Evaluation of Laser Coding Particulate Composition, Health Effects, and Safety Climate at a Brewery

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Contents

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The cover photo is a close-up image of sorbent tubes, which are used by the HHE Program to measure airborne exposures. This photo is an artistic representation that may not be related to this Health Hazard Evaluation. Photo by NIOSH.

Highlights of this Evaluation

The Health Hazard Evaluation Program received a request from a union representative at a brewery. The union was concerned about employees' exposure to odors and particulate at the laser coding stations on the can-packing lines.

What We Did

- We evaluated the can-packing lines at the brewery in September 2017.
- We collected bulk particulate samples from the local exhaust ventilation filter housing cabinets.
- We collected air samples to screen for volatile and semivolatile compounds.
- We reviewed standard operating procedures for changing filters and other maintenance of the local exhaust ventilation systems at the laser coding stations.
- We reviewed medical records, illness and injury logs, exposure assessment records, safety data sheets, and the company's respiratory protection program.
- We administered 34 voluntary questionnaires to can-packing-line employees and other concerned employees about work practices, training, safety climate, work-related health concerns, and medical history.

Some can-packing-line employees had symptoms consistent with workplace exposures. We found metals, acrylates, and benzophenone in filter particulate and volatile compounds and benzophenone in brewery air. The company can improve maintenance on the local exhaust system and further train employees to reduce possible exposures. Safety climate at the brewery was positive overall.

What We Found

- Packing line employees received instructions to wear N95 filtering facepiece respiratory protection to reduce exposure to particulate during local exhaust ventilation and maintenance. However, these employees were not included in the company respiratory protection program.
- Some employees reported work-related symptoms consistent with workplace exposures and reported work-related injuries. About half of the injuries required medical attention beyond first aid.
- Employees reported receiving only informal training on cleaning the laser coding local exhaust ventilation system, usually from a coworker.
- Few employees reported feeling well-informed about the materials they work with.
- Strengths in supervisor compliance and coaching practices contributed to an overall positive safety climate. We identified need for improvement in caring practices, such as praising employees who work safely, and helping employees anticipate problems before they occur.

- Bulk dust from the local exhaust ventilation unit contained several metals, photoinitiators, and all but one of the acrylates we analyzed for.
- Air samples contained primarily ethanol and acetaldehyde.
- Air samples contained benzophenone, a photointiator.
- The company respiratory protection program listed all use of filtering facepiece respirators during cleaning activities as voluntary, which conflicted with written procedures.

What the Employer Can Do

- Formalize a mandatory annual training program for packing line employees on when and how to safely clean the laser coding local exhaust ventilation systems' reusable filter.
- Train employees in procedures to follow the laser coding local exhaust ventilation reaction plan.
- Have supervisors recognize employees when they see them performing tasks safely.
- Implement a medical surveillance program to identify and track skin or respiratory conditions if employees continue to report symptoms after optimizing local exhaust ventilation and conducting additional training on local exhaust ventilation system maintenance.
- Include employees who maintain and clean local exhaust ventilation units in the company respiratory protection program.
- Include additional dust control measures in the filter-cleaning standard operating procedure, such as wetting the filters when they are still inside the cabinet.

What Employees Can Do

- Report health signs or symptoms to your supervisor or the safety and health office.
- Participate fully in offered training related to your job duties.

Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
AIHA	American Industrial Hygiene Association
AOEC	Association of Occupational and Environmental Clinics
CAS	Chemical Abstract Service
CFR	Code of Federal Regulations
EPA	Environmental Protection Agency
HDDA	1,6-hexanediol diacrylate, CAS number 13048-33-4
HEPA	High efficiency particulate air
LEV	Local exhaust ventilation
mg/m^3	Milligrams per cubic meter
ND	Not detected
NIOSH	National Institute for Occupational Safety and Health
NOSC	Nordic Occupational Skin Questionnaire
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PPE	Personal protective equipment
REL	Recommended exposure limit
SOP	Standard operating procedures
STEL	Short-term exposure limit
SVOC	Semivolatile organic compound
TLV®	Threshold limit value
TMPTA	Trimethylolpropane triacrylate, CAS number 15625-89-5
TPGDA	Tripropylene glycol diacrylate, CAS number 42978-66-5
TWA	Time-weighted average
UV	Ultraviolet
VOC	Volatile organic compound
WEEL	Workplace environmental exposure level

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Introduction

The National Institute for Occupational Safety and Health (NIOSH) received a health hazard evaluation request from a union representative at a brewery. The request concerned exposure to odors and particulate at the laser coding stations on the can-packing lines. In September 2017, we met with union, employee, and employer representatives. We administered a questionnaire on can-packing-line employees' work practices, training, perceptions of safety climate, and concerns about work-related safety and health. We also collected area air and dust samples for carton coating ingredients. In addition, we reviewed health and safety records, standard operating procedures (SOPs), and safety data sheets for products used at the brewery.

Background and Process

Employees in this facility brew and package beer for distribution and sale. Employees work three shifts, and the brewery operates 24 hours per day. After the beer is brewed on-site, it is moved to the canning and bottling lines. There were about 42 canning line employees and 60 bottling line employees at the time of our visit. At those lines, employees operate machinery that fills the cans or bottles, runs the cans or bottles through a pasteurizer, and then packages them in cardboard cartons.

Ten to twelve can-packing employees worked each shift during our evaluation. Can lines included Lines 10, 20, 35, and 80. On most lines, laser coders etched identification codes onto cartons. This process created particulate and fumes from the carton and its coatings. Line 10 was the only can line that did not use the laser etching process.

Custom local exhaust ventilation (LEV) units removed dust and fumes from the laser coding stations. Air collected at the laser coder filtered through a washable fabric high-efficiency particulate air (HEPA) filter, a disposable adsorbent cell, and carbon pellets before being exhausted into the facility. Employees were responsible for replacing the disposable adsorbent cell and cleaning the fabric filter as dictated either by preventive maintenance schedules or by the back pressure gauge on the LEV unit.

In early 2016, the package material coating was changed by the supplier to include an ultraviolet (UV) light-cured coating. According to employees and management, this new coating produced more airborne particulate than the previous coating when the laser coder applied the identification code.

Methods

We had several objectives for this evaluation:

- Determine if maintenance policies for LEV are adhered to, and if employees have been trained to do maintenance on the LEV units.
- Characterize the composition of the dust that originates from the laser-etching process.
- Determine if volatile organic compounds (VOCs) are in the air during the laser-etching process.

- Find out if employees self-report acute exposure to dust when the LEV is not functioning.
- Characterize employee work-related health concerns, and evaluate whether employees' have self-reported symptoms that are consistent with exposures to 1,6-hexanediol diacrylate (HDDA), benzophenone, acrylate esters, or acrylic acids.
- Assess whether training or tenure impacts an employee's willingness to stop production.
- Evaluate how employees perceive the safety climate at the workplace.

Document Review

We received safety data sheets from the company for the chemicals used on the canning and bottling lines. After review, we contacted the manufacturer of the UV-coatings used on the beverage cartons to learn more about the specific acrylates and photoinitiators (such as benzophenone) used in the coating manufacture. Additionally, we reviewed:

- Training materials, maintenance SOPs, and the company's respiratory protection program
- Personal exposure monitoring results from the packing area for benzophenone and metals tested by the company
- Filter dust composition analyses for metals provided by the company
- LEV manufacturer equipment manuals

Dust and Area Air Sampling

We collected bulk dust samples from inside the LEV cabinets using two methods. First, we used metal spatulas to scoop bulk dust into glass jars sealed with a Teflon™-lined lid. We also used a vacuum sampler consisting of a mixed cellulose ester filter connected to a personal air sampling pump.

We analyzed these samples for metals, volatile and semivolatile components of the UV-cured coatings, including benzophenone, HDDA, trimethylolpropane triacrylate (TMPTA), tripropylene glycol diacrylate (TPGDA), 1-hydroxy-cyclohexyl phenyl ketone (Chemical Abstract Service [CAS] Number 947-19-3), and benzyl dimethyl ketal (CAS Number 2235-01-0) using NIOSH method 7303 and modified U.S. Environmental Protection Agency (EPA) method 8270 [EPA 1998; NIOSH 2019].

We collected area air samples at the following locations:

- Near the Line 80 LEV housing unit and in the operator work area
- Near the Line 35 LEV housing unit and in the operator work area
- At the walkway adjacent to canning lines
- Inside the Line 20 LEV housing unit and in the operator work area
- In the area at least 20 feet away from canning lines

We collected area air samples to qualitatively screen for VOCs and semivolatile organic compounds (SVOCs) using thermal desorption tubes with pumps calibrated to 100-cubic centimeters per minute. We collected the samples for about 90 minutes and then analyzed them according to NIOSH method 2549 [NIOSH 2019]. This type of sampling identifies volatile and semivolatile compounds in the air, but it is not quantitative. During the screening, we specifically analyzed the air samples for benzophenone, HDDA, TMPTA, TPGDA, 1-hydroxy-cyclohexyl phenyl ketone, and benzyl dimethyl ketal using the National Institute of Standards and Technology 2011 mass spectral library (NIST/EPA/NIH Mass Spectral Database NIST11, Scientific Instrument Services).

Questionnaire

We invited all can-packing-line operators from each shift to complete an anonymous, written questionnaire containing validated scales as well as questions developed specifically for this evaluation. The questionnaire focused on work practices, training, work-related health concerns, medical history, and safety climate. The items included yes/no, check all that apply, scaled, and open-ended response options. Each section of the questionnaire is described below.

Work Practices and Training

We asked participants if they maintain the laser coding LEV system on the line they work, if they were trained to do so, and if needed, would they stop production to clean or change the laser coding LEV filter. We asked how many times, on average, they clean or change the laser coding LEV filter in a week. We asked if they have had a large amount of carton dust from the laser etcher on their clothing or skin, and if so, whether it happened while they were changing a laser coding LEV filter. We also asked an open-ended question about how they know when a laser coding LEV filter needed to be cleaned or changed.

We asked employees if they believed they are well-informed about the materials they work with, for example, what the work materials are made of, if they are dangerous, and how to handle them safely. This was followed by an open-ended question asking what, if anything, they would like more information about regarding work materials.

Work-related Health Concerns

We asked employees to rate their overall level of concern about their work-related health with the following questionnaire item: "On a scale from 0 (not concerned at all) to 10 (very much concerned), how concerned are you about your health as it relates to your work at this plant?" Responses of 0–3 indicated a low amount of concern, 4–6 indicated a moderate level of concern, and scores of 7 or greater indicated a high level of concern [Clark et al. 2011]. Employees were also asked an open-ended question about what makes them concerned about their work-related health, if applicable.

Medical History

General Symptoms

We asked employees yes/no questions about symptoms associated with solvent, acrylate, and/or benzophenone exposure they may have experienced within the last four-week period.

Respiratory History

We asked employees if they had a history of asthma. If employees responded yes, they were asked the following questions:

- If a health care provider told them they had asthma, or if it was assumed
- If they have asthma symptoms, at what age did it begin
- If their asthma had worsened since working on the packing lines
- If they had an attack of asthma in the last 12 months
- If they were taking any medicine for asthma

Additionally, we asked two screening questions derived from the European Community Respiratory Health Survey [Grassi et al. 2003]. The screening questions were "Have you had wheezing or whistling in your chest at any time in the last 12 months?" and "Have you been woken up by a feeling of tightness in your chest at any time in the last 12 months?" Employees were asked to exclude symptoms secondary to a cold when addressing wheezing or whistling in the chest. If employees reported wheezing or whistling in their chest within the last 12 months, they were asked "Have you been at all breathless when the wheezing or whistling noise was present?" Employees were asked if they smoked (never, currently, or formerly). If employees responded that they were current or former smokers, they were asked the number of packs per day and the number of years smoked.

Dermatitis History

Employees were asked a yes/no question if they had dermatitis on their hands, fingers, wrists, forearms, face, or neck at any time in the last 12 months (or since beginning their position). If employees responded "yes," they were asked yes/no questions about whether the dermatitis was on their:

- Hands or fingers
- Wrists or forearms
- Face or neck

Some screening questions for dermatitis were derived from the Nordic Occupational Skin Questionnaire (NOSC-2002) [Susitaival et al. 2003]. Employees were asked if contact with materials at work made their dermatitis worse. They were given an open-ended response option to describe anything that made their dermatitis worse at work.

We asked employees a yes/no question if they had any other health symptoms at work, but not when away from work. If employees answered "yes," we asked an open-ended question about those symptoms.

Work-related Injury and Illness Reporting

We reviewed Occupational Safety and Health Administration (OSHA) 300 Logs and Workers' Compensation documentation of work-related injuries and illnesses for the brewery from 2015–2017. Additionally, we asked employees who reported specific health concerns to provide medical documentation of their conditions. We reviewed medical records given to us by three or fewer employees. To protect the employees' confidentiality, the results of these medical records will not be further discussed in this report.

We asked employees a yes/no question if they had any injuries or illnesses due to work in the plant. If "yes," employees were asked if the injury/illness:

- Kept them away from work for more than a day
- Led to a work restriction or transfer
- Required medical treatment beyond first aid
- Caused loss of consciousness

If employees indicated they had a work-related injury/illness, we asked them a yes/no question about whether they reported this injury to a company representative or plant medical professional.

Safety Climate

We included a validated measure of safety climate to assess employee perception of the priority their direct supervisor places on safety [Johnson 2007; Zohar and Luria 2005]. The safety climate scale ranged from 1 (strongly disagree) to 5 (strongly agree). These safety climate items focus on employee perceptions of their supervisors' behaviors based on three main themes: caring (informing employees of policies/procedures), compliance (monitoring and controlling to ensure compliance), and coaching (instructing and guiding employees) [Johnson 2007].

We asked questions about whether the employee had reported a health or safety concern to the employer or union, and if so, to rate their level of satisfaction with how their concern was addressed.

Workplace Observations and Conversations

We observed employees working on the can-packing lines and at their workstations on the days of our visit. Minimum personal protective equipment (PPE) for can-packing-line employees included steel-toed shoes, a bump cap, safety glasses, and ear plugs. We spoke to employees about the process of cleaning the filters from the LEV units at the laser coding stations. Filters were not cleaned during our site visit, so we did not observe the process. Prior to and during our visit, we spoke with employees about their work on the packing lines and LEV, including maintenance practices.

Results and Discussion

Document Review

SOPs, Respiratory Protection Program, and Communication Products

In our review of the maintenance SOPs, we looked at the task description and health and safety guidance. We reviewed them to identify what the company expected of employees and to determine if the company expectations matched the self-reported and observed practices of employees. Prior to our site visit, we reviewed the following SOPs:

- LEV biweekly cleaning (written 4/4/2007 and revised 1/17/17)
- LEV carbon [filter] and media replacement (written 6/21/11 and revised 3/17/14)
- LEV mechanical electrical preventive maintenance (written 6/21/11 and revised 7/24/14)
- LEV reaction plan (written and revised 1/19/17)

Generally, the SOPs we reviewed addressed administrative controls and PPE use during tasks with potentially high exposures to particulate, such as cleaning and replacing reusable filters. The SOPs detailed what skin protection (gloves, coveralls) and respiratory protection (N95 filtering facepiece respirators) should be worn. Employees and management reported that odors and airborne particulate were better controlled after the SOPs were updated following the introduction of the UV-coating on the carton. LEV units were maintained by company maintenance staff and by the manufacturer upon company request, but were not regularly tested for appropriate flow or capture velocity at the hood face.

The “LEV biweekly cleaning SOP” required employees to use the following equipment: dust mask/respirator, white suit, rubber cleaning gloves, plastic bags, and a step ladder. A note in the SOP recommended a dust mask/respirator, and the company supplied N95 filtering face piece respirators for this purpose. We observed an N95 respirator available for use at the LEV unit. To clean the HEPA filter, the SOP instructed employees to remove it from its housing, place it in a plastic bag, rinse out the housing, clean the filter using a low pressure hose, and set the filter aside to dry. Employees were to install a clean, dry HEPA filter in the housing. A photo from the SOP showed an employee putting a large cylindrical filter in a plastic bag while wearing a white full body suit, gloves, boots, a filtering facepiece respirator, safety glasses, and a bump cap. A directive to minimize dust aerosolization was above the photo. The LEV manufacturer recommends that people who service the LEV unit wear a protective mask and vinyl gloves when removing dust from the unit.

The “LEV preventive maintenance SOP” required the following equipment and materials: safety glasses, hearing protection, three fuses, and flexible ducting. It stated that a “dust mask for voluntary use is available.” According to the SOP, the tasks involved inspecting electrical lines, hose condition and connections, indicator lights, fuses and switches, vacuum piping, the air pressure regulator, filter condition, and the quality of seals, hardware, and welds. The photos showed the technician is wearing gloves, but they were not listed in the required materials.

In the “LEV carbon and media replacement SOP,” required equipment and materials included safety glasses, hearing protection, gloves, dust mask, goggles, and task materials (i.e., a shop vacuum, laser coding LEV drum, carbon, and a nonhazardous waste label). A note in the SOP recommended a dust mask. The objective of the task was to replace the activated carbon in the laser coding LEV final exhaust drum.

The “LEV reaction plan” stated that employees should shut down the packing line and contact maintenance if they detect odors that persist after checking for obstruction at the LEV hood or changing the filters.

The company respiratory protection program included a list of tasks during which the company required employees to wear respiratory protection. Maintenance and cleaning tasks did not appear on this list. Furthermore, can-packing-line employees were not included in the company respiratory protection program. But in our conversations with packing line employees and through review of the maintenance SOPs, these employees were to wear respirators during filter cleaning. The SOPs on LEV maintenance and filter cleaning either recommended or required filtering facepiece respirators for these tasks. According to OSHA [2009], if respiratory protection is required or if employees are advised by management to use a dust mask (N95 filtering facepiece respirator), it would not be considered voluntary use.

In advance of the carton material coatings change, the capacity of LEV units was not tested and SOPs were not updated by management, according to revision dates and conversations with management and employees. Management spoke to the LEV manufacturer about maintenance schedules, but those discussions did not cover testing for adequate LEV airflow or capture velocities.

After the introduction of the UV-cured inks onto the cartons, employees initially reported poorer control of odors and particulate. The adsorbent cell change-out schedule was changed to be more frequent (from every 6 months to every 3 months). The pressure drop gauges also became indicators of filter performance and were marked with acceptable ranges. In January 2017, about a year after the change to UV-coating, SOPs were updated to include more frequent HEPA filter replacement and cleaning. Employees and management representatives said that when the LEV unit was working appropriately, odors and particulate were not an issue.

We reviewed communication products about the LEV systems that management gave to employees from prior to the introduction of the cartons with UV-coating (August 2015), when the UV-coated cartons were introduced (January 2016), and from a year after of the new carton materials (February 2017). The August 2015 presentation discussed the exposure monitoring results for packing employees taken around that time. In January 2016, management told employees that they had consulted with the LEV manufacturer about the filter cleaning schedule, repositioned LEV hoods (nozzles) at each line, and developed pressure drop performance markers for each LEV rather than using a standard pressure differential for all LEV. In January 2017, about a year after the introduction of the UV-cured cartons, management modified the filter cleaning and replacement schedule and established the LEV reaction plan. In February 2017, management informed employees of the changes to the preventive maintenance schedule and the LEV reaction plan at department meetings.

Contractor Personal Sampling Results

The company hired a contractor to conduct partial shift, personal exposure monitoring (215 minutes and 193 minutes) for benzophenone on employees working at the laser coding stations. Benzophenone was not detected (minimum detectable concentrations of 0.05 and 0.06 milligrams per cubic meter [mg/m^3]). Other personal monitoring results (sample length not specified) did not find detectable metals (3 samples) or dust (1 sample) in the air. The contractor also measured personal exposures during the cleaning and changing of filters from the dust collector. The sample length, work description, and PPE use were not described.

The contractor found nondetectable concentrations of aluminum, barium, cobalt, titanium, and particulate in the air, however, the particulate sampling used was not sensitive enough to measure concentrations at or below relevant occupational exposure limits (OELs). The contractor's minimum detectable concentration for particulate was 31 mg/m^3. This exceeds applicable full-shift OELs set by OSHA (15 mg/m^3) and the American Conference of Governmental Industrial Hygienists (ACGIH; 10 mg/m^3) [ACGIH 2019, 29 CFR 1910]. Therefore, even though the contractor reported nondetectable concentrations, it was impossible to determine if employees were exposed above applicable OELs. In a bulk particulate sample taken from the laser coding LEV filter housing, the company primarily measured aluminum, with lower concentrations of titanium, copper, barium, zinc, chromium, lead, and cobalt.

Workplace Observations

According to management, the LEV manufacturer designed the LEV ductwork layout with similar fan housings and filtration units at each line. The units are maintained by company employees, who consult with the manufacturer when necessary. Each LEV filtration unit was comprised of three stages: an adsorbent cell in the top compartment (discarded every three months), a cylindrical HEPA filter in the bottom compartment (cleaned and replaced weekly according to the labels on the LEV units and weekly or biweekly according to the cleaning SOP), and charcoal pellets (changed every 3 or 6 months). Figure 1 is a photo of the LEV unit. The manufacturer supplied all parts, according to the company.

Figure 1. Filter housing of the LEV unit. The top compartment holds the disposable filter and the bottom compartment holds the washable filter. Photo by NIOSH.

Each LEV unit had two modes: automatic and manual. In the automatic mode, the ventilation is activated when the packing machine is actively packing beer in cartons. It is off when the packing line is not active. The manual mode turns the ventilation machine on, regardless of the status of the packing line (Figure 2).

The LEV on Line 35 was wired incorrectly when it was installed; therefore, the machine was on manual mode when it appeared to be on automatic mode. According to management, this meant that the LEV was always running. Employees expressed concern that the wiring caused the LEV to be off when the laser coder was running. Prior to our visit, the machine was relabeled to reflect the actual wiring.

In the short-term, using the manual (always on) mode would still be effective in removing particulate and odors created during the laser coding process. However, keeping the LEV on at all times could impact the effectiveness of the preventive maintenance schedule.

Employees mechanically removed or “knocked” particulate off the filter using a “manual clean” button, before the filter housing cabinet was opened. Employees reported that they sometimes noticed an odor at the laser coding area of the packing line before the pressure drop gauge (Figure 2) on the LEV unit indicated the filters needed to be changed and cleaned. An odor does not necessarily mean low or high exposure, but it can indicate that a change in ventilation performance has occurred if there is typically no odor present.

We observed an N95 filtering facepiece respirator stored on top of a laser coding LEV unit. We did not observe any employees wearing N95 respirators during our visit.

Figure 2. The controls and filter pressure drop gauge on the front of a LEV filter housing unit. The gauge is labeled with ranges where the filter performance is "good" (green), should be "monitored" (yellow), or should be "changed" (red). A knob on the top right shows the current LEV mode as "auto" or "manual." Photo by NIOSH.

Particulate and Area Air Sampling

We collected samples of (1) the coarse bulk particulate from the bottom of the laser coding LEV filter housing unit and (2) the fine bulk particulate from the filter surface in the housing unit at each of the can-packing lines (Lines 80, 35, and 20). Full sampling results can be found in Appendix A. In general, we found metals and VOCs in the particulate from the LEV filter housing units. In two of three coarse particulate samples (taken at Lines 80 and 20), aluminum was the most abundant metal detected (21,000 to 31,000 milligrams per kilogram [mg/kg]). This is consistent with the particulate composition results from the contractor analysis. In the third sample (collected from Line 35), calcium was the most abundant at 52,000 mg/kg, which was about 180 times higher than what was found in the other coarse particulate samples. Other metals we found in lower concentrations included titanium, iron, potassium, magnesium, strontium, barium, and zinc. Ingredients of the UV-cured coating on the cartons were measured in the particulate from the laser coding filter housing and can be found in Table 1. The only ingredient not detected was TMPTA. Benzophenone, benzyl dimethyl ketal, TPGDA, and HDDA were measured in the particulate. Potential health impacts of exposure to these compounds are discussed in Appendix B.

Table 1. Estimated bulk concentration (microgram per gram) of specific SVOCs in particulate from the laser coding LEV filter housing units on Lines 80, 20, and 35.

Specific SVOC	Line 80	Line 35	Line 20
Benzophenone	710	31	340
HDDA	55	10	160
TMPTA*	ND	ND	ND
TPGDA	50	190	200
1-Hydroxy-cyclohexyl phenyl ketone	270	150	190
Benzyl dimethyl ketal	430	240	360

ND = not detected

*The estimated limits of detection for Line 80, Line 35, and Line 20 are 0.6, 4, and 4 nanograms/sample, respectively. This estimation is based on one-tenth the response of the internal standard, an assumed 1:1 response ratio, and adjustment for the weight of the bulk used for the analysis.

In the area air samples, the major compounds identified were ethanol and acetaldehyde. Other compounds identified included methyl ethyl ketone, acetic acid, ethyl acetate, bromoform, 2-butoxyethanol, and other volatile and semivolatile compounds.

The specific compounds of interest—benzophenone, TMPTA, TPGDA, HDDA, 1-hydroxy-cyclohexyl phenyl ketone, and benzyl dimethyl ketal—do not easily evaporate into the air at room temperature. Of these, benzophenone was the only compound detected in the area air samples.

Questionnaire

Thirty-four employees completed a questionnaire, including 32 can-packing-line employees, and two bottle-packing-line employees who asked to participate. Table 2 describes the participant demographic information.

Table 2. Participant demographic information (n = 34)

Demographic characteristic	Number (%)
Male	28 (82)
Age in years	
18–25	4 (12)
26–35	13 (38)
36–45	5 (15)
46–55	8 (24)
56+	4 (12)
Years with company	
< 1	4 (12)
1–5	13 (38)
6–10	3 (9)
11–15	4 (12)
16–20	8 (24)
21–25	0 (0)
26+	2 (6)
Race*	
Asian	0 (0)
Black or African American	12 (36)
White	17 (52)
Hawaiian/Pacific Islander	1 (3)
Other	3 (9)
Hispanic or Latino ethnicity*	1 (3)
Current smoker	2 (6)

*n = 33

Work Practices and Training

We asked employees if they believed they are well-informed about the materials they work with, for example, what the materials were made of, if they were dangerous, and how they could be handled safely. Of the 34 employees who responded, 8 (24%) indicated "yes," 22 (65%) indicated "somewhat," and 4 (12%) indicated "no." Employees were given the opportunity to explain what they would like to know more about, and 9 (26%) chose to do so. Of these 9 employees, 4 (44%) reported they would like more information about the exposures related to laser coding of UV-cured cartons. Others stated they would like more information in general about exposures in the plant, where the exposures are the greatest, and what potential health effects are associated with exposures.

We asked employees a yes/no question about whether they maintain the laser coding LEV system as part of their job duties, including routine cleaning and changing of the filter. Of 34 employees, 31 (91%) responded "yes." When asked if they had been trained to maintain the laser coding LEV system, including routine cleaning and changing of the filter, 18 (53%) replied "yes." Of the 18 employees reporting they had been trained, 17 (94%) said a coworker had trained them, and one person wrote that a "supervisor, coworker, or member of the company safety office" had trained them.

We asked employees whether they would stop production if the laser coding LEV filter needed cleaning or changing, as stated in the SOPs. Of 33 employees who answered this question, 28 (85%) responded "yes." We asked employees how many times on average they cleaned or changed a laser coding LEV filter in a week. Responses (n = 28) ranged from 0–4, with a median of once a week. Eight (29%) employees reported cleaning or changing the LEV filter zero times per week.

Work-related Health Concerns

Employees were asked to rate their level of concern about their work-related health on a scale from 0 (not concerned at all) to 10 (very much concerned). The average concern score was 6.0 (n = 34), indicating a moderate level of concern overall. On the basis of individual health concern scores, 9 (27%) employees indicated a low level of health concern, 10 (29%) indicated a moderate level of health concern, and 15 (44%) indicated a high level of health concern.

Of the 34 employees who completed the questionnaire, 30 (88%) responded to the open-ended question asking them to explain their work-related health concern rating. The most frequently named concerns were exposure to particulate from the laser coding LEV systems (n = 12), exposure to various chemicals at work (n = 11), exposure to particulate (not specifically stated as particulate from the laser coding; n = 8), exposure to mold (n = 7), poor air quality (n = 5), and physical safety hazards (n = 5).

Medical History

General Symptoms

We asked all 34 employees if they experienced symptoms over the past four-week period that were caused by or made worse by their work. We asked about symptoms caused by exposure to solvents (including isopropanol), acrylates, and/or benzophenone. However, these symptoms are not specific to any one chemical. These results are shown in Table 3. In addition to the symptoms reported in Table 3, two or fewer employees reported shortness of breath, nausea or vomiting, or wheals or hives.

Table 3. Frequency of affirmative responses for symptoms caused by or contributed to by work over the last four-week period, n = 34

Symptom	Frequency of “yes” responses (%)
Two or more symptoms	16 (47%)
Irritation of the nose or throat	13 (38%)
Headaches	12 (35%)
Cough	9 (27%)
Unusual tiredness/fatigue	8 (24%)
Irritation of the eyes	7 (21%)
Dizziness or lightheadedness	3 (9%)

Ten employees (29%) reported that they had a large amount of carton particulate generated from the laser coding on their skin or clothing in the last 12 months. We did not define what constituted a “large amount” of carton particulate for employees. We evaluated whether employees with these self-reported exposures had a higher prevalence of symptoms than individuals who did not report a large amount of carton particulate on their skin or clothing. We found that headaches occurred more commonly in individuals with a large amount of carton particulate on their clothing or skin than in those without such an event (58% vs. 14%; $P < 0.05$). There were no significant differences in prevalence of the remaining symptoms between the employees with a large exposure to carton particulate than those without such an exposure.

Area air samples near the can-packing lines, including at operator work locations, showed the presence of isopropanol, methyl ethyl ketone, and other organic solvents in the work area that can cause or contribute to headaches. The employees who worked on Lines 35 (4 employees) and 80 (5 employees) reported headaches more commonly than those working on other lines. We were unable to evaluate whether employees who reported maintaining the ventilation unit had higher levels of symptom reporting than those who did not, because only three participants reported that they did not maintain the ventilation unit.

Respiratory Health

Acrylates are a broad class of chemicals that use acrylic acid as a building block. They are used to make acrylic fibers, fire-retardant fabrics, coatings, adhesives, and prostheses [Kromhout et al. 2018]. Three acrylates may be present in some UV-gloss coatings used to coat beer can cartons: HDDA, TMPTA, and TPGDA. Acrylate exposure has been associated with allergic reactions, including allergic contact dermatitis, respiratory symptoms, and irritant symptoms [Kieć-Świerczyńska et al. 2017; Sasseville 2012; Walters et al. 2017]. We did not detect TMPTA in the bulk particulate samples we took, although small quantities of other acrylates were detected. We did not detect acrylates in any area air samples.

The Association of Occupational and Environmental Clinics (AOEC) classifies asthmagens as substances that can cause asthma. Some acrylates are considered asthmagens [AOEC, no date]. Additionally, certain metals (e.g., aluminum) have been associated with wheezing, dyspnea, impaired lung function, and occupational asthma [Abramson et al. 1989]. Workers exposed to fine aluminum particulate have been shown to have a high incidence of pulmonary fibrosis, though the fibrogenic potential of aluminum has been debated [ATSDR 2008].

We asked all participants if they had a history of asthma. Three employees reported that they had been diagnosed with asthma by a healthcare provider. All three employees reported these diagnoses were made before starting work at the brewery and that their condition had not worsened since beginning work in the packing lines. We did not ask participants if they used respiratory protection during cleaning, so we are unable to determine if respirators conveyed protection to these employees. However, acrylate particulate exposures during the laser coding process does not appear to have caused, contributed to, or exacerbated these employees' asthma.

Dermatitis

Acrylates, benzophenones, and certain metals have been described as potent skin sensitizers [Dittmer et al. 2018; Greenspoon et al. 2013; Hernando et al. 2013; Karlsson et al. 2011; Kieć-Świerczyńska et al. 2017; Sasseville 2012; Sasseville et al. 2011]. We asked all participants if they had experienced dermatitis in the past 12 months, or since starting work at the brewery if less than 12 months. Eight participants (24%) reported having dermatitis, with five (15%) having it on their hands or fingers and four (12%) on their wrists or forearms. Two or fewer participants reported dermatitis on their face or neck. Five of the eight (63%) participants with a history of dermatitis noted that their dermatitis was made worse when in contact with materials or chemicals at work. Some participants felt that touching paper from the cartons and contact with pasteurizer water were causes of their worsening dermatitis. Five of seven (71%) employees who reported dermatitis (one employee did not report their line number) worked on Line 80. Additional information about contact dermatitis can be found in Appendix C.

The bulk particulate samples we collected from the LEV equipment contained acrylate particulate. Employees may have come into contact with acrylates while conducting maintenance or clean-up tasks on the ventilation unit. Skin contact with acrylates or solvents can cause dermatitis, and we measured acrylates in the particulate collected from the HEPA filter. We did not ask about specific ingredients in pasteurization water. Typically, pasteurization water can include additives that limit the growth of bacteria and rust, and may cause irritation to the skin.

Work-related Injury and Illness Reporting

We asked participants if they had any injuries or illnesses due to work in the brewery. Fifteen (44%) employees reported a work-related injury or illness while working at the brewery. Of those 15 participants, 13 (87%) reported the injury/illness to their supervisor. Seven (47%) participants reported that their injury/illness required a level of care greater than first aid, 5 (33%) stated that the injury resulted in work restriction or transfer, and 3 (20%) reported that they were away from work for more than one day. No employees suffered a loss of consciousness as a result of their injury/illness.

From January 2015 through August 2017, the brewery recorded 13 injuries/illnesses on the OSHA 300 Logs: 10 (77%) were injuries and 3 (23%) were "other illnesses." Six (46%) of the 13 employees who reported an injury were listed as packers on the OSHA 300 Logs. One individual reported developing a respiratory illness following an exposure to carton particulate. We discussed this event with the company, union, and employee representatives, who informed us that this event occurred after the LEV system's filter housing unit failed, releasing carton particulate into the employee's face. This incident occurred before the introduction of the UV-coated cartons. The employee was no longer working at the company at the time of our evaluation.

Safety Climate

We asked participants questions related to safety climate, or the perception of the importance their supervisor places on safety [Zohar 1980]. Table 4 shows employees' agreement status with each of the safety climate items. To simplify the information, scores of 3 were considered neutral, scores of 1 or 2 indicated disagreement, and scores of 4 or 5 indicated agreement.

Table 4. Employees' level of agreement with safety climate items (n = 34)

MY DIRECT SUPERVISOR	Median*	Agree n (%)	Neutral n (%)	Disagree n (%)
Compliance practices (α† = 0.83)				
Makes sure we follow all the safety rules (not just the most important ones)	4.0	25 (74)	4 (12)	5 (15)
Insists that we obey safety rules when fixing equipment or machines	4.0	22 (65)	6 (18)	6 (18)
Is strict about working safely when we are tired or stressed	4.0	19 (56)	11 (32)	4 (12)
Refuses to ignore safety rules when work falls behind schedule	4.0	22 (65)	3 (9)	9 (26)
Coaching practices (α = 0.87)				
Discusses how to improve safety with us	4.0	24 (71)	4 (12)	6 (18)
Uses explanations (not just compliance) to get us to act safely (n = 33)	4.0	19 (58)	8 (24)	6 (18)
Frequently tells us about the hazards in our work	3.5	18 (53)	5 (15)	11 (32)
Caring practices (α = 0.93)				
Is strict about safety at the end of the shift, when we want to go	4.0	18 (53)	7 (21)	9 (26)
Frequently talks about safety issues throughout the workweek	4.0	17 (50)	10 (29)	7 (21)
Spends time helping us learn to see problems before they arise	3.0	9 (26)	11 (32)	14 (41)
Says a "good word" to workers who pay special attention to safety	3.0	15 (44)	9 (26)	10 (29)

*Based on a scale from 1 (strongly disagree) to 5 (strongly agree).

†A statistical test to determine whether multiple scale items are measuring the same construct, or idea. The scale is from 0–1, with a higher score being more desirable. Scores of 0.7 or greater indicate an acceptable level of consistency.

The median overall safety climate score approached agreement with the safety climate items (α = 0.95; median = 3.7; n = 33). Areas needing improvement include helping employees anticipate problems before they arise, praising safe work, and telling employees about the hazards in the work.

Safety climate is important because of its potential for explaining variation in safety-related outcomes. For example, the measure of safety climate used in this evaluation has been shown to be highly and significantly correlated with observed safety behavior (a higher safety climate score is associated with more safety behaviors), and significantly negatively correlated with days off work following an injury (a higher safety climate is associated with fewer days off following an injury) [Johnson 2007]. Zohar [2000] suggests that employees' perceptions of safety climate inform them of how to behave to please their supervisors: if priority is not given to safety, then the employees will likely focus their attention on other goals, such as production.

We asked all 34 employees several questions about their perceptions of how the employer and the union addressed safety and health concerns. Twenty (59%) employees indicated they had reported a health or safety concern to management in the past, and of these, 7 (35%) were "satisfied" with how the concern was addressed. Five (15%) employees indicated they had reported a health or safety concern to the union, and of these, 4 (80%) were either "satisfied" or "very satisfied" with how the concern was addressed.

Limitations

Our evaluation was subject to limitations. First, we used thermal desorption tubes to identify volatile and semivolatile compounds during normal operations, which does not account for exposures that occur during maintenance activities or when exposure controls are not functioning well. Additionally, the voluntary nature of our survey may have led to greater participation by employees who were more likely to self-report work-related health concerns or symptoms.

Conclusions

When the new carton coating was introduced, the existing maintenance procedures and filter change-out schedule were not able to sufficiently control odors and perhaps particulate exposures. After employees expressed concerns of more frequent odors and ventilation system malfunctions, the filter changes were more frequently scheduled and the pressure drop ranges were reevaluated. This improved the LEV system performance. At the time of our visit, we found benzophenone in the area air samples, but no other photoinitiators or acrylates. We found various metals, primarily aluminum, in the dust collected by the LEV system. Some employees on the can-packing lines had nonspecific symptoms consistent with workplace exposures, including dermatitis and headaches. Safety climate can be improved by helping employees anticipate problems before they arise, praising safe work, and telling employees about the hazards in the work.

Recommendations

On the basis of our findings, we recommend the actions listed below. We encourage the brewery to use a labor-management health and safety committee or working group to discuss our recommendations and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for the specific situation at the brewery.

Our recommendations are based on an approach known as the *hierarchy of controls*. This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and PPE may be needed.

Engineering Controls

Engineering controls reduce employees' exposures by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls protect employees effectively without placing primary responsibility of implementation on the employee.

1. Evaluate the performance of the LEV system at least annually. The evaluation should include measuring the volumetric flow rate of the LEV and comparing it to the unit's expected rate as provided by the manufacturer.
2. Consult the LEV manufacturer or a qualified ventilation engineer to ensure that the LEV system design specifications and maintenance procedures are sufficient before making any changes to the laser coding operations or line speed, including changes to the carton or carton coatings.

Administrative Controls

The term *administrative controls* refers to employer-dictated work practices and policies to reduce or prevent hazardous exposures. Their effectiveness depends on employer commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that policies and procedures are followed consistently. Below is a list of administrative controls we recommend:

1. Wet the HEPA filter prior to its removal from the LEV housing to prevent dust from getting into the air during filter removal. Current LEV maintenance SOP calls for rinsing the LEV cabinet with water, after removal of the filter. If the filter cannot be wetted while in the housing due to manufacturer guidelines, do so immediately upon filter removal from housing.
2. Develop and provide annual standardized training that is consistent with the existing SOPs. At a minimum, the initial training should be provided in person by an individual that management has determined is proficient in safely operating, cleaning, and performing maintenance of the LEV housing unit.
3. Create a filter change-out schedule that is linked to production (such as cartons used or hours of operation) rather than to a time period or LEV system dysfunction.
4. Ask line operators to report earlier indicators of declining performance (such as decline in filter effectiveness and increased production of dust) and use reports to improve maintenance plans and prevent potential dust and VOC exposures on the lines.
5. Train employees on the various hazards associated with each job on the canning lines. Make sure employees understand what potential exposures there are on the job and what engineering controls and PPE should be used to reduce or eliminate the exposures.
6. Enforce consistent PPE use in areas where dermal exposure to acrylates, benzophenone, or metal particulate can occur. Remind employees that they are required to wear long pants, long-sleeved shirts, and appropriate gloves whenever they could come in contact with materials containing these substances.

7. Evaluate all new processes, process changes, or product changes with regard to their impact on employee exposure and possible effects on employee respiratory and dermal health before changes are implemented. As part of managing the health risks associated with product changes, consult with the product manufacturers about reported health risks.
8. Implement a medical surveillance program for employees exposed to carton particulate during laser coding if they continue to report symptoms after optimizing engineering controls and additional training. Incorporate a screening medical questionnaire into the monitoring program that focuses on skin and respiratory symptoms. The questionnaire should be given before placement in a job with potential exposure and periodically thereafter. Questionnaire responses can help identify work areas and tasks that need additional evaluation and employees who need additional medical follow-up. A medical surveillance program helps prevent, identify, and manage skin and respiratory disease among included employees.
9. Encourage employees to report all potential work-related symptoms to their supervisors. Employees with persistent symptoms should be evaluated by an occupational medicine physician or a medical provider specializing in workplace illnesses. The AOEC has an online directory of such providers at http://www.aoec.org/directory.htm. Employees with definite or possible occupational skin or respiratory diseases should be protected from exposures to substances that cause or exacerbate the disease.
10. Encourage employees to discuss their work exposures with their primary healthcare provider and to share air sampling records and health concerns with them.
11. Improve communication between the employer and employees regarding responses to employee health and safety concerns. Improving communication may lead to more favorable employee perceptions of the employer's trustworthiness and approachability when it comes to health and safety concerns. A supervisor or manager who is sensitive to the employees' concerns should communicate directly with those who report health and safety concerns. Actions to consider include the following:
    - Actively listen to employees' concerns in a nonjudgmental manner. Employees should feel that their concerns are taken seriously.
    - Completely inform employees of the specific steps being taken to assess the problem, what has been determined, and what remains to be determined. A combination of written reports and face-to-face meetings is valuable.
    - Regularly share information with employees rather than waiting until a definitive cause of the problem is discovered; this will reduce the chance of distorted information.
12. Supervisors should praise employees for safe behavior.

Personal Protective Equipment

PPE is the least effective means for controlling hazardous exposures. Proper use of PPE requires a comprehensive program and a high level of employee involvement and commitment. The right PPE must be chosen for each hazard. Supporting programs such as training, filter change-out schedules, and medical assessment may be needed. PPE should not be the sole method for controlling hazardous exposures. Rather, PPE should be used until effective engineering and administrative controls are in place.

1. Include canning line employees in the respiratory protection program as required by the OSHA Respiratory Protection Standard [29 CFR 1910.134].
2. Clearly communicate to employees the reasons for changing PPE requirements, if changes are made.

Appendix A: Tables

Table A1. Metal concentrations in coarse particulate (mg/kg) and metal presence in fine particulate from LEV filter housing units

Analyte	Line 80		Line 20		Line 35		Coarse dust		Fine dust (µg/sample)
	Coarse	Fine	Coarse	Fine	Coarse	Fine	MDC	MQC	LOD
Aluminum	31,000	+	21,000	+	22,000	+	10	45	0.2
Antimony	[3.2]	ND	ND	ND	ND	ND	3	11	0.4
Arsenic	[3.5]	ND	ND	ND	ND	ND	3	12	0.4
Barium	48	+	40	+	49	+	0.2	0.79	0.02
Beryllium	ND	ND	[0.13]	+	[0.13]	ND	0.05	0.19	0.006
Cadmium	ND	ND	ND	ND	ND	ND	0.1	0.39	0.01
Calcium	290	+	300	+	52,000	+	3	12	0.2
Chromium	14	+	9.2	+	11	+	0.3	1.2	0.05
Cobalt	3.9	+	1.7	+	11	+	0.2	0.58	0.02
Copper	470	+	970	+	690	+	0.4	1.6	0.03
Iron	1,000	+	760	+	890	+	2	6.5	0.8
Lanthanum	31	+	27	+	16	+	0.2	0.63	0.02
Lead	19	+	16	+	13	+	1	3.7	0.1
Lithium	31	+	25	+	23	+	0.6	1.9	0.07
Magnesium	92	+	74	+	1,500	+	0.5	1.7	0.05
Manganese	2.7	+	1.7	+	160	+	0.08	0.27	0.02
Molybdenum	8.3	ND	11	+	22	+	0.3	1.2	0.03
Nickel	[1.5]	+	ND	+	ND	+	0.5	1.8	0.08
Phosphorus	420	+	370	+	370	+	6	21	0.5
Potassium	420	+	330	+	390	+	2	7.2	0.3
Selenium	ND	ND	ND	ND	ND	ND	10	42	1
Silver	ND	ND	ND	ND	ND	ND	0.1	0.47	0.02
Strontium	60	+	97	+	150	+	0.09	0.32	0.006
Tellurium	11	ND	[6.1]	ND	[6.2]	ND	3	8.7	0.3
Thallium	ND	ND	ND	ND	ND	ND	1	3.9	0.5
Tin	[1.6]	+	[2]	+	ND	+	1	4.5	0.08
Titanium	1,200	+	340	+	310	+	0.06	0.19	0.01
Vanadium	23	+	18	+	18	+	0.4	1.3	0.05
Yttrium	3.7	+	3.1	+	2.6	+	0.07	0.25	0.003
Zinc	35	+	20	+	60	+	0.5	1.9	0.02
Zirconium	15	+	5.6	+	21	+	0.09	0.31	0.02

[ ] = Estimated concentration: this concentration was between the minimum detectable and minimum quantifiable concentrations.

µg/sample = Micrograms per sample

+ = Metal was measured above the limit of detection in the sample.

Appendix B: Occupational Exposure Limits and Health Effects

NIOSH investigators refer to mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents when evaluating workplace hazards. OELs have been developed by federal agencies and safety and health organizations to prevent adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected if their exposures are maintained below these levels. Some may have adverse health effects because of individual susceptibility, a preexisting medical condition, or a hypersensitivity (allergy). In addition, some hazardous substances act in combination with other exposures, with the general environment, or with medications or personal habits of the employee to produce adverse health effects. Most OELs address airborne exposures, but some substances can be absorbed directly through the skin and mucous membranes.

Most OELs are expressed as a time-weighted average (TWA) exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short-term exposure limit (STEL) or ceiling values. Unless otherwise noted, the STEL is a 15-minute TWA exposure. It should not be exceeded at any time during a workday. The ceiling limit should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits; others are recommendations.

- The U.S. Department of Labor OSHA permissible exposure limits (PELs) [29 CFR 1910 for general industry; 29 CFR 1926 for construction industry; and 29 CFR 1917 for maritime industry] are legal limits. These limits are enforceable in workplaces covered under the Occupational Safety and Health Act of 1970.
- NIOSH recommended exposure limits (RELs) are based on a critical review of the scientific and technical information and the adequacy of methods to identify and control the hazard. NIOSH RELs are published in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends risk management practices (e.g., engineering controls, safe work practices, employee education/training, PPE, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects.
- Another set of OELs commonly used and cited in the United States is the ACGIH threshold limit values (TLVs). The TLVs are developed by committee members of this professional organization from a review of the published, peer-reviewed literature. TLVs are not consensus standards. They are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2019].

Outside the United States, OELs have been established by various agencies and organizations and include legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/GESTIS/GESTIS-Internationale-Grenzwerte-für-chemische-Substanzen-limit-values-for-chemical-agents/index-2.jsp, contains international limits for more than 2,000 hazardous substances and is updated periodically.

OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 91-596, sec. 5(a)(1)]. This is true in the absence of a specific OEL. It also is important to keep in mind that OELs may not reflect current health-based information.

When multiple OELs exist for a substance or agent, NIOSH investigators generally encourage employers to use the lowest OEL when making risk assessment and risk management decisions. NIOSH investigators also encourage use of the hierarchy of controls approach to eliminate or minimize workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., LEV, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) PPE (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health. Control banding focuses on how broad categories of risk should be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement existing OELs.

HDDA, TPGDA, and TMPTA

Acrylates address a class of chemicals that are based on acrylic acid—salts and esters of acrylic acid are used in several industries to create polymers. Acrylates can be used, among other things, as coatings, adhesives, bonders, and sealers. Acrylates are reactive and polymerization can be initiated using UV light.

HDDA (CAS number 13048-33-4), one of the acrylates we measured, is used as an UV-initiated crosslinking agent for inks, coatings, adhesives, and dental sealants. HDDA has been found to cause skin sensitization and irritation in several animal studies and human case reports [Bjorkner 1984; Botella-Estrada et al. 1922; Clemmensen 1984; Nethercott et al. 1983; Parker and Turk 1983; van der Walle 1983]. It has an American Industrial Hygiene Association (AIHA) workplace environmental exposure level (WEEL) exposure limit of 1 milligram per cubic meter or 0.11 parts per million at typical indoor temperatures and pressure [AIHA 1998]. This OEL was established to prevent skin irritation and due to analogous structure with their irritating chemicals. NIOSH, ACGIH, and OSHA have not established OELs for HDDA.

OELs have not been established for TPGDA (CAS number 42978-66-5), although it has been identified as a skin, eye, and respiratory irritant. It may also cause sensitization and allergic skin reaction [Aalto-Korte 2017; ECHA 2018; Nylander-French and French 2000; Skotnicki and Pratt 1998].

Technical grade TMPTA (CAS number 15625-89-5) was recently classified as a human carcinogen and asthmagen [AOEC, no date; Kromhout et al. 2018]. The AIHA established a WEEL of 1 milligram per cubic meter of air for TMPTA [AIHA 1981]. TMPTA was not found in this workplace.

Benzophenone, Benzyl dimethyl ketal, and 1-Hydroxy-cyclohexyl phenyl ketone

Used in a variety of industries, benzophenone exposure can occur occupationally through inhalation and skin contact. Benzophenone is used as a photoinitiator and wetting agent in UV-cured inks and plastics, and as a fixative to prevent UV damage to scents and coloring agents [IARC 2013]. NIOSH, OSHA, and ACGIH have not established OELs for benzophenone. AIHA established a WEEL of 0.5 milligram per cubic meter of air for benzophenone [AIHA 2003]. The basis of the WEEL was subchronic animal feeding studies in which liver injury was indicated. Inhalation data were not available for assessment at the time of evaluation.

Benzyl dimethyl ketal (CAS number 2235-01-0) and 1-hydroxy-cyclohexyl phenyl ketone (CAS number 947-19-3) are a photoinitiators that are used to start polymerization of acrylate polymers. They do not have OELs established by NIOSH, OSHA, or ACGIH. 1-hydroxy-cyclohexyl phenyl ketone may cause skin and eye irritation [NCBI, no date].

Appendix C: Contact Dermatitis

Contact dermatitis makes up 90% to 95% of all occupational skin diseases [Ingber and Merims 2004; Lushniak 2004]. Contact dermatitis, both irritant and allergic, is an inflammatory skin condition caused by skin contact with agents such as chemical irritants (irritant contact dermatitis) or allergens (allergic contact dermatitis). Irritant contact dermatitis is skin inflammation due to direct cell damage from a chemical or physical agent, while allergic contact dermatitis is a delayed immune reaction. Over 57,000 chemicals are reported to cause skin irritation, but only 3,700 chemicals are known skin allergens [Belsito 2005]. Usually, only a small percentage of people are susceptible to skin allergens.

In contact dermatitis, the skin initially turns red and can develop bumps and small, oozing blisters. After several days, crusts and scales form. Stinging, burning, and itching often occur. With no further contact with the agent, the dermatitis usually disappears in 1 to 3 weeks. With chronic exposure, deep fissures, scaling, and darkening of the skin can occur. Exposed areas of the skin, such as hands and forearms, have the greatest contact with irritants or allergens and are most commonly affected. Over 80% of occupational contact dermatitis involves the hands [Belsito 2005; Flyvholm et al. 2007; Warshaw et al. 2003]. If the agent gets on clothing, it can cause dermatitis at areas of greatest contact, such as thighs, upper back, armpits, and feet. Dusts can produce dermatitis at areas where the dust accumulates and is held in contact with the skin, such as under the collar and belt line, at the tops of socks or shoes, and in skin creases, such as inside elbows and behind knees. Mists can produce dermatitis on the face and neck. Irritants and allergens can be transferred to distant areas of the body, such as the trunk or genitalia, by unwashed hands or from areas of accumulation, such as under rings or in finger webs.

It is often impossible to clinically distinguish irritant contact from allergic contact dermatitis, as both can have a similar appearance and both can result in an acute, subacute, or chronic condition. Irritant contact dermatitis can be caused by many factors. The most common skin irritant at work is wet work, defined as exposure of skin to liquid for more than 2 hours per day, use of occlusive gloves for more than 2 hours per day, or frequent hand washing [Chew and Maibach 2003; Slodownik et al. 2008]. Other common causes of irritant contact dermatitis include soaps and detergents, solvents, food products, cleaning agents, plastics and resins, petroleum products and lubricants, metals, and machine oils and coolants [Chew and Maibach 2003; Slodownik et al. 2008]. Frictional irritant contact dermatitis can be caused by low humidity, heat, paper, tools, metals, fabrics, plastics, fibrous glass and other particulate dusts, and cardboard, among other causes [McMullen and Gawkrodger 2006; Morris-Jones et al. 2002].

Causes of allergic contact dermatitis include plants such as poison ivy, metallic salts, germicides, plastic resins, rubber additives, and fragrances [Mathias 1990]. In patients with occupational contact dermatitis who were skin-patch tested, the most common relevant allergens included thiuram mix, carba mix, bacitracin, methyldibromo glutaronitrile/phenoxyethanol, formaldehyde, glutaraldehyde, methylmethacrylate, nickel, cobalt, and chromium [Warshaw et al. 2007, 2008].

Studies on the prognosis of occupational contact dermatitis stress the importance of primary prevention. One study found that 32% of 124 surveyed patients had severe hand dermatitis 5 years after they were initially diagnosed with irritant hand dermatitis. Severity was measured by self-reported frequency of relapses, frequency of dermatologist visits, and use of topical corticosteroids [Jungbauer et al. 2004].

Another study found that 25% of 540 surveyed patients had persistently severe or aggravated symptoms a year after initial diagnosis of occupational hand dermatitis. Poor prognosis was associated with the presence of atopic dermatitis and being 25 years of age or older. Prognosis was not affected by whether the dermatitis was irritant or allergic. Those with severe occupational hand dermatitis at baseline had a higher risk of taking sick leave and job loss in the following year than those with mild cases. The study found no significant improvement in the disease after the change of job [Cvetkovski et al. 2006]. Widespread hand dermatitis on initial examination was found to be the greatest factor for a poor long-term prognosis in a third study [Meding et al. 2005]. In addition, many skin disorders, including contact dermatitis, have been shown to have a significant impact on quality of life [Cvetkovski et al. 2005; Fowler et al. 2006; Kadyk et al. 2003; Lan et al. 2008].

Preventing Contact Dermatitis

Avoiding irritants and allergens, in addition to wet work, is the first step in dermatitis prevention. Liberal use of skin moisturizers helps to prevent contact dermatitis by maintaining a healthy skin barrier—helping to repair this barrier if it has been compromised [Chew and Maibach 2003]. The following list provides strategies in the prevention of occupational contact dermatitis:

- Identifying irritants and allergens
- Substituting chemicals that are less irritating or allergenic
- Establishing engineering controls to reduce exposure
- Emphasizing personal and occupational hygiene
- Establishing educational programs to increase awareness in the workplace
- Using PPE, such as gloves and special clothing [NIOSH 1988]
- In some cases of allergic contact dermatitis, employees may have to be reassigned (with retention of pay and employment status) to areas where exposure is minimal or nonexistent.

Chemical changes in industrial materials have been beneficial. For example, the addition of ferrous sulfate to cement to reduce the hexavalent chromium content has been effective in reducing occupational allergic contact dermatitis in Europe [Goh and Gan 1996]. Avoiding the use of formaldehyde releasing biocides in metal working fluids will likely reduce contact dermatitis among machinists [Aalto-Korte et al. 2008]. Protective gloves can reduce or eliminate skin exposure to hazardous substances if used correctly. Gloves can also cause or worsen hand dermatitis (by permeation and penetration) if selected poorly and used improperly (by contamination) [Foo et al. 2006].

The use of PPE may occlude irritants or allergens next to the skin, and PPE components may directly irritate the skin. Therefore, the correct use of PPE is at least as important as the correct selection of materials [Kwon et al. 2006]. Similarly, the excessive pursuit of personal hygiene in the workplace may actually lead to misuse of soaps and detergents and cause irritant contact dermatitis. Proper hand washing methods and adequate moisturizing are valuable in preventing contact dermatitis [Warshaw 2003]. The effectiveness of barrier creams is controversial because data on the protective nature of these topical products during actual working conditions involving high-risk exposures are limited. Educating the workforce about skin care, exposures, and PPE use is an especially important measure in the prevention of occupational contact dermatitis [Loffler et al. 2006; Schwanitz et al. 2003; Weisshaar et al. 2006].

The following list provides tips on proper hand washing [Warshaw et al. 2003]:

- Avoid hot water; use lukewarm or cool water instead.
- Use mild cleansers without perfume, coloring, or antibacterial agents.
- Pat hands dry, especially between fingers.
- Apply skin moisturizer generously after hand washing and repeat throughout the day.
- Avoid rubbing, scrubbing, the use of washcloths, and the overuse of soap and water.

This additional list provides tips for the workplace [Warshaw et al. 2003]:

- Remove rings before work.
- Wear protective gloves in cold weather and for dusty work.
- Wear tight-fitting leather gloves for frictional exposures.
- When performing wet work, wear cotton gloves under vinyl or other nonlatex gloves.
- Avoid immersing hands; use running water if possible.

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