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Benzene Exposure Assessment for Use of a Mineral Spirits–Based Degreaser

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This study examines benzene emissions from the use of a metal parts washer ("degreaser") supplied with a mineral spirits solvent containing either 9 or 58 ppm benzene. Air samples were obtained during a one-hour session of relatively vigorous parts cleaning activity using a degreaser station equipped with wet brush and sprayer attachments and a compressed air hose. Two methods were utilized to assess airborne benzene levels: U.S. EPA TO-14 (summa stainless steel canister) and NIOSH 1501 (charcoal tube). Overall, both methods provided similar results, excepting detection limit differences. The first simulation was performed with recycled solvent (9 ppm benzene in solvent) showing average one-hour airborne benzene levels $\leq$33 ppbv in the worker's breathing zone and directly above the parts cleaning tank. Average airborne benzene concentrations 18 inches away from the tank were below 2 ppbv during the 60-minute cleaning protocol. The second simulation with benzene-spiked recycled solvent (58 ppm benzene) showed airborne benzene levels averaging 500 ppbv measured over the 60-minute cleaning period in the worker's breathing zone and directly above the tank, while average concentrations 18 inches from the tank perimeter were 63 ppbv. The data indicate that average and peak exposures to airborne benzene were roughly proportional to the solvent benzene content, although the brief peak exposures exhibited greater variance probably related to aerosol generation associated with the use of the brush and/or spraying attachment. Under this selected upper bound exposure simulation, we found that cleaning parts using a recycled mineral spirits–based solvent in an open warehouse setting did not result in exposures in excess of the current occupational exposure limit of 0.5 ppm averaged over 8 hours for solvent benzene content between 9 and 58 ppm.

Keywords Benzene, Exposure, Degreaser, Solvent

Petroleum distillate mixtures often contain a relatively broad range of aromatic hydrocarbons, including benzene, at parts per million levels. Benzene is classified as a known human carcinogen.[1–3] The mineral spirits mixture examined in this study (solvent naphtha, heavy aliphatic, hydrotreated) is one example of a petroleum distillate. Processing of mineral spirits, especially the use of hydrotreatment, can result in a reduction of the benzene content to low part per million levels.[3] Benzene is one of the most volatile components of mineral spirits, since it has a higher vapor pressure than the C-9 to C-12 hydrocarbons that comprise most of the mass in a given mineral spirits mixture. Consequently, benzene and other lighter hydrocarbons are released more readily in vapor emissions from mineral spirits use, which means its concentration declines quickly unless more is added by the user.

Workers using benzene-containing petroleum hydrocarbon products may not be aware of benzene hazards associated with some product applications. The federal Occupational Safety and Health Administration (OSHA) hazard communication standard[4] requires that carcinogenic substances be specifically listed on the product Material Safety Data Sheet when the concentration is at least 0.1 percent by weight, that is, above 1000 parts per million (ppm). The standard also specifies that listing is required if the use of the product can result in exposures that would exceed an established OSHA Permissible Exposure Limit or American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Value (TLV®), or could present a health risk to employees.

Explicit methods for determining compliance under the latter considerations are not provided in the OSHA hazard communication regulations. However, disclosure of benzene content below 1000 ppm for certain products may be appropriate to avoid transient exposures that may exceed OSHA standards under certain product applications.

The purpose of the current study is to examine the benzene emissions and exposure concentrations for workers using

An abbreviated version of this research was presented as a poster session at the Society of Toxicology annual meeting in March 2000.

or working in the vicinity of a commercial degreaser station supplied with a recycled mineral spirits solvent. This study was designed to examine peak and time-weighted average (TWA) exposures for mineral spirits solvent containing two different trace benzene concentrations (9 and 58 ppm) during a standardized 60-minute protocol of relatively vigorous metal parts cleaning in a warehouse setting.

METHODS

Solvent Material Tested

The degreasing solvent used in these studies is a recyclable degreaser mixture that is comprised of approximately 99 percent (all percents by weight) solvent naphtha (heavy aliphatic, hydrotreated light petroleum distillate), along with 0.1 percent perchloroethylene (introduced by users). The product specifications call for a density range from 770 to 880 g/L and a vapor pressure of 1 to 2 mm Hg at 20°C (68°F). A green dye is added to the solvent such that the final product is a clear green liquid. The vast majority of this mixture (90+%) is comprised of straight chain and branched chain aliphatic hydrocarbons, having 9 to 12 carbons on average. Each of the studies reported here utilized a typical batch of freshly recycled product, and thus the initial benzene levels reflected those present in the product after distillation of used product and adding back sufficient fresh solvent to meet current product volume demands.

The concentrations of benzene and other constituents in the hydrotreated naphtha as measured using two different gas chromatographic (GC) analytical methods (see below) are identified in Table I. As can be seen, EPA Method 8240 (EPA, 1997) involving an extraction step followed by GC with mass spectrophotometric detection (MS) gave a result of 3.6 ppm benzene (estimated value, below laboratory reporting limit), while analysis by direct-inject GC separation with photoionization detection (PID) method gave a result of 9 ppm in the first worker exposure assessment study. Similarly, the GC/MS method gave a result of 53 ppm benzene and the direct-inject GC/PID method gave a result of 58 ppm in the second worker exposure study. For purposes of this study, we assumed the direct-inject GC/PID method to be more accurate.

Degreaser Station Description

The degreaser station utilized in the worker exposure assessment studies (Studies 1 and 2) was a rectangular steel structure with a lid that closes to limit vaporization of solvent when not in use. As illustrated in Figure 1, the degreaser station has a solvent reservoir for storing approximately 30 gallons of solvent, with a metal working surface covering half of the reservoir surface area. The working surface (24″ × 21.5″) and solvent surface (24″ × 21.5″) when the station is initially filled are both approximately 36 inches from average breathing zone height for a standing adult person using the degreaser. This station has an electric recirculating pump that supplies solvent to two cleaning attachments. One attachment, the pressurized manual hand-spray nozzle, is similar to a standard garden hand-trigger sprayer for rinsing parts under pressure. The other attachment, a solvent-fed brush, is a small cone-shaped brush fitted with a hose that provides continuous solvent flow through three concentric rings of stiff nylon bristles for brush-cleaning of parts.

An air compressor was set up for the operation to air dry parts. This air spray hose is not a component of the degreaser station but could be used to more rapidly dry the cleaned parts. The practice of drying parts using compressed air was included to enhance the conservatism of the worker exposure scenario.

Setting of the Studies

The degreaser exposure studies were conducted in a warehouse facility in the greater Los Angeles area. The degreaser station was located approximately 2 feet from a wall, facing

TABLE I
Test solvent concentrations of selected compounds

	Study 1 average concentration (ppm)[A]		Study 2 average concentration (ppm)[B]	
Compound	Method 8240	Direct injection	Method 8240	Direct injection
Benzene	3.6[C]	9	53 ± 1.4[C,D]	58
Toluene	548 ± 84[C]		168 ± 34[C]	
Perchloroethylene	291 ± 55[C]		221 ± 25[C]	
Total xylenes	161 ± 23[C]		240 ± 31[C]	

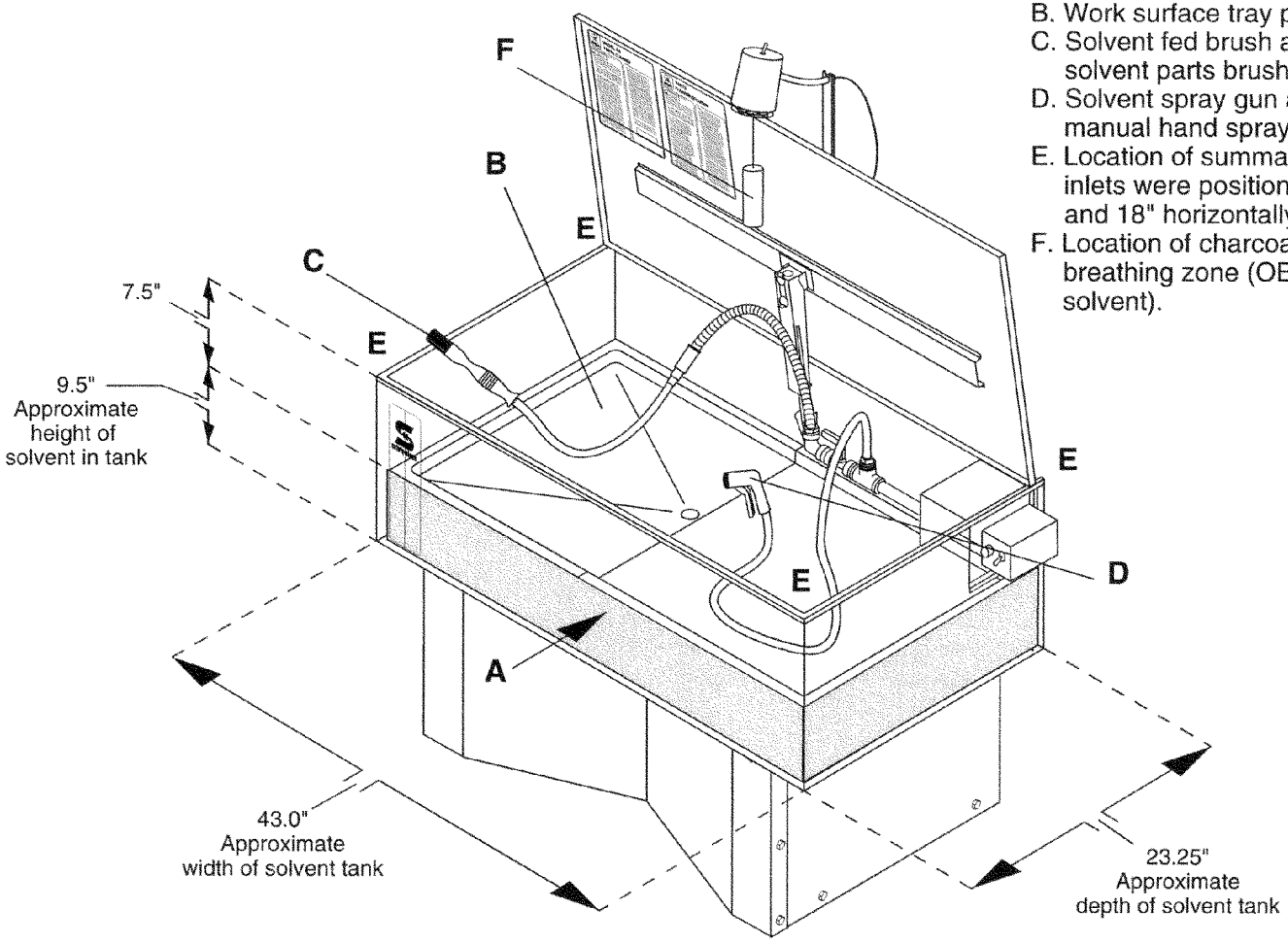
[A]Study 1 was conducted in December 1998 using recycled degreaser solvent directly from the factory (i.e., as purchased by industrial users).

[B]Study 2 was conducted in February 1999 using recycled degreaser solvent that was spiked with pure benzene at a target level of adding 50,000 ppb to the recycled solvent mixture.

[C]Data expressed as mean ± standard error for n = 4 for all compounds except benzene in study 1, which is the average of two matrix spike samples corrected for the spike added (two unspiked samples were nondetect for benzene).

[D]Concentration measured before spiking with benzene was 2.8 ppm.

A. Solvent reservoir approximately 50% of top surface was exposed during testing to simulate normal use.
B. Work surface tray provides resting area for parts.
C. Solvent fed brush attachment (continuous flow solvent parts brush).
D. Solvent spray gun attachment (pressurized manual hand spray nozzle).
E. Location of summa canister and charcoal tube inlets were positioned 24" above the tanks edge and 18" horizontally from corners.
F. Location of charcoal tube sampler for operator breathing zone (OBZ) height samples (33" above solvent).



NOT TO SCALE - Drawing depicts approximate configuration.

Image depicted is the Safety-Kleen Model 44 Parts Washer

FIGURE 1
Solvent degreaser station schematic.

outward into a portion of a warehouse facility that measured approximately 200 feet long by 300 feet wide by 30 feet high. A smoke test was conducted after each study to examine the air flow characteristics; the second study was videotaped for later analysis. The smoke tests indicated primarily vertical flow of air above the degreaser station at a linear flow rate of approximately 0.5 feet per second with the degreaser open (and not being used).

The warehouse testing area had two large garage doors of dimensions 10 by 16 feet that were open during both studies, but provided no appreciable air flow disturbance in the immediate area of the degreaser station. There were no overhead fans in the building, and air flow characteristics were dominated by the two large garage doors that were typically open during working hours. There were no external air flow disturbance events during the 60 minute degreasing protocol period that would significantly influence the air flow characteristics of the testing area. Indoor and outdoor temperatures during both studies were between 65 and 70°F.

The first worker exposure assessment experiment (Study 1) was conducted in December, and the ambient temperature was 66°F and the relative humidity at 11 percent both inside and outside the warehouse building. The temperature of the degreasing solvent was 63°F. Ambient indoor and outdoor air samples were taken before the solvent material was loaded into the degreaser station in the morning. Several summa canister samples were taken to examine baseline airborne benzene levels in the warehouse and outdoors prior to the cleaning simulation. The main sampling event, that is, during the 60-minute degreaser use protocol, began approximately 30 minutes after the degreaser station was filled with solvent.

The second worker exposure assessment experiment (Study 2) was conducted in February, and the ambient temperature was 68°F and the relative humidity at 10 percent both inside and outside the warehouse building. The temperature of the degreasing solvent was 65°F. All test procedures used in the second study were identical to those described above for the first study.

Degreaser Station Use Protocol

A protocol was developed for Studies 1 and 2 to simulate aggressive parts washing, which would overestimate exposure potential with respect to using agitation with the pressurized manual hand-spray nozzle attachment, the solvent-fed brush attachment, and the separate air hose equipment. A basket of metal parts (39 pieces of bent and tubular copper and galvanized metal fittings approximately 2 to 3 inches long) was used for both studies. As illustrated in Figure 2, the 60-minute protocol simulated a series of soaking, spray rinsing, brushing, compressed air spraying, and inspecting events that were considered to be representative of fairly vigorous degreasing activity over an hour of using the solvent degreasing station.

Sampling and Analytical Methods

Worker exposures to airborne benzene in Studies 1 and 2 were assessed using U.S. EPA Method TO-14 and NIOSH Method 1501. The TO-14 method uses certified clean stainless steel summa canisters for collecting integrated and grab air samples. The integrated samples were collected in each study over the entire 60-minute protocol described above and illustrated in Figure 2. The sampler inlets were located 18 inches outside each of the four corners of the degreaser station, but displaced

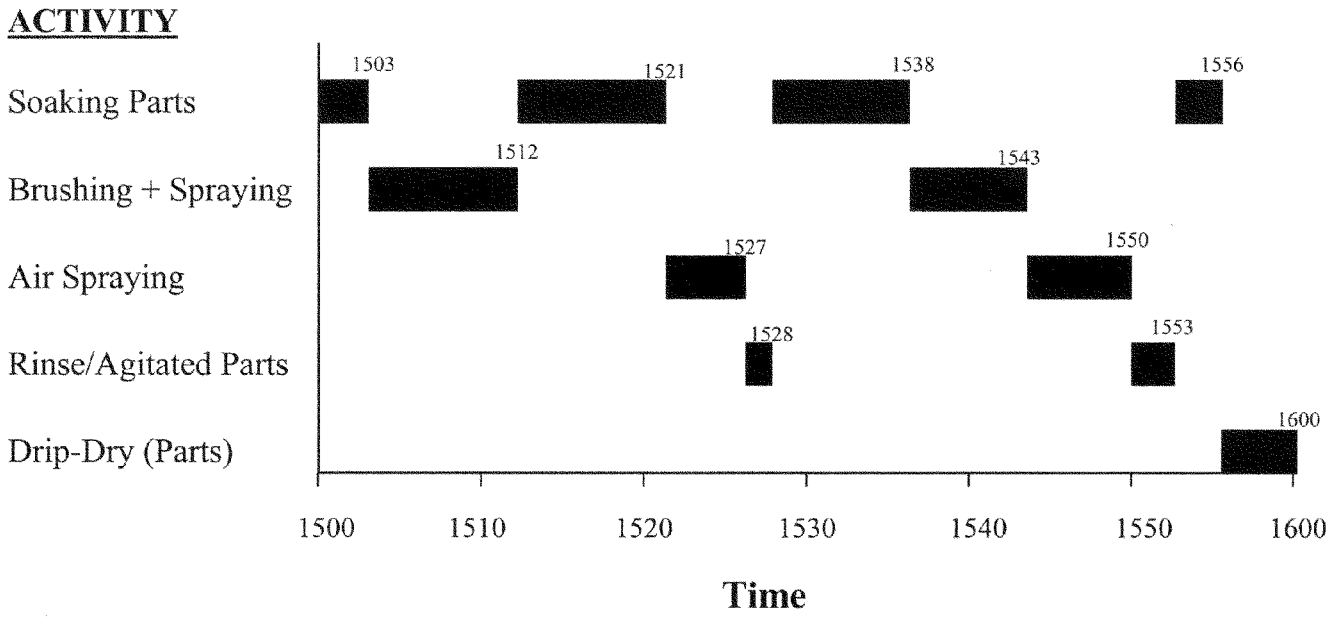


FIGURE 2
Timeline for degreasing activity.

24 inches above the edge of the tank (at a height of 59 to 60 inches approximating breathing zone height).

The summa canisters for integrated samples were pre- and post-calibrated at a constant metered sampling rate of approximately 0.18 liters per minute, collecting approximately 11 liters total per canister. Each canister, including ambient indoor and outdoor samples was assayed by Method TO-14 for benzene and perchloroethylene. Grab samples were obtained to assess short-term benzene exposure concentrations associated with parts washing activities that are expected to generate an aerosol.

Airborne concentrations of PERC were measured concurrently with benzene for all samples taken by U.S. EPA Method TO-14. The ratio of background-corrected concentrations of benzene:PERC was utilized as a quality control check in regard to data consistency.

All analytical work for the TO-14 samples was conducted by Air Toxics laboratories in Folsom, California, following standard operating procedures in accordance with certified EPA laboratory protocols. Labeled summa canisters with chain-of-custody records were logged in and then re-labeled with a laboratory code.

The U.S. EPA TO-14 methodology[7] utilizes summa canister collection techniques combined with GC/MS to measure a broad range of volatile organic compounds. Organic compounds from the air samples are concentrated at cryogenic temperatures and are then thermally desorbed into a capillary GC system for separation and analysis using electron capture detection (ECD) or flame ionization detection (FID). The canister is pressurized with ultra-high-purity nitrogen to 10–15 pounds per square inch, the final pressure is recorded, and a measured portion of the gas sample (typically 100 to 500 ml) is loaded onto the GC column using a cryotrapping system.

Samples are analyzed on a Hewlett Packard 5890 Series II gas chromatograph and a Hewlett Packard 5971 MDS quadrupole mass spectrometer detector. Compounds are calibrated by the external standard procedure using NIST-traceable air standards. The relative percent difference of a duplicate pair is about 30 percent at 5 ppbv and the average method detection limit is approximately 0.1 ppbv for the compounds of interest in this study. Compounds detected were identified using a library search to obtain the best spectrum match.

NIOSH Method 1501[8] using charcoal tubes was utilized to provide cross-check data for the integrated TO-14 benzene sampling results in the worker exposure assessment studies. The charcoal tube inlets were co-located above the corners of the degreaser station and were collected over the same timeframe as described above for the TO-14 sampling canisters. This method was also used to obtain grab samples in the worker's breathing zone and above the parts tray inside the degreaser tank (within 12 inches of the parts). Ambient indoor and outdoor samples and trip blanks were also collected.

The NIOSH Method 1501 has an analytical detection limit of 0.9 μg. Samples were collected at flow rates between 184 and 195 cc/min for sample volume of between 10.9 and 11.4 liters. The limit of detection for this one-hour sample ranged from 20 to 30 ppbv or about two orders of magnitude higher than the TO-14 approach (typically 0.1 to 0.2 ppbv for the TO-14 approach).

The charcoal tubes were analyzed for benzene in accordance with NIOSH Method 1501 at Health Sciences Associates laboratory (Los Alamitos, CA), which is certified by American Industrial Hygiene Association (AIHA) to perform this method. The charcoal tubes were extracted with methylene chloride, concentrated, and analyzed using gas chromatography with flame ionization detection (NIOSH, 1994).

Two data sets were generated for the worker exposure assessment studies to examine the benzene content of the tested solvent mixtures. One data set was generated in accordance with standard operating procedures for U.S. EPA Method 8240[9] at Southwest Research Institute Laboratories (San Antonio, TX). The samples were taken in 40 ml volatile organics analysis vials and were shipped on ice with chain of custody records to the laboratory. The samples were logged in and assigned a laboratory code. A measured volume of solvent was dissolved in distilled water, extracted, and analyzed in accordance with the published method using a Finnigan-E GC/MS with packed column technique to reach a detection limit as low as 10 ppbv for the blank solutions. The final concentrations in μg/L were adjusted to reflect parts per million (ppm) using an assumed solvent density of 0.8 g/ml. Benzene was the primary target analyte, although other compounds measured at the same dilution using Method 8240 are also reported in Table I.

The second data set for the worker exposure assessment studies was generated by direct injection of an aliquot of the solvent mixture (1 microliter) into an HP5890 gas chromatograph fitted with two 5 percent phenyl methyl silicone capillary columns (0.32 mm I.D. $\times$ 50 m length and 1:35 split ratio for aromatic hydrocarbons; 0.25 μm I.D. $\times$ 30 m length and 1:200 split ratio for halogenated compounds) and photoionization (PID @ 250°C for hydrocarbons) and electron capture detectors (ECD @ 300°C for halogenated compounds). The temperature program for halogenated compounds included an injector temperature of 225°C, an initial column temperature of 40°C for 2 minutes followed by a ramp of 30°C per minute for 7 minutes and 20 additional minutes at 250°C. The temperature program for aromatic hydrocarbon compounds included an injector temperature of 225°C, an initial column temperature of 40°C for 6 minutes followed by a ramp of 10°C per minute for 6 minutes, then a second ramp of 70°C per minute and a hold at 250°C for 11 minutes.

RESULTS

The concentrations of benzene and other selected compounds in the degreaser solvents utilized in the worker exposure assessment studies are summarized in Table I. The original benzene concentrations were similar in the mineral spirits mixture used in each study before spiking (3 to 4 ppm by EPA Method 8240, 9–10 ppm by direct-inject GC/PID method). Study 2

involved spiking the product to a target benzene concentration of approximately 50 ppm greater than the standard amount present in recycled solvent. The benzene concentration results for both studies show lower reported levels associated with analysis by the U.S. EPA Method 8240 as compared to the direct injection method.

If one assumes the direct injection method (avoiding extraction steps) is the more accurate result, then the U.S. EPA method underpredicted the benzene concentration by about 60 percent in Study 1 (9 ppm benzene in solution), wherein benzene levels were nondetectable and had to be estimated from matrix spike data. At the spiked concentration of 58 ppm benzene in solution in Study 2, the differential between methods was considerably less (about 9%) and the benzene peak was within the quantifiable range for U.S. EPA Method 8240.

Airborne benzene concentrations determined in area samples collected using integrated EPA TO-14 and NIOSH Method 1501 are summarized in Table II. Background indoor air measurements obtained before the simulation and outdoor ambient concentrations are also identified. The average airborne benzene concentration measured at breathing zone height about 18 inches from the perimeter of the degreaser station using the EPA method was 1.9 ppbv at a solvent benzene content of 9 ppm and 63 ppbv at a solvent benzene content of 58 ppm (a 33-fold airborne concentration increase for a 6.4-fold increase in solvent benzene content). Parallel samples measured at 18 inches

TABLE II
Airborne benzene concentrations measured by NIOSH and USEPA sampling and analysis protocols

Sample type	Location	Solvent benzene content (ppm)	NIOSH method airborne benzene (ppb)	USEPA method airborne benzene (ppb)
Experiment No. 1				
Area-60 min.	Outdoors	0	ND (<30)	0.81
Area-60 min.	Indoors	0	ND (<20)	0.88
Area-60 min.	Degreaser perimeter	9	ND (<20)	4.8
	18 inches above the	9	ND (<30)	2.7
	4 corners of tank	9	No data[A]	1.4
		9	ND (<30)	2.1
Area-60 min.	Personal sampler	9	ND (<30)	NS
Area-60 min.	Over tank	9	33	NS
Grab-<60 sec.	12 in. from parts			
	During brushing	9	NS	160
	During air spraying	9	NS	120
Experiment No. 2				
Area-60 min.	Outdoors	0	NS	1.4
Area-60 min.	Indoors	0	ND (<20)	1.4
Area-60 min.	Degreaser perimeter	58	87	100
	18 inches above the	58	44	39
	4 corners of tank	58	93	80
		58	35	34
Area-60 min.	Personal sampler	58	440	NS
Area-60 min.	Over tank	58	550	NS
Grab-<60 sec.	12 in. from parts			
	During brushing-1	58	NS	530
	During air spraying	58	NS	220
	During brushing-2	58	NS	730
Grab-<60 sec.	18 in. above tank after solvent transfer	58	NS	800
Grab-<60 sec.	Operator breathing zone			
	Parts submerged/soaking	58	NS	140
	Parts up from soak, draining	58	NS	110

NA = Not applicable; NS = No sample taken.
ND = Not detected at reporting limit listed in parentheses.
[A]One of the four perimeter samples registered 58 ppb using the NIOSH method and was judged as an invalid sample because all other perimeter samples using both NIOSH and U.S. EPA methods were ND or below 5 ppb, including the co-located summa canister sample (at 1.4 ppb).

from the perimeter of the degreaser station using the NIOSH Method were below the limit of detection ($\leq$33 ppbv) at a solvent benzene content of 9 ppm and averaged 65 ppbv at a solvent benzene content of 58 ppm. These perimeter measurements can be considered plausible upper bound exposure conditions for individuals working adjacent to the degreaser station.

In each experiment, two integrated samples were obtained to evaluate upper bound exposures to individuals actively using the degreaser for 60 minutes, in accordance with the activity protocol identified in Figure 2. Both samples were obtained using NIOSH Method 1501 for airborne benzene. As shown in Table II, a personal sampler device in the operator's breathing zone during the entire 60-minute degreaser use protocol showed no detectable airborne benzene (detection limit 33 ppbv) at a solvent benzene content of 9 ppm (Study 1), and 440 ppbv airborne benzene at a solvent benzene content of 58 ppm (Study 2, an increase of at least 13-fold in airborne benzene concentration for a 6.4-fold increase in solvent benzene content). Similarly, an area sample taken at breathing zone height directly over the rear portion of the degreaser station showed 33 ppbv airborne benzene at a solvent benzene content of 9 ppm (Study 1), and 550 ppbv airborne benzene at a solvent benzene content of 58 ppm (Study 2, an increase of nearly 17-fold in airborne benzene for a 6.4-fold increase in solvent benzene content). The differences in ratios may be due to slight differences in parts cleaning activity and/or local air flow between the two experiments.

Peak benzene exposures associated with parts washing in the worker exposure assessment studies are also identified in Table II. Airborne benzene concentrations measured in 60-second grab samples at 12 inches above the metal parts during cleaning activities averaged 140 ppbv at a solvent benzene content of 9 ppm (Study 1, n = 2), and averaged 492 ppbv at a solvent benzene content of 58 ppm (Study 2, n = 3). Grab samples obtained in the operator breathing zone during periods after active brushing (when the parts were soaking in the tank) averaged 125 ppbv (n = 2) at a solvent benzene content of 58 ppm (Study 2). The airborne benzene concentration was 800 ppbv at 18 inches above the degreaser tank immediately after transfer of the 58 ppm benzene content solvent from the storage barrel into the degreaser station (Study 2) based on another summa canister grab sample.

The highest airborne benzene concentrations in both experiments were obtained during active use of the solvent sprayer and brushing attachments and the separate compressed air hose used for drying parts. Visible solvent aerosols were observed intermittently during vigorous brushing or spraying of the metal parts.

All analytical work performed by the various laboratories involved was of satisfactory quality based on the standard operating procedures applicable to the respective analytical methods. Laboratory and trip blanks, matrix spikes, and instrument calibration curves were within normal quality control limits. Results for benzene: PERC ratios (background subtracted) for all samples taken by U.S. EPA Method TO-14 demonstrated a high degree of data consistency utilizing this method. In Study 1 at 9 ppm solvent benzene content, the mean ratio of airborne benzene:PERC (ppbv) was 0.035 with a standard error of 0.0036 (n = 7). In Study 2 at 58 ppm solvent benzene content, the mean ratio of airborne benzene:PERC was 0.59 with a standard error of 0.041 (n = 10).

DISCUSSION

The current study provides evidence that certain products with a benzene content below the 0.1 percent OSHA reporting threshold but above the typical mineral spirits levels (for hydrotreated light petroleum distillate, <10 ppm) may be associated with worker exposures exceeding current OSHA workplace exposure limits on a transient basis in vigorous use applications. The study demonstrated that airborne benzene exposures in a warehouse setting are well below the OSHA workplace exposure limits at a degreaser solvent benzene content of 9 ppm. Peak concentrations adjacent to the parts during active washing were well below the OSHA permissible exposure limit of 500 ppbv (PEL, applicable as an 8-hour time-weighted average) as well as the short-term exposure limit of 2500 ppbv (STEL, applicable as a 15-minute maximum not to be exceeded more than 4 times per work day).

However, spiking the solvent with benzene to achieve a benzene content of 58 ppm led to 1-hour average exposures that approached the PEL. If such work activity were to be performed over an entire work day it is likely that employee exposures could approach regulatory limits, although mass balance considerations indicate that the benzene concentration in a heavy use scenario would drop off quickly.

The results of this study were compared to theoretical estimates of maximum air concentrations above an organic mixture. The partial pressure of any component of a mixture can be estimated using Raoult's Law:

$$P' = X * VP \quad [1]$$

where X is the mole fraction of the component in the mixture and VP is the vapor pressure of the pure component. Using a vapor pressure of 0.125 atmospheres for pure benzene, and assuming that the mole fraction is approximated by the weight fraction, the benzene concentration in air immediately above the mixture would be:

$$C_{air}\ (ppb) = 125 * C_{liquid}\ (ppm) \quad [2]$$

Thus, one would expect the air concentrations to increase at a similar rate with concentrations in the liquid mixture. However, the data indicate a much lower rate of increase in air concentrations as the benzene content in the solvent mixture increases. This could be due to either experimental conditions (e.g., non-equilibrium conditions and dilution effects) or deviations from Raoult's Law at the relatively low mole fraction of benzene in the solvent mixture evaluated.

The exact configuration of the degreaser station (e.g., solvent capacity, exposed surface area, distance from solvent level to breathing zone) and usage patterns by employees (e.g., use of sprayer, brush, and air hose attachments, duration of cleaning activity, nature of parts being cleaned, etc.) are likely to be important with respect to both worker exposures and the loss rate of volatiles like benzene from the solvent mixture. We chose to conservatively address these parameters by designing a relatively long and rigorous course of parts cleaning using a freshly recycled solvent mixture. The worker exposure assessment studies involved fairly rigorous cleaning of parts that generated visible aerosols and also involved intermittent use of a compressed air hose that perturbs local air flow and mixing. These conditions were considered to represent upper bound benzene emissions and maximal worker exposures relevant to standard uses of this degreaser station.

It is also important to consider that the trace levels of benzene initially present in the solvent will diminish with repeated use, likely showing an exponential pattern of benzene loss over the period the degreaser station is used. Hence, the highest benzene exposures under any given set of degreaser use conditions will occur immediately after replacing the solvent. Such elevated exposures will be relatively short lived. For example, the solvent benzene content is approximately halved after about 5 hours of degreaser operation and is reduced by an order of magnitude within 16 hours of recirculation mode operation (data not shown).

Increased temperature also could increase the rate of benzene and other vapor emissions during operation of a degreaser, resulting in higher benzene exposures than measured in the current studies (i.e., average solvent temperature was 63 to 65°F and indoor air temperatures were 65 to 68°F). One can reasonably expect the vapor emission rates and associated exposure concentrations to approximately double for every 10°C (18°F) increase in temperature.[5,6] Although higher temperatures will likely cause higher short-term exposures to benzene, this also corresponds to a more rapid benzene loss rate from the solvent and considerably lower benzene exposures with each subsequent use as compared to use under cooler conditions. Thus, an apparent balance is likely to be present between temperature conditions and frequency of use with respect to longer-term average exposures during degreasing activities.

Ventilation conditions are also important in determining whether the data in the current study is relevant to a given set of workplace environmental conditions. The current worker exposure assessment studies were conducted in a moderate size warehouse building with two open garage doors at one end of the building; the indoor atmosphere was relatively undisturbed with the exception of the degreaser operator activities (which included use of a compressed air hose to dry the parts intermittently as shown in Figure 2). Conditions creating turbulence or winds blowing across the degreaser unit could transiently raise the exposures to nearby workers and raise or lower exposures to the operators. However, detailed consideration of ventilation influences was not within the scope of the current study. The applicability of the current study to a given workplace exposure prediction must consider comparability of the workplace ventilation conditions, as well as temperature, frequency and duration of degreaser use, and, most importantly, the initial benzene content of the solvent utilized.

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