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Evaluation of COSHH Essentials for Vapor Degreasing and Bag Filling Operations

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COSHH Essentials is a system of workplace risk management developed by the UK Health and Safety Executive for use by proprietors of small and medium sized enterprises. COSHH Essentials recommends exposure control approaches based on a chemical's potential health hazards, scale of use and ability to become airborne. More specifically, chemicals are grouped into hazard bands based on their potential health hazards, and each hazard band is associated with a 10-fold range of 8 h time weighted average airborne concentrations, termed exposure bands. The recommended control approaches are intended to limit air concentrations to within or below the exposure bands. Using air monitoring data from NIOSH Health Hazard Evaluations and Control Technology Assessments, we evaluated the ability of COSHH Essentials to select adequate control technology for vapor degreasing and bag filling operations, and the ability of the recommended control approaches to successfully limit air concentrations. We identified two types of misclassification errors. 'Under-controlled' errors were instances in which the airborne concentration exceeded the upper limit of the chemical's exposure band in the presence of control technology; such errors were observed in 78% (139/179) and 48% (76/159) of measurements collected at vapor degreasing and bag filling operations, respectively. 'Over-controlled' errors were instances in which the airborne concentration was within or below the chemical's exposure band in the absence of control technology, although conditions of use prompt COSHH Essentials to recommend controls; such errors were observed in 61% (102/167) and 8% (3/26) of measurements collected at vapor degreasing and bag filling operations, respectively. In our use of COSHH Essentials, we found that for many particulate substances toxicological information was difficult to obtain. Given the high prevalence of the control errors, we judge it is important that COSHH Essentials provide the exposure bands and information on the evaluation of control technology performance to users. In addition, we identify a number of questions for further research and outline a prospective study, which will systematically describe how small business owners use COSHH Essentials, and the frequency of under-controlled errors in practice.

Keywords: COSHH Essentials; control banding; model evaluation; Health Hazard Evaluations

INTRODUCTION

The UK Health and Safety Executive (HSE) has developed an approach to workplace risk management called COSHH Essentials. It is available to intended users, that is, proprietors of small and medium sized enterprises, both on-line (http://www.coshh-essentials.org.uk/) and as a booklet (HSE, 2003). COSHH Essentials involves 'control banding' because it groups chemical substances into *hazard bands* based on their potential health hazards. When a particular work task is analyzed in COSHH Essentials, the hazard band of the chemical substance, the scale of use and the ability of the chemical substance to become airborne are integrated to allocate the work task to a control approach (Table 1). The control approaches are analogous to biosafety levels 1–4, and include the categories: general dilution ventilation, engineering controls, containment controls and specialist advice. COSHH Essentials details the recommended control approaches in task-specific guidance sheets, each of which includes an illustration of task-specific control technology and a safety check list.

The purpose of the recommended control technologies is, of course, to limit the airborne concentration of chemical substances. The extent to which the

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Table 1. Steps to use COSHH Essentials

Step	Description
(1) Hazard classification	The European Union's R-phrases are used to assign the chemical substance to hazard band A (low hazard), B, C, D (high hazard) and/or S (skin hazard)
(2) Scale of use[a]	The volume of the chemical substance, frequency and duration of task are reported
(3) Ability to become airborne	For liquids, volatility is determined based on the boiling point or vapor pressure and the process temperature. For solids, dustiness is used, and may be low, medium or high
(4) Control approach	Steps 1-3 are used with a matrix to identify the appropriate control approach: (1) dilution ventilation, (2) engineering controls, (3) containment controls or (4) specialist advice
(5) Task-specific guidance	The control approach level is used to identify the guidance sheet for the specific task and provides an example of the control approach

[a]In the original descriptions of this process, the scale of use and ability to become airborne were combined into exposure prediction bands (Maidment, 1998).

Table 2. The association between hazard bands and exposure bands, where exposure bands are the target airborne contaminant concentration (Brooke, 1998)

Hazard band	Exposure band	
	Vapors (p.p.m.)	Dusts/mists (mg/m^3)
A	>50–500	>1–10
B	>5–50	>0.1–1
C	>0.5–5	>0.01–1
D	≤0.5	≤0.01
E	Expert opinion needed	
S	Skin and eye precautions	

airborne concentrations should be limited, however, is not explicit in COSHH Essentials. The supporting documentation for COSHH Essentials, which is available in the peer-reviewed literature (Brooke, 1998; Maidment, 1998; Russell *et al*., 1998), defines target airborne concentrations termed *exposure bands*. The exposure bands span 10-fold ranges in concentration, and are directly associated with each hazard band (Table 2). The exposure bands have the following meaning: For a chemical substance classified in, say, hazard band B, the 8 h time weighted average (TWA) airborne concentration in the workplace should be <50 p.p.m. if the airborne substance is a vapor or gas or <1 mg/m^3 if it is an aerosol. For a chemical in hazard band B, control below the band's minimum concentration of 5 p.p.m. or 0.1 mg/m^3 is not deemed necessary. Whether the exposure bands pertain to the concentration of the contaminant in the general area or in the breathing zone of the workers is unspecified.

COSHH Essentials was designed to be a health-conservative approach, and the exposure bands compare well with the occupational exposure limits in the UK (Russell *et al*., 1998; Brooke, 1998). However, a practical question is whether the control technologies recommended reliably limit the airborne concentrations of chemical substances to within or below the exposure bands. To this end Tischer *et al*. (2003) compared airborne exposure measurements taken by Bundesanstalt fur Arbeitsschutz und Arbeitsmedizin (the German authority for the risk assessment of new and existing substances) and measurements submitted by industry with the COSHH Essentials' recommended exposure bands. They reported that the preponderance of airborne concentrations was within or below the exposure bands, but exposure was not adequately limited in certain situations. In particular, when medium-volatility or high-volatility liquids (varnishes, organic solvents and adhesives) were handled in small quantities in the presence of general dilution ventilation, and when powders (dyestuffs and grinding wheel production) were handled in the presence of local exhaust ventilation, 5–22% and 5–7% of air samples, respectively, were greater than the exposure bands.

To extend the evaluation of COSHH Essentials' ability to select adequate control technology, we investigated vapor degreasing and bag filling operations, which are common industry operations that involve a variety of chemical substances. Relevant air monitoring data were identified from Health Hazard Evaluations (HHEs) and Control Technology Assessments (CTAs) completed by the National Institute for Occupational Safety and Health (NIOSH) between the years 1981 and 2002. Toxicity information for the chemicals monitored were input into COSHH Essentials on-line interface to identify the hazard band, and the reported operating conditions were used to identify the appropriate control approach and task-specific guidance. Subsequently, the exposure band was identified for each chemical substance based on its hazard band classification. To evaluate the effectiveness of the controls applied, we compared the maximum air concentrations of the exposure bands to the NIOSH monitoring data for each chemical substance, with consideration for the presence or absence of control technologies.

Two types of misclassification errors were considered. 'Under-controlled' errors were instances in which the airborne concentration exceeded the upper limit of the chemical's exposure band in the presence of applied control technology. 'Over-controlled' errors were instances in which the airborne concentration was below the upper limit of the chemical's exposure band in the absence of control technology, yet the conditions of use cause a control technology to be prescribed by COSHH Essentials. While performing this analysis, we also discovered that for many particulate substances, toxicological information useful in COSHH Essentials was difficult to obtain.

METHODS

We relied on NIOSH HHEs and CTAs for air monitoring data associated with vapor degreasing and bag filling operations for several reasons: The NIOSH documents are readily obtained, they include a sampling rationale and descriptions of the work tasks, and the investigators employed standardized sampling and analytical methods. HHEs are available for the years 1981–1996 on CD-ROM. Applicable reports were identified using the search terms: vapor degreasers, degreasing operations, degrease, degreaser, bag filling, bagging operations, sack and bagging. CTAs and more contemporary HHEs were identified by searching the NIOSHTIC-2 database (http://www2a.cdc.gov/nioshtic-2/default.html) using the same search terms. Documents not available electronically were requested from NIOSH. To be included for analysis, the HHEs and CTAs had to contain personal or area air samples for the process of interest. A total of 30 HHEs and four CTAs, which represented 34 facilities overall, met the inclusion criterion for vapor degreasing tasks, and 20 HHEs and two CTAs, which represented 22 facilities overall, met the inclusion criterion for bag filling operations.

A limitation of the air monitoring data is that the monitoring periods were not randomly selected by investigators. Instead, sampling was performed on days convenient to investigators, although efforts were typically made to capture exposures on high production days, or days that included the hazard of interest. Further, often the job titles and location of workers during the air monitoring period were incompletely described. This made it difficult to associate air samples with a particular operation if multiple vapor degreasing or bag filling operations were present. From each report we extracted information on the chemical substance, scale of use, ability to become airborne and control methods. With regard to the latter item, many reports did not include complete information on the presence, type or capture efficiency of control technologies.

Given that these reports were conducted by a federal agency, it can be hypothesized that the operations described reflect atypically poor health and safety practices, or that they disproportionately represent large, unionized workplaces. On the first point, we note that of the 708 air sampling results identified for analysis, 84 (12%) of the measurements exceeded relevant Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) values. A number of these exceedences, however, do not reflect 'illegal' exposures because they were area or short-term air samples. On the second point, 38% of the reports noted that the investigation was requested by a union, and more facilities for which the workforce size was reported had more than 100 employees versus less than 100 employees (Table 3). Differences in the airborne concentration of contaminants between large versus small or between union versus non-union workplaces may exist, but cannot be meaningfully quantified based on the NIOSH documents. Although we cannot say that the NIOSH air monitoring data represent typical or atypical exposure levels for the processes studied, we can presume that the exposures described do not reflect the ideal level of health protection.

Table 3. Descriptive statistics of HHE and CT Reports

Condition	Vapor degreasing	Bag filling	Totals
Union request	12/34 (35%)	10/22 (45%)	22/56 (39%)
Operation specific[a]	26/34 (76%)	4/22 (18%)	30/56 (54%)
LEV[b] presence unknown	12/34 (35%)	10/22 (45%)	22/56 (39%)
LEV known to be present	13/34 (38%)	7/22 (32%)	20/56 (36%)
LEV capture velocity acceptable	2/13 (15%)	2/8 (25%)	4/21 (19%)
>100 employees	14	9	23
<100 employees	4	5	9
Number of samples collected[c]	424	284	708
Samples exceeding OSHA standards[d]	24 (6%)	60 (21%)	84 (12%)

[a]Request to NIOSH for the investigation was explicitly with regard to vapor degreasing or bag filling operatons, otherwise the evaluation of these operations were incidental.
[b]Local Exhaust Ventilation (LEV) includes slot and containment ventilation systems, and does not include condensation coils, closing tank doors and automatic shut off valves for vapor degreasing tanks.
[c]Samples of mixture components are counted individually.
[d]Not all samples are 8 h or 15 min time weighted averages, and as such, an exceedence of the OSHA standard may not reflect an illegal exposure. Respirable dust samples were compared with respirable dust standards, while total dust standards were compared with total dust standards.

We used three sources to identify the Risk phrases (R-phrases) for chemical substances reported in the NIOSH documents, where a R-phrase is a standardized numerical code with an associated description concerning toxic effects and health risk defined by the European Union (2001). First, we identified R-phrases from the National Chemical Emergency Centre's CSE Lite (http://www.the-ncec.com/cselite), which is an on-line interface to a database of chemical labels (which include R-phrases), supply labels and exposure limits required in the UK. The R-phrases included in this database have been assigned by the UK HSE. Next, we turned to the Hazardous Substance Data Base (HSDB) (http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB), managed by the National Institutes of Health, in which toxicity information from the peer-reviewed literature is compiled. Toxicity information so obtained was used with the R-phrase criteria published by the European Union (2001) to assign R-phrases to each chemical substance. Our final sources of R-phrases were Material Safety Data Sheets (MSDSs). MSDSs containing R-phrases were identified through the internet search engine Google (http://www.google.com/).

For each chemical substance, we compared sampling results and the upper limit of the appropriate exposure band. Personal and area samples of all durations were included. When a series of air samples were taken and clearly intended to reflect an exposure period of longer duration, the average result was used. Airborne concentrations averaged over the duration of sampling were preferred to 8 h TWA as they better reflect the intensity of exposure. Comparisons were also made between the air sampling results and the OSHA PELs to provide a more universal measure of health and safety performance. When the OSHA exposure limits were *ceiling* concentrations, comparisons were made as though the ceiling concentration were an average concentration.

Owing to the limited information on control technologies in the NIOSH reports, we were unable to determine the capture or containment efficiency of the controls. Classification of control status was reduced to present, absent or unknown. Control technology was determined to be present if engineering controls such as containment or local exhaust ventilation were identified or described. Control technology was determined to be absent if there was a statement declaring that no exhaust ventilation system was present. Because industrial vapor degreaser tanks are almost always equipped with condensation coils to prevent excessive loss of cleaning solvent, we reasonably assumed that condensation coils were present even when NIOSH did not explicitly mention their presence. Therefore, a vapor degreasing operation for which control technology was determined to be absent, probably had condensation coils in place. This classification was made for vapor degreasing tanks because the COSHH Essentials control technology recommendations are for local or containment exhaust ventilation, in addition to condensation coils. All remaining situations were classified as unknown.

RESULTS

Vapor degreasing operations

Vapor degreasing is a common industrial operation and utilizes a variety of solvents. In the 34 reports, seven solvents (Table 4) were found in use as pure solvents or in mixtures (% weight is included if reported):

- 1,1,1-trichloroethane and perchloroethylene,
- 1,1,1-trichloroethane (96.5%) with 1,4-dioxane (2.5%),
- 1,1,1-trichloroethane (57%) with isopropanol (18%) and Freon (25%),

Table 4. Chemical substances identified in vapor degreasing operations and the recommendations of COSHH Essentials

Chemical	CAS no.	R-phrase[a]	Mixture cutoff[b]	OSHA PEL (p.p.m.)	Hazard group[a]	Exposure band[c] (p.p.m.)	Control approach[d]	Task-specific guidance[d]
1,4-Dioxane	123-91-1	36/37, 40, 66, Carc. Cat. 3[e]	>1%	100	D	<0.5	Special	Sheet 400
Freon 113	76-13-1			500	A	<500	Engineering	Sheet 227
Isopropanol	67-63-0	36, 67	>20%	400	A	<500	Engineering	Sheet 227
Methylene chloride	75-09-2	40, Carc. Cat. 3	>1%	25	D	<0.5	Special	Sheet 400
Perchloroethylene	127-18-4	40, Carc. Cat. 3	>1%	100	D	<0.5	Special	Sheet 400
1,1,1-Trichloroethane	71-55-6	20	>25%	350	B	<50	Engineering	Sheet 227
Trichloroethylene	79-01-6	36/38, 40, 45, 67, Carc. Cat. 3, Mut. Cat. 3[f]	>1%	100	E	N/A	Special	Sheet 400

[a]Obtained from National Chemical Emergency Centre.
[b]Obtained from the European Commission R-phrase documentation (European Union, 2001).
[c]Brooke (1998).
[d]Obtained from the on-line COSHH Essentials interface.
[e]Carcinogen, Category 3.
[f]Mutagen, Category 3.

- 1,1,1-trichloroethane with Freon,
- trichloroethylene with Freon,
- methylene chloride (54%) with Freon (46%), and
- 1,1,1-trichloroethane with trichloroethylene.

Step 1. Hazard Group Classification. Hazard classification in COSHH Essentials requires knowledge of the appropriate R-phrase for each chemical substance. For six of the seven solvents, excepting Freon, the R-phrases were obtained from the National Chemical Emergency Centre's CSE Lite database. The R-phrases were subsequently input into the on-line interface of COSHH Essentials to obtain the hazard group classifications (Table 4). Freon is not currently in use, so no R-phrase information is available in CSE Lite. Toxicity information in the HSDB did not indicate any R-phrases for Freon: The oral LD_{50} in rats is greater than the R-phrase criterion for acute toxicity, and it is not clear which R-phrase should be assigned for cardiac arrhythmias. Lacking other indications, Freon was assigned to hazard group A.

For mixtures of chemicals, the hazard group classification is assigned by COSHH Essentials based on the most toxic of the mixture components if the more toxic component is present above its concentration cut-off criteria. This approach to the treatment of mixtures is incompatible with the approach in the US, where OSHA regulations identify exposure limits of mixtures only when the mixture components have similar health effects. In this case, the sum of the ratios of the component exposure levels to their respective PELs may not exceed 1 (Title 29 US Code of Federal Regulations Part 1910.1000 (d)(2)(i)). To permit comparisons with PELs in the US, hazard group classifications were assigned to each mixture component independently of the other mixture components. The effect of this choice, if any, is to increase the number of air samples that are within or below the exposure band, because the air concentration of the less toxic mixture component is compared with its own exposure band rather than the lower exposure band of the more toxic mixture component.

Step 2. Scale of Use. The vapor degreasers for which the volume was included in the NIOSH reports contained ten to ninety gallons of solvent. This volume, which COSHH Essentials defines as a *medium* quantity of solvent, is better described in *liters* rather than *cubic meters*. COSHH Essentials (on-line version only) inquires about the volume of chemical substance used in a task or process, implying that when a mixture is used, it is the volume of mixture rather than the volume of the components that is of interest. For uniformity, the duration and frequency of use was assumed to be 10 min per use period and 10 use periods per day. The total exposure from this duration and frequency combination approaches the high-end of usage documented in the NIOSH reports. COSHH Essentials was not very sensitive to duration and frequency of use; a 2-fold increase of exposure duration was required to change the recommended control intensity for only certain chemical substances. Frequency and duration of use are not considered in the booklet version of COSHH Essentials (HSE, 2003).

Step 3. Ability to become airborne (Volatility). To assess volatility in COSHH Essentials, the operating temperature and boiling point or vapor pressure of the chemical substance must be known. Vapor degreasing tanks operate near the boiling point of the solvent, which suggests the degreasing chemicals have medium or high volatility. However, vapor degreasing tanks typically have control systems like condensation coils and vapor level thermostats, and OSHA considers such tanks to have a zero effective rate of vapor evolution when the operating procedure is excellent (Title 29 US Code of Federal Regulation Part 1926.57 Table D-57.10). In addition, COSHH Essentials' on-line interface prevents the assignment of operating temperatures above the boiling point of the solvent. As a result, the appropriate operating temperature is unclear: based on the fact that vapor degreasing involves heating the solvent, we assumed an operating temperature of 5°C below the boiling point of the solvent. We note, however, that the assignment of medium or high volatility lead to the same recommended control approach for chemicals in hazard groups B, C, D or E, while assignment of low volatility decreases the recommended control approach by one level (HSE, 2003).

Step 4. Control Approach. For the solvents identified, two control approaches, Engineering and Special, are recommended by COSHH-Essentials (Table 4).

Step 5. Task-Specific Guidance. 'Engineering' controls for vapor degreasing operations, Control Guidance Sheet 227, include: lip/slot exhaust ventilation, cooling coils and a hoist system (HSE, 2003). 'Special' guidance, Control Guidance Sheet 400, informs users that more 'specific and specialist advice' than can be provided by COSHH Essentials is necessary (HSE, 2003). Such advice may come in the form of a HSE guidance document or an expert, such as a qualified occupational hygienist. Though not at issue here, a 'Containment' system may be recommended for vapor degreasing operations, Control Guidance Sheet 321, which includes an enclosed load/unload area with exhaust system, cooling coils, automatic lid and hoist system (HSE, 2003).

Control Approach Effectiveness. Among 167 vapor degreasing air samples taken in the absence of control technologies, 102 were within or below the respective exposure band such that the over-controlled error proportion was 61% (102/167), as

Table 5. Attainment of occupational exposure limits and the relative frequency of control errors in vapor degreasing and bag filling operations by air sample

Control technology status	No. ⩽ exposure band	No. > exposure band	Control errors	% ⩽ OSHA PEL[b]
Vapor degreasing				
Absent (n = 167)[a]	102	65	Over-controlled error: 61%	96
Present (n = 179)	40	139	Under-controlled error: 78%	91
Unknown (n = 78)	55	23	⩽ Exposure band: 71%	97
Bag filling				
Absent (n = 36)	3	33	Over-controlled error: 8%	56
Present (n = 159)	83	76	Under-controlled error: 48%	91
Unknown (n = 89)	41	48	⩽ Exposure band: 46%	67

[a]The n value indicates the number air samples.
[b]To provide an indication of legal compliance in the workplaces, the percentage of air samples that are less than or equal to the OSHA PEL are indicated.

Table 6. Attainment of occupational exposure limits and the relative frequency of control errors in vapor degreasing and bag filling operations for personal breathing zone air samples

Control technology status	No. ⩽ exposure band	No. > exposure band	Control errors	% ⩽ OSHA PEL[b]
Vapor degreasing				
Absent (n = 122)[a]	81	41	Over-controlled error: 66%	100
Present (n = 113)	25	88	Under-controlled error: 78%	96
Unknown (n = 38)	27	11	⩽ Exposure band: 71%	92
Bag filling				
Absent (n = 28)	2	26	Over-controlled error: 7%	53
Present (n = 104)	52	52	Under-controlled error: 50%	97
Unknown (n = 61)	32	29	⩽ Exposure band: 52%	72

[a]The n value indicates the number air samples.
[b]To provide an indication of legal compliance in the workplaces, the percentage of air samples that are less than or equal to the OSHA PEL or NIOSH REL are indicated.

shown in Table 5. That is, 61% of the measurements satisfied the respective exposure bands but the conditions of use called for exposure control technology to be applied. Among 179 vapor degreasing air samples taken in the presence of control technologies, 140 were above the respective exposure band such that the under-controlled error proportion was 78% (140/179), as shown in Table 5. That is, 78% of the measurements exceeded the upper limits of the respective exposure bands despite the application of control technology. When only personal breathing zone air samples are considered (Table 6), the over-controlled proportion was 66% (81/122) and the under-controlled proportion was 78% (88/113).

Note that if the current OSHA PELs were used to establish target exposure bands, the over-controlled error proportion would increase to 96%, and the under-controlled error proportion would decrease to 9%. However, with the exception of methylene chloride, the OSHA PELs for the vapor degreasing chemicals listed in Table 4 have not been updated in ∼40 years. Therefore, it would not be health-conservative, in general, to use the OSHA PELs to set target exposure criteria.

Over-controlled errors identify situations in which the introduction of control technologies recommended by COSHH Essentials is unnecessary, in theory, and would be a waste of resources. One would expect that over-controlled errors are more frequent for less hazardous work tasks, which would probably be assigned to the control intensity ‘Engineering’ rather than ‘Special’ simply because the airborne concentrations in the exposure bands are higher. An over-controlled error was assigned to 84% (98/117) of the measurements of chemical substances assigned to the control intensity ‘Engineering’ and lacking local exhaust ventilation. In comparison, an over-controlled error was assigned to only 8% (4/50) of the measurements of chemical substances assigned to the control intensity ‘Special’ and lacking local exhaust ventilation.

Interpretation of under-controlled errors is complicated by the fact that not all control technologies identified in the NIOSH reports provided optimum capture or containment efficiency. We cannot clarify the issues of capture or containment efficiency owing to sporadic evaluation of these performance indicators, but we estimate that the relative frequency of under-controlled errors associated with containment controls is less than that associated with local exhaust ventilation controls. Of the 38 measurements of vapor degreasing tanks assigned the ‘Engineering’ control approach and had slot exhaust ventilation in place, 30 were above the exposure band such that the under-controlled error proportion was 79% (30/38). In comparison, of 24 measurements taken at vapor degreasing operations assigned the 'Special' control approach and had containment ventilation in place (vacuum vapor degreasing operations), four were above the exposure band such that the under-controlled proportion was 17% (4/24). One final note, of 117 measurements taken of vapor degreasing tanks assigned the 'Special' control approach and had slot exhaust ventilation, 105 were above the exposure band such that the under-controlled error proportion was 90% (105/117). This error proportion, however, may be overstated because some of these operations might not have been evaluated by a specialist, who, in turn, might have recommended a more intense control system or chemical substitution.

Bag filling operations

Nineteen chemical substances were identified in the twenty-two NIOSH reports concerning bag filling operations (Table 7). Chemical Abstract Society Numbers (CAS#s) could not be identified for four materials (petroleum resins, oiled sulfur compounds, starch dust and sugar beet pulp) because they are complex mixtures not clearly described in the NIOSH reports and/or natural products. For a number of substances, such as ammonium phosphate/sulfate fertilizers, no exposure limits have been explicitly defined by OSHA; this circumstance suggests they fall into the OSHA category of nuisance dust. These general dust standards, however, are not appropriate for the pharmaceutical Zeranol, an estrogen. We note that the NIOSH REL listed for Folpet are actually those for Captan, a closely related fungicide, and that the exposure limit for cement mix is for Portland cement, which was a component of the cement mix under process during the NIOSH evaluation.

Step 1. Hazard Group Classification. While the R-phrases for the chemical substances identified in vapor degreasing tasks were readily obtained from the CSE Lite database, the same information was available for only 4 of the 19 substances identified in bag filling tasks: Folpet, manganese dioxide, nickel (elemental) and sodium azide. Toxicity information was available in the HSDB for an additional five substances: carbon black, graphite, lithium carbonate, quartz (crystalline silica) and zinc oxide. Sugar beet pulp was assigned the R-phrase 49, based on

Table 7. Chemical substances identified in bag filling operations

Chemical	CAS no.	R-phrases	OSHA PEL[a] (NIOSH REL[b])
Ammonium phosphate/sulfate fertilizers	7783-28-0, 7783-20-2	None[c]	Nuisance dust
Carbon black	1333-86-4	37, 48/20[d]	(3.5 mg/m^3)
Cement mix (Portland cement)	(65997-15-1)	36, 49, 66[e]	15 mg/m^3T, 5 mg/m^3R
Fibrous glass dust	65997-17-3	–	(5 mg/m^3, 3f/cc)
Folpet	133-07-3	20, 36, 40, 43, Car Cat 3[e]	(5 mg/m^3)[g]
Graphite	7782-42-5	37	15 mppcf (2.5 mg/m^3)
Lithium carbonate	554-13-2	67, Cat 3 Repro[d]	Nuisance dust
Manganese dioxide	1313-13-9	20/21[f]	5 mg/m^3C as Mn
Nickel catalyst	7440-02-0	40,43, Car Cat 3[f]	1 mg/m^3 as Ni
Petroleum resins			Nuisance dust
Sulfur compounds, oiled			Nuisance dust
Quartz dust	14808-60-7	49[d]	Varies with quartz content
Sodium acid pyrophosphate	7758-16-9	36, 38[d]	Nuisance Dust
Sodium azide	26628-22-8	28[f]	(0.3 mg/m^3C)
Starch dust		None[h]	15 mg/m^3T, 5 mg/m^3R
Sugar (sucrose)	(57-50-1)	None[i]	15 mg/m^3T, 5 mg/m^3R
Sugar beet pulp (crystalline silica)	(14808-60-7)	49[d]	Varies with quartz content
Zeranol	26538-44-3	–	–
Zinc oxide	1314-13-2	48/20[d]	15 mg/m^3T, 5 mg/m^3R

[a]ACGIH. C indicates a ceiling airborne concentration. R indicates the respirable dust fraction, while T indicates total dust.
[b]In the absence of an appropriate PEL, the NIOSH Recommended Exposure Level is reported.
[c]EFMA (2005).
[d]Assigned based on toxicity information from the HSDB and European Union R-phrase criteria (European Union, 2001). Silica is in IARC Group 1, so it is assigned R-phrase 49.
[e]Davco Construction Materials Pty Ltd (2003).
[f]From the National Chemical Emergency Centre CSE Lite Database.
[g]Standard for Captan, CAS#133-06-2.
[h]National Starch (2005).
[i]Mallinckrodt Baker Inc. (2004).

Table 8. Recommendations of COSHH Essentials for bag filling operations

Chemical substance	Hazard group[a]	Exposure band (mg/m^3)	Scale of use[b]	Ability to become airborne[c]	Control intensity[a]	Task-specific guidance[a]
Ammonium phosphate/ sulfate fertilizers	A	>1–10	L	M	Engineering	Sheet 206
Carbon black	C	>0.01–0.1	L	H	Special	Sheet 400
Cement mix	E	<0. 01	L	H	Special	Sheet 400
Fibrous glass dust	COSHH Essentials is not applicable					
Folpet	D/S	<0.01	L	M	Special	Sheet 400
Graphite	C	>0.01–0.1	L	H	Special	Sheet 400
Lithium carbonate	A	>1–10	L	M	Engineering	Sheet 206
Manganese dioxide	B/S	>0.1–1	L	M	Containment	Sheet 313
Nickel catalyst	D/S	<0.01	L	H	Special	Sheet 400
Petroleum resins	A	<10	L	L	General ventilation	Sheet 100
Sulfur compounds, oiled	A	<10	M	M	General ventilation	Sheet 100
Quartz dust	E	<0.01	L	M	Special	Sheet 400
Sodium acid pyrophosphate	A/S	>1–10	L	H	Engineering	Sheet 206
Sodium azide	D	<0.01	L	M	Special	Sheet 400
Starch dust	A	>1–10	L	H	Engineering	Sheet 206
Sugar	A	>1–10	L	M	Engineering	Sheet 206
Sugar beet pulp	E	<0.01	L	M	Special	Sheet 400
Zeranol	COSHH Essentials is not applicable					
Zinc oxide	C	>0.01–0.1	L	M	Special	Sheet 400

[a]Identified using the on-line interface of COSHH Essentials.
[b]L indicates a large quantity and M a medium quantity. No small quantities were identified to be in use.
[c]H indicates high dustiness; M, medium dustiness; and L, low dustiness.

concern regarding exposure to crystalline silica; this IARC Group 1 substance is found in the soil and sand associated with the vegetable and may become airborne during processing (Pestell Minerals & Ingredients, 2003). R-phrases for ammonium phosphate/sulfate fertilizers, cement mix, starch dust and sugar were identified on MSDSs containing R-phrases assigned by the manufacturer or distributor of the chemical substance.

Four substances remained unclassified after these three information sources were examined. The content of the petroleum resins and oiled sulfur compounds were not clearly identified in the NIOSH reports, and so their classification is unclear. In the NIOSH report involving petroleum resins, the investigators used the nuisance dust standard as the health criterion by which to evaluate the airborne concentration. As we have not identified any toxicity evidence to suggest another classification is appropriate, we default to hazard class A, which is associated with an exposure band comparable with the OSHA PEL for nuisance dust. Similarly, we default to hazard class A for oiled sulfur compounds. Zeranol, an estrogen used to promote animal growth, is unclassifiable because its estrogenic effects, including gynecomastica (Mallinckrodt Veterinary Inc., 1994), do not strictly meet any R-phrase classifications. COSHH Essentials, however, does not apply to veterinary medicines (HSE, 2003), so zeranol measurements were excluded from analysis. Air samples of fibrous glass dust were also excluded from analysis. Fibrous glass is not explicitly excluded from COSHH Essentials, like asbestos (HSE, 2003), but COSHH Essentials' exposure bands do not include the unit fibers/cc and we could not identify appropriate R-phrases.

The hazard group of each chemical substance for which an R-phrase had been determined was identified using the on-line interface of COSHH Essentials; the appropriate exposure bands are presented in Table 8.

Step 2. Scale of Use. The bag filling operations were typically packaging operations. The volumes are better described in terms of kilograms or tons, which COSHH Essentials indicates as having a *medium* or *large* scale of use. Many of these operations were full-shift operations, but a few were batch processes. For uniformity, the duration and frequency of use was assumed to be 60 min per filling period and four filling periods per day. Other duration and frequency combinations were investigated, but the assignment of the control intensity was not sensitive to these changes.

Step 3. Ability to become airborne. For solids, COSHH Essentials frames the ability to become airborne in terms of dustiness. *Low* dustiness is associated with chemical substances in the form of pellets, for example, whereas *medium* and *high* dustiness are associated with chemical substances taking the form of crystals/granules and fine light powders, respectively.

Step 4. Control Approach. For the chemical substances identified in bag filling operations, four control approaches are recommended by COSHH Essentials (Table 8): General Ventilation, Engineering, Containment and Special.

Step 5. Task-Specific Guidance. 'General ventilation' controls, Control Guidance Sheet 100, are not specific to any industrial operation, but rely on the principle of dilution ventilation using mechanical or natural ventilation (HSE, 2003). 'Engineering' controls for bag filling operations include recommendations for general bag filling, Control Guidance Sheet 206, and high-throughput bag filling, Control Guidance Sheet 207. In both circumstances, the recommendations include a ventilated enclosure around the filling point, a hopper at floor level to capture spills (ventilated in the high-throughput case), means of closing the bag within the ventilated enclosure, and minimization of dust emissions during filling (HSE, 2003). For the 'Containment' control approach, control guidance sheets are not specific to bags or sacks, but address filling and emptying international bulk carriers, Control Guidance Sheet 307; kegs, Control Guidance Sheet 311; and packets, Control Guidance Sheet 313. All control guidance sheets recommend providing a ventilated enclosure for the operation and a seal between the filling head and the container (HSE, 2003). The 'Special' guidance, Control Guidance Sheet 400, is the same as that identified in the context of vapor degreasing.

Control Approach Effectiveness. Among 36 air samples collected for bag filling operations without control technology, three were within or below the respective exposure bands such that the over-controlled error proportion was 8% (3/36), as shown in Table 5. Among 159 air samples collected for bag filling operations in the presence of control technology, 76 were above the respective exposure bands such that the under-controlled error proportion was 48% (76/159), as shown in Table 5. When only personal breathing zone samples were considered (Table 6), the over-controlled error proportion was 7% (2/28), and the under-controlled error proportion was 50% (52/104). The relative frequencies of the two types of errors were lower in bag filling tasks than in vapor degreasing tasks for both personal and area samples, and for personal samples alone.

Note that if the current OSHA PELs (or in their absence the NIOSH RELs) were used to establish target exposure bands, the over-controlled error proportion would increase to 56%, and the under-controlled error proportion would decrease to 9%.

Similar to the case of vapor degreasing, the proportion of over-controlled errors was higher among air samples taken in the absence of control technologies of chemical substances assigned the control intensity 'Engineering' (39%, 18/46) than assigned the control intensity 'Special' (6%, 5/79).

As with vapor degreasing operations, the interpretation of under-controlled errors is complicated by the fact that not all of the observed control technologies met performance standards for airflow rates or capture efficiency, nor were they of the approach recommended by COSHH Essentials. Among those bag filling tasks assigned to the 'Engineering' approach and had slot exhaust ventilation, one of two measurements were above the exposure band, indicating an under-controlled error of 50% (1/2). No bag filling tasks assigned the 'Containment' or 'Special' approach had containment ventilation system. However, of the 91 measurements taken of bag filling tasks with chemical substances assigned the 'Containment' or 'Special' control intensities when slot exhaust ventilation was present, 75 measurements were above the exposure band such that the under-controlled error proportion was 82% (75/91).

DISCUSSION

This paper has illustrated the process of using COSHH Essentials to identify task-specific control technologies, and has described some of the difficulties that can be encountered, namely: identification of appropriate toxicological information, compatibility of the treatment of mixtures with US occupational health and safety rules, mistaken identification of tasks in need of additional control technologies (over-controlled errors) and inadequate efficacy of control technologies (under-controlled errors).

We found it difficult to obtain the R-phrases for certain chemical substances, particularly for solid chemicals such as poorly described mixtures and natural plant materials. There are at least three reasons that R-phrases may not be available: (1) toxicity testing and/or epidemiology indicate no health effects, for example, starch dust; (2) toxicity testing and/or epidemiology indicate health effects that do not meet the criteria for any R-phrases, for example, Freon and (3) no toxicity testing or epidemiology can be located, for example, oiled sulfur compounds. Unfortunately, this difficulty can compromise selecting the appropriate control technology in COSHH Essentials. In particular, if no R-phrases for a chemical are selected by the user of COSHH Essentials, the chemical is assigned to hazard band A by default, which may be inappropriate. We also found that the treatment of mixtures in COSHH Essentials is not compatible with current OSHA regulations. The impact of this difference is uncertain as COSHH Essentials or similar schemes are not widely used in the US outside the pharmaceutical industry.

The high prevalence of both over-controlled and under-controlled errors suggests that air monitoring is necessary to ensure that control technologies are not installed unnecessarily and, if installed, perform with appropriate efficacy. Unnecessary installation of control technology wastes resources and can potentially decrease productivity. On the other hand, where control technologies are appropriately implemented, control efficacy can decrease over time owing to poor maintenance, changes in the operation, or changes in the general area airflow. Typically, the function of exhaust ventilation systems is measured indirectly by the airflow through the hood, but air velocity per se does not indicate that airborne contaminants are sufficiently controlled. More appropriate measures of control efficacy are the airborne chemical exposure levels and/or the exhaust ventilation system's capture efficiency, that is, the fraction of contaminant emitted by the source that is captured by the system. Given the high prevalence of control errors, we judge it is important that COSHH Essentials include information on the evaluation of control technology performance to enable intended users, the proprietors of small and medium sized enterprises, to accurately evaluate worker exposure.

CONCLUSIONS

Unlike the work of Tischer *et al*. (2003), our analysis of vapor degreasing and bag filling operations does not support the view that COSHH Essentials will accurately identify operations in need of control technologies, and that the control technologies will, in practice, adequately control exposures. The difference between our conclusions and those of Tischer *et al*. (2003) may be owing to differences in available data, or owing to systematic difference in health and safety performance between Germany and the US. However, both evaluations were done with data collected by federal public health agencies in a variety of industry sectors. Given the significantly different findings, we believe it is important that COSHH Essentials be tested systematically before it is promoted outside the UK.

Our results suggest several research questions. First, do proprietors of small businesses obtain the correct COSHH Essential input parameters? Second, does COSHH Essentials correctly identify operations in need of additional controls? Third, do the COSHH Essential recommendations lead to adequate control of the operation? And finally, do the proprietors of small businesses apply and interpret COSHH Essentials correctly, and in the same manner as a trained industrial hygienist?

A potential study would be prospective and include small businesses in a number of industry segments. After a brief orientation to COSHH Essentials, the proprietor and a trained industrial hygienist would independently apply COSHH Essentials to selected operations in the workplace and each identify the recommended control approach. Exposure monitoring would be conducted after the conclusions of COSHH Essentials were documented, but before any changes were made, to describe the actual exposure intensity: This would permit quantification of over-controlled errors. The monitoring results would be immediately provided to the proprietor and employees. When the measurements indicate that airborne concentrations are above the exposure band, although they may below the OSHA PEL, proprietors would be expected to apply COSHH Essentials. Follow-up exposure monitoring would be conducted to identify under-controlled errors; if further corrective action were needed, the proprietor would be strongly encouraged to enlist the services of a trained industrial hygienist. When preliminary measurements indicate that airborne concentrations are within or below the exposure band, proprietors may choose to apply COSHH Essentials and adjust controls or work practices accordingly. Follow-up exposure monitoring would also be conducted in these 'compliant' workplaces. If controls had not been implemented, the follow-up sampling would confirm that exposure levels had remained within or below the exposure band such that no decision error had been made. If controls had been implemented, the follow-up sampling would confirm that the controls had not inadvertently increased exposure intensity.

In addition to quantifying the rates of misclassification errors in practice, this prospective study would document how small business proprietors interpret and utilize COSHH Essentials and determine if trained industrial hygienists and proprietors obtain the same recommendations from COSHH Essentials.

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