Am. Ind. Hyg. Assoc. J. 50(4):216–223 (1989)

A Method for Monitoring Dermal Exposure to Volatile Chemicals

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Absorptive pads of charcoal cloth were developed and tested for monitoring the deposition of volatile toxic materials on skin. The dosimeters can retain over 60% of volatile deposits such as toluene or dichloropropene droplets over an 8-hr workday. Evaporation from liquid deposits and vapor adsorption onto the dosimeters are factors which can complicate the interpretation of exposure data. Evaporation was inversely proportional to the log of the deposit size (volume), vapor pressure, and the air humidity. Vapor adsorption was proportional to the vapor concentration, exposure duration, and the log of air velocity. A procedure is offered for estimating the initial size of the liquid deposit from retained mass. The charcoal cloth dosimeter's accuracy and precision are optimal in situations involving possible dermal exposure to toxic materials with low to moderate volatility or with low vapor concentration, *Le.*, those where dermal exposure may be equal to or more significant than respiratory exposure.

Introduction

The human skin is known to be variable permeable to miscellaneous toxic chemicals which are present in the workplace.[1-5] For instance, a large number of mostly low volatility substances, such as organophosphate pesticides,[3,6,7] enter the body primarily through the skin. The dermal route also can play an important role even for volatile chemicals, especially in a well ventilated workplace. In order to fully assess chemical exposure in such cases, one should evaluate the dermal exposure as well as the more traditional airborne exposure. Partly because of the historic emphasis of industrial hygiene on exposure via the respiratory route, the quantitive evaluation of such dermal exposures is poorly developed.

Direct evaluation of dermal exposure usually is far more complicated than that of the respiratory exposure. The main difficulties arise from the variability in deposition rates onto the body, the effect of clothing, the duration of actual skin contact with the chemical, and the importance of time in the retention and permeation of the chemical through the skin. Toxic materials may reach the skin as an aerosol (fallout of mist or soluble powder), spray (ballistic droplets versus mist), or via immersion, contact with contaminated surfaces (*e.g.*, tools or rags), or permeation through clothing (protective or otherwise). Distribution patterns of the deposited liquids over the skin in each case will be different, thus complicating quantitative evaluation. Nevertheless, several direct methods for monitoring dermal exposure have been developed since the early sixties, such as dermal dosimeters or patches,[8,9] hand or skin rinse,[8,10] the fluorescent tracer,[11] and the fiber optics luminescence skin monitor.[12]

Since volatile materials tend to disappear from surfaces rather quickly, the above methods in their present state of development will not be suitable for monitoring volatile dermal deposits. For instance, it was shown that even deposits of relatively low volatility compounds such as parathion and Kelthane®, are retained only partially (30% and 70%, respectively) on a fabric patch following 3-hr exposure at field conditions.[13] More volatile chemicals, such as organic solvents or fumigants, therefore, will disappear from a gauze dosimeter in a much shorter time. In fact, the authors' preliminary studies showed that only 0.1% of a 25-µl deposit of toluene was retained on a traditional 16-layer gauze pad after 10 min.

This report describes studies on charcoal cloth as a potential absorptive dermal dosimeter for evaluating deposition of volatile liquids on clothing or skin. Charcoal cloth is a 100% charcoal fabric which has shown good retention properties to various solvents and pesticides.[13] It was anticipated, however, that quantitative measurements using charcoal cloth as dermal dosimeters could be confounded by two factors: (1) partial evaporation from adsorbed liquids during the study and (2) adsorption of ambient vapors of the studied material onto the dosimeter.

The first factor will result in underestimating the initial amount of liquid which has deposited on the dosimeter. To account for this factor, the retention efficiency (RE) of the dosimeter for liquid depositions can be defined as follows:

$$RE\,(\%) = \frac{\text{Retained Liquid Deposit}}{\text{Initial Liquid Deposit}} \times 100 \qquad (1)$$

where "retained liquid deposit" is the amount of liquid remaining on the dosimeter at the end of the study.

Because of the second factor, the total amount of chemical collected on the dosimeter would include depositions from both the liquid phase and the vapor phase. Since charcoal cloth has a much higher adsorptive surface area than human skin, the amount of vapors adsorbed onto the dosimeter would be several times higher than the amount which could be adsorbed onto a similar area of human skin. From industrial hygiene perspectives, only the liquid portion would be of significance. This amount would be:

$$\text{Retained Liquid Deposit} = \text{Total Amount} - \text{Adsorbed Vapors} \qquad (2)$$

Equations 1 and 2 can be combined to yield the following:

$$\text{Initial Liquid Deposit} = \frac{\text{Total Amount} - \text{Adsorbed Vapors}}{RE/100} \qquad (3)$$

The total amount can be obtained from desorption and analysis of the dosimeter. In order to characterize the other

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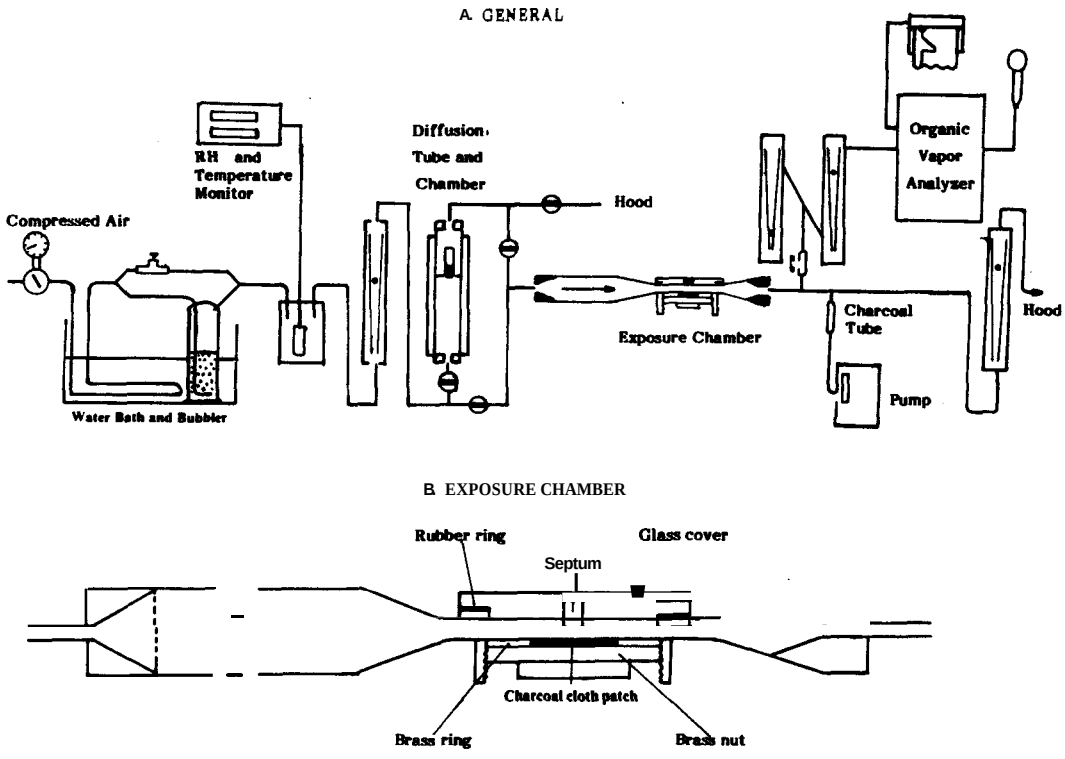

Figure 1—Apparatus for the testing of the charcoal cloth patches.

factors, the authors studied, in laboratory settings, the adsorptive capacity of charcoal cloth for volatile liquids, the retention efficiency at various conditions, and the rate at which vapors adsorb onto the charcoal cloth.

Materials and Methods

Laboratory study of charcoal cloth dosimeters was carried out in a controlled test atmosphere which included a vapor generation system (Figure 1). The dual monitoring system measured (a) the total chemical evaporation from deposited liquids by means of charcoal tubes (400/200 mg, SKC West, Inc., Fullerton, Calif.) connected to a Gilian personal air sampling pump (Gilian Instrument Corp., Wayne, N.J.) and (b) a continuous record of the evaporation rate using an Organic Vapor Analyzer (OVA) (Foxboro Analytical, North Haven. Conn.). The airflow into the OVA was monitored by Matheson model 602 rotameter (Matheson Gas Products, Inc., Secaucus, N.J.). An identical rotameter also was installed on a sidestream to dilute sampled vapors when necessary. An additional rotameter was installed at the outlet of the apparatus to verify that no losses from the airstream occurred along the study system.

The commercially available charcoal cloth (MDA Scientific, Glenview, Ill.) is derived from cellulose fabric which was treated chemically and physically to become 100% charcoal. cloth is a flexible, light (120 g/m^2) fabric with a large specific surface area (350 to 1400 m^2/g).[14] The breaking strength of the cloth is only 1.5 kg/cm, however, much lower than fabrics normally used for clothing.

Patches for laboratory experiments were made of one to six layers of 4.0-cm diameter circles sewn together. As these dosimeters were intended for use on workers in the field, it was necessary to protect the fragile cloth from potential abrasion. As a result, each dosimeter was tightly covered with a thin polyester fabric ("Horizon East" Japan, imported by Skinner, New York, N.Y.). Consequently, patches for laboratory tests also were covered tightly by the same fabric. Each patch was placed at the center of the exposure chamber and was allowed to equlibrate with the relative humidity and temperature for 10 min.

capacity of Charcoal Cloth

The capacity of charcoal cloth was studied by dosing a series of single circles with increasing volumes of toluene. The solvent was injected onto the center of each circle by means of a syringe with a nontapered needle (point style 3, Hamilton Co., Reno, Nev.) inserted through a septum in the glass cover of the chamber. Each circle was left in the chamber until no evaporation could be detected by the OVA and then was removed for extraction and analysis. Toluene was selected for this and other studies because of its polarity and moderate volatility.

Retention Efficiency for Volatile Liquids

A series of experiments was carried out to characterize the retention of liquid chemicals by charcoal cloth as well as the evaporation from such deposits. The effects of the following factors on evaporation loss were studied: (1) number of charcoal cloth layers in a dosimeter, (2) deposit size, (3) vapor pressure and polarity of the chemical, (4) relative humidity, (5) air temperature, and (6) air velocity. The procedure of dosing the patch was asdescribed above. In most experiments, evaporation from the dosimeter was monitored by separate charcoal tubes during the first 10 min after deposition ("short-term loss") and during the following 170 min ("long-term

loss"). The evaporation during the first interval was monitored by the OVA also. Evaporation losses in both intervals of each run then were combined to obtain the total 3-hr loss. The total loss was later combined with the portion recovered from the patch for mass-balance evaluation.

Adsorption of Vapors

For the vapor adsorption studies, the airstream first was passed through a vapor generation chamber, which contained a diffusion tube (Figure 1), before entering the exposure chamber. The amounts of toluene vapors generated were controlled by varying temperature, diffusion tube diameter, and diffusion path length. Charcoal cloth dosimeters used in these studies were made of two layers only.

At the end of each run, the dosimeters were divided into segments of two charcoal cloth layers each. Each segment was placed in a 4-dram vial with a Teflon@-linedcap, and wasdesorbed into 10 mL of carbon disulfide. Patches dosed with n-butanol or n-propanol were desorbed into a mixture of 10:1 (v:v) carbon disulfide:2-propanol. Patches dosed with ethanol were desorbed into 10:1 carbon disulfide:n-propanol mixture. Each section of the charcoal tubes was desorbed into 5 mL of the desorbing solvent. All vials were hand shaken for 30 sec prior to analysis.

The samples were analyzed on a Shimadzu GC-FID (Shimadzu Co., Columbia, Md.) equipped with a 10 ft, 1/8 in. O.D., 10% FFAP column on 80/100 chromosorb AW (Supelco, Inc., Bellefonte, Pa.) at the following conditions: carrier gas was nitrogen at 130 mL/min, flame gases were hydrogen at 75 mL/min and air at 700 mL/min, and detector temperature was 165° C. Five-μL aliquots were injected.

The desorption efficiency for each solvent was determined as follows. Two circles of charcoal cloth were dosed with 10 μL of the tested solvent while in a 4-dram vial. The vials were sealed for 3 hr, after which 10 mL of the desorbing reagent was introduced. The vials were hand shaken for 30 sec, and the solution then was analyzed. Calculated desorption efficiencies for each chemical are listed in Table I.

TABLE I
Desorption and Analysis Data for Chemicals Desorbed from Charcoal Cloth and Tube

	Desorption Efficiency		Column	Retention
Chemical	Charcoal Cloth	Charcoal Tube	Temp. (°C)	Time (min)
n-Hexane	100	100	95	0.49
Octane	99	99	100	0.70
Decane	100	99	100	1.37
Ethanol	92	99	110	1.58
Propanol	92	100	100	1.09
Butanol	94	97	140	1.18
Benzene	100	100	125	0.81
Toluene	98	100	125	1.18
o-Xylene	99	100	125	1.38
1,3-DCP	96	97	145	1.37

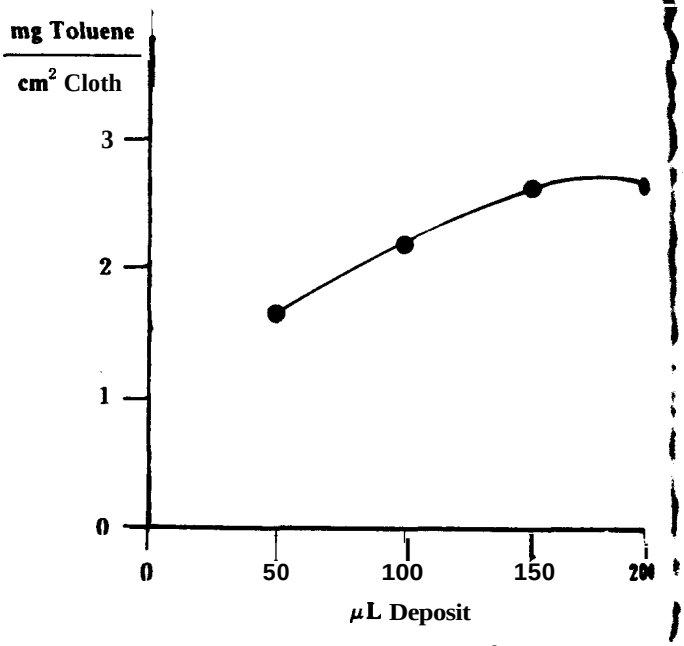

Figure 2—Capacity of charcoal cloth for toluene.

Charcoal Cloth *Field Dosimeters*

Six sets of three field dosimeters were prepared for testing the retention efficiency in field conditions. Each dosimeter was made of four 7.8 x 5.2-cm charcoal cloth layers sewn together and covered by the protective polyester fabric. The dosimeters were backed by a strong, polyethylene coated belting material which preserved the rectangular shape of the dosimeters and protected it against wetting by sweat. The dosimeters were kept in "zip-loc" polyethylene bags while not in use, to prevent adsorption of ambient vapors. After sampling, the dosimeters were returned to their bags and were stored in -20° C or less until desorption. The entire field dosimeter was desorbed into 70 mL of carbon disulfide and analyzed in a manner similar to that described above.

Results

Capacity of Charcoal Cloth

Figure 2 presents the average toluene content per cm^2 of cloth calculated for each dose level. With increasing dose this content approached a maximum of 2.8 mg/cm^2 or about 65 μL of toluene per gram of charcoal cloth. Such capacity for liquid toluene approximates only 10% of the reported charcoal cloth capacity for vapors of an unknown chemical.[14] This capacity gap probably resulted from the cloth having a relatively small number of intermediate size pores which are more accessible to liquids,[15] compared to the number of micropores, which adsorb primarily vapors. It is believed that further activation would enlarge the pores increasing their capacity for liquids.

Retention Efficiency for Volatile Liquids

Results of all retention efficiency studies are summarized in Table II. Mass balance on the retentionsand the corresponding total evaporation losses in all experiments indicated 96 ± 2.4% recovery. Thus, nearly all the applied solvent in each run could be accounted for.

(1) Evaporation pattern: Figure 3 describes the temporal evaporation pattern from a 25-μL toluene deposit remaining on a 4-layer dosimeter for up to 8 hr after deposition. The evaporation rate was high immediately after the deposition, decreased rapidly in the following few minutes, and remained low thereafter. The 10-min short-term loss accounted for about 28% of the initial dose, while only an additional 6% evaporated thereafter. This evaporation pattern recurred in all other studies, although the proportions between long-term and short-term losses were different.

(2) Number of layers in the dosimeter: a significant difference (about 16%) in retention efficiencies for 25 μL of toluene was found between 2-layer and 4-layer dosimeters but not between 4-layer and 6-layer dosimeters. A 4-layer dosimeter is preferred over the thicker 6-layers because of lower costs of preparation and analysis and ease of handling. Therefore, all other test dosimeters and field dosimeters were made of four charcoal cloth layers.

(3) Deposit size, air velocity, and relative humidity: The 3-hr evaporation loss was found to increase geometrically with the dose (μL) and air velocity (ft/min) (Equations 4 and 5, respectively) and exponentially with relative humidity (Equation 6).

$$\text{Log(loss)} = 1.29 + 0.169\ \text{Log(dose)} \qquad R^2 = 0.98 \qquad (4)$$

$$\text{Log(loss)} = 1.34 + 0.0932\ \text{Log(air velocity)} \qquad R^2 = 0.88 \qquad (5)$$

$$\text{Log(loss)} = 1.2 + 0.0057(\%RH) \qquad R^2 = 0.99 \qquad (6)$$

(4) Volatility and polarity: The 3-hr evaporation loss was found to increase geometrically with the vapor pressure (Figure 4). While the regression lines for the solvent groups were steeper with increasing solvent polarity, statistical analysis of the data via analysis of the covariance indicated that the difference among the slopes was not significant at $p = 0.05$. Thus, a single regression line was constructed for all these liquids.

(5) Temperature: The retention efficiency for 25 uL of toluene was 69.0 ± 0.5% and 20° C and 66.5 ± 2.1% at 30°C. This difference, although significant at $p = 0.05$, is relatively small. Thus, temperature effects within the normal work environment range can be ignored.

TABLE II
Retention Efficiencies and Losses (%) of Solvents from Charcoal Cloth Patches[A]

Variable	Variable Value		Total Loss Mean	Total Loss SD	Long-Term Loss Mean	Long-Term Loss SD	Retention (%) Mean	Retention (%) SD	Total Recovery Mean	Total Recovery SD
Number of layers in patch	2		44.0	2.8	5.4	0.6	53.2	3.4	97.3	2.1
	4		31.2	0.5	3.1	0.3	69.0	0.5	loo.	0.5
	6		30.9	2.5	4.4	1.1	69.3	1.0	loo.	1.4
Deposit size (μL)	1		20.0	4.1	4.0	0.8	78.4	6.0	98.4	1.4
	5		24.8	2.4	3.8	0.6	69.7	0.4	92.9	2.1
	25		31.2	0.5	3.1	0.3	69.0	0.5	loo.	0.5
	100		44.4	2.0	8.9	1.1	54.9	2.1	99.3	4.1
Solvent vapor pressure (mmHg)	decane	0.7	12.8	2.1	1.4	0.4	86.7	1.5	99.5	0.9
	butanol	4.1	19.4	2.3	4.7	1.0	79.4	2.9	98.8	2.7
	o-xylene	4.7	17.8	0.9	2.4	0.3	80.4	1.3	98.2	1.1
	octane	10.	27.8	1.6	0.5	0.5	67.9	1.1	95.7	2.5
	propanol	14.4	35.2	3.8	12.1	1.3	64.3	0.5	99.4	1.5
	1,3-DCP	19.	33.7	2.4	7.2	1.2	63.5	2.0	96.6	2.3
	toluene	24.7	31.2	0.5	3.1	0.3	69.0	0.5	loo.	0.5
	ethanol	43.6	58.6	6.7	27.2	2.9	35.8	3.1	94.4	4.1
	benzene	74.4	53.0	2.3	11.7	1.1	42.9	0.9	95.8	0.5
	hexane	120.	62.8	8.9	8.0	2.0	38.3	2.4	101.	3.5
Temp. (° C)	20		31.2	0.5	3.1	0.3	69.0	0.5	100.	0.5
	30		31.8	2.6	4.6	1.0	66.5	2.1	97.9	1.9
Relative humidity (%)	30		23.0	1.7	3.5	0.5	75.9	0.1	98.9	1.2
	50		31.2	0.5	3.1	0.3	69.0	0.5	loo.	0.5
	65		36.8	2.1	9.5	1.5	62.2	4.2	99.3	1.0
	80		44.8	2.3	14.5	1.0	52.2	0.9	97.0	0.4
	100		66.5				33.5	0.5		
Air velocity (fpm)	12		27.1	3.0	3.3	1.1	74.3	1.0	101.5	2.2
	29		31.2	0.5	3.1	0.3	69.0	0.5	loo.	0.5
	72		34.0	1.0	4.7	0.6	66.1	1.0	100.	1.1
	128		33.5	4.7	4.2	2.4	66.5	4.7	loo.	7.1

[A] Loss and retention data are the average of 3 runs. Runs were performed with 25 μL of solvent on 4-layer patches at 20° C, 50% RH, and 29 fpm air velocity unless otherwise stated. Toluene was used to study variables other than the vapor pressure.

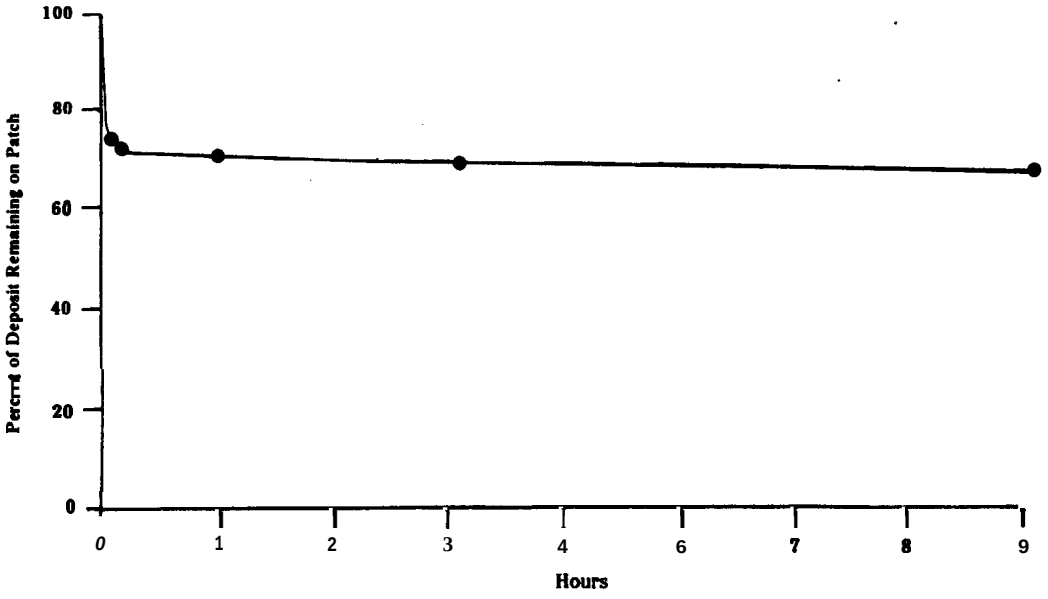

Figure 3—Percent of 25-μL toluene deposits remaining on 4-iayer patches at 20° C, 50%RH, and 29 ft/min air velocity. SDs are contained within circles.

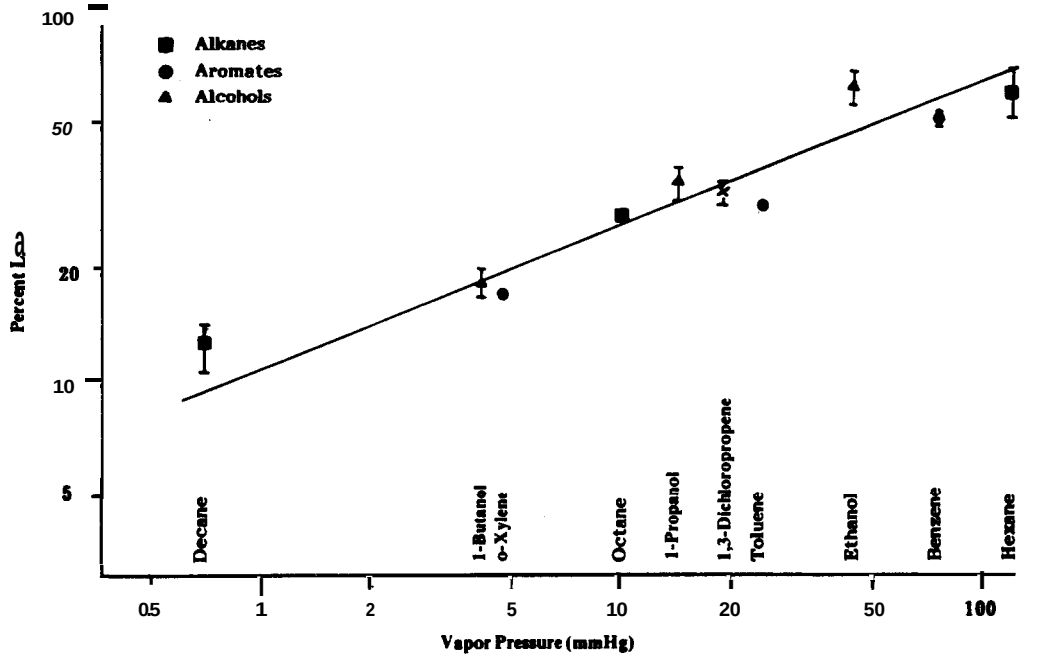

Figure 4—Effect of the vapor pressure on the total loss over 3 hr for 25-μL deposits at 50% RH and 29 ft/min air velocity.

(6) Summary Model: The effects of the above factors on the retention efficiency of a 4-layer dosimeter were combined into a single expression. The data in Table II were log-transformed and submitted to multiple regression analysis. This analysis showed that the effect of the air velocity on liquid retention efficiency could be deleted with no significant change in the "goodness of fit," thus yielding the following empirical model:

$$RE = 100 - 0.43VP^{0.30} \times RH^{0.76} \times DOSE^{0.155} \quad (7)$$

$R^2 = 0.85$; C.V. = 7.3% (coefficient of variance)

where

RE = retention efficiency (%);
VP = vapor pressure (mm Hg);
RH = relative humidity (%); and
DOSE = initial liquid deposit (uL).

(7) Retention on gauze pad: The retention of toluene on a traditional 16-layer gauze pad also was measured for comparison purpose. The pad was dosed and analyzed in a similar way as the charcoal cloth pads. The analysis showed that of the 25 μL of toluene deposited on the pad, only 0.02 μL (0.1%) remained after IO-min exposure in the ch

Adsorption of Vapors

The combined effect of vapor concentration and exposure duration on the amounts of toluene vapor adsorbed per unit area of charcoal cloth can be described by a linear model (Figure 5). The effect of air velocity on vapor adsorption can be expressed by a geometric model (Figure 6). It was assumed that very little interaction exists among the above three variables as long as the absorbed amount does not approach the charcoal cloth maximum capacity (see above). It can be further assumed (but not tested herein) that adsorption of vapor is primarily a colligative phenomenon. Under this assumption, the data were submitted to SPSS multiple regression analysis with log-transformed air velocity data, the regression line was forced through the origin, and the following empiric equation resulted:

$$AD = 0.021 \times t \times C \times V^{.25} \qquad (8)$$

$$R^2 = 0.99; \quad C.V. = 5\%$$

where

AD = amount adsorbed (μmol/cm^2);
t = exposure duration (hr);
C = vapor concentration (ppm); and
V = air velocity (m/min).

Charcoal Cloth Field Dosimeters

Equation 3 provides the basic framework for evaluating the initial liquid deposit on the charcoal dosimeter. This equation requires the knowledge of the retention efficiency (Equation 7) and vapor adsorption (Equation 8). Note, that Equation 7 requires, in turn, the knowledge of the initial liquid deposit (DOSE). By rearranging Equation 1 to read

$$\text{Initial Liquid Deposit} = \frac{\text{Retained Liquid} \times 100}{\text{Retention Efficiency}} = \frac{RL \times 100}{RE}$$

one can rewrite Equation 7 as follows:

$$RE = 100 - 0.43VP^{0.30} \; RH^{0.76} \; (RL \times 100/RE)^{0.155} \qquad (9)$$

Where RL is the amount of liquid retained on the dosimeter by the end of the monitoring period. This equation can be solved by a trial-and-error technique. Table III presents estimated values for the retention efficiency calculated by a FORTRAN program for different values of retained liquid, relative humidities, and vapor pressures. Once the retention efficiency is known, the initial liquid deposit can be evaluated from Equation 3.

Field Testing of the Summary Model

The accuracy of the summary model was tested in field conditions using six sets of three dermal dosimeters each. These dosimeters were dosed with known amounts of either

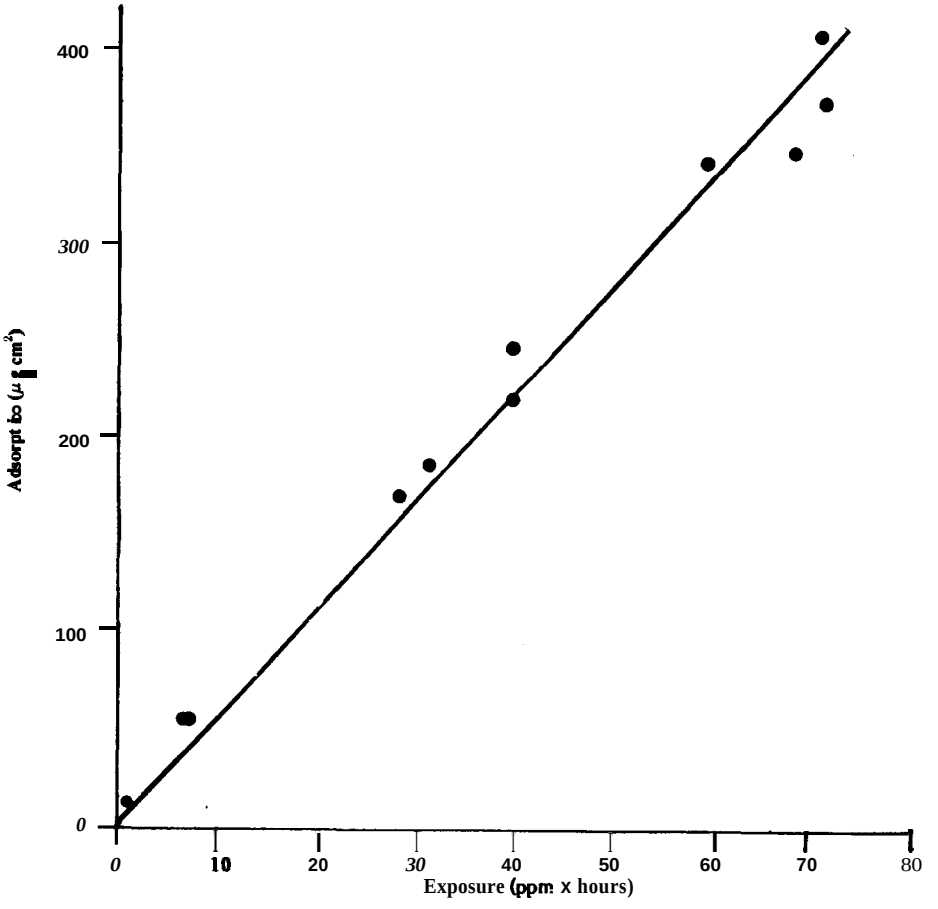

Figure 5—Adsorption of toluene vapors on charcoal cloth patches at 29 ft/min air velocity.

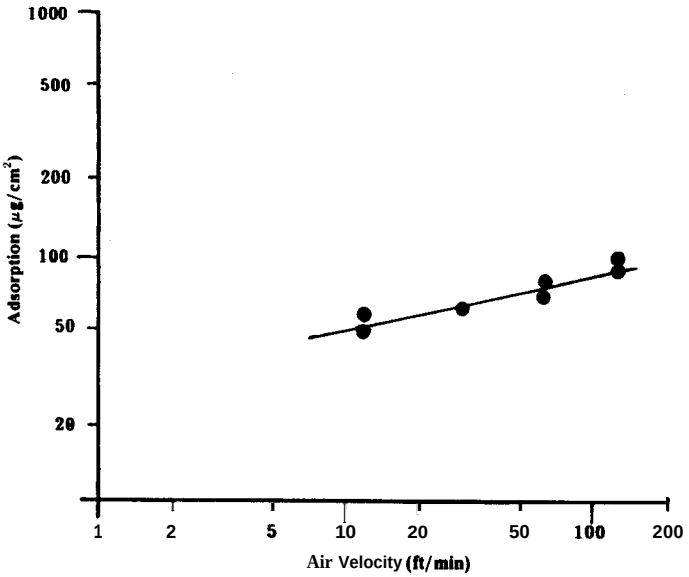

Figure 6—Effect of air velocity on the adsorption of toluene vapor onto charcoal cloth during 1 hr exposure at 7.5 ppm.

toluene or Telone II® (a fumigant containing 92% 1,3-dichloropropene) under agricultural field conditions and immediately were placed on the coverall of the investigator for 3 to 6 hr. The results of each experiment, as given in Table VI, indicated that retention efficienciespredicted by the model were within 20% of those observed.

Discussion

Both laboratory and field studies have demonstrated the ability of charcoal cloth dosimeters to retain significant portions of volatile liquids deposited over a workday period. The effects of some variables have been characterized and can be accounted for. The value of some variables, however, cannot always be measured. For example, Figure 3 illustrates how evaporation loss is affected by the time elapsed since deposition. In actual sampling, this elapsed time may be unknown. Also not known is whether the liquid had deposited as a few larger droplets or many small ones. The possible errors these variables introduce, however, and the overall precision of the method, were evaluated elsewhere.[16] It was shown that the method precision improved as the chemical volatility decreased. The coefficient of variance (C.V.) of the estimated retention efficiency (RE) was calculated to be

$$C.V.(RE) = 18\,(100/RE - 1).$$

The method's sensitivity and accuracy also can be greatly affected by the adsorption of vapors. High vapor concentration in the vicinity of the dosimeter may result in high "background" adsorption which could mask small liquid deposits and also would increase the uncertainty in estimating the retained liquid fraction. For example, according to Equation 5, 35 cm^2 of dosimeter exposed to about 5-ppm toluene vapor for 8 hr could adsorb about 12 mg of toluene. With such background only large liquid deposits, about 40 mg or more, could be confidently identified as being of a liquid source. It is believed that vapor adsorption may be reduced by reducing activation of the charcoal and by covering the charcoal with a fabric more resistant to vapor but not liquid diffusion.

The dosimeters ideally should be used for monitoring highly toxic materials which are either harmful to the skin or can permeate the skin readily. Materials with high volatility (*e.g.*, vapor pressure around 10 mm Hg and higher) should be monitored only where ventilation effectively reduces vapor concentration. Chemical volatility also affects the usefulness of these dosimeters in a different fashion: a liquid deposit on the skin is subject to evaporation to the air on one side and to percutaneous absorption on the other side. Thus, increased volatility means short contact period on the skin and ,therefore, minimal dermal absorption. The chemical toxicity and the work practices also should be considered in each case in order to determine whether the amounts of material likely to reach the worker's skin could indeed be harmful and warrant monitoring.

Similar to the gauze pad dosimeters, charcoal cloth dosimeters may be used for monitoring exposure of uncovered skin and used underneath or over the worker's clothing. Hand or face exposure can be monitored by attaching dosimeters to thin cotton gloves or an operator's hat, respectively. Outside clothing exposure can be monitored by attaching dosimeters to an operator's gear by means of Velcro. Material permeating through clothing can be documented by attaching dosimeters to an operator's underclothing or to elastic bands wrapped around the extremities.

It is assumed that dosimeters not covered by workers' clothing will have similar retention characteristics as those used under similar conditions in the laboratory tests. Therefore, the quantitative model can be used for calculating the initial deposit on these dosimeters. Use of dosimeters underneath clothing may help to evaluate the effectiveness of

TABLE III
Estimated Retention Efficienciesfor Charcoal Cloth Patches as a Function of Vapor Pressure, Retained Liquid, and Humidity

Vapor Pressure (mmHg)	0.3				1.0				4.0				10				15			
Retain Liquid (μL)	10	25	60	100	10	25	60	100	10	25	60	100	10	25	60	100	10	25	60	100
Relative Humidity (%)																				
30	94	93	92	92	92	90	89	88	87	85	83	82	83	81	77	75	81	78	75	72
50	91	90	89	88	88	86	84	83	81	78	75	73	75	71	66	63	72	67	61	58
70	89	87	85	84	84	82	79	77	75	72	67	64	67	62	55	51	62	56	49	
90	87	84	82	81	81	78	74	72	70	75	60	56	60	52	44	38	53	45	34	26

TABLE IV
Retention Efficiency (RE) of Field Test Dosimeters

Chemical	Vapor Pressure (mmHg)	Dose (μL)	Relative Humidity (%)	Wind Velocity (fpm)	Expected RE (%)	Observed RE (%)
Toluene	24.7	5	44	350	75.4	68.3
Toluene	24.7	10	47	55	70.6	66.1
Toluene	24.7	25	44	350	67.8	58.6
Toluene	24.7	50	47	55	63.1	59.7
1,3-DCP	19.3	3	80	570	67.1	65.4
1,3-DCP	19.3	10	80	570	62.1	50.8

protective clothing *in siru.* but it is expected that because of high humidity, dosimeters inside clothing will have lower retention characteristics.

The ultimate goal for monitoring dermal exposure is to evaluate the potential harm posed by a process or setting. The dermal dosimeter can be useful in the first step toward such a goal, evaluating the amount of chemical deposited onto the skin. This may be sufficient for irritants or allergens, but for systemic toxicants, one would further need to know both the absorbed dose and the dose-response relationship. Estimating the absorbed dose is a field which still offers more questions than answers.[16] One approach would employ the percutaneous flux rate and the evaporation rate of a chemical to estimate "exposure time" and the fraction of a deposition which would be absorbed dermally. For example. 1,3-dichloropropene has a measured vapor pressure of approximately 20 mmHg and an estimated human dermal flux of about 30 $\mu g/cm^2/min$.[15] It was shown that a 5-μL deposit will evaporate from 3.14 cm^2 of exposed rat skin within 1 min, while a 50 uL deposit over the same area will evaporate in about 4 min. Based on the above data, it can be estimated that 0.5% to 1% of a 1,3-dichloropropene deposit would be absorbed by human skin if left in open air.[15] With more research, a general model could be developed which will allow quantitative estimation of the absorbed fractions of volatile dermal doses.

Conclusion

Dermal exposure to a volatile chemical may prove at times to be as significant as the respiratory exposure. This will be true for readily absorbed substances where work practices and available protective clothing do not provide adequate protection to the skin. The charcoal cloth dosimeters were developed for direct monitoring of the dermal exposure to such chemicals. Depending on the exposure characteristics, the dosimeters can be used for quantitative evaluation of volatile liquid deposits, qualitative indicators of chemical contact with the skin, or as a means for *in siru* testing of the effectiveness of protective clothing. While it was shown that the dosimeters can retain volatile deposits over a workday period, more work is needed to minimize confounding effects of vapor adsorption and continuous evaporation and to increase the dosimeter's capacity.

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22 March 1988; Revised 24 September 1988