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Measurement of Air Concentrations of Volatile Aerosols in Paint Spray Applications

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Spray painting creates aerosols containing droplets and solvent vapors. This work investigated whether traditional vapor sampling measures provide reliable estimates of inhalation exposure during spray painting of automobiles. Measurements of aerosol vapor and droplets were made in spray booths where base coat paint and clear coat finish are applied to automobile bodies. The measurement arrays for both test stand and personal monitoring consisted of charcoal sorbent tubes (CST), diffusion monitors, and glass fiber filters followed by charcoal tubes (F-CST). Xylene and toluene were tested as representative solvents. Measured air concentrations of xylene averaged about 2 ppm at base coat and less than 1 ppm at clear coat applications. Toluene concentrations averaged about 0.1 ppm for both processes. Toluene concentrations and xylene concentrations at clear coat operations as measured by diffusion monitors exceeded those measured by the other samplers. We attribute the apparent increase in sampling rate to membrane damage caused by the solvents. Comparison of F-CST and CST samplers showed that droplets produced during the spraying of both base coat and clear coat operations retain liquid solvent when the droplets reach the breathing zone of workers. The fraction of airborne solvent represented by the droplets will be influenced by both the solvent vapor pressure in the mixture and the original droplet size. For the solvents and processes tested here droplets contained up to 50 percent of airborne solvent. Thus, we recommend the use of prefiltered CSTs for monitoring worker exposure to solvents in spray application processes.

Cohen, B.S.; Brosseau, L.M.; Fang, C.-P.; Bowers, A.; Snyder, C.: Measurement of Air Concentrations of Volatile Aerosols in Paint Spray Applications. Appl. Occup. Environ. Hyg. 7(8):514–521; 1992.

Introduction

Spray painting creates aerosols containing paint droplets and solvent vapors. Exposure sampling commonly evaluates the presence of solvent vapors but does not explicitly consider the presence of residual solvent in paint droplets and its possible contribution to a worker's overall exposure. The work reported here investigated whether common vapor sampling measures provide reliable estimates of inhalation exposure during spray painting of automobiles.

Contemporary automobile paint application occurs in two separate steps. A color-containing base coat is first applied to a primed automobile body; this is followed by application of a clear coat layer. The automobile body may be baked to set the color base coat prior to clear coat application, or baking may take place after both coats are in place. Paint color varies from car to car along an assembly line depending on production needs. The chemical compositions of the coats differ, as do the formulations for each color, but organic solvents are used in all cases. Concern for worker exposure has resulted in paints with less potential for toxicity, by the use of high solids paints and by substitution with less toxic solvents. Nonetheless, exposure to solvents does occur and should be properly quantitated.

The National Institute for Occupational Safety and Health recommends the use of solid sorbent tubes (coconut shell charcoal, 100 mg/50 mg) for sampling volatile hydrocarbons (e.g., toluene, xylene, and other organic solvents). Air containing solvent vapors is drawn through the tubes by use of a pump, and hydrocarbon molecules are adsorbed to active sites on the charcoal. In the workplace it is now also common to use passive dosimeters. Sample collection by these small badge-type samplers depends on the diffusion of vapors through a permeable membrane to a charcoal trap. Both types of samples are considered representative of vapor exposure.

In situations where aerosols are generated, however, exposure cannot be assumed to result only from vapors. Malek *et al.*(1) demonstrated that during spray application of polyester resin solutions, aerosols created by spraying can contribute significantly to a worker's inhalation exposure to volatile organic contaminants. In some instances the aerosol droplets may be the most significant source of solvent exposure. For example, Peterson *et al.*(2) showed that for an outdoor polyurethane spray application, the evolution of toluene diisocyanate (TDI) vapor was insignificant.

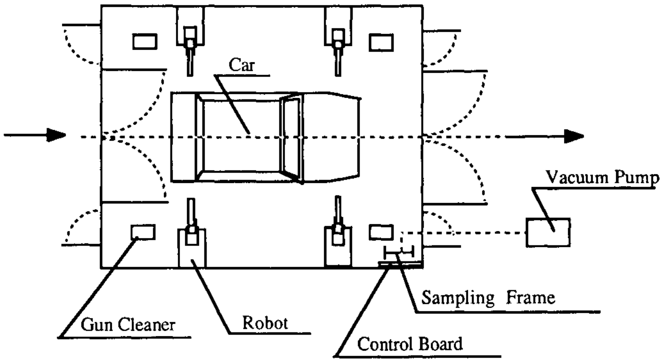

FIGURE 1. Schematic of an automated paint spray booth at plant 1 showing position of flexible robotic sprayers, control panel, and sampling frame location. Samples were collected only between spray applications when robots were not in use.

They demonstrated that airborne concentrations of TDI downwind of the spray gun resulted solely from aerosol droplets.

The spray application of base coat and clear coat paints through high pressure nozzles produces aerosols that contain resins, paint pigments, additives, and solvents. Chan *et al.*⁽³⁾ reported on the size distribution of solids in paint overspray aerosols in automotive spray painting booths. Their results indicate that a significant amount of the droplets is inhalable. High technology manufacturing processes utilizing robotics and electrostatic spray painting equipment also produce aerosols in which many of the particles are in the respirable size range. Thus, whether application is by more traditional manually operated nozzles or modern electrostatic robotic guns, worker exposure will be to both vapor and inhalable aerosols.

Experimental Methods

Paint Booths

Measurements of aerosol vapor and droplets were made in spray booths where paint is applied to automobile bodies. Initial experiments were carried out in completely automated booths where workers are present only occasionally. Subsequent measurements were made in booths where manual application requires the continuous presence of workers.

In a typical base coat application booth on a completely automated coating line the automobile body enters the booth, entrance and exit doors shut, and paint is applied by four robotic arms (Figure 1). No personnel are present in the paint booth. After the base coat is applied the doors open and the automobile body moves to the next station. Computer controls are located within the booth; when adjustments are needed an operator enters the booth between paint applications. We located a test stand (sampling frame) with a sampling array at the position that would be occupied by the operator when adjusting controls. In these booths sampling was done only during the process intervals between car painting, when a worker might be present. At this automobile assembly plant (plant 1) measurements were made only on test stands and only in the base coat application area.

The majority of our experimental measurements were made in paint booths where the manual application of base or clear coat is carried out (plant 2). Each spray operator is assigned a specific portion of the automobile, as shown in Figure 2. After manual spraying the car body proceeds through a robotic spray area, then to another booth for manual application of clear coat. Measurements in the two manual spray booths were made with sampling arrays on test stands. In addition, personal sampling was carried out in both paint and clear coat operations. This facility runs two parallel pairs of paint lines, and sampling was done entirely on one pair of the lines.

Ventilation at the tested booths was directed vertically downward through high efficiency ceiling filters to a water scrubber beneath grilled flooring. Air velocity was measured at about 37 m/min (120 ft/min) at both painter and test stand locations.

Samplers

The measurement arrays consisted of charcoal sorbent tubes (CST) (SKC Lot 120), diffusion monitors (DM) (3M Co. 3500), glass fiber filters (Whatman GF/A 37-mm diameter) followed by charcoal tubes (F-CST), and midget impingers. The first two sampler types were expected to measure only vapor exposures, while the third and fourth capture both droplets and vapor. With the F-CSTs solvent droplets collected by the glass fiber filter evaporate as air continues to be drawn through the sampler. The back-up CST thus collects solvent vapor initially airborne plus the vapor from the evaporated droplets.

The CSTs were operated at a flow of approximately 0.2 to 0.5 L/min. The passive DMs collect vapor on a charcoal substrate with an effective flow of about 0.0273 L/min for xylene and 0.0314 L/min for toluene.⁽⁴⁾ F-CST samplers were operated at flows of 1–2 L/min. The impingers were operated at a flow of 0.5 L/min and were used in series to permit evaluation of collection efficiency.

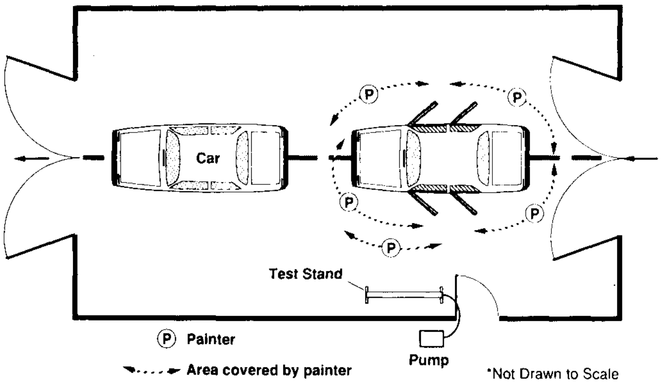

FIGURE 2. Schematic of paint spray booth at plant 2. Sets of personal monitors were worn by sprayers who move about the auto body approximately as shown. Test stand is about 2.5 m from nearest spray gun.

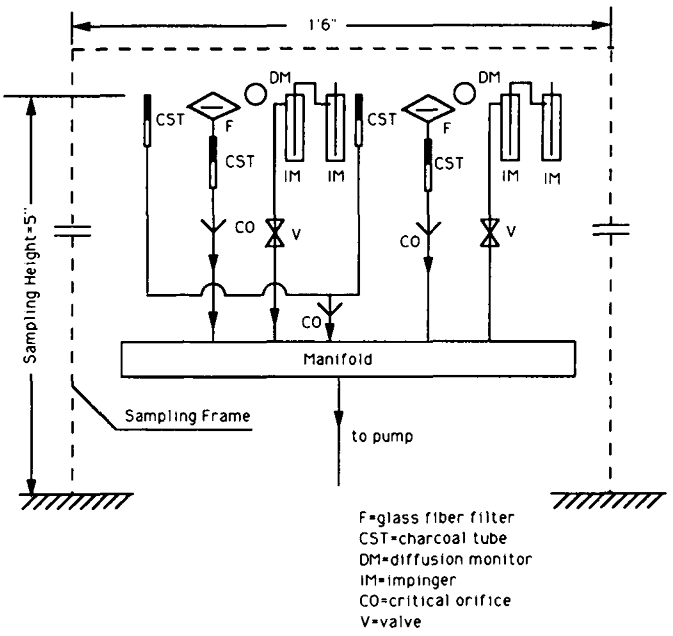

FIGURE 3. Schematic of test stand samplers deployed at plant 1.

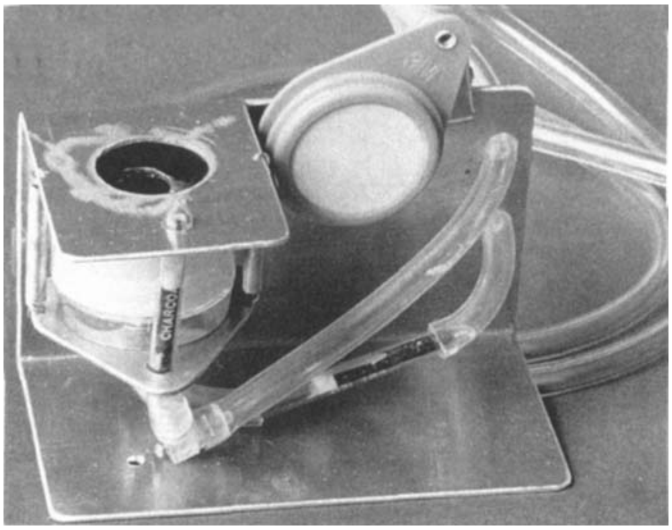

FIGURE 4. Personal monitoring sampler holder shown with F-CST, CST, and DM. This was clipped to the worker's protective overshirt near the lapel. The plate shown at bottom rests against the chest wall with the CST and filter inlets facing out. Air was drawn through the F-CST and CST by a belt-mounted pump.

Initial test stand experiments employed closed face filter cassettes with 4-mm diameter inlets. After personal sampling was started, all filter cassette inlets were enlarged to 15 mm to match the inlet of the Institute of Occupational Medicine Personal Sampler.(5) The inlet sampling efficiency of that sampler is reported to match the inspirable mass fraction recommended by the American Conference of Governmental Industrial Hygienists Air Sampling Procedures Committee.(6)

A typical test stand sampling array consisted of the three types of samplers placed side by side in several groups (Figure 3). Several filter and charcoal tube samplers were placed near the sampling array, but no air was drawn through them. These samplers served as field blanks. Flow to all CST and F-CST samplers was controlled by critical orifices.

Small aluminum holders that clip onto a lapel were made for personal sampling (Figure 4). They held three kinds of monitors: a CST, an F-CST, and a DM. The DM was mounted so that it was protected from direct deposition of droplets. Membranes were checked for paint deposition after sampling and samples were discarded if the membrane appeared to have been damaged. Flow provided by belt-mounted personal sampling pumps was divided by a valve mounted in the holder. Flows through the active samplers were approximately the same as for test stand samplers. All flows were checked with a direct-reading bubble meter, with samplers positioned either on the test stand or on the personal sample holder, before and after each sampling period.

Analytical Methods

Xylene was chosen as a representative solvent because it was present in all of the paints at concentrations varying from 1 to 30 percent by weight. The concentration depends upon the color of the paint and other desired qualities such as whether the finish will be metallic. Toluene (mass concentration 0.1 to 1 percent) was chosen for secondary analysis to examine whether differences in vapor pressure cause

TABLE I. Summary of Field Sampling

		Sample Location		Booth[B]		Operation		Sampler[C]					Analysis	
Trip Number	Plant[A]	Personal	Test Stand	East	West	Paint	Clear	F-CST	CST	DM	Imp	I-CST	Xylene	Toluene
1	1		X			X		X	X	X			X	
2	2		X	X		X		X	X	X			X	
3	2	X		X	X	X		X	X	X			X	X
4	2	X		X	X	X		X	X	X			X	X
5	2	X	X	X		X		X	X	X	X		X	X
6	2	X	X	X		X		X	X	X	X	X	X	X
7	2	X	X	X	X	X	X	X	X	X	X	X	X	X
8	2	X	X	X	X		X	X	X	X			X	X

[A] Plant 1: automated paint booth; plant 2: partial manual operation.

[B] Booth: operating paint line at which indicated sampling was done.

[C] F-CST: glass fiber filters followed by charcoal tubes; CST: charcoal sorbent tubes; DM: diffusion monitors; Imp: midget impingers; I-CST: impactor followed by charcoal tube.

TABLE II. Mean Solvent Concentrations for All Sampler Sets (mg/m^3)

	Xylene				Toluene			
	N[A]	F-CST[B]	CST	DM	N[A]	F-CST	CST	DM
Base Coat Applications								
All sets	53	11.10	9.47	9.50	41	0.346	0.388	0.498
Test stand samplers	23	10.60	9.02	8.62	11	0.421	0.344	0.617
Personal monitors	30	11.49	9.81	10.17	30	0.318	0.403	0.455
Clear Coat Applications								
All sets	21	4.44	2.31	4.86	21	0.472	0.280	0.582
Test stand samplers	8	1.08	1.11	1.85	8	0.212	0.145	0.406
Personal monitors	13	6.18	3.05	6.70	13	0.788	0.470	0.782

[A]Number of samples
[B]F-CST: glass fiber filters followed by charcoal tubes; CST: charcoal sorbent tubes; DM: diffusion monitors.

detectable differences in the partition of vapor and droplet contributions to exposure. Vapor pressure at 25°C is 9 and 22 mmHg for *m*-xylene and toluene, respectively.

Two gas chromatographs were used sequentially during the course of these studies, a Varian model 2700 and a Varian model 3700 (Varian, Walnut Creek, California). Both instruments were equipped with flame ionization detectors (FID) and interfaced to a Hewlett-Packard 3390 integrator (Hewlett-Packard, Avondale, Pennsylvania). Identical column, detector, and injector temperatures were used in both instruments: column, 105°C; injector, 245°C; detector, 140°C. Identical gas flows were used in the FID of each instrument: hydrogen (30 ml/min) and air (300 ml/min). The same column was used in each instrument: 1/8 in. × 6 ft stainless steel containing 10 percent UC-98 on 80-100 WAW DMCS. Helium was used as the carrier gas in both instruments and two different carrier gas flow rates were used. Studies with the model 2700 instrument used a 12-ml/min flow rate resulting in retention times of 3.75 min for toluene and 7 min for xylene. Studies with the model 3700 instrument used a 44-ml/min flow rate resulting in retention times of 1.2 min for toluene and 1.9 min for xylene.

Calibration curves were constructed for both xylene and toluene dissolved in carbon disulfide. For these curves, concentrations of xylene ranged from 0 to 2171.5 $\mu g/ml$ and concentrations of toluene ranged from 0 to 51.9 $\mu g/ml$. All points on the calibration curves were run in quadruplicate. Peak heights for toluene and xylene were compared to the height of a solvent peak eluting at 0.5 min, which was used as an internal standard. Correlation coefficients for the two calibration curves were 0.998 for xylene and 0.994 for toluene.

Field samples of xylene and toluene, with the exception of impinger samples, were collected on CSTs and DMs as described above. After collection, samples were desorbed with carbon disulfide. Desorption of DMs was carried out with 1 ml carbon disulfide while CSTs were desorbed with 2 ml carbon disulfide. For the CSTs, desorption efficiencies for both xylene and toluene were determined by injecting known amounts of the compounds into CSTs, passing 10 L of air through the CSTs, and then desorbing with carbon disulfide. The mean desorption efficiency for xylene was 106 ± 6 percent standard error and for toluene was 95 ± 3 percent. Efficiencies of DM desorption were determined by inserting a clean filter over the charcoal bed, injecting a known quantity of solvent onto the filter, and capping the monitor. Monitors were then kept at room temperature for 4 h and stored overnight in a freezer to mimic sample storage. Mean desorption efficiencies were 87 ± 1 percent and 94 ± 3 percent for xylene and toluene respectively.

To assess whether breakthrough occurred in the CSTs during sampling, both the front and rear chambers of all the CSTs used during the field assays were analyzed for xylene and toluene. Of the 259 CSTs used in the field assays only 43 showed any xylene present on the backup section while only 2 showed any toluene. The mean percentage of xylene found in the rear chambers of those samplers was 0.27 ± 0.08 percent standard error, while the mean percentage of toluene in the rear chambers of the two samplers was 1.82 percent. Neither xylene nor toluene were detected in filter field blanks, but some diffusion onto the charcoal in open blank tubes was detected.

Results

Sampling demographics are summarized in Table I which shows (1) plant and paint booth locations at which samples were collected, (2) the distribution between test stand and personal samples, (3) whether sampling was dur-

TABLE III. Summary of Significant Differences between F-CST, CST, and DM Samplers ($p < 0.05$)*

	Xylene	Toluene
Base Coat Applications		
All sets	F-CST > CST = DM	DM > F-CST
Test stand samplers	F-CST > CST = DM	DM > F-CST = CST
Personal monitors	F-CST = CST = DM	DM > CST > F-CST
Clear Coat Applications		
All sets	DM = F-CST > CST	DM = F-CST >CST
Test stand samplers	DM > CST = F-CST	DM > F-CST > CST
Personal monitors	DM = F-CST > CST	DM = F-CST > CST

*See Table II for abbreviations.

TABLE IV. Measured Concentrations of Xylene at Base Coat Applications at Plant 2*

Trip Number	Booth	Sample Location	Mean Xylene Concentration, Standard Error (mg/m^3) F-CST	CST	DM	Number of Samples
2	Right	Test stand	1.27	1.02	1.27	6
			0.42	0.28	0.28	
3	Right	Personal	15.25	14.75	18.21	6
			2.25	1.48	1.96	
	Left	Personal	4.75	6.38	6.40	6
			1.19	1.16	1.42	
4	Right	Personal	7.99	7.81	8.03	3
			0.69	0.91	0.68	
	Left	Personal	8.40	6.32	5.70	3
			0.91	1.34	1.53	
5	Right	Personal	16.04	9.58		4
			6.45	1.58		
	Right	Test stand	4.17	4.58		4
			0.98	1.28		
	Left	Personal	13.01	13.88		4
			1.42	1.41		
6	Right	Personal	10.73	8.41	8.38	8
			2.59	1.80	1.27	
	Right	Test stand	19.48	16.68	16.17	8
			0.61	1.25	0.50	
7	Left	Personal	28.05	17.37	14.82	3
			9.56	4.56	3.49	
	Left	Test stand	13.22	10.63	7.44	3
			2.22	0.91	0.91	

*See Table II for abbreviations.

ing application of base or clear coat, (4) the types of samplers, and (5) whether analysis was for toluene and/or xylene. The use of impingers was discontinued after two trials because readings were erratic and blanks were high; those results are not reported here.

Mean measured concentrations for each of the three types of samplers are reported for base coat and clear coat applications (Table II). Results are shown for all samples combined into one data set, and then separately for samples deployed on test stands, and for those worn as personal monitors. In all cases a set consisted of an F-CST, a CST, and a DM. During the first sampling trip concentrations measured by DMs deployed on the test stand are not comparable with CST results because active sampling was done intermittently. These were not included in the general comparisons shown below.

A random block analysis of variance (ANOVA) was used to compare concentrations as measured by different types of samplers. This analysis takes into account the grouping of the samplers into sets, or blocks, each containing F-CST, CST and DM. The null hypothesis is rejected ($p < 0.05$) when concentrations measured by these samplers differ. Since the random block ANOVA cannot specify which means differ, testing continued with Tukey's Honestly Significant Difference Test.

Results of comparing the concentrations measured by the three types of samplers are summarized in Table III.

Base Coat Applications

Mean concentrations of xylene (with standard deviation) at plant 1, as measured by DM, CST and F-CST samplers ($n = 5$), were 5.9 ± 1.4, 5.1 ± 1.2 and 6.5 ± 1.0 mg/m^3, respectively. Concentrations at plant 2 for measurements made during base coat applications are shown in Tables IV and V.

Mean concentrations of xylene for all sampling trips (range 0.3–44 mg/m^3; 1.5–10 ppm) were more than an order of magnitude greater than those of toluene (range 0–1.6 mg/m^3; 0–0.42 ppm). The changing ratios of xylene to toluene (e.g., Tables IV and V) reflect differences in paint composition, which varied with paint color and over time as formulations changed, as well as differences in solvent vapor pressure.

When all base coat samples were combined into one data set there were significant differences between the three types of samplers for xylene. Results indicated that concentrations measured by F-CSTs were greater than those measured with CSTs, but CST and DM results did not differ. A similar relationship was found when sets deployed on test

TABLE V. Measured Concentrations of Toluene at Base Coat Applications at Plant 2*

Trip Number	Booth	Sample Location	Mean Toluene Concentration, Standard Error (mg/m^3) F-CST	CST	DM	Number of Samples
3	Right	Personal	0.44	0.61	0.90	6
			0.07	0.09	0.07	
	Left	Personal	0.21	0.41	0.52	6
			0.04	0.05	0.16	
4	Right	Personal	0.35	0.38	0.37	3
			0.04	0.03	0.02	
	Left	Personal	0.54	0.63	0.37	3
			0.20	0.27	0.19	
5	Right	Personal	0.42	0.32		4
			0.20	0.13		
	Right	Test stand	0.29	0.28		4
			0.18	0.16		
	Left	Personal	0.40	0.47		4
			0.10	0.09		
6	Right	Personal	0.20	0.21	0.43	8
			0.04	0.04	0.04	
	Right	Test stand	0.44	0.36	0.66	8
			0.03	0.03	0.07	
7	Left	Personal	0.24	0.17	0.53	3
			0.06	0.03	0.02	
	Left	Test stand	0.37	0.32	0.63	3
			0.06	0.00	0.05	

*See Table II for abbreviations.

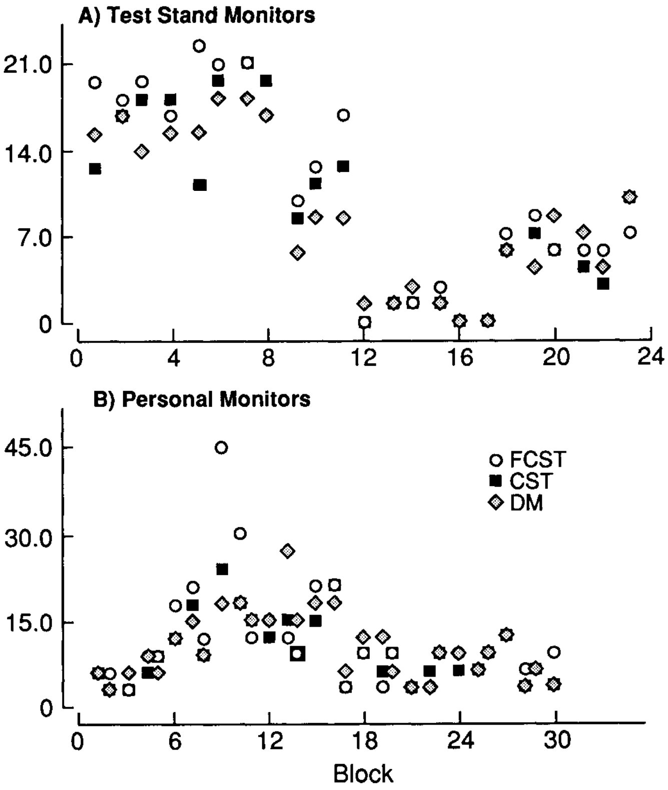

FIGURE 5. Concentration of xylene at base coat application as measured with different samplers (mg/m^3) as measured by (A) test stand monitors and (B) personal monitors.

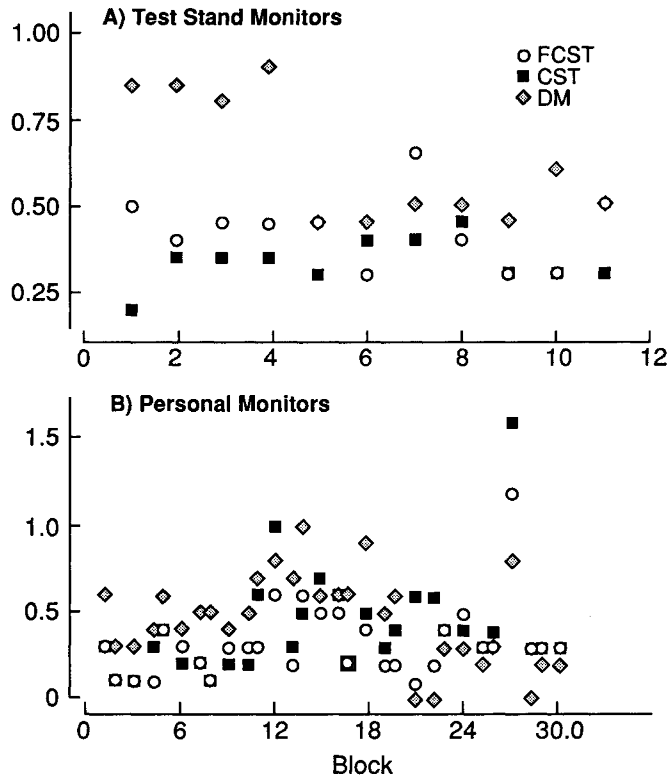

FIGURE 6. Concentration of toluene at base coat application as measured with different samplers (mg/m^3) as measured by (A) test stand monitors and (B) personal monitors.

stands were examined separately (Figure 5A; Table VIA); however, no difference was found between concentrations measured by the various samplers worn as personal monitors (Figure 5B; Table VIB).

For all toluene data the DMs indicated significantly higher concentrations than either F-CST or CST samplers (Figure 6; Table VII). There were significant differences between samplers whether deployed on test stands or worn on workers, but in most cases these are attributable to higher concentrations measured by the DMs. It is not clear why the personal monitor CSTs measured higher concentrations than F-CSTs, but the statistical significance is marginal (Table VII).

Clear Coat Applications

Mean concentrations of xylene during clear coat applications (with standard errors) were 4.86 ± 1.25, 4.44 ± 1.10, and 2.31 ± 0.44 mg/m^3, and toluene concentrations were

TABLE VI. Random Block Analysis of Variance for Concentration of Xylene at Base Coat Application as Measured with Different Samplers (mg/m^3)

(A) Test Stand Samples				(B) Personal Samples			
Source	DF*	SS*	MS*	Source	DF	SS	MS
Block	22	3049.52	138.61	Block	29	3515.4	121.2
Sampler	2	50.25	25.12	Sampler	2	47.3	23.6
Error	44	162.52	3.69	Error	58	749.4	12.9
TOTAL	68	3262.29		TOTAL	89	4312.1	

F = 6.808; > F(0.05, 2, 44) = 4.05; Reject H_0

F = 1.83; < F(0.05, 2, 58) = 3.97; Accept H_0

Rank Mean:

3 F-CST = 10.6	3-1 q = 6.837*
2 CST = 9.02	3-2 q = 5.456*
1 DM = 8.62	2-1 q = 1.381 ns

$q_{critical}$ (0.05, 3, 44) = 3.442

CONCLUDE F-CST > CST = CST = DM

*DF: degrees of freedom; SS: sum of squares; MS: mean squares.

TABLE VII. Random Block Analysis of Variance for Concentration of Toluene at Base Coat Application as Measured with Different Samplers (mg/m^3)

(A) Test Stand Samples.

Source	DF*	SS*	MS*
Block	10	0.1614	0.0161
Sampler	2	0.4388	0.2194
Error	20	0.3344	0.0167
TOTAL	32	0.9346	

$F = 13.14$; $> F(0.05, 2, 20) = 4.46$; Reject H_0

Rank Mean:

3 DM $= 0.617$ 3-1 $q = 9.448$*
2 F-CST $= 0.421$ 3-2 $q = 6.783$*
1 CST $= 0.344$ 2-1 $q = 2.665$ ns
$q_{critical}$ $(0.05, 3, 20) = 3.578$
Conclude DM > F-CST = CST

(B) Personal Samples

Source	DF	SS	MS
Block	29	4.0407	0.1393
Sampler	2	0.2841	0.1421
Error	58	1.7377	0.0300
TOTAL	89	6.0625	

$F = 4.737$; $< F(0.05, 2, 58) = 3.94$; Accept H_0

Rank Mean:

3 DM $= 0.455$ 3-1 $q = 6.024$*
2 CST $= 0.403$ 3-2 $q = 2.286$ ns
1 F-CST $= 0.318$ 2-1 $q = 3.737$*
$q_{critical}$ $(0.05, 3, 58) = 3.399$
Conclude DM = CST > F-CST

*DF: degrees of freedom; SS: sum of squares; MS: mean squares.

0.582 ± 0.073, 0.472 ± 0.150, and 0.280 ± 0.076 for DM, F-CST, and CST, respectively (Table II). The large variability is expected as these results are averaged over two sampling trips as well as for test stand and personal monitors. Mean concentrations for individual sampling sessions measured during the last field trip are shown in Table VIII.

When concentrations are compared for different samplers (Tables II and III), it is clear that these do not follow the pattern seen for base coat applications. In all cases the diffusion monitors measured concentrations greater than or equal to the F-CST and greater than the CST samplers.

Discussion

Our initial experiments were made on test stands at plant 1. These showed that concentrations of xylene measured by F-CST samplers exceeded those with CSTs, and concentrations measured with CSTs exceeded those measured with DMs. With this evidence of the presence of droplets we proceeded with personal monitoring. The measurements with personal monitors did not show any differences between samplers. We hypothesized that these results were caused by differences in the size distribution of droplets collected at test stands compared with personal monitors. The result of our investigation of droplet size is reported elsewhere.(7)

TABLE VIII. Concentrations Measured during Clearcoat Applications at Plant 2 (Trip 8)

Booth	Sample Location	Mean Xylene Concentration, Standard Error (mg/m^3), Number of Samples F-CST*	CST*	DM*	Mean Toluene Concentration, Standard Error (mg/m^3), Number of Samples F-CST	CST	DM
Right	Personal	6.16	2.48	3.43	1.14	0.46	0.80
		2.13	1.02	0.84	0.49	0.25	0.20
		5	5	5	5	5	5
Left	Personal	4.74	2.99	5.20	0.55	0.39	0.81
		0.76	0.62	0.69	0.15	0.11	0.13
		5	5	5	5	5	5
Right	Test stand	0.73	0.58	1.49	0.22	0.13	0.47
		0.01	0.13	0.16	0.03	0.00	0.03
		5	5	4	5	4	4
Left	Test stand	1.40	1.51	2.21	0.20	0.15	0.35
		0.03	0.02	0.10	0.04	0.01	0.01
		5	5	4	5	5	4

*F-CST: glass fiber filters followed by charcoal tubes; CST: charcoal sorbent tubes; DM: diffusion monitors.

The relationship between xylene concentrations measured by the three sampler types (Table III) for all base coat applications showed F-CST > CST but CST and DM results were not different.

The higher concentration registered by DMs than by CSTs for xylene in clear coat, and for toluene in all cases, is unexpected. For toluene in base coat this cannot be attributed to bias in sample collection, as the measurements were made on the same samples, and from the same chromatographs, analyzed for xylene. In addition the discrepancy is not likely to have resulted from calibration bias because the result only compares the toluene concentrations among the various samplers. Although artifacts could have occurred at these extremely low concentrations, a reasonable explanation may be bias in the sampling rate provided by the supplier. The reported flow rate for these monitors has been questioned for styrene.(8) In that case the uptake was thought to be lower than that supplied by the manufacturer, requiring the concentration to be corrected by a factor of about 1.2. The supplier does not accept that factor for styrene.(9) In the case of toluene our data suggest that, under these sampling conditions, the uptake rate is greater than reported by a factor of about 1.8. Another possibility is that the properties of the diffusion barrier are affected by liquid solvent in droplets even without visible damage to the membrane.

The discrepancy seen for toluene, and the xylene results for clear coat applications, introduces some uncertainty concerning the uptake rate reported for xylene. Results of other work in progress at this laboratory and the report of Pristas(10) are consistent with the supplied uptake rate.

Nonetheless, we decided to examine the results of the comparative testing using only the F-CST and CST samplers.

When measurements with F-CST and CST samplers are compared (Table IX) the results generally support our hypothesis that droplets are present, collected by filters, and evaporated onto the follow-up CSTs. This data set is not identical with that analyzed for Tables III and VI because several additional sampler sets, incomplete because DM values were missing, could be included for these analyses. At base coat applications about 15 percent of the airborne xylene may be in droplets, as estimated from the overall mean concentrations of xylene. For clear coating, again estimated from overall means, the droplets may hold almost 50 percent of the airborne xylene. The concentration measured by the F-CSTs significantly exceeds that of the CSTs for xylene for all groupings of the data, except clear coat test stand samples. The nonconforming group is one of the smallest sample sets.

For toluene, the more volatile solvent, there is no clear difference for base coat applications, but for clear coating about 40 percent of the airborne toluene may be in droplets. The potentially larger fraction that may be attributable to droplets at clear coat applications is consistent with the larger droplet sizes noted for clear coat spraying.(7)

Conclusions

Measured air concentrations of xylene averaged about 2 ppm at base coat and less than 1 ppm at clear coat applications. Toluene concentrations averaged about 0.1 ppm for both processes. These concentrations were well below the threshold limit value of 100 ppm for these solvents (434 mg/m^3 for xylene and 377 mg/m^3 for toluene).

Passive diffusion monitors are very convenient and appear to have worked well in these field experiments for measurement of xylene vapors. Our comparisons have been carried out in atmospheres with extremely low concentrations of solvent, but the results suggest that the sampling rate for toluene under these conditions is about 1.8 times that reported by the manufacturer.

Droplets produced during the spraying of both base coat and clear coat operations do retain some liquid solvent when the droplets reach the breathing zone of workers. The fraction of airborne solvent concentration represented by the droplets will be influenced by both the solvent vapor pressure in the mixture and the original droplet size. For the solvents and processes tested here droplets may contain up to 50 percent of airborne solvent concentrations. Thus, prefiltered charcoal sorbent tubes should be used to monitor worker exposure to solvents at spray application processes.

TABLE IX. Summary of Significant Differences between F-CST and CST Samplers ($p < 0.05$)*

	Xylene	Toluene
Base Coat Applications		
All sets	F-CST > CST	F-CST = CST
Test stand samplers	F-CST > CST	F-CST = CST
Personal monitors	F-CST > CST	CST > F-CST
Clear Coat Applications		
All sets	F-CST > CST	F-CST > CST
Test stand samplers	F-CST = CST	F-CST > CST
Personal monitors	F-CST > CST	F-CST > CST

*See Table VIII for abbreviations.

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References

1. Malek, R.F.; Daisey, J.M.; Cohen, B.S.: The Effect of Aerosol on Estimates of Inhalation Exposure to Airborne Styrene. Am. Ind. Hyg. Assoc. J. 47:524-529 (1986).
2. Peterson, J.E.; Copeland, R.A.; Hoyle, H.R.: Health Hazards of Spraying Polyurethane Foam Out-Of-Doors. Am. Ind. Hyg. Assoc. J. 23:345-352 (1962).
3. Chan, T.L.; D'Arcy, J.B.; Schreck, R.M.: High Solids Paint Overspray Aerosols in a Spray Painting Booth: Particle Size Analysis and Scrubber Efficiency. Am. Ind. Hyg. Assoc. J. 47:411-417 (1986).
4. 3M Occupational Health and Safety Products Division: 3M Organic Vapor Monitor: Sampling Rate Validation Protocol. 3M Center, St. Paul, MN.
5. Mark, D.; Vincent, J.H.: A New Personal Sampler for Airborne Total Dust in Workplaces. Ann. Occup. Hyg. 30:89-102 (1986).
6. ACGIH: Particle Size Selective Sampling in the Workplace. American Conference of Governmental Industrial Hygienists, Cincinnati, OH (1985).
7. Brosseau, L.M.; Fang, C.P.; Snyder, C.; Cohen, B.S.: Particle Size Distribution of Automobile Paint Sprays. Appl. Occup. Environ. Hyg. 7(9); 1992.
8. Geuskens, R.R.M.; Jongen, M.J.M.; Ravensberg, J.C.; van der Tuin, J.; Leenheers, L.H.; van der Wal, J.F.: Comparison of Active and Diffusive Sampling Methods for Environmental Monitoring of Styrene. Appl. Ind. Hyg. 5(6):364-369 (1990).
9. Pieper, R.M.: Letter: From Our Readers. Appl. Ind. Hyg. 5(12):826 (1990).
10. Pristas, R.: Benzene in Air—Organic Vapor Monitors Versus Charcoal Tubes. Am. Ind. Hyg. Assoc. J. 52(7):297-304 (1991).

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