IN-DEPTH SURVEY REPORT: EVALUATION OF ENGINEERING CONTROLS FOR THE MIXING OF FLAVORING CHEMICALS

at

Gold Coast Ingredients, Inc.
Commerce, CA

REPORT WRITTEN BY:
Kevin H. Dunn, M.S., C.I.H.
Alan Echt, M.P.H., C.I.H.
Alberto Garcia, M.S.

REPORT DATE:
January 2008

REPORT NUMBER:
EPHB 322 – 11a

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
Division of Applied Research and Technology
Engineering and Physical Hazards Branch
4676 Columbia Parkway, Mail Stop R-5
Cincinnati, Ohio 45226-1998

SITE SURVEYED:	Gold Coast Ingredients, Inc. Commerce, CA
NAICS CODE:	311
SURVEY DATES:	July 9-12, 2007
SURVEYS CONDUCTED BY:	Kevin H. Dunn, NIOSH Alan Echt, NIOSH Alberto Garcia, NIOSH
EMPLOYER REPRESENTATIVES CONTACTED:	Jon Wellwood

DISCLAIMER

IN-DEPTH SURVEY REPORT: EVALUATION OF ENGINEERING CONTROLS FOR THE MIXING OF FLAVORING CHEMICALS

EXECUTIVE SUMMARY

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of a local exhaust ventilation system installed in the liquid compounding room at Gold Coast Ingredients, Inc. The ventilation control system was developed and installed by Gold Coast in conjunction with a contractor to reduce the potential for employee exposure to harmful flavoring chemicals. The ventilation system for the compounding room was developed following an initial visit by NIOSH in November 2006. Following that survey, recommendations on the design and implementation of engineering controls were provided to the company in a letter dated February 7, 2007. This survey was conducted to evaluate the installation of new ventilation controls for the weighing and pouring of chemicals on the bench top and the mixing of large scale batches of flavorings in mixing tanks.

Evaluations were based on a variety of tests including tracer gas experiments, air velocity measurements, and smoke release observations. The experiments showed that generally there is good capture by the all LEV hoods under the tested conditions. Tracer gas tests were performed under a variety of conditions including the movement of the emission source to areas across the bench top surface to evaluate the spatial capture efficiency. Also, experiments were conducted using a mannequin to evaluate the effect of the disturbance of the body on the performance of the hoods. Capture efficiencies were calculated based on measurements of the concentration of tracer gas in the exhaust duct under test conditions versus the concentration when tracer was released directly into the duct (100% capture condition). The measured capture efficiencies exceeded 95% for all hoods installed. Air visualization tests and velocity measurements indicated good capture characteristics and were consistent with the results of tracer gas testing. Despite the test results indicating excellent hood performance, air samples collected during the survey indicated that flavored powder packaging done in one of the ventilated booths yielded high worker exposures and a corresponding increase in concentrations of diacetyl in the general flavoring production area. This is likely to be due to issues associated with the operation/location of the proximity switches in those booths.

Based on the results in this report, the following recommendations are made to further improve the local exhaust ventilation in the liquid compounding room:

- Evaluate the design and operation of the proximity switches in the booth-type hoods for all processes including powder packaging and any other auxiliary procedures. Check all operations being conducted in these booths to evaluate whether the worker is being adequately protected during all tasks.
- Install hood static pressure gauges on each hood to provide important information on hood performance. Include the recording of hood static pressure and performance of hood airflow checks into the preventative maintenance schedule.
- Extend the bench-top hood side baffles to the edge of the bench. The extension of the side baffles on the bench-top hoods will further enclose the operation and improve performance by minimizing the effect of cross drafts on hood capture.
- Discontinue the use of floor fans and wall-mounted fans as they interrupt the capture of the hood and reduce hood performance by creating drafts within the room. Consider

using ceiling-mounted supply registers to provide lower velocity and more uniform cooling/air movement in the compounding room.

- Consider upgrading hood and duct materials to higher gauge galvanized steel when appropriate. Upgrading to a higher gauge (thicker) galvanized sheet metal will improve the system's ability to withstand the wear and tear of ordinary use.
- Consider installing an indication of exhaust fan operating status (on/off) such as a light for each hood so that workers know when the system is operating and they are being protected when working with the hoods.
- Provide worker training on proper techniques for using hoods such as clearing the bench of unnecessary chemicals/materials and as much as possible to reduce the obstruction of airflow into the slot exhaust
- Consider using the booth for packaging of liquid flavorings and pouring of high priority chemicals until other controls are in place for these tasks. Ensure that the workers use proper techniques and that the control system allows for activation of the exhaust fan when performing these tasks.
- Consider reworking the roof-top exhaust stack design to ensure that hood exhaust is effectively discharged.

INTRODUCTION

As part of a technical assistance request from the California Division of Occupational Safety and Health (Cal/OSHA) in 2006, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an engineering control evaluation of Gold Coast, Inc. at their Commerce, California plant on July 9 -12, 2007. Gold Coast is participating in the Flavoring Industry Safety and Health Evaluation Program (FISHEP), a voluntary special emphasis program. This program was initiated by the California Department of Health Services (CDHS) and the California Division of Occupational Safety and Health (Cal/OSHA) in 2006 to identify workers with flavoring-related lung disease such as bronchiolitis obliterans (BO) and institute preventive measures in the California flavoring industry. Under FISHEP, companies must report the results of worksite industrial hygiene assessments to CDHS, and implement control measures recommended by Cal/OSHA.

This site was selected for inclusion in this investigation at the specific request of Cal/OSHA. The primary objective of the engineering control survey was to evaluate a new local exhaust ventilation system implemented for the liquid flavoring compounding process. A secondary goal was to evaluate and document the performance of control techniques in reducing potential health hazards to common processes within the flavoring production industry.

The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology (DART) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness. Since 1976, EPHB (and its forerunner, the Engineering Control and Technology Branch) has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique.

Background

Occupational exposures in the flavoring industry have been associated with respiratory disease, including bronchiolitis obliterans, an uncommon lung disease characterized by fixed airways obstruction. Previous NIOSH health hazard evaluations have documented cases of this illness among workers in the popcorn industry, and similar respiratory disorders have been observed among flavoring mixers (NIOSH 1986, Kreiss et al. 2002, Akpinar-Elci et al. 2004, Kanwal et al. 2006). In California, at least seven workers involved in the production of flavorings have been diagnosed with obstructive lung disease since 2004 (CDC 2007).

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 different chemicals used. Although there are thousands of flavoring compounds in use, few have occupational exposure limits. Due to the complex mixed exposures within the industry and the absence of inhalation toxicology data for most chemicals, engineering controls are being recommended as a primary means of providing exposure control.

Currently, there is no model or standard guidance for engineering controls for flavoring processes and, as a result, a wide range of systems have been observed, many with marginal effectiveness. Cal/OSHA has requested that NIOSH assist in the development of exposure control guidance for the flavoring industry. The goals of this technical assistance include: 1) to identify and evaluate engineering controls utilized within the industry; 2) to develop and evaluate the efficacy of new engineering controls to reduce occupational exposures, and; 3) to disseminate study results to workers, trade associations, public health officials and stakeholders. As a part of this request, NIOSH is providing some assistance to flavoring companies to reach their goal of developing engineering controls.

Where possible, it is always best to use engineering controls to reduce exposure followed by administrative controls such as implementing new work practices. The use of respirators is the least attractive option given the burdens placed on the worker to properly use the equipment and upon the employer to administer a respiratory protection program properly. However, given the recent identification of severe obstructive lung disease in workers in the flavoring industry, an approach which seeks to reduce worker exposure immediately is necessary. This approach must include a respiratory protection program for all employees who work or enter the production area.

Facility Description

Gold Coast manufactures and distributes liquid and powdered flavors to other companies for use in a variety of food products. The facility has been producing flavorings and extracts since the 1990s. Approximately 800 different flavors are produced at this facility, requiring ~ 1,000 chemicals or natural ingredients. The facility consists of a liquid production room, powder production room, color room, walk-in cooler and freezer, two spray-drying areas, raw materials warehouse, finished products warehouse, laboratory, quality control, and offices.

The production workers measure and pour flavoring ingredients which are then transferred to open tanks for liquid flavoring compounding or to ribbon blenders for powdered flavoring production. Computerized batch tickets are used to pull ingredients for the various flavors from the warehouse. Exposures vary dramatically depending upon the flavor formulations being completed on a particular day. An employee can work with numerous flavoring chemicals daily depending upon the size and complexity of a batch order. It was not unusual to observe at least 7 different batches being compounded concurrently by different employees in the production areas. The majority of flavors manufactured are on an as ordered basis, with little advance notice.

Description of Processes and Controls

This survey is focused on the liquid production area since controls were installed in this room and were not yet implemented in the powder production or spray dryer areas. The liquid production room contains both stationary and mobile open tanks for mixing liquid flavoring ingredients. There are several small and medium mobile tanks which can be moved throughout the facility according to need of the batch or formulation. Employees typically prepare small quantities of flavoring ingredients on top of a bench top. Workers then complete mixes by pouring the bench-top key ingredients and other chemicals into large mixing tanks, typically manually transferring the ingredients directly into the tank.

Following the initial walkthrough in November 2006, recommendations on the design and implementation of engineering controls were provided to the company in a letter, dated February 7, 2007. A new local exhaust ventilation system was developed and installed in the liquid production room by Gold Coast in conjunction with a contractor from May through June 2007. Two main types of local exhaust ventilation hoods were designed and installed within the liquid compounding room at the facility. A layout of the liquid production room is shown in Figure 1. The first type is a ventilated bench-top, back-draft slotted hood used to control worker exposure to chemicals during small batch mixing, weighing, and pouring activities which comprise a majority of the workday (see Figure 2). Overall, five bench-top ventilated workstations were installed in the liquid compounding room. The second hood type is a small booth hood which allows for the rolling in of large mixing tanks (see Figure 3). The primary function of this hood is to collect chemical vapors when the worker is pouring flavoring ingredients into the large mixers and to contain evaporative losses when a flavor is being mixed. A total of three of these hoods were installed in the liquid compounding room. A third type of hood designed to control vapors from the largest mixer was partially installed but was not operational and thus not evaluated during the survey (Hood #4, see Figure 1).

Each hood is connected to a unique dedicated duct and exhaust fan system resulting in nine fans located on the rooftop with discharge stacks connected to each fan/hood combination. Bench top hood numbers 1, 2, 3, 5, and 9 are each serviced individually by a Dayton Model 4C661B 18 inch belt-drive, tubeaxial fan with a one horsepower motor. Ventilated booth-type hood numbers 6, 7, and 8 are individually connected to a Dayton Model 3C411B 24 inch belt-drive tubeaxial fan. Hood dimensions and details are given in Table 1. Each fan is controlled by a proximity switch which activates the fan when they make contact with or come within a certain distance of an object. When someone is mixing/weighing chemicals, the fan is activated and shuts down following the cessation of activities or when the bench top is cleared. The booth-type hoods are activated when a mixing tank is placed in the booth far enough back to trigger the proximity switch. No indication of fan operational status (on/off) is in place for any of the exhaust hoods.

METHODS

Local Exhaust Ventilation Characterization

A variety of methods were used to evaluate the local exhaust ventilation system (see Table 2). Initial characterization included measuring exhaust flowrates, face (capture) velocity and slot velocity for each hood. In addition to the face and slot velocity measurements, a smoke tracer is used to confirm that the direction of the airflow is correct and to assess the effect of secondary airflows on hood performance. Tracer gas tests and real-time exposure monitoring methods were also performed to evaluate quantitative capture efficiency for each hood.

Hood Velocity Measurements

Equipment

A Velocicalc Plus Model 8388 thermal anemometer (TSI Incorporated, St. Paul, MN) was used to measure air speeds at the face of each hood. This instrument was also used to measure velocity pressures in the ducts to evaluate exhaust flow rate.

Procedure

The face velocity tests were performed by dividing the opening of the hood into equal area grids of approximately 1 square foot and measuring the velocity at the center of each grid (see Figure 4). Hood face velocities were taken at each grid point averaged over a period of 5 seconds. To measure the velocities achieved by the control at each grid point, the anemometer was held perpendicular to the air flow direction at those points. In addition, the air velocities were measured across all slots for each hood to evaluate distribution of exhaust. Slot velocities were logged approximately every 12 inches across the length of the slot.

Hood exhaust flow rates were calculated based on pitot tube measurements of duct velocities. Readings were taken at the center of annular rings of equal area in the duct cross section. 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.

Airflow Visualization Test

Equipment

A Rosco fog machine model 1500 (Rosco Laboratories, Inc., Stamford, CT) was used to visualize air movement inside and around the periphery of the hood.

Procedure

Smoke was released around the edge of and inside the hood to qualitatively visualize the airflow patterns in and around the hood and to determine whether it was being effectively captured and removed by the ventilation system. If the smoke was captured quickly and directly 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 seconds), 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. Finally, smoke was injected into the base of a 5 gallon bucket to allow for the observation of contaminant capture during simulation of bench top pouring activities.

Tracer Gas Capture Test

Equipment

The tracer gas, sulfur hexafluoride (SF6), was supplied through a model FMA 5518 mass flow controller (Omega Inc., Stamford, CT) set to produce about 2-3 parts per million (ppm) in the exhaust outlet of the system. The release mechanism used to test the bench top hoods was a tracer gas ejector developed according to ASHRAE Standard 110-1995 for evaluation of fume hoods (see Figure 5). 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 (see Figure 6). This coil delivered low momentum tracer gas distributed across the surface of the mixing tank cross section. The concentration of the SF6 was measured in the exhaust duct at a location above the hood and below the roof. Each hood in the liquid compounding room was evaluated with the exception of hood #4 which was not installed at the time of testing.

In order to sample this air stream uniformly, the hood exhaust air was drawn through a 1/4 in. diameter sample probe constructed from copper tubing having 3/64 in. diameter holes spread evenly across the duct diameter. These probes were mounted inside each hood exhaust duct perpendicular to the air flow. Air was drawn from these probes through tygon tubing using an AirCon 2 high volume air sampler (Gilian Instrument Corporation, West Caldwell, New Jersey) at approximately 15 liters per minute (lpm) and routed to the analyzer. Prior to being drawn into the analyzer, the air was filtered using a Carbon-Cap 150 activated carbon/HEPA filter (Whatman Inc., Florham Park, NJ) to remove dust and volatile compounds. The SF6 concentration was measured using a MIRAN 205B Sapphire portable ambient air analyzer (Thermo Environmental Instruments, Franklin, MA). The exhaust from the analyzer was routed to an adjacent hood exhaust to minimize the possibility of contaminating the compounding room with SF6 (and affecting test results). Real-time SF6 concentration was collected from the MIRAN through a USB 12-bit analog and digital I/O module (Measurement Computing Corp, Norton, MA) and logged on a laptop computer.

Procedure

Hood capture efficiency is defined as the ratio of the captured contaminant to the total amount of contaminant released by the process. The tracer gas test helps quantify the capture effectiveness of the hood. Since the real contaminant cannot be used in many cases, a surrogate is used for evaluation. When using a surrogate contaminant (tracer gas), it is important to simulate the contaminant generation mechanism as closely as possible. The tracer gas mixture, 10% sulfur hexafluoride (SF6) in air, was released at a constant rate at various points to determine the capture efficiency of each hood at these release points. Release points included areas where workers typically process flavorings on the work benches and inside the mixing tanks where flavoring ingredients can evaporate.

Exhaust duct tracer gas concentration was logged every second for a period of 2 to 4 minutes. The C100 concentration corresponding to 100% capture was measured by releasing the SF6 directly into a duct supplying the exhaust intake in that part of the system. This measurement was made immediately before each hood capture test to detect and correct for drift at the100% level. Following the completion of the C100 test, a second test was performed with the tracer gas being emitted from a device used to simulate the actual release of the chemicals being used. When testing the bench-top hoods, a tracer gas ejector which emitted a low flow gas in all directions was used to simulate the evaporation of chemicals from a container. When testing the booth hoods, an area source which consisted of a perforated copper tubing coil was used. The relative concentration in the exhaust as a result of tracer dosing when simulating the pollutant is then measured in the exhaust duct. The ratio of the simulation concentration to the C100 concentration yields the hood capture efficiency for the test conditions (see Figure 7).

Control On/Off Test

Equipment

A MiniRAE 2000 (RAE Systems Inc., San Jose, CA) photoionization detector (PID) was used to measure volatile organic compound concentrations during control on/off tests.

Procedure

The PID was placed on a NIOSH researcher to evaluate engineering control effectiveness during weighing, pouring and whisking of alcohol. These tests were conducted on hoods 9 and 2 within the Gold Coast liquid production room. Alcohol was used due to its low toxicity and good detection using the personal PID. The researcher performed the different tasks for a period of approximately 3 minutes and 30 seconds. During this test procedure, alcohol was poured from a 5 gallon bucket into a stainless steel canister and then vigorously whisked. This sequence of tasks was repeated with the ventilation system turned 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.

Exhaust Re-entrainment Evaluation

Equipment

A Rosco fog machine model 1500 (Rosco Laboratories, Inc., Stamford, CT) was used to visualize air movement on the roof at the exhaust fan/duct outlet. Also, a Velocicalc Plus Model 8388 thermal anemometer (TSI Incorporated, St. Paul, MN) was used to measure air speeds at the exhaust duct outlet.

Procedure

Smoke was released within each hood in the production room while a researcher on the roof, accompanied by a Gold Coast employee, observed the movement of the smoke following the emission of the air through the exhaust stack (see Figure 8). The test helped evaluate the potential for re-entrainment of exhaust into any air intakes or roof openings. There were no air supply intakes on the roof of the facility. However, a few roof vents located on the roof deck provide a potential opening for hood exhausts to re-enter the facility. In addition, air velocity measurements were taken at the center of the exhaust duct opening to evaluate the discharge velocity of the hood exhaust.

RESULTS

Hood Velocity Measurements

The capture velocity of the hood is defined as the velocity created by the hood at the point of contaminant generation (Goodfellow and Tahti, 2001). For enclosing hoods, the capture velocity is the air velocity measured at the face of the hood. To provide uniform velocity across the face of a hood, exhaust slots are typically used. When designed properly, they distribute the suction evenly across the hood face providing uniform capture characteristics.

The average air velocity measured across the face of each hood is shown in Table 3. Average face velocities for each bench-top hood were well above the recommended capture velocity of 100 feet per minute (fpm). The highest average face velocity was 205 fpm for hood 5 while the lowest measured was 164 fpm at hood 2. These velocities were fairly uniform across the opening of each hood face. Average face velocities for the booth-type hoods were lower than the bench-top hoods and ranged from 69 fpm for hood 8 to 80 fpm for hood 6. Slot velocities were generally uniform across all slots for every hood. The slot velocities ranged from a low of 1030 fpm to a high of 2800 fpm across all hoods.

Airflow Visualization Test

The smoke tests indicated good capture for all bench-type hoods. 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 when testing hoods 1, 5 and 9. Tests performed using a five gallon container with smoke release showed good capture at each bench-top hood. This test was done to simulate pouring of chemicals inside the hood. The booth-type hoods also showed good capture although with generally more leakage along the outside perimeter of the hood. These leakages were likely due to cross draft turbulence and lower capture velocities at the face of these hoods than the bench-top hoods.

Tracer Gas Capture Test

The quantitative collection efficiencies are shown for each hood in Table 4. The capture efficiencies ranged from 89%-100% for all hoods tested under various test conditions. Multiple tests were conducted on 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 makeup air was entering the room, see Figure 1). Tests were conducted with the SF6 ejector source located at the center of the bench as well as both the left and right side. The lowest capture efficiency was observed when the source was located on the bench top outside of the side baffle nearest to the room opening. In addition, a test was performed with and without a mannequin in front of hood 9 to assess the effect of the body wake on contaminant capture efficiency. The capture efficiencies with and without the mannequin were both greater than 98%. This test indicated that the presence of the mannequin did not have an appreciable effect on capture efficiency.

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 (see Figure 9 a, b, and c). Three separate control on/control off tests were conducted to evaluate the effectiveness of these hoods under more realistic conditions. The first two tests were conducted on bench-top exhaust hood 9 and the third test was on hood 2. The results from these tests are shown in Figure 10. 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. The high relative standard deviations from the control off tests show the variability of exposure due to worker activities and turbulent room drafts. This was greatly reduced when the control was turned on. However, as Figure 9 indicates, there were still a few short high instantaneous exposures when the control was on. These concentration spikes were noted when the operator would pick up the 5 gallon bucket and moved the alcohol near the monitor probe which was below the breathing zone area. Once the pour started, however, the concentration dropped down to background.

Exhaust Re-entrainment Evaluation

The blower for each hood exhaust was located on the roof of the facility and connected to an exhaust duct that extended off the deck of the roof between 22 inches and 40 inches. The exhaust duct was angled at 90 degrees to exhaust air parallel to the roof line (see Figure 8). The centerline velocity measured in the exhaust outlet stream ranged from 2100 fpm to 3250 fpm (see Table 5). The smoke release indicated that under certain wind conditions, the exhaust could re-enter the building through a roof vent opening. However, given the variability of wind fields, the amount of exhaust which can be re-entrained is hard to predict.

DISCUSSION

Bench Top Hood Performance

The results of each of the performance tests discussed above indicated good overall performance of the bench-top exhaust hoods. The capture efficiency for each hood ranged from 89%-100% under the test conditions. The addition of these hoods without additional makeup air in the room resulted in considerable cross drafts which may affect hood performance, although this was not seen in the tests conducted. The bench-top hood face velocities were all well above the standard fume hood control velocity range of 80-100 fpm. While the high exhaust flowrates seen with these hoods increase capture velocity at distances further from the hood face, the additional velocity increases energy expenditure and produces cross drafts which may negatively impact the capture efficiency of the hoods in the room. Reducing the face velocities to 100 fpm nominally should improve the overall performance of the hoods, reduce energy costs for the system, and reduce system noise.

There are a few additional areas where changes in the system could improve performance or durability of the system. The bench top 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 considerable cross drafts measured in the room. By extending these side baffles, the effectiveness of these hoods would be increased. If accessibility is a concern, the additional side baffles could be made from a heavy duty strip curtain. Also, an observation of the hoods during the day showed the accumulation of mixing vessels and other items inside the hood which block the slots and decrease effectiveness of the hoods. The tests conducted during this evaluation were performed with a clean bench and thus reflect an ideal condition: hood performance may be different under actual usage conditions. It's important to provide the workers with training on proper use of the hoods to provide the best performance. In addition, the use of floor fans and wall mounted fans is discouraged as these can disturb airflow and reduce the effectiveness of the hood. Observations from the smoke tests indicated turbulence and swirling around hood 1 which may be due to the wall mounted fan in the corner of the room. The use of ceiling diffusers for cooling and general air movement would help reduce this turbulence and improve hood effectiveness.

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 capture efficiency for each hood ranged from 96% to 100% under the test conditions. The booth hood face velocities ranged from 69-80 fpm and were generally below the standard fume hood control velocity range of 80-100 fpm. However, when work is done well within the 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 air sampling during the work shift indicated that some chemicals were not adequately captured by the system. As presented elsewhere (McKernan and Dunn, 2007) diacetyl exposures of approximately 17 ppm, 10 ppm, and 9 ppm were observed while a worker packaged or manually sifted powder product inside the booth-type hoods (see Figure 11). Additional details regarding these task-based samples can also found in Table 6 and in the NIOSH exposure assessment report.

Given the high diacetyl concentrations measured during powder packaging, it is possible that the exhaust fan was not operating during that task. The exhaust fans on these booths are activated when an object (such as a tank) comes within an inch or so of a proximity switch mounted on the back of the booth. This feature decreases electricity usage by shutting down the fans while the booths are not in use. If the powder packaging apparatus did not effectively engage this switch, the fan would not have come on and the contaminant would not have been captured. Therefore, it is possible that the dust and vapors emitted during this process were not adequately captured and contributed to the personal and area diacetyl concentrations measured during this operation. 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. A visual indicator such as a fan operational light should be connected to the fan circuit and mounted on the booth to indicate to the employee that he/she is being adequately protected.

Another potential cause for high exposure to chemicals when working within these booths is the improper positioning of the flavoring ingredients and the worker. If the worker is positioned between the contaminant and the exhaust hood, the chemicals can be drawn directly through the worker breathing zone increasing exposure. Also, the process must be fully contained within these booths. A review of packaging activities performed in one of the booths showed that some operations extended beyond the booth side baffles and into the general mixing room area. When activities are conducted outside of the booth, the protection of the system is marginalized and chemicals may escape to other areas of the room potentially exposing other workers. Since these booths may not have been initially designed for packaging activities, these operations (as well as any others) occurring within the booth should be reviewed and the workers should be trained on proper work practices and to evaluate the operational status of the booth.

It is important to check and confirm that the system is operating as designed and that the workers are being adequately protected and to periodically measure hood airflows. A simple measurement called hood static pressure provides important information on the performance since any change in airflow will result in a change in hood static pressure. For hoods that prevent high exposures to hazardous airborne contaminants, the American Conference of Governmental Industrial Hygienists (ACGIH) Operation and Maintenance Manual recommends the installation of a fixed hood static pressure gauge (ACGIH 2007a).

In addition to monthly monitoring of the hood static pressure, the types of measurements which should be made to ensure adequate system performance include smoke tube testing, hood slot/face velocity and potentially duct velocity measurements using an anemometer. These system evaluation tasks must become part of a routine preventative maintenance schedule to check system performance.

The implementation of ventilated booths in the liquid production room provides a good engineering control which can be used for a variety of tasks including large tank ventilation. Other operations such as powder packaging and pouring/redistribution of diacteyl and other high priority chemicals can be more safely completed in these booths once the workers have been properly trained on proper use and new operation safeguards such as the one mentioned above are implemented. Important topics for training include verifying fan operation status and making sure that the worker knows to always position the contaminant source between him and the exhaust hood.

Exhaust Re-entrainment

The ACGIH Ventilation Design Manual recommends that a good stack discharge velocity is 3000 fpm since it prevents downwash for winds up to 22 miles per hour (ACGIH 2007b). A stack velocity above 2600 fpm should prevent rain from entering the stack when the fan is operating. The best shape for a stack is a vertical straight cylinder. Rain caps are not recommended because they deflect the exhaust and affect the ability of the stack to adequately discharge the pollutant.
For stacks that are only operated intermittently, a stack design that includes a drain can be incorporated (ASHRAE 2007). The American National Standards Institute (ANSI)/American Industrial Hygiene Association (AIHA) standard Z9.5 recommends a minimum stack height of 10 feet above adjacent roof lines (ANSI/AIHA 2003). The stack height may be subject to local building codes—the acceptable stack height should be investigated before any changes are made.

Currently, the exhaust stack is routed at 90 degrees once it exits the fan on the roof, with a height above the roof deck of approximately 2-4 feet. This configuration may allow for some re-entrainment of the exhaust into the building through the roof vents depending on the wind speed and direction. During smoke tests, some re-entrainment was observed through these vents. Modifying these exhaust stacks in accordance with the ACGIH and ASHRAE recommendations would reduce the possibility of re-entrainment while protecting the system from rain.

RECOMMENDATIONS

1. Evaluate the alternative uses of the booth-type hoods. Check all operations being conducted in these booths to evaluate whether the worker is being adequately protected during all tasks.
2. Install hood static pressure gauges on each hood to provide important information on hood performance. Place an indelible mark on each gauge indicating optimal static pressure. Include the recording of hood static pressure and performance of hood airflow checks into the preventative maintenance schedule.
3. Extend the bench-top hood side baffles to the edge of the bench. This can be done using flexible strip curtains if side accessibility or interference is a concern.
4. Discontinue the use of floor fans and wall-mounted fans as they can reduce hood performance by creating drafts within the room. Consider using ceiling-mounted supply registers to provide lower velocity and more uniform cooling/air movement in the compounding room.
5. Consider upgrading hood and duct materials to higher gauge galvanized steel when appropriate. Upgrading to a higher gauge (thicker) galvanized sheet metal will improve the system's ability to withstand the wear and tear of ordinary use.
6. Consider installing an indication of exhaust fan operating status (on/off) such as a light for each hood so that workers know that they are being protected when working with the hoods. Train workers on the new fan indication system so that they understand what the light(s) mean and what to look for before they begin work.
7. Provide worker training on proper techniques for using hoods such as clearing the bench of unnecessary chemicals/materials and as much as possible to reduce the obstruction of airflow into the slot exhaust. Worker training should include a discussion of the proper use of booth type hoods such as proper orientation of worker and contaminants (e.g. worker should not get between the source of exposure and the exhaust hood).
8. Consider using the booth for packaging of liquid flavorings and pouring of high priority chemicals until other controls are in place for these tasks. Ensure that the workers use proper techniques and that the control system allows for activation of the exhaust fan when performing these tasks.
9. Consider reworking the roof-top exhaust stack design to ensure that hood exhaust is effectively discharged. This would include changing the design to a vertical stack with a discharge velocity of between 2000-3000 fpm and the addition of a stack rain drain (see ASHRAE Fundamentals, ASHRAE 2007).

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the exposure assessment contributions from Dr. Lauralynn Taylor McKernan as well as the field support from Dr. Ed Burroughs, Mr. James Couch and Mr. Kevin L. Dunn. The authors acknowledge the significant collaboration with Dr. Rachel Bailey, Mr. Kelly Howard and Mr. Dan Leiner for this work. We acknowledge the technical support from Mr. Dan Farwick, Mr. Kevin L. Dunn, Mr. Donald Booher, and Mr. Karl Feldman. We also appreciate the technical assistance provided by Mr. Nicholas Sestito, Dr. Deborah V.

Myers, and Ms. Jennifer Topmiller. Finally, we would like to acknowledge Mr. Jose Esparza of Gold Coast who provided tireless support throughout the duration of the field survey.

REFERENCES

ACGIH (American Conference of Governmental Industrial Hygienists) [2007a]. Industrial Ventilation: A Manual of Recommended Practice for Operational and Maintenance, 1st edition: Cincinnati, OH.

ACGIH (American Conference of Governmental Industrial Hygienists) [2007b]. Industrial Ventilation: A Manual of Recommended Practice for Design, 26th edition: Cincinnati, OH.

ANSI/AIHA (American National Standards Institute/American Industrial Hygiene Association). [2003]. American National Standard Z9.5-2003, Laboratory Ventilation, AIHA: Fairfax, VA

ANSI/ASHRAE (American National Standards Institute/ American Society of Heating Refrigerating and Air-conditioning Engineers). [1995]. American National Standard 110-1995, Method of Testing Performance of Laboratory Fume Hoods, ASHRAE: Atlanta, GA.

ASHRAE (American Society of Heating Refrigerating and Air-conditioning Engineers) [2007]. Heating, Ventilating, and Air-Conditioning Applications, Inch-Pound edition: Atlanta, GA.

Akpinar-Elci M., Travis WD, Lynch DA, Kreiss K: Bronchiolitis obliterans syndrome in popcorn plant workers. Eur. Respir. J. 24:298-302.

CDC [2007]. Fixed Obstructive Lung Disease Among Workers in the Flavor-Manufacturing Industry --- California, 2004—2007. Morbidity and Mortality Weekly Report. MMWR 56(16):389-393.

Dunn K. [2007]. Letter of October 13, 2006 from K. Dunn, Centers for Disease Control, National Institute for Occupational Safety and Health to J. Wellwood , Gold Coast Ingredients.

Goodfellow H. and Tahti E.[2001]. Industrial Ventilation Design Guidebook. Academic Press, London, UK.

Kanwal R, Kullman G, Piatitelli C, Boylstein R, Sahakian N, Martin S, Fedan K, Kreiss K [2006]. Evaluation of flavorings-related lung disease risk at six microwave popcorn plants. J. Occup. Environ. Med. 48:149-157.

Kreiss K, Gomaa A, Kullman G, Fedan K, Simoes E, Enright P. [2002]. Clinical bronchiolitis in workers at a microwave-popcorn plant. N. Engl. J. Med. 347:3301-338.

McKernan, LT and Dunn, KH [2007]. Evaluating Occupational Exposures and Work Practices at Gold Coast Ingredients, Inc. A Technical Assistance Report to California/Occupational Safety and Health Administration, Centers for Disease Control, National Institute for Occupational Safety and Health.

NIOSH [1986]. Hazard Evaluation and technical assistance report: International Bakers Services, Inc. South Bend, IN. Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control, National Institute for Occupational Safety and Health, NIOSH HETA Report No. 85-171-1710.

TABLES

Table 1. Hood characteristics and face velocity measurements

Hood #	Type	Dimensions H (in)	W (in.)	D (in.)	Face Area (ft.^{2})	Number of Slots	Slot Width (in.)
1	Bench Top	37 in.	44	17	11	4	5/8
2	Bench Top	37	44	17	11	4	5/8
3	Bench Top	38	44	17	11	4	5/8
5	Bench Top	37	44	22	11	4	5/8
6	Booth	79	48	46	26	6	5/8
7	Booth	90	48	49	30	6	5/8
8	Booth	91	60	48	38	6	5/8
9	Bench Top	35	45	15	11	4	5/8

Table 2. Test Methods and Objectives.

Method	Description	Objective
Hood velocity measurements	Hood Face velocities and slot velocities were measured with an air flow meter. Overall hood exhaust flow rates were measured by pitot traverse in the exhaust duct.	These measurements are made to evaluate contaminant capture velocity at the hood face. A capture velocity of 80-100 fpm is recommended. Slot velocities are measured to evaluate the proper design of the hood—even flow across the hood is evaluated. Velocity pressure measurements are made in the exhaust duct to measure the overall exhaust flowrate 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 provides qualitative evaluation of hood capture effectiveness. Criteria for performance evaluation include observation of effective smoke containment. Notes are made on the time required for smoke to clear out of hood and if any smoke escapes 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 provides a quantitative evaluation technique on contaminant capture. Tracer gas concentrations measured inside the exhaust duct provide a basis for evaluating % of contaminant captured.
Control On/Off Test	Tasks such as weighing and mixing of alcohol were performed inside of 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 versus off provide indication of hood effectiveness.
Exhaust Re-entrainment Test	Smoke was released in each hood using a Rosco Fog Generator. Air velocities from each exhaust stack were measured.	Rooftop observations of airflow help identify areas where contaminants might re-enter the facility. Exhaust stack air velocity measurements were compared to applicable design standards.

Table 3 Hood face velocity and exhaust flow rate measurements.

Hood #	Type	Average Face Velocity (fpm)	Standard Deviation	Exhaust Flow Rate (cfm)
1	Bench Top	191	21	1663
2	Bench Top	164	14	1552
3	Bench Top	177	30	1560
5	Bench Top	205	26	1581
6	Booth	80	15	2045
7	Booth	73	21	2028
8	Booh	69	18	2806
9	Bench Top	189	38	1506

Table 4. Hood tracer gas quantitative capture efficiency test results.

Hood Number (Type)	Capture Efficiency	Notes
Hood 1 (Bench top)	89-97%	Testing was performed with source at various locations within the hood. Lowest capture efficiency was obtained when source was placed at far right corner of hood near door opening.
Hood 2 (Bench top)	98%	Test 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 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 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 performed with area source (coiled dispersion tube) placed inside mixing tank.
Hood 7 (Booth-type)	96%	Test performed with area source (coiled dispersion tube) placed inside mixing tank.
Hood 8 (Booth-type)	98%	Test performed with area source (coiled dispersion tube) placed inside mixing tank.
Hood 9 (Bench top)	98-99%	Test was performed with and without mannequin.

Table 5. Roof-top stack exhaust discharge characteristics.

Hood #	Distance from base of exhaust opening to roof deck (in.)	Roof exhaust opening diameter (in.)	Exhaust outlet velocity (fpm)
1	22	20	3200
2	22	20	3250
3	22	20	3100
5	22	20	2100
6	40	24	2100
7	38	24	2500
8	39	24	2500
9	25	20	2500

Note: There are several facility roof vent openings which are situated 4 to 8 inches from roof deck.

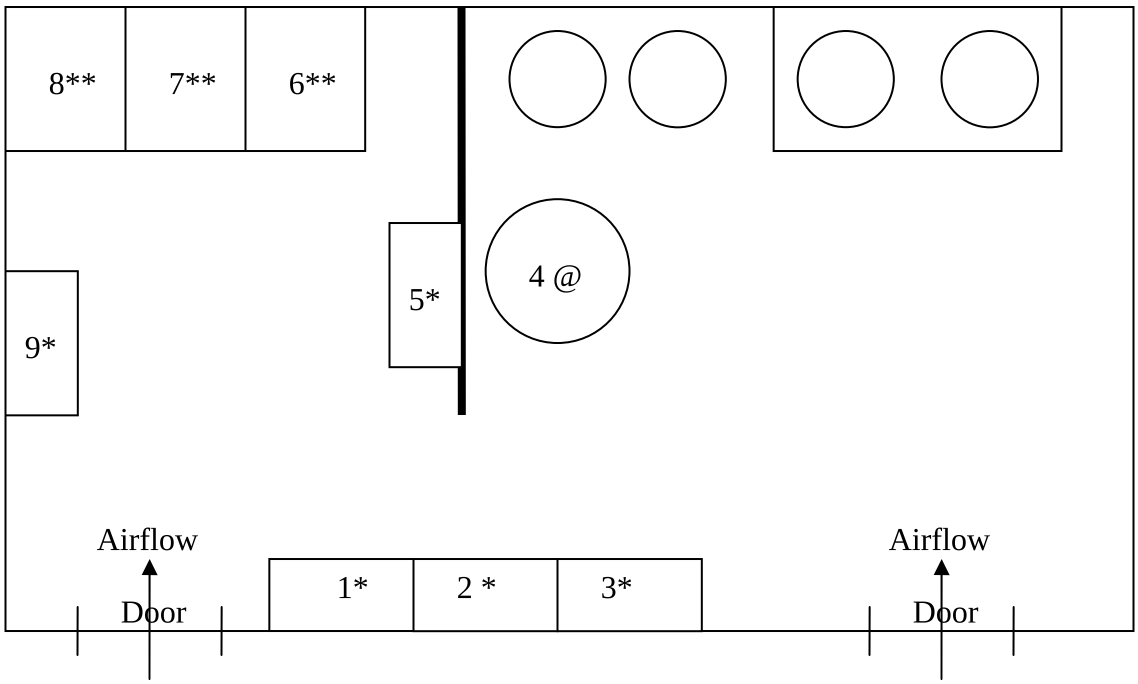
Table 6. July Site Visit Personal Task-Based Sampling Results

Area	Task Description	Duration (minutes)	Analyte	Result (ppm)	Batch Flavor
Liquid	Scooping butter from metal bin into boxes; Worker leaned into bin remove all powder	8	Diacetyl	17.38	Butter flavor natural wonf.
Liquid	Worker prepares for task (setting up boxes, moving equipment, etc). Worker scoops powder (one scoop at a time) over head into a mechanical sifter.	61	Diacetyl	9.32	Butter flavor N/A powder.
Liquid	Worker used exhaust hood to scoop out butter flavor powder into smaller packages.	10	Diacetyl	10.0	Butter Flavoring (powder).

Notes:
This information is synthesized from the Gold Coast Ingredients, Inc NIOSH exposure assessment report (McKernan and Dunn, 2007). Task based samples for diacetyl were collected according to a modified U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Method PV2118. This modified OSHA method used larger collection tubes (400/200 milligram silica gel tubes) which have greater collection capacity and minimize carryover of contaminant to the backup tube. Task based diacetyl samples were collected at a flow rate of 0.05 liters per minute (LPM) for the duration of the task or flavor formulation.

FIGURES

Figure 1. Liquid compounding room layout.



Note: Drawing not to scale. Numbers reflect exhaust hoods. Hood 4 was not fully installed during the survey and was not evaluated.

* Bench-top Hoods
** Booth Hoods
@ Hood not installed at time of evaluation

Figure 2. Bench top exhaust hood.

Figure 3. Ventilated booth-type exhaust hood.

Figure 4. Hood face velocity measurement grid layout. Note: dots represent measurement points.

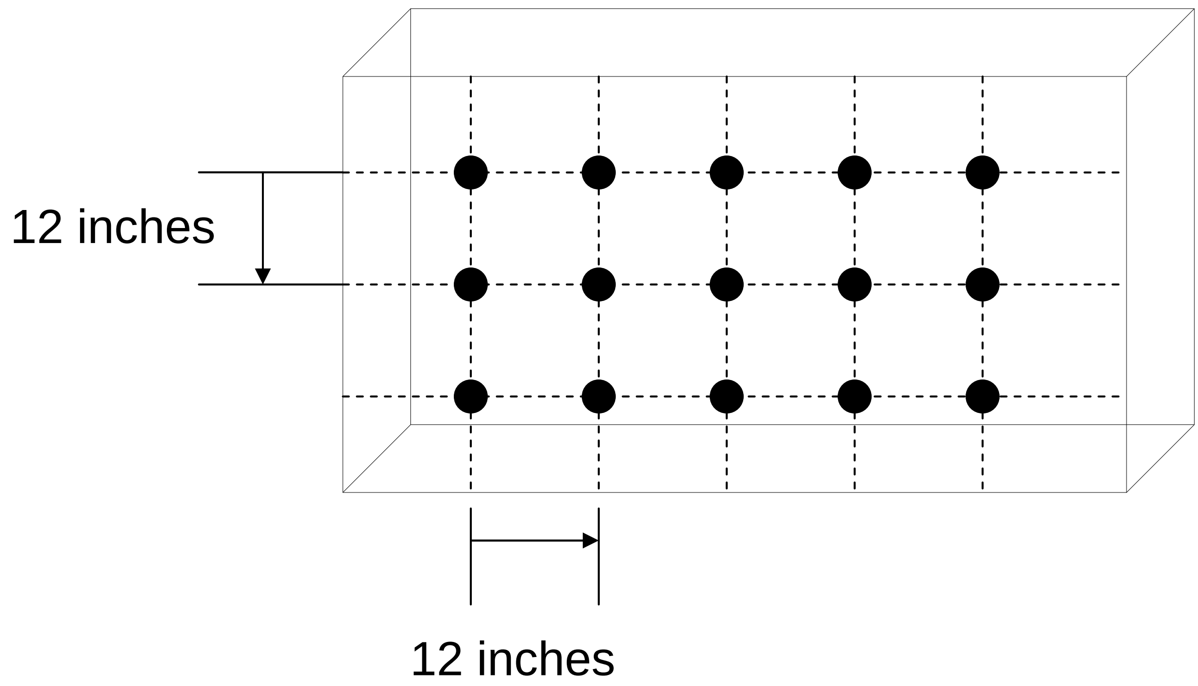


Figure 5. ASHRAE ejector setup with mannequin.

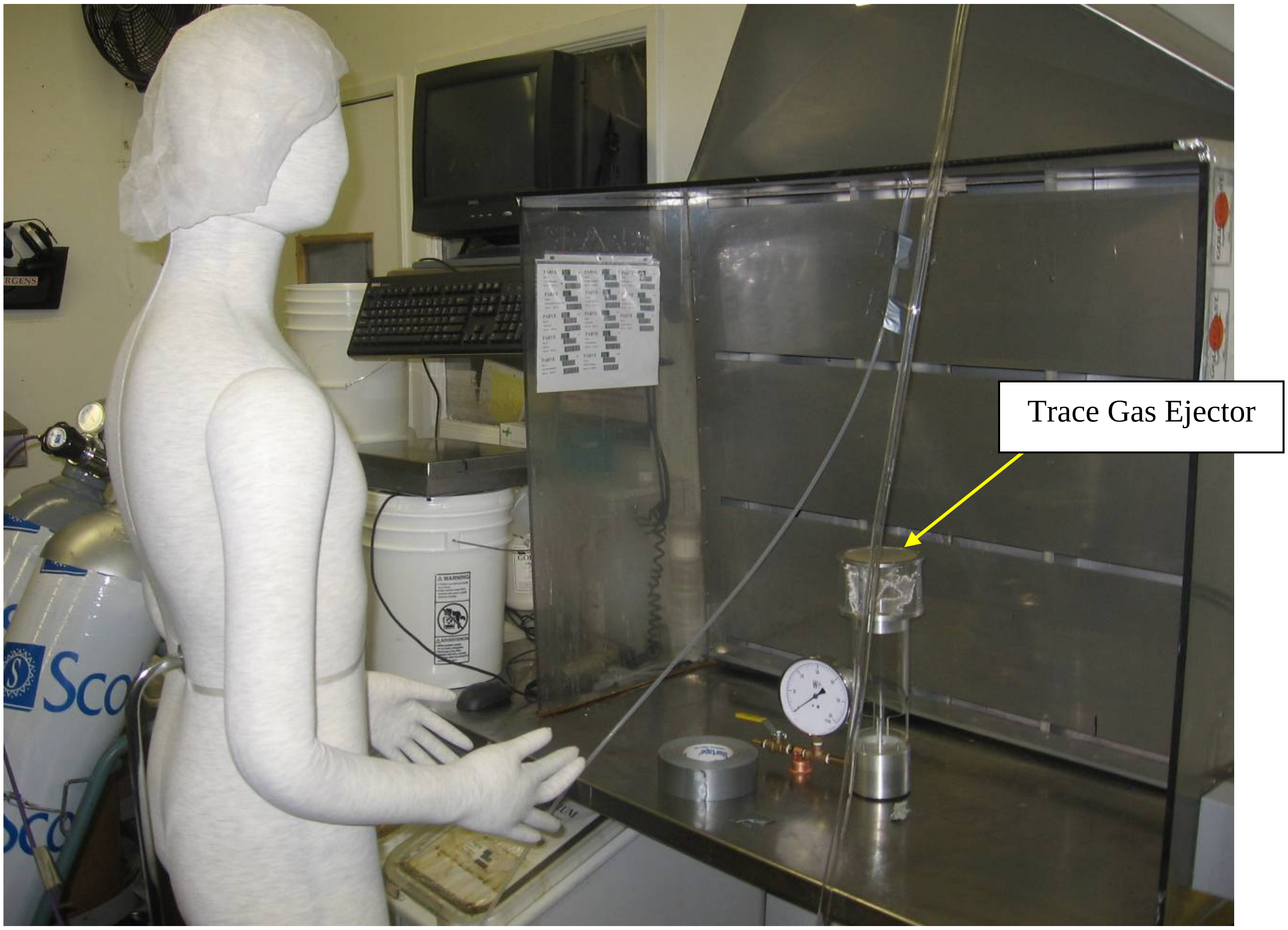


Figure 6. SF6 source coil for booth testing.

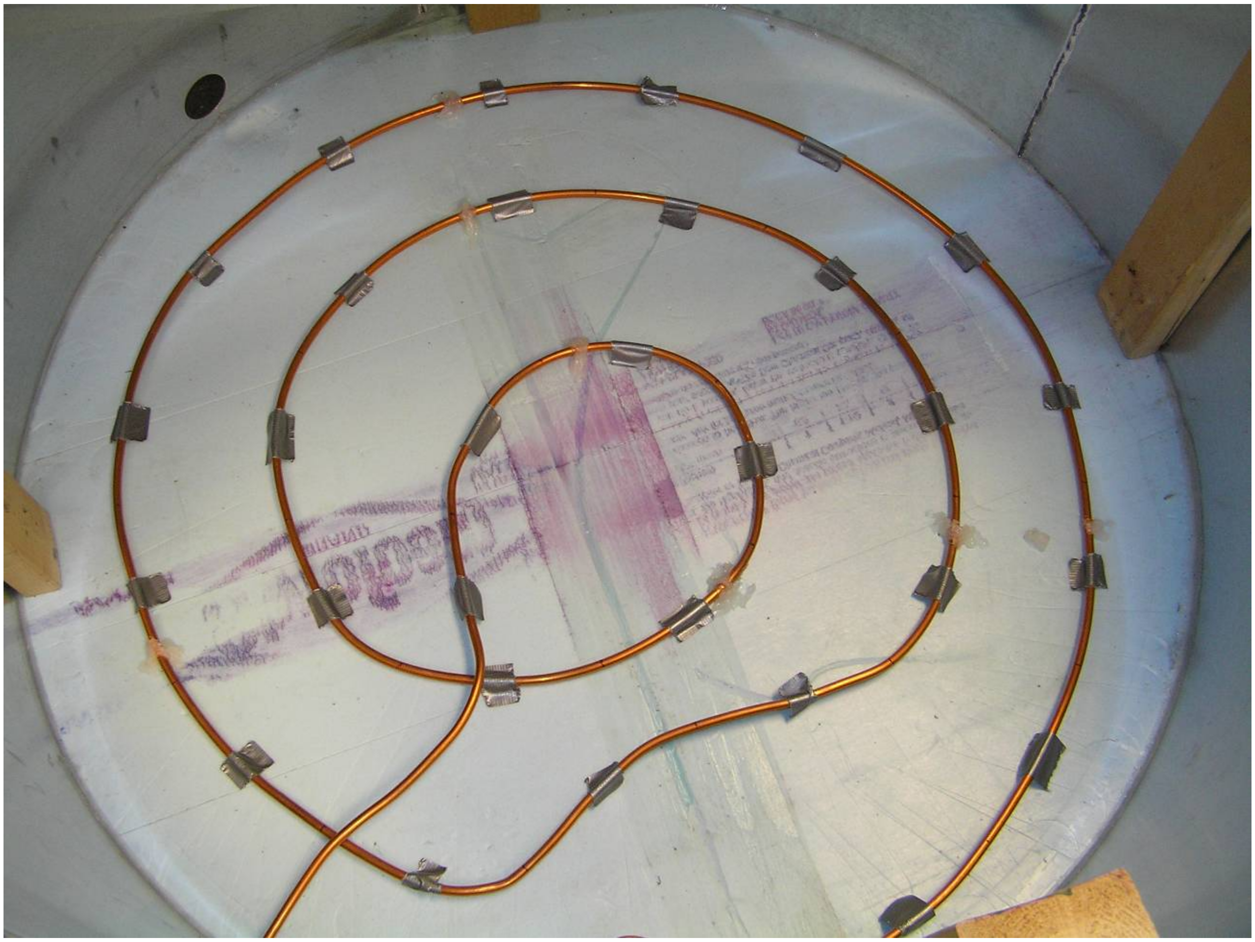


Figure 7. Example of tracer gas test plot

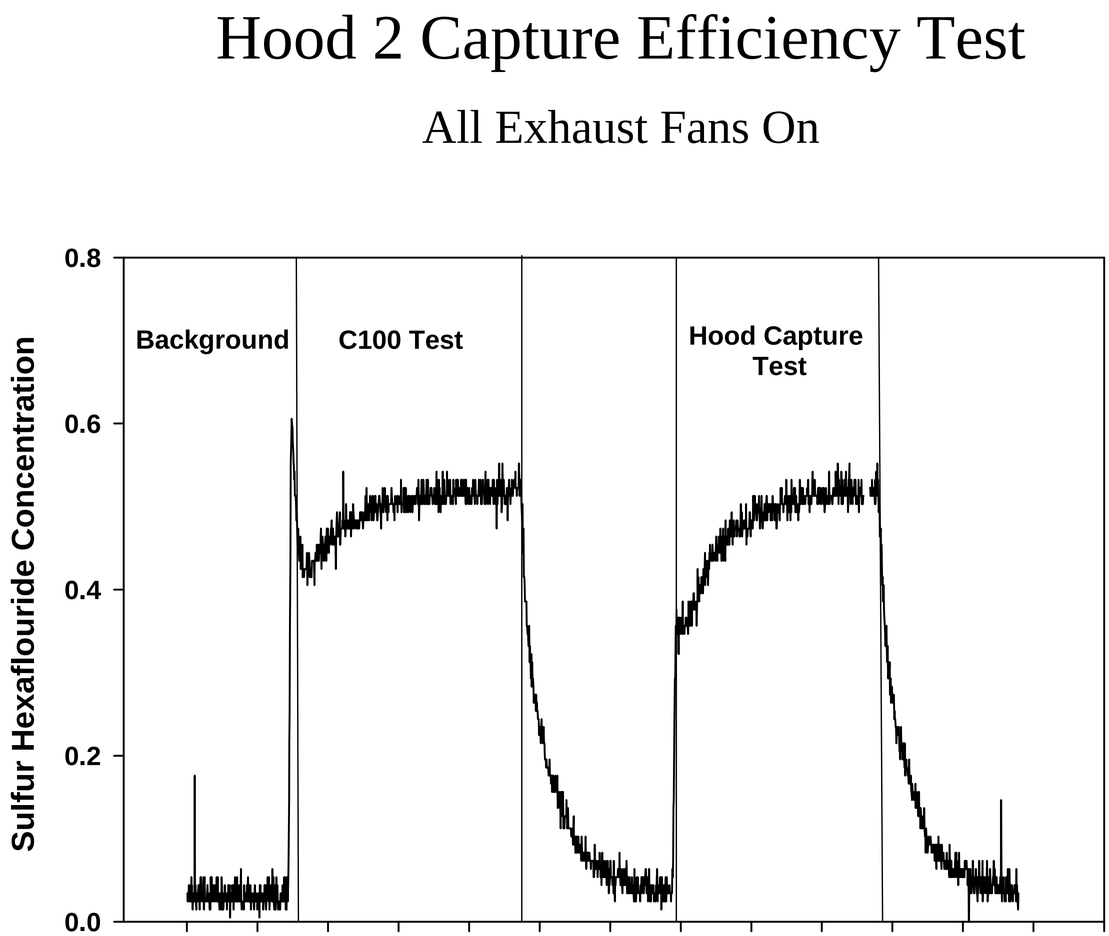


Figure 8. Rooftop re-entrainment smoke test.

Figure 9. Real-time evaluation of bench top exhaust hoods--control on/off.

Test 1—Hood 9 Control On/Off Test

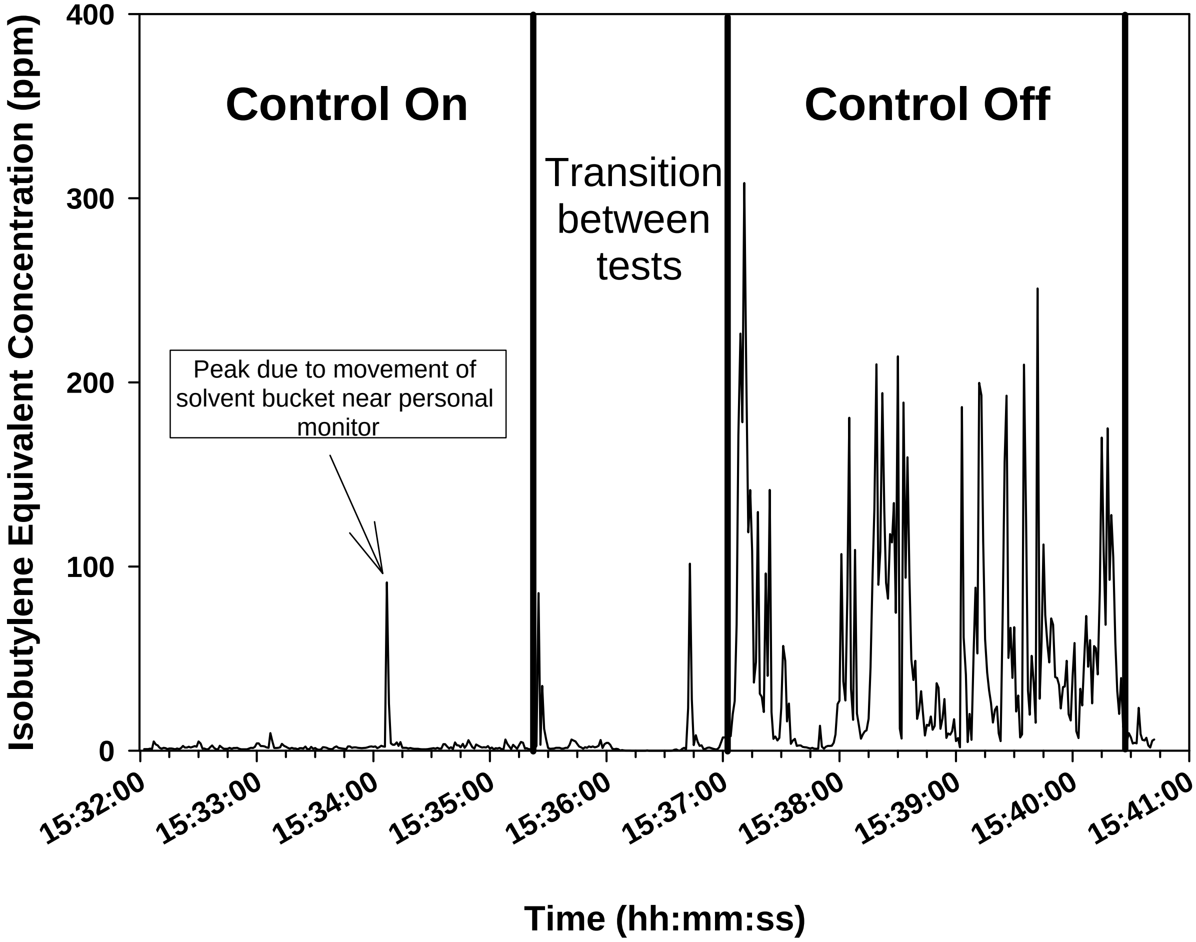


Figure 9. Real-time evaluation of bench top exhaust hoods--control on/off.

Test 2—Hood 9 Control On/Off

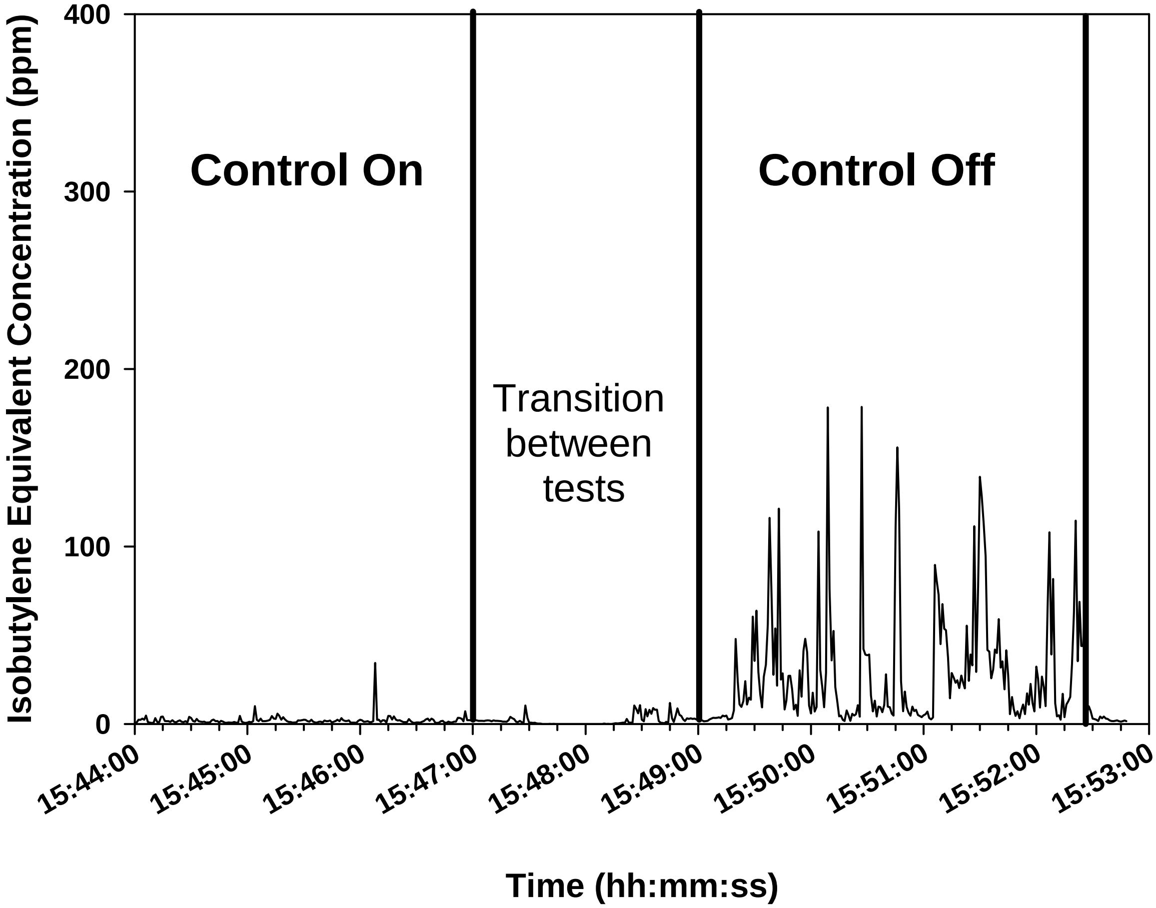


Figure 9. Real-time evaluation of bench top exhaust hoods--control on/off.

Test 3—Hood 2 Control On/Off Test

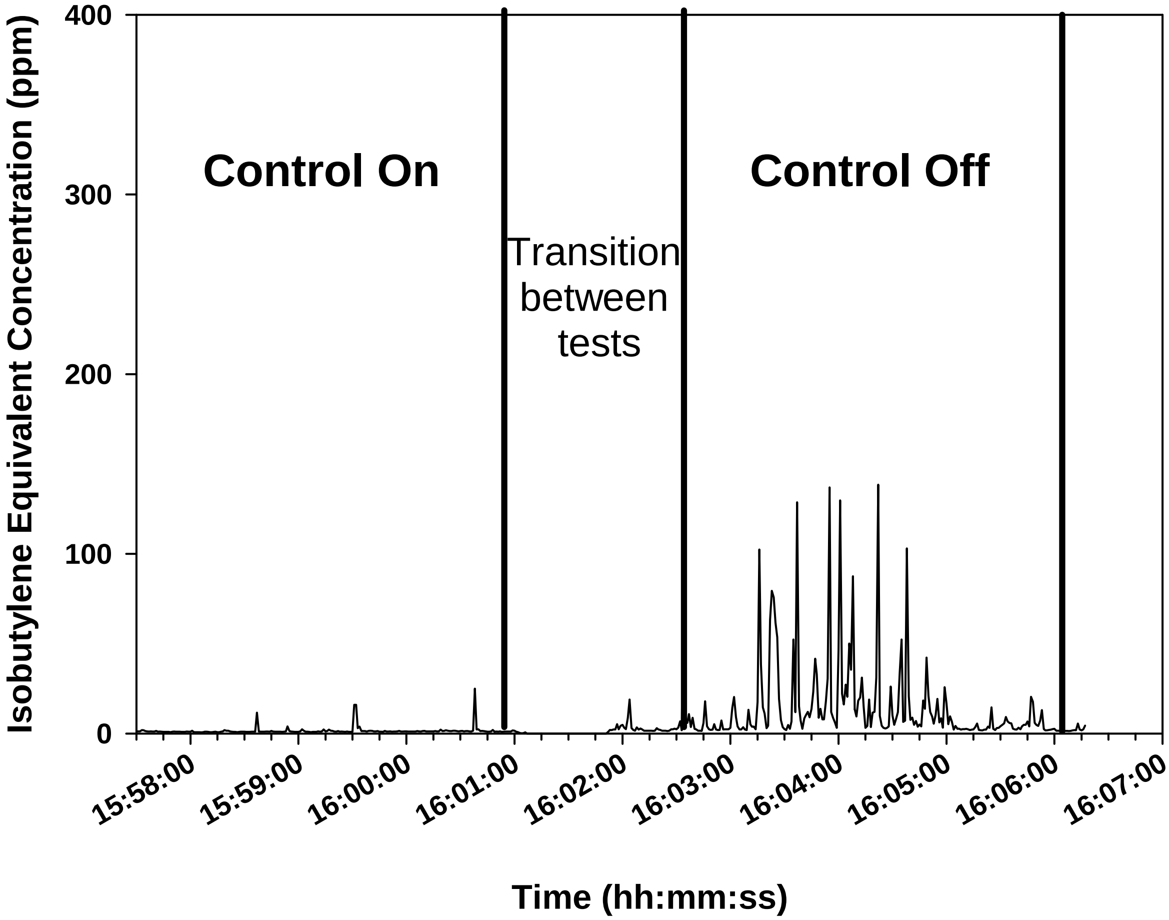


Figure 10. Average concentration and standard deviation for control on/off bench top tests.

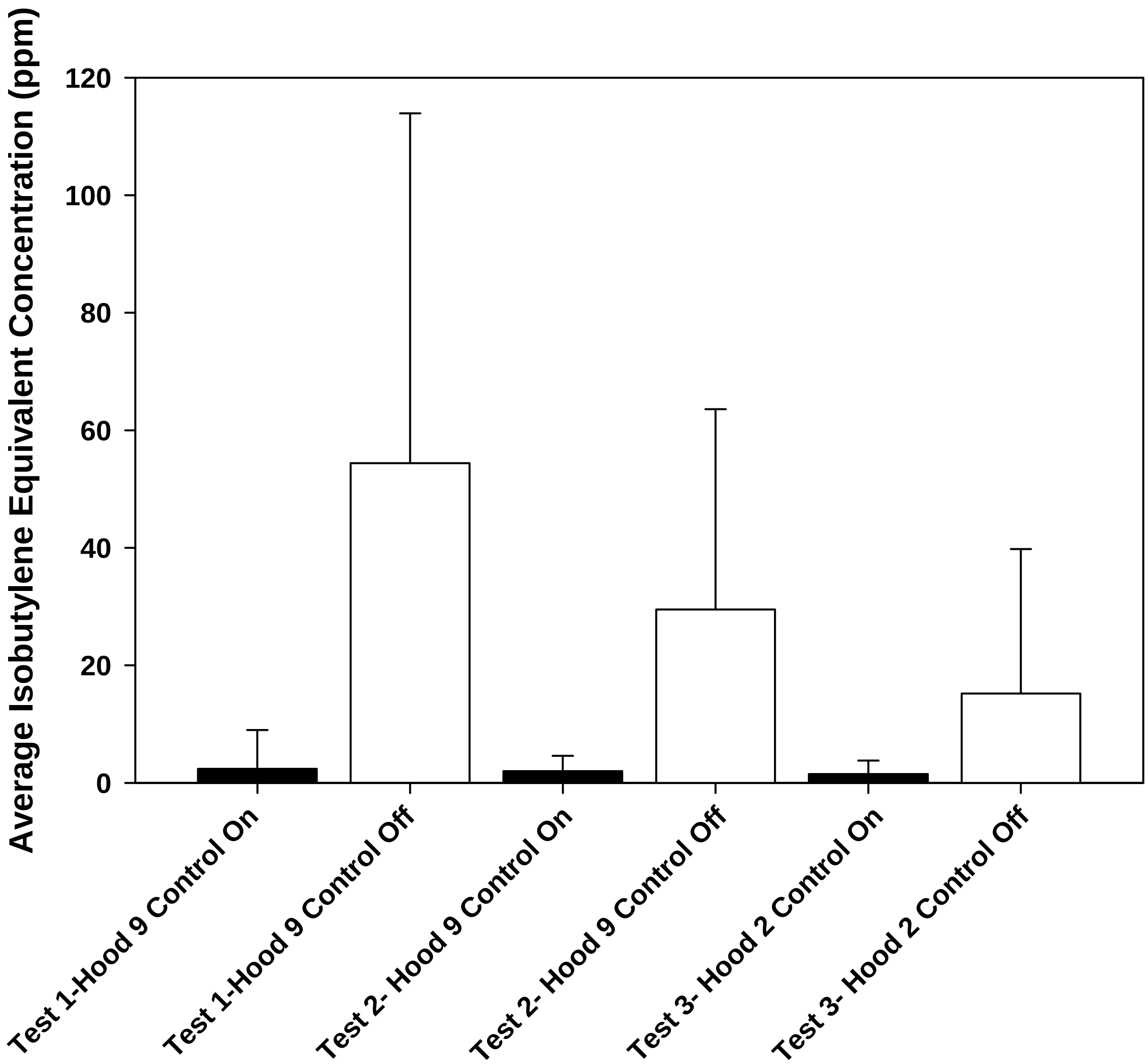


Figure 11. Employee packaging butter flavored powder inside ventilated booth.