

Engineering Case Reports

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Engineering Case Reports

Evaluation of a Local Exhaust Ventilation System for Controlling Exposures During Liquid Flavoring Production

BACKGROUND

In May, 2000, the National Institute for Occupational Safety and Health (NIOSH) investigated a cluster of eight cases of the rare lung disease bronchiolitis obliterans (BO) among individuals working in the manufacture of microwave buttered popcorn.^(1,2) Subsequent work by NIOSH in other microwave popcorn plants identified more workers with this illness.⁽²⁾ The prevalence of airways obstruction and respiratory symptoms was greater in workers with longer work histories of mixing butter flavorings and in packaging workers located near oil and flavoring tanks. In 2004, following the diagnosis of BO in two flavoring manufacturing employees, the California Department of Public Health (CDPH) and Department of Industrial Relations, Division of Occupational Safety and Health (Cal/OSHA) initiated an industry-wide investigation of lung disease in flavoring manufacture. Severe obstructive lung disease was subsequently documented in seven California workers who were involved in the production of a wide variety of food flavorings.⁽³⁾

Employees within the flavoring production industry have complex exposures in terms of the physical form of the agents (solid, liquid, and gas) and the number of chemicals used. Exposures vary dramatically depending on the flavor formulations completed on a particular day. An employee can make numerous flavor formulations daily depending on the size and complexity of a batch order. It was not unusual to observe multiple batches being compounded concurrently by different employees in the same production area. The majority of flavors are manufactured on an as-ordered basis, with little advance notice. Although there are thousands of flavoring compounds in use, only a small number have occupational exposure limits.⁽⁴⁾ Data documenting occupational exposures in flavoring manufacturing are limited, and the industry is largely unstudied. With the lack of occupational exposure limits for a majority of the thousands of flavoring chemicals, the development of engineering control guidance is critical to help reduce the risk of flavoring-related obstructive lung disease.

In November 2006, NIOSH researchers conducted a walk-through evaluation in a food flavorings production facility. Engineering control recommendations were then provided to the company. This article describes the results of an evaluation of new ventilation controls for weighing and pouring flavoring chemicals on the bench top and mixing large-scale batches of flavorings in mixing tanks that were installed following the walk-through.

Process and Engineering Control Description

The company is a wholesale flavor and color manufacturer that produces more than 1500 flavors in liquid, powder, spray dried, natural, natural and artificial, or artificial forms. The liquid flavor compounding area was a focus of our study and consisted of both stationary and mobile open tanks for mixing liquid flavoring ingredients.

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FIGURE 1. Small batch mixing ventilated workstation exhaust hood.

There were several small- and medium-sized mobile tanks that were moved throughout the production room according to need of the batch or formulation. Employees typically poured and mixed small quantities of flavoring ingredients on top of a bench and then completed large pours directly into the mixing tank. Occasionally, larger pours were made from drums directly into the mixing tank.

A new local exhaust ventilation system was developed and installed in the liquid production room in the May–June 2007 timeframe and consisted of two main types of local exhaust ventilation hoods. The first was a ventilated bench top, back draft, slotted hood used to control worker exposure to chemicals during small batch mixing, weighing, and pouring activities that comprised a majority of the workday (Figure 1). These workstations measured approximately 3 feet in height by 3.5 feet in width with a bench top depth of 1.5 feet. The hood plenum was tapered from top to bottom and included four 5/8-inch slots across the hood face. Overall, five such ventilated workstations were installed in the liquid compounding room.

The second hood was more like a booth that allowed for the containment of large mobile mixing tanks (Figure 2). These booths ranged from 6.5 to 7.5 feet in height by 4 feet in width

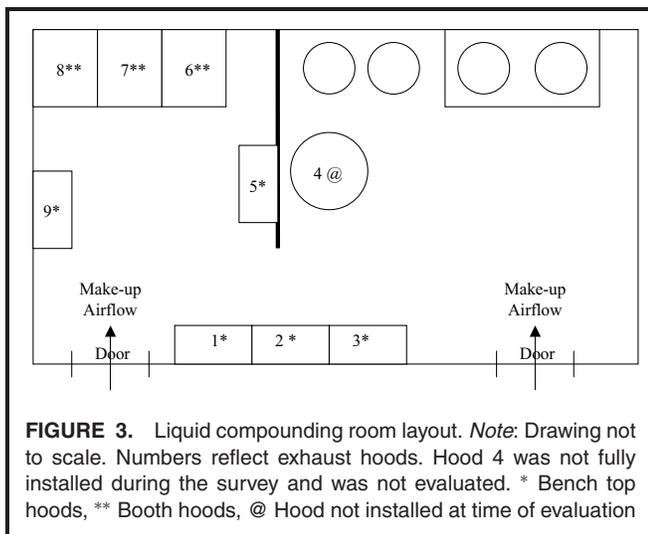


FIGURE 2. Large mixing ventilated booth-type exhaust hood.

and 4 feet in depth and collected chemical vapors while the worker poured flavoring ingredients into the large mixers. The booth also contained evaporative losses when a flavor was being mixed. The booth hood plenum was tapered from top to bottom and included six 5/8-inch slots across the hood face. Three of these hoods were installed in the liquid flavoring compounding room. A layout of the liquid production room is shown in Figure 3.

METHODS

A variety of methods were used to evaluate the local exhaust ventilation system (Table I). Initial characterization included measuring exhaust flow rates, face (capture) velocity, and slot velocity for each hood. The capture velocity of the hood is defined as the velocity created by the hood at the point of contaminant generation.⁽⁵⁾ For enclosing hoods, the capture velocity is the air velocity measured at the face of the hood. Exhaust slots are typically used to provide uniform velocity across the face of a hood. When designed properly, exhaust slots distribute the suction evenly across the hood face, providing uniform capture characteristics. In addition, a smoke tracer was used to visualize the airflow and assess the effect



of secondary airflows on hood performance. Tracer gas (TG) tests and control on/off real-time exposure monitoring were also performed to evaluate quantitative capture efficiency for each hood.

Indirect measures of engineering control efficacy were used to evaluate the installed ventilation systems, since direct

measurement of air concentration is difficult based on potential confounders, including production-based variables (e.g., many workers using different chemicals in close proximity, type and quantity of chemicals used, etc.) and work practice differences (inter-worker variability).

Hood Velocity Measurements

A Velocicalc Plus Model 8388 air velocity meter (TSI Incorporated, St. Paul, Minn.) was used to evaluate overall exhaust flow rate by measuring air speeds at the face of each hood and velocity pressures in the exhaust ducts. The face velocity tests were performed by dividing the opening of the hood into equal area grids of approximately 1 ft² and measuring the velocity at the center of each grid. Hood face velocities taken at each grid point were averaged over a period of 5 sec. In addition, the air velocities were measured across all slots for each hood to evaluate distribution of exhaust. Hood exhaust flow rates were calculated based on 10-point Pitot tube traverses of exhaust ducts. The velocity pressures were measured at each point, converted into duct velocities, and averaged across the cross section. The average duct velocity was multiplied by the duct cross-sectional area to yield the average exhaust flow rate.⁽⁶⁾

TABLE I. Test Methods and Objectives

Method	Description	Objective
Hood velocity measurements	Hood face velocities and slot velocities were measured with an airflow meter. Overall hood exhaust flow rates were measured by pitot traverse in the exhaust duct.	These measurements were made to evaluate contaminant capture velocity at the hood face. A capture velocity of 100 ft/min was recommended. Slot velocities were measured to evaluate the proper design of the hood—even flow across the hood was evaluated. Velocity pressure measurements were made in the exhaust duct to measure the overall exhaust flow rate for each hood.
Airflow visualization test	Smoke was generated in and around the periphery of the hood opening using a Rosco fog generator.	This test provided qualitative evaluation of hood capture effectiveness. Criteria for performance evaluation included observation of effective smoke containment. Notes were made on the time required for smoke to clear out of hood and if any smoke escaped from the hood.
Tracer gas capture test	Tracer gas was released inside hood to simulate process contaminant generation. Measurements of tracer gas concentration were made inside the exhaust duct.	Tracer gas testing provided a quantitative evaluation technique on contaminant capture. Tracer gas concentrations measured inside the exhaust duct provided a basis for evaluating percentage of contaminant captured.
Control on/off test	Tasks such as weighing and mixing of alcohol were performed inside the bench top hood. Real-time personal measurements of exposure were made during these tasks with the exhaust fan on and off.	This test measured the quantitative effectiveness of the hood during normal work tasks. Comparisons of personal exposures with the exhaust on vs. exhaust off provided an indication of hood effectiveness.

Airflow Visualization Test

A Rosco fog machine model 1500 (Rosco Laboratories, Inc., Stamford, Conn.) was used to visualize air movement inside and around the periphery of the hood. Smoke was released around the edge of and inside the hood to view the airflow patterns in and around the hood and to qualitatively determine whether it was being effectively captured and removed by the ventilation system. If the smoke was pulled away from where the worker would be positioned and was captured quickly and completely by the hood, it was a good indication of acceptable control design and performance. If the smoke escaped from the hood and went into the room or if the amount of time required to clear the smoke from the hood was excessive (greater than 15–30 sec), the hood design was considered marginal. Also, the adverse effect of cross drafts on the hood was evaluated by releasing smoke near the edge of the hood face to look for areas where the smoke was not effectively captured.

Tracer Gas (TG) Capture Test

Control efficiency was measured quantitatively by releasing TG at a constant rate where contaminant control was desired and then measuring the corresponding downstream TG concentration inside the exhaust duct.⁽⁷⁾ The first step was to release the TG inside the duct to find the concentration, C₁₀₀, corresponding to 100% capture; this was done before and after TG experiments were made. Then, the TG was released at a typical process contaminant emission point, resulting in a concentration C in the duct. The capture efficiency at the release point was calculated as C/C₁₀₀. The TG used was a mixture of 10% sulfur hexafluoride in air and was released at a constant rate to determine the capture efficiency of each hood. The TG concentration was measured using a MIRAN 205B Sapphire

portable ambient air analyzer (Thermo Environmental Instruments, Franklin, Mass.).

When using a surrogate contaminant (TG), it is important to simulate the contaminant generation mechanism as closely as possible. Release points included areas where workers typically process flavorings on the work benches and inside the mixing tanks where flavoring ingredients can evaporate. The TG release mechanism used to test the ventilated workstations was a tracer gas ejector developed according to ASHRAE Standard 110-1995 for evaluation of fume hoods (Figure 4).⁽⁸⁾ For the ventilated booth hoods, evaporation of chemicals was simulated using an area source consisting of a copper tubing coil perforated with uniformly spaced 1/16 inch diameter holes that was mounted inside a 4 ft diameter mixing tank. A mannequin was used in some of the TG tests to evaluate the effect of the body on the performance of the ventilated workstations.

Control On/Off Test

A MiniRAE 2000 (RAE Systems Inc., San Jose, Calif.) photoionization detector (PID) was used to measure volatile organic compound concentrations during control on/off tests. These tests were conducted on two ventilated workstations within the liquid production room. Ethanol was used as the working fluid due to its low toxicity and good detection using the personal PID. A NIOSH researcher performed a series of different tasks for a period of approximately 3 min and 30 sec.

A PID was placed on the researcher to evaluate engineering control effectiveness during typical bench top tasks, including weighing, pouring, and whisking of chemicals. During this test procedure, ethanol was poured from a 5-gal bucket into a stainless steel canister and then vigorously whisked. This sequence of tasks was repeated with the ventilation system turned

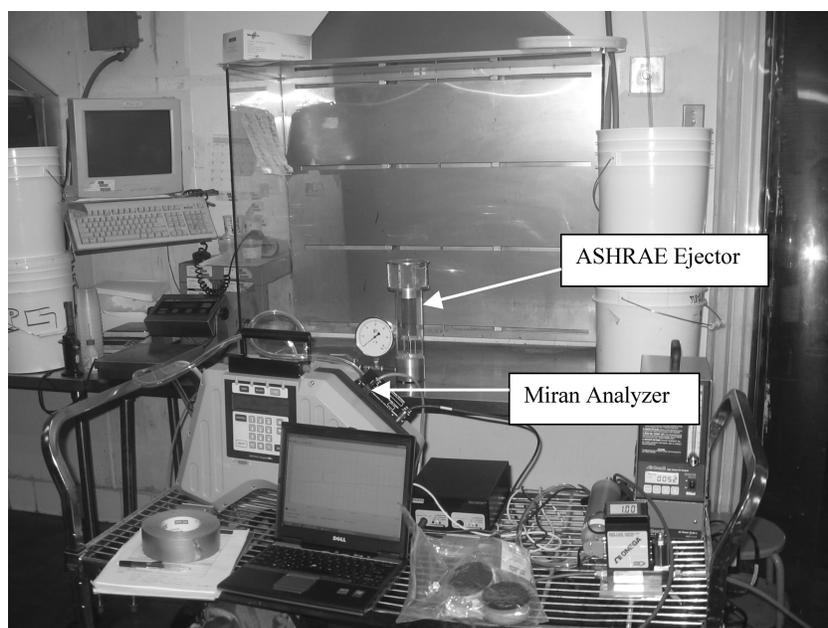


FIGURE 4. Tracer gas test setup

TABLE II. Hood Face Velocity and Exhaust Flow Rate Measurements

Hood No.	Hood Type	Average Face Velocity (ft/min)	Standard Deviation	Exhaust Flow Rate (ft ³ /min)
1	Workstation	191	21	1663
2	Workstation	164	14	1552
3	Workstation	177	30	1560
5	Workstation	205	26	1581
6	Booth	80	15	2045
7	Booth	73	21	2028
8	Booth	69	18	2806
9	Workstation	189	38	1506

Note: Standard deviation is calculated from the face velocities of all points across the face of the measurement grid for each hood.

on and again when the system was turned off. The evaluation of these simulated tasks was performed to provide a more realistic evaluation of control effectiveness during common worker activities. Overall, there were three trials with the control on and three with the control off. To minimize interference from background processes, this testing was performed after the end of the shift when no other flavoring mixing was being conducted.

The percent reduction for control on was calculated for each trial using the equation below:

$$\% \text{reduction} = \frac{\bar{C}_{nc} - \bar{C}_c}{\bar{C}_{nc}} \times 100$$

where

\bar{C}_{nc} = Average ethanol concentration when control is turned off (no control state)

\bar{C}_c = Average ethanol concentration when control is turned on (control state)

RESULTS

Hood Velocity Measurements

The average air velocity measured across the face of each hood is shown in Table II. Average face velocities for each ventilated workstation were well above the recommended capture velocity of 100 feet per minute (ft/min) for similar lab fume hoods.⁽⁹⁾ The highest average face velocity was 205 ft/min, while the lowest measured was 164 fpm. These velocities were reasonably uniform across the opening of each hood face. Average face velocities for the booth-type hoods were lower than the ventilated workstations and ranged from 69 ft/min to 80 ft/min. Slot velocities were generally uniform across all slots for every hood and ranged from 1030 ft/min to 2800 ft/min.

Airflow Visualization Test

The smoke tests indicated good capture for all ventilated workstations. Smoke was generally captured both directly and quickly when released in the interior of the hood and along the perimeter. However, turbulence due to cross drafts caused some leakage in ventilated workstations located near the door between the production room and the warehouse. This was due to the fact that all make-up air came from the warehouse and created strong drafts into the rooms near these doors (Figure 3). The booth-type hoods also showed good capture although with generally more leakage along the outside perimeter of the hood. These leaks were likely due to cross draft turbulence and lower capture velocities at the face of these hoods than the ventilated workstations.

Tracer Gas Capture Test

The quantitative collection efficiencies are shown for each hood in Table III. The capture efficiencies ranged from

TABLE III. Hood Tracer Gas Quantitative Capture Efficiency Test Results

Hood No. (Type)	Capture Efficiency (%)	Notes
Hood 1 (Bench top)	89–97	Testing was performed with TG emission source at various locations within the hood. The lowest capture efficiency was obtained when source was placed at far right corner of hood near door opening.
Hood 2 (Bench top)	98	Test was performed without mannequin in front of hood. ASHRAE ejector source was located in middle of bench inside of side baffle.
Hood 3 (Bench top)	100	Test was performed with mannequin in front of hood. ASHRAE ejector source was located in middle of bench inside of side baffle.
Hood 5 (Bench top)	98	Test was performed with mannequin in front of hood. ASHRAE ejector source was located in middle of bench inside of side baffle.
Hood 6 (Booth type)	97	Test was performed with area source (coiled dispersion tube) placed inside mixing tank.
Hood 7 (Booth type)	96	Test was performed with area source (coiled dispersion tube) placed inside mixing tank.
Hood 8 (Booth type)	98	Test was performed with area source (coiled dispersion tube) placed inside mixing tank.
Hood 9 (Bench top)	98–99	Test was performed with and without mannequin to evaluate the effects of airflow blockage on hood performance.

89–100% for all hoods tested under various test conditions. Multiple tests were conducted at Hood 1, since it was believed that this hood was more likely to be affected by cross drafts than other hoods due to its proximity to the room opening, where make-up air was entering the room (Figure 3). Tests were conducted with the SF6 ejector source located at the center of the bench as well as both the left and right side for Hood 1. The lowest capture efficiency on this hood was observed when the source was located on the bench top outside of the side baffle nearest to the room opening.

Control On/Off Test

The data show a clear reduction in exposure during pouring and whisking activities when the local exhaust ventilation system is activated (Figure 5). Three separate control on/control off tests were conducted to evaluate the effectiveness of the ventilated workstations. The results from these tests are shown in Figure 6. When the ventilation system was activated, the task based average concentration was reduced by 96%, 93%, and 90% in Tests 1, 2, and 3, respectively (Figure 6). As Figure 5a indicates, there were still a few short, high, instantaneous exposures when the control was on. These concentration spikes were noted when the operator picked up the 5-gal bucket (containing ethanol) and moved the alcohol near the monitor probe, which was located in a chest shirt pocket. Once the pour started, however, the concentration dropped down to background.

DISCUSSION

Ventilated Workstation Performance

The results of each of the performance tests discussed above indicated good overall performance of the ventilated workstations. The TG capture efficiency for all workstations ranged from 89–100% under the test conditions. The control on/off test results were also in close agreement with reductions ranging from 90–96% during the performance of typical work tasks. The ventilated workstation hood face velocities were all well above the standard fume hood control velocity range of 80–100 ft/min.⁽⁹⁾ While the high exhaust flowrates seen with these hoods increase capture velocity at distances farther from the hood face, the additional velocity increases energy expenditure and produces cross drafts that may negatively impact the capture efficiency of the hoods in the room. Reducing the face velocities to around 100–120 ft/min may not adversely impact the overall performance of the hoods and should reduce energy costs and system noise. At the time of the survey, the ability to make hood exhaust flow changes was not possible; no dampers or electric fan controls were put into place during initial installation.

A few design concerns were noted. One was that the workstation bench top area extends 5 inches beyond the end of the side baffles. This means that the work done closest to the employee may be affected by the cross drafts measured in the room. By extending these side baffles to the edge of the

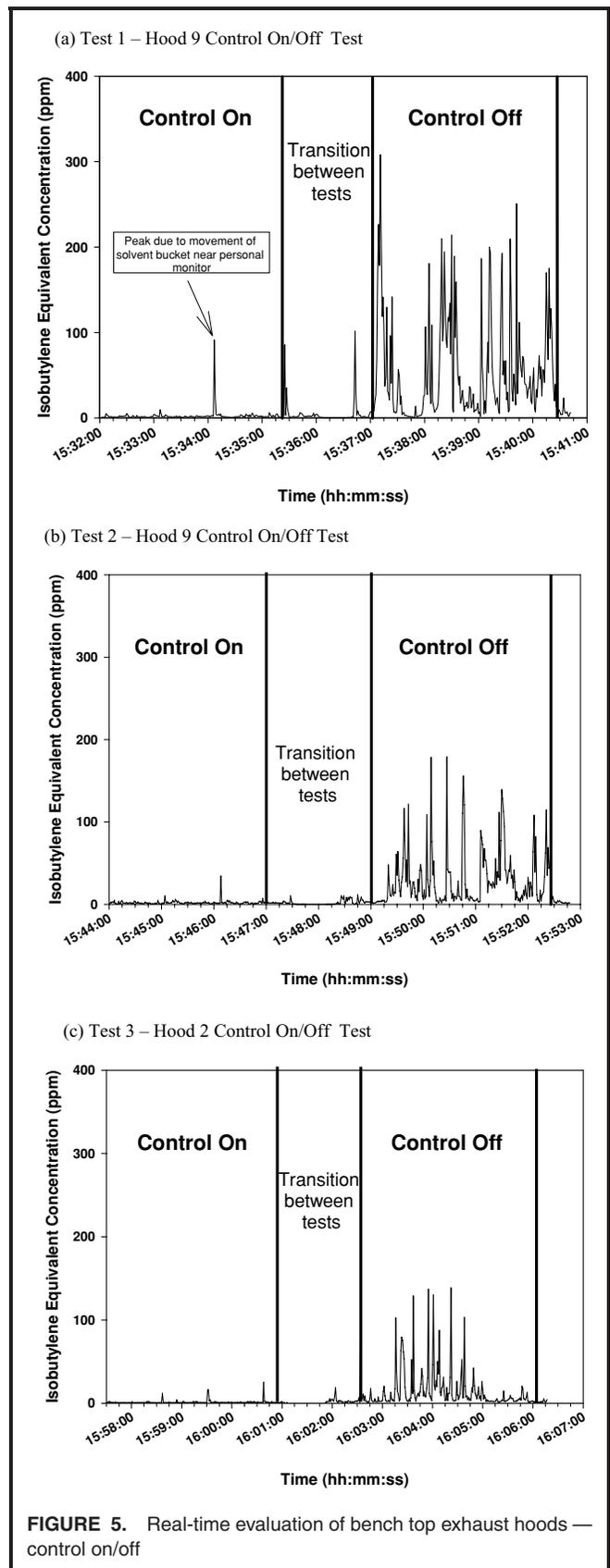


FIGURE 5. Real-time evaluation of bench top exhaust hoods — control on/off

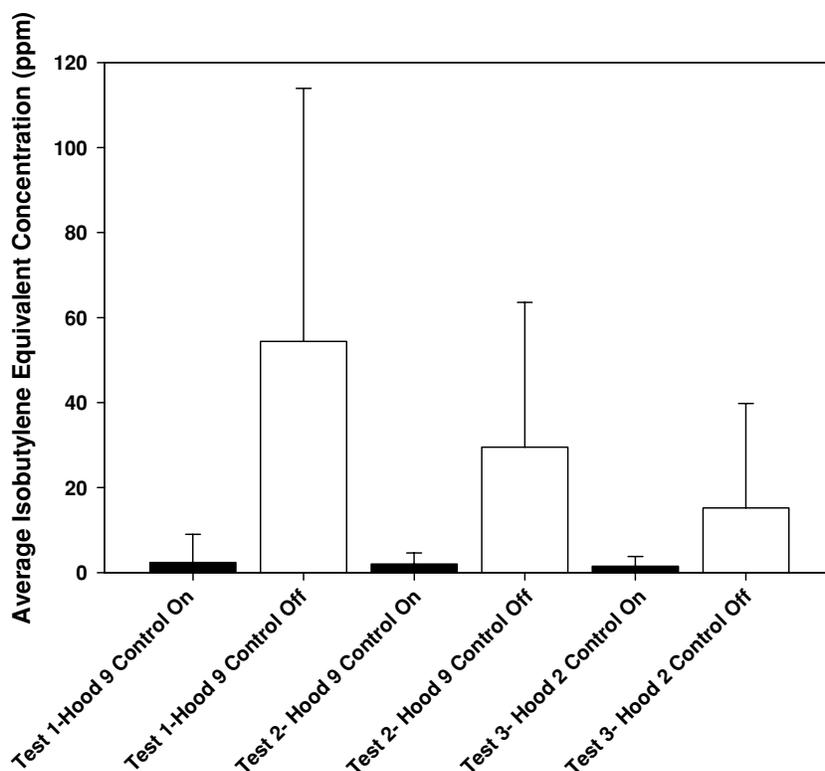


FIGURE 6. Average concentration and standard deviation for control on/off bench top tests. Note: Standard deviation is calculated from the time series of personal VOC concentrations for each individual test.

work area or beyond, the effectiveness of these hoods would be increased. A second concern was that the addition of these hoods without additional make-up air in the room resulted in considerable cross drafts that may affect hood performance. No additional supply air was installed with the addition of the ventilated workstations and booths, so air entered the rooms through the doors to the warehouse to replace the air that was exhausted (Figure 3). This resulted in large drafts near the doors and caused significant cross drafts, particularly at those hoods located near the doors.

Ventilated Booth Hood Performance

The results of each of the performance tests discussed above indicated good performance of the booth-type exhaust hoods overall. The TG capture efficiency for each hood ranged from 96% to 100% under the test conditions. The booth hood face velocities ranged from 69–80 ft/min and were generally below the standard fume hood control velocity range of 80–100 ft/min.⁽⁹⁾ However, when work is done within the envelope of booth, the influence of cross drafts should be minimized and these control velocities may be acceptable.

NIOSH investigators found that the booth hoods exhibited good capture when testing the emission of contaminants from a mixing tank. However, data from industrial hygiene sampling conducted during this engineering control survey indicated that some chemicals were not adequately captured by

the system. A review of videotape and photos taken during the sampling revealed that deficiencies in the design and operation of these hoods may have compromised the performance. Some work extended beyond the envelope of the booth side baffles, and thus, some chemicals may not have been adequately captured.

Also, the exhaust fans on these booths are activated when an object (such as a mixing tank) comes within an inch or so of a proximity switch mounted on the back of the booth. If the switch is not effectively engaged, the fan will not start up, and the contaminant will not be captured. Unfortunately, the background noise levels in the room make it hard for operators to determine if the individual exhaust fans are on simply by listening. Therefore, it is possible that chemicals emitted during this process were not adequately captured and contributed to exposure of other workers within the production room. The implementation of a visual exhaust fan on/off indicator such as a light for each hood would let workers know when the system is operating and that they are being protected.

CONCLUSIONS

The Flavoring and Extract Manufacturers Association (FEMA) designated 34 flavoring chemicals as “high priority.” These substances were considered to pose respiratory hazards in the workplace. FEMA stated that these chemicals

“merit a higher degree of attention to the manner in which they will be handled and processed and should be carefully considered for the application of protective measures such as engineering controls, special handling procedures and personal protective equipment.”⁽⁴⁾

Simple exhaust hoods based on existing designs can dramatically reduce worker exposure during the use and mixing of flavoring chemicals. The ventilated workstation designs were adapted from welding bench designs available in the ACGIH[®] ventilation design manual.⁽¹⁰⁾ The ventilated booth hoods were adapted from spray paint booth designs also available in that manual. The implementation of ventilated booths in the liquid production room provides a good engineering control that can be used for a variety of tasks, including large tank ventilation.

Other operations such as packaging of powder flavorings and pouring of diacetyl and other high priority chemicals can be more safely completed in these booths. However, workers must first be trained on proper use, and new operational safeguards should be implemented. Important topics for training include verifying fan operation status and making sure that the worker knows to always position the contaminant source between the exhaust hood and himself.

Another important design consideration when implementing new exhaust ventilation is the determination of the need for additional supply air to replace the air exhausted. The lack of adequate replacement air may result in high drafts, reduction in ventilation system performance, and difficulty in opening doors due to high-pressure differentials.

It is important to check and confirm that the system is operating as designed and that the workers are being adequately protected by periodically measuring hood airflows. For hoods that prevent high exposures to hazardous airborne contaminants, the ACGIH operation and maintenance manual recommends the installation of a fixed hood static pressure gauge.⁽⁶⁾ In addition to frequent monitoring of the hood static pressure, the types of measurements that should be made to ensure adequate system performance include smoke tube testing and hood slot/face velocity measurements using an anemometer. These system evaluation tasks must become part of a routine preventive maintenance schedule to check system performance.

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REFERENCES

1. **Kreiss, K., A. Goma, G. Kullman, K. Fedan, E.J. Simoes, and P.L. Enright:** Clinical bronchiolitis obliterans in workers at a microwave-popcorn plant. *N. Engl. J. Med.* 347(5):330–338 (2002).
2. **Kanwal, R., G. Kullman, C. Piacitelli, et al.:** Evaluation of flavorings-related lung disease risk at six microwave popcorn plants. *J. Occup. Environ. Med.* 48(2):149–157 (2006).
3. **Materna, B., J. Quint, J. Prudhomme, et al.:** Fixed obstructive lung disease among workers in the flavor-manufacturing industry—California, 2004–2007. *MMWR* 56(16):389–393 (2007).
4. “Respiratory Health and Safety in the Flavor Manufacturing Workplace.” [Online] Available at <http://www.femaflavor.org/html/public/RespiratoryRpt.pdf> (Accessed April 23, 2008).
5. **Goodfellow, H.D., and E. Tähti:** *Industrial Ventilation Design Guidebook*. San Diego, Calif.: Academic, 2001. p. 543.
6. **ACGIH[®]:** *Industrial Ventilation: A Manual of Recommended Practice for Operation and Maintenance*. Cincinnati, Ohio: ACGIH, 2007. pp. 3-3 to 3-5, 3-16 to 3-19.
7. **European Committee for Standardization:** *Safety of Machinery—Evaluation of the Emission of Airborne Hazardous Substances—Part 4: Capture Efficiency of an Exhaust System – Tracer Method*. Brussels: European Committee for Standardization, 1996.
8. **American National Standards Institute (ANSI), and American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE):** *Methods of Testing Performance of Laboratory Fume Hoods* (ANSI/ASHRAE 110-1995) [Standard]. Atlanta: ASHRAE, 1995.
9. **American National Standards Institute (ANSI), and AIHA:** *Laboratory Ventilation* [Standard] (ANSI/AIHA Z9.5-2003). Fairfax, Va.: AIHA, 2003.
10. **ACGIH[®]:** *Industrial Ventilation: A Manual of Recommended Practice for Design*. Cincinnati, Ohio: ACGIH, 2007. pp. 13–155.