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Evaluation of COSHH Essentials: Methylene Chloride, Isopropanol, and Acetone Exposures in a Small Printing Plant

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The current study evaluated the Control of Substances Hazardous to Health (COSHH) Essentials model for short-term task-based exposures and full-shift exposures using measured concentrations of three volatile organic chemicals at a small printing plant. A total of 188 exposure measurements of isopropanol and 187 measurements of acetone were collected and each measurement took ∼60 min. Historically, collected time-weighted average concentrations (seven results) were evaluated for methylene chloride. The COSHH Essentials model recommended general ventilation control for both isopropanol and acetone. There was good agreement between the task-based exposure measurements and the COSHH Essentials predicted exposure range (PER) for cleaning and print preparation with isopropanol and for cleaning with acetone. For the other tasks and for full-shift exposures, agreement between the exposure measurements and the PER was either moderate or poor. However, for both isopropanol and acetone, our findings suggested that the COSHH Essentials model worked reasonably well because the probabilities of short-term exposure measurements exceeding short-term occupational exposure limits (OELs) or full-shift exposures exceeding the corresponding full-shift OELs were <0.05 under the recommended control strategy. For methylene chloride, the COSHH Essentials recommended containment control but a follow-up study was not able to be performed because it had already been replaced with a less hazardous substance (acetone). This was considered a more acceptable alternative to increasing the level of control.

Keywords: control banding; COSHH Essentials; exposure assessment; occupational exposure limits; risk assessment tool; R-phrases

INTRODUCTION

There is much uncertainty regarding the health effects of exposure to chemicals, and it is not possible to precisely predict a specific health response to any given exposure. This lack of clear understanding causes industrial hygienists to use best judgment in determining an acceptable working environment. This judgment often is based on a body of prior knowledge codified in published occupational exposure standards, many of which have entered local and national regulations as occupational exposure limits (OELs), particularly for airborne substances. These limits have been published for many chemicals, and are based on the premise that control of workplace exposures below these values will result in a safe working environment for the majority of workers. It is known that OELs are not necessarily protective values for every individual and that the occurrence of unforeseen health effects or a reappraisal of known health effects may later invalidate established values. Further, for many chemicals there is insufficient data on which to set an OEL. However, OELs have been set for many commonly encountered chemicals and there is an encouraging trend toward international

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consensus in these standards. Thus OELs form an important foundation for expert judgment and can be used as a benchmark against which to consider different methods for assessing exposures, their risks, and the efficacy of controls. Since it is rarely possible to measure each worker's exposure and its variation over time, recourse is made to mathematical models, such as stochastic models based on field measurements of randomly sampled workers or deterministic models that do not require an input of sampling measurement data.

Two serious issues for exposure assessment are the option of determining short-term versus long-term exposure average concentrations and the rate at which individual exposure determination may exceed the OEL. These issues are related. If the significant health end points (e.g. irritation, narcosis, and acute poisoning) are known to result from short episodes of typically high concentration, it makes the most sense to use short periods of exposure estimation and to make sufficient determinations to ensure a high probability of the workplace being free of these 'acute' hazards. On the other hand, the hygienist will want to ensure the probability of any single exposure exceeding the OEL is low since the consequences may be immediate and dramatic. However, the thresholds for the onset of short-term effects are well known and large safety margins are normally included in setting the OEL, so that minor excursions may not be immediately dangerous to life or health. If the significant health end points are the result of cumulative exposures causing chronic damage (e.g. liver, kidney, or lung disease), then a long-term average measure of exposure is more appropriate. While some OELs include the concept of a (working) lifetime average exposure, this particular timescale is impractical when wishing to take action to prevent ill-health. Therefore, the typical time-period compromise used to assess long-term exposures is the daily shift average. The long-term consequences of an exposure above a daily OEL may not be significant when averaged over a lifetime, but the threshold to guard against chronic disease is less certain than is the threshold triggering acute effects, so that more caution may be warranted.

Short-term exposure measurement techniques have been developed for assessing short-term OELs promulgated for chemicals with acute modes of action. However, if such exposures are assumed to occur randomly during a work shift, then assessing the probability of overexposure to a short-term OEL during that shift would require a large number of randomly spaced samples. A more cost-effective approach involves incorporating expert judgment to identify high-risk situations, typically through a task-based approach. Under this paradigm, short-term exposures are assumed to be the result of specific tasks and that identifying these tasks and measuring exposures during the task will result in an accurate quantification, not just of the maximum short-term exposure risks but also of the most significant contributions to the long-term daily average exposure. Expert analysis of this kind is, however, subject to well-known (Flegal *et al.*, 1986; Hawkins and Evans, 1989) and documented errors of oversight and misclassification. Part of the popularity of the task-based exposure assessment approach is that it can lead automatically to task-based approaches to control.

The Health and Safety Executive (HSE) in Great Britain developed a risk management tool called Control of Substances Hazardous to Health (COSHH) Essentials intended to be utilized by small- and medium-sized enterprises (Brooke, 1998; Maidment, 1998; Russell *et al.*, 1998). It provides a control recommendation based on the combination of toxicological hazard assessment and exposure assessment. The COSHH Essentials tool assigns a target exposure range with low risk based on the hazardous nature of the substance, i.e. the more hazardous the chemical, the lower the assigned target exposure range. It then uses the amount and physical characteristics of a chemical and temperature of the process to determine an exposure prediction level (EPL). The EPL combined with the control strategy determines a predicted exposure range (PER) for each type of control strategy. The program then recommends the appropriate control strategy which, for the input parameters, would give a PER matching the target exposure range (Maidment, 1998). The toxicological hazard assessment is based on so-called risk phrases (R-phrases) used in the European Union (EU) to describe risks (see http://ecb.jrc.it/classification-labelling/). These R-phrases, which might more precisely be called hazard phrases, are required information on material safety data sheets in the EU. The exposure assessment portion of COSHH Essentials was based on a set of historic measurements obtained in specific occupations by the HSE, presumably in the course of exposure assessment investigations, many of which were undertaken for regulatory purposes. Since most OELs are long-term time-weighted averages (TWAs), it might be assumed that the database used to develop COSHH Essentials might also be dominated by long-term measurements. Such a criticism has also been leveled against the Estimation and Assessment of Substance Exposure (EASE) model, a slightly older and more complex deterministic model, which could be said to be a progenitor of COSHH Essentials. The only published evaluation of the exposure prediction aspects of COSHH Essentials involved comparison to a German database of exposure measurements that might similarly be biased toward long-term average measurements (Tischer *et al.*, 2003). However, many proponents of the COSHH Essentials model are adamant that it was formulated as a task-based assessment tool, in which case its exposure predictions could also be compared against short-term OELs. In general, it can be concluded that the exposure assessment model of COSHH Essentials ought to be rigorously validated with prospectively collected field measurements, at least for task-based exposures, and perhaps also for full-shift exposures (Maidment, 1998; Tischer *et al.*, 2003; Jones and Nicas, 2006; Hashimoto *et al.*, 2007; Evans and Garrod, 2006; Money *et al.*, 2006).

This study evaluated the COSHH Essentials model at a small printing plant serving a university in the southeast USA with historically collected data of methylene chloride (dichloromethane; CAS 75-09-2) and prospectively collected field measurements of isopropanol (propan-2-ol; CAS 67-63-0) and acetone (propan-2-one; CAS 67-64-1). Repeated measurements of personal air samples were taken, and the exposure distribution curve was estimated based on these air samples for full-shift average concentrations and for short-term average concentrations, typically dominated by single tasks. The accuracy of the exposure range predicted from the COSHH Essentials model was then compared to the measured exposure distribution curve by estimating the probability of a worker's exposure exceeding the upper limit (L_U) of the PER. Then, the recommended control scenarios from the model were examined for reasonableness in the light of prevailing regulatory and advisory OEL standards by estimating the probability of a worker's exposure exceeding the OELs. In this work, we have used a probability of 5% (0.05) to make a judgment. This figure is based on the criterion used by the National Institute for Occupational Safety and Health (NIOSH) for acceptability of exposures in US workplaces (Leidel *et al.*, 1977).

METHODS

Sample collection at a printing plant

The printing plant had three active printing presses and 25 employees working on the production floor, although only a small number of these actually ran the presses and thus were closely exposed to chemicals used in cleaning or to the ink solvent evaporating during the printing process. More employees were indirectly exposed at a lower level as general ventilation to the room was provided through the heating ventilation and air conditioning (HVAC) system and emissions from the production process were not controlled. In this study, only three employees directly involved with running and cleaning the presses were included. All task-based activities (i.e. cleaning and print preparation) were manually performed and the frequencies and job durations of each task are listed in Table 1. Figure 1 shows several printing presses of the print shop.

Methylene chloride. Employee exposures resulted from cleaning the rollers on the presses. Personal samples were collected historically by industrial hygiene students at the university conducting health hazard evaluations (HHEs) of the print shop as part of their education. The HHEs were conducted during the years 1993–2000 with the exception of 1994 and 1997. Seven TWA measurements were available for analysis. The boiling point of methylene chloride is 40°C and it was used at ambient temperatures of ~23°C. Also, small quantities (<2.5 l) of the cleaning solution were used for this operation. However, the frequency and duration of cleaning were not known. Thus, it was assumed that the exposures remained constant over the time frame evaluated and the same frequency and duration as used for acetone were used to simulate exposures in the COSHH Essentials model.

Table 1. Tasks and physical characteristics of chemicals

Task	Chemicals	Physical state	BP (°C)	OT (°C)	Freq[a]	Duration (min)[b]	Control strategy[c]	n[d]
Cleaning	Methylene chloride (55–65% w/w)	Liquid	40	23	10	10	General ventilation	7
	Isopropanol (10–20% w/w)	Liquid	83	23	10	10	General ventilation	30
	Acetone (40–50% w/w)	Liquid	56.5	23	10	10	General ventilation	30
Printing process	Isopropanol (99% w/w)	Liquid	83	23	1	480	General ventilation	73
	Acetone	Liquid	56.5	23	—[e]	—[e]	General ventilation	73
Print preparation	Isopropanol	Liquid	83	23	—[e]	—[e]	General ventilation	85
	Acetone	Liquid	56.5	23	—[e]	—[e]	General ventilation	84

BP = boiling point temperature; OT = operating temperature.
[a]Freq = number of times used per day.
[b]Time duration per use.
[c]Exposure control running at the time of sample collection.
[d]Number of total measurements.
[e]Chemicals were not used for these tasks. However, due to the existence of residual concentrations of these chemicals, these were included and simulated in the COSHH Essentials (1 frequency and 480 min duration was used).

Fig. 1. The view of printing presses in the print shop.

Isopropanol and acetone. Three tasks were mainly involved in the printing process: (i) cleaning of the rollers, (ii) printing process, and (iii) print preparation. Among these tasks, it was expected that the cleaning task might produce the highest exposure. The cleaning solution is composite of volatile organic compounds including isopropanol (10–20% w/w) and acetone (40–50% w/w), with the remainder being VM&P naphtha (CAS No. 8032-32-4). When a mixture of chemicals exists that does not have common critical health effects, the generally accepted procedure is to analyze the mixture according to its separate components and select the most rigorous control of the indicated controls (Maidment, 1998; AIHA, 2007). Historical surveys of this printing operation indicated that both isopropanol and acetone exposures were higher in comparison to their respective exposure limits than were exposures to VM&P naphtha [Neither the US NIOSH nor the US Occupational Safety and Health Administration (OSHA) classify VM&P naphtha as an occupational carcinogen (American Conference of Governmental Industrial Hygienists, ACGIH, 2008) gives a classification of A3—Confirmed animal carcinogen with unknown relevance to humans]. The authors recognize that VM&P naphtha is defined as carcinogenic according to Commission Directive 2008/58/EC and REACH Compliance-Annex I of Directive 67/548/EEC and mutagenic by Commission Directive 2008/58/EC. Local standards were employed in this study]. Isopropanol and acetone have boiling points of 83 and 57°C, respectively, and the operating temperature of the printing plant was ~23°C. The cleaning operation was performed ~10 times per day, with each time small quantities (<2.5 l) being used for ~10 min. The printing process involved mainly isopropanol (99.9%) as a fountain solution additive. The fountain solution additive was stored in a container with a loose-fitting lid with a capacity of ~19 l. This solution is continuously used in the printing process. During the task of printing preparation, no chemicals were used. However, isopropanol and acetone from the cleaning and printing tasks might accumulate in the room air over time due to the absence of a local exhaust ventilation system.

Personal samples were collected from three employees using personal sampling pumps and adsorbent tubes. The collected samples were analyzed by Method 69 from the OSHA Manual of Analytical Methods for acetone (Orbo 91, Carbosieve S-III tubes, SUPELCO Inc., Bellefonte, PA, USA) and Method 1400 from the NIOSH Manual of Analytical Methods for isopropanol (226-01, coconut charcoal tubes, SKC Inc., Eighty Four, PA, USA). Analysis was carried out by NIOSH or its contract laboratory. Four separate sampling campaigns were performed over 3 years; 13–17 December 2004, 29 March to 1 April 2005, 13–17 February 2006, and 7–10 March 2006. Each individual measurement was for ~60 min. A total of 188 measurements for isopropanol and 187 measurements for acetone were collected. One of the acetone measurements was lost during analysis. Table 1 shows tasks and physical characteristics of chemical components.

COSHH Essentials tool

The recommended engineering controls depend on the toxicity of the substances in conjunction with an exposure estimate. In the COSHH Essentials model, R-phrases are used to gauge human health toxicity. R-phrases can be found from several resources, but in our experience, R-phrases obtained from different resources were not always consistent. Other researchers (Rudén and Hansson, 2003; Zalk and Nelson, 2008) also commented on the inaccuracy of R-phrases and the problem this causes for the critical role they play in the COSHH Essentials. In 1992, the Globally Harmonized Scheme for Classification and Labeling of Chemicals was initiated from the

United Nations Conference on Environment and Development to provide consistent chemical hazards classification. It is to be hoped that this project will eventually provide consistent information to control banding model users. Over the next few years, it will be adopted in the EU (2008a), but for the current study, the best source of R-phrases was the European Commission Joint Research Centre Institute for Health and Consumer Protection (EU, 2008b). After obtaining the R-phrases, the hazard band for each chemical was estimated. The hazard band was D (very toxic on single exposure, reproductive hazard) for the methylene chloride and A (skin and eye irritants) for both isopropanol and acetone (note Table 2). Then, the target exposure band (TEB) was obtained based on the R-phrases. Due to the high toxicity, the TEB of methylene chloride was <0.5 p.p.m. and the TEB of the isopropanol and acetone ranged from 50 to 500 p.p.m.

Given the information of the boiling point of liquid and operating temperature, the volatility of methylene chloride, isopropanol, and acetone was classified as high, medium, and medium, respectively. The quantities used in the solution fell into either small-scale operation (<2.5 l) or medium-scale operation (between 2.5 and 1000 l), as shown in Table 2. The small quantities of material with medium and high volatility correspond to EPL Band 2 while the medium scale with medium volatility corresponds to EPL3. The user should be careful in defining the amount of chemicals and volatility. For example, an increase of operating temperature could change volatility from low to medium (or high) and thus result in a different EPL band. For the control strategy of general ventilation in place at the time of sampling, EPL band 2 for small quantities of methylene chloride, isopropanol and acetone leads to a PER of 5 to 50 p.p.m., while EPL band 3 for medium quantities of isopropanol leads to a PER of 50 to 500 p.p.m.

Given the considerations of health hazard and exposure potential detailed above, COSHH Essentials recommends containment control for the methylene chloride and general ventilation control for the others. As noted, general ventilation was the control method at the time of sample collection.

Analysis

For the isopropanol and acetone measurements, each individual sample can be treated as a task-based exposure measurement. This is reasonable because a single task dominated most of the sampled time and a change in task was often taken as an opportunity to change samples. The actual sampling time ranged from 9 to 82 min (average 44 min) for the cleaning, 15 to 148 min (average 63 min) for the printing process, and 32 to 102 min (average 64 min) for the print preparation. These results were

Table 2. Required components for COSHH Essentials tool and control strategy prediction

Task	Chemicals	Required components for the COSHH Essentials tool				Prediction of control strategy
		Volatility	Quantity (PER)[a]	R-phrases[b]	Hazard band (TEB)	
Cleaning	Methylene chloride (55–65% w/w)	High	Small[c] (5–50 p.p.m.)	20, 22, 40, Carc.Cat.3	D (<0.5 p.p.m.)	Containment
	Isopropanol (10–20% w/w)	Medium	Small[c] (5–50 p.p.m.)	36, 67	A (50–500 p.p.m.)	General ventilation
	Acetone (40–50% w/w)	Medium	Small[c] (5–50 p.p.m.)	36, 66, 67	A (50–500 p.p.m.)	General ventilation
Printing process	Isopropanol (99% w/w)	Medium	Medium[d] (50–500 p.p.m.)	36, 67	A (50–500 p.p.m.)	General ventilation
	Acetone	Medium	Small[e] (5–50 p.p.m.)	36, 66, 67	A (50–500 p.p.m.)	General ventilation
Print preparation	Isopropanol	Medium	Small[e] (5–50 p.p.m.)	36, 67	A (50–500 p.p.m.)	General ventilation
	Acetone	Medium	Small[e] (5–50 p.p.m.)	36, 66, 67	A (50–500 p.p.m.)	General ventilation

[a]PER—this range is derived from the combination of an EPL and a control strategy.
[b]Classification of R-phrases found from http://ecb.jrc.it/classification-labelling/.
[c]Small = <2.5 l.
[d]Medium = 2.5–1000 l.
[e]Assumed small quantities of substances, 1 frequency and 480 min duration.

used in the task-based analysis of COSHH Essentials exposure predictions and were also compared to short-term regulatory and advisory limit values (where available) in evaluating the control recommendations from the model. Hashimoto *et al.* (2007) evaluated the COSHH Essentials against measurement-based comprehensive risk assessment at 12 workplaces of a petroleum company in Japan. In their study, exposures where the monitoring time exceeded 15 min were converted to the 8-h TWA exposures to compare with the ACGIH threshold limit values (TLVs)–TWA. In this study, however, only those shifts where at least 300 min of exposure had been measured were compared to exposure limits for 8-h TWAs. Full-shift exposures were estimated using the TWA calculated for each employee using equation (1), where C_i is the concentration of the ith measurement of the day and T_i is the sampling time of the ith measurement of the day. Values below the limit of detection (LOD) for the chemical mass on the adsorbent tubes were imputed with the $\mathrm{LOD}/\sqrt{2}$. A total of 25 full-shift exposures were used in the analysis.

$$\mathrm{TWA} = \frac{\sum_{i=1}^{n} C_i T_i}{\sum_{i=1}^{n} T_i}. \tag{1}$$

Note that the full-shift TWA exposure was not separated by task unlike the short-term exposure. This makes sense because in small firms workers do not usually perform one task for a full-shift. For example, on one typical day, a worker was involved in 196 min of print preparation, 176 min of printing, and 81 min of cleaning. The next day the same worker spent 0 min in print preparation, 122 min in printing, and 210 min in cleaning.

The data were analyzed by determining the probability distribution and finding the probabilities of being above or below the PER or the applicable OEL. In order to generate the probability distribution curve, the distribution of measurements were simulated by resampling the initial data, with replacement, until a sample size of 1000 data points was reached. This resampled data set was used to estimate the parameters of probability distributions to see which distribution the data would best fit. For each condition, the distribution of best fit, even after testing with the Anderson–Darling test, was the two-parameter (shape and scale) lognormal distribution. Then, the probability of being higher than the upper limit or being less than the lower limit of the predicted range was estimated.

The control method at the time of sampling and the recommended method resulting from the COSHH Essentials were evaluated in the light of prevailing regulatory and advisory standards such as the ACGIH TLV, OSHA permissible exposure limits (PEL), and British HSE workplace exposure limits (WELs).

RESULTS AND DISCUSSION

Short-term exposure of single tasks

Isopropanol exposure. Five of 30 measurements (cleaning task) and four of 85 measurements (print preparation) were above the upper limit of the PER, as shown in Fig. 2. Seventy-two of 73 measurements for the printing process were below the lower limit of the PER. Note that the PER of the printing process was from 50 to 500 p.p.m. while the PER of the other tasks was from 5 to 50 p.p.m. due to the use of different amount of solution. The estimated average employee exposure was 35.5, 21.5, and 22.5 p.p.m. for the cleaning, printing process, and print preparation, respectively (Table 3). The measured data had fairly moderate or high variability [coefficient of variation (CV) = 0.87 (cleaning), 0.54 (printing process), and 0.58 (print preparation)].

Except for the printing process, overall the model reasonably predicted the PER for the other tasks; the probability of exposure measurements between the upper limit and the lower limit of the PER ($L_L < P < L_U$) was 0.72, 0.118, and 0.81 for the cleaning, printing process, and print preparation, respectively. For the printing process, it was highly unlikely that an employee's exposure would exceed the upper limit of the PER ($P > L_U = 0.0001$), whereas the cleaning and print preparation showed the opposite results.

It is interesting to note that the employees' exposures for the cleaning were higher than those for the printing process, whereas the PER of the printing process (50–500 p.p.m.) was wider than the PER of the cleaning (5–50 p.p.m.) by a factor of 10. These model predictions were driven by the quantities of substances used. The isopropanol was used as an additive in the printing process. The additive was in a reservoir with an ~19 l capacity, which sat next to the press. The existence of the large reservoir put the isopropanol exposure into a higher expected exposure band. However, it might not be the actual cause of the employee isopropanol exposures as only small quantities evaporate during the print process. Logs kept during the sampling process indicated that significant amounts of time were spent cleaning the presses. It is possible that the model predicted high exposures because of the reservoir, but the actual exposures resulted from much smaller quantities of isopropanol cleaner used in the near-field during the work shift.

Acetone exposure. The average employee exposure for the cleaning (41.4 p.p.m.) was significantly higher than the other two tasks shown in Table 3 and Fig. 3; 10 of 30 measurements were above the

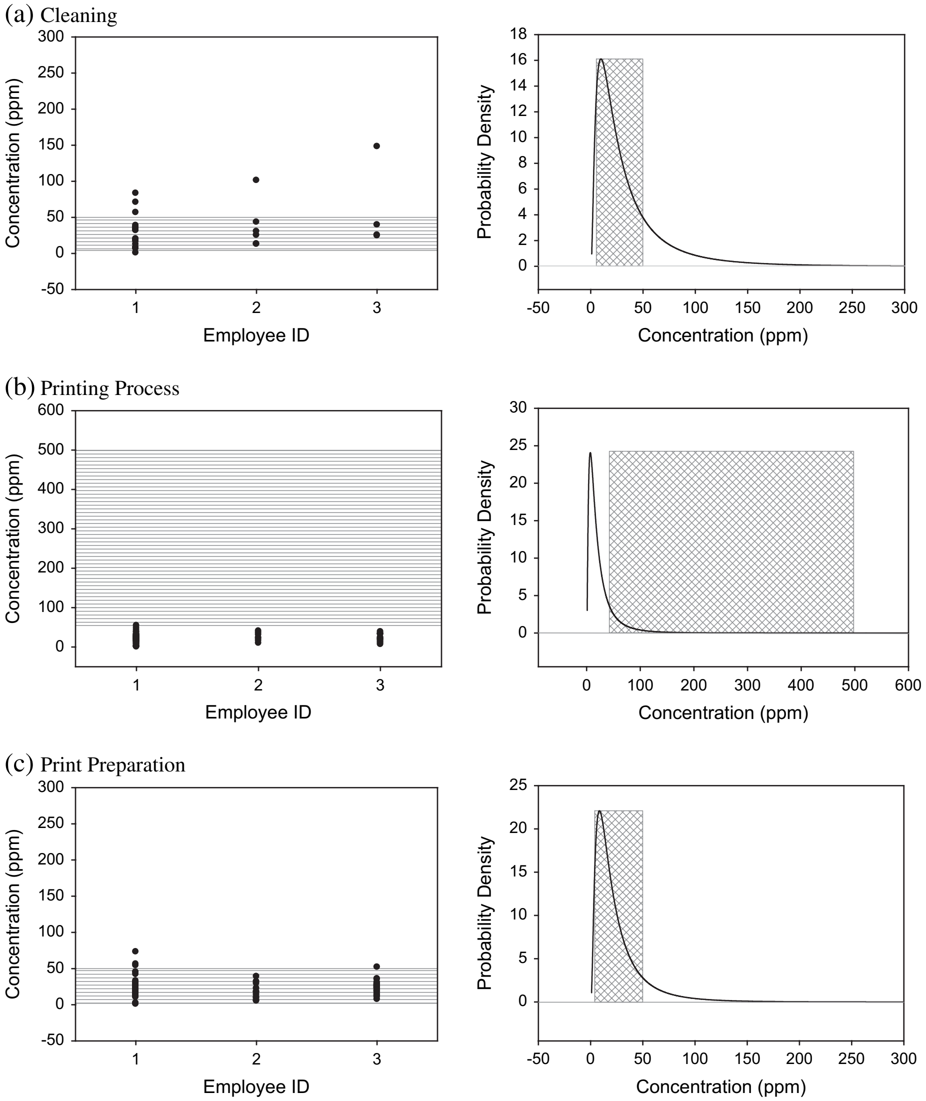

Fig. 2. Isopropanol short-term measurements and estimated probability distribution (note: the shaded areas represent the PER).

Table 3. Probability estimation for short-term exposure and full-shift exposure

	Chemical	Task	Mean (CV)[a]	$P < L_L$ of PER[b]	$P > L_U$ of PER[c]	$L_L < P < L_U$[d]
Short-term exposure	Isopropanol	Cleaning	35.5 (0.87)	0.0488	0.2291	0.7221
		Printing	21.5 (0.54)	0.8820	0.0001	0.1179
		Print preparation	22.5 (0.58)	0.0690	0.1224	0.8086
	Acetone	Cleaning	41.4 (0.87)	0.1603	0.2941	0.5456
		Printing	11.4 (1.30)	0.5853	0.0767	0.3380
		Print preparation	13.6 (1.28)	0.5024	0.0742	0.4234
Full-shift exposure	Methylene chloride	—	6.9 (0.88)	0.5693	0.0182	0.4125
	Isopropanol	—	25.8 (0.85)	0.8392	0.0002	0.1606
	Acetone	—	12.1 (1.60)	0.4578	0.1203	0.4219

[a]CV = standard deviation divided by the mean.
[b]Probability of exposure measurements less than the lower limit of the PER.
[c]Probability of exposure higher than the upper limit of the PER.
[d]Probability of exposure between the upper limit and the lower limit of the PER.

upper limit of the PER. Because acetone was not used during the printing process and print preparation, the average exposure of these tasks rather represented the background concentration at the sampling date due to the existence of residual concentrations of this chemical. The measured data showed high variability [CV = 0.87 (cleaning), 1.30 (printing process), and 1.28 (print preparation)], probably caused by different locations and work patterns of the employees.

The COSHH Essentials model reasonably predicted the PER for the cleaning ($L_L < P < L_U = 0.55$), whereas the probabilities of the other tasks ($L_L < P < L_U$) were <0.5. Approximately, half of the measurements for the printing process and print preparation were lower than the lower limit of the PER ($P < L_L = 0.59$ for the printing process and $P < L_L = 0.50$ for the print preparation). This might happen because acetone was not directly used for these tasks and thus a lot of exposure measurements were below or close to the limit of quantitation.

Full-shift exposure

Methylene chloride exposure. As shown in Fig. 4, the estimated distribution of methylene chloride exposures was well below or within the COSHH Essentials predicted range. Four of seven measurements were below the lower limit of the PER, and the rest were between the lower and upper limits of the PER. The estimated average employee exposure was 6.9 p.p.m. or approximately one-seventh of the upper limit. The predicted range adequately encompassed employee exposures at the upper end of the distribution ($P > L_U = 0.0182$), while more than

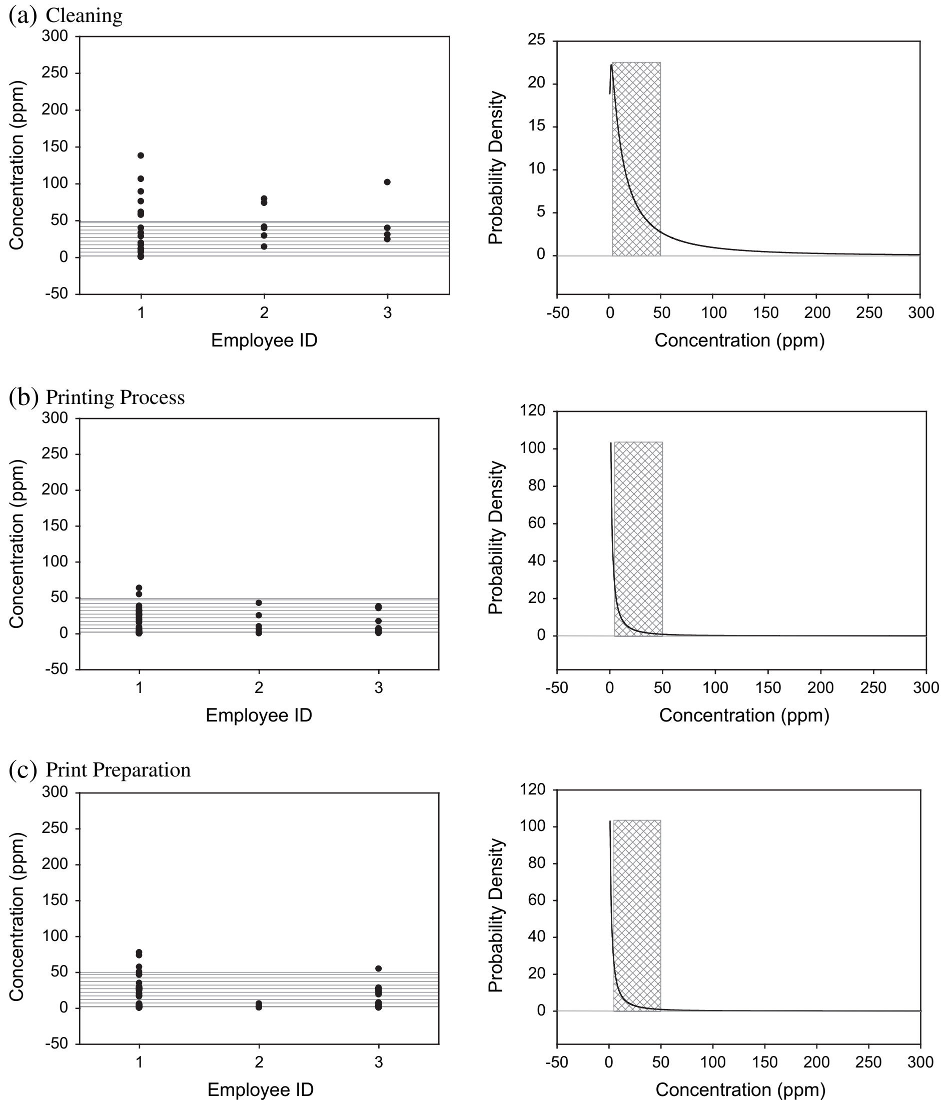

Fig. 3. Acetone short-term measurements and estimated probability distribution (note: the shaded areas represent the PER).

half was below the lower limit of the PER ($P < L_L = 0.57$). Approximately, 41% of the probability distribution curve was captured within the PER indicating a moderate result in predicting the methylene chloride exposures based on these data.

Isopropanol exposure. The average employee exposure was 25.8 p.p.m. and high variability among the employees' measurements was observed (CV = 0.85). Fig. 5 shows that all TWA measurements were below the lower limit of the COSHH Essentials exposure predicted range. The estimated probability of an employee exposure being less than the lower limit was 0.8392, indicating that most data would fall below the lower limit of the exposure band. On the other hand, the probability of being higher than the upper limit was only 0.0002, indicating that an employee exposure would be unlikely higher than the upper limit of the band. The COSHH Essentials model worked poorly in predicting the isopropanol exposures based on these data because only 16% of the probability distribution curve was within the range of the PER.

Acetone exposure. Among 25 full-shift measurements, eight measurements were below the lower limit of the PER and the rest of measurements were within the predicted band shown in Fig. 6. The average employee exposure was 12.1 p.p.m. due to the inclusion of data measurements where acetone was not directly used during the printing process and print preparation. It also showed high variability (CV = 1.60). The probability of an employee's exposure being less than the lower limit ($P < L_L$) was 0.4578 and 0.1203 for exposures exceeding the upper limit ($P < L_U$). The probability of exposures within the range of the PER was moderate ($L_L < P < L_U = 0.4219$), showing a better performance than the PER for full-shift exposures to isopropanol.

Engineering controls

The COSHH Essentials model provides an adequate control strategy by combining two prediction bands, the PER and TEB. Adequacy of the recommended control strategy was tested using the probability of exposures exceeding the regulatory or recommended OELs. If the probability of exposures exceeding an OEL is >0.05, the recommended control strategy might not be appropriate. Table 4 shows the results for the short-term and full-shift exposures.

Given those conditions of health hazard and exposure potential at the printing plant, the COSHH Essentials model recommended containment control (Control strategy 3) for the methylene chloride, whereas the control method at the time of sampling was general ventilation. All measured exposures

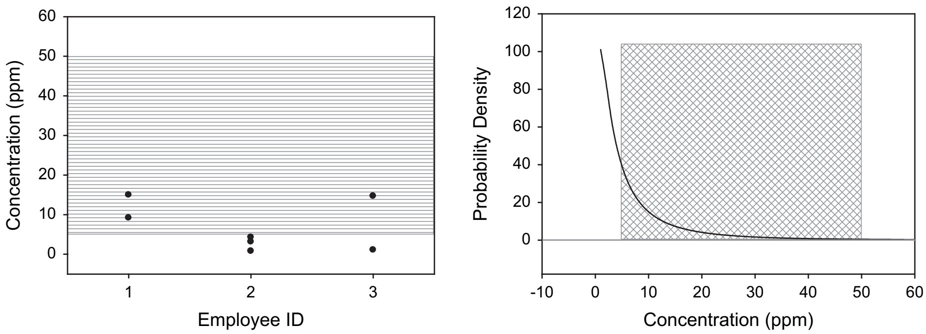

Fig. 4. Methylene chloride full-shift measurements and estimated probability distribution (note: the shaded areas represent the PER).

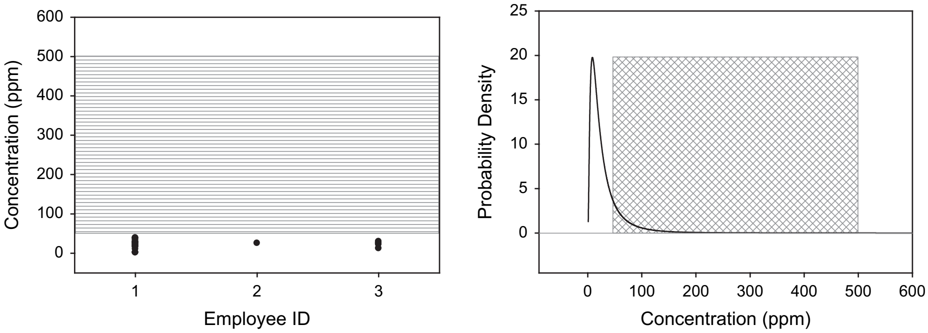

Fig. 5. Isopropanol full-shift measurements and estimated probability distribution (note: the shaded areas represent the PER).

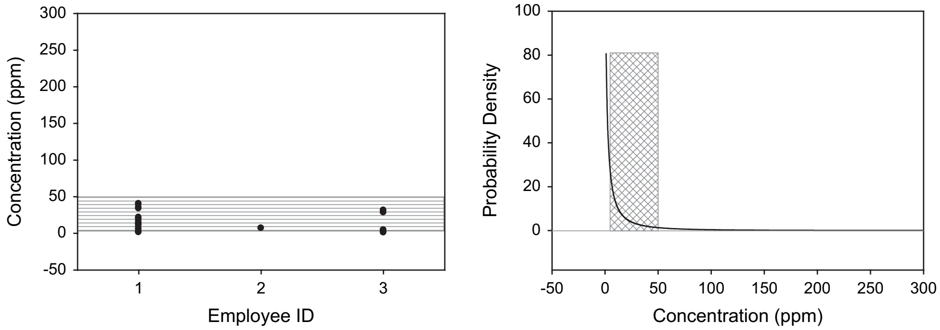

Fig. 6. Acetone full-shift measurements and estimated probability distribution (note: the shaded areas represent the PER).

Table 4. Probability of exposures exceeding OELs for short-term and full-shift exposure

	Chemical	Task	STEL or TWA[a] (p.p.m.)			$P >$ OELs[b]		
			ACGIH TLV	OSHA PEL	HSE WEL	ACGIH TLV	OSHA PEL	HSE WEL
Short-term exposure	Isopropanol	Cleaning	400	—	500	0.0019	—	0.0008
		Printing				0.0003		0.0001
		Print preparation				0.0002		<0.0001
	Acetone	Cleaning	750	—	1500	0.0095	—	0.0025
		Printing				0.0022		0.0006
		Print preparation				0.0008		0.0002
Full-shift exposure	Methylene chloride	—	50	25	100	0.0182	0.0648	0.0038
	Isopropanol	—	200	400	400	0.0062	0.0006	0.0006
	Acetone	—	500	1000	500	0.0071	0.0023	0.0071

[a]STEL for the short-term exposure and TWA for the full-shift exposure.
[b]Probability of exposures exceeding the OELs.

were less than the OELs, ACGIH TLV–TWA (50 p.p.m.), OSHA PEL–TWA (25 p.p.m.), and HSE WEL–TWA (100 p.p.m.). Without providing the recommended control method, the probability of exposure exceeding the ACGIH TLV, OSHA PEL, and HSE WEL was 0.0182, 0.065, and 0.0038, respectively, as shown in Table 4. Comparing the probability against the OSHA PEL showed that the general ventilation through the HVAC system was inadequate although the probabilities of exposure exceeding the ACGIH TLV and HSE WEL were generally low. However, methylene chloride is a suspected carcinogen (R40-Limited evidence of a carcinogenic effect) and thus, the printing plant no longer uses it and has replaced it with a less hazard substance, acetone, after consulting with a certified industrial hygienist. Therefore, further evaluation was not able to be performed.

For the isopropanol and acetone exposures, the model recommended general ventilation (Control strategy 1) which agreed with the control method at the time of sample collection. All exposure measurements including the short term and full shift were significantly lower than the OELs. The probability of exposure exceeding the ACGIH TLV-short-term exposure limit (STEL)/TWA, OSHA PEL–TWA, and HSE WEL–STEL/TWA was <0.01, as shown in Table 4. Employee exposures would be unlikely to exceed any of the OELs. Because the model recommended the same control method as in place at the time of sampling, further evaluation was not performed.

DISCUSSION AND CONCLUSIONS

The COSHH Essentials risk assessment tool is simple and easy to use (Maidment, 1998; Garrod *et al.*, 2007). According to the 'Summary of the Technical Basis for COSHH Essentials', the COSHH Essentials is a task-based model. One might therefore assume that it is to be used for task-based exposures since the user is guided into conducting a separate assessment for each individual task and very likely that the model prediction targets a short-term task. This leads to a dilemma. If it is a short-term task-based model and a separate assessment for each task requires a different control procedure for each task, then the user may need to provide controls for a process that occurs infrequently and adds only minimally to the total exposure. It also seems that R-phrases determining substances into the appropriate hazard group from A (least hazardous substances) to E (special cases) encompass the short-term and long-term exposures. For example, acute exposures that cause irritation or other immediate health effects are quite likely to be addressed by short-term exposure assessments, whereas cancer or other chronic health effects are caused by long-term exposure. Thus, it is likely that a mixture of short-term and long-term measurements was used in developing the database as was done with the related EASE model (Tickner *et al.*, 2005; Cherrie et al., 2003).

In the current study, evaluation of the COSHH Essentials tool was performed against both short-term task-based exposures and full-shift exposures using measured concentrations of three chemical vapors at a small printing plant. These measurements can be considered surrogates for other chemicals with similar volatility characteristics, so that it might be expected that if the model works in this case, then it should work for other, similar, vapors in similar situations of use. The average exposures for those tasks where the chemicals were not directly in use, i.e. in the printing process for acetone and in the print preparation process for isopropanol and acetone, exposures were lower than in those tasks for which they were in use, i.e. cleaning in the case of isopropanol and acetone. The average exposure to isopropanol in the printing process was lower than for cleaning because exposures did not result from a near-field source.

For the short-term exposures, overall, the COSHH Essentials model worked reasonably well in the prediction of the PER for the cleaning and print preparation with isopropanol and for the cleaning with acetone. A poor prediction of the PER was observed for exposure to isopropanol in the printing process and for acetone in the printing process and print preparation. Also, it seemed that better predictions were made for the use of small quantities of chemicals than where medium quantities were involved. For the full-shift exposures, agreement between the TWA measurements and the PER was moderate for the methylene chloride ($L_L < P < L_U = 0.41$) and acetone ($L_L < P < L_U = 0.42$) and poor for the isopropanol ($L_L < P < L_U = 0.16$).

Several studies (Tischer *et al.*, 2003; Jones and Nicas, 2006; Hashimoto *et al.*, 2007) evaluated the COSHH Essentials. Tischer *et al.* (2003) evaluated the model on the basis of exposure measurements from BAuA field studies and existing chemical exposure data. They found good agreements between the measurements of the solid substances and the model predicted ranges. For the industries that used solvents, however, they found exposure levels were within or below the predicted ranges with organic solvent of liter quantities and above the predicted ranges with small scale of solvent. Hashimoto *et al.* (2007) also evaluated the COSHH Essentials model at 12 workplaces of a petroleum company in Japan and concluded positively for the use of control banding tool. Unlike those studies by Tischer *et al.* (2003) and Hashimoto *et al.* (2007), negative result was found from a study by Jones and Nicas (2006). Jones and Nicas (2006) evaluated the COSHH Essentials model by defining undercontrolled errors and overcontrolled errors using data from NIOSH HHEs and Control Technology Assessment. They defined undercontrolled errors as ‘instances in which the airborne concentration exceeded the upper limit of the chemical’s exposure band in the presence of control technology’ and overcontrolled errors as ‘instances in which the airborne concentration was within or below the chemical’s exposure band in the absence of control technology’. Thirty-four vapor degreasing industries and 22 bag filling industries were included in their study and they suggested systematic evaluation of the model before promoting it outside the UK. However, in the COSHH Essentials model, the recommended control strategy is driven by the combination of PER and TEB of chemical, so the PER cannot be evaluated as the sole test of reasonableness of the model. Evans and Garrod (2006) also stated that ‘COSHH Essentials is not intended as a predictor of exposure; it is a package of measures that identifies an approach that will provide adequate control.’ After comparing the exposure measurements with PER, the recommended control strategy was evaluated by estimating the probability of exposure exceeding the OEL in the current study. For the methylene chloride, the control method at the time of sampling was general ventilation and the model suggested containment control strategy. Thus, a COSHH Essentials evaluation would have highlighted a problem situation, which was also the expert opinion. The chemical was replaced with a less hazardous substance, acetone. Thus, no further evaluation was performed. For the isopropanol and acetone, the model recommended the Control strategy 1 (general ventilation) which was the same as the control method at the time of sampling. Because the probability of exposure exceeding the OELs was <0.01 for both short-term and full-shift exposures, we can agree with the conclusions of the COSHH Essentials model that the printing plant was adequately controlled and no further action was required. Balsat *et al.* (2003) suggested that the COSHH Essentials or EASE model did not work well for substances having a STEL or ceiling value because of the variability of exposure during operations. The model in the present study, however, worked well based on these data even though those chemicals have STELs. Therefore, although some of the short-term measurements were above the PER (but still significantly lower than the STELs), the findings in this study showed that the recommended control strategy was adequate for the task-based exposure scenarios.

The web-based COSHH Essentials model (HSE, 2005) also provides a set of guidance based on specific job tasks to help users in small- and medium-sized enterprises without seeking for a professional consultant. For example, dermatitis is a main health risk by exposing to chemicals used in printing tasks including cleaning. Thus, the guidance of the COSHH Essentials describes good practice to minimize employees' exposure due to frequent contact with chemicals such as skin management, appropriate personal protective equipment, cleaning and housekeeping, and training and supervision.

In conclusion, the COSHH Essentials risk assessment model worked reasonably well for both short-term task-based exposure measurements and full-shift exposure measurements. However, the conclusion is limited to only a few chemicals in small or medium amounts as evaluated in this particular workplace situation where general ventilation was in use. To fully evaluate the COSHH Essentials model, these limited parameters should be considered in planning future studies.

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