix C
Phase Three Coatings Study

Table C-1. Application and Curing Procedures of Coatings Systems

PROCEDURE	Coatings System					
	1	2	3	4	5	6
Sealer Application						
1) Sand/air blast/wipe	x ^a	x	x	x	x	x
2) Apply sealer to side 1 (mils wet)	3	3	3	1	3	3
3) Ambient flash(min)	20	15	15		10	10
4) Apply sealer to side 2 as step 2)	x				x	x
5) Ambient flash(min)	20	15			10	10
6) Dry at 140°F (min)	10	15			10	10
7) UV cure with H lamp, 1 pass (W/in)			700	400		
UV belt speed (f/min)			7	41		
UV total energy (mj/cm2)			5200	380		
8) Ambient cool(min)	10	5	5		10	10
9) Apply sealer to side 2 as step 2)			x	x		
10) Ambient flash(min)			15			
11) Repeat UV cure step 7) above			x	x		
12) Ambient cool(min)			5			
13) Sand/air blast/wipe	x	x	x	x	x	x
Topcoat Application						
1) Apply topcoat to side 1 (mils wet)	3	3	3	0.8	3	3
2) Ambient flash(min)	20	15	15		10	10
3) Apply topcoat to side 2 as step 1)	x	x			x	x
4) Ambient flash(min)	20	15			10	10
5) Dry at 140°F(min)	20	15			10	10
6) UV cure with H lamp, 1 pass (W/in)						
UV belt speed (f/min)			700	400	700	
UV total energy (mj/cm2)			7	47	24	
7) Repeat UV cure step 6) for side 2			5200	340	1500	
8) Ambient cool(min)	30	5	5		10	10
9) Apply topcoat to side 2 as step 1)			x	x		
10) Ambient flash (min)			15			
11) Repeat UV cure step 6) above			x	x		
12) Ambient cool(min)			5	5		
CURE TIME (min. for one side only)	70	60	30.3	<0.1	40	40

^a x means step was performed

Table C-2. Emission Factors of Test Squares of PBV with Heat Curable Acid Catalyzed Alkyd-Urea Coatings System

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²·hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A4	B3	B5	C3	Mean of B3 and B5	%RSD of B3 and B5	Mean of "mean of B3 and B5", A4, and C3	%RSD of "mean of B3 and B5", A4, and C3
Identification of target compounds > 5 µg/(m ² ·hr) on DNPH cartridges								
Formaldehyde	370	420	450	400	440	5	400	9
Acetaldehyde	76	66	45	27	56	27	53	47
Acetone	500	700	550	420	630	17	520	20
Propionaldehyde	16	16	-	-	16	0	16	0
2-Butanone	-	-	-	-				
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				
Valeraldehyde	44	37	24	-	31	30	37	26
m-Tolualdehyde	-	-	-	-				
Hexanal	240	180	130	49	160	22	150	64
Identification of target compounds > 5 µg/(m ² ·hr) on multisorbent cartridges								
1-Pentanol	180	150	130	120	140	10	150	20
Limonene	120	73	49	23	61	28	68	72
Junipene	110	55	34	27	45	33	61	72
Terpenes	560	390	230	87	310	36	320	74
1-Butanol	950	980	700	620	840	24	800	21
Toluene	19	24	13	11	19	42	16	28
2-Methyl-1-butanol	69	54	49	44	52	7	55	23
Butyl acetate	51	51	30	22	41	37	38	39
1,2-Propanediol	16	15	16	13	16	5	15	11
Ethylbenzene	360	340	210	170	280	33	270	35
m,p-Xylene	890	800	530	420	670	28	660	36
2-Heptanone	810	710	400	290	560	39	550	47
o-Xylene	300	260	150	120	210	37	210	43
Propylbenzene	140	110	59	48	85	43	91	51
Ethyl 3-ethoxypropionate	140	98	121	82	110	15	110	26
1-Methyl-2-pyrrolidinone	-	15	-	6	15	0	11	61
2-(2-Butoxyethoxy)ethanol	1800	1500	1400	1800	1500	5	1700	10
Naphthalene	39	11	12	23	12	6	25	56
Hexyl acetate	630	470	250	220	360	43	400	52
Indan	21	14	8	7	11	39	13	55
C3-Benzenes	1700	1300	690	580	1000	43	1090	52
C4-Benzenes	310	190	120	90	160	31	187	60
Dipropylene glycol, methyl ether	-	-	-	-				
Unknown 1	-	-	-	-				
Unknown 2	-	-	-	-				

Continued

Table C-2. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A4	B3	B5	C3	Mean of B3 and B5	%RSD of B3 and B5	Mean of "mean of B3 and B5", A4, and C3	%RSD of "mean of B3 and B5", A4, and C3
TVOC analysis of multisorbent cartridges	7200	5700	3900	3600	4800	27	5200	35
Sum of target compounds > 5 µg/(m ² •hr) on multisorbent and DNPH cartridges	10000	9000	6400	5700	7700	24	7800	28

PBV = veneered particleboard

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Table C-3. Emission Factors of Test Squares of PBV with Two Component Waterborne Polyurethane Coatings System

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²·hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A5	B7	B8	C4	Mean of B7 and B8	%RSD of B7 and B8	Mean of "mean of B7 and B8", C4, and A5	%RSD of "mean of B7 and B8", C4, and A5
Identification of target compounds > 5 µg/(m ² ·hr) on DNPH cartridges								
Formaldehyde	24	27	22	12	25	14	20	35
Acetaldehyde	46	56	46	25	51	14	41	34
Acetone	450	560	500	500	530	8	490	8
Propionaldehyde	15	15	16	-	16	5	15	2
2-Butanone	-	-	-	-				
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				
Valeraldehyde	26	40	25	-	33	33	29	16
m-Tolualdehyde	-	-	-	-				
Hexanal	150	180	140	48	160	18	120	52
Identification of target compounds > 5 µg/(m ² ·hr) on multisorbent cartridges								
1-Pentanol	19	26	20	6	23	18	16	56
Limonene	82	67	54	21	61	15	55	57
Junipene	39	31	22	7	27	24	24	67
Terpenes	380	210	160	76	190	19	220	70
1-Butanol	-	-	-	-				
Toluene	-	-	-	-				
2-Methyl-1-butanol	-	-	-	-				
Butyl acetate	-	-	-	-				
1,2-Propanediol	-	-	-	-				
Ethylbenzene	-	-	-	-				
m,p-Xylene	-	-	-	-				
2-Heptanone	10	11	9	3	10	14	8	53
o-Xylene	-	-	-	-				
Propylbenzene	-	-	-	-				
Ethyl 3-ethoxypropionate	-	-	-	-				
1-Methyl-2-pyrrolidinone	-	-	7	-	7	0	7	0
2-(2-Butoxyethoxy)ethanol	87	18	25	19	22	23	43	91
Naphthalene	-	-	-	-				
Hexyl acetate	-	-	-	-				
Indan	-	-	-	-				
C3-Benzenes	-	-	-	-				
C4-Benzenes	36	33	26	8	30	17	25	60
Dipropylene glycol, methyl ether	-	-	-	-				
Unknown 1	-	-	-	-				
Unknown 2	-	-	-	-				

Continued

Table C-3. (Continued)

	<u>Emission Factors of Test Squares</u>				<u>Mean and %RSD of Emission Factors</u>			
	$\mu\text{g}/(\text{m}^2\cdot\text{hr})$				Mean of	%RSD	Mean of "mean of	%RSD of "mean
	A5	B7	B8	C4	B7 and	of B7	B7 and B8", C4,	of B7 and B8",
					B8	and B8	and A5	C4, and A5
TVOC analysis of multisorbent cartridges	820	650	730	310	690	8	610	43
Sum of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent and DNPH cartridges	1400	1300	1100	700	1200	12	1100	33

PBV = veneered particleboard

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Table C-4. Emission Factors of Test Squares of PBV with Water Based Non Air Inhibited Unsaturated Polyester Coatings System

	<u>Emission Factors of Test Squares</u> $\mu\text{g}/(\text{m}^2\cdot\text{hr})$				<u>Mean and %RSD of Emission Factors</u>			
	A1	A2	B1	C5	Mean of A1 and A2	%RSD of A1 and A2	Mean of "mean of A1 and A2", B1, and C5	%RSD of "mean of A1 and A2", B1, and C5
Identification of target compounds > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	69	71	70	70	70	2	70	0
Acetaldehyde	61	72	70	60	67	12	66	8
Acetone	310	370	490	310	340	12	380	25
Propionaldehyde	16	18	17	15	17	8	16	7
2-Butanone	-	-	-	-				
Butyraldehyde	18	17	20	16	18	4	18	11
Benzaldehyde	26	26	36	29	26	0	30	17
Valeraldehyde	57	57	62	45	57	0	55	16
m-Tolualdehyde	-	-	-	-				
Hexanal	300	300	320	220	300	0	280	19
Identification of target compounds > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
1-Pentanol	44	48	54	30	46	6	43	28
Limonene	98	110	97	58	100	8	85	28
Junipene	59	71	73	44	65	13	61	25
Terpenes	240	260	210	130	250	6	200	31
1-Butanol	-	5	-	5	5	0	5	0
Toluene	-	-	-	5			5	0
2-Methyl-1-butanol	-	-	-	-				
Butyl acetate	-	-	-	-				
1,2-Propanediol	17	25	-	38	21	27	30	41
Ethylbenzene	-	-	-	-				
m,p-Xylene	-	-	-	-				
2-Heptanone	14	16	18	11	15	9	15	24
o-Xylene	-	-	-	-				
Propylbenzene	-	-	-	-				
Ethyl 3-ethoxypropionate	-	-	-	-				
1-Methyl-2-pyrrolidinone	12	14	6	27	13	11	15	70
2-(2-Butoxyethoxy)ethanol	300	360	390	770	330	13	500	48
Naphthalene	-	-	-	-				
Hexyl acetate	-	-	-	-				
Indan	-	-	-	-				
C3-Benzenes	-	-	-	-				
C4-Benzenes	38	49	43	26	44	18	38	27
Dipropylene glycol, methyl ether	-	-	-	-				
Unknown 1	170	170	200	180	170	0	180	8
Unknown 2	180	150	290	280	170	12	250	27

Continued

Table C-4. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A1	A2	B1	C5	Mean of A1 and A2	%RSD of A1 and A2	Mean of "mean of A1 and A2", B1, and C5	%RSD of "mean of A1 and A2", B1, and C5
TVOC analysis of multisorbent cartridges	1500	1500	1800	1700	1500	0	1700	9
Sum of target compounds > 5 µg/(m ² •hr) on multisorbent and DNPH cartridges	2000	2200	2500	2400	2100	7	2300	9

PBV = veneered particleboard

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Table C-5. Emission Factors of Test Squares of PBV with UV Curable Acrylate Coatings System

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A3	A7	B4	C7	Mean of A3 and A7	%RSD of A3 and A7	Mean of "mean of A3 and A7", B4, and C7	%RSD of "mean of A3 and A7", B4, and C7
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	13	38	16	13	26	69	18	36
Acetaldehyde	53	110	64	59	82	49	68	17
Acetone	250	640	450	260	450	61	390	28
Propionaldehyde	17	20	17	12	19	11	16	21
2-Butanone	-	-	-	-				
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	14	-			14	0
Valeraldehyde	-	51	19	13	51	0	28	74
m-Tolualdehyde	-	-	-	-				
Hexanal	51	260	91	67	160	92	110	44
Identification of target compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
1-Pentanol	8	35	15	5	22	89	14	60
Limonene	27	100	35	16	64	81	38	63
Junipene	8	47	15	6	28	100	16	67
Terpenes	87	270	99	40	180	72	110	64
1-Butanol	-	-	-	-				
Toluene	22	30	22	18	26	22	22	18
2-Methyl-1-butanol	-	-	-	-				
Butyl acetate	-	-	-	-				
1,2-Propanediol	-	-	-	-				
Ethylbenzene	29	53	35	22	41	41	33	30
m,p-Xylene	98	180	120	73	140	41	110	31
2-Heptanone	5	17	7	-	11	77	9	31
o-Xylene	26	54	35	19	40	49	31	35
Propylbenzene	-	-	-	-				
Ethyl 3-ethoxypropionate	-	-	-	-				
1-Methyl-2-pyrrolidinone	-	-	-	-				
2-(2-Butoxyethoxy)ethanol	29	8	-	-	19	80	19	0
Naphthalene	-	-	-	-				
Hexyl acetate	-	-	-	-				
Indan	-	-	-	-				
C3-Benzenes	-	-	-	-				
C4-Benzenes	12	46	17	6	29	83	17	66
Dipropylene glycol, methyl ether	-	-	-	-				
Unknown 1	-	-	-	-				
Unknown 2	-	-	-	-				

Continued

Table C-5. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A3	A7	B4	C7	Mean of A3 and A7	%RSD of A3 and A7	Mean of "mean of A3 and A7", B4, and C7	%RSD of "mean of A3 and A7", B4, and C7
TVOC analysis of multisorbent cartridges	670	1200	830	660	940	40	810	17
Sum of target compounds > 5 µg/(m ² •hr) on multisorbent and DNPH cartridges	740	2000	1100	630	1400	64	1000	39

PBV = veneered particleboard

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Table C-6. Emission Factors of Test Squares of PBV with Water Based UV Curable Multi-functional Acrylate-free Emulsion Coatings System

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A8	B6	C6	C2	Mean of C6 and C2	%RSD of C6 and C2	Mean of "mean of C6 and C2", B6, and A8	%RSD of "mean of C6 and C2", B6, and A8
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	19	20	19	19	19	0	19	3
Acetaldehyde	44	45	30	38	34	17	41	15
Acetone	380	490	250	560	410	53	430	13
Propionaldehyde	11	13	-	-			12	12
2-Butanone	-	-	-	-				
Butyraldehyde	-	-	-	-				
Benzaldehyde	19	17	14	19	17	21	18	8
Valeraldehyde	22	20	12	17	15	24	19	21
m-Tolualdehyde	-	-	-	-				
Hexanal	110	110	53	66	60	15	93	31
Identification of target compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
1-Pentanol	16	18		8	8	0	14	38
Limonene	42	43		27	27	0	37	24
Junipene	15	14		9	9	0	13	25
Terpenes	120	120		59	59	0	100	35
1-Butanol	8	8		7	7	0	8	8
Toluene	-	-		-				
2-Methyl-1-butanol	-	-		-				
Butyl acetate	-	-		-				
1,2-Propanediol	-	-		-				
Ethylbenzene	-	-		-				
m,p-Xylene	-	-		-				
2-Heptanone	7	8		5	5	0	7	23
o-Xylene	-	-		-				
Propylbenzene	-	-		-				
Ethyl 3-ethoxypropionate	-	-		-				
1-Methyl-2-pyrrolidinone	-	-		5	5	0	5	0
2-(2-Butoxyethoxy)ethanol	-	7		5	5	0	6	24
Naphthalene	-	-		-				
Hexyl acetate	-	-		-				
Indan	-	-		-				
C3-Benzenes	-	-		-				
C4-Benzenes	20	19		10	10	0	16	34
Dipropylene glycol, methyl ether	18	38		17	17	0	24	49
Unknown 1	-	-		-				

Continued

Table C-6. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²·hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A8	B6	C6	C2	Mean of C6 and C2	%RSD of C6 and C2	Mean of "mean of C6 and C2", B6, and A8	%RSD of "mean of C6 and C2", B6, and A8
Unknown 2	-	-		-				
TVOC analysis of multisorbent cartridges	670	590		370	370	0	540	29
Sum of target compounds > 5 µg/(m ² ·hr) on multisorbent and DNPH cartridges	850	990		870	870	0	900	8

PBV = veneered particleboard

Mean = arithmetic mean of values > 5 µg/(m²·hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²·hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²·hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²·hr).

Table C-7. Emission Factors of Test Squares of PBV with Polyurethane Dispersion Coatings System

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A6	B2	C1	C8	Mean of C1 and C8	%RSD of C1 and C8	Mean of "mean of C1 and C8", B2, and A6	%RSD of "mean of C1 and C8", B2, and A6
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	25	44	28	32	30	9	33	30
Acetaldehyde	46	110	53	44	49	13	68	53
Acetone	370	690	580	350	470	35	510	32
Propionaldehyde	15	25	11	11	11	0	17	42
2-Butanone	-	-	-	-				
Butyraldehyde	-	12	-	-			12	0
Benzaldehyde	18	27	14	-	14	0	20	34
Valeraldehyde	38	91	43	39	41	7	57	53
m-Tolualdehyde	-	-	-	-				
Hexanal	280	500	280	260	270	5	350	37
Identification of target compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
1-Pentanol	37	82	28	27	28	3	49	60
Limonene	73	122	42	62	52	27	82	44
Junipene	65	94	26	61	44	57	68	38
Terpenes	100	160	76	120	98	32	120	29
1-Butanol	-	7	-	-			7	0
Toluene	-	6	-	-			6	0
2-Methyl-1-butanol	-	-	-	-				
Butyl acetate	-	-	-	-				
1,2-Propanediol	-	-	-	-				
Ethylbenzene	-	-	-	-				
m,p-Xylene	-	-	-	-				
2-Heptanone	17	33	16	15	16	5	22	44
o-Xylene	-	-	-	-				
Propylbenzene	-	-	-	-				
Ethyl 3-ethoxypropionate	-	-	-	-				
1-Methyl-2-pyrrolidinone	1800	2700	2300	3100	2700	21	2400	22
2-(2-Butoxyethoxy)ethanol	7	8	-	7	7	0	7	8
Naphthalene	-	-	-	-				
Hexyl acetate	-	-	-	-				
Indan	-	-	-	-				
C3-Benzenes	-	-	-	-				
C4-Benzenes	27	53	17	21	19	15	33	54
Dipropylene glycol, methyl ether	69	360	220	380	300	38	240	64
Unknown 1	-	-	-	-				
Unknown 2	-	-	-	-				

Continued

Table C-7. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A6	B2	C1	C8	Mean of C1 and C8	%RSD of C1 and C8	Mean of "mean of C1 and C8", B2, and A6	%RSD of "mean of C1 and C8", B2, and A6
TVOC analysis of multisorbent cartridges	2600	3200	2200	3000	2600	22	2800	12
Sum of target compounds > 5 µg/(m ² •hr) on multisorbent and DNPH cartridges	3000	5100	3700	4500	4100	14	4100	26

PBV = veneered particleboard

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Table C-8. Emission Factors of Test Squares of Unfinished PBV (Lab Coupons)

	Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$						Mean and %RSD of Emission Factors							
	A12	A11	B11	B12	C11	C12	Mean of A12 and A11	%RSD of A12 and A11	Mean of B11 and B12	%RSD of B11 and B12	Mean of C11 and C12	%RSD of C11 and C12	Mean of all means	%RSD of all means
Identification of target compounds > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges														
Formaldehyde	160	170	140	140	110	140	170	4	140	0	130	16	150	14
Acetaldehyde	69	67	76	60	41	51	68	2	68	17	46	15	61	21
	430	430	520	480	280	370	430	0	500	6	330	19	420	20
Propionaldehyde	23	21	24	19	17	19	22	6	22	16	18	8	21	11
2-Butanone	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Butyraldehyde	15	-	-	-	-	-	15	0	-	-	-	-	15	0
Benzaldehyde	20	28	22	24	22	21	24	24	23	6	22	3	23	6
Valeraldehyde	78	83	72	71	41	47	81	4	72	1	44	10	65	29
m-Tolualdehyde	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hexanal	470	520	410	500	270	280	500	7	460	14	280	3	410	29
Identification of target compounds > 5 $\mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges														
1-Pentanol	70	75	67	83	44	33	73	5	75	15	39	20	62	33
Limonene	89	90	87	76	64	65	90	1	82	10	65	1	79	16
Junipene	99	128	72	110	74	50	110	19	91	30	62	27	90	27
Terpenes	160	200	160	150	160	180	180	16	160	4	170	8	170	6
1-Butanol	6	6	6	7	-	-	6	0	7	11	-	-	6	6
Toluene	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2-Methyl-1-butanol	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Butyl acetate	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1,2-Propanediol	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ethylbenzene	-	-	-	-	-	-	-	-	-	-	-	-	-	-
m,p-Xylene	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2-Heptanone	16	16	17	16	11	11	16	0	17	4	11	0	15	21
o-Xylene	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Propylbenzene	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ethyl 3-ethoxypropionate	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1-Methyl-2-pyrrolidinone	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Continued

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Table C-8. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>						<u>Mean and %RSD of Emission Factors</u>							
	A12	A11	B11	B12	C11	C12	Mean of A12 and A11	%RSD of A12 and A11	Mean of B11 and B12	%RSD of B11 and B12	Mean of C11 and C12	%RSD of C11 and C12	Mean of all means	%RSD of all means
2-(2-Butoxyethoxy)ethanol	-	-	-	8	-	-			8	0			8	0
Naphthalene	-	-	-	-	-	-								
C3-Benzenes	-	-	-	-	-	-								
C4-Benzenes	40	42	38	36	25	25	41	3	37	4	25	0	34	24
Dipropylene glycol, methyl ether	-	-	-	-	-	-								
Unknown 1	-	-	-	-	-	-								
Unknown 2	-	-	-	-	-	-								
TVOC analysis of multisorbent cartridges	1100	1200	990	1200	840	745	1200	6	1100	13	790	9	1000	21
Sum of target compounds > 5 µg/(m ² •hr) on multisorbent and DNPH cartridges	1700	1900	1700	1800	1200	1300	1800	8	1800	4	1300	5	1600	18

PBV = veneered particleboard

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Table C-9. Emission Factors of Test Squares of Unfinished PBV (Field Coupons)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²·hr)</u>						<u>Mean and %RSD of Emission Factors</u>							
	A9	A10	B9	B10	C9	C10	Mean of A9 and A10	%RSD of A9 and A10	Mean of B9 and B10	%RSD of B9 and B10	Mean of C9 and C10	%RSD of C9 and C10	Mean of all means	%RSD of all means
Identification of target compounds > 5 µg/(m ² ·hr) on DNPH cartridges														
Formaldehyde	150	120	160	130	160	170	140	15	150	14	170	4	150	10
Acetaldehyde	62	62	69	70	63	62	62	0	70	1	63	1	65	6
Acetone	380	370	490	470	380	350	380	2	480	3	370	6	410	15
Propionaldehyde	22	19	22	20	25	20	21	10	21	7	23	16	21	5
2-Butanone	-	-	-	-	-	-								
Butyraldehyde	14	-	14	-	-	-	14	0	14	0			14	0
Benzaldehyde	26	18	25	24	23	23	22	26	25	3	23	0	23	5
Valeraldehyde	77	59	84	84	65	66	68	19	84	0	66	1	73	14
m-Tolualdehyde	-	-	-	-	-	-								
Hexanal	520	360	510	480	410	430	440	26	500	4	420	3	450	9
Identification of target compounds > 5 µg/(m ² ·hr) on multisorbent cartridges														
1-Pentanol	62	58	77	76	53	55	60	5	77	1	54	3	64	18
Limonene	84	110	87	88	60	59	97	19	88	1	60	1	81	24
Junipene	100	90	110	93	78	96	95	7	100	12	87	15	90	7
Terpenes	240	300	200	190	160	150	270	16	200	4	160	4	210	27
1-Butanol	5	5	6	6	-	-	5	0	6	0			6	13
Toluene	-	-	-	-	-	-								
2-Methyl-1-butanol	-	-	6	-	-	-			6	0			6	0
Butyl acetate	-	-	-	-	-	-								
1,2-Propanediol	-	-	-	-	-	-								
Ethylbenzene	-	-	-	-	-	-								
m,p-Xylene	-	-	-	-	-	-								
2-Heptanone	14	17	17	16	13	12	16	14	17	4	13	6	15	14
o-Xylene	-	-	-	-	-	-								
Propylbenzene	-	-	-	-	-	-								
Ethyl 3-ethoxypropionate	-	-	-	-	-	-								
1-Methyl-2-pyrrolidinone	-	-	-	-	-	12					12		12	

Continued

Table C-9. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>						<u>Mean and %RSD of Emission Factors</u>							
	A9	A10	B9	B10	C9	C10	Mean of A9 and A10	%RSD of A9 and A10	Mean of B9 and B10	%RSD of B9 and B10	Mean of C9 and C10	%RSD of C9 and C10	Mean of all means	%RSD of all means
2-(2-Butoxyethoxy)ethanol	-	-	8	-	-	-			8	0			8	0
Naphthalene	-	-	-	-	-	-								
Hexyl acetate	-	-	-	-	-	-								
Indan	-	-	-	-	-	-								
C3-Benzenes	-	-	-	-	-	-								
C4-Benzenes	35	51	42	43	29	26	43	26	43	2	28	8	38	23
Unknown 1	-	-	-	-	-	-								
Unknown 2	-	-	-	-	-	-								
TVOC analysis of multisorbent cartridges	1100	1100	1300	1100	920	910	1100	0	1200	12	920	1	1100	13
Sum of target compounds > 5 µg/(m ² •hr) on multisorbent and DNPH cartridges	1800	1600	1900	1800	1500	1500	1700	8	1900	4	1500	0	1700	12

PBV = veneered particleboard

"-" = value < 5 µg/(m²•hr)

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

TVOC = total volatile organic compounds

Table C-10. P-values for Comparing Means of Log (Emission Factors) of Compounds

COMPOUND							
Alcohols							
1-Pentanol	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+) ^a					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0008(+)	0.0001(-) ^b	0.0870	0.0001(-)	0.0001(-)	0.1687
1-Butanol	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(-)					
	Coating 3	0.0001(-)					
	Coating 4	0.0001(-)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.0023(-)	0.2337	0.0002(-)	0.0780	0.1039
2-Methyl-1-butanol	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0349(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.2414	0.0118(+)	0.0001(+)	0.5049	0.0304(-)
1,2-Propanediol	P(i/j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0476(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
Terpenes							
Limonene	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.6228					
	Coating 3	0.1184					
	Coating 4	0.0547					
	Coating 5	0.1483					
	Coating 6	0.1538					
	unfinished PBV	0.1225	0.0433(-)	0.8525	0.0010(-)	0.0055(-)	0.9806
Junipene	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0103(+)					
	Coating 3	0.5882					
	Coating 4	0.0003(+)					
	Coating 5	0.0006(+)					
	Coating 6	0.3420					
	unfinished PBV	0.0375(-)	0.0001(-)	0.1208	0.0001(-)	0.0001(-)	0.2626

Continued

Table C-10. (Continued)

COMPOUND							
Terpenes	P(i,j)	Coating 1					
	Coating 2	0.2072					
	Coating 3	0.3354					
	Coating 4	0.0019(+)					
	Coating 5	0.0048(+)					
	Coating 6	0.0220(+)					
	unfinished PBV	0.1374	0.9000	0.6519	0.0268(-)	0.0571	0.2460
Indan	P(i,j)	Coating 1					
	Coating 2	0.0001(-)					
	Coating 3	0.0001(-)					
	Coating 4	0.0001(-)					
	Coating 5	0.0001(-)					
	Coating 6	0.0001(+)					
Aromatic Hydrocarbons Toluene	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0349(-)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.2414	0.0118(-)	0.0001(+)	0.5049	0.0304(-)
m,p-Xylene	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
o-Xylene	P(i,j)	Coating 1					
	Coating 2	0.0001(-)					
	Coating 3	0.0001(-)					
	Coating 4	0.0001(-)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
Ethylbenzene	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					

Continued

Table C-10. (Continued)

COMPOUND							
Naphthalene	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
Propylbenzene	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
C ₃ -Benzenes	P(i,j)	Coating 1					
	Coating 2	0.0001(-)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(-)					
C ₄ -Benzenes	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(-)					
	Coating 3	0.0001(-)					
	Coating 4	0.0001(-)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
	unfinished PBV	0.0001(+)	0.0546	0.8464	0.0011(-)	0.0048(-)	0.6644
Esters							
Butyl acetate	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
Ethyl-3-ethoxypropionate	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(+)					
Hexyl acetate	P(i,j)	Coating 1					
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(-)					
	Coating 6	0.0001(-)					

Continued

Table C-10. (Continued)

COMPOUND							
Alkyl Ethers							
2-(2-Butoxyethoxy)ethanol	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(-)					
	Coating 3	0.0307(-)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0001(-)					
	unfinished PBV	0.0001(+)	0.0002(+)	0.0001(+)	0.2157	0.3125	0.2146
Dipropylene glycol, met							
Dipropylene glycol, met	P(i/j)	Coating 1					
	Coating 2	0.9392					
	Coating 3	0.0153(-)					
	Coating 4	0.0153(-)					
	Coating 5	0.0001(-)					
	Coating 6	0.0001(-)					
Unknown 1							
Unknown 1	P(i/j)	Coating 1					
	Coating 2	1.0000					
	Coating 3	0.0001(-)					
	Coating 4	0.7874					
	Coating 5	0.8780					
	Coating 6	0.8246					
Unknown 2							
Unknown 2	P(i/j)	Coating 1					
	Coating 2	1.0000					
	Coating 3	0.0001 (-)					
	Coating 4	0.7609					
	Coating 5	0.9141					
	Coating 6	0.9676					
Aldehydes and Ketones							
Formaldehyde	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(-)					
	Coating 4	0.0001(-)					
	Coating 5	0.0001(-)					
	Coating 6	0.0001(-)					
	unfinished PBV	0.0001(-)	0.0001(-)	0.0001(-)	0.0001(-)	0.0001(-)	0.0001(-)
Acetaldehyde	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.3020					
	Coating 3	0.1035					
	Coating 4	0.0631					
	Coating 5	0.4270					
	Coating 6	0.1277					
	unfinished PBV	0.1733	0.0181(-)	0.6433	0.4576	0.0317(-)	0.7364

Continued

Table C-10. (Continued)

COMPOUND							
Acetone	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.7215					
	Coating 3	0.0777					
	Coating 4	0.0944					
	Coating 5	0.2792					
	Coating 6	0.8982					
	Lab coupon	0.1943	0.3543	0.4872	0.5594	0.9099	0.2443
Propionaldehyde	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.2339					
	Coating 3	0.0182(-)					
	Coating 4	0.0191(-)					
	Coating 5	0.7986					
	Coating 6	0.0090(-)					
	unfinished PBV	0.0026(-)	0.0496(-)	0.5602(-)	0.5440	0.0050(-)	0.8128
Butyraldehyde	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	1.0000					
	Coating 3	0.0001(-)					
	Coating 4	0.9971					
	Coating 5	0.8610					
	Coating 6	0.1642					
	unfinished PBV	0.2969	0.2969	0.0001(+)	0.2951	0.3920	0.6073
Benzaldehyde	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	1.0000					
	Coating 3	0.0001(-)					
	Coating 4	0.1396					
	Coating 5	0.0001(-)					
	Coating 6	0.0001(-)					
	unfinished PBV	0.0001(-)	0.0001(-)	0.5889	0.0001(-)	0.6725	0.0802
Valeraldehyde	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.8894					
	Coating 3	0.0545					
	Coating 4	0.8062					
	Coating 5	0.4478					
	Coating 6	0.0402(-)					
	unfinished PBV	0.0195(-)	0.0140(-)	0.7824	0.0107(-)	0.1089	0.9098
n-Hexanal	P(i,j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.6757					
	Coating 3	0.0048(-)					
	Coating 4	0.2359					
	Coating 5	0.2347					
	Coating 6	0.0003(-)					
	unfinished PBV	0.0001(-)	0.0001(-)	0.0979	0.0001(-)	0.0001(-)	0.6304

Continued

Table C-10. (Continued)

COMPOUND							
2-Heptanone	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(-)					
	Coating 3	0.0001(-)					
	Coating 4	0.0001(-)					
	Coating 5	0.0001(-)					
	Coating 6	0.0001(-)					
	unfinished PBV	0.0001(+)	0.0027(-)	0.9591	0.0008(-)	0.0023(-)	0.0513
1-Methyl-2-pyrrolidone	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.1949					
	Coating 3	0.0518					
	Coating 4	0.1088					
	Coating 5	0.1483					
	Coating 6	0.0001(-)					
	unfinished PBV	0.0135(+)	0.2267	0.0001(+)	0.4022	0.4024	0.0001(+)
TVOC	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0034(+)					
	unfinished PBV	0.0001(+)	0.0008(-)	0.0046(+)	0.1037	0.0004(-)	0.0001(+)
Summed Compounds	P(i/j)	Coating 1	Coating 2	Coating 3	Coating 4	Coating 5	Coating 6
	Coating 2	0.0001(+)					
	Coating 3	0.0001(+)					
	Coating 4	0.0001(+)					
	Coating 5	0.0001(+)					
	Coating 6	0.0034(-)					

^a The plus sign indicates that the mean emission factor of test squares of PBV finished with Coatings System j (j = 1, 2, 3, 4, 5, and 6) was statistically higher than the mean emission factor for test squares of unfinished PBV (lab coupons); this is equivalent to saying that the mean emission factor for test squares of unfinished PBV was statistically lower than the mean emission factor for test squares of PBV finished with Coating System j.

^b The minus sign indicates that the mean emission factor for test squares of PBV finished with Coatings System j (j = 1, 2, 3, 4, 5, and 6) was statistically lower than the mean emission factor for test squares of unfinished PBV (lab coupons); this is equivalent to saying that the mean emission factor for test squares of unfinished PBV was statistically higher than the mean emission factor for test squares of PBV finished with Coatings System j.

Appendix D
Phase Three Fiber Panel Study

Table D-1. Select Physical Properties of Fiber Panels (As Reported by Panel Manufacturers)

	A	B ¹	C	D ²	E ²	F	N ²
Density, lb/ft ³	26 - 28	41	20	48	48	43.9	55
Modulus of Rupture, lb/in ² (psi)	1086 (cross direction)	3709	1000 - 1300 ³	5600	5200	2509	3200
	1052 (long direction)	4					
Modulus of Elasticity, psi x 10 ³	86	476	150-200	575	520	447	450
Internal Bond, psi		100		130	115	98	320
Hardness, lb	230	820	330	1150	1150		2200
Screw Holding - Face, lb		320	76 ^a	325	325	233	575
Screw Holding - Edge, lb		270	254 ^b	275	275	192	400
Water Absorption (24-hour water soak) %	15	31		16-8	16-8	18.2	
Thickness Swell (24-hour water soak test) %		9		8-6	8-6	6.8	
Linear Expansion, 50% to 90% Relative Humidity (RH)	0.262% (cross direction)	0.295%	0.15 - 0.20%	0.25%	0.24%		
	0.196 (long direction)						

¹ Based on the average of all panel thicknesses produced. Actual results may vary depending on panel thickness and production type.

² Average values for 3/4" panels.

³ As tested according to ASTM D 1037¹³ @ 50% RH

⁴ Blank cells indicate data not provided or measured by manufacturer.

^a As tested according to ANSI A208.1¹⁴ @ 50% RH

^b As tested according to ANSI A208.1¹⁴ @ 50% RH

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 = ammonia treated medium density fiberboard with urea-formaldehyde (UF) resin

F = particleboard with UF resin

N = particleboard with phenol-formaldehyde resin

Table D-2. Select Properties and Attributes of Engineered Fiber Panels used to Construct Engineered Wood Products

Engineered wood products	Select properties and attributes of engineered fiber panels used to construct engineered wood products
CABINETS	Glue bond durability, Surface integrity, Surface smoothness, Panel flatness Dimensional stability Load bearing -Shelf/bottom deflection Front frame loading Impact resistance - Shelves, doors, bottoms Door racking, Drawer integrity Fastener holding - Screws, staples, hinges Finish resistance - Stains, chemicals, hot/cold cycling, water, detergent
COUNTERTOPS	Glue bond durability, Surface integrity Panel flatness, Dimensional stability Flexural (bending) stiffness
FLOORS	Glue bond durability, Surface veneer thickness, Dimensional stability, Impact resistance Machinability
FLOORS, SUB	Glue bond durability, Internal bond, Dimensional stability, Hardness Structural strength
FURNITURE	Same as Cabinets above, plus Veneer thickness, Aesthetic qualities Edge integrity for shaping /contours
ROOF DECKING	Glue bond durability, Structural performance Deflection/impact resistance Flexural (bending) stiffness
SHELVES	Glue bond durability Edge machinability/shaping Flexural (bending) stiffness
WALLS/CEILINGS INTERIOR FINISH	Glue bond durability, Dimensional stability Structural properties, Finish durability Flame spread ratings

Tables D3 through D14 present emissions data for Products A through N, H, I, J, M, and O. Chamber air samples from these products were collected on DNPH and multisorbent cartridges. Chamber air samples collected on DNPH cartridges were analyzed by HPLC; target aldehydes and ketones greater than $5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ were reported. Chamber air samples collected on multisorbent cartridges were analyzed by GC/MS; individual compounds greater than $5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ were reported, as well as TVOC. For most products, the TVOC estimate was much larger than the sum of individual compounds greater than $5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$; this occurred because the TVOC estimate included many compounds below the $5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ limit for reporting.

Table D-3. Emission Factors of Test Squares Cut from Panels of Recycled Newspaper

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²·hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A1-1	A2-2	A3-1	A3-2	Mean of A3-1 and A3-2	%RSD of A3-1 and A3-2	Mean of "mean of A3-1 and A3-2", A1-1, and A2-2	%RSD of "mean of A3-1 and A3- 2", A1-1, and A2- 2
< 24 hour conditioning								
Identification of target compounds > 5 µg/(m ² ·hr) on DNPH cartridges								
Formaldehyde	20	15	8	12	10	28	15	33
Acetaldehyde	28	27	18	21	20	11	25	19
Acetone	40	26	32	32	32	0	33	22
Propionaldehyde	6	6	-	-			6	0
2-Butanone	7	-	-	-			7	0
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				
Valeraldehyde	7	6	5	-	5	0	6	17
<i>m</i> -Tolualdehyde	-	-	-	-				
<i>n</i> -Hexanal	13	9	9	6	8	28	10	29
Identification of compounds > 5 µg/(m ² ·hr) on multisorbent cartridges								
Undecane	6	6	7	8	8	9	7	13
Dodecane	6	6	9	9	9	0	7	25
1-Hexanol, 2-ethyl-	4	6	-	-			5	28
Sum of compounds > 5 µg/(m ² ·hr) on multisorbent cartridges	16	18	16	17	17	4	17	6
TVOC analysis of multisorbent cartridges	180	190	210	210	210	0	210	7
30 day conditioning								
Identification of target compounds > 5 µg/(m ² ·hr) on DNPH cartridges								
Formaldehyde	21	17	13	12	13	6	17	25
Acetaldehyde	20	16	16	18	17	8	18	12
Acetone	-	-	-	-				
Propionaldehyde	5	5	-	-			5	0
2-Butanone	5	5	-	-			5	0
Butyraldehyde	-	-	-	-				
Benzaldehyde	6	5	-	-			6	13
Valeraldehyde	8	5	5	-	5	0	6	29
<i>m</i> -Tolualdehyde	-	-	-	-				
<i>n</i> -Hexanal	31	12	10	7	9	25	17	71

Continued

Table D-3. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	A1-1	A2-2	A3-1	A3-2	Mean of A3-1 and A3-2	%RSD of A3-1 and A3-2	Mean of "mean of A3-1 and A3-2", A1-1, and A2-2	%RSD of "mean of A3-1 and A3- 2", A1-1, and A2- 2
TVOC analysis of multisorbent cartridges	180	210	110	190	150	38	180	17

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

Table D-4. Emission Factors of Test Squares Cut from Panels of Wheatboard with Methylene Diisocyanate Resin

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	B1-1	B3-1	B2-1	B2-2	Mean of B2-1 and B2-2	%RSD of B2-1 and B2-2	Mean of "mean of B2-1 and B2-2", B1-1, and B3-1	%RSD of "mean of B2-1 and B2-2", B1-1, and B3-1
< 24 hour conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	6	9	12	9	11	20	9	27
Acetaldehyde	76	79	76	96	86	16	80	6
Acetone	92	84	52	79	66	29	81	17
Propionaldehyde	5	-	7	5	6	24	6	13
2-Butanone	-	5	3	-	3	0	4	35
Butyraldehyde	8	9	6	7	7	11	8	16
Benzaldehyde	-	-	-	-	-	-	-	-
Valeraldehyde	6	-	6	-	6	0	6	0
<i>m</i> -Tolualdehyde	-	-	-	-	-	-	-	-
<i>n</i> -Hexanal	-	-	-	-	-	-	-	-
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
Acetic acid, methyl ester	-	4	7	-	7	0	6	39
Methane, dichloro-	-	-	-	11	11	0	11	0
Propane, 2-methoxy-2-methyl-	-	2	-	33	33	0	18	125
Hexane	-	-	-	14	14	0	14	0
Furan, 2-methyl-	-	4	-	6	6	0	5	28
2-Butanone	-	4	-	7	7	0	6	39
Toluene	-	-	-	15	15	0	15	0
Benothiazole	-	-	-	6	6	0	6	0
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	-	14	7	92	50	121	32	79
TVOC analysis of multisorbent cartridges	51	74	53	210	130	85	85	48
28 day conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	7	7	7	7	7	0	7	0
Acetaldehyde	18	20	19	24	22	16	20	9
Acetone	-	-	-	-	-	-	-	-
Propionaldehyde	-	-	5	6	6	13	6	0
2-Butanone	5	5	5	5	5	0	5	0
Butyraldehyde	-	-	-	-	-	-	-	-
Benzaldehyde	-	-	-	-	-	-	-	-

Continued

Table D-4. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	B1-1	B3-1	B2-1	B2-2	Mean of B2-1 and B2-2	%RSD of B2-1 and B2-2	Mean of "mean of B2-1 and B2-2", B1-1, and B3-1	%RSD of "mean of B2-1 and B2-2", B1-1, and B3-1
Valeraldehyde	-	-	-	-				
<i>m</i> -Tolualdchye	-	-	-	-				
<i>n</i> -Hexanal	-	-	-	-				
TVOC analysis of multisorbent cartridges	68	72	65	51	58	17	66	11

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPB = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPB cartridges are "quantitated" emission factors.

Table D-5. Emission Factors of Test Squares Cut from Panels of Recycled Corrugated Cardboard

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	C1-1	C3-2	C1-2	C2-2	Mean of C1-1 and C1-2	%RSD of C1-1 and C1-2	Mean of "mean of C1-1 and C1-2", "mean of C2-2, and C3-2"	%RSD of mean of C1-1 and C1-2, C2-2, and C3-2
< 24 hour conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	28	26	25	25	25	0	26	6
Acetaldehyde	49	57	85	61	73	23	60	20
Acetone	260	270	120	220	170	42	230	24
Propionaldehyde	14	14	17	17	17	0	15	12
2-Butanone	9	-	12	6	9	47	9	0
Butyraldehyde	-	NR	-	-				
Benzaldehyde	-	NR	-	-				
Valeraldehyde	5	NR	-	-			5	0
<i>m</i> -Tolualdehyde	-	NR	-	-				
<i>n</i> -Hexanal	7	NR	7	6	7	11	7	5
Identification of target compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Acetic acid, methyl ester	-	-	7	-	7	0	7	0
2-Propanol, 2-methyl-	56	14	47	49	48	3	39	57
Acetic acid ethenyl ester	-	-	5	3	4	35	4	0
2,3-Butanedione	-	-	7	4	6	39	6	0
Acetic acid, ethyl ester	13	7	15	10	13	28	11	31
1-Pentene	-	-	5	-	5	0	5	0
Acetic acid, propyl ester	-	-	5	3	4	35	4	0
Benzothiazole	-	-	-	12	12	0	12	0
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges	69	21	91	81	86	8	59	57
TVOC analysis of multisorbent cartridges	190	150	190	190	190	0	180	13
26 day conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	17	15	15	15	15	0	16	7
Acetaldehyde	7	9	7	9	8	18	8	13
Acetone	-	-	-	-				
Propionaldehyde	-	-	-	-				
2-Butanone	7	7	7	7	7	0	7	0
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				

Continued

Table D-5. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	C1-1	C3-2	C1-2	C2-2	Mean of C1-1 and C1-2	%RSD of C1-1 and C1-2	Mean of "mean of C1-1 and C1-2", 2", C2-2, and C3- 2	%RSD of mean of C1-1 and C1- 2
Valeraldehyde	-	-	-	-				
<i>m</i> -Tolualdehyde	-	-	-	-				
<i>n</i> -Hexanal	-	-	-	-				
TVOC analysis of multisorbent cartridges	68	47	52	97	75	43	63	23

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

"NR" = not reported

Table D-6. Emission Factors of Test Squares Cut from Panels of Medium Density Fiberboard with Methylene Diisocyanate Resin

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	D1-1*	D2-2**	D3-1**	D3-2**	Mean of D3-1 and D3-2	%RSD		
						of D3-1 and D3- 2	Mean of "mean of D3-1 and D3-2", D2-2, and D1-1	%RSD of "mean of D3-1 and D3-2", D2-2, and D1-1
< 24 hour conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	7	9	11	7	9	31	8	14
Acetaldehyde	26	30	43	24	34	40	30	13
Acetone	-	-	-	-				
Propionaldehyde	-	-	-	-				
2-Butanone	-	-	-	-				
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				
Valeraldehyde	-	-	-	-				
m-Tolualdehyde	-	-	-	-				
Hexanal	-	-	-	-				
Identification of target compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Acetic acid, methyl ester		-	8	-	8	0	8	0
Methane, dichloro-		8	-	-			8	0
Propane, 2-methoxy-2-methyl-		19	-	-			19	0
Hexane		23	-	-			23	0
Heptane		-	5	-	5	0	5	0
Toluene		7	-	-			7	0
2-Furancarboxaldehyde		-	5	-	5	0	5	0
Alpha-Pinene, (-)-		-	5	-	5	0	5	0
Limonene		6	6	-	6	0	6	0
3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-		7	8	5	7	33	7	5
alpha-Terpineol		20	23	14	19	34	19	6
Junipene		10	10	6	8	35	9	16
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges		100	70	25	48	67	74	50
TVOC analysis of multisorbent cartridges		230	160	94	130	37	180	41
30 day conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	13	6	6	7	7	11	9	46
Acetaldehyde	16						16	0

Continued

Table D-6. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	D1-1*	D2-2**	D3-1**	D3-2**	Mean of D3-1 and D3-2	%RSD of D3-1 and D3- 2	Mean of "mean of D3-1 and D3-2", D2-2, and D1-1	%RSD of "mean of D3-1 and D3-2", D2-2, and D1-1
Acetone	-							
Propionaldehyde	-							
2-Butanone	-							
Butyraldehyde	-							
Benzaldehyde	-							
Valeraldehyde	-							
<i>m</i> -Tolualdehyde	-							
<i>n</i> -Hexanal	-							
Identification of target compounds $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
alpha-Terpineol	-	-	-	6	6	0	6	0
TVOC analysis of multisorbent cartridges	53	30	38	75	57	46	47	31

Mean = arithmetic mean of values $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

%RSD – relative standard deviation (as a percentage of the mean) of values $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test square D1-1, the 24 hour chamber air sample collected on the multisorbent cartridge was not analyzed (as indicated by the blank cells).

**For test squares D2-2, D3-1, and D3-2, 30 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the DNPH cartridges were not analyzed for the other target compounds (as indicated by the blank cells).

Table D-7. Emission Factors of Test Squares Cut from Panels of Ammonia-treated Medium Density Fiberboard with Urea-Formaldehyde Resin

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	E1-2**	E2-2*	E3-1	E3-2**	Mean of E3-1 and E3-2	%RSD of E3-1 and E3-2	Mean of "mean of E3-1 and E3-2", E1-2, and E2-2	%RSD of "mean of E3-1 and E3-2", E1-2, and E2-2
< 24 hour conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	99	93	100	99	100	1	97	4
Acetaldehyde	25	43	51	43	47	12	38	31
Acetone	-	-	-	-				
Propionaldehyde	-	-	-	-				
2-Butanone	-	-	-	-				
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				
Valeraldehyde	-	-	-	-				
m-Tolualdehyde	-	-	-	-				
Hexanal	-	-	6	5	6	13	6	0
Identification of compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Acetic acid, methyl ester	26		71	67	69	4	48	64
Heptane	-		6	-	6	0	6	0
Endo-fenchol	5		10	8	9	16	7	40
2-Propanone, 1-cyclohexylidene-	-		5	-	5	0	5	0
3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	7		14	12	13	11	10	42
endo-Borneol	6		12	10	11	13	9	42
.alpha.-Terpineol	26		51	44	48	10	37	41
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges	70		170	141	160	13	120	53
TVOC analysis of multisorbent cartridges	160		290	260	280	8	220	39
28 day conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	180	160	230	210	220	6	190	16
Acetaldehyde			20		20	0	20	0
Acetone			-					
Propionaldehyde			-					
2-Butanone			-					
Butyraldehyde			-					
Benzaldehyde			-					

Continued

Table D-7. (Continued).

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	E1-2**	E2-2*	E3-1	E3-2**	Mean of E3-1 and E3-2	%RSD of E3-1 and E3-2	Mean of "mean of E3-1 and E3-2", E1-2, and E2-2	%RSD of "mean of E3-1 and E3-2", E1-2, and E2-2
Valeraldehyde			-					
<i>m</i> -Tolualdehyde			-					
<i>n</i> -Hexanal			-					
Identification of compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Acetic acid, methyl ester	-	-	8	5	7	33	7	0
Acetic acid	-	-	6	-	6	0	6	0
1- α -Terpineol	-	12	15	16	16	5	14	18
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges		12	29	21	25	23	19	50
TVOC analysis of multisorbent cartridges	41	75	100	92	96	6	71	39

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNP_H = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNP_H cartridges are "quantitated" emission factors.

*For test square E2-2, the 24 hour chamber air sample collected on the multisorbent cartridge was not analyzed (as indicated by the blank cells); the 28 day chamber air sample collected on the DNP_H cartridge was only analyzed for formaldehyde; the air sample was not analyzed for the other target compounds (as indicated by the blank cells).

**For test squares E1-2 and E3-2, 28 day chamber air samples collected on DNP_H cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

Table D-8. Emission Factors of Test Squares Cut from Panels of Particleboard with Urea-Formaldehyde Resin

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	F2-2*	F3-2*	F1-1*	F1-2	Mean of F1-1 and F1-2	%RSD of F1-1 and F1-2	Mean of "mean of F1-1 and F1-2", F2-2, and F3-2	%RSD of "mean of F1-1 and F1- 2", F2-2, and F3-2
< 24 hour conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	290	290	380	360	370	4	320	14
Acetaldehyde	68	80	58	67	63	10	70	13
Acetone	110	130	120	130	130	5	120	10
Propionaldehyde	31	37	33	36	35	6	34	9
2-Butanone	6	6	7	6	7	11	6	5
Butyraldehyde	-	5	-	-	-	-	5	0
Benzaldehyde	-	-	-	-	-	-	-	-
Valeraldehyde	15	21	17	19	18	8	18	17
<i>m</i> -Tolualdehyde	-	-	-	-	-	-	-	-
<i>n</i> -Hexanal	120	150	150	150	150	0	140	12
Identification of compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Methane, oxybis-	30	13	-	11	11	0	18	58
Acetic acid, methyl ester	24	22	-	21	21	0	22	7
Pentanal	15	14	6	5	6	13	12	45
2-Furancarboxaldehyde	9	-	-	-	-	-	9	0
Alpha-Pinene, (-)-	460	230	150	180	170	12	290	53
Camphene	13	8	-	10	10	0	10	24
2-Beta-Pinene	250	180	95	140	120	27	180	36
.beta.-Myrcene	5	5	5	8	7	33	6	16
Benzaldehyde	5	-	-	-	-	-	5	0
Delta.3-Carene	96	80	54	75	65	23	80	20
Alkene	11	11	10	13	12	18	11	3
Limonene	40	31	25	33	29	20	33	18
.beta.-Phellandrene	10	8	6	10	8	35	9	13
2-Octenal, (E)-	7	-	-	-	-	-	7	0
Ethanone, 1-phenyl-	5	-	-	-	-	-	5	-
Nonanal	24	-	5	-	5	0	15	93
E'-O-Fenchol	5	-	-	-	-	-	5	0
Alpha-Campholen Aldehyde	7	-	-	-	-	-	7	0
Pinocarveol	9	-	-	-	-	-	9	0
Bicyclo[2.2.1]hept-2-en-7-ol	6	-	-	-	-	-	6	0
N-Acetyl-N-Phenyl	21	9	5	7	6	0	12	0
Ethanol, 2-(2-butoxyethoxy)-	-	-	-	-	-	-	-	-
Decanal	35	-	-	-	-	-	35	0

Continued

Table D-8. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	F2-2*	F3-2*	F1-1*	F1-2	Mean of F1-1 and F1-2	%RSD of F1-1 and F1-2	Mean of "mean of F1-1 and F1-2", F2-2, and F3-2	%RSD of "mean of F1-1 and F1- 2", F2-2, and F3-2
Bicyclo[3.1.1]hept-2-ene-2- carboxaldehyde, 6,6-d	18	6	-	5	5	0	10	75
Bicyclo[3.1.1]hept-3-en-2- one, 4,6,6-trimethyl-	6	-	-	-			6	0
Junipene	16	5	5	7	6	24	9	68
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges	1130	620	360	530	450	27	730	48
TVOC analysis of multisorbent cartridges	1450	900	600	820	710	22	1000	38
26 day conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	250	240	320	310	320	2	270	15
Acetaldehyde				13	13	0	13	0
Acetone				-				
Propionaldehyde				10	10	0	10	0
2-Butanone				5	5	0	5	0
Butyraldehyde				-				
Benzaldehyde				-				
Valeraldehyde				17	17	0	17	0
<i>m</i> -Tolualdehyde				-				
<i>n</i> -Hexanal				110	110	0	110	0
Identification of compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Pentanal	8	10	11	9	10	14	9	12
2-Furancarboxaldehyde	-	6	-	-			6	0
Alpha-Pinene, (-)-	11	20	15	47	31	73	21	48
2-Beta-Pinene	-	-	-	16	16		16	0
1-Decyne	6	-	7	7	7	0	7	11
Bornylene	-	-	-	6	6	0	6	0
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges	25	35	32	84	58	63	39	43

Continued

Table D-8. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	F2-2*	F3-2*	F1-1*	F1-2	Mean of F1-1 and F1-2	%RSD of F1-1 and F1-2	Mean of "mean of F1-1 and F1-2", F2-2, and F3-2	%RSD of "mean of F1-1 and F1- 2", F2-2, and F3-2
TVOC analysis of multisorbent cartridges	180	210	210	270	240	18	210	14

Mean = arithmetic mean of values > 5 µg/(m²•hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²•hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²•hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²•hr).

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test squares F1-1, F2-2, and F3-2, 26 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

Table D-9. Emission Factors of Test Squares Cut from Panels of Particleboard with Phenol-Formaldehyde Resin

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	N1-2	N3-1*	N2-1*	N2-2*	Mean of	%RSD	Mean of "mean of N2-1 and N2-2", and N1-2, and N3-1	%RSD of "mean of N2-1 and N2-2", and N1-2, and N3-1
					of N2-1 and N2-2	of N2-1 and N2-2		
< 24 hour conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	32	14	33	43	38	19	28	45
Acetaldehyde	180	38	170	190	180	8	130	63
Acetone	800	190	810	900	860	7	620	60
Propionaldehyde	47	11	52	47	50	7	36	60
2-Butanone	19	5	19	22	21	10	15	58
Butyraldehyde	58	14	54	56	55	3	42	58
Benzaldehyde	77	32	75	80	78	5	62	42
Valeraldehyde	66	62	330	350	340	4	160	100
<i>m</i> -Tolualdehyde	-	-	-	-	-	-	-	-
<i>n</i> -Hexanal	170	170	950	990	970	3	440	105
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
1,3-Butadiene, 2-methyl-	6	-	-	5	5	0	6	13
Unknown	-	20	-	-	-	-	20	0
Acetic acid, methyl ester	110	21	92	54	73	37	68	66
Hexane	6	-	-	5	5	0	6	13
2-Butenal, (E)-	10	-	7	6	7	11	8	30
Butanal	-	-	8	8	8	0	8	0
2-Butanone	6	-	5	-	5	0	6	13
3-Penten-2-ol	13	5	8	6	7	20	8	50
Heptane	12	10	6	5	6	13	9	36
1-Butanol	5	-	-	-	-	-	5	0
Pentanal	160	29	99	34	67	69	85	79
Toluene	6	-	-	-	-	-	6	0
Octane	41	16	41	45	43	7	33	45
Acetic acid	-	-	11	11	11	0	11	0
1-Pentanol	69	20	63	71	67	8	52	53
1,4-Pentadiene, 3-ethenyl-	19	-	17	15	16	9	18	12
Bicyclo[2,2,1]hept-2-ene,2,7,7-Trimethyl-	-	-	-	-	-	-	-	-
Tricyclene	-	-	13	13	13	0	13	0
2-Heptanone	26	7	27	29	28	5	20	57
Heptanal	12	-	-	-	-	-	12	0
Alpha-Pinene, (-)-	230	89	200	180	190	7	170	43
Camphene	82	5	83	73	78	9	55	79
1,3,5-Cycloheptatriene	-	-	5	5	5	0	5	0

Continued

Table D-9. (Continued)

	<u>Emission Factors of Test</u>				<u>Mean and %RSD of Emission Factors</u>			
	<u>Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				Mean of	%RSD	Mean of "mean of	%RSD of "mean of
	N1-2	N3-1*	N2-1*	N2-2*	N2-1 and N2-2	of N2-1 and N2-2	N2-1 and N2-2", and N1-2, and N3-1	N2-1 and N2-2", and N1-2, and N3-1
C3-Benzene	5	-	6	-	6	0	6	13
Pentanoic acid	-	-	14	25	20	40	20	0
2-Beta-Pinene	180	21	160	150	160	4	120	72
Furan, 2-pentyl-	-	-	12	12	12	0	12	0
2-Heptenal, (E)-	23	8	24	19	22	16	18	47
Benzaldehyde	62	26	57	62	60	6	49	41
Delta.3-Carene	9	-	11	16	14	26	11	28
7-Octen-4-ol	12	-	11	13	12	12	12	0
Benzene, 4-ethenyl-1,2-dimethyl-	6	-	6	5	6	13	6	6
Limonene	51	10	48	46	47	3	36	63
Benzene, 1-methyl-4-(1-methylethyl)-	26	-	27	27	27	0	27	3
Hexanoic acid	6	-	47	79	63	36	35	117
2-Octenal, (E)-	20	7	21	23	22	6	16	50
1-Octanol	12	-	11	12	12	6	12	3
2,5-Hexanedione	-	-	6	6	6	0	6	0
Fenchone	6	-	8	10	9	16	8	28
1,6-Heptadiene, 2,3,6-trimethyl-	-	-	5	5	5	0	5	0
Endo-Fenchol	15	-	16	18	17	8	16	9
Alpha-Campholene Aldehyde	23	-	28	33	31	12	27	20
Trans-Verbenol	9	-	11	13	12	12	11	20
Bicyclo[2.2.1]hept-2-en-2-amine, N,N-dimethyl-	13	-	15	18	17	13	15	17
Camphor	10	-	11	11	11	0	11	7
Bicyclo[3.1.1]heptan-3-one, 2,6,6-trimethyl-, (1	5	-	-	-	-	-	5	0
Phenol, 4-methyl-	-	-	26	26	26	0	26	0
1,3,7-Octatriene, 2,7-dimethyl-	10	-	11	-	11	0	11	7
1-Borneol	9	-	8	10	9	16	9	0
1-alpha.-Terpineol	16	7	16	18	17	8	13	41
Bicyclo[3.1.1]hept-2-ene-2-carboxaldehyde, 6,6-d	9	-	15	20	18	20	13	45
cis-Carveol	5	-	5	6	6	13	5	7
Bicyclo[3.1.1]hept-3-en-2-one, 4,6,6-trimethyl-	8	-	12	16	14	20	11	39
Ethanone, 1-(2-methylphenyl)-	6	-	9	11	10	14	8	35
2-Decenal, (Z)-	-	-	5	5	5	0	5	0
Junipene	14	-	20	22	21	7	18	30
Sum of compounds > 5mg/m2/h on multisorbent cartridges	1400	300	1400	1300	1400	5	1000	64

Continued

Table D-9. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	N1-2	N3-1*	N2-1*	N2-2*	Mean of	%RSD	Mean of "mean of N2-1 and N2-2", and N1-2, and N3-1	%RSD of "mean of N2-1 and N2-2", and N1-2, and N3-1
					N2-1 and N2-2	of N2-1 and N2-2		
TVOC analysis of multisorbent cartridges	2200	660	2100	2100	2100	0	1700	51
29 Day conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	14	6	18	15	17	13	12	45
Acetaldehyde	44						44	0
Acetone	182						180	0
Propionaldehyde	7						7	0
2-Butanone	5						5	0
Butyraldehyde	10						10	0
Benzaldehyde	19						19	0
Valeraldehyde	40						40	0
<i>m</i> -Tolualdehyde	-							0
<i>n</i> -Hexanal	91						91	0
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
Acetic acid, methyl ester	17	9	40	22	31	41	19	60
2-Propanol	31	-	-	36	36	0	34	9
Heptane	6	-	-	-			6	0
Pentanal	32	-	27	27	27	0	30	13
Acetic acid	5	-	7	-	7	0	6	23
1-Pentanol	30	10	22	20	21	7	20	49
Heptanal	10	-	8	8	8	0	9	13
Alpha-Pinene, (-)-	7	13	7	8	8	9	9	37
Benzaldehyde	17	6	15	14	15	5	13	49
D-Fenchyl alcohol	-	-	6	5	6	13	6	0
Camphor	-	-	5	-	5	0	5	0
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	160	38	140	140	140	0	110	60

Continued

Table D-9. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	N1-2	N3-1*	N2-1*	N2-2*	Mean of	%RSD)	Mean of "mean of N2-1 and N2-2", and N1-2, and N3-1	%RSD of "mean of N2-1 and N2-2", and N1-2, and N3-1
					of N2-1 and N2-2	of N2-1 and N2-2		
TVOC analysis of multisorbent cartridges	450	200	420	400	410	3	350	38

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test squares N2-1, N2-2, and N3-1, 29 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

Table D-10. Emission Factors of Test Squares Cut from Panels of Veneered Wheatboard with Methylene Diisocyanate Resin

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	H11-2**	H13-2*	H2-1**	H2-2	Mean of	%RSD	Mean of "mean of H2-1 and H2-2", and H1-2, and H3-2	%RSD of "mean of H2-1 and H2-2", and H1-2, and H3-2
					H2-1 and H2-2	of H2-1 and H2-2		
< 24 hour conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	980	810	780	920	850	12	880	10
Acetaldehyde	37	24	23	27	25	11	29	25
Acetone	-	-	-	-	-	-	-	-
Propionaldehyde	-	-	-	-	-	-	-	-
2-Butanone	-	-	-	5	5	0	5	0
Butyraldehyde	-	-	-	-	-	-	-	-
Benzaldehyde	-	-	-	-	-	-	-	-
Valeraldehyde	-	-	-	-	-	-	-	-
<i>m</i> -Tolualdehyde	-	-	-	-	-	-	-	-
<i>n</i> -Hexanal	-	-	-	-	-	-	-	-
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
2-Butanone	5	-	-	-	-	-	5	0
TVOC analysis of multisorbent cartridges	78	43	37	28	33	20	51	47
29 day conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	360		570	580	580	1	470	33
Acetaldehyde				8	8	0	8	0
Acetone				-	-	-	-	-
Propionaldehyde				-	-	-	-	-
2-Butanone				-	-	-	-	-
Butyraldehyde				-	-	-	-	-
Benzaldehyde				-	-	-	-	-
Valeraldehyde				-	-	-	-	-
<i>m</i> -Tolualdehyde				-	-	-	-	-
<i>n</i> -Hexanal				4	4	0	4	0

Continued

Table D-10. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	H1-2**	H3-2*	H2-1**	H2-2	Mean of	%RSD	Mean of "mean of H2-1 and H2-2", and H1-2, and H3-2	%RSD of "mean of H2-1 and H2-2", and H1-2, and H3-2
					of H2-1 and H2-2	of H2-1 and H2-2		
TVOC analysis of multisorbent cartridges	52		39	41	40	4	46	18

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test squares H1-2 and H2-1, 29 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

*For test square H2-1, the 29 day chamber air sample collected on the DNPH cartridges was not analyzed (as indicated by the blank cells).

Table D-11. Emission Factors of Test Squares Cut from Panels of Vinyl Overlaid Wheatboard with Methylene Diisocyanate Resin

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	I1-1*	I3-1*	I2-1*	I2-2*	Mean of I2-1 and I2-2	%RSD of I2-1 and I2-2	Mean of "mean of I2-1 and I2-2", and I1-1, and I3-1	%RSD of "mean of I2-1 and I2-2", and I1-1, and I3-1
< 24 hour conditioning								
Identification of target compounds $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	21	14	16	16	16	0	17	21
Acetaldehyde	26	28	19	15	17	17	24	25
Acetone	-	-	-	-				
Propionaldehyde	-	-	-	-				
2-Butanone	390	360	370	350	360	4	370	5
Butyraldehyde	-	-	-	23	23	0	23	0
Benzaldehyde	-	-	-	-				
Valeraldehyde	-	-	-	-				
<i>m</i> -Tolualdehyde	-	-	-	-				
<i>n</i> -Hexanal	7	6	5	-	5	0	6	17
Identification of compounds $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
Methane, dichloro-	7	-	-	4	4	0	6	39
Propane, 2-methoxy-2-methyl-	15	-	-	10	10	0	13	28
Furan, 2-methyl-	-	-	13	-	13	0	13	0
3-Buten-2-one	-	6	5	5	5	0	6	13
2-Butanone	170	140	190	120	160	31	160	10
2-Propenoic acid, 2-methyl-, methyl ester	6	5	6	4	5	28	5	11
2-Pentanone, 4-methyl-	58	66	64	49	57	19	60	8
Toluene	190	190	190	140	170	21	180	6
Unknown	18	20	23	13	18	39	19	6
Sum of compounds $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	460	430	490	350	420	24	440	5
TVOC analysis of multisorbent cartridges	540	500	620	420	520	27	520	4
29 day conditioning								
Identification of target compounds $\geq 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	5	-	5	-	5	0	5	0
Acetaldehyde								
Acetone								
Propionaldehyde								
2-Butanone								
Butyraldehyde								

Continued

Table D-11. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	I1-1*	I3-1*	I2-1*	I2-2*	Mean of	%RSD	Mean of "mean of	%RSD of "mean of
					I2-1 and I2-2	of I2-1 and I2-2	I2-1 and I2-2", and I1-1, and I3-1	I2-1 and I2-2", and I1-1, and I3-1
Benzaldehyde								
Valeraldehyde								
<i>m</i> -Tolualdehyde								
<i>n</i> -Hexanal								
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
2-Butanone	25	31	32	46	39	25	32	22
2-Pentanone, 4-methyl-	9	10	13	13	13	0	11	20
Toluene	56	51	63	60	62	3	56	9
Unknown	8	6	6	-	6	0	7	17
Sum of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges	98	98	110	120	120	6	110	12
TVOC analysis of multisorbent cartridges	160	150	200	200	200	0	170	16

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test squares I1-1, I2-1, I2-2, and I3-1, 29 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

Table D-12. Emission Factors of Test Squares Cut from Panels of Vinyl Overlaid Wheatboard with Methylene Diisocyanate Resin

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	J2-2*	J3-1*	J1-1**	J1-2*	Mean of	%RSD	Mean of "mean of	%RSD of "mean of
					J1-1 and J1-2	of J1-1 and J1-2	J1-1 and J1-2", and J2-2 and J3-1	J1-1 and J1-2", and J2-2 and J3-1
< 24 hour conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	14	16	13	14	14	5	15	9
Acetaldehyde	64	63	54	59	57	6	61	7
Acetone	-	-	-	-				
Propionaldehyde	10	12	8	11	10	22	11	13
2-Butanone	7	7	6	7	7	11	7	4
Butyraldehyde	7	7	7	8	8	9	7	4
Benzaldehyde	-	-	-	-				
Valeraldehyde	-	-	-	-				
m-Tolualdehyde	-	-	-	-				
Hexanal	6	7	6	5	6	13	6	12
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								
Acetic acid, methyl ester	5	6	5	6	6	13	6	9
TVOC analysis of multisorbent cartridges	50	56	58	67	63	10	56	11
29 day conditioning								
Identification of target compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on DNPH cartridges								
Formaldehyde	12	10	9	9	9	0	10	15
Acetaldehyde								
Acetone								
Propionaldehyde								
2-Butanone								
Butyraldehyde								
Benzaldehyde								
Valeraldehyde								
m-Tolualdehyde								
Hexanal								
Identification of compounds $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$ on multisorbent cartridges								

Continued

Table D-12. (Continued)

	<u>Emission Factors of Test Squares, $\mu\text{g}/(\text{m}^2\cdot\text{hr})$</u>				<u>Mean and %RSD of Emission Factors</u>			
	J2-2*	J3-1*	J1-1**	J1-2*	Mean of J1-1 and J1-2	%RSD of J1-1 and J1-2	Mean of "mean of J1-1 and J1-2", and J2-2 and J3-1	%RSD of "mean of J1-1 and J1-2", and J2-2 and J3-1
TVOC analysis of multisorbent cartridges	58	70		54	54	0	61	14

Mean = arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH = dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test squares J1-2, J2-2, and J3-1, 29 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

**For test square J1-1, the 29 day chamber air sample collected on DNPH cartridges was only analyzed for formaldehyde (the air sample was not analyzed for the other target compounds [as indicated by the blank cells]); the 29 day chamber air samples collected on the multisorbent cartridge was not analyzed (as indicated by the blank cells).

Table D-13. Emission Factors of Test Squares Cut from Panels of Painted Recycled Corrugated Cardboard

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	M1-1	M3-1*	M2-1**	M2-2*	Mean of M2-1 and M2-2	%RSD of M2-1 and M2-2	Mean of "mean of	%RSD of "mean
							of M2-1 and M2-2", and M1-1 and M3-1	of M2-1 and M2-2", and M1-1 and M3-1
< 24 hour conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	35	47	39	43	41	7	41	15
Acetaldehyde	36	49	39	31	35	16	40	20
Acetone	35	45	73	-	73	0	51	39
Propionaldehyde	?	?	80	57	69	24	69	0
2-Butanone	12	10	11	9	10	14	11	11
Butyraldehyde	-	8	-	-			8	0
Benzaldehyde	20	24	23	20	22	10	22	9
Valeraldehyde	8	9	-	-			9	8
m-Tolualdehyde	-	-	-	-				
Hexanal	6	6	5	-	5	0	6	10
Identification of compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
2-Propanol	9	17		10	10	0	12	36
2-Propanol, 2-methyl-	3	6		-			5	47
Disulfide, dimethyl	6	-		-			6	0
Toluene	14	14		12	12	0	13	9
2-Furancarboxaldehyde	75	8		49	49	0	44	77
Benzaldehyde	11	10		9	9	0	10	10
2-Furancarboxylic acid, methyl ester	4	-		-			4	0
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges	120	54		80	80	0	85	39
TVOC analysis of multisorbent cartridges	300	230		250	250	0	260	14
28 day conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	18	15	10	13	12	18	15	22
Acetaldehyde	12						12	0
Acetone	15						15	0
Propionaldehyde	26						26	0
2-Butanone	-							
Butyraldehyde	-							
Benzaldehyde	9						9	0

Continued

Table D-13. (Continued)

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²·hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	M1-1	M3-1*	M2-1**	M2-2*	Mean of M2-1 and M2-2	%RSD of M2-1 and M2-2	Mean of "mean of M2-1 and M2-2", and M1-1 and M3- 1	%RSD of "mean of M2-1 and M2-2", and M1-1 and M3-1
Valeraldehyde	-							
<i>m</i> -Tolualdehyde	-							
<i>n</i> -Hexanal	-							
Identification of compounds > 5 µg/(m ² ·hr) on multisorbent cartridges								
2-Furancarboxaldehyde	39	43	34	35	35	2	39	11
Propanoic acid, 2-methyl-, 2,2- dimethyl-1-(2-hydroxy-1- methylethyl)propyl ester	39	6	6	16	11	64	19	95
Propanoic acid, 2-methyl-, 3- hydroxy-2,4,4-trimethylpentyl ester	35	10	7	16	12	55	19	74
Sum of compounds > 5 µg/(m ² ·hr) on multisorbent cartridges	110	59	47	67	57	25	75	40
TVOC analysis of multisorbent cartridges	180	150	110	140	130	16	150	16

Mean = arithmetic mean of values > 5 µg/(m²·hr).

%RSD = relative standard deviation (as a percentage of the mean) of values > 5 µg/(m²·hr).

DNPH = dinitrophenylhydrazine

"-" = value < 5 µg/(m²·hr)

TVOC = total volatile organic compounds

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were < 5 µg/(m²·hr).

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

*For test squares M2-2, and M3-1, 28 day chamber air samples collected on DNPH cartridges were only analyzed for formaldehyde; the air samples were not analyzed for the other target compounds (as indicated by the blank cells).

**For test square M2-1, the 24 hr chamber air sample collected on the multisorbent cartridge was not analyzed (as indicated by the blank cells); the 28 day chamber air sample collected on the DNPH cartridge was only analyzed for formaldehyde (the air sample was not analyzed for the other target compounds (as indicated by the blank cells)).

Table D-14. Emission Factors of Test Squares Cut from Panels of Veneered Wheatboard (made with Methylene Diisocyanate Resin) Coated and Cured with Two Component Waterborne Polyurethane Coatings System

	<u>Emission Factors of Test Squares,</u> <u>µg/(m²•hr)</u>				<u>Mean and %RSD of Emission Factors</u>			
	O1-2	O3-1	O2-1	O2-2	Mean of O2-1 and O2-2	%RSD of O2-1 and O2-2	Mean of "mean of O2-1 and O2-2", and O1-2 and O3-1	%RSD of "mean of O2-1 and O2-2", and O1-2 and O3-1
28 day conditioning								
Identification of target compounds > 5 µg/(m ² •hr) on DNPH cartridges								
Formaldehyde	200	160	150	170	160	9	170	13
Acetaldehyde	15	15	13	16	15	15	15	2
Acetone	-	-	-	-				
Propionaldehyde	-	-	-	-				
2-Butanone	5	-	5	-	5	0	5	0
Butyraldehyde	-	-	-	-				
Benzaldehyde	-	-	-	-				
Valeraldehyde	-	-	-	-				
m-Tolualdehyde	-	-	-	-				
n-Hexanal	6	5	6	6	6	0	6	10
Identification of compounds > 5 µg/(m ² •hr) on multisorbent cartridges								
Methane, oxybis-	-	-	6	-	6	0	6	0
2-Propanone	-	-	13	-	13	0	13	0
Methane, dichloro-	-	-	7	-	7	0	7	0
Methane, dichloro-	-	-	17	-	17	0	17	0
Propane, 2-methoxy-2-methyl-	-	-	7	-	7	0	7	0
Benzene, methyl-	-	6	9	-	9	0	8	28
Octane	8	10	7	8	8	9	9	16
Cyclohexane, 1,1,3-trimethyl-	-	-	-	5	5	0	5	0
Cyclohexane, 1,2,4-trimethyl-, (1.alpha.,2.beta.,4.beta.)-	5	7	-	10	10	0	7	34
Hexane, 2,3,4-trimethyl-	6	10	6	7	7	11	8	29
Octane, 3-methyl-	6	10	6	7	7	11	8	29
Nonane	27	40	26	29	28	8	32	23
3-Hexyne	-	6	-	-		0	6	0
Cyclohexane, propyl-	7	9	7	8	8	9	8	13
Sum of compounds > 5 µg/(m ² •hr) on multisorbent cartridges	59	98	110	74	92	28	83	25

Continued

Table D-14. (Continued)

	<u>Emission Factors of Test Squares</u> $\mu\text{g}/(\text{m}^2\cdot\text{hr})$				<u>Mean and %RSD of Emission Factors</u>			
	O1-2	O3-1	O2-1	O2-2	Mean of O2-1 and O2-2	%RSD of O2-1 and O2-2	Mean of "mean of O2-1 and O2-2", and O1-2 and O3-1	%RSD of "mean of O2-1 and O2-2", and O1-2 and O3-1
TVOC analysis of multisorbent cartridges	150	190	250	170	210	27	180	17

Mean – arithmetic mean of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

%RSD – relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$.

DNPH – dinitrophenylhydrazine

"-" = value $< 5 \mu\text{g}/(\text{m}^2\cdot\text{hr})$

TVOC = total volatile organic compounds

Emission factors for compounds identified on multisorbent cartridges are "estimated" emission factors.

Emission factors for compounds identified on DNPH cartridges are "quantitated" emission factors.

Appendix E
Precision of Chamber Air Concentrations

Tables E-1 through E-3 present precision of chamber air samples. For each test square, chamber air samples were collected on three separate cartridges: one DNPH cartridge and two multisorbent cartridges (see Figure 4-2 in the report for the arrangement of the cartridges). For a select number of test squares, chamber air samples collected on both multisorbent cartridges were analyzed; the results of these "duplicate" measurements were used to evaluate precision. As discussed in Section 8.3.1, precision of chamber air samples is expressed as the percent relative standard deviation (%RSD) between duplicate air samples.

Table E-1. Precision of Chamber Air Concentrations for Component Study

	Chamber Air Concentrations, $\mu\text{g}/\text{m}^3$		Mean and %RSD of Concentrations	
	PBVST2-1	PBVST2-1D ^a	Mean PBVST2-1	%RSD PBVST2-1
1-Butanol	260	260	260	0
1-Pentanol	66	62	64	4
2-Methyl-1-Butanol	25	25	25	0
Acetone	130	120	130	5
2-Heptanone	12	12	12	0
Hexyl Acetate	-	-		
Ethyl-3-Ethoxy-Propionate	10	11	11	7
o-Xylene	-	-		
Ethylbenzene	-	-		
Naphthalene	-	-		
Junipene	34	33	34	2
2-(2-Butoxyethoxy)ethanol	770	740	760	3
	PBVS2-1	PBVS2-1D	Mean PBVS2-1	%RSD PBVS2-1
1-Butanol	360	350	360	7
1-Pentanol	29	28	29	1
2-Methyl-1-Butanol	-	-		
Acetone	150	110	130	28
2-Heptanone	19	19	19	0
Hexyl Acetate	5	5	5	0
Ethyl-3-Ethoxy-Propionate	-	-		
o-Xylene	-	-		
Ethylbenzene	-	-		
Naphthalene	-	-		
Junipene	87	85	86	1
2-(2-Butoxyethoxy)ethanol	320	310	320	7

^a "D" indicates duplicate air sample

"-" = value $< 5 \mu\text{g}/\text{m}^3$.

Mean = arithmetic mean of values $> 5 \mu\text{g}/\text{m}^3$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/\text{m}^3$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/\text{m}^3$.

Table E-2. Precision of Chamber Air Concentrations for Coatings Study

	Chamber Air Concentrations, $\mu\text{g}/\text{m}^3$		Mean and %RSD of Concentrations	
	B3	B3-D*	Mean B3	%RSD B3
1-Pentanol	140	150	150	5
Limonene	74	73	74	1
Junipene	58	53	56	6
Terpenes	420	350	390	13
1-Butanol	990	970	980	1
Toluene	24	24	24	0
2-Methyl-1-butanol	53	55	54	3
Butyl acetate	52	50	51	3
1,2-Propanediol	16	15	16	5
Ethylbenzene	340	340	340	0
m,p-Xylene	810	790	800	2
2-Heptanone	720	700	710	2
o-Xylene	260	250	260	3
Propylbenzene	110	100	110	6
Ethyl 3-ethoxypropionate	99	97	98	1
1-Methyl-2-pyrrolidinone	18	13	16	23
2-(2-Butoxyethoxy)ethanol	1500	1400	1500	5
Naphthalene	11	11	11	0
Hexyl acetate	470	460	470	2
Indan	14	14	14	0
C3-Benzenes	1300	1200	1300	5
C4-Benzenes	190	180	190	4
Dipropylene glycol, methyl ether	-	-		
Unknown 1 (approx. 27.50 min)	-	-		
Unknown 2 (approx. 27.85 min)	-	-		
TVOC	5800	5600	5700	2
	C5	C5D	Mean C5	%RSD C5
1-Pentanol	30	29	30	2
Limonene	58	57	58	1
Junipene	42	45	44	5
Terpenes	120	140	130	11
1-Butanol	5	-	5	0
Toluene	-	5	5	0
2-Methyl-1-butanol	-	-		
Butyl acetate	-	-		
1,2-Propanediol	-	38	38	0
Ethylbenzene	-	-		
m,p-Xylene	-	-		
2-Heptanone	12	11	12	6
o-Xylene	-	-		

Continued

Table E-2. (Continued)

	Chamber Air Concentrations, $\mu\text{g}/\text{m}^3$		Mean and %RSD of Concentrations	
	C5	C5D	Mean C5	%RSD C5
Propylbenzene	-	-		
Ethyl 3-ethoxypropionate	-	-		
1-Methyl-2-pyrrolidinone	20	34	27	37
2-(2-Butoxyethoxy)ethanol	880	660	770	20
Naphthalene	-	-		
Hexyl acetate	-	-		
Indan	-	-		
C3-Benzenes	-	-		
C4-Benzenes	25	26	26	3
Dipropylene glycol, methyl ether	-	-		
Unknown 1 (approx. 27.50 min)	170	180	180	4
Unknown 2 (approx. 27.85 min)	380	170	280	53
TVOC	1500	1800	1700	12
	C1	C1D	Mean C1	%RSD C1
1-Pentanol	28	29	29	2
Limonene	42	62	52	27
Junipene	26	53	40	48
Terpenes	76	93	85	14
1-Butanol	-	-		
Toluene	-	-		
2-Methyl-1-butanol	-	-		
Butyl acetate	-	-		
1,2-Propanediol	-	-		
Ethylbenzene	-	-		
m,p-Xylene	-	-		
2-Heptanone	16	16	16	0
o-Xylene	-	-		
Propylbenzene	-	-		
Ethyl 3-ethoxypropionate	-	-		
1-Methyl-2-pyrrolidinone	2300	3000	2700	18
2-(2-Butoxyethoxy)ethanol	-	-		
Naphthalene	-	-		
Hexyl acetate	-	-		
Indan	-	-		
C3-Benzenes	-	-		
C4-Benzenes	17	19	18	8
Dipropylene glycol, methyl ether	220	370	300	35
Unknown 1 (approx. 27.50 min)	-	-		
Unknown 2 (approx. 27.85 min)	-	-		
TVOC	2200	3000	2600	22

Continued

Table E-2. (Continued)

	<u>Chamber Air Concentrations, $\mu\text{g}/\text{m}^3$</u>		<u>Mean and %RSD of Concentrations</u>	
	C12	C12D	Mean C12	%RSD C12
1-Pentanol	33	33	33	0
Limonene	65	66	66	1
Junipene	50	51	51	1
Terpenes	180	180	180	0
1-Butanol	-	-		
Toluene	-	-		
2-Methyl-1-butanol	-	-		
Butyl acetate	-	-		
1,2-Propanediol	-	-		
Ethylbenzene	-	-		
m,p-Xylene	-	-		
2-Heptanone	10	11	11	7
o-Xylene	-	-		
Propylbenzene	-	-		
Ethyl 3-ethoxypropionate	-	-		
1-Methyl-2-pyrrolidinone	-	-		
2-(2-Butoxyethoxy)ethanol	-	-		
Naphthalene	-	-		
Hexyl acetate	-	-		
Indan	-	-		
C3-Benzenes	-	-		
C4-Benzenes	25	24	25	3
Dipropylene glycol, methyl ether	-	-		
Unknown 1 (approx. 27.50 min)	-	-		
Unknown 2 (approx. 27.85 min)	-	-		
TVOC	740	750	750	1
	A10	A10-D	Mean A10	%RSD A10
1-Pentanol	58	58	58	0
Limonene	110	100	110	6
Junipene	91	89	90	2
Terpenes	290	300	300	2
1-Butanol	5	5	5	0
Toluene	-	-		
2-Methyl-1-butanol	-	-		
Butyl acetate	-	-		
1,2-Propanediol	-	-		
Ethylbenzene	-	-		
m,p-Xylene	-	-		
2-Heptanone	17	17	17	0
o-Xylene	-	-		
Propylbenzene	-	-		

Continued

Table E-2. (Continued)

	Chamber Air Concentrations, $\mu\text{g}/\text{m}^3$		Mean and %RSD of Concentrations	
	A10	A10-D	Mean A10	%RSD A10
Ethyl 3-ethoxypropionate	-	-		
1-Methyl-2-pyrrolidinone	-	-		
2-(2-Butoxyethoxy)ethanol	-	-		
Naphthalene	-	-		
Hexyl acetate	-	-		
Indan	-	-		
C3-Benzenes	-	-		
C4-Benzenes	51	50	51	1
Dipropylene glycol, methyl ether	-	-		
Unknown 1 (approx. 27.50 min)	-	-		
Unknown 2 (approx. 27.85 min)	-	-		
TVOC	1100	1100	1100	0
	B9	B9-D	Mean B9	%RSD B9
1-Pentanol	81	73	77	7
Limonene	92	83	88	7
Junipene	119	106	110	8
Terpenes	200	190	200	4
1-Butanol	6	6	6	0
Toluene	-	-		
2-Methyl-1-butanol	-	6	6	0
Butyl acetate	-	-		
1,2-Propanediol	-	-		
Ethylbenzene	-	-		
m,p-Xylene	-	-		
2-Heptanone	18	16	17	8
o-Xylene	-	-		
Propylbenzene	-	-		
Ethyl 3-ethoxypropionate	-	-		
1-Methyl-2-pyrrolidinone	-	-		
2-(2-Butoxyethoxy)ethanol	-	8	8	0
Naphthalene	-	-		
Hexyl acetate	-	-		
Indan	-	-		
C3-Benzenes	-	-		
C4-Benzenes	45	40	43	8
Dipropylene glycol, methyl ether	-	-		
Unknown 1 (approx. 27.50 min)	-	-		
Unknown 2 (approx. 27.85 min)	-	-		
TVOC	1300	1200	1300	5

Continued

Table E-2. (Continued)

	Chamber Air Concentrations, $\mu\text{g}/\text{m}^3$		Mean and %RSD of Concentrations	
	C9	C9-D	Mean C9	%RSD C9
1-Pentanol	52	54	53	3
Limonene	60	60	60	0
Junipene	76	80	78	4
Terpenes	150	160	160	4
1-Butanol	-	-		
Toluene	-	-		
2-Methyl-1-butanol	-	-		
Butyl acetate	-	-		
1,2-Propanediol	-	-		
Ethylbenzene	-	-		
m,p-Xylene	-	-		
2-Heptanone	13	13	13	0
o-Xylene	-	-		
Propylbenzene	-	-		
Ethyl 3-ethoxypropionate	-	-		
1-Methyl-2-pyrrolidinone	-	-		
2-(2-Butoxyethoxy)ethanol	-	-		
Naphthalene	-	-		
Hexyl acetate	-	-		
Indan	-	-		
C3-Benzenes	-	-		
C4-Benzenes	29	29	29	0
Dipropylene glycol, methyl ether	-	-		
Unknown 1 (approx. 27.50 min)	-	-		
Unknown 2 (approx. 27.85 min)	-	-		
TVOC	910	920	920	1

* "D" indicates duplicate air sample

"-" = value $< 5 \mu\text{g}/\text{m}^3$.

Mean = arithmetic mean of values $> 5 \mu\text{g}/\text{m}^3$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/\text{m}^3$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/\text{m}^3$.

Table E-3. Precision of Chamber Air Concentrations for Fiber Study

	<u>Chamber Air</u>		<u>Mean and %RSD of</u>					
	<u>Concentrations, $\mu\text{g}/\text{m}^3$</u>		<u>Concentrations</u>					
	B3-1	B3-1D*	Mean B3-1	%RSD B3-1				
< 24 hour conditioning								
Acetic acid, methyl ester	4	4	4	0				
Methane, dichloro-	-	-						
Propane, 2-methoxy-2-methyl-	2	-	2	0				
Hexane	-	-						
Furan, 2-methyl-	4	-	4	0				
2-Butanone	4	-	4	0				
Toluene	-	-						
Benzothiazole	-	-						
TVOC	84	64	74	19				
28 day conditioning								
TVOC	66	79	73	13				
					C2-2	C2-2D	Mean C2-2	%RSD C2-2
< 24 hour conditioning	C1-2	C1-2D	Mean C1-2	%RSD C1-2				
Acetic acid, methyl ester	4	10	7	61	-	-		
2-Propanol, 2-methyl-	13	82	48	103	47	51	49	6
Acetic acid ethenyl ester	-	5	5	0	-	3	3	0
2,3-Butanedione	9	5	7	40	2	6	4	71
Acetic acid, ethyl ester	10	20	15	47	8	12	10	28
1-Pentene	5	-	5	0	-	-		
Acetic acid, propyl ester	-	5	5	0	-	3	3	0
Benzothiazole	-	-			-	12	12	0
TVOC	110	270	190	60	160	220	190	22
< 24 hour conditioning	D3-1	D3-1D	Mean D3-1	%RSD D3-1				
Acetic acid, methyl ester	6	9	8	28				
Methane, dichloro-	-	-						
Propane, 2-methoxy-2-methyl-	-	-						
Hexane	-	-						
Heptane	3	8	6	64				
Toluene	-	-						
2-Furancarboxaldehyde	5	4	5	16				
Alpha-Pinene, (-)-	5	4	5	16				
Limonene	7	6	7	11				
3-Cyclohexen-1-ol, 4-methyl-1-(1-methylethyl)-	9	8	9	8				
.alpha.-Terpinol	25	21	23	12				
Junipene	11	8	10	22				
TVOC	170	160	170	4				

Continued

Table E-3. (Continued)

	<u>Chamber Air</u>		<u>Mean and %RSD of</u>	
	<u>Concentrations, µg/m³</u>		<u>Concentrations</u>	
< 24 hour conditioning	E1-2	E1-2D	Mean E1-2	%RSD E1-2
Acetic acid, methyl ester	29	24	27	13
Heptane	-	-		
Endo-Fenchol	6	4	5	28
2-Propanone, 1-cyclohexylidene-	-	-		
3-Cyclohexen-1-ol, 4-methyl- 1-(1-methylethyl)-	8	7	8	9
endo-Borneol	7	4	6	39
.alpha.-Terpineol	28	23	26	14
TVOC	170	150	160	9
26 day conditioning	F2-2	F2-2D	Mean F2-2	%RSD F2-2
Pentanal	-	8	8	0
2-Furancarboxaldehyde	-	-		
Alpha-Pinene, (-)-	11	11	11	0
2-Beta-Pinene	-	-		
1-Deeyne	6	-	6	0
Bornylene	-	-		
TVOC	190	180	190	4
< 24 hour conditioning	N2-1	N2-1D	Mean N2-1	%RSD N2-1
1,3-Butadiene, 2-methyl-	5	4	5	16
Unknown	-	-		
Acetic acid, methyl ester	94	90	92	3
Hexane	5	4	5	16
2-Butenal, (E)-	6	8	7	20
Butanal	8	8	8	0
2-Butanone	-	5	5	0
3-Penten-2-ol	6	9	8	28
1-Heptene	-	3	3	0
Heptane	5	7	6	24
1-Butanol	-	4	4	0
Pentanal	19	65	42	77
Pentanal	15	98	57	104
Toluene	4	4	4	0
Octane	45	38	42	12
Acetic acid	11		11	0
1-Pentanol	64	51	58	16
1-Pentanol	6	4	5	28

Continued

Table E-3. (Continued)

	Chamber Air		Mean and %RSD of	
	Concentrations, $\mu\text{g}/\text{m}^3$		Concentrations	
< 24 hour conditioning	N2-1	N2-1D	Mean N2-1	%RSD N2-1
1,4-Pentadiene, 3-ethenyl-	15	20	18	20
Bicyclo[2,2,1]hept-2-ene, 2,7,7-Trimethyl-	-	3	3	0
< 24 hour conditioning	N2-1	N2-1D	Mean N2-1	%RSD N2-1
Tricyclene	13	-	13	0
2-Heptanone	29	25	27	10
Heptanal	-	-		
Alpha-Pinene, (-)-	180	220	200	14
Camphene	73	93	83	17
1,3,5-Cycloheptatriene	5		5	0
C3-Benzene	-	6	6	0
Pentanoic acid	25	2	14	120
2-Beta-Pinene	150	170	160	9
Furan, 2-pentyl-	12	-	12	0
2-Heptenal, (E)-	19	29	24	29
Benzaldehyde	62	53	58	11
Delta.3-Carene	16	6	11	64
7-Octen-4-ol	13	10	12	18
Benzene, 4-ethenyl-1,2-dimethyl-	5	6	6	13
Limonene	46	49	48	4
Benzene, 1-methyl-4-(1-methylethyl)-	27	26	27	3
Hexanoic acid	79	14	47	99
2-Octenal, (E)-	23	18	21	17
1-Octanol	12	11	12	6
2,5-Hexanedione	6	-	6	0
Fenchone	10	7	9	25
1,6-Heptadiene, 2,3,6-trimethyl-	5	-	5	0
Endo-Fenchol	18	15	17	13
Alpha-Campholene Aldehyde	33	23	28	25
trans-Verbenol	13	8	11	34
Bicyclo[2.2.1]hept-2-en-2-amine, N,N-dimethyl-	18	12	15	28
Camphor	11	10	11	7
Bicyclo[3.1.1]heptan-3-one, 2,6,6-trimethyl-, (1	4	4	4	0
Phenol, 4-methyl-	26	-	26	0
1,3,7-Octatriene, 2,7-dimethyl-	-	11	11	0
1-Borncol	10	6	8	35

Continued

Table E-3. (Continued)

	<u>Chamber Air</u>		<u>Mean and %RSD of</u>	
	<u>Concentrations, $\mu\text{g}/\text{m}^3$</u>		<u>Concentrations</u>	
l.alpha.-Terpineol	18	14	16	18
Bicyclo[3.1.1]hept-2-ene-2-carboxaldehyde, 6,6-d	20	10	15	47
< 24 hour conditioning	N2-1	N2-1D*	Mean N2-1	%RSD N2-1
Bicyclo[3.1.1]hept-3-en-2-one, 4,6,6-trimethyl-	16	7	12	55
Ethanone, 1-(2-methylphenyl)-	11	8	10	22
2-Decenal, (Z)-	5	4	5	16
Junipene	22	19	21	10
TVOC	2100	2100	2100	0
29 day conditioning	N2-2	N2-2D	Mean N2-2	%RSD N2-2
Acetic acid, methyl ester	22	-	22	0
2-Propanol	26	45	36	38
Heptane	-	-	-	-
Pentanal	30	24	27	16
Acetic acid	-	-	-	-
1-Pentanol	21	18	20	11
Heptanal	8	8	8	0
Alpha-Pinene, (-)-	7	8	8	9
Benzaldehyde	14	13	14	5
D-Fenchyl alcohol	-	5	5	0
Camphor	-	-	-	-
TVOC	400	400	400	0
< 24 hour conditioning	I2-2	I2-2D	Mean I2-2	%RSD I2-2
Methane, dichloro-	2	5	4	61
Propane, 2-methoxy-2-methyl-	5	16	11	74
Furan, 2-methyl-	-	-	-	-
3-Buten-2-one	6	4	5	28
2-Butanone	120	130	130	5
2-Propenoic acid, 2-methyl-, methyl ester	4	4	4	0
2-Pentanone, 4-methyl-	48	51	50	4
Toluene	140	140	140	0
Unknown	14	11	13	17
TVOC	400	440	420	7
< 24 hour conditioning	M1-1	M1-1D	Mean M1-1	%RSD M1-1
2-Propanol	11	6	9	42
2-Propanol, 2-methyl-	3	-	3	0
Disulfide, dimethyl	7	5	6	24
Toluene	15	13	14	10

Continued

Table E-3. (Continued)

	Chamber Air		Mean and %RSD of	
	Concentrations, $\mu\text{g}/\text{m}^3$		Concentrations	
< 24 hour conditioning	M1-1	M1-1D	Mean M1-1	%RSD M1-1
2-Furancarboxaldehyde	120	30	75	85
< 24 hour conditioning	M1-1	M1-1D	Mean M1-1	%RSD M1-1
Benzaldehyde	12	9	11	20
2-Furancarboxylic acid, methyl ester	5	3	4	35
TVOC	360	230	300	31
28 day conditioning	M2-1	M2-1D	Mean M2-1	%RSD M2-1
2-Furancarboxaldehyde	34	34	34	0
Propanoic acid, 2-methyl-, 2,2-dimethyl-1-(2-hydroxy-1-methylethyl)propyl ester	-	6	6	0
Propanoic acid, 2-methyl-, 3-hydroxy-2,4,4-trimethylpentyl ester	6	8	7	20
TVOC	110	110	110	0
28 day conditioning	O2-2	O2-2D	Mean O2-2	%RSD O2-2
Methane, oxybis-	-	-		
2-Propanone	-	-		
Methane, dichloro-	-	-		
Methane, dichloro-	-	-		
Propane, 2-methoxy-2-methyl-	-	-		
Benzene, methyl-	-	-		
Octane	8	8	8	0
Cyclohexane, 1,1,3-trimethyl-	5	5	5	0
Cyclohexane, 1,2,4-trimethyl-, (1.alpha.,2.beta.,4.beta.)-	10	9	10	7
Hexane, 2,3,4-trimethyl-	8	7	8	9
Octane, 3-methyl-	7	7	7	0
Nonane	31	28	30	7
3-Hexyne	-	-		
Cyclohexane, propyl-	8	7	8	9
TVOC	180	170	180	4

* "D" indicates duplicate air sample

"-" = value $< 5 \mu\text{g}/\text{m}^3$.

Mean = arithmetic mean of values $> 5 \mu\text{g}/\text{m}^3$.

%RSD = relative standard deviation (as a percentage of the mean) of values $> 5 \mu\text{g}/\text{m}^3$.

Blank cells under "mean" and/or "%RSD" columns indicate that all values for calculating these parameters were $< 5 \mu\text{g}/\text{m}^3$.

Appendix F
Accuracy Calculations

Table F-1. Summary of Accuracy Calculations

	VOCs	Aldehydes and Ketones
Screening Study (semi-quantitative analysis for VOCs)	^a	not evaluated
Component Study	not evaluated	2 spiked cartridges analyzed for 13 compounds; accuracy goals met (see Table F-2)
Coatings Study	3 sets analyzed; accuracy goals met	3 spiked cartridges analyzed; accuracy goals met for 10 of 13 compounds (see Table F-3)
Fiber Study (semi- quantitative analysis for VOCs)	^a	3 spiked cartridges analyzed for formaldehyde; accuracy goals met for 2 of 3 cartridges; very low recovery was found for third cartridge, which may have been due to a bad injection

^a accuracy not evaluated for semi-quantitative measurements of VOCs

Table F-2. Accuracy Data for Component Study

Spiked Compounds	Percent Recovery	
	Cartridge 1	Cartridge 2
Formaldehyde	114	106
Acetaldehyde	115	109
Acetone	116	111
Acrolein	129	117
Propionaldehyde	99	91
Crotonaldehyde	121	111
2-Butanone	98	90
Methacrolein	128	116
Butryaldehyde	98	89
Benzaldehyde	103	94
Valeraldehyde	98	91
m-Tolualdehyde	91	90
Hexanal	92	77

Table F-3. Accuracy Data for Coatings Study

Spiked Compounds ^a	Percent Recovery of Amount Spiked		
	Cartridge 1	Cartridge 2	Cartridge 3
Formaldehyde	110	100	98
Acetone	180	154	160
Acrolein	110	100	95
Propionaldehyde	100	100	100
Crotonaldehyde	95	99	96
Butryaldehyde	97	86	93
Benzaldehyde	110	97	110
Valeraldehyde	82	82	81
m-Tolualdehyde	120	130	120
Hexanal	99	97	100

^aContamination and stability problems prevented analysis of acetaldehyde, 2-butanone, and methacrolein.

Appendix G
Names and Addresses of Coatings and Fiber Panel Participants

The following coatings and fiber panel participants agreed to have their names and addresses appear in this report.

Bayer Corporation - supplier of two-component polyurethane coatings system
100 Bayer Road
Pittsburgh, PA 15205-9741
Contact: Mike Dvorchak, Ph: 412-777-4149

Gridcore Systems International - manufacturer of panel made from recycled corrugated cardboard
1400 Canal Avenue
Long Beach, CA
90813
Contact: Bob Noble, Ph: 562-901-1492

The Homaoste Company - manufacturer of panel made from recycled newspaper
Box 7240
West Trenton, NJ
08628-0240
Contact: Manker Mills, Ph: 800-257-9491

PrimeBoard, Inc. - manufacturer of unfinished and finished wheatboard panels
2111 N 3M Drive
Wahpeton, ND
58075
Contact: Kevin Smith, Ph: 800-943-2823

R&D Coatings, Inc. - supplier of acrylate coatings system
P.O. Box 325
Wexford, PA
15090
Contact: Don Eshenbaugh, Ph: 412-935-6830

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before complete)

1. REPORT NO. EPA-600/R-98-146		2.		3.	
4. TITLE AND SUBTITLE The Application of Pollution Prevention Techniques to Reduce Indoor Air Emissions from Engineered Wood Products				5. REPORT DATE November 1998	
				6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) C. M. Brockmann, L. S. Sheldon, D. A. Whitaker, and J. N. Baskir				8. PERFORMING ORGANIZATION REPORT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Research Triangle Institute P. O. Box 12194 Research Triangle Park, North Carolina 27709				10. PROGRAM ELEMENT NO.	
				11. CONTRACT/GRANT NO. CR822002	
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Air Pollution Prevention and Control Division Research Triangle Park, NC 27711				13. TYPE OF REPORT AND PERIOD COVERED Final; 10/93 - 1/98	
				14. SPONSORING AGENCY CODE EPA/600/13	
15. SUPPLEMENTARY NOTES APPCD project officers are Kelly W. Leovic and Elizabeth M. Howard, Mail Drop 54, 919/541-7717.					
16. ABSTRACT The report gives results of an investigation of pollution prevention options to reduce indoor emissions from a type of finished engineered wood. Emissions were screened from four types of finished engineered wood: oak-veneered particleboard coated and cured with a heat-curable, acid-catalyzed alkyd-urea sealer and topcoat (PBVST); oak-veneered handboard 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). Within the scope of the emissions and performance tests of the study, three types of coatings were found to have significantly lower emission factors of summed volatile organic compounds (VOCs) and formaldehyde relative to those for the heat-curable, acid-catalyzed alkyd-urea coatings: a two-component waterborne polyurethane, an ultraviolet (UV)-curable acrylate, and a UV-and-heat-curable multi-functional acrylate-free emulsion. Three types of engineered fiber panels were identified as having significantly lower emission factors of summed VOCs and formaldehyde relative to those for particleboard: medium-density fiberboard made with methylene diisocyanate (MDI), a wheat-board panel made with MDI resin, and a panel made from recycled corrugated cardboard. All three fiber panels are in the market place.					
17. KEY WORDS AND DOCUMENT ANALYSIS					
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group	
Pollution	Volatility	Pollution Prevention	13B	20M	
Emission	Formaldehyde	Stationary Sources	14G		
Wood Products	Polyurethane Resins	Indoor Air	11L	11I, 11J	
Particle Boards	Paperboards	Engineered Wood Products	11G		
Sealers	Melamines		11A		
Coatings	Acrylates	Volatile Organic Compounds (VOCs)	11C		
Organic Compounds			07C		
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