



# Inside IAQ

*EPA's Indoor Air Quality Research Update*

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## EVALUATION OF LOW-VOC LATEX PAINTS

Low-volatile organic compound (VOC) latex paints are advertised as the "perfect choice" for application in occupied buildings (e.g., hospitals, nursing homes, schools, hotels, offices, and homes) during normal business hours. IEMB recently evaluated four commercially available low-VOC interior latex paints. Formaldehyde emissions were detected in two of the paints, and detailed analyses were performed on the one paint with the highest formaldehyde emissions. This paint is promoted by its manufacturer as "no solvent" and "VOC free" based on EPA Reference Method 24. The sales brochure claims "virtually no harmful emissions into the air" and "no unfriendly or irritable odors."

A bulk analysis was performed by extracting the paint with methanol and then analyzing the extract by gas chromatography/mass spectrometry (GC/MS). While Method 24 measures only the total volatile organic compound (TVOC) content, bulk analysis provides more accurate and precise data for the content of individual VOCs. It was found that most of the individual VOC concentrations in the paint were below or near the quantification limit of the analytical techniques used. The TVOC content (less than 0.1 wt.%) was well below that (about 5 wt.%) of an ordinary latex paint.

Small chamber tests were also performed on the paint. The flow-through, dynamic chambers have a volume of 53 liters and are constructed with electropolished stainless steel interior surfaces to minimize adsorption of VOCs. Small fans were used to enhance mixing and provide a velocity near the test surface of 5–10 cm/s, which is typical of indoor environments. Emissions testing was conducted by placing freshly painted (2–3 minutes) gypsumboard (16.3 x 16.3 cm) in the chamber, painted side up. The chamber was closed, and clean air (< 5µg/m<sup>3</sup> TVOCs) flow was started through the chamber. A flow rate of 0.44 L/min, equivalent to 0.5 air change per hour, was used. Testing was conducted at 23°C with an inlet relative humidity (RH) of 50%.

Small chamber tests also showed very low VOC emissions for this paint; however, the peak concentration of formaldehyde in the chamber air reached as high as 2.0 mg/m<sup>3</sup> about 30 minutes after painting. The chamber air formaldehyde concentration decreased by about 85% in the

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first 24 hours, and the concentration decrease slowed down considerably in the second 24 hour period. After 120 hours, the formaldehyde concentration was 0.16 mg/m<sup>3</sup>.

Formaldehyde is a primary upper respiratory tract irritant, and its odor is characterized as "pungent." The lowest listed odor detection threshold is 0.04 mg/m<sup>3</sup>. Symptoms of eye, nose, and throat irritation, such as tearing, running nose, and a burning sensation in these areas, are relatively common with formaldehyde exposure. Formaldehyde is also classified as a probable carcinogen based on sufficient evidence in animal studies. The World Health Organization guideline for indoor air formaldehyde concentrations is 0.1 mg/m<sup>3</sup>. The U.S. Department of Housing and Urban Development recommends that indoor formaldehyde concentrations from all sources not exceed 0.5 mg/m<sup>3</sup>. The California Air Resources Board recommends for homes an "action level" of 0.12 mg/m<sup>3</sup> and a "target level" of 0.06 mg/m<sup>3</sup> or lower.

It was suspected and later confirmed that the biocide used in the paint was a source of the formaldehyde (up to 50%). (Biocide is used as an additive to prevent paint degradation by microbial growth.) However, the source of the remainder of the formaldehyde is not certain, though it is possible that it is from the paint formulation, side reactions, or other additives.

The results illustrate that "no-VOC" does not necessarily mean no-emissions. The common indoor air definition of VOC only includes those organic compounds with boiling points between 50 and 260°C. A number of hazardous air pollutants (e.g., formaldehyde with a boiling point of -21°C) are not accounted for by this definition. Also, the VOC contained in the bulk paint may not be the VOC emitted since VOCs can be formed as byproducts of chemical reactions after the paint is applied.

The results also indicate that EPA Reference Method 24 is probably not an adequate method for measuring the VOC content of low-VOC latex paints. Since it is a gravimetric method relying on the difference between weight loss upon heating and water content of the sample paint, the analytical precision is 1.5 and 4.7% for within- and between-laboratory data, respectively. Current bulk analysis and emission test results showed that the VOC contents of low-VOC latex paints (e.g., less than 0.1%) are well within the uncertainty range of Method 24, and the method is apparently not precise enough to accurately define the VOC content of those paints.

IEMB has shared the results from this study with the paint manufacturer who was willing to reformulate the paint. To determine the extent of formaldehyde emissions from interior paints on the market, a major effort involving the testing of a number of interior paints would be needed. (EPA Contact: John Chang, 919-541-3747, jchang@engineer.aeerl.epa.gov)

## ***A COMPILATION OF DATA ON EMISSIONS FROM INDOOR SOURCES***

There is a growing amount of data in the scientific and technical literature on pollutant emissions from indoor sources. Most of the data have been reported by researchers interested in developing testing methods, understanding mechanisms of mass transfer from source to air, or studying a particular class of indoor sources. IEMB has been compiling such data primarily to support its in-house source characterization studies by seeing where the data gaps are, and to develop descriptive statistics that might be useful in designing new products, buildings, or ventilation systems. This article summarizes the approach being taken by IEMB and the current status of the compilation.

An Excel spreadsheet is used as the structure of the compilation. Twenty fields (columns in the spreadsheet) have been established; they are listed and described in Table 1. Note that data are included only from references that report *emission factors* (pollutant emission rate per unit of source), or experimental data from which emission factors can be calculated.

Table 2 summarizes the source categorization scheme used. Source categories and examples of source "types" are shown. IEMB is trying to use a nomenclature that is compatible with industrial and commercial terminology, which can be variable.

While care is taken in selecting references, there are no detailed acceptability criteria. Articles and reports from peer-reviewed scientific and technical literature are preferred; these are labeled "primary" references in the bibliography listed in Table 3. References that may not have been through peer review but appear to have been based on good measurement practices are labeled "secondary" references in the bibliography. References that summarize results from studies by other authors are used very little in this database; those that have been are labeled "tertiary" references in the bibliography.

The database currently has about 5000 records covering about 60 source types, extracted from about 60 references. Emphasis to date has been on development of the structure and data entry guidelines. One round of quality assurance (QA) has been completed, and a second QA review is planned. Over the next year, the emphasis will shift to additional data entry and analysis. IEMB has started to look at the data with an eye toward developing representative emission factors for product, building, and heating, ventilating, and air-conditioning (HVAC) system design. Developers of other emission data bases will also be contacted to compare compilation and analysis approaches. Comments are welcome, as are recommendations for additional references. (EPA Contact: W. Gene Tucker, 919-541-2746, tucker.gene@epa.gov)

Table 1. Names of fields in indoor emissions database

Name of Field	Description Data Entry Guidelines
Record Number	Number assigned to first field of each record. Records (rows) generally represent emissions data for a single pollutant or pollutant class from a single sample, or set of samples, of a source type. Occasionally, a record will represent two or more pollutants.
<b>Source Information</b>	
Category	Source category of the sample that was tested. (See Table 2 for listing of source categories.)
Type	Source type of the sample that was tested. (See Table 2 for listing of some source types.) Use judgement creating new source types; consider author's descriptions.
NAICS	North American Industrial Classification System code number. (NAICS replaced the Standard Industrial Classification, or SIC, system in 1997.) Enter the code of the source category—or, if possible—the source type. See <a href="http://www.theodora.com/sic_index.html">http://www.theodora.com/sic_index.html</a> or <a href="http://www.census.gov/epcd/naicscod.txt">www.census.gov/epcd/naicscod.txt</a> for listing of NAICS codes and titles, and <a href="http://www.naics4.html">www/naics4.html</a> .
<b>Emission Testing Information</b>	
Reference	Code for the reference from which the emissions data were obtained. Use first three letters of first author's last name followed by the last two digits of year the data were published. If same author (or more than one author with the same three first letters of last name) published more than once during same year, add lower-case a, b, etc. to distinguish them.
Specific Identification	Specific information about the source sample that expands on the "source type" entry (such as composition data, condition or history of the product from which the sample was taken). If the author's description differs from the description used in the Category and Type fields, enter it here.
Age of Tested Sample	Time that elapsed between when the source sample was first put into use and when emission sampling occurred. If sample was purchased at a store, that should be noted in the "specific identification" field. If the reference presents both an empirical model and tabulated emission factors, enter the tabulated values and describe the model in the "comment" field. If an empirical emission model is presented and measured emission factors are not clearly tabulated, records should be created for the following preselected ages, <i>limited to the time period for which the model is applicable</i> : 1 hour, 24 h, 168 h (1 week), 730 h (1 month), and 8760 h (1 year). In these cases, note that a specific age has been selected: e.g., enter "24 h (modeled age)."
<b>Pollution Information</b>	
Name	Chemical name of the pollutant (or other name, if is not a single chemical substance).
CASN	Chemical Abstract Service (CAS) Number for the pollutant. For a listing of CAS numbers, see <a href="http://webbook.nist.gov/chemistry/name-ser.htm">http://webbook.nist.gov/chemistry/name-ser.htm</a> .
Test Methods/ Conditions	Enter information such as chamber size, material of construction, air change rate or flow, temperature and relative humidity during testing, and air sampling rate or volume.
Analytical Method	Enter the method(s) used to chemically or physically characterize the pollutant in the air sample.

Name of Field	Description Data Entry Guidelines
<b>Emission Factors</b>	
Units	Emission factors should be reported in units of <u>emission rate per unit of source</u> . (Units for emission rate are general by <i>mass per time</i> ; units of source are <i>area</i> for surface materials, or a <i>single product</i> for sources like machines or pieces of furniture). Emission factors for physical or chemical pollutants should therefore be entered in units of $\mu\text{g/h per m}^2$ for surface materials, or $\mu\text{g/h per unit of product}$ for other source types. If other units are used in the reference, convert to the units and note in the "comments" field that the conversion has been made. Units for biological pollutants such as fungi should be entered as reported; colony-forming units (CFUs) are often used instead of mass.
Number of Measurements, N	The number of measurements that were made to establish the values entered into the next four fields. Where N=1, the emission factor value should be entered into the "mean" field. When it is not clear from the reference how many measurements were made, enter "?."
Minimum	Minimum value, where multiple emission measurements of a single same sample, or set of similar samples) are reported in the reference.
Median	Median value, where multiple emission measurements (of a single same sample, or set of similar samples) are reported in the reference.
Mean (SD)	Mean and standard deviation values, where reported. If a single measurement is reported in the reference, enter it in this field.
Maximum	Maximum value, where multiple measurements (of a single sample, or set of similar samples) are reported in the reference.
<b>Emissions Modeling</b>	
Yes/No	Enter Y or N, depending on whether the reference includes a mathematical model that represents measurements taken. Note that references dealing only with purely theoretical models or discussion of emission models (i.e., references that do not report new data) are not to be covered in this data base.
Half-Time	Time, in hours, for the emission factor to go from its maximum value to half the maximum, as estimated by the model. Also enter standard deviation for the half-time, if reported.
<b>Comments</b>	
	Use this field to note special information on the reference that might be useful to users of the data base. If emissions modeling was reported, enter the mathematical form of the model and values for coefficients; also note range of applicability (e.g., for time or temperature). Note any adjustments made to reported data (e.g., change of emission factor units or conversion of chamber concentration data to emission factors). If the value entered in the emission factor field was calculated from the model, note that in this field. When emission factor data were not obtained directly from the reference, but through contact with an author, note by a statement such as "The value for this emission factor, which is difficult to estimate from Figure x of the reference, was obtained directly from the author."

Table 2. Source categories and types

Category	Type (Examples)	Category	Type (Examples)						
Adhesives	Carpet adhesive Flooring adhesive General adhesive	Miscellaneous Materials	Brick Ceramic tile Clothing Concrete Glass Metal Microbial culture Misc. stored material Mortar Paper-based material Stone						
Cabinetry	Kitchen cabinets								
Caulks & Seals	Caulk, general Sealant, general								
Cleaning Agents (see also pesticides)	Detergent Disinfectant Misc. cleaning agents Solvent-based cleaner								
Floor Materials	Carpet-synthetic fiber Carpet-wool fiber Carpet cushion Carpet system Cork flooring Linoleum Sheet vinyl flooring Tile vinyl flooring Wood flooring Other flooring								
				Furnishings	Drapery Drapery lining Office furniture-metal Office furniture-upholstered Office furniture-wood Residential furniture-metal Residential furniture-upholstered Residential furniture-wood Other furnishings				
						HVAC Systems and Components (see also space heating and cooking equipment)	Air cleaning device Air moving equipment Cooling coils Ductwork Heating coils Humidification equipment		
								Insulation Products	Fibrous insulation Foam insulation
Occupants and Occupant Activities	Animals (pets) Cleaning Cooking Human occupants- bioeffluents Smoking Human occupants- other activities								
Paints and Coatings	Oil-based finish Solvent-based paint Stain Varnish Water-based finish Water-based paint Wax								
Personal Care Items	Hair spray Other PCIs								
Pesticides (see also cleaning agents)	Moth repellent Other pesticides								
Space Heating and Cooking (See also HVAC systems and components)	Electric Gas fueled Oil fueled Solid fuel								
Wall and Ceiling Materials (other than paints and coatings)	Ceiling tile Gypsum board Plaster Wall paneling Wallpaper/wall covering Other wall and ceiling materials								
Wood Products	Fiber panel material (e.g., insulation board, hardboard) Particleboard Plywood Solid natural wood product Veneer Waferboard/chipboard Other wood products								

Table 3. References cited to date

ALE96	Alevantis, L. E. (1996). California Department of Health Services, Berkeley, California. (3°)	HOD93	Hodgson, Wooley, and Daisy (1993). <i>Jour. of Air and Waste Manag. Assoc.</i> <b>43</b> :316-324. (1°)	SEL80	Selway, Allen, and Wadden (1980). <i>Am. Ind. Hyg. Assoc. Journal.</i> <b>41</b> :455-459. (1°)
ALL78	Allen, Wadden, and Ross (1978). <i>Am. Ind. Hyg. Assoc. Jour.</i> <b>39</b> (6):466-471. (1°)	HOR97	Horn, Ullrich, and Seifert (1997). Proc. of IAQ'97, Healthy Buildings (ASHRAE). <b>3</b> : 533-538. (2°)	SMI90	Smith, Donovan, and Ensor (1990). Proceedings of Indoor Air '90, <b>3</b> :647-652. (2°)
ANT97	Anttonen et al. (1997). Proceedings of IAQ'97, Healthy Buildings (ASHRAE). <b>3</b> : 575-579. (2°)	HOW97	Howard, McCrillis, and Krebs (1997). Engineering Solutions to IAQ Problems. pp 3-15. (2°)	STR91	Strobridge and Black (1991). Proceedings of IAQ '91, Healthy Buildings (ASHRAE). 292-298. (2°)
BAT91	Batterman, Bartoletta, and Burge (1991). Presented at 84th Annual Meeting of AWMA. (2°)	KER90	Kerr and Sauer (1990). Proceedings of Indoor Air '90, <b>3</b> :759-763. (2°)	TEP95	Tepper et al. (1995). <i>American Industrial Hygiene Association Journal.</i> <b>56</b> :158-170. (1°)
BAY90	Bayer and Papanicolopoulos (1990). Proceedings of Indoor Air '90, <b>3</b> :725-730. (2°)	LAR97	Larsen and Funch (1997). Proceedings of IAQ'97, Healthy Buildings (ASHRAE). <b>3</b> :611-616. (2°)	TIC86	Tichenor and Mason (1986). EPA/600/D-86/088. (1°)
BER97	Bernheim and Levin (1997). Proc. of IAQ '97, Healthy Buildings (ASHRAE). <b>3</b> :599-604. (2°)	LEO96	Leovic et al. (1996). <i>Jour. of Air and Waste Management Association.</i> <b>46</b> :821-829. (1°)	TIC88a	Tichenor et al. (1988). EPA/600/D-88/086. (2°)
BLA91	Black, Pearson, and Work (1991). Proc. of IAQ'91, Healthy Buildings (ASHRAE). 267-272. (2°)	LEO97	Leovic et al. (1997). Proceedings of IAQ'97, Healthy Buildings (ASHRAE). <b>3</b> :623-628. (2°)	TIC88b	Tichenor, Sparks, and Jackson (1988). EPA/600/2-88/061. (1°)
BRO97	Brockmann et al. (1997). Engineering Solutions to IAQ Problems, pp. 403-420 (1°)	LUN97	Lundgren, Jonsson, and Ek-Olausson (1997). IAQ'97, Healthy Bldgs (ASHRAE). <b>1</b> :287-292. (2°)	TIC88c	Tichenor and Mason (1988). <i>Jour. APCA.</i> <b>38</b> (3):264-268. (1°)
CHA92	Chang and Guo (1992). <i>Indoor Air.</i> <b>2</b> :146-153. (1°)	MAY96	Mayo, Figley, and Robinson (1996). Presented at Clean Air '96, Orlando, Florida. (3°)	TIC89	Tichenor (1989). <i>Environment International.</i> <b>15</b> :389-396. (1°)
CHA94	Chang and Guo (1994). <i>Indoor Air.</i> <b>4</b> :35-39. (1°)	MOR96	Morrison and Hodgson (1996). Proceedings of Indoor Air '96, <b>3</b> :585-590. (2°)	TIC91	Tichenor and Guo (1991). EPA/600/D-91/155. (1°)
CHA97	Chang et al. (1997). <i>Indoor Air.</i> <b>7</b> :241-247. (1°)	MUL94	Muller and Black (1994). Presented at the American Industrial Hygiene Conf., May 1994. (2°)	TUC88	Tucker (1988). Proceedings of Healthy Buildings '88, <b>1</b> :149-157. (3°)
COL93	Colombo, De Bortoli, and Tichenor (1993). Proceedings of Indoor Air '93, <b>2</b> :573-578. (2°)	NAG95	Nagda, Koontz, and Kennedy (1995). <i>Indoor Air.</i> <b>5</b> :189-195. (1°)	VAN90	Van der Wal, Steenlage, and Hoogveen (1990). Proc. Indoor Air '90, <b>3</b> :611-616. (2°)
DAV91	Davidson et al. (1991). Proceedings of IAQ'91, Healthy Buildings (ASHRAE). 299-303. (2°)	NEL87	Nelms, Mason, and Tichenor (1987). EPA/600/D-87/165. (1°)	VAN97	Van der Wal, Hoogveen, and Wouda (1997). <i>Indoor Air.</i> <b>7</b> :215-221. (1°)
FIS95	Classification of Indoor Climate, Construction, and Finishing Materials. FiSIAQ Publication 5E. Finnish Society of Indoor Air Quality and Climate, Espoo, Finland, 1995. (2°)	NIU97	Niu et al. (1997). Engineering Solutions to IAQ Problems. pp. 547-554. (2°)	WAL87	Wallace (1987). <i>Atmospheric Environment.</i> <b>21</b> (2):385-393. (1°)
FOR97	Fortmann et al. (1997). Engineering Solutions to IAQ Problems, pp. 117-127. (1°)	NOR97	Norheim et al. (1997). Engineering Solutions to IAQ Problems. pp 71-81. (2°)	WOL93	Wolkoff et al. (1993). <i>Indoor Air.</i> <b>3</b> :113-123. (1°)
FUN97	Funch, Winther, and Larsen (1997). Proc. IAQ'97, Healthy Buildings (ASHRAE). <b>3</b> :617-622. (2°)	ROA96	Roache et al. (1996). Proceedings of Indoor Air '96, <b>2</b> :657-662. (2°)	WOL96	Wolkoff and Nielsen (1995). <i>Atmospheric Environment.</i> <b>30</b> (15): 2679-2689. (1°)
HAN86	Hansen and Anderson (1986). <i>Am. Ind. Hyg. Assoc. Jour.</i> <b>47</b> (10):659-665. (1°)	SAA92	Saarela (1992). Proceedings of IAQ '92, Environments for People (ASHRAE). 349-354. (2°)	WOR94	Worhan (1994). Presented at National Coalition on IAQ conference, Tampa. (2°)
HAW92	Hawkins et al. (1992). <i>American Industrial Hygiene Association Journal.</i> <b>53</b> (5):275-282. (1°)	SAA97	Saarela, Tirkkonen, and Suomi-Lindberg (1997). IAQ'97, Healthy Bldgs (ASHRAE). <b>3</b> :545-550. (2°)	ZHA97	Zhang et al. (1997). Proceedings of IAQ'97, Healthy Buildings (ASHRAE). <b>3</b> :521-526. (2°)
HET95	Hetes, Moore, and Norheim (1995). EPA/600/R-95-045. (3°)				

1° = primary  
2° = secondary  
3° = tertiary

## VOLATILE ORGANIC EMISSIONS FROM PRINTED CIRCUIT BOARD LAMINATES

The printed circuit board is a vital operating component in many electronic products; e.g., personal computers (PCs), telephones, fax machines, and photocopiers. Offgassing from printed circuit boards is most prominent during the initial use period when electrical heating occurs in the product. This is especially true in the case of PC monitors, where internal operating temperatures can range from 60 to 70°C.

In this evaluation, IEMB worked cooperatively with Research Triangle Institute (RTI) to measure emissions from printed circuit board laminates (without circuitry) to determine if an alternative laminate would be less emitting than conventional laminates. The complete study can be found in the EPA Report, *Personal Computer Monitors: A Screening Evaluation of Volatile Organic Emissions from Existing Printed Circuit Board Laminates and Potential Pollution Prevention Alternatives*, April 1998 (EPA-600/R-98-034, NTIS PB98-137102).

### Methodology

Because laminates used in PC monitors are subjected to high operating temperatures, they were selected as test laminates for this project. As shown in the test matrix in Table 4, eight samples of the following types of base/resin printed circuit board laminates were evaluated: Glass/lignin-containing epoxy (G/L), Glass/epoxy (G/E), Paper/phenol (P/P), and Paper/ reformulated phenolic (P/RP).

The screening evaluation was conducted to determine if the glass/lignin-containing epoxy resin and the reformulated phenolic laminates would be less emitting than conventional laminates which are made primarily from paper/phenol. Glass/epoxy laminates were included in the evaluation because they exist primarily in central processing units (CPUs).

The glass/lignin-containing epoxy and glass/epoxy laminates were acquired from U.S. manufacturers. The paper/phenol laminate was acquired from an overseas manufacturer because

almost all phenol-based laminates are produced overseas. The reformulated phenolic laminate is also produced overseas and has been in use in Europe within the past 5 years.

Participating manufacturers were sent "sampling kits" with sampling instructions and steel cans. A designated person at each manufacturing facility was responsible for:

- 1) Collecting a laminate sample from the production line;
- 2) Cutting the laminate sample size to 0.15 by 0.25 m; and
- 3) Immediately sealing the laminate in a labeled, precleaned, air-tight, 7.85-L steel can provided.

Each can was shipped overnight to RTI, inspected upon arrival, and then stored at -10 °C for about 4 months. Immediately prior to testing, the sealed storage cans containing the laminates were removed from the freezer, and the laminate samples were transferred to individual clean steel cans for testing. The cans were the same type as those used for storage. Inside the can, each laminate sample was placed on its edge, leaning against the side of the can, in order to maximize the exposed area. The lid of each test can was fitted with Teflon inlet and outlet tubes which were attached to the supply air manifold and sampling ports. This allowed continuous regulated air flow through the chambers during testing.

The test cans were then placed in a temperature-controlled oven maintained at 65±3°C. Oven temperature and RH of the supply air (50±5% RH at 23°C) were continuously monitored. As the air was warmed to 65°C, the RH in the test cans dropped to approximately 6%.

Total air flow to the system was controlled, monitored, and recorded using mass flow controllers. Just prior to placing the test cans containing the laminate samples in the oven, each can was purged with clean air to flush the cans of laboratory air. Collection of air samples from the test cans began within 10 minutes of placing the test samples in the cans. Flows were measured and adjusted immediately after the test cans were placed in the oven, during the middle, and again at the end of testing. The flow rate was 131 mL/minute (approximately 1.02

Table 4. Test matrix for circuit board laminate evaluation

Laminate	Air Samples								
	Background <sup>b</sup>	G/L-1A <sup>a</sup>	G/L-1B	G/L-2	G/E-1	G/E-2	P/P	P/RP-A	P/RP-B
Air sample type; VOC <sup>c</sup>	1	1	1	1	1	1	1	1	1
VOC duplicate	1	1	1	1	1	1	1	1	1
Aldehyde/ketone	1	1	1	1	1	1	1	1	1
Number of sampling intervals		9	9	9	9	9	9	9	9
Number of air samples taken	3	27	27	27	27	27	27	27	27

<sup>a</sup> Laminates supplied without circuitry; copper coated on one side. Sample G/L-2 was copper coated on both sides.

<sup>b</sup> A background air sample was taken from two separate test cans prior to the start of the test.

<sup>c</sup> Includes phenol and cresols.

air changes per hour). Air samples were analyzed for VOCs (including phenol and cresols) and aldehydes/ketones. A list of target compounds were identified from an initial set of air samples taken for each laminate sample. Quantitative analysis of these target compounds was then conducted for all subsequent air samples taken for each laminate sample.

## Results

The data presented in Figures 1 and 2 summarize the results of the aldehydes/ ketones and VOCs emitted from each of the eight printed circuit board laminates, respectively. The data are expressed in terms of concentration ( $\mu\text{g}/\text{m}^3$ ) and illustrate the sum of measured concentrations for all identified compounds emitted from each printed circuit board laminate at  $t = 0$  or 5 hours and  $t = 336$  hours (14 days). Emission factors over time are presented in the report referenced on page 6.

Figure 1 shows that, at time  $t = 0$  hours, the sum of measured aldehydes/ketones emitted from the paper/reformulated phenolic and the paper/phenol laminates ranged from 3,900 to 6,400  $\mu\text{g}/\text{m}^3$ . For the same time point, the sum of measured aldehydes/ketones emitted from the glass/lignin laminates ranged from 200 to 270  $\mu\text{g}/\text{m}^3$ , and emissions from the glass/epoxy laminates ranged from 33 to 200  $\mu\text{g}/\text{m}^3$ . After 336 hours, the sum of measured aldehydes/ketones emitted from the paper/reformulated phenolic and the paper/phenol laminates ranged from 650 to 870  $\mu\text{g}/\text{m}^3$ . The sum of measured aldehydes/ketones emitted from the glass/lignin laminates after 336 hours ranged from 42 to 53  $\mu\text{g}/\text{m}^3$ , and concentrations from the glass/epoxy laminates ranged from 17 to 25  $\mu\text{g}/\text{m}^3$ . Other observations from the data in Figure 1 are:

- 1) In the first hours of simulated on-time operation at 65°C, the paper/phenolic resin-based laminates emit more aldehydes/ketones than the glass/lignin or glass/epoxy laminates. It appears that offgassing of volatile compounds would continue beyond the 336 hours of this screening evaluation.
- 2) Concentrations for the glass/epoxy sample 2 laminate are greater than those for the glass/epoxy sample 1. This difference could be due to the fact that the glass/epoxy sample 2 laminate is manufactured by a different company than the glass/epoxy sample 1 laminate.
- 3) All three glass/lignin laminate samples and the two glass/epoxy laminates show average concentrations 95% lower than the paper/reformulated phenolic resin-based laminates.

Figure 2 shows that, at time  $t = 0$  or 5 hours, the sum of measured VOC concentrations (excluding aldehydes/ketones) from the paper/reformulated phenolic and the paper/phenol laminates ranged from 9,600 to 23,000  $\mu\text{g}/\text{m}^3$ . Concentrations from the glass/lignin laminates ranged from less than 1,300 to 1,700  $\mu\text{g}/\text{m}^3$ , and concentrations from the glass/epoxy laminates ranged from less than 1 to 15  $\mu\text{g}/\text{m}^3$ . After 336 hours, VOC concentrations from the paper/reformulated phenolic and the paper/phenol laminates ranged from 3,900 to 6,200  $\mu\text{g}/\text{m}^3$ . For the same time interval, VOC

concentrations for the glass/lignin and glass/epoxy laminates ranged from nearly 0 to 100  $\mu\text{g}/\text{m}^3$ .

Other observations from the data in Figure 2 are:

- 1) As was the case for the aldehydes and ketones, all three glass/lignin laminate samples and the two glass/epoxy laminates show an average sum of measured concentrations of VOCs to be 95% lower than the paper/reformulated phenolic resin-based laminates.
- 2) VOC concentrations from both glass/epoxy laminates are virtually negligible. This is a good indication, on a screening basis only, that VOC concentrations from glass/epoxy laminates would probably not contribute significantly to indoor air emissions.
- 3) VOC concentrations at  $t = 5$  hours from the paper/reformulated phenolic laminates are lower than for the paper/phenol, whereas aldehyde/ketone concentrations from the paper/reformulated phenolic laminates (Figure 1) were higher than for the paper/phenol. However, at  $t = 336$  hours, VOC concentrations from the paper/reformulated phenolic laminates are higher than for the paper/phenol.

## Conclusions

Conclusions from this screening evaluation are:

- **Glass/lignin laminates result in lower concentrations of volatile compounds than paper/phenolic resin-based laminates.** Although this test was conducted on only eight laminate samples of four different laminate types, the results show that, for the samples tested, glass/lignin-containing epoxy resin laminates emit lower concentrations of volatile compounds than the paper/phenolic resin-based laminates during simulated PC monitor on-time operation at 65°C. The data also suggest that, if these laminates were used as pollution prevention alternatives for paper/phenol circuit board laminates in PC monitors, reductions in VOC emissions from PC monitors could be achieved. Alternatively, an initial exposure period at an elevated temperature would be a possible control option to reduce volatile emissions prior to operation in an indoor environment.
- **Volatile emissions from glass/epoxy laminates are relatively low compared to glass/lignin and paper/phenol laminates.** Although glass/epoxy laminates appear to be good substitutes for paper/phenol laminates, they are not predominantly used in PC monitors. This is because glass/epoxy laminates are designed for high-speed applications and data processing, whereas PC monitors do not perform the same operating functions or experience the same operating conditions as CPUs.
- **In general, concentrations decay over time.** The results show that a majority of the compounds decayed to low levels ( $\sim 50 \mu\text{g}/\text{h}\cdot\text{m}^2$ ) after 336 hours at 65°C. However, the data clearly show that some of the compounds would likely have continued to emit from the laminates beyond the 336 hours of the test. (EPA Contact: Kelly Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

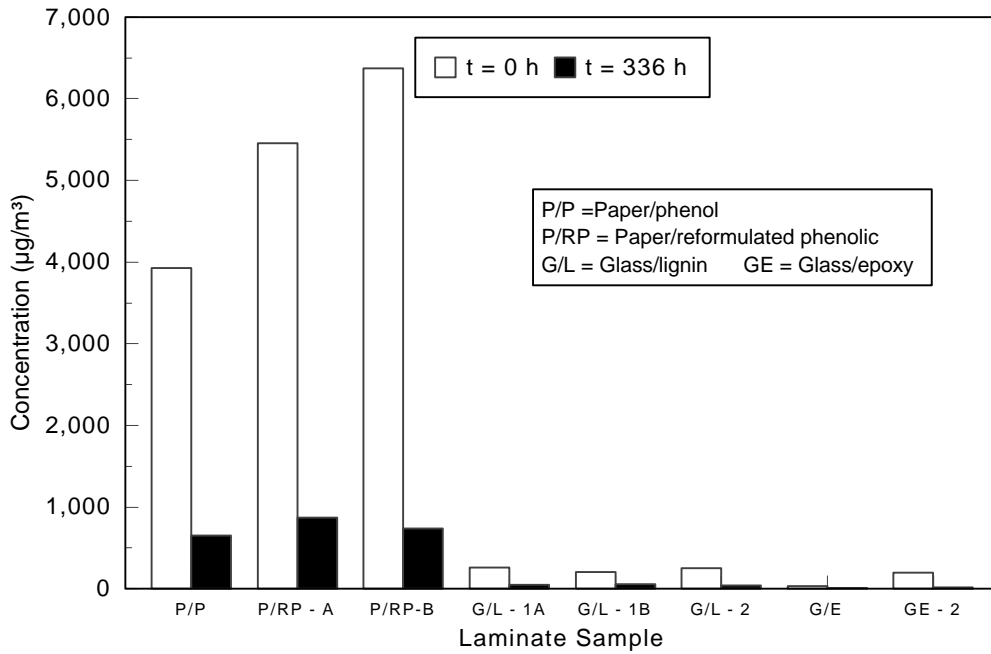


Figure 1. Sum of measured concentrations at t = 0 h and t = 336 h for all reported aldehydes and ketones for each laminate tested

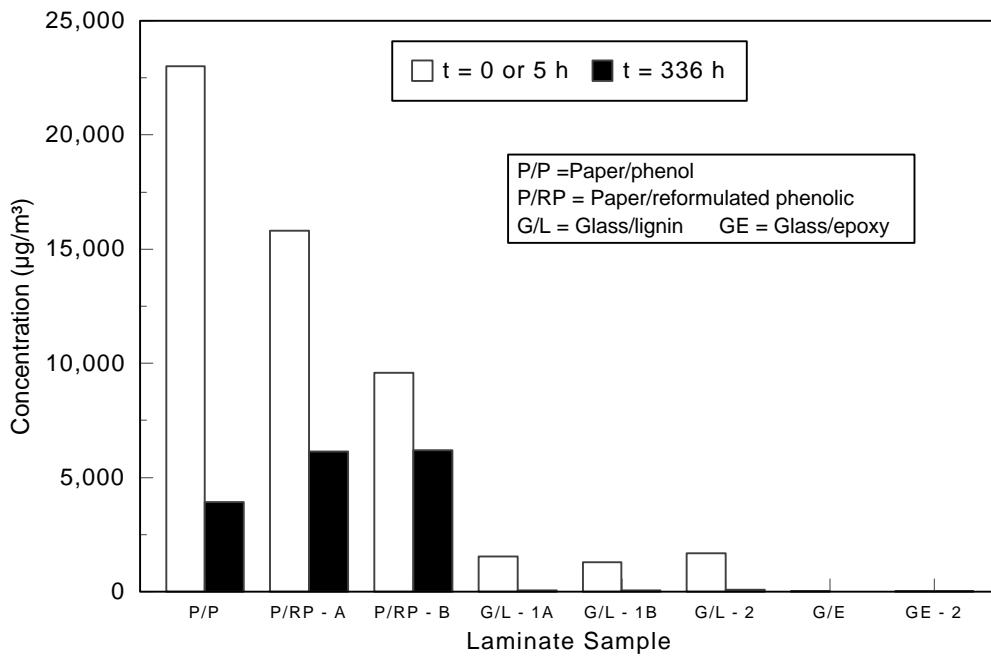


Figure 2. Sum of measured concentrations at t = 0 or 5 h and t = 336 h for all reported VOCs for each laminate tested, excluding aldehydes and ketones.



## **FACTORS INFLUENCING IAQ, IMMUNITY, AND HEALTH**

In June 1995, a conference on IAQ, Immunity, and Health was held at North Carolina State University in Raleigh, NC. It was cosponsored by the Cornell University Institute for Comparative and Environmental Toxicology, the Cornell Center for the Environment, and North Carolina State University and provided an opportunity to examine a significant societal inhalation toxicology issue. The program, which brought together leading national scientists as well as policy formulators, also included important policy perspectives for discussion of scientific data application. This article provides an overview of the proceedings by the organizing committee.

Discussions focused on how indoor air pollutants, including both industrially and naturally derived volatile chemicals and allergens, as well as cofactors (e.g., levels of outside air pollutants such as ozone), might affect upper respiratory tract symptoms and immune response. The need to consider the entire range of outdoor pollution factors (e.g., particulates, pollen, ozone, NO<sub>2</sub>) as well as indoor chemical emissions and the entire range of allergens (e.g., dust mites, mold spores, rodent and insect allergens) was stressed by several presenters. In the case of VOC emissions, the relevance of evaluation methodologies to actual exposure conditions was emphasized. This was required to avoid potential erroneous interpretations of results as they relate to actual risk. For example, carpet emissions were reported to become significant only at temperatures exceeding 62°C; however, this was not usually the case under conditions that actually occur in typical indoor environments.

Exposure scenarios to measure inhalation responses were discussed by several presenters. In particular, issues concerned the exposure methodologies (e.g., whole body, head, nose and mouth, nose only, intratracheal), dose response, and the type of endpoints that would be important for determining health implications. Endpoints that were discussed included sensory irritation, sensitivity to infection, allergic challenge responses (including asthmatic-type responses), cellular and biochemical changes in nasal lavage, hypersensitivity pneumonitis, and pulmonary function endpoints.

An overall consideration of immune effector functions in the context of inhalation exposure was presented, and several presenters described the chemical mediators and/or biomarkers associated with inflammatory reactions. In particular, the codependent relationship of the neurological and immunological systems in controlling inflammatory reactions was detailed.

Additional sympathetic nervous system neurotransmitters such as norepinephrine were discussed as regulators of immune cell activity. This was extended beyond model neuroimmune interactions for a consideration of the

integrative topics of stress, psychology, and altered immune capacity. Within this discussion, it was shown that specific stressors can exert targeted effects over certain portions of the immune system.

Potential individual genetic (allelic) variation in response to indoor air was considered and was particularly relevant given the possible existence of hypersusceptible subpopulations of humans for certain stimuli-induced symptomologies. In this case, the investigators reported on a rodent model for hypersensitive pneumonitis.

The symptomology of multiple chemical sensitivity (MCS) was delineated, as well as the approaches to enhanced health of the patients. The unclear etiology of both MCS and sick building syndrome was discussed, as well as the data and hypotheses that might link these conditions to immune and/or inflammatory processes. The potential for psychoneurogenic associations with MCS was considered, and additional presentations described the physiological linkages involving the nervous and other (e.g., immune) systems, and the opportunity to investigate possible underlying biochemical involvement in MCS symptomology was enhanced. Therefore, the determination of cause-effect relationships in MCS symptomology should be more readily approachable in the future.

The role of specific biomarkers for detection of differential sensitization was discussed. Significant progress has been made in the areas of inflammation and immunomodulation. This occurred with the development of both functional assays and biomarkers for the detection of respiratory versus contact sensitizing potential of environmental factors. Similar progress has been made relative to nonspecific inflammatory processes. This research progress pertains not only to the direct capacity of indoor air factors to serve as potential sensitizers but also to the possibility that such factors could alter the host relative to sensitizing potential and/or the challenge response to allergens. The biomarkers described here offer a potentially sensitive and economical method for screening emissions from indoor products for their sensitizing and/or host-allergy response potential.

The combined presentations point to a research and evaluation direction for indoor air and immunity issues in which cross-disciplinary expertise should contribute to the effective resolution of these issues. Two presentations crossed the science-policy boundary to provide specific examples of the opportunities for effective outreach to the general public. In these presentations, the benefits of a consolidated effort for the translation of specific indoor air and health findings into cost-effective remedial action within communities were also discussed. (EPA Contact: Mary Jane Selgrade, 919-541-2657, selgrade.maryjane@epa.gov)

## **MODELING EMISSIONS FROM WATER-BASED CLEANING SUPPLIES**

Executive Order 12873, issued Oct. 20, 1993, requires federal agencies to purchase “environmentally preferable” products. As a pilot project under this executive order, EPA and the General Services Administration worked together to develop guidance for federal agencies to select environmentally preferable cleaning supplies. These cleaners are biodegradable degreasers. They are generally diluted with water before use, and are frequently applied using a hand-held pump spray. Three types of chemical compounds are of primary concern in these cleaners: terpenes, butyl cellulose (2-butoxyethanol), and ethoxylated nonylphenol surfactants. The largest potential exposure is to the cleaning staff, but there is also exposure to building occupants.

EPA encountered difficulty evaluating the risk associated with indoor air exposures because the method used to compare risks relied on overly simplified indoor air models. The goal of this research is to improve upon EPA’s indoor emission models for water-based cleaners. The first phase of work focuses on improving models for evaporative emissions from films or pools, and validating them in the laboratory. Emissions from the aerosol will be examined later.

### Products Tested

Two different water-based cleaners have been selected for this work. The first (Cleaner A) is a 2-butoxyethanol-based product with an ethoxylated nonylphenol surfactant. The second (Cleaner B) is a terpene-based cleaner. Both cleaners will be analyzed by gas chromatography/mass spectrometry (GC/MS) to identify and quantify VOCs that may be emitted during and after use.

### Headspace Measurements

Headspace measurements are being made over various cleaner dilutions to determine partition coefficients, and hence Henry’s Law constants. Headspace measurements will also be made over various dilutions of a laboratory formulated cleaner surrogate, containing only 2-butoxyethanol (at the same concentration as Cleaner A) and water. The data will be used to:

- Provide input for modeling;
- Compare to Henry’s Law predictions made by a structure/activity relationship program (HENRYWIN v3.00, SRC-HENRY for Microsoft Windows, 1994-1997); and
- Compare the partition coefficients of the diluted cleaner to those of the VOCs and water to see whether the surfactants and minor constituents have any effect on partitioning. If there is a large effect, it may be necessary to do additional work before emissions can be successfully modeled and predicted.

### Models

In the past, IEMB has developed and verified mass-transfer-based models to predict the evaporative emissions from

solvent-based indoor coating materials based on Raoul’s Law. However, the emissions from aqueous solutions behave in a different manner which conforms to Henry’s Law.

The proposed models have the potential to predict the emissions based on the product formulation. A series of chamber tests will be conducted to evaluate these candidate models. For the purposes of modeling the evaporative emissions, the surfactant (ethoxylated nonylphenols) is considered to be non-volatile.

*The Pool Evaporation Models*—Two mass transfer source models, called P1 and P2, are proposed for estimation of the VOC emissions from a liquid pool (or bucket). Model P1 was found in the literature (Little, J.C., 1992, “Applying the two-resistance theory to contaminant volatilization in showers,” *Environ. Sci. Technol.*, 26, 1341-1349). Both models are based on Henry’s Law and the following expression for mass transfer for evaporative emissions:

$$E = k_T (C_s - C)$$

where E = emission factor, mg/m<sup>2</sup>/h;

k<sub>T</sub> = the overall gas-phase mass transfer coefficient, m/h;

C<sub>s</sub> = VOC concentration at air/liquid interface,

calculated based on Henry’s Law, mg/m<sup>3</sup>; and

C = VOC concentration in the bulk air, mg/m<sup>3</sup>.

When the VOC concentration at the interface is considered constant, there is an explicit solution for the indoor concentration (model P1). All the parameters can be estimated from the properties of the source and the environment, and the model is simple enough to be used in a spreadsheet. Chamber testing will reveal whether models using this simplification predict emissions sufficiently well for water-based cleaners.

However, when the volume of the cleaner liquid is limited, the pollutant concentration in the liquid may not hold constant. For instance, water evaporation may concentrate the solute. On the other hand, fast emission of the solute (with large Henry’s Law constant) may result in decreased concentration in the liquid. These factors could be important for small or shallow pools, such as those used in small chamber testing. Therefore, model P2 modifies P1 to include the effects of changes in liquid concentration. Model P2 should be especially useful in interpreting data from small chamber tests, where the solvent pool is often small and the VOC concentration in the liquid may change significantly during the test period. P2 consists of three differential equations, which can be solved numerically.

*Film Evaporation Models*—IEMB is evaluating three new source models for predicting the VOC emissions from water-based cleaners applied to hard surfaces (i.e., emissions from the thin film). For the convenience of discussion, the models will be called F1, F2, and F3, where F stands for “film.”

Model F1 is a comprehensive mass transfer model that takes into consideration VOC emissions from both the wet and dry films. The term “dry film” here means the thin film of organic liquid left on the surface due to water evaporation. Models F2 and F3 are derived from F1 with different degrees of simplification. Model F3 does not require the Henry’s Law constant and is simple enough to be implemented in a spreadsheet.

Model F1 takes into consideration three mass transfer processes:

- The rate of VOC emissions from the wet film, described by Henry’s Law and gas-phase molecular diffusion;
- The rate of VOC emissions from the “dry” film, described by the simplified vapor barrier (VB) model (Guo, Z, et al., 1997 “Predicting the Emissions of Individual VOCs from Petroleum-Based Indoor Coatings,” *Atmospheric Environment*, Vol. 32, No. 2, pp. 231-237); and
- The rate of dry film formation due to water evaporation, described by a model similar to the VB model. This mass transfer process affects the VOC emission rates from both the wet and dry films.

Model F2 is a simplified version of model F1. Since the first-order decay rate constant, k, is inversely proportional to the film thickness (Clausen, P. A., 1993, “Emission of volatile and semivolatile organic compounds from water-borne paints – the effect of the film thickness,” *Indoor Air* 3, 269-275) and the dry film is very thin, k is usually very large. The simplifying assumption is, therefore, that the VOC emission from the dry film is an instantaneous process.

Model F3 is derived from model F2 by assuming that:

- The wet emission is insignificant compared to the dry emission; and
- Water evaporation roughly follows the first-order decay pattern.

Information about the product and the environment required by each of the three models is given in Table 5. All the parameters are easy to come by, except the Henry’s Law constant. There are three ways to find the Henry’s Law constant:

- Compiled Henry’s Law constants in the literature;
- Experimental determination; and
- Theoretical calculation based on the molecular structure.

Chamber Testing

Three “bucket” tests will be run. In these tests, an open cylindrical container of diluted cleaner will be placed in a small chamber, and emissions measured for about a day. The purposes of these tests are to:

Table 5. Summary of all parameters included in the three film models

Category	Parameter	Model F1	Model F2	Model F3
Environment	Room volume	X	X	X
	Air flow rate	X	X	X
	Relative Humidity	X	X	X
	Air velocity <sup>1</sup>	X	X	
Pollutant	Molecular formula of VOC	X	X	
	Henry’s Law constant	X	X	
	Vapor pressure <sup>2</sup>	X		
	Diffusivity in air <sup>3</sup>	X		
Test Product	VOC content in liquid	X	X	X
	Source area	X	X	X
	Amount applied	X	X	X

<sup>1</sup> used to estimate gas-phase mass transfer coefficients for VOC and water.

<sup>2</sup> used to estimate the decay rate constant for dry emissions (k).

<sup>3</sup> used to estimate gas-phase mass transfer coefficient for VOC

- Determine the overall mass transfer coefficient using Cleaner A;
- Verify whether the P1 and P2 models work for butoxyethanol in Cleaner A; and
- Verify the model for other compounds/products, using Cleaner B.

Chamber testing will also be conducted to provide data to compare to the performance of the film evaporation models. RH proved difficult to control in initial tests in the small chamber, because the control systems and geometry of the small chamber produced an unrealistically high RH. Because the compounds of interest are somewhat polar and hydrophilic, humidity may affect the emission behavior. Therefore, this work will be performed in a large chamber. (EPA Contact: Betsy Howard, 919-541-7915, bhoward@engineer.aeerl.epa.gov)

## ANTIMICROBIAL AGENTS USED IN HVAC SYSTEMS

Biocides or antimicrobial agents can be used to manage biological contamination in HVAC systems as an alternative to HVAC component replacement. All commercial biocides and antimicrobial products are regulated and must be registered in compliance with the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). IEMB has begun a study of biocides and antimicrobial agents used in HVAC systems. The study, which will take place within the next year, includes:

- 1) *Determining the efficacy of biocides and antimicrobial agents used in HVAC systems.* This will be accomplished by surveying commercial biocides and antimicrobial products used in HVAC systems; surveying the industry to determine product use and preferences; and conducting tests on 10 biocides and antimicrobial agents using cultured samples of fungi, mold, and bacteria.
- 2) *Investigating the application effectiveness of biocides and antimicrobial agents used in HVAC systems.* This will be accomplished by testing various concentrations (manufacturers' recommended concentration and 50% recommended) of 10 products for 30 and 60 days using dynamic chambers and evaluating the effectiveness on fungi, mold, and bacteria and by testing the impact of organic load to act as a barrier to chemical reaction.
- 3) *Determining the relationship between RH and microbial growth.* The effectiveness of biocides and antimicrobial agents will be tested at RH levels of 60, 85, and 100% of saturation.
- 4) *Determining the impact of biocides and antimicrobial agents on IAQ.* Microbial emissions will be measured from inoculated and treated surfaces. (EPA Contact: Marc Menetrez, 919-541-7981, mmenetrez@engineer.aeerl.epa.gov)

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## SUMMARIES OF RECENT PUBLICATIONS

This section provides summaries of recent publications on EPA's indoor air research. The source of the publication is listed after each summary.

***Cost Analysis of Activated Carbon vs. Photocatalytic Oxidation for Removing Organic Compounds from Indoor Air***—A cost comparison has been conducted of 1 m<sup>3</sup>/s indoor air cleaners using granular activated carbon (GAC) vs. photocatalytic oxidation (PCO) for treating a steady-state inlet VOC concentration of 0.27 mg/m<sup>3</sup>. The commercial GAC unit was costed assuming that the inlet VOCs had a reasonable carbon sorption affinity, representative of compounds having four or more atoms (exclusive of hydrogen). A representative model PCO unit for indoor air application was designed and costed, using VOC oxidation rate data reported in the literature for the low inlet concentration assumed here, and using a typical illumination intensity. The analysis shows that, for the assumptions used here, the PCO unit would have an installed cost more than 10 times greater, and an annual cost almost 7 times greater, than the GAC unit. It also suggests that PCO costs cannot likely be reduced by a factor greater than 2 to 4, solely by improvements in

the PCO system configuration and reductions in unit component costs. Rather, an improved catalyst having a higher quantum efficiency would be needed, increasing reaction rates and reducing illumination requirements relative to the catalysts reported in the literature. GAC costs would increase significantly if the VOCs to be removed were lighter and more poorly sorbed than assumed in this analysis. Source: Accepted for publication in *J. of the Air & Waste Management Assoc.* (EPA Contact: D. Bruce Henschel, 919-541-4112, bhenschel@engineer.aeerl.epa.gov)

***Enhanced Allergic Responses to House Dust Mite by Oral Exposure to Carbaryl in Rats***—Epidemiological studies have demonstrated an association between use of carbamate insecticides, including carbaryl, and increased incidence of allergic asthma in farmers. In this study, the effect of oral carbaryl exposure on the development of allergic responses to house dust mites (HDMs) was examined in female Brown Norway rats. Rats were gavaged for two weeks with 0, 2, 10, or 50 mg/kg/day of carbaryl. They were sensitized with a subcutaneous injection of HDM in aluminum hydroxide adjuvant 3 days

after the beginning of carbaryl exposure and challenged with antigen via the trachea one day after the final carbaryl ingestion. In 2 days, antigen specific cell proliferation in pulmonary lymph nodes was significantly higher in the 50 mg/kg group than in controls, while antigen specific splenocyte proliferation was decreased in groups dosed with 2, 10, and 50 mg/kg carbaryl. Total protein and lymphocyte numbers in bronchoalveolar lavage (BAL) fluid were also increased in the 50 mg/kg group. In 7 days, immune-mediated pulmonary inflammation (eosinophils), antigen specific immunoglobulin (Ig) E level in serum, and antigen specific IgE and IgA levels in BAL fluid were significantly elevated in the 50 mg/kg group. No apparent change was observed for lactate dehydrogenase and eosinophil peroxidase in BAL fluid, while the number of BAL macrophages were decreased in groups dosed with 10 and 50 mg/kg carbaryl. This suggests that carbaryl may cause systemic immune suppression, while enhancing pulmonary allergic responses to HDM antigen. Source: *Toxicological Sciences*; In Press, *Toxicol Sci.* March, 1998 (EPA Contact: Wumin Dong, 919-541-7808, dong.wumin@epa.gov)

**Entrainment by Ligament-Controlled Effervescent Atomizer-Produced Sprays**—An innovative spray nozzle for use with precharged aerosol containers was developed and evaluated. The new design allows for the reformulation of selected aerosol consumer products using water and air in place of VOC solvents and hydrocarbon propellants. This article discusses the entrainment of ambient air into sprays produced by this effervescent atomizer. Entrainment data were analyzed using a model together with measured momentum rate data that were collected as part of this study. The analysis shows that entrainment by sprays produced using this type of atomizer is predicted to be within about 35%. Source: *International Journal of Multiphase Flow*, vol. 23, no. 5, pp. 865-884, 1997 (EPA Contact, Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

**Evaluation of a Test Method for Measuring Indoor Air Emissions from Dry-Process Photocopiers**—A four-laboratory evaluation of a large chamber test method for measuring emissions from office equipment was conducted. A single dry-process photocopier was shipped to each of the four laboratories along with supplies (i.e., toner and paper). Results demonstrate that the test method was used successfully in the different chambers to measure emissions from the copier. Differences in chamber design and construction appeared to have had minimal effect on the results for the VOCs. Percent relative standard deviation (%RSD) was used to provide a simplistic view of interlaboratory precision. Excluding problems with suspected analytical bias observed from one of the laboratories, the precision was excellent for the VOCs with RSDs of less than 10% in most cases. Less precision was observed among the laboratories for aldehydes/ketones (RSD of 23.2% for formaldehyde). The precision for ozone emission rates among three of the laboratories was excellent (RSD of 7.9%). Source: Accepted for Publication by the *J. Air & Waste Management Association*, May 1998 (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

**Evaluation of Low-Emitting Products for Use in the Indoor Environment**—IEMB recently completed cooperative research on the application of pollution prevention techniques to reduce indoor air emissions from aerosol consumer products, engineered wood products, and office equipment. For aerosol consumer products, one project focused on developing measurement methods and models that can be used by manufacturers to better understand aerosol behavior so that more efficacious and less toxic products can be developed. A second project resulted in the development and evaluation of an innovative spray nozzle for use with pressurized aerosol containers. The new design will allow manufacturers to reformulate selected aerosol consumer products using water and air in place of VOC solvents and hydrocarbon propellants. To evaluate emissions from engineered wood products, emissions were screened from four common types of finished engineered wood used indoors. Acid-catalyzed alkyd-urea coatings and particleboard were subsequently identified as the primary emission sources. Laboratory testing identified three types of fiber panels as low-emitting alternative materials: fiber panels made with medium density fiberboard and methylene diisocyanate resin, wheat straw and methylene diisocyanate resin, and corrugated cardboard. Three types of lower-emitting coatings were identified: a two component water-borne polyurethane, an aliphatic urethane acrylate, and a water-based acrylic. All three fiber panels and coatings are commercially available. A fourth project resulted in the development of a test guidance method to measure office equipment emissions. The method was evaluated by testing four dry-process photocopiers in one chamber and then conducting a round-robin evaluation of one copier. Another component of this project evaluated emissions from printed circuit board laminates. Source: Proceedings of the Annual Air & Waste Management Association Meeting, San Diego, June 1998 (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

**Evaluation of Sink Effects on VOCs from a Latex Paint**—The sink strength of two common indoor materials, carpet and gypsum board, was evaluated by environmental chamber tests with four VOCs: propylene glycol, ethylene glycol, 2-(2-butoxyethoxy)ethanol, and Texanol. These oxygenated compounds represent the major VOCs emitted from a latex paint. Each chamber test included two phases. Phase 1 was the dosing/ sorption period during which sink materials (pieces of carpet and gypsum board samples) were exposed to the four VOCs. The sink strength of each material tested was characterized by the amount of the VOCs adsorbed or absorbed. Phase 2 was the purging/ desorption period during which the chambers with the dosed sink materials were flushed with purified air. The remission rates of the adsorbed VOCs from the sinks were reflected by the amount of the VOCs being flushed. Phase 1 results indicated that the sink strength for the four target compounds is more than 1 order-of-magnitude higher than that for other VOCs previously tested by EPA. The high sink strength reflected the unusually high sorption capacity of common indoor materials for the four VOCs. Phase 2 results showed that remission was an extremely slow process. If all the VOCs adsorbed were remittable, it would take more than a year to completely flush out the VOCs from the sink materials tested. The long remission process can result in chronic and low level exposure to the VOCs after painting the interior walls and surfaces. Source: Accepted for Publication in the *J. of the Air & Waste Management Association* (EPA Contact: John C. S. Chang, 919-541-3747, jchang@engineer.aeerl.epa.gov)

**Increased Immune and Inflammatory Responses to Dust Mite Antigen in Rats Exposed to 5 ppm NO<sub>2</sub>**—Immune hypersensitivity to HDM is a frequent cause of respiratory allergy. The objective of this study was to determine whether exposure to NO<sub>2</sub>, a common indoor air pollutant, modulates immune responses to HDM and influences immune-mediated lung disease. Brown Norway rats were immunized ip with 100 µg semipurified antigen and *Bordetella pertussis* adjuvant and challenged 2 weeks later with an intratracheal injection of 50 µg of a crude antigen preparation. Exposure to 5 ppm NO<sub>2</sub> for 3 hours after both immunization and challenge procedures resulted in significantly higher levels of antigen-specific serum IgE, local IgA, IgG, and IgE antibody than air controls, and increased numbers of inflammatory cells in the lungs. Lymphocyte responsiveness to antigen in the spleen and MLN was also significantly higher in NO<sub>2</sub>-exposed animals. These data show that exposure to a common air pollutant can upregulate specific immune responses and subsequent immune-mediated pulmonary inflammation. Source: *Fundam. Appl. Toxicol.* **31**, 65-70 (EPA Contact: Mary Jane E. Selgrade, 919-541-2657, selgrade.maryjane@epa.gov)

**Indoor Air Emissions from Office Equipment: Test Method Development and Pollution Prevention Opportunities**—EPA and RTI conducted cooperative research to identify pollution prevention approaches for reducing emissions from office equipment. The project included: 1) forming a group of technical advisors; 2) preparing a literature review on the operation of, and emissions from, office equipment as well as pollution prevention opportunities; 3) developing and evaluating an *Emissions Testing Guidance Document for Dry-Process Photocopy Machines*; and 4) identifying and evaluating pollution prevention options. Because no standard test method exists to measure emissions from office equipment (e.g., ozone, VOCs, aldehydes/ ketones, inorganic gases, and particles), it is difficult to compare data from different studies. Thus, the focus of this project was the development and evaluation of a large chamber test method for measuring emissions from dry-process copiers. The goal is to apply the method to better understand emissions from office equipment and to develop lower emitting machines. The test method was evaluated in two phases. Phase I was a single laboratory evaluation of the method at RTI using four mid-range dry-process copiers. Phase I results indicated that the test method provided acceptable performance for characterizing emissions, adequately identified differences in emissions between machines both in compounds emitted and their emission rates, and was capable of measuring both intra- and inter-machine variability in emissions. Phase II was a four-laboratory round-robin evaluation of the method. A single dry-process copier was shipped to each of the four laboratories along with supplies (i.e., toner and paper). Phase II results demonstrate that the method was used successfully in the different chambers to measure emissions and that differences in chamber design and construction appeared to have had minimal effect. Source: EPA Report, "Indoor Air Emissions from Office Equipment: Test Method Development and Pollution Prevention Opportunities," EPA-600/R-98-080 (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

**Indoor Emissions from Conversion Varnishes**—Conversion varnishes are two-component, acid-catalyzed varnishes that are commonly used to finish cabinets. They are valued for their water- and stain-resistance, as well as their appearance. They have been found, however, to contribute to indoor emissions of organic compounds. For this project, three commercially available conversion varnish systems were selected. An EPA Method 24 analysis was performed to determine total volatile content, and a sodium sulfite titration method was used to determine uncombined (free) formaldehyde content of the varnish components. The resin component was also analyzed by GC/MS (EPA Method 311 with an MS detector) to identify individual organic compounds. Dynamic small chamber tests were then performed to identify and quantify emissions following application to coupons of typical kitchen cabinet wood substrates, during both curing and ageing. Because conversion varnishes cure by chemical reaction, the compounds emitted during curing and ageing are not necessarily the same as those in the formulation. Results of small chamber tests showed that the amount of formaldehyde emitted from these coatings was 2.3 to 8.1 times the amount of free formaldehyde applied in the coatings. A long-term test showed a formaldehyde emission rate of 0.17 mg/m<sup>2</sup>/h after 115 days. Source: Accepted for Publication in the *J. of the Air & Waste Management Association* (EPA Contact: Elizabeth M. Howard, 919-541-7915, bhoward@engineer.aeerl.epa.gov)

**Ligament-Controlled Effervescent Atomization**—The operating principles and performance of a new type of spray nozzle are presented. This nozzle, termed a “ligament-controlled effervescent atomizer,” was developed to allow consumer product manufacturers to replace VOC solvents with water and hydrocarbon propellants with air, while meeting the following criteria: that the spray mean drop size remain below 70 µm, that the atomizing air consumption be less than 0.009, and that atomizer performance be uncompromised by the increase in surface tension or by changes in viscosity. The current atomizer differs from previous effervescent designs through inclusion of a porous disc located immediately upstream of the nozzle exit orifice. The purpose of this disc is to control the diameter of ligaments formed at the injector exit place. Atomizer performance is reported in terms of the spray Sauter mean diameter, with drop size data analyzed using a model developed from first principles. The model describes the spray formation process as the breakup of individual cylindrical ligaments subject to a gas stream. Ligament diameter is estimated from manufacturer supplied pore size data for the porous disc. The model correctly predicts the experimentally observed relationship between Sauter mean diameter and air-to-liquid ratio by mass, liquid surface tension, and liquid viscosity. Source: *Atomization and Sprays*, vol. 7, pp. 383-406, 1997 (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@ engineer.aeerl.epa.gov)

**Transfer of Allergic Airway Responses with Serum and Lymphocytes from Rats Sensitized to Dust Mite**—HDM antigen is one of the most common allergens associated with extrinsic asthma. In a model of allergic lung disease, Brown Norway rats were sensitized to HDM with alum and *Bordetella pertusis* adjuvants to produce high levels of IgE antibody and experience bronchoconstriction, increased airway hyperresponsiveness (AHR) to acetylcholine, and pulmonary inflammation after antigen challenge. The purpose of this study was to determine whether these asthmatic symptoms could be transferred from sensitized animals to naive recipients via humoral or cellular factors. Syngeneic recipient rats were injected with either HDM or bovine serum albumin from lymph nodes of sensitized or control rats, respectively. Other groups received a tail-vein injection of serum from either HDM-sensitized or control rats. Antigen challenge in rats injected with sensitized cells caused increases in pulmonary inflammation and in AHR, but no changes in immediate bronchoconstriction as compared with control recipients. Antigen challenge in serum recipients resulted in immediate bronchoconstriction but had no effect on AHR or on pulmonary inflammation. These data show that immune-mediated lung inflammation and AHR are promoted by antigen-specific lymphocytes, whereas immediate allergic responses are caused by serum factors. Source: *Respir. Crit. Care Med.* 1998; 157:000-000. (EPA Contact: Daniel L. Costa, 919-541-2532, costa.daniel@ epa.gov)

## GLOSSARY

AHR - Airway Hyperresponsiveness  
BAL - Bronchoalveolar Lavage  
CAS - Chemical Abstract Service  
CPU - Central Processing Unit  
FIFRA - Federal Insecticide, Fungicide, and Rodenticide Act  
GAC - Granular Activated Carbon  
GC/MS - Gas Chromatography/Mass Spectrometry  
G/E - Glass/epoxy  
G/L - Glass/lignin  
HDM - House Dust Mite  
HVAC - Heating, Ventilating, and Air-Conditioning  
IAQ - Indoor Air Quality  
IEMB - Indoor Environment Management Branch  
MCS - Multiple Chemical Sensitivity  
NAICS - North American Industrial Classification System  
NRMRL - National Risk Management Research Laboratory  
PC - Personal Computer  
PCO - Photocatalytic Oxidation  
P/P - Paper/Phenol  
P/RP - Paper/Reformulated Phenolic  
QA - Quality Assurance  
RH - Relative Humidity  
RSD - Relative Standard Deviation  
RTI - Research Triangle Institute  
TVOC - Total Volatile Organic Compound  
VB - Vapor Barrier  
VOC - Volatile Organic Compound

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