



Inside IAQ

EPA's Indoor Air Quality Research Update

VOC EMISSIONS FROM LATEX PAINT: SINK EFFECTS

Interior latex paint – used for ceilings, walls, and wood products – is a source of volatile organic compounds (VOCs) in the indoor environment. Emissions are primarily from the release of organic solvents commonly used as coalescents and from freeze/thaw stabilizers in the paint. Over the past 2 years, EPA has been evaluating VOC emissions from latex paint. Efforts have been concentrated on a flat white latex paint with a vinyl acetate monomer. VOC emissions from this paint consist of four major compounds: propylene glycol, ethylene glycol, butoxyethoxyethanol (BEE), and Texanol. Initial testing identified significant substrate effects on VOC emission profiles and, as a result, “real” substrates such as gypsum board and wood were suggested for future testing. Models were also developed and validated for prediction of both short- and long-term emission rates.

To further assess the impact of VOC emissions from latex paint on indoor air quality (IAQ) and human exposure, sink effects (i.e., the adsorption and desorption interactions between the emitted VOCs and the interior surfaces) were evaluated in environmental chambers. This article covers the results of the sink effect evaluations of two common indoor materials, carpet and gypsum board, on the four major VOCs emitted from the latex paint tested.

Method

Each chamber test included two phases. Phase 1 was the dosing/adsorption period during which sink materials (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. Phase 2 was the purging/desorption period during which the chambers containing the dosed sink materials were flushed with purified air. The reemission rates of the adsorbed VOCs from the sinks were reflected by the amount of the VOCs being flushed.

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Results

Tables 1 and 2 summarize results for the adsorption and the desorption phases, respectively. Chamber concentration profiles are in Figures 1 through 4 for the adsorption and desorption of ethylene glycol and Texanol on gypsum board.

If there were no sink effects and the chamber air was well mixed, mass balance indicates that the chamber VOC concentration in the adsorption phase, C_s , should approach the value of C_{in} (the average inlet concentration) as:

$$C_s = C_{in} (1 - e^{-Nt}) \quad (1)$$

where t = time, h , and N =air exchange rate, h^{-1} .

The chamber VOC concentration during the desorption phase, C_d , should decrease exponentially:

$$C_d = C_{do} e^{-Nt} \quad (2)$$

where C_{do} = chamber VOC concentration at the inception of desorption phase, mg/m^3 .

Figures 1 and 3 show that, during the adsorption phase, the chamber outlet concentrations, C_s , were considerably lower than those predicted by Equation (1) which assumes no sink. The differences between the predicted concentration and the actual chamber concentration were attributed to sink effects. Table 1 shows that, even at the end of the 168 hour adsorption period, chamber concentrations, C_{out} , were still considerably lower than C_{in} .

The sink effects during the desorption phase are reflected by the differences between the concentrations predicted by Equation (2) and the chamber data shown in Figures 2 and 4. Equation (2) predicts that, without sink effects, the chamber concentration should decrease to below $0.1 mg/m^3$ within 10 h. Nevertheless, experimental data in Figures 2 and 4 show that the actual chamber concentrations were well above $0.1 mg/m^3$. Table 2 indicates that, when carpet was the sink material, the chamber concentrations, C_{end} , were greater than $0.1 mg/m^3$ even after 300 hours of purging.

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Table 1. Mass Balance for the Dosing Period (Adsorption)

Test Compound	Test Material	C_{in} (mg/m^3)	Dosing Period (h)	C_{out} (mg/m^3)	Dosage (mg/m^2)	M_{ads} (mg/m^2)	M_{ads}/C_{in} (m)
Propylene Glycol	Gypsum	5.32	168	1.53	893	488	91.7
Ethylene Glycol	Gypsum	7.12	168	3.69	1196	628	88.2
BEE	Gypsum	3.43	168	1.83	576	317	92.4
Texanol	Gypsum	5.43	168	2.68	921	483	89.0
Propylene Glycol	Carpet	5.38	168	2.11	903	627	116.5
Ethylene Glycol	Carpet	5.68	168	2.56	954	662	116.5
BEE	Carpet	3.80	169	1.72	642	264	69.5
Texanol	Carpet	6.21	169	4.60	1049	232	37.4

C_{in} = average inlet concentration

C_{out} = outlet concentration at the end of dosing period

M_{ads} = mass adsorbed by the sink by the end of dosing period

Table 2. Mass Balance for the Purging Period (Desorption)

Test Compound	Test Material	C_{end} (mg/m^3)	Purging Period (h)	M_{ads} (mg/m^2)	M_{des} (mg/m^2)	M_{des}/M_{ads} (%)
Propylene Glycol	Gypsum	0.09	356	488	55.7	11
Ethylene Glycol	Gypsum	0.11	356	628	76.8	12
BEE	Gypsum	0.03	387	317	43.4	14
Texanol	Gypsum	0.08	387	483	85.5	18
Propylene Glycol	Carpet	0.45	291	627	204	33
Ethylene Glycol	Carpet	0.52	291	662	246	37
BEE	Carpet	0.13	340	264	78	30
Texanol	Carpet	0.16	340	232	163	70

C_{end} = outlet concentration at the end of purging period

M_{des} = mass desorbed from sink during purging period

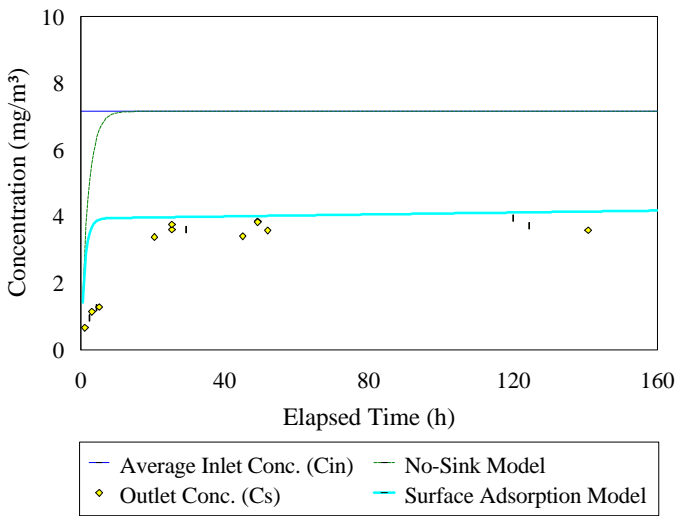


Figure 1. Adsorption of Ethylene Glycol from Gypsum Board in Dosing Phase

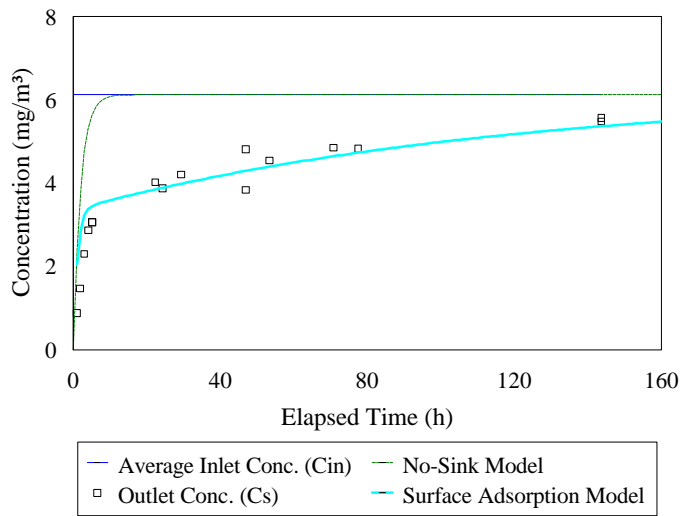


Figure 3. Adsorption of Texanol from Gypsum Board in Dosing Phase

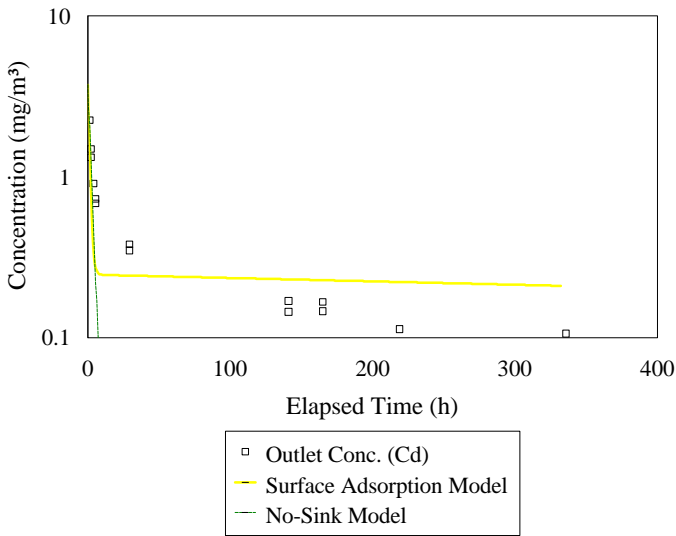


Figure 2. Desorption of Ethylene Glycol from Gypsum Board in Purging Phase

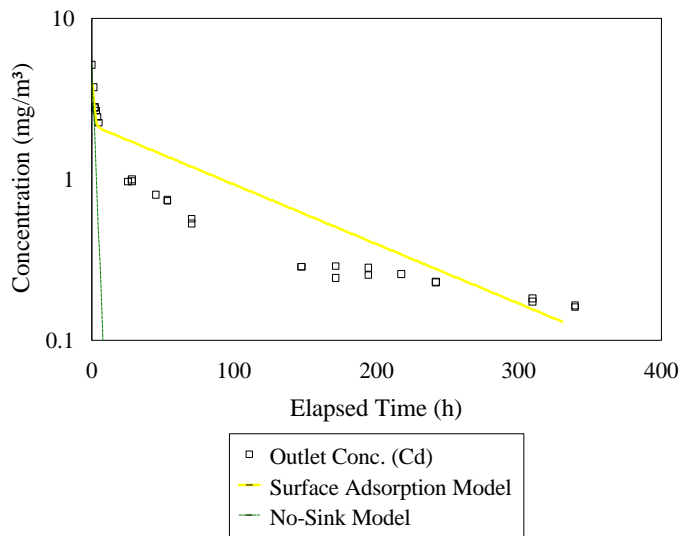


Figure 4. Desorption of Texanol from Gypsum Board in Purging Phase

Sink Strength

The sink strength of the gypsum board and carpet test samples can be characterized by a factor K_e defined as:

$$K_e = M_e/C_e \quad (3)$$

where M_e = sink surface organic concentration in equilibrium with C_e , mg/m^2 , and C_e = gas-phase organic concentration in equilibrium with M_e , mg/m^3 .

K_e is the equilibrium capacity of the sink surface for the specific VOC. That is, K_e indicates the maximum quantity (mg/m^2) of the VOC adsorbed by the test sample in equilibrium with the gas-phase VOC concentration (mg/m^3).

If equilibrium were reached at the end of the adsorption phase, the chamber concentration should be equal to the inlet concentration and can be considered as C_e . M_e should be equal to the amount of VOC adsorbed per unit area, M_{ads} , at the end of each adsorption phase:

(Continued on Page 4)

$$M_{ads} = NV(A_{in} - A_{out})/S \quad (4)$$

where, A_{in} = area under C_{in} curve in chamber concentration profile for adsorption phase, (mg/m³)h; A_{out} = area under C_{out} curve in chamber concentration profile for adsorption phase, (mg/m³)h; and S = sink surface area, m².

However, Table 1 shows that equilibrium was not reached at the end of the adsorption phase in any of the chamber tests.

The estimated values for M_{ads} , based on chamber data and Equation (4), are listed in Table 1. By definition, M_e should be greater than the M_{ads} estimated for current cases. Correspondingly, the value of K_e should always be greater than that of M_{ads}/C_{in} listed in the last column of Table 1.

The sink strengths measured in this study are much higher than those measured in previous studies. For example, earlier IEMB research measured the sink strength of a carpet and a wallboard for tetrachloroethylene and ethylene. The values of K_e were in the range of 0.142 to 0.97 m. Another IEMB study estimated the sink strength in a test house (a combination of carpet and gypsum board) for four alkane species: octane, nonane, decane, and undecane. The values of K_e were in the range of 0.90 to 6.25 m. It is apparent that the values of M_{ads}/C_{in} listed in Table 1 and the corresponding K_e values are considerably greater than those K_e values measured in these previous studies. One explanation is that the sink strength is a function of the physical and chemical properties of the VOCs being adsorbed and desorbed. It is also possible that the sink strength of materials such as carpet and gypsum board toward oxygenated polar compounds is considerably higher than that toward non-polar VOCs.

Reemissions

Table 2 shows that, after approximately 300 h of purging with clean air, the majority of the VOCs adsorbed still remained in the sinks. Overall, after over 300 h, less than 18 and 70% of the VOCs were reemitted from the gypsum board and the carpet, respectively. Assuming that all the VOCs in the sinks are reemittable and that the reemissions proceed at a level similar to the purging rates measured at the end of the desorption period, it will take several years for all the VOCs adsorbed to reemit. The extremely slow reemission process reflects the extraordinarily high sink strength estimated from the adsorption data.

Surface Adsorption/Desorption Model

To account for the sink effects, a model based on a first order reversible surface adsorption/desorption phenomenon was applied. According to the model, the chamber concentration during the adsorption phase can be predicted by Equation (5) with initial conditions, $C_s = 0$ at $t = 0$,

$$C_s = C_{in} \{1 - [(N - r_1)\exp(-r_2t) - (N - r_2)\exp(-r_1t)] / (r_2 - r_1)\} \quad (5)$$

and the desorption phase chamber concentration predicted by Equation (6) with initial conditions, $C_d = C_{do}$ at $t = 0$,

$$C_d = \{[Lk_dM_{do} - (N+Lk_a - r_2) C_{do}]\exp(-r_1t) - [Lk_dM_{do} - (N+Lk_a - r_1)C_{do}]\exp(-r_2t)\} / (r_2 - r_1) \quad (6)$$

where, k_a = adsorption rate constant, m/h, k_d = desorption rate constant, h⁻¹; M_{do} = sink surface organic concentration at the beginning of the desorption phase, mg/m², N = air exchange rate, h⁻¹, L = chamber loading (S/V), m⁻¹, V = volume at chamber, m³, and r_1 and r_2 = two parameters estimated by

$$r_{1,2} = \{(N + Ak_a/V + k_d) \pm [(N + Ak_a/V + k_d)^2 - 4Nk_d]^{0.5}\} / 2 \quad (7)$$

Equations (5), (6), and (7) were used to analyze the chamber data, and the values of sink parameters, k_a and k_d , were estimated by a non-linear regression curve fit routine, implemented on a microcomputer. As illustrated by Figures 1 through 4, the model fit the adsorption phase data reasonably well (Figures 1 and 3) but failed to predict the slow reemission process (Figures 2 and 4). In general, the reemission model tended to overpredict, and a better fit was obtained if one assumed that only part of the adsorbed VOCs were reemittable. The poor fit of the surface adsorption/desorption model to the long and slow reemission data seems to imply that other mechanisms (such as diffusion or chemical reaction) were controlling the desorption process.

Summary

In summary, the carpet and gypsum board tested have significant sink effects on the four VOCs evaluated: propylene glycol, ethylene glycol, BEE, and Texanol. Analysis of environmental chamber data indicated that the sink strength of the carpet and the gypsum board toward the four VOCs is orders-of-magnitude higher than that toward other VOCs studied previously (i.e., tetrachloroethylene, ethylene, and alkane species). It is suspected that the physical/chemical properties of those oxygenated polar compounds may have significant effects on the sink behavior. If all the VOCs in the sinks are reemittable, it will take years to complete the desorption process for the four VOCs tested in this study. A sink model based on surface adsorption and desorption assumptions failed to simulate the chamber data during the long-term reemission process but predicted the adsorption phase fairly well. It is likely that the adsorption/desorption of those four VOCs were not controlled by surface phenomena but involved mechanisms such as chemisorption and/or diffusion related processes. To determine whether 100% of the adsorbed VOCs were reemittable, long-term desorption data would be needed. (EPA Contact: John Chang, 919-541-3747, e-mail, jchang@engineer.aeerl.epa.gov)

THE EFFECTIVENESS OF ANTIMICROBIAL SURFACE TREATMENTS

The efficacies of three commercially available fungicidal surface treatments for heating, ventilating, and air-conditioning (HVAC) systems are being evaluated in a joint project between IEMB and the National Air Duct Cleaning Association (NADCA). The treatments are designed to prevent the regrowth of microorganisms in HVAC systems.

Poor source control and/or ineffective filtration can cause the interior surfaces of HVAC systems to become soiled with dirt, dust, and debris over time. Non-porous surfaces such as galvanized sheetmetal can be treated using current air duct cleaning (ADC) methods. Such techniques and equipment are well established and are generally very effective. (See related article on page 6, "Field Study on Residential Air Duct Cleaning.")

However, if the HVAC surface is porous and is contaminated with microbiological growth, as can occur on fiberglass duct lining (FGDL), effective remediation procedures are not well established. In fact, the EPA recommends that microbially contaminated FGDL be removed rather than treated in-place.

Because FGDL replacement can be very expensive, some ADC companies treat the contaminated FGDL in-place by: 1) vacuuming the contaminated FGDL to remove as much surface deposition and contamination as possible, 2) misting or fogging the HVAC system with a biocide to kill the microbial growth, and 3) encapsulating the remaining contamination in-place with a fungicidal protective coating.

The primary objective of this research will be to determine the efficacy of three commercially available fungicidal encapsulants in preventing microbial regrowth over a period of 1 to 2 years when coated on existing contaminated FGDL. Two simultaneous phases will be conducted: 1) in-situ field experiments conducted at EPA's IAQ test house in Cary,

NC, and 2) laboratory experiments using static and dynamic test chambers. The 121 m² IAQ test house is 20 years old including the air handler and duct work. The duct material is galvanized sheetmetal and flexible ducts with FGDL. The main supply air ductwork is located in the crawl space, and the air handler is located in a closet in the living area.

The *in-situ* field experiments will involve applying the three encapsulants on selected patches of FGDL in the test house supply air ductwork. Surface samples from this ductwork show that it is contaminated primarily with the fungus *cladosporium*. Bioaerosol sampling in the air shows a predominance of the fungus *Penicillium spp.*

Once applied, long-term monitoring microbiological evaluations will be performed every 3 months for a period of 1 to 2 years. Field evaluations will include:

- sampling surface microbials on each coated patch,
- moisture meter readings,
- sampling the HVAC evaporator condensate during the cooling season,
- measuring temperature and relative humidity (RH) indoors and outdoors,
- measuring duct temperature and RH, and
- monitoring heating and cooling system duty cycle.

FGDL samples will be taken from the IAQ test house and coated with the encapsulants for use in the laboratory growth studies. Dynamic chambers will be used to determine growth factors under "worst case" conditions of very high RH. Static chambers will be used to evaluate the performance of the encapsulants using an American Society of Testing and Materials (ASTM) method developed under EPA sponsorship.

All air duct cleaning services, equipment, and personnel are being provided by NADCA under the authority of the Federal Technology Transfer Act. (EPA Contact: Russell N. Kulp, 919-541-7980; rkulp@engineer.aeeri.epa.gov)

FIELD STUDY ON RESIDENTIAL AIR DUCT CLEANING

A nine-home field study was conducted to investigate the impact of mechanical ADC methods on IAQ and system performance. ADC services were provided by NADCA. The objectives were to: evaluate mechanical ADC methods commonly used on non-porous surfaces; measure pre- and post-ADC environmental system parameters to investigate any impacts on IAQ; and measure system performance pre- and post-ADC. Surface treatments, such as biocides and encapsulants were not a part of the field study. All nine residences are located in the Research Triangle area of NC.

Methods

Eight of the residences in the field study were occupied and the ninth was the EPA's IAQ test house (TH). Each house was equipped with a central heating and air-conditioning (HAC) forced air distribution system. ADC had not been performed on the air handling unit (AHU) or duct system for at least 10 years. All occupants were nonsmokers and none of the houses had IAQ complaints. Table 3 shows the characteristics of each house.

Sampling procedures and instrumentation were identical for each of the test houses, and measurements were made during a 1-week study of each house. Pre- and post-ADC measurements included: supply and return air duct dust surface mass; airborne particle mass (PM) and fiber measurements; microbial bioaerosol and surface sampling; temperature; RH; carbon dioxide; and system performance factors such as static pressure, air flow rates, motor current, and refrigerant temperature.

The mechanical ADC methods and equipment used by NADCA varied according to the house air distribution system, configuration, and accessibility. ADC methods included portable negative air systems to collect and remove loosened dust and debris. Silica-carbide rotating brushes, air washing with compressed air and air whips, contact vacuuming, and hand wiping were used to loosen the dust and debris. Substantial effort was required to clean the AHUs.

AHUs were substantially disassembled and cleaned using hand wiping and contact vacuuming. The fan, impeller, and scroll housing were removed and wet-cleaned using a non-toxic cleaning fluid. The condensate drain pan, piping, and pumps were inspected and cleaned as necessary. System filters were removed and cleaned or replaced. System cooling coils were wet-cleaned in place using a non-toxic cleaner. Heating coils were wiped and hand vacuumed.

Table 3. Characteristics of Field Study Test Houses

House ID #	House Age (yrs)	House Size (m ²)	# of Floors	Duct Age (yrs)	AHU Age (yrs)	Duct Material
TH	20	121.2	1	20	20	a
2	22	141.2	1	22	22	b
3	18	134.7	1	18	0.5	c
4	10	183.9	2	10	10	d
5	9	185.8	2	9	9	d
6	28	181.6	1.5	NA	NA	b
7	25	92.9	1.5	25	NA	c
8	26	185.8	2	26	26	b
9	35	139.3	2	35	NA	b

a - Galvanized sheet-metal ducts with internal fiberglass ductliner insulation and insulated flexible branch ducts

b - Galvanized sheet-metal ducts with external fiberglass wrap insulation

c - Galvanized sheet-metal ducts with external fiberglass wrap in insulation and insulated flexible branch ducts

d - Insulated flexible ducts

NA - Not available

NADCA routinely performed numerous visual inspections during the cleaning to ensure that the ADC process was proceeding satisfactorily. Access to the ductwork was generally through end-caps and flexible duct connections. Access doors were installed in the ductwork when access to work areas was difficult. Registers and diffusers were removed and wet-cleaned using a non-toxic cleaning fluid.

Results

The mechanical ADC methods used were effective in removing deposited dust deposition from the duct surfaces. Figure 5 shows pre- and post-ADC supply duct deposition levels. Pre-ADC measurements ranged from 1.0 to 35.1 g/m², whereas post-ADC measurements ranged from 0.12 to 1.11 g/m².

Indoor respirable (PM_{2.5}) and inhalable (PM₁₀) particle mass concentrations in the houses were relatively low, ranging from 4.2 to 32.7 µg/m³, consistent with studies in houses without tobacco smoking. Interpretation of the PM measurement data was difficult because outdoor concentrations had an apparently strong influence on indoor concentrations. The outdoor concentrations varied over the course of each week-long study making it difficult to determine if the changes in indoor concentrations after ADC were the result of cleaning or changes in occupant activities.

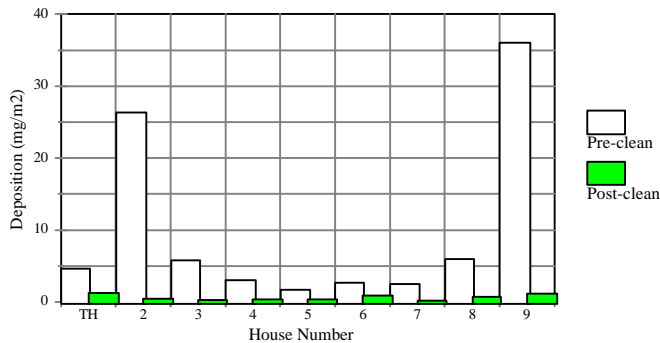


Figure 5. Supply Duct Deposition Levels

A comparison of average pre- and post-ADC bioaerosol levels showed a reduction in airborne fungi; however, these reductions are not considered substantial. Initially, the test houses were not biocontaminated; therefore, a small change would not be surprising. Pre-ADC airborne fungi levels in the supply ducts ranged from 14 to 646 colony forming units (cfu)/m³ while the post-ADC levels ranged from 2 to 300 cfu/m³. Bacteria in samples collected from the surfaces of the HAC system were highly variable. Pre-ADC bacteria levels ranged from 5 to 1100 cfu/cm² in the supply ducts and from 5 to 2300 cfu/cm² in the return ducts, with a mean of less than 200 cfu/cm² in most houses. Mean concentrations of return air bacteria levels were lower after ADC in six of seven houses measured; however, in the supply ducts, this was true for only four of the occupied houses. Pre-ADC versus post-ADC differences were generally small. Fungal levels were generally higher than bacteria levels and ADC had the most impact on the ducts with the highest levels of fungi and noticeably reduced the level of fungi in surface samples collected from ducts in most houses.

Measurements of system performance factors suggest that ADC had a positive impact. Because of the small sample size and the limited duration of the measurements, it is not possible to quantitatively determine the significance of ADC on system performance and energy use. Generally it resulted in increased air flow to the house. Supply air flows increased between 4 to 32% in eight of the houses based on measurements at the floor registers and diffusers in the house. Part of the increase in supply air flow rates may have been attributable to minor duct repair. Return air flows measured at the return air grilles increased 14 to 38% at two houses, but were not substantially different after ADC at the other seven houses.

AHU blower motor current increased after ADC in four of the houses where the measurements were performed. Static pressure increased in the return air duct at the six houses with complete measurements. The increase in blower motor current and in static pressure in the return air ducts suggest improved system performance. There was no clear trend for changes in static pressure in the supply ducts or the differential pressures across the cooling coil. Refrigerant line surface temperatures did not provide useful information.

Summary

HAC systems contaminated with dirt and dust are potential IAQ emission sources. Research shows that HAC total VOC emission rates and odors may be effectively reduced by removing deposition. This field study demonstrated that mechanical ADC methods can be an effective source management tool when applied to non-porous bare sheet-metal ducts. Porous surfaces, such as FGDL, were not evaluated because houses with FGDL systems, but without visible surface microbial contamination, were not identified during selection of the study houses. When FGDL becomes microbially contaminated, the EPA recommends removal and replacement rather than any form of ADC. Further research is required to evaluate ADC effectiveness on porous surfaces.

Differentials in indoor PM levels from pre-ADC to post-ADC could not be detected. This is consistent with previous research and is probably due to the strong influence of outdoor PM sources.

Mechanical ADC methods alone did not substantially reduce bioaerosol and surface microbial levels; however, surface treatments such as biocides or encapsulants may be required if it is determined that substantial reductions are necessary. To fully evaluate this, future research could include comparisons using mechanical ADC in combination with surface treatments.

Results of measurements of HAC system-related parameters suggest that there is a positive impact on HAC system performance from mechanical ADC. These measured impacts cannot be considered significant due to the small sample size and the short monitoring period. Further research would help substantiate these findings. (EPA Contact: Russell N. Kulp, 919-541-7980, rkulp@engineer.aeerl.epa.gov)

EMISSIONS FROM ACID-CATALYZED VARNISHES

Practically all furnishings sold in the U.S. have a coating on the surface to provide water and stain protection and to enhance appearance. One type of coating used extensively in the furniture industry is the alkyd/urea-formaldehyde topcoat. These are thermosetting resins and are frequently called conversion varnishes or catalyzed finishes. They do not cure by drying, as do many coatings, but by a chemical reaction, creating a durable water- and chemical-resistant coating that protects the wood during its use.

Conversion varnishes are of interest for ambient air quality because of emissions during manufacturing. From an indoor air perspective, these varnishes are of interest because VOCs, including formaldehyde, may be emitted during use. EPA has conducted analyses to gain an understanding of the magnitude of emissions from conversion varnishes and to develop methods and protocols for testing and analysis of these emissions.

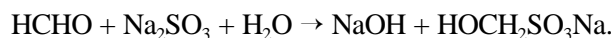
Method

Three conventional conversion varnish systems, coded A, B, and C, were obtained from three different manufacturers.

Four tests were run:

- *EPA Method 24* - Determination of Volatile Matter Content, Water Content, Density, Volume Solids, and Weight Solids of Surface Coatings;
- *Proposed EPA Method 311* - Analysis of Hazardous Air Pollutant Compounds by Direct Injection into a Gas Chromatograph;
- *Determination of Free Formaldehyde* - Determination of content in amino resin; and
- *Small Chamber Testing* - Determination of emission rate profiles.

The free formaldehyde content of the amino resins was determined using a method based on the quantitative liberation of sodium hydroxide when formaldehyde reacts with sodium sulfite:



The small chamber tests were conducted according to the procedures in ASTM D5116-90, except that alterations were necessary to accommodate the required high-temperature drying period specified by the manufacturer for two of the varnishes. Stainless steel 53-L chambers were used. One chamber was outfitted with heating jackets. Three thermocouples were placed inside the chamber to monitor chamber air, substrate surface temperature, and internal

temperature of the substrate. The chamber air temperature was monitored in the center of the chamber directly below the mixing fan. Each test was performed with a temperature protocol developed using the manufacturer's recommendations for curing temperatures and times.

The organic solvents used in these varnishes are fairly volatile. The majority of the VOCs from these solvents are released into the air within several hours of application. A comparison of emissions measurements on three different substrates (glass, oak board, oak veneered hardboard) showed no effect of substrate on emissions.

Results

The free formaldehyde contents of the three conversion varnish systems ranged from 1.46 to 5.35 mg/g varnish. Results of small chamber tests confirmed that the amount of free formaldehyde (HCHO) initially applied to the surface represents only a fraction of the total formaldehyde emitted.

Formaldehyde is generated during cure and ageing. For the three conversion varnishes tested, the total formaldehyde emissions are 2 to 8 times the amount of free formaldehyde applied. Varnish B has the highest short-term emission rate, and varnish C the lowest. Two factors may have contributed to this result: 1) varnish B has the highest free formaldehyde content, and 2) higher curing temperatures may accelerate the emissions.

The long-term emission data show a very different picture. The decay of the formaldehyde emission rate is a slow process. Varnish C has the highest rate, but the three varnishes follow a very similar pattern. Even 3000 hours (125 days) after application the formaldehyde emission rate is greater than 0.1 mg/m²/hr.

The long-lasting formaldehyde emissions can cause elevated concentrations in indoor environments. To assess the impact, we assume that a set of kitchen cabinets is installed in a typical house (300 m³ volume) with a formaldehyde emission rate of 0.5 mg/m²/hr, which is about the rate at 42 days (1000 hours) after varnish application. Figure 6 shows the expected formaldehyde concentrations for various loadings (5 to 20 m²) and air exchange rates (0.1 to 1.0 air changes per hour). For example, at 0.5 air exchanges per hour, the indoor formaldehyde concentration due to cabinets alone could be 16 µg/m³ (12 ppb) if the source area is 5 m², and 67 µg/m³ (50 ppb) if the source area is 20 m². The irritancy threshold for formaldehyde is 100 ppb. (EPA contact: Betsy Howard, 919-541-7915, bhoward@engineer.aeerl.epa.gov)

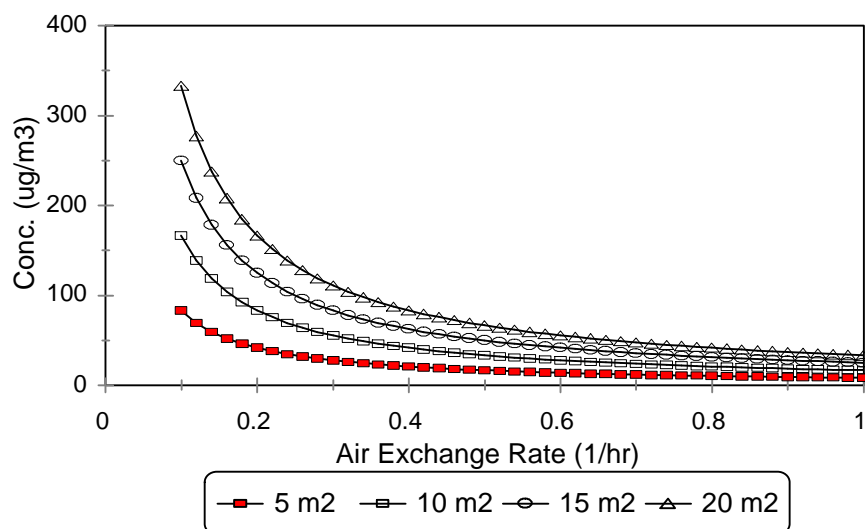


Figure 6. Predicted Indoor HCHO Concentrations in a 300 m³ House Due to Installation of Kitchen Cabinets With Varnish Applied 1000 Hours Previously

MEASURING TONER EMISSIONS USING HEADSPACE ANALYSIS

As part of a larger project to identify pollution prevention approaches for reducing indoor air emissions from office equipment (see related article on page 10, “A Large Chamber Test Method for Measuring Emissions from Office Equipment”), headspace analyses were performed to evaluate three toners. The three toners are each manufactured by the same company in different plants but use the same raw materials. It was hoped that the results might help to provide insight into options for developing lower emitting toners. The headspace tests are simpler and less labor intensive than the large chamber test method discussed on page 10.

For each headspace test, 50 mg of toner powder was placed in a 28.3 mL container and allowed to equilibrate for 1.5 hours at which time a 1 mL headspace air sample was taken for analysis using a gas chromatograph-flame ionization detector. Tests were conducted at 150°C which is within the range of typical fusing temperatures in dry-process photo-

copy machines (100-160°C). Four of the major VOCs identified in earlier large chamber tests – ethylbenzene, *m,p*-xylene, styrene, and *o*-xylene – were quantified (Table 4).

The headspace concentrations shown in Table 4 show concentrations from Toners A and B that are typically 2-5 times higher than concentrations from Toner C. According to the Material Safety Data Sheets, all three toners are composed of: 80-90% by weight styrene/acrylate copolymer; 5-10% by weight carbon black; 5-10 % polypropylene wax; 1-3 % titanium dioxide; and less than 1 % quarternary ammonium salt.

Toner C is manufactured using the extrusion process. Toners A and B are manufactured using the Banbury® process. The extrusion process (Toner C) is more modern and, in addition, the toner can be manufactured under a vacuum, which may decrease the amount of VOCs in the toner. These preliminary results indicate that it may be of value to further investigate the extrusion process as a potential option for producing lower-emitting toners. (EPA Contact: Kelly Leovic, 919-541-7717, e-mail:kleovic@engineer.aeerl.epa.gov)

Table 4. Toner Headspace Concentrations (ng/mL)

Chemical Emitted	Toner A	Toner B	Toner C
Ethylbenzene	1100	950	220
<i>m,p</i> -Xylene	1100	930	470
Styrene	290	260	130
<i>o</i> -Xylene	740	660	290

A LARGE CHAMBER TEST METHOD FOR MEASURING EMISSIONS FROM OFFICE EQUIPMENT

Indoor air emissions from dry-process photocopier machines include: VOCs, ozone, and particles. These emissions can contribute to adverse health effects such as eye, nose, and respiratory system irritation, and several are listed as hazardous air pollutants under the Clean Air Act.

IEMB, Research Triangle Institute, and a group of industry technical advisors are working together to better understand indoor air emissions from office equipment so that lower-emitting equipment can be developed. The project includes: 1) reviewing the literature on emissions from office equipment (summarized in *Inside IAQ*, Spring/Summer 1995, EPA/600/N-95/004); 2) developing a standard test method to characterize emissions; 3) measuring emissions from dry-process photocopier machines using this test method; and 4) identifying pollution prevention approaches (e.g., source reduction) for reducing emissions.

Review of the literature showed that no standard test method exists to evaluate emissions from office equipment, thus making it difficult to compare the results from different studies. To address this lack of standardization, a test method specific to measuring emissions from office equipment was developed as part of this project. The method was then evaluated at Research Triangle Institute using four dry-process photocopier machines. This article covers the test method and the results from using the test method to evaluate emissions from the four machines.

Test Method

The test method developed as part of this project uses flow-through dynamic chambers because they are generally applicable to all types of equipment and generally mimic typical use conditions found in an office. Unique characteristics of the test method include:

- **Chamber Size:** The test chamber's linear dimensions must be a minimum of 1.4 times the dimensions of the equipment tested in accordance with typical industry testing procedures.
- **Heat Generation:** Depending on the machine, heat generation in the chamber may be a problem. To account for this, the method specifies a temperature range of 28.5 ± 2.5 °C and an air exchange rate of 2 changes per hour. RH within the chamber is maintained between 30 and 35%. (A RH of 35% at 31°C represents a mass of water equivalent to 50% RH at 23°C.)

- **Limited Paper Supply:** A finite paper supply for copier machines limits the duration of the test. For this study, a paper supply of 2000 sheets was used for each test. This supply was copied after 20 to 40 minutes for the four dry-process photocopier machines evaluated.
- **Toner Carryover:** When testing equipment that uses toner, a toner depletion and replenishment procedure is followed to avoid carryover of the previous toner between tests.
- **Power Requirements:** The type of outlet required varies among copiers. Installation of new outlets, changing outlets, or multiple outlets may be required.
- **Remote Starting:** Remote starting of the machines is necessary to maintain chamber integrity. Problems can be minimized if an experienced service technician installs, sets up, and checks out the equipment.

Before placing the photocopier machine in the chamber, background levels of target pollutants in the chamber air are measured. A service representative from the manufacturer serviced and installed the photocopier in the chamber prior to testing. A toner recommended by the manufacturer was used for each test, and the same type of paper – containing 20% recycled materials – was used for all testing. A standard image, representing about 15% coverage, was used to represent a typical maximum image for copying.

The chamber air was then measured with the equipment idling (i.e., powered but not operating) to obtain data on off gassing. For this study, 2000 copies were copied for each test, and an integrated chamber air sample was collected from the start of operation until 2 hours (4 air changes) after the paper supply was exhausted. The 2000 sheets were copied after 20 to 40 minutes (depending on the machine) for a total sample collection time of 140 to 160 minutes.

Chamber air concentrations of VOCs were collected with multisorbent tubes and analyzed by gas chromatograph/mass spectrometry. Aldehyde/ketone samples were collected on 2,4-dinitro phenylhydrazine-coated silica cartridges and analyzed by high performance liquid chromatography. Ozone was monitored continuously using a DASIBI monitor. Particle concentrations were monitored continuously for two of the four machines using a LAS-X optical particle counter.

Results

The estimated emission rates for the four mid-range dry-process photocopier machines tested in this study are shown in Table 5. Emissions of VOCs are consistently lower for Copier 4, which uses a mono-component toner, than for the three machines that use dual-component toners (Copiers 1, 2, and 3). However, emission rates for many of the aldehydes and ketones are higher for Copier 4. Also, ozone levels for Copier 4 are higher than for the other three machines tested.

The data presented in Table 4 also show that, although the same compounds are emitted from all four machines, the emission rates of these compounds can vary considerably between machines. For example, the emission rate for ethylbenzene is 28,000 µg/h for Copier 1 and <50 µg/h for Copier 4.

Limited particulate data were collected for two of the four machines tested. Results showed that operation of one of the machines increased particulate levels to 30 times chamber background levels for particles smaller than 2 µm in diameter.

Summary

Results of this study have provided valuable information on the performance of the test method and on emission characteristics of selected dry-process photocopiers. The test method provided acceptable performance for characterizing emissions from dry-process photocopy machines. Percent recovery for calculated emission rates for standard materials emitted into the chamber at known rates was greater than 85%. Precision of replicate tests using both standard emitters and photocopiers was good (less than 10% Relative Standard Deviation). In order to evaluate the performance of the test method in different laboratories, a round-robin evaluation in four different U.S. laboratories was recently performed, and the results will be presented in a future issue of *Inside IAQ*.

For the four machines tested in this study, the compounds with the highest emission rates overall were ethylbenzene (28,000 µg/hour), *m,p*-xylene (29,000 µg/hour), *o*-xylene (17,000 µg/hour), 2-ethyl-1-hexanol (14,000 µg/hour), and styrene (12,000 µg/hour). To put these results in perspective, chamber air concentrations of styrene were about 100 µg/m³

for one machine. Since emissions were tested using chamber conditions that might approximate conditions found in office buildings, it is likely that the indoor air concentrations of this magnitude would also be found in offices. (EPA Contact: Kelly Leovic, 919-541-7717, e-mail: kleovic@engineer.aerl.epa.gov)

Table 5. Estimated VOC and Ozone Emission Rates from Four Dry-Process Photocopiers (µg/h · copier)

Chemical	Copier 1	Copier 2	Copier 3	Copier 4
Ethylbenzene	28,000	360	2,400	<50
<i>m,p</i> -Xylene	29,000	510	6,100	100
Styrene	9,900	3,000	12,000	300
<i>o</i> -Xylene	17,000	850	4,500	<50
Propylbenzene	790	460	2,100	<50
2-Ethyl-1-hexanol	230	5,600	14,000	130
<i>n</i> -Nonanal	1,100	3,900	3,600	2,000
<i>n</i> -Undecane	2,000	62	70	103
Formaldehyde	<500	<500	2,600	2,200
Acetaldehyde	710	<500	960	1,200
Acetone	2,000	>100	>500	2,800
Benzaldehyde	1,800	3,800	2,600	<100
Ozone	3,000	1,300	4,700	7,900

GLOSSARY OF ACRONYMS

ACS-Air Conveyance System	IEMB-Indoor Environment Management Branch
ADC-Air Duct Cleaning	MS-Mass Spectrometer
AHU-Air Handling Unit	NADCA-National Air Duct Cleaning Association
AMSI-Aerosol Mass Spectral Interface	NRMRL-National Risk Management Research Laboratory
ASTM-American Society of Testing and Materials	NTIS-National Technical Information Service
A&WMA-Air & Waste Management Association	OA-Outdoor Air
BEE-Butoxyethoxyethanol	PIV-Particle Image Velocimetry
FGDL-Fiberglass Duct Lining	PCO-Photocatalytic Oxidation
GAC-Granular Activated Carbon	PM-Particle Mass
HAC-Heating and Air-Conditioning	RH-Relative Humidity
HUD-Housing and Urban Development	TH-Test House
HVAC-Heating, Ventilating, and Air-Conditioning	VOC-Volatile Organic Compound
IAQ-Indoor Air Quality	

An international symposium, *Engineering Solutions to Indoor Air Quality Problems*, was held July 21-23, 1997, in Research Triangle Park, NC. The symposium was cosponsored by APPCD and the Air & Waste Management Association (A&WMA) and was attended by more than 100 participants. Summaries of the IEMB-sponsored oral and poster papers presented at the Symposium follow. Proceedings from the Symposium will be available from A&WMA (412-232-3444) in early 1998. Copies of the IEMB papers should soon be available from the National Technical Information Service (703-487-4650).

Characterization of VOC Emissions From an Alkyd Paint-Tests have been performed to identify VOCs emitted from alkyd paint, to characterize the emission profiles, and to determine the emissions rates. The approach includes both analysis of the paint formulation to identify and quantify VOC concentrations and dynamic small chamber emissions tests to characterize the emissions after application. The predominant constituents of the paint selected for testing are alkanes (C9-C12) and C8-C9 aromatics. Primer and paint have been applied to glass, gypsum, and pine to assess substrate effects in small chamber emissions tests. The VOCs in these solvent-based paints are rapidly emitted after application, with over 90% of the target VOCs emitted during the first 24 hours following application. The data do not indicate any substantial effect of the substrate on the VOC emissions. In addition to the alkanes and aromatics, aldehydes are detected in the emissions during paint drying. (EPA Contact: John Chang, 919-541-3747; jchang@engineer.aeerl.epa.gov)

Characterizing Sink Effects in Large Environmental Chambers-IEMB conducted experiments to characterize the capacity of a large chamber to absorb and re-emit VOCs. Test mixtures used were: 1) octane, nonane, decane, undecane, and dodecane; and 2) ethyl benzene, octanol, p-dichlorobenzene, decane, dodecane, and ethylene glycol. This paper presents the methods used to characterize sink behavior of the chamber, the results, and a discussion of the implications for source characterization using large chambers. (EPA Contact: Mark A. Mason, 919-541-4835; mmason@engineer.aeerl.epa.gov)

Cost Analysis of Activated Carbon vs. Photocatalytic Oxidation for Removing VOCs from Indoor Air-The capital, operating, and maintenance costs were compared for VOC air cleaning by in-duct granular activated carbon (GAC) and photocatalytic oxidation (PCO) units for new (i.e., non-retrofit) office buildings. A steady concentration of 1 ppm VOC was assumed in the indoor air. Even with the relatively optimistic assumptions for the PCO system, this analysis suggests that a VOC air cleaner based on current PCO technology could have an installed cost about 10 times higher, and a total annual operating cost about 2 times higher than the costs of a comparable GAC air cleaner. (EPA Contact: D. Bruce Henschel, 919-541-4112; bhenschel@engineer.aeerl.epa.gov)

Defining Requirements and Data Outcomes for Environmental Verification Program for Indoor Air Products-Building on existing test methods, IEMB and Research Triangle Institute are developing a test protocol for office furniture as part of EPA's Environmental Technology Verification Program. The method will be validated at Research Triangle Institute and Air Quality Sciences and then will be submitted for approval by a stakeholders group. Results will be provided to clients, but will also be incorporated in a database of industry-specific statistical averages which may be used for modeling pollutant concentrations within a building. A matrix of data outcomes such as emission factors, room concentrations, emission rates, input for models, time to reach acceptable level of emissions, exposures, and risk factors will be developed. (EPA Contact: Leslie E. Sparks, 919-541-2458; lsparks@engineer.aeerl.epa.gov)

Design of an Aerosol Mass Spectral Interface-An Aerosol Mass Spectral Interface (AMSI) has been designed and constructed to chemically characterize aerosol consumer products. The product is sprayed into the AMSI, reduced to dry particles, and passed into the mass spectrometer (MS) for characterization for real-time, on-line analysis. Chemical separation is achieved mass spectrally. The AMSI can also be operated to introduce only specific sizes of aerosol particles into the MS allowing for chemical characterization by particle size. The AMSI has been successfully used on a particle beam MS and on an atmospheric MS. The AMSI is being applied to help analyze aerosol consumer products so that industry can produce lower-emitting, more efficacious products. (EPA Contact: Kelly Leovic, 919-541-7717; kleovic@engineer.aeerl.epa.gov)

Development of a Digital Optical Measurement System for Analysis of Aerosol Spatial Distribution in the Indoor Environment

A new technique to measure aerosol spatial distribution in realistic rooms is presented. This measurement system is based on Particle Image Velocimetry (PIV) which has non-intrusive, simultaneous, and whole field measurement features. Tracer particles and representative aerosols are introduced into the indoor air, illuminated by a light sheet, and photographed. The particle size, a velocity vector map, and concentration spatial distribution can be obtained by applying different data analysis techniques and calibration procedures. The results from this research can be used to help understand aerosol spatial distribution indoors which can be used to evaluate occupants' exposure to indoor pollutants and assist manufacturers in developing more efficacious aerosol consumer products. (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

Investigation of Contact Vacuuming for Remediation of Fungally Contaminated Duct Materials-The objectives of this research program were to: 1) determine, under constant temperature, RH, and air flow test conditions, whether fungal spore levels on HVAC duct material surfaces could be substantially reduced by thorough vacuuming; and 2) evaluate whether subsequent fungal growth would be limited or contained by a single mechanical cleaning treatment. Three duct materials were tested: two new FGDLs (one containing an antimicrobial treatment) and one new galvanized steel duct material. All were artificially soiled. Results show that notable amounts of surface dust were removed and surface spore levels could be reduced in the short-term on all materials by vacuuming. However, fungal re-growth occurred within 6-12 weeks. (EPA Contact: John Chang, 919-541-3747; jchang@engineer.aeerl.epa.gov)

Energy Consumption Comparisons for High Efficiency vs. Low Efficiency Central Filters

In addition to the increased initial cost associated with a high efficiency filter as compared to a standard low efficiency filter, differences in pressure losses and changes in air flow associated with various levels of filter load can impact the energy consumption of the system. This paper discusses the results of an analysis of yearly energy consumption for high and low efficiency filters applied to a representative commercial office building located in three different climatic regions. Using computer simulation, yearly energy consumption is estimated for two different HVAC system types for two of the most common packaged system sizes. (EPA Contact: Leslie E. Sparks, 919-541-2458; lsparks@engineer.aeerl.epa.gov)

Evaluation of Sink Effects on VOCs from a Latex Paint

The sink strengths of two common indoor materials, carpet and gypsum board, were evaluated by environmental chamber tests using four VOCs: propylene glycol, ethylene glycol, BEE, and Texanol. Results indicate that the sink strengths measured were more than 1 order-of-magnitude higher than those for other VOCs previously tested by EPA. The high sink strengths reflect the unusually high adsorption capacity of common indoor materials for the four VOCs. Results also show that reemission 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 reemission process can result in chronic and low level exposure to the VOCs after painting interior walls and surfaces. (See related article on page 1, "VOC Emissions From a Latex Paint: Sink Effects.") (EPA Contact: John C. S. Chang, 919-541-3747; jchang@engineer.aeerl.epa.gov)

Fungal Emission Rates and Their Impact on Indoor Air-Duct materials were allowed to develop *Penicillium* and *aspergillus* contaminations in a constant temperature and high RH environment. Almost no spore release was seen over 6 weeks with a constant 95% RH, while surface growth increased at least 2 orders of magnitude. After 6 weeks, the RH was decreased in 5% increments at 1 hour intervals. Decreasing RH had little effect on the emission rate until the RH was between 60 and 65%, when a spike of *Penicillium* was detected. In another experiment, the impact of HVAC system cycling was measured on fiberglass duct liner contaminated with *Penicillium*. The RH was set at either 55 or 95%, and the air flow was 2.5 m/s. At 95% RH, only periodic spore emissions were detected. At 55% RH a much higher release was detected. (EPA Contact: John Chang, 919-541-3747; jchang@engineer.aeerl.epa.gov)

Identification and Evaluation of Pollution Prevention Techniques to Reduce Indoor Emissions from Engineered Wood Products

Emissions were screened from four products: veneered particleboard with sealer and topcoat; veneered hardboard with stain, sealer, and topcoat; particleboard overlaid with vinyl; and particleboard overlaid with melamine. Total VOCs were highest from veneered particleboard with sealer and topcoat. The acid catalyzed alkyd-urea sealer and topcoat and the particleboard were the primary emission sources. Three types of coatings were identified as potential substitutes: a 2-component waterborne polyurethane; an aliphatic urethane acrylate; and a water-based acrylic. Four types of fiber panels were identified as potential alternatives for particleboard: fiber panels made with medium density fiberboard using methylene diisocyanate resin; wheat straw; corrugated cardboard; and recycled newspaper. (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

Indoor Air Quality Large Building Characterization Project Planning-

Three buildings were characterized by examining radon concentrations and IAQ as affected by building ventilation dynamics. Measurements included: carbon dioxide, particle concentrations, temperature, RH, pressure differentials, radon (indoor, ambient, and sub-slab), and outdoor air (OA) intake flow rates. The OA intake was adjusted when possible, and fan cycles were controlled while tracer gas measurements were taken in all zones. Techniques to vary OA and pressure differential, and track IAQ were incorporated into the experimental plan and are discussed with project rationale. (EPA Contact: Marc Y. Menetrez, 919-541-7981; mmenetrez@engineer.aeerl.epa.gov)

Indoor Emissions from Conversion

Varnishes-Three commercially available conversion varnish systems were evaluated. Results confirmed that the amount of free formaldehyde initially applied to the surface represents only a fraction of the total amount of formaldehyde emitted, implying that formaldehyde is formed as a result of the curing reaction. Long-term (133 days) tests showed a formaldehyde emission rate greater than 0.14 mg/m²/hr, which can cause elevated concentrations in indoor environments. (See related article on page 8, "Emissions from Acid-Catalyzed Varnishes.") (EPA Contact: Betsy M. Howard, 919-541-7915; bhoward@engineer.aeerl.epa.gov)

Large Indoor Air Test Chamber Characterization

-A 30 m³ stainless steel test chamber is being used by IEMB to characterize emissions from products and processes that cannot readily be studied using small chambers. Initial experiments have evaluated chamber performance and the comparability to two other chambers recently built in Canada and Australia. Tests have evaluated critical factors that may influence experiments: 1) the ability to maintain a wide variety of temperature and RH set points; 2) air velocities within the chamber at different flow conditions; 3) mixing of pollutants at different flow and temperature conditions; and 4) adsorption of organic compounds by chamber walls, air ducts, and components of the air-conditioning system. (EPA Contact: Betsy M. Howard, 919-541-7915; bhoward@engineer.aeerl.epa.gov)

A Research Plan for Determining the Penetration of Ambient Particles into Buildings

-Most people receive over 90% of their exposure to airborne fine particles indoors. IEMB has begun a study to determine the relationship between the outdoor and indoor particle size distributions and concentrations, and to determine the factors that affect their relationship. The study will include a detailed theoretical analysis of the ways that particles can enter the indoor environment and an analysis of the effects of these entry pathways on the particle concentration and particle size distribution indoors. This presentation will summarize the scientific literature on relationships between outdoor and indoor fine particles, the approach being taken to theoretical analyses of particle penetration into buildings, and the approach to the complementary experimental studies. (EPA Contact: Ronald B. Mosley, 919-541-7865; rmosley@engineer.aeerl.epa.gov)

Pilot Air Conveyance System Design, Characterization, and Cleaning

-The objective of this project was to develop and refine surface and airborne contamination measurement techniques that could be used to evaluate air conveyance system (ACS) cleaning in support of a field study to be conducted later. (See related article on page 6, "Field Study on Residential Air Duct Cleaning.") A pilot air conveyance system using full-size residential HAC equipment was constructed and operated to provide a controlled, artificially soiled, ACS environment. Three types of duct systems were evaluated with the proposed measurement methods under unsoiled and soiled conditions. Each duct system was then cleaned by professional ACS cleaners and reevaluated. As a result of the pilot study, the surface contamination measurement methods were evaluated over a range of conditions and improved. Surface contamination (microbial and total dust) measurements and visual inspections showed that the pilot unit was effectively cleaned by the methods applied. Submicron and larger particle counts were reduced following ACS cleaning, and respirable particle mass was reduced for two of the three duct systems used. (EPA Contact: Russell M. Kulp, 919-541-7980; rkulp@engineer.aeerl.epa.gov)

Pilot Study to Evaluate the Impact of Air Duct Cleaning on Indoor Air Quality in Residences

-A nine-home pilot study was performed to evaluate the effectiveness of air duct cleaning methods, to test sampling and analysis methods that might be used to measure the impact of air duct cleaning on IAQ and energy use, and to collect an initial data set in occupied residences. (See related article on page 6, "Field Study on Residential Air Duct Cleaning.") (EPA Contact: Russell M. Kulp, 919-541-7980; rkulp@engineer.aeerl.epa.gov)

Reducing Solvent and Propellant Emissions from Consumer Products-

The development of a spray dispenser that removes the need for VOC solvents and hydrocarbon propellants, replacing them with water and air, respectively, is discussed. Maintaining, or improving, spray performance using such a dispenser requires insensitivity to the increases in product viscosity and surface tension that result from replacement of alcohol by water. It also requires a dispenser that consumes considerably less propellant since air (a gas) will be substituted for a hydrocarbon (liquid) without an increase in container volume or pressure rating. Such a dispenser was designed by researchers at Purdue. Results for a variety of liquid viscosities and surface tensions spanning the range of current and anticipated consumer products are included. (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

Research Agenda on Air Duct Cleaning-

Duct cleaning practices include: source control by removal of contaminants from the air ducts and related HVAC system components; application of antimicrobial agents to kill bacteria and fungi; encapsulants and sealants to contain imbedded contaminants; and the introduction of ozone to mask odors and kill microbiological organisms. In addition to the direct costs of acquiring duct cleaning services, long-term costs or savings may be experienced by the consumer due to duct-cleaning-related changes in energy use and health care expenditures. Four priority research areas are discussed for the purpose of reducing risk and pollutant exposure: source removal/control techniques; application and use of antimicrobial agents; HVAC system sealants/ encapsulants; and use of ozone in ventilation systems. (EPA Contact: Russell M. Kulp, 919-541-7980; rkulp@engineer.aeerl.epa.gov)

RISK - An IAQ Model for Windows- RISK, a computer model for calculating individual exposure to indoor air pollutants from sources, is presented. The model calculates exposure due to individual, as opposed to population, activity patterns. Source emissions models include empirical first and second order decay and mass-transfer models. The model allows for consideration of the effects of room-to-room air flows, air exchange with the outdoors, and air cleaners on the concentration/time history of pollutants. Comparison of model predictions with data from experiments conducted in IEMB's IAQ test house is discussed. The model predictions are generally in good agreement with the test house measurements. (EPA Contact: Leslie E. Sparks, 919-541-2458, lsparks@engineer.aeerl.epa.gov)

Round-Robin Evaluation of a Test Method to Evaluate Indoor Air Emissions From Dry-Process Photocopiers-

A test method for measuring emissions from office equipment and a specific version of the method for the evaluation of dry-process photocopy machines were developed. Because different test chambers may not perform similarly because of sink effects, temperature and humidity control, air exchange, and pollutant monitoring, a "round-robin" evaluation was performed in four U.S. laboratories. Results demonstrate that the test method developed can be used successfully in different chambers to measure VOCs from dry-process photocopiers. Excluding problems with suspected analytical bias observed from one of the laboratories, the precision between laboratories was excellent with relative standard deviations below 10% in most cases. (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

SUMMARIES OF OTHER 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. Publications with NTIS numbers are available (prepaid) from the National Technical Information Service (NTIS) at: 5285 Port Royal Road, Springfield, VA 22161, 703-487-4650 or 800-553-6847.

Characterization of Emissions from Conversion Varnishes-

Emissions from three commercially available conversion varnish coating "systems" (stain, sealer, and topcoat) were measured. Formaldehyde emissions were 6-7 times the free formaldehyde content, indicating that the formaldehyde is formed during the curing process. Results of formulation analyses and emission tests are described in this paper. Source: Proceedings: The Emission Inventory: Key to Planning, Permits, Compliance and Reporting, New Orleans, LA, September 4-6, 1996. (EPA Contact: Elizabeth M. Howard, 919-541-7915, bhoward@engineer.aeerl.epa.gov)

Effects of Fan Cycling on the Particle Shedding of Particulate Air Filters Used for IAQ Control-

Loaded fiberglass and synthetic organic media bag filters were tested in a laboratory test duct for total particle and bioaerosol shedding as the fan cycled off and on. No measurable particle shedding was observed due to fan cycling. Source: Proceedings of Indoor Air'96. (EPA Contact: Russ N. Kulp, 919-541-7980, rkulp@engineer.aeerl.epa.gov)

(Continued on Page 16)

Reducing Indoor Air Emissions from Dry-Process Photocopy Machines-

Emissions from dry-process photocopy machines include: VOCs, ozone, and particles. A number of the compounds emitted can contribute to adverse health effects such as eye, nose, and respiratory system irritation, and several are listed as hazardous air pollutants under the Clean Air Act. Through measuring emissions in a large chamber, reviewing the literature, and interacting with industry, a number of potential pollution prevention approaches for reducing emissions from dry-process photocopy machines have been identified: 1) formulating toners using high purity raw

materials and state-of-the-art manufacturing processes; 2) using a charged roller system (rather than electrically charged corona wires) to reduce ozone emissions; 3) minimizing the need for and/or improving equipment maintenance to improve machine performance; 4) reducing temperature of the fusing operation to reduce the VOC volatilization from the toner; and 5) improving transfer efficiency of the toner to the paper to minimize toner emissions. Source: In proceedings of Healthy Buildings/IAQ '97, Washington, DC, Sept. 27 - Oct. 2, 1997. (EPA Contact: Kelly W. Leovic, 919-541-7717, kleovic@engineer.aeerl.epa.gov)

Update on EPA's Air Duct Cleaning Research Activities-

The paper focuses on the IEMB/NADCA pilot field study conducted in nine homes during the summer of 1996 (see related article on page 6, "Field Study on Residential Air Duct Cleaning"). The objectives of the study were to collect information on: 1) the effectiveness of currently available air duct cleaning methods used on residential heating and air-conditioning systems, 2) the impact of air duct cleaning on residential IAQ, and 3) the impact of air duct cleaning on energy usage. Source: In proceedings of Indoor Environments '97 Symposium, "Setting the Standard for Healthy Building Management," held in Baltimore, MD, April 7-9, 1997. (EPA Contact: Russell N. Kulp, 919-541-7980, rkulp@engineer.aeerl.epa.gov)

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