IN-DEPTH SURVEY REPORT:
EVALUATION OF ENGINEERING CONTROLS FOR THE PRODUCTION OF LIQUID AND POWDER FLAVORING CHEMICALS

At

Kerry Ingredients and Flavours, Inc.
formerly Mastertaste, Inc.
Commerce, CA

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The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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I. Executive Summary

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of engineering controls installed for the control of exposure to chemicals during liquid and powder flavoring production at Mastertaste, Inc. The engineering controls were developed by Mastertaste in conjunction with an industrial ventilation contractor to reduce the potential for employee exposure to harmful flavoring chemicals. The systems evaluated included: 1) a ventilated lid developed to contain chemical vapors from a large mixing tank; 2) a bag dump hood installed on a powder blender; 3) a fume extraction hood used during liquid and powder flavor packaging; and, 4) a ventilated workstation used to contain vapors during small batch mixing activities.

Evaluations were based on a variety of tests including air velocity measurements, airflow visualization (smoke tracer), and control on/off testing using real-time monitoring techniques. The experiments showed that the ventilated mixing tank lid contained vapors during mixing and pouring. The results of control on/off tests on the new mixing tank ventilated lid hood showed a reduction of 76% during the actual production of a liquid caramel flavoring. Some tasks performed outside of the envelope of the hood were not adequately controlled. The mixing of pre-cursor key ingredients were conducted in the open room without controls and contributed to elevated worker exposure. The use of a fume-extraction hood during the packaging of the liquid caramel mix resulted in a reduction of 93% compared to the standard packaging procedures without controls.

Face velocity measurements were taken on each hood within the powder mixing room. While air velocities were high at the face for all hoods, the decay in face velocity moving across the width of the larger blenders may result in poor capture. The local exhaust ventilation (LEV) hood for the smallest capacity blender (250 pounds) showed that the ventilated side-draft slot hood reduced dust exposure by 96% during bag dumping activities. The discharge hood reduced dust exposure by 96% during emptying of the blender, and the use of the fume extraction hood reduced dust exposure by 65% during powder packaging.

Smoke tracer and control on/off tests conducted on selected hoods in the H2 mixing room showed good capture characteristics. The evaluation of one ventilated bench-top workstation in the H2 mixing room showed an exposure reduction of 97% during staged tasks such as weighing, hand-whisking, and pouring.

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

- Consider re-designing local exhaust ventilation hoods on the large ribbon blenders. The slotted rim exhaust has limited effectiveness and can only capture chemical contaminants up to about 18-24 inches from the hood face. A better enclosure design could improve performance while reducing required flowrate and energy usage.

- Consider adding an articulating arm to the fume extraction hood used in the powder packaging area. This arm could better support the weight of the hood and allow the worker to position the hood so that the dust could be collected more effectively.
- Consider process changes such as pre-mixing of key ingredients which include diacetyl or other high-priority chemicals. Use the ventilated workstations in the H2 room for pre-mixing before adding these chemicals in the larger mixers to reduce worker exposure during preparation.
- Install 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.
- Consider installing an indication of exhaust fan operating status (on/off) such as a light for each hood in the H2 room so that workers know that they are being protected when working with the hoods.
- Provide worker training on proper techniques for using ventilated workstations, such as clearing the bench of unnecessary chemicals/materials and as much as possible reducing the obstruction of airflow into the slot exhaust (storing chemicals and supplies on benches obstructs airflow). Also, opening chemical containers outside of the workstation enclosure can result in migration of chemical vapors and potentially expose other employees working inside the room.

II. 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 Mastertaste, Inc. at their Commerce, California plant on September 17-19, 2007. Mastertaste 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 to 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.

The site visit was conducted by request from Mastertaste management. The primary objective of the engineering control survey was to evaluate existing local exhaust ventilation systems implemented for the liquid flavoring and powder production processes as well as to evaluate a new control designed for large scale liquid flavoring mixing. A secondary goal was to evaluate and document the performance of control techniques in reducing potential exposures from common processes in 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 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 BO, 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 1985; Kreiss, Gomaa et al. 2002; Kanwal, Kullman et al. 2006). In California, at least seven workers involved in the production of flavorings have been diagnosed with obstructive lung disease since 2004 (Centers for Disease Control and 2007).

Employees within the flavoring production industry have complex exposures in terms of the physical form of the agents (solid, liquid, and vapor) 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. Finally, 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

The Mastertaste Commerce facility manufactures and distributes liquid and powdered flavors to other companies for use in a variety of food products. The facility consists of a chemical storage room (H3 room), small batch mixing/weigh-out room (H2 room), liquid production room, powder production room, candy/confectionary production room, walk-in cooler and freezer, raw materials warehouse, laboratory, quality control room, kitchen/culinary test and design room, and administrative offices.

Description of Processes and Controls

This survey was focused on engineering controls currently in use as well as newly-designed controls for production of liquid and powder flavorings. Flavors are produced by compounding ingredients identified on recipes on computer batch tickets. These tickets identify the order and quantity of ingredients which need to be added to make a flavor formulation. High priority chemicals, i.e., substances that may pose a respiratory hazard as designated by the Flavoring Extract and Manufacturing Association (FEMA) (FEMA 2004) are identified and appropriate respiratory protection is also highlighted on the batch ticket. Some chemicals, such as diacetyl, are cold-stored to reduce volatility during use.

Powders or pastes are typically mixed within industrial ribbon blenders in the powder production room. In these mixers, a powdered starch or other carbohydrate is combined with a liquid or paste flavoring agent. Blending ingredients is a source of potential exposures, depending upon the work practices employed when dumping bags of powders (which may produce visible airborne dust), pouring ingredients into the blender, discharging of the blender, and packaging the blended material. When the blending is completed, the powder product is discharged into a bulk tote and finally packaged into smaller containers.

H2 Room-Small Batch Liquid Mixing

The H2 room houses a series of ventilated work stations used for the preparation of key flavoring ingredients. Operations performed at these workstations include the measuring, weighing, and pouring of flavoring ingredients. The production workers pull bulk flavoring chemicals from the H3 storage room and pre-mix key liquid flavoring ingredients in the H2 room. The operations in the H2 room typically consist of measuring, weighing, and mixing of small batches of ingredients which will be used downstream in larger final batches mixed in the larger liquid production room. The finished key ingredients are stored on wire shelving in the H2 room and moved into the liquid production room as required to prepare larger batches of flavorings.

Ingredients are mixed by hand prior to being transferred and stored in small containers (typically in 1 to 5 gallon containers) for use in larger batches. Computerized batch tickets specify the ingredients for the various flavors. A notation on the batch sheet informs the employee when a high priority chemical ingredient (as designated by Flavor and Extract Manufacturers Association (FEMA 2004))is used. When these ingredients are used, all employees in the room are required to don respiratory protection, and the supervisor must sign off verifying that appropriate actions have been taken prior to the start of the operation. An employee may work with numerous flavor formulations daily depending upon the size and complexity of a batch order.

The ventilated workstations in use in the H2 room are back-draft slotted hoods housed in an enclosure. Each hood has four slots (13/16 inch in width) used to distribute the flow across the face of the hood. The enclosure, constructed from plastic strip curtains and support rods, surrounds the hood and provides the worker access through an opening in the front (see Figure 1). Inside this enclosure, there is a bench, and one or two scales as well as other items (stainless mixing vessels, packaging materials, bar code scanner etc.) Overall, six identical, ventilated workstations are installed in the H2 room.

Liquid Production Room-Large Batch Liquid Mixing

The liquid production room consists of stationary or mobile mixing tanks, homogenizers, working/compounding/filling stations, and various storage tanks (including sugar and propylene glycol). There are several small and medium mobile tanks which can be moved throughout the facility according to need of the batch or formulation. Larger stationary mixing tanks are positioned along the perimeter of the room. Employees typically weigh out flavoring ingredients on a bench top. Workers then complete mixes by pouring the precursor ingredients and other ingredients directly into the mixing tank. A notation on the batch sheet informs the employee when a high priority chemical ingredient (as designated by FEMA as a respiratory hazard) is used. When these ingredients are used, the employee puts out signage and dons a respirator.

Only those employees in the immediate vicinity of the mixing tank must wear respiratory protection during the pouring and mixing of these ingredients. Other employees in the room away from the tank are not required to use respiratory protection. Currently, there is no local exhaust ventilation in this room although plans are being considered to add ventilated workstations and booths for operations with high priority chemical ingredients.

Powder Blending Room

The powder blending room contains four stationary blenders and one mobile blender. The four fixed blenders are Blender II (250 pound capacity), Blender RR (600 pound capacity), Blender JJ (1500 pound capacity), and Blender HI (3000 pound capacity). Each stationary blender is mounted on a stand and is outfitted with local exhaust vents both on the top of the blender where bags of ingredients and flavors are dumped into the blender and on the bottom where the finished product is discharged (see Figure 2). The exhaust pickups on the top of the blender are mounted on each side of the blender and include a perforated plate on the inlet. A simple rectangular hood is used on the blender product discharge valve and can be positioned by the operator for optimal dust pickup (see Figure 3). A product packaging station is also located in the powder production room. This station consists of a 4-inch (in) x 8-in plain rectangular hood connected with flexible ducting so that the operator can move the exhaust for best capture (see Figure 4). The product capture hood, however, does not have any intrinsic support and must be positioned where the hood weight can be supported.

In addition, a large mixing tank outfitted with a new exhaust hood developed for control of evaporation of diacetyl and high priority chemicals was placed in this room for evaluation (see Figure 5). This hood consisted of a standard hinged mixing tank lid with a 4 inch circular takeoff which was connected to the exhaust ventilation system by flex ducting. A 12-in x 4-in opening was machined into the lid to allow chemicals to be poured into the mixing tank. This opening decreased the open area of the tank which reduces the amount of ventilation required to maintain negative pressure as well as the appropriate capture velocity for the tank.
One common exhaust fan services all local exhaust hoods and pickups in this room. Damper valves or blast gates on the inlet of each takeoff allow the operator to shut off other hoods to divert the exhaust flow to the hood currently in use. The operating procedure requires the operator to shut off all other hoods to increase airflow and improve collection effectiveness of the hood in use.

III. Methods

Local Exhaust Ventilation Characterization

A variety of methods was used to evaluate the local exhaust ventilation system (see Table 1). Initial characterization included measuring exhaust flowrates, hood face velocity, and slot velocity (where applicable). In addition to the face and slot velocity measurements, a smoke tracer was used to confirm that the direction of the airflow was correct and to assess the effect of secondary airflows on hood performance. Real-time exposure monitoring was also performed to quantify the capture efficiency for one ventilated workstation in the H2 room, a new exhaust hood for a large mixing tank (ventilated lid), and for a 250 pound small powder blender (Blender II). In the H2 room, two ventilated workstations were evaluated. The first workstation (designated as workstation 1) was located near the door connecting the H2 room with the warehouse. This workstation was evaluated because it was considered to be the worst case due to its position near the open door and the cross drafts created by makeup air entering the room. The second workstation (designated as workstation 5) was the fifth workstation from the entrance to the room. It was located farther away from the door at a position well within the H2 room away from the warehouse door.

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.

Procedure

The capture velocity of the hood is defined as the velocity created by the hood at the point of contaminant generation (Goodfellow and Tähti 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.

H2 Room—Ventilated workstation evaluation

In this room, two (of six) workstations were evaluated. A review of previous test results conducted by a consultant showed that the exhaust ventilation in this room was reasonably balanced, resulting in similar performance at each workstation. The face velocity tests were performed by dividing the opening of the workstation into a grid of equal area rectangles approximately 6-in x 10-in and measuring the velocity at the center of each grid (see Figure 6). 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, air velocities were measured across all slots for both exhaust hoods to evaluate distribution of exhaust. Slot velocities were logged approximately every 9 inches across the length of the slot.

Powder blending room evaluation

Air velocity measurements at the exhaust hood openings were made for all blenders within the room (see Table 2). Measurements were made at three points across the face of the intake and averaged. These measurements were repeated for three conditions: 1) only the blender hood open; 2) both the blender and discharge hood open, or; 3) only the discharge hood open. In addition, hood centerline measurements were taken at a distance of 1 foot and 2 feet from the face of the hood to document the decay in capture velocity with increasing distance from the hood's face.

Hood Qualitative Smoke Tracer Test

Equipment

A Wizard stick handheld smoke generator (Zero Toys, Inc., Concord, MA) was used to visualize air movement inside and around the periphery of the hood.

Procedure

H2 Room—Ventilated workstation evaluation

Smoke was released around the periphery of the hood and in the interior of the workstation to qualitatively evaluate the capture and determine areas of concern. By releasing smoke at points in and around the hood, the path of the smoke, and thus any airborne material potentially released at that point, could be qualitatively determined. 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 was slow to be captured when released at a certain point, or took a circuitous route to the air intake for the exhaust, the hood design was considered marginal. Smoke release observations were made in the interior of the hood to look for reverse flow and at the edges of the hood to identify escape. Also, the adverse effect of cross drafts on the workstation was evaluated by releasing smoke near the periphery of the hood face. This evaluation was performed on two workstations.

Powder blending room evaluation

Smoke was released at the face of each blender bag dump and product discharge hood. The smoke tracer was then moved increasingly further away from the face towards the furthest point where powders could be released during typical work tasks. By releasing smoke at points along the front of the blender, the path of the smoke, and thus any airborne material potentially released at that point, could be qualitatively determined.

Real time Exposure Monitoring Test

Equipment

MiniRAE 2000 and ToxiRAE (RAE Systems Inc., San Jose, CA) photoionization detectors (PID) were used to measure volatile organic compound concentrations during liquid flavoring mixing control on/off tests. The PID is an instrument which responds to a wide array of volatile chemicals with ionization potentials within the response range of the instrument. It does not provide identification of specific chemicals but can be used for comparison of exposures among a variety of tasks. The unit was calibrated with isobutylene, and thus all measurements are shown in isobutylene equivalent concentrations.

A HazDust IV aerosol photometer (Environmental Devices Corp., Plaistow, NH) was used to measure particulates to evaluate dust exposure during powder blending control on/off tests. The HazDust IV unit was outfitted with a thoracic sampling inlet. Measurements were not corrected using gravimetric filters so the reported concentrations should only be interpreted as relative measures.

Procedure

H2 Room-Ventilated workstation evaluation

To evaluate the H2 Room workstation ventilation, a PID was placed on a NIOSH researcher. This monitor logged real-time volatile concentrations to evaluate engineering control effectiveness during weighing, pouring and whisking of ethanol. Ethanol 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 1 minute and 46 seconds. During this test procedure, ethanol was poured from a 5 gallon bucket into a stainless steel pail, weighed 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. In addition, area monitors were placed at locations throughout the room to evaluate the migration of chemicals from these workstations to other areas inside the room. These tests were conducted only on the workstation closest to the warehouse door (designated as workstation 1), since it was most likely to be adversely affected by cross drafts due to the makeup air.

Powder blending room evaluation

To evaluate the effectiveness of the local exhaust hood on the 250 pound powder blender (blender II), a personal aerosol photometer was outfitted onto a worker. The powder used was dextrose which is a common carrier for powder-based flavorings. No flavorings were added to the mix during the evaluation. The evaluation included bag dumping and product packaging. The worker dumped five 50 pound bags of dextrose into the blender, turned on the blender and discharged the blender into a carboy. The powder was then packaged into 15 gallon polypropylene lined cardboard containers. The initial trial was conducted with the local exhaust ventilation turned on. Then the same amount of material was blended and packaged with the exhaust system turned off. This process was completed twice, each time on separate days of the survey.

Large Mixing Tank Hood Evaluation

To evaluate the new large mixing tank hood, a PID was placed on a worker while he prepared a caramel liquid flavoring recipe. The batch was split into two equal halves with the worker performing the initial mix with the experimental hood in place and connected to an exhaust duct.

The second half of the batch was prepared according to the standard procedures (prior to the fabrication of the new hood design) which included using plastic covering over the mixing tank to contain volatiles within the mixture. The evaluation included preparing the mix to the completion of packaging the final product. During the new process, packaging was completed using a simple exhaust hood positioned by the worker near the product containers. The product packaging hood was the same hood as used for the powder packaging tasks evaluated (described above).

<u>Large production room evaluation</u>

To evaluate the potential for migration of vapors within the large batch mixing room, real-time VOC monitors were positioned at various locations throughout the room while typical mixing activities were completed (see Figure 7). Notes on the various mixes and locations of work were collected during this time period to help interpret the sampling results.

IV. RESULTS

<u>H2 Room-Ventilated workstation evaluation</u>

The average air velocities measured across the face of workstations 1 and 5 were 134 feet per minute (fpm) and 125 fpm, respectively. Air velocity measurements varied considerably across the face of the hood opening, ranging from 45-177 fpm on workstation 1 and from 61-165 fpm on workstation 5. However, on the whole, they were above 100 fpm at most points across the face for both hoods and specifically at all points within the typical working area of the hood. Lower face velocities tended to be in the upper and lower corners of the hood face. Slot velocities were generally uniform across all slots for both hoods. The slot velocities ranged from 800-1250 fpm across all slots on workstation 1 and from 890-1295 fpm on workstation 5.

The smoke tests showed good capture for both workstations 1 and 5. Smoke was generally captured both directly and quickly when released in the interior of the hood and along the perimeter. However, turbulence due to strong cross drafts caused some deflection of the plastic side curtains on workstation 1. This is due to the placement of this workstation near the door to the warehouse area. All exhaust hood makeup air coming in to this room is supplied through the door producing large air currents near this opening.

Control on/off tests were conducted on ventilated workstation 1. The data show a reduction in exposure during the weighing, pouring, and whisking of ethanol when the local exhaust ventilation system is activated (see Table 3 and Figures 8 and 9). Three separate control on/control off tests were conducted to evaluate the effectiveness of the hood during the conduct of typical work tasks. Figure 8 includes real-time data from both the control on and off tests overlaid on the same graph. Figure 9 shows the average concentration reduction from all the trials combined as well as the lower 95% confidence interval for the mean reduction. When the ventilation system was activated, the task based average concentration was reduced by 97%. Figure 8 shows the variability in instantaneous exposure during the control off test due to worker activities and turbulent room drafts. This variability was reduced when the control was turned on. However, as Figure 8 shows, there was one peak exposure when the control was on during trial 3. This concentration spike was noted when the 5 gallon bucket of ethanol was raised close to the monitor probe after pouring the mixture into the stainless steel canister. Once the pour ended, the concentration dropped down to background. This result illustrates the important influence of work practices on potential exposures even when effective engineering controls are in place.

The area PID monitors (positioned throughout the room) showed that vapors were migrating from the workstation being evaluated to other locations throughout the room. These concentrations declined as distance increased away from the workstation.

Powder blender room evaluation

The air velocities measured at the hood openings are shown in Table 2. In general, the exhaust velocities were good at the bag dump hood face but decayed rapidly with distance. For example, on blender HI, the face velocity of the left hood was 850 fpm. This velocity decreased to 88 fpm at a distance of one foot from the hood face and to 32 fpm at 2 feet. All of the other blenders exhibited similar drop-offs in capture velocity across the blender opening. The discharge hoods generally had higher exhaust velocities at the hood face due to smaller opening areas compared with the upper bag dump hoods. They also showed better capture characteristics during smoke tracer tests. The hoods had adequate capture up to about 12- inches from the hood face.

Control on/off tests were conducted on the smallest blender in the room (blender II). The data from these tests show reductions in exposure during bag dumping, discharging of product into a bulk container, and packaging of powders when the local exhaust ventilation system is turned on. This process was completed twice, each time on separate days of the survey. The results from these tests are shown in Table 3 and Figures 10 and 11. When the ventilation system was activated, the task based average concentration was reduced by 96%, 97%, and 64% in bag dumping, discharging of products, and product packaging, respectively (see Table 3). Product packaging activities performed with the control on showed the lowest reduction in exposure with instantaneous dust concentrations up to 12 mg/m^3. As can be seen in Figure 10, the real-time data show a significant number of peak exposures during product packing even when the hood is turned on. Both the bag dump and product discharge tasks showed reasonable control of dust exposure during these worker activities.

Large Mixing Tank (Ventilated Lid) and Product Packaging Hood Evaluation

Worker task-based average exposure was reduced during liquid caramel flavor mixing and packaging when each exhaust hood was utilized. One test was conducted to evaluate the effectiveness of each of these hoods. The mixing task was evaluated using the large mixing tank hood, whereas the packaging task used the simple rectangular hood located in the powder blending room. The results from these tests are shown in Figures 12a, 12b, and 13. With the control on, the task-based average concentration was reduced by 76% in mixing and 93% in packaging the caramel, respectively. During the caramel mixing task with the control on, there were still some peak exposures likely due to the mixing of precursor ingredients which occurred outside of the mixing tank. As can be seen in Figures 12a and 12b, the use of the product packaging hood significantly reduced worker peak exposures.

Large production room evaluation

The results of the real-time VOC area monitoring are shown in Figures 14, 15, and 16. They are broken out by location within the production room to improve the readability of the graphs provided. There was only one substantial peak during the 6 hour monitoring period on unit 9 (see Figure 14). There were subsequent smaller peaks noted on unit 3, although it is not possible to determine whether these peaks are associated. In general, VOC concentrations were low (typically less than 35 ppm isobutylene equivalent) with few signature events to help evaluate the potential of vapor migration within the room.

V. DISCUSSION

H2 Room—Ventilated workstation evaluation

The results of the performance tests discussed above showed good overall performance for both of the ventilated workstations that were evaluated. The control on/off tests for workstation 1 showed a reduction in average exposure of 97% when performing typical mixing tasks such as weighing, pouring, and whisking. The lack of dedicated 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 face velocities for both workstations 1 and 5 were above the standard fume hood control velocity range of 80-100 fpm(American National Standards Institute. and American Society of Heating Refrigerating and Air-conditioning Engineers. 1995), and smoke tests confirmed good capture characteristics for both. The use of flexible side curtain enclosures around the hoods helped define the control area and protect against cross drafts for work performed within this envelope.

Area PID monitors indicated migration of VOC throughout the room during the conduct of control on/off testing. These results showed that when chemicals are opened *outside* of the hood enclosure, vapors quickly migrate to other work areas in the room due to the flow of make-up air into the room from the warehouse.

Powder blending room evaluation

The results of each of the tests discussed above showed good performance for the blender II bag dump hood as well as the product discharge hood (see Table 3). However, the product packaging hood was only marginally effective based on the results of the control on/off tests. The control on/off tests showed reductions of 96% and 97% for the bag dump and product discharge tasks, respectively. The powder packaging tests showed a reduction of 64% in the task-based average concentration.

The blender bag dump hoods generally had high capture velocities at the face of the hoods overall. However, most of the blender bag dump openings are too large for a standard rim exhaust to work effectively. The blender openings range from 21-in in length (blender II) to 39-in (blender HI). Typical rim exhausts are limited in the area where they can provide adequate capture velocity and should not be used to capture contaminants beyond about 24-in from the hood face(Goodfellow and Tähti 2001). This was seen in capture velocity measurements made 1 and 2 feet away from the face of the blender hoods. Typically, the air velocity decayed about one order of magnitude about 1 foot away (from about 900 fpm to 90 fpm, for example) to less than the resolution of the air velocity meter at 2 feet (about 10 fpm or less).

Using a ventilated enclosure around the ribbon blender opening should provide better capture during bag dump activities. The American Conference of Governmental Industrial Hygienists (ACGIH) Industrial Ventilation Manual provides design guidance which may be applicable to this operation including design plates, VS-15-20, Toxic Material Bag Opening, and VS-50-10, Bin and Hopper Ventilation. In general, the primary design parameter from these plates is enclosing the top of the blender as much as possible and designing for a face velocity of 150-250 fpm. In addition to these design plates, there are several commercial vendors who provide ventilated bag dump stations which may be effective.

The blender powder discharge hoods showed adequate capture based on the results of all tests performed. The real-time control on/off showed a reduction of about 96% during the discharging of blender II. The key design parameters for these hoods are adequate air velocity and proximity to the discharge source. The air velocity for most of these hoods was around 2000 fpm at the hood face allowing an adequate capture velocity up to 12-in or more from the hood face.

The powder product packaging hood was only marginally effective primarily due to design deficiencies (measured reduction of 65% versus control off). The simple rectangular hood is connected to a flexible metal ducting without proper weight support. This requires the worker to position the hood where there is adequate structural support for the hood (on the edge of a table for instance). This often means that the hood will not be well positioned to capture the powders effectively. The addition of an articulating arm which provides both structural support and ability to move the hood means that the worker can best position the hood to capture visible dust.

When working with highly hazardous material, the ACGIH Ventilation Design Manual recommends using an enclosing hood rather than a moveable capture hood such as the one described above(American Conference of Governmental Industrial Hygienists. 2007). During packaging of materials containing hazardous substances, a partially enclosing booth might provide better worker protection. A back-draft ventilated workstation such as the ones used in the H2 room could be modified to provide better worker protection. A design such as the one specified in the ACGIH Ventilation Design Manual plates VS-15-10 and VS-15-11, Weigh Hood Assembly Dry Material, which was designed for the manual handling of dry powders, might better contain the powder and reduce worker exposure during packaging.

Large Mixing Tank and Product Packaging Hood Evaluation

The large mixing tank hood showed good containment of vapors within the mixing tank. This was confirmed at the pour opening by air velocity measurements and smoke tracers. The overall exhaust flow rate for this hood was minimized by reducing the size of the pour opening. The control on/off tests performed during the preparation of a caramel mix showed a reduction of 76% in exposure based on real-time measurements. However, observations of this process indicated that further reductions could be achieved if the process was improved. Figures 12a-b show how the overall exposures were reduced. However, there were still some peak exposures with the control on that were similar to the control off values. This is likely due to the fact that some mixing of recipe precursors occurred outside of the mixing tank. A change in procedure to complete all precursor mixing (at least those which include high priority chemicals) at the ventilated workstations in the H2 room would reduce exposures during the large batch preparation process.

The packaging of the final caramel mix involved the manual transfer of the finished product from the large mixing tank to a 55 gallon product carboy. The worker used a 5 gallon bucket to manually collect caramel liquid flavoring through a discharge valve on the mixing tank. When the 5 gallon container was full, the worker poured the contents into the 55 gallon drum. When the control on test was conducted, the worker used a simple 4 inch by 8 inch rectangular hood. The worker positioned the hood near the mixing tank discharge valve to collect vapors during the filling of the 5 gallon bucket. When he transferred the full bucket into the 55 gallon carboy, he re-positioned the hood to a point closer to the carboy fill port. This hood was the same one used during product packaging for the powder blender product. As such, the addition of an articulating support arm would help improve hood effectiveness by allowing the worker to better position the hood for maximum collection efficiency.

Large production room evaluation

Due to the absence of substantial spikes in recorded exposures during observed operations and inability of the researchers to document all activities occurring within the room during the monitoring period, it is impossible to interpret the data conclusively. A more controlled experiment would need to be conducted to effectively evaluate vapor migration within the room. However, previous studies have shown that vapors can travel a substantial distance within flavoring production rooms.

More rigorous testing could be performed to address whether current work practice guidelines are sufficient to protect all of the workers in the room. However, given the variety of chemicals used in flavor production and the lack of occupational exposure limits and toxicological data on many of these chemicals, an approach which seeks to reduce exposure through process controls (e.g., enclosure, local exhaust ventilation) should be the primary goal.

VI. RECOMMENDATIONS

It is important to confirm that the LEV system is operating as designed and that the workers are being adequately protected, as well as to periodically measure exhaust airflows. A standard 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 ACGIH Operation and Maintenance Manual citation recommends the installation of a fixed hood static pressure gauge(American Conference of Governmental Industrial Hygienists. 2007).

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

1. Consider re-design of local exhaust ventilation hoods in place on the large ribbon blenders. The use of slotted rim exhaust is limited in its effectiveness to capture chemical contaminants to about 18-24 inches from the hood face. A better enclosure design could improve performance while reducing the required air flow and energy usage.
2. Consider adding an articulating arm design to the extraction hood used in the powder packaging area. This arm could better support the weight of the hood and allow the worker to position the hood so that the dust could be collected more effectively.
3. Consider process changes such as pre-mixing of key ingredients which include diacetyl or other high-priority chemicals at the ventilated workstations in the H2 room prior to using these chemicals in the larger mixes to reduce worker exposure during preparation.
4. Install 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.
5. 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.
6. Provide worker training on proper techniques for using ventilated workstations such as clearing the bench of unnecessary chemicals/materials as much as possible to reduce the obstruction of airflow into the slot exhaust (storing chemicals and supplies on benches obstructs airflow). Also, opening chemical containers outside of the workstation enclosure can result in migration of chemical vapors and potentially expose other employees working inside the room.

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Table 1. 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.
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 versus off provide indication of hood effectiveness.

Table 2. Blender hood characteristics and velocity measurements.

Blender (capacity)	Blender Opening Dimensions		Hood Opening Dimensions		Average Face Velocity (fpm) at hood opening			Notes
	Width (in)	Length (in)	Height (in)	Length (in)	Test Condition			
					1	2	3	
RR	24	60	5	20	535	343		Left blender hood measurements
			5	20	530	342		Right blender hood measurements
			3	8		1478	1885	Left discharge hood measurements
			4	8		1543	2005	Right discharge hood measurements
JJ	32	33	10	24	355	282		Left blender hood measurements
			10	24	330	295		Right blender hood measurements
			4	8		1790	2367	Discharge hood measurements
II	48	21	5	20	523			Left blender hood measurements
			5	20	742			Right blender hood measurements
			4	8		1717	2267	Discharge hood measurements
HI	44	39	5	20	893	813		Left blender hood measurements
	44	38	5	20	903	792		Right blender hood measurements
			4			2370	2400	Circular simple discharge hood (diam = 4 in)

Note: Test Condition 1 = Blender hood open only
Test Condition 2 = Both blender and product discharge hoods open
Test Condition 3 = Product discharge hood open only

Table 3. Control ON/OFF Test Results--Average reduction of exposure on real-time samples for simulated powder production and small batch liquid production activities.

Process		**Control ON**		**Control OFF**		**Average Reduction**	**95% Lower Confidence Limit**
		Day 1	**Day 2**	**Day 1**	**Day 2**		
Powder Production	**Bag Dump**	0.47	0.24	7.14	12.2	**0.96**	**0.92**
	Product Discharge	0.01	0.19	1.27	3.79	**0.97**	**0.92**
	Product Packaging	4.71	4.16	10.48	15.11	**0.64**	**0.24**
Liquid Production H2 Room	**Run 1**	0.07		4.19			
	Run 2	0.04		11.30			
	Run 3	0.74		13.58			
	Average	**0.25**		**9.49**		**0.97**	**0.92**

Note: Day 1 is September 18th
Day 2 is September 19th

Figure 1. H2 Room ventilated work station.

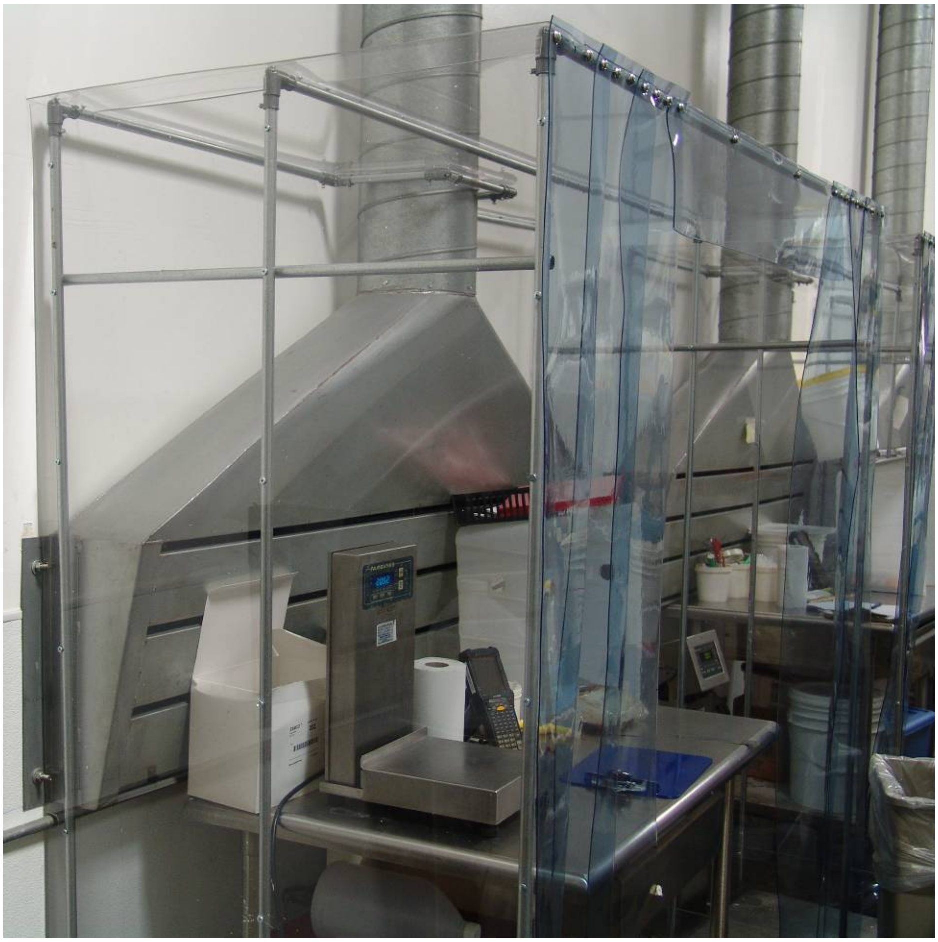


Figure 2. Powder blending room (blender HI in the foreground).

Figure 3. Blender discharge exhaust hood.

Figure 4. Powder flavoring packaging hood.

Figure 5. Large mixing tank exhaust hood.

Figure 6. Ventilated work station face velocity test grid.

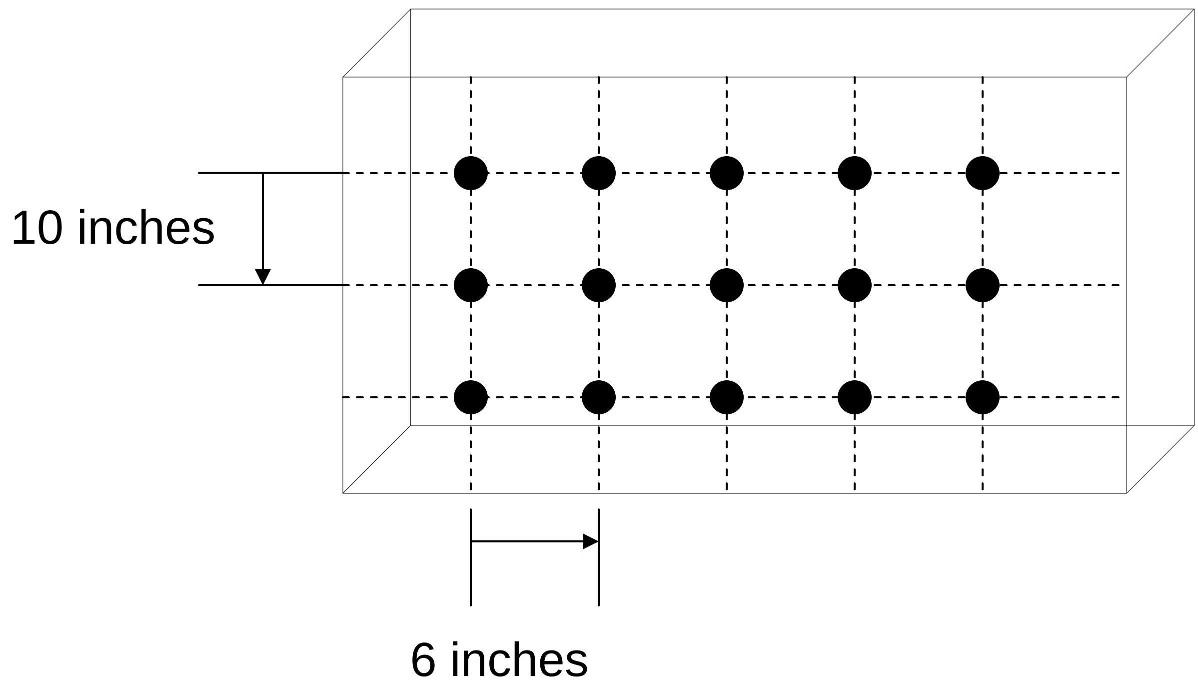
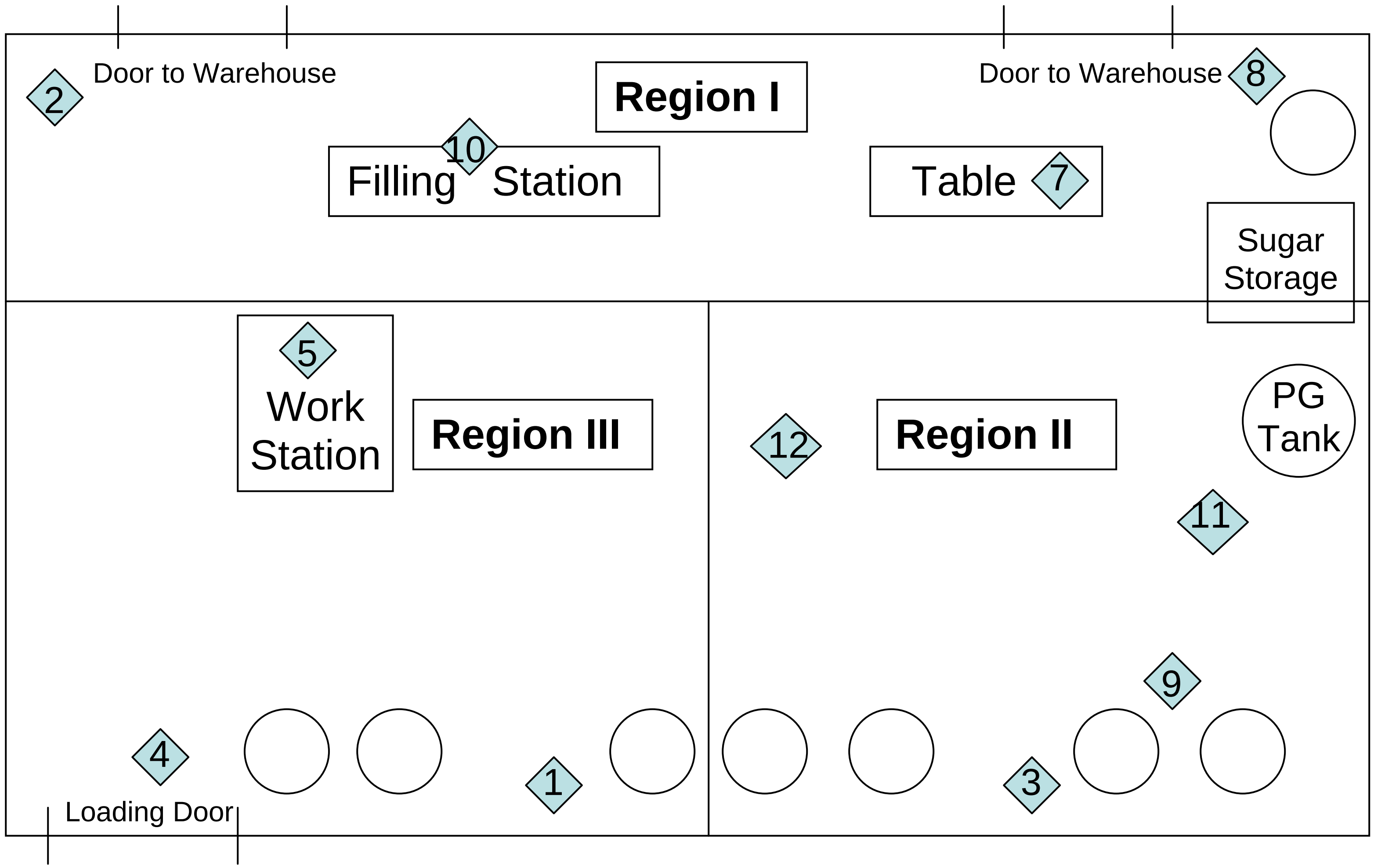


Figure 7. Liquid mixing room layout with VOC monitor locations.



Note: Circles represent mixing tanks and diamonds represent VOC monitor locations.
VOC monitor #6 was not used in the evaluation.

Figure 8. H2 Room control On/Off ventilated workstation tests--Instantaneous VOC concentrations.

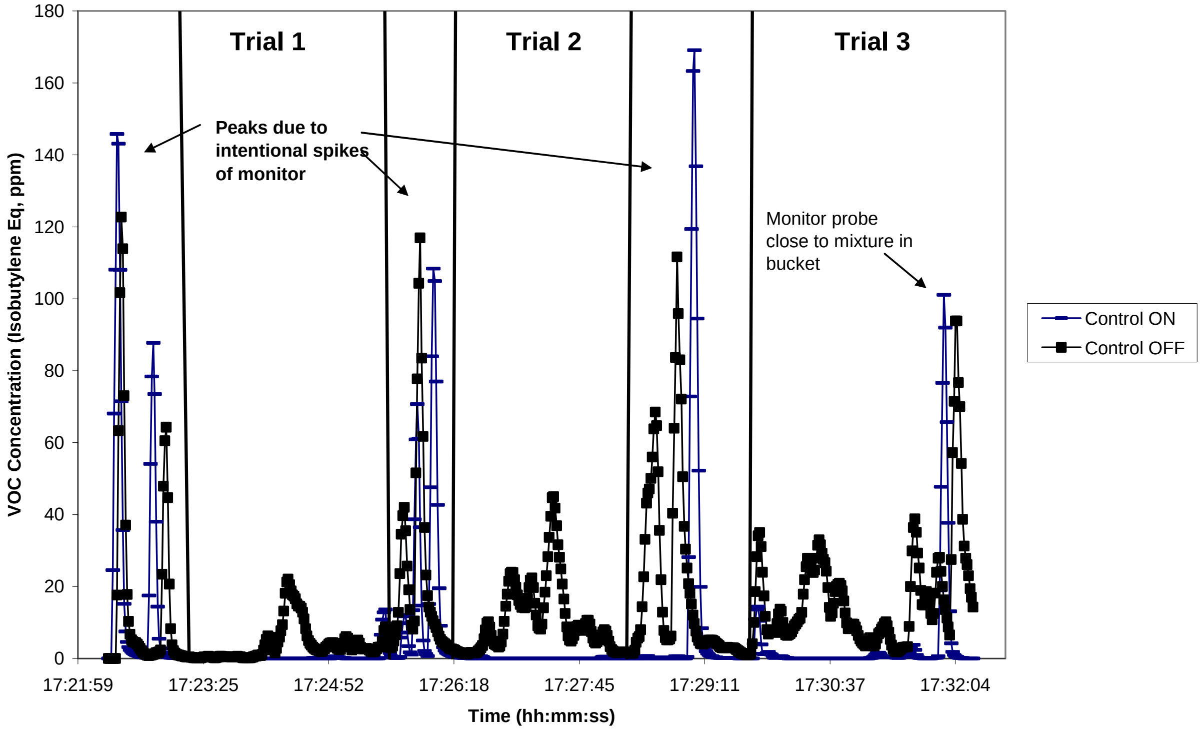


Figure 9. H2 Room control On/Off ventilated workstation tests--Average VOC reductions during simulated small batch mixing activities.

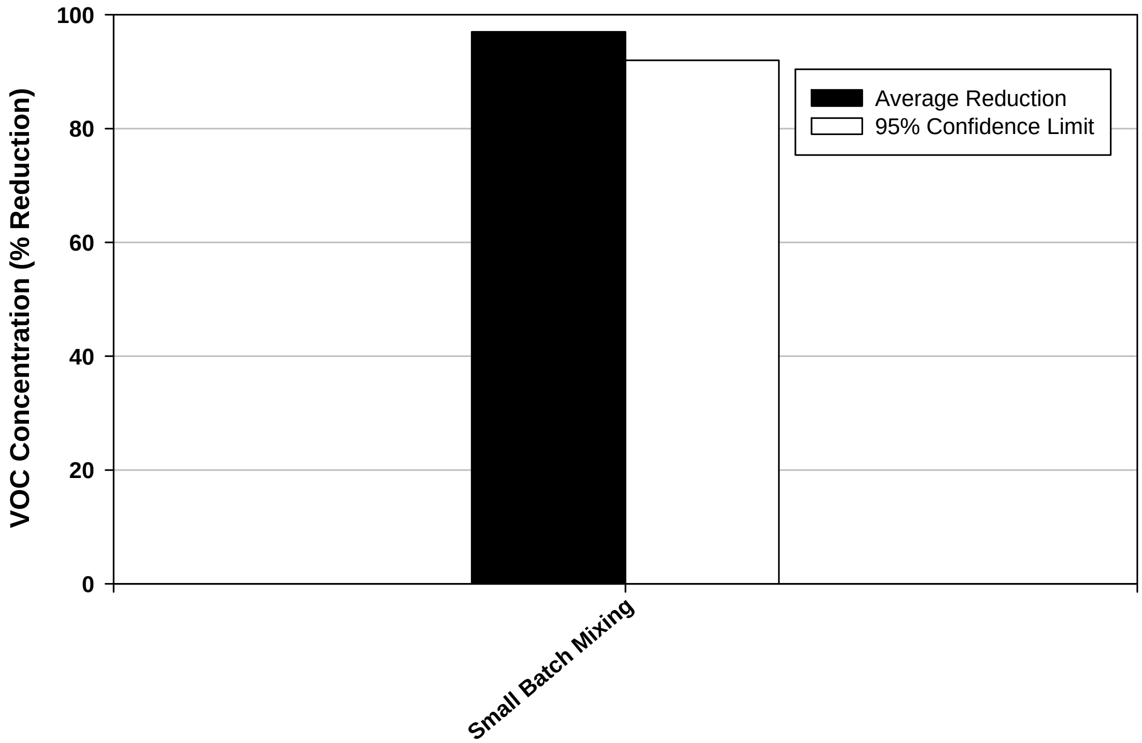


Figure 10. Blender II Control On/Off tests--Instantaneous dust concentrations.

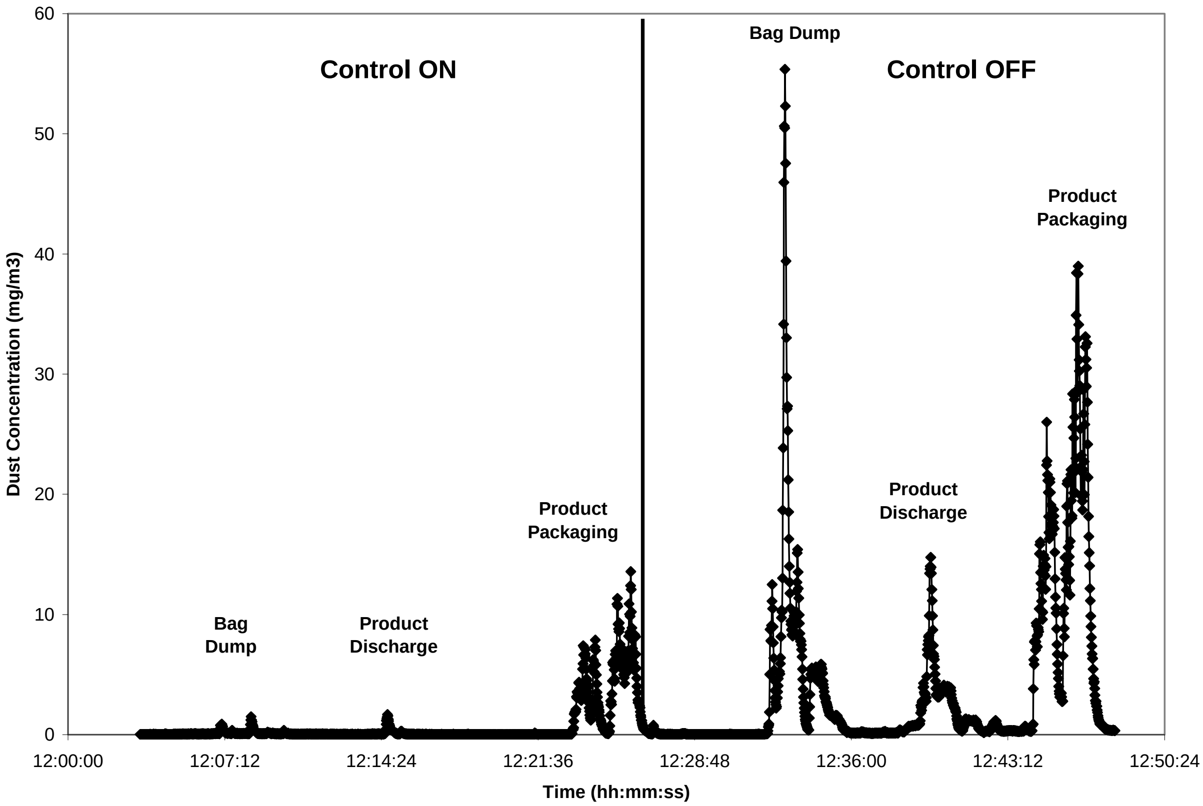


Figure 11. Blender II Control On/Off tests--Average dust concentration reductions by task during simulated powder production activities.

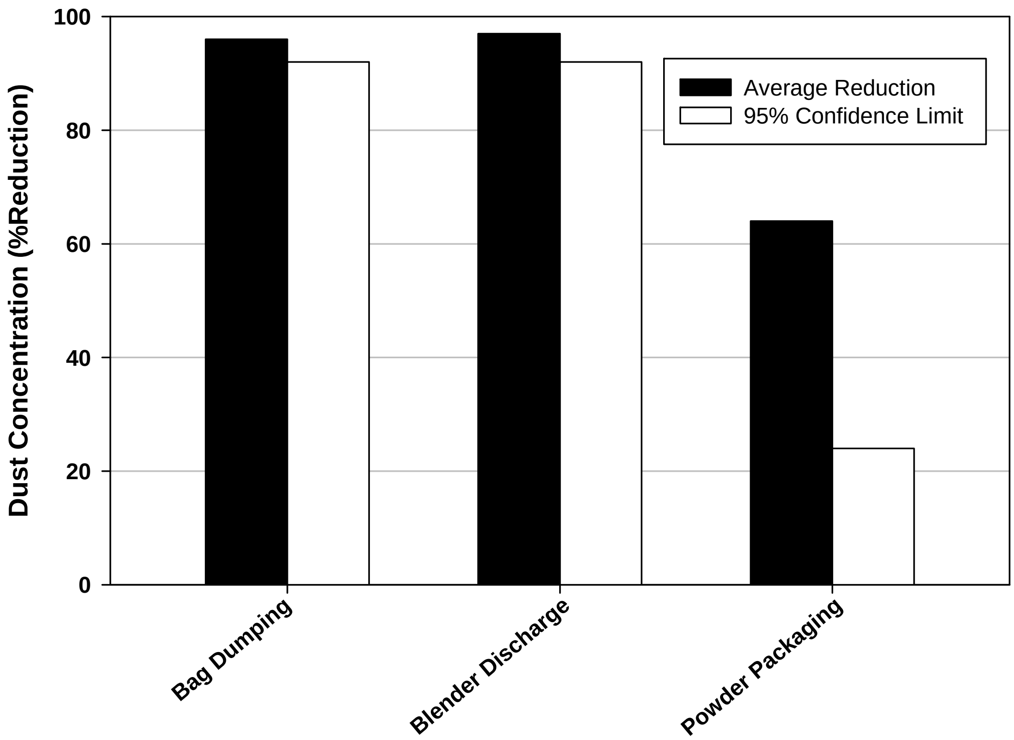


Figure 12a. Mixing tank experimental and packaging hood Control On test--Instantaneous VOC concentrations.

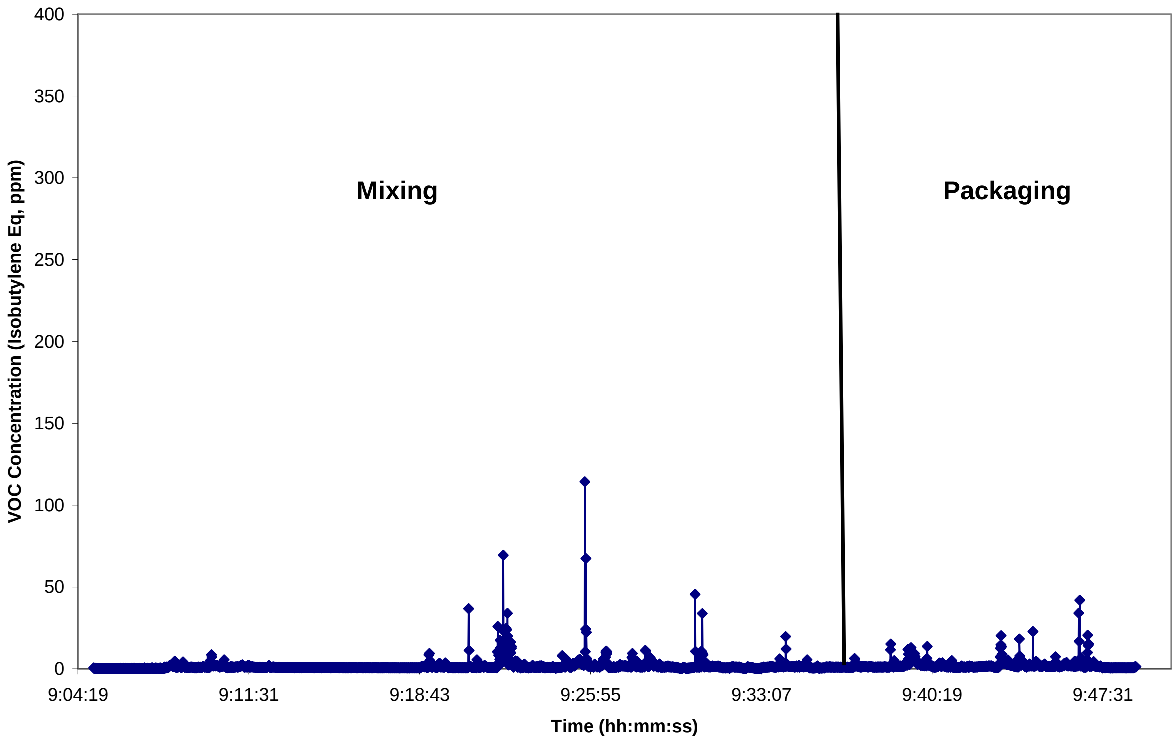


Figure 12b. Mixing tank experimental and packaging hood Control Off test--Instantaneous VOC concentrations.

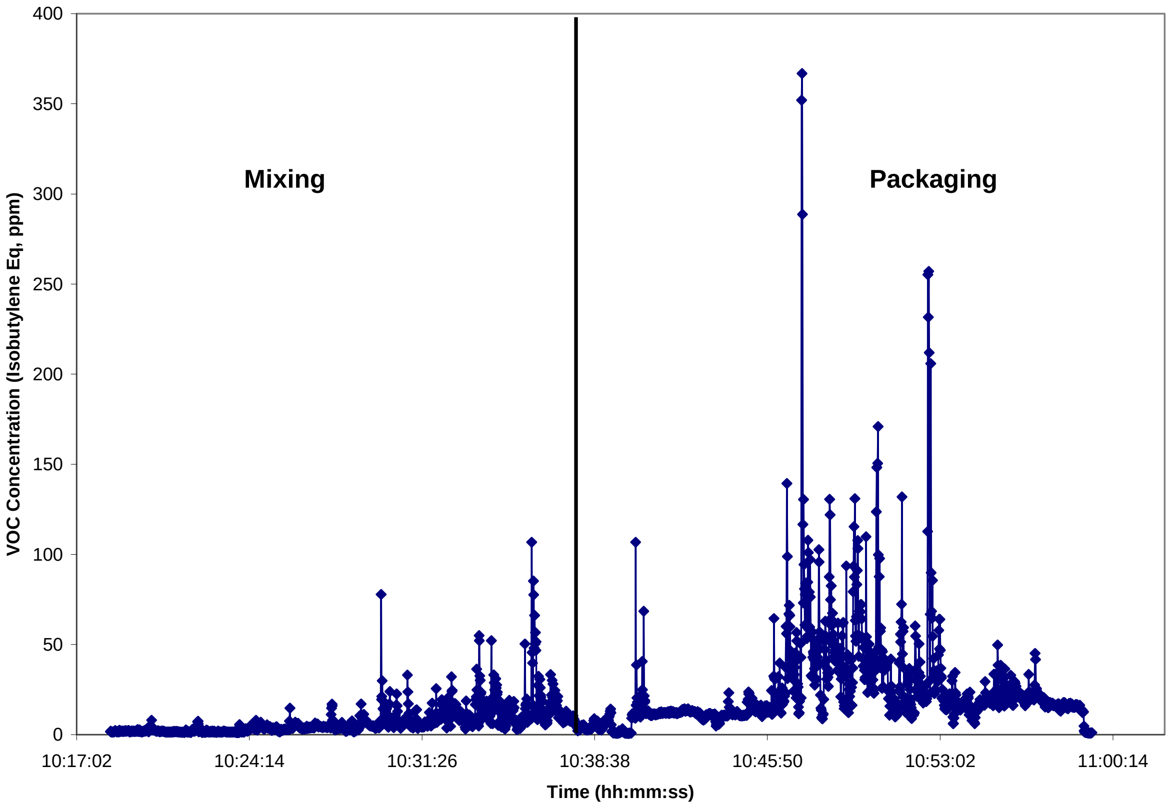


Figure 13. Mixing tank experimental and packaging hood control On/Off test--Task average VOC concentrations.

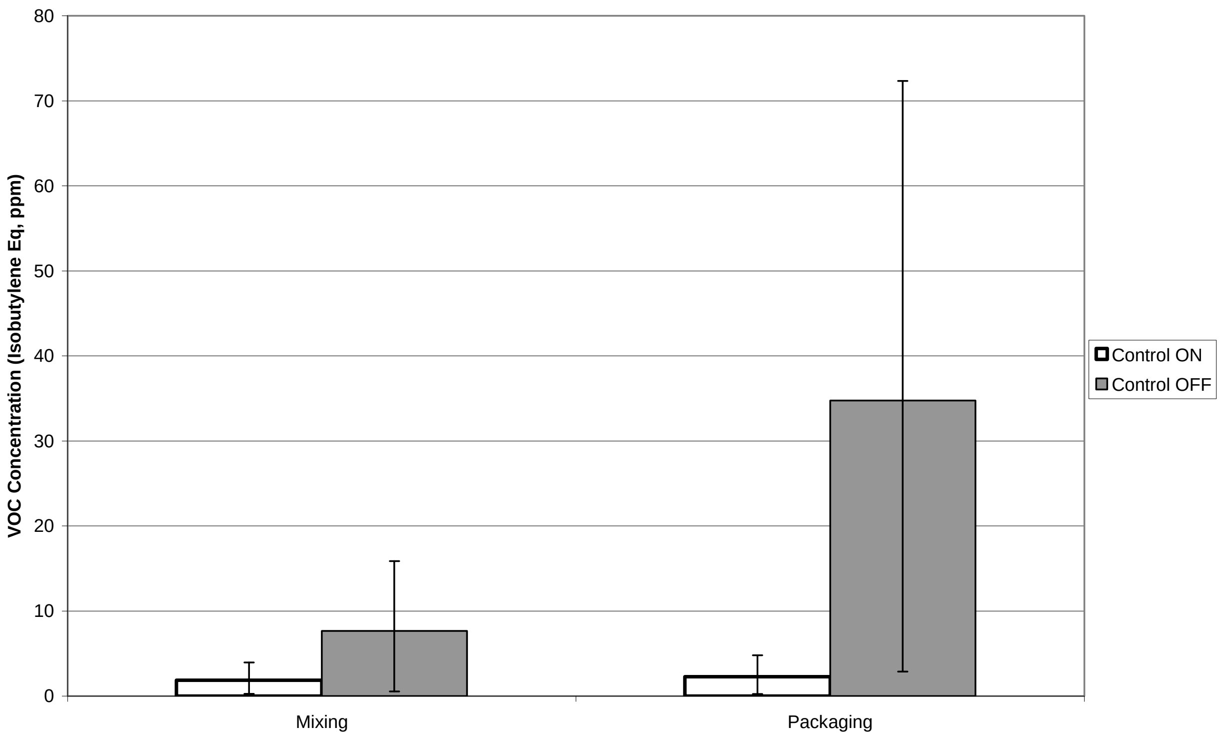
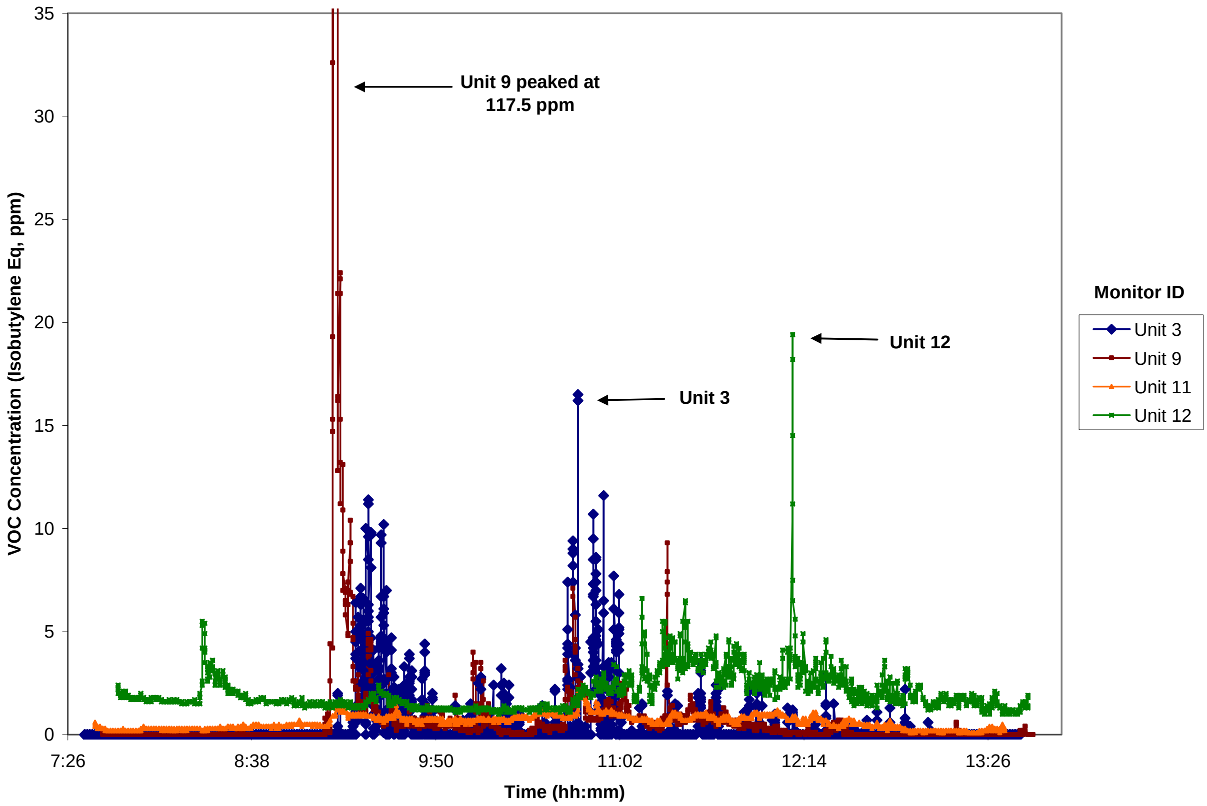
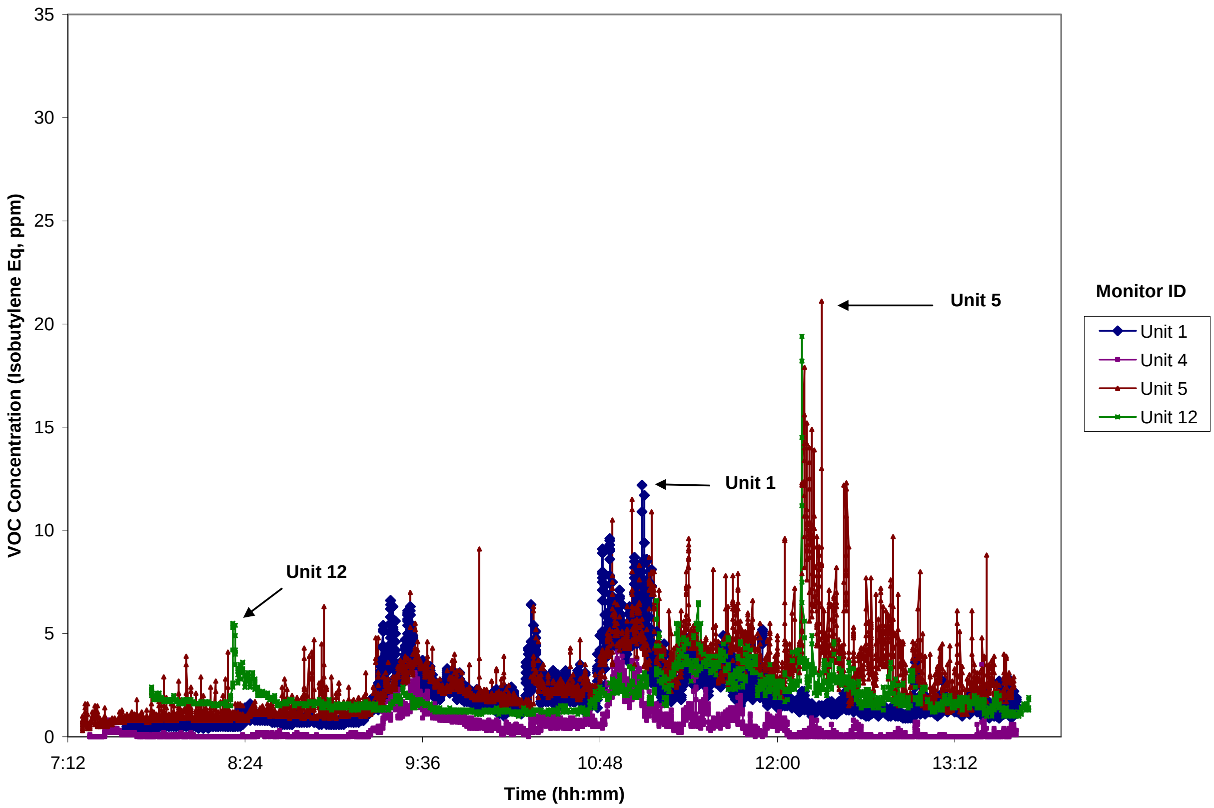


Figure 14. Large Mixing Room Area VOC Concentrations--Region I.



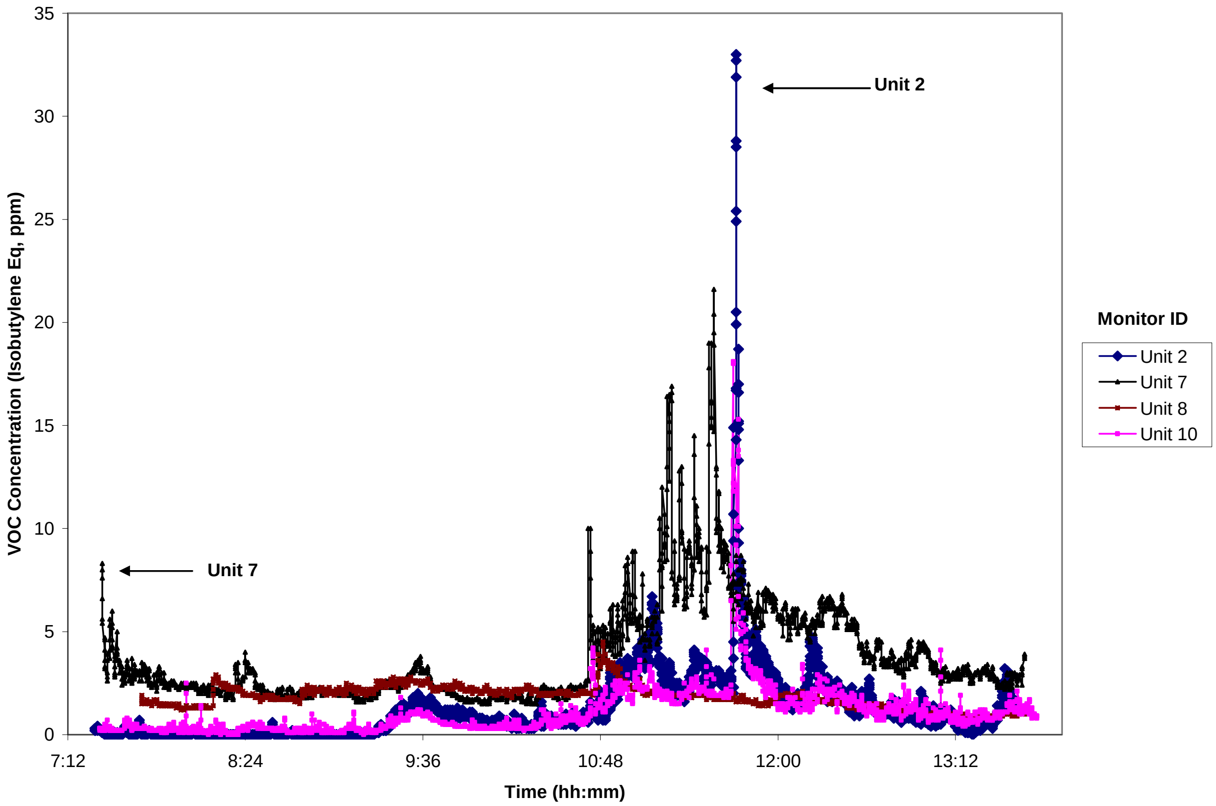
Note: Monitor locations are shown on Figure 7

Figure 15. Large Mixing Room Area VOC Concentrations--Region II.



Note: Monitor locations are shown on Figure 7

Figure 16. Large Mixing Room Area VOC Concentrations--Region III.



Note: Monitor locations are shown on Figure 7