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This technical report is dedicated to the memory of Dr. David Fraser. Dr. Fraser was my graduate advisor and I will sorrowfully miss his guidance and suggestions.

To the members of NIEHS Health and Safety Branch;

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ABSTRACT

Thomas C. Smith, "A Performance Evaluation of NIEHS Laboratory Fume Hoods" (under the direction of Dr. Michael Flynn and Dr. John Dement)

The laboratory hoods found at the National Institute of Environmental Health Sciences were quantitatively tested and evaluated in terms of containment performance. The hoods were challenged with a tracer gas, Sulfur Hexafluoride, and peak concentrations leaking from the hood were measured in the breathing zone of a mannequin. The tests proved that laboratory hood performance is subject to baffle position, face velocity, tracer gas challenge height and bottom slot obstructions. These factors had statistically significant effects, $P < 0.0001$, on overall containment efficiency. The results helped to identify the parameters which could be manipulated by the employee, the Health and Safety Branch and facility engineers to provide optimum performance and reduction of hood leakage to below 0.1 ppm.

INTRODUCTION

Laboratory hoods are the primary means of protection for laboratory employees working with potentially hazardous materials. Their use was intended to reduce employee exposure by capturing and removing hazardous contaminants. Many design modifications have occurred since the original laboratory fume hood. However, as better techniques to measure hood performance are developed, difficulties in the design, installation, and use become more evident.

Laboratory hoods are complex in design and are subject to a wide variety of factors which affect performance. Criteria for testing "as manufactured" hood performance are well documented and advances are being made for quantitative "as used" hood performance tests (5,7,8,10,12,19,21). The importance of "as used" testing cannot be underestimated as present methods are limited to face velocity measurements and visual smoke tests which provide only a qualitative measurement of hood performance and do not measure containment efficiency (21).

Improved test procedures allow for assessment of many variables that affect hood performance and containment. Variables such as room air supply, traffic about the hood, and employee work practices have been adequately tested and reported in recent literature (3,6,9,10,16,18,20,21,23). The results of these efforts prove the benefits of an aerodynamic sill and good work practices such as reducing sash height and reduction of motion in and about the hood. However, relatively little research has been attempted to assess the effects of baffle design and slot position on laboratory hood performance.

Inappropriate baffle design and slot positioning can significantly affect the performance of a laboratory hood (11). There are no standards for baffle and slot design and varying designs exist among hood manufacturers. Some manufacturers provide adjustable baffles which allow for manipulation of the air distribution within the hood. The adjustments are made in accordance with the type of aerosol being generated. A top slot is opened for working with "lighter than air" vapors and conversely a bottom slot is opened when working with "heavier than air" vapors (2,3,11). This "heavier than air", "lighter than air" rationale, however, bears no relevance due to the effective specific gravity resulting from turbulent mixing in the hood (2,3).

Adjustable baffles can often lead to undesirable air flow patterns and potentially increased leakage from the hood. The familiar roll effect or development of a stable vortex above the sash can increase the potential for leaks from the hood (10,11). Certain baffle settings are more conducive to forming this vortex and increase the potential for leaks

(10,11).

The objective of this study was to assess the performance of typical laboratory hoods at the National Institute of Environmental Health Sciences (NIEHS). The study was to include testing of several hoods to determine their effectiveness of hazard containment at different baffle settings and under normal use conditions. The experimental parameters tested were baffle settings, face velocity, challenge position, and effect of bottom slot obstructions.

LITERATURE REVIEW

Laboratory hoods are designed to provide employee protection from exposure to a wide variety of hazardous materials. It was estimated that nearly 800,000 hoods are in operation across the nation and according to the Scientific Apparatus Makers Association (SAMA), this figure may be conservative (3,22). Laboratory hood performance is subject to a wide variety of use and external factors. A great deal of literature has been generated in attempts to provide hood specifications, develop effective testing methods, evaluate factors affecting performance and improve aerodynamic efficiency. However, further work needs to be done as improved methods of testing indicate hazard containment is often less than desirable and design features critical to overall hood performance have not yet been evaluated.

Laboratory Hood Description

The laboratory hood is defined as a ventilated, enclosed work space intended to capture, contain and exhaust fumes, vapors and particulate matter generated inside the enclosure (19). A typical laboratory hood consists of side, back and top enclosing panels, a floor or countertop and an access opening called the face. The face area is varied by a moveable sash. Contaminant removal and air flow distribution is regulated by an exhaust plenum equipped with a baffle and adjustable slot system (19). Refer to Figure 1. for a typical auxiliary air laboratory hood.

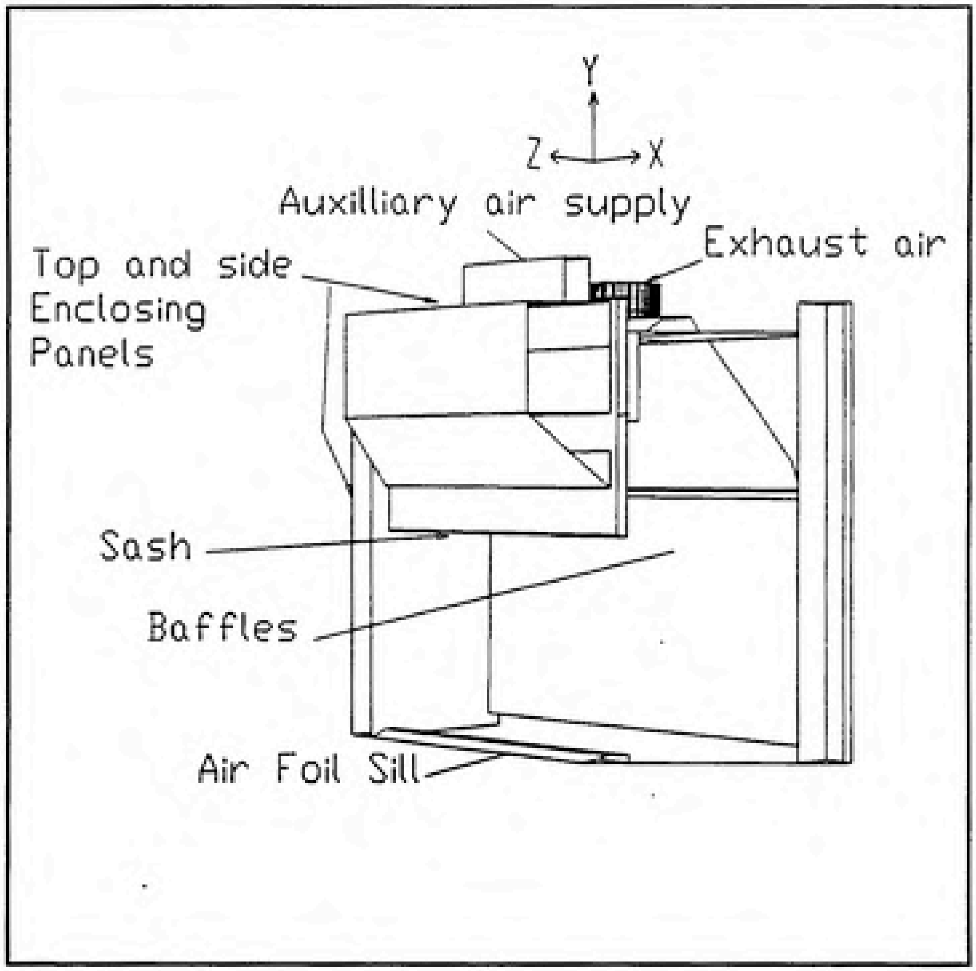


Figure 1. Three Dimensional Auxiliary Air Laboratory Hood Diagram

Laboratory hoods can be generalized into two main categories, by-pass air hoods and auxiliary air hoods.

Special hoods, such as perchloric acid hoods, radioactive hoods, and walk-in hoods, also exist. A by-pass hood is intended to exhaust room air through the face when the sash is open and through a diffusion grill when the sash is closed. The rationale for the by-pass hood was to ultimately provide user safety while enabling a somewhat constant amount of air to be exhausted. It was designed to work in conjunction with the rest of the ventilation system in order to manage the laboratories air handling needs. An auxiliary air hood is characterized by having a supply air duct in addition to an exhaust duct. The design was intended to reduce energy costs by reducing the amount of tempered air exhausted by supplying nontempered air from the outdoors. The auxiliary air enters a plenum above the hood opening and is diffused over the hood face. If designed and maintained properly, the auxiliary air hood can be safer than standard by-pass hoods as a result of the clean air purging the breathing zone of the hood user (4,8).

Standards and Performance Guidelines

In an effort to provide uniformity and reliability in laboratory hoods, standards and recommendations have been written to establish safety requirements and performance guidelines. Several organizations including the American Conference of Governmental Industrial Hygienists (ACGIH), the American Society for Heating, Refrigeration, and Air

Conditioning Engineers (ASHRAE), SAMA, and the EPA have developed standards and criteria for the construction, testing and use of laboratory hoods. All were found to contain similarities pertaining to laboratory hood design, installation and suggested work practices. A brief list of similarities consists of the following:

1. Provide uniform exhaust air distribution in the hood. There should be no more than a 10 - 25% variation in point-to-point face velocity with the sash fully open and unobstructed.
2. Use corrosion resistant materials suitable for expected work.
3. Avoid sharp corners at jambs and sill. Tapered or round inlets are desirable; an aerodynamic sill is desirable.
4. Hood should be located away from heavy traffic aisles and doorways.
5. Experimental procedures should be performed at least six inches into the hood enclosure.
6. Users should not store chemicals or apparatus in hood.
7. Users should attempt to lower hood sash as low as possible.
8. Attempts should be made to keep slots free of obstructions.

These recommendations, however, lack specific design criteria.

Hood standardization is difficult as hood performance is susceptible to ventilation system efficiency and air requirements unique to each laboratory.

Face Velocity Criteria

Safe hood operation has long been associated with the magnitude of the average face velocity. This face velocity was traditionally based on the type of material being used in the hood (19). Class A hoods were designated for high toxicity materials such as tetraethyl lead, beryllium compounds and radioactive materials. These hoods had characteristic face velocities on the order of 125 to 150 feet per minute (0.64 - 0.76 m/s). Class B hoods were designated for general use purposes and had face velocities typically 80 to 125 feet per minute (0.41 - 0.64 m/s). Class C hoods were for very low toxicity materials or nuisance dusts and odors. Face velocities ranged from 50 to 80 feet per minute (0.25 - 0.41 m/s). The designation of safe velocities differs among the standards mentioned, however, most recommend face velocities within a range of 50 - 150 feet per minute (1,2,8,19).

A great deal of controversy exists over the designation of an average face velocity as an indicator of hood safety. Development of accurate quantitative leak tests indicate that any specific face velocity would be inappropriate due to the interaction of external factors. Proper face velocities should be based on the unique conditions applying to a specific hood and not necessarily on the material in use (2,3,5,17). External factors relating to this phenomenon will be covered in detail later.

Laboratory Hood Performance Tests

Laboratory hood tests to determine safe operating conditions and containment efficiency have undergone a great deal of research and accurate testing methods are continuously being developed. Traditional tests involve the measurement of face velocities and observation of smoke patterns within the hood. These tests, being based on face velocity guidelines found in the standards, have provided only qualitative measurements of hood efficiency (21). The development of technology to detect and accurately measure contaminant concentrations have led to more quantitative hood tests. Quantitative tests however, are fairly complicated and require extensive calibration and setup (21). The need to establish safe operating environments have dictated the development of hood testing methods that can be quantitative yet simple enough to apply in a routine hood monitoring program.

At present, essentially three standard quantitative hood tests exist (21). These include the ASHRAE tracer gas test, an EPA Sulfur Hexafluoride (SF_6) test, and a modified version of the EPA SF_6 test method (21). The ASHRAE test, Standard

110P "Method of Testing Performance of Laboratory Fume Hoods", developed by Caplan and Knutson utilizes freon, R-12, or Sulfur Hexafluoride tracer gas and infrared spectrometry for detection. The gas was diffused into the hood through a specially designed ejector. The release rate can be controlled and concentrations of tracer gas are measured escaping from the hood face with a Miran 1A Infrared Gas Analyzer. The EPA SF_6 method developed by Chamberlin and Leahy was adopted as "Laboratory Fume Hood Specifications and Alternate Performance Testing Requirements for Pre-Purchase Testing". This method involves challenging the hood with the SF_6 tracer gas through a twelve-point discharge manifold. Measurements are taken in the exhaust duct and along the face with an, ITI Leakmeter II Model 61, electron capture detector. The modified version of the EPA test, developed by Hampl, utilizes an electron capture gas chromatograph for detection with a modification of the tracer gas ejector (21). The modified ejector uses a tubing jet with discharge holes that can be expanded to create a multiple point discharge source. Due to the complexity of the experimental apparatus, the standard quantitative test methods are difficult to apply in field testing (21). As a result they have been applied mainly as pre-purchase tests performed by laboratory hood manufacturers (4,8,21).

Compliance of "as manufactured" hoods does not necessarily indicate a hood will perform safely after installation (4,8). Thus, methods which are relatively unobtrusive and can simulate actual use conditions are being developed to test "in-use" hoods. These test methods provide a means to assess employee exposure resulting from various activities such as pipetting or centrifugation (10). The results obtained have also enabled the determination of external factors and hood design elements affecting performance that may be unique to each hood.

Factors Affecting Hood Performance

Room air supply, traffic about the hood and work practices such as sash height, contaminant location and storage of materials in the hood are external factors demonstrated in recent literature to have a dramatic effect on laboratory hood containment and performance (6,7,10,13,18). Room air currents can significantly affect hood performance by disrupting flow in the hood. Potential to reentrain contaminants into the room air is possible if substantial air currents exist near the hood face. Caplan and Knutson recommend laboratory air replacement systems have supply velocities of no more than one half to two thirds the face velocity of the hood (6). Further recommendations include use of perforated ceiling panels and careful location of hoods with respect to this supply (6). The location of the hood in the laboratory has been shown to be of importance as well. Cross drafts developed by opening and closing doors and to flow toward the top slot (11). The upward movement of air combined with the horizontal flow of air through the face produces the rolling effect or vortex. Air and thus, contaminants are forced into this vortex (18).

The rationale for adjustable slots was to provide uniform air distribution within the hood corresponding to a variety of use conditions. Adjustments to the slots are made in accordance with the type of materials or processes in the hood (11). The top slot is to be opened when using "lighter than air" gases and the bottom slot is to be opened when using "heavier than air" gases. The amount of turbulence within the hood, however, results in a relatively uniform concentration of air and contaminant (10,13). Even with vapors that have densities much different than air, resulting changes in effective specific gravity are found to be negligible (2,11).

Adjustable slots may be important, however, in the case of unusual processes or extraordinary conditions. Processes involving extreme thermal effects or lead to a significant alteration of the local densities may require slot adjustments. The laboratory hood, however, may not be the proper control device for these types of activities (11).

Based on the literature reviewed, laboratory hoods are subject to a wide variety of use and external factors which affect performance. Development of quantitative hood tests have indicated hood efficiency is often less than desirable. Testing has shown the effect of laboratory conditions, design modifications and the need for good work practices. Further work is required, however, to develop nonintrusive quantitative test methods and evaluate and modify hood design elements, such as baffle design and slot configuration, that are critical to aerodynamic performance and containment efficiency.

METHODOLOGY

The objective of this study was to test the performance of typical laboratory hoods found at the National Institute of Environmental Health Sciences. The following factors were evaluated for possible effects on hood performance:

1.) Baffle Settings;

2.) Contaminant Challenge Position;

3.) Exhaust Flow, Face Velocity;

4.) Bottom Slot Obstructions.

The project was designed to provide a method for reducing possible exposure by evaluating the elements affecting performance that are within the control of the worker, Health and Safety Branch and facility engineers. The project consisted of a survey of hood users, development of a system that could be used as part of a routine hood monitoring program, and evaluation of the factors of hood design and typical use conditions which influence hood performance.

Hood Use Questionnaire

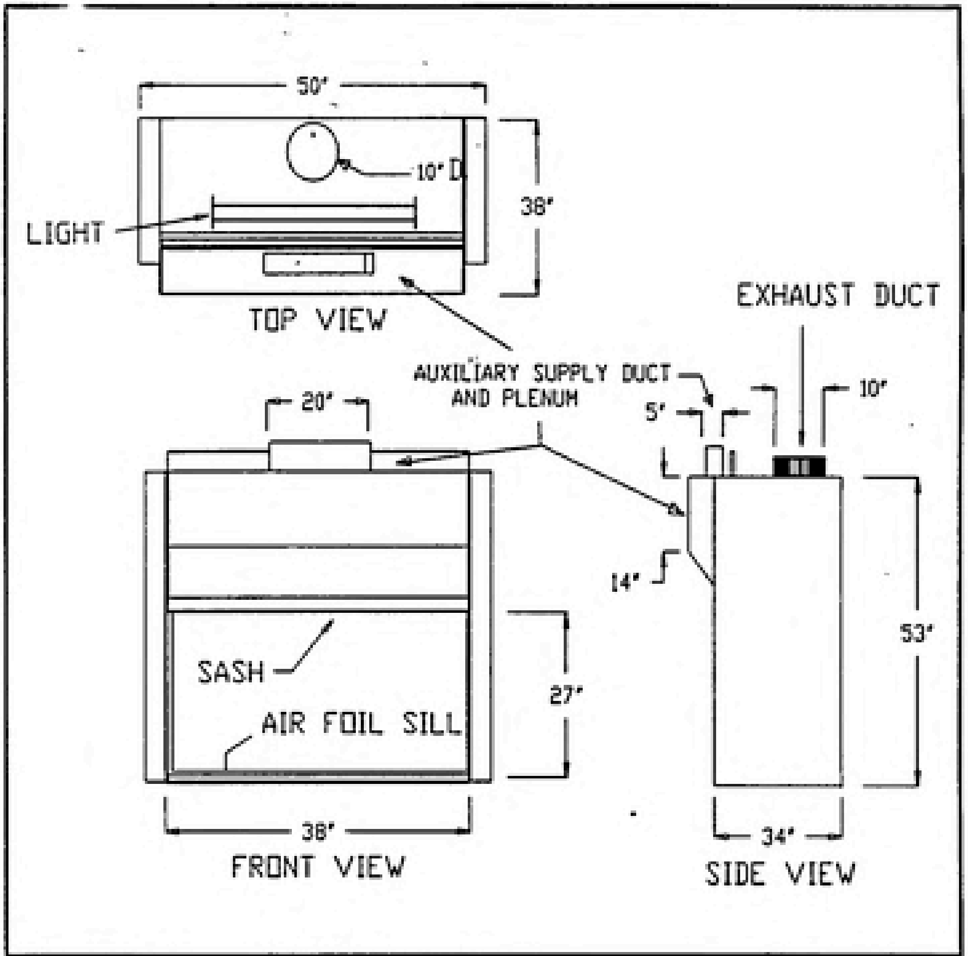
A survey was performed to assess employee work practices and general knowledge of hood functions. The survey was administered to 50 laboratory hood users selected at random throughout NIEHS. Results were obtained through personal interviews. All employees were asked the same questions regarding the length of time spent using the hood, type of materials and processes used in the hood, knowledge of hood accessories and functions, and complaints. Refer to Appendix I. for a copy of the questionnaire.

Laboratory Hood Description

Three Hamilton Industries Auxiliary Supply, Vectaire Fume Hoods were tested. All three hoods were 4 ft. in width and had the dimensions shown in Figure 2. The Vectaire hood includes a three way adjustable baffle (Figure 3.), vertical sash, air foil sill and is equipped with a flow monitoring alarm system.

The hoods were located in three separate rooms of similar size and layout. The hoods were well positioned in the rooms with respect to walls, doors, and replacement air supply (Figure 4.). The hoods in rooms C158 and C148 shared the same exhaust and auxiliary supply ducts, however the third room, D315, was part of separate system.

The hoods are connected to the ventilation system by 10" rectangular duct with the exhaust passing through a bag-in bag-out HEPA filtration unit. The exhaust duct contains no less than 4 - 90 degree bends with 90 degree branch entries to the main. The flows are controlled and regulated by pneumatically operated dampers. The control system attempts to regulate auxiliary supply and exhaust volumes through total and static pressure differentials.



All Units = inches

Figure 2. Laboratory hood dimensions

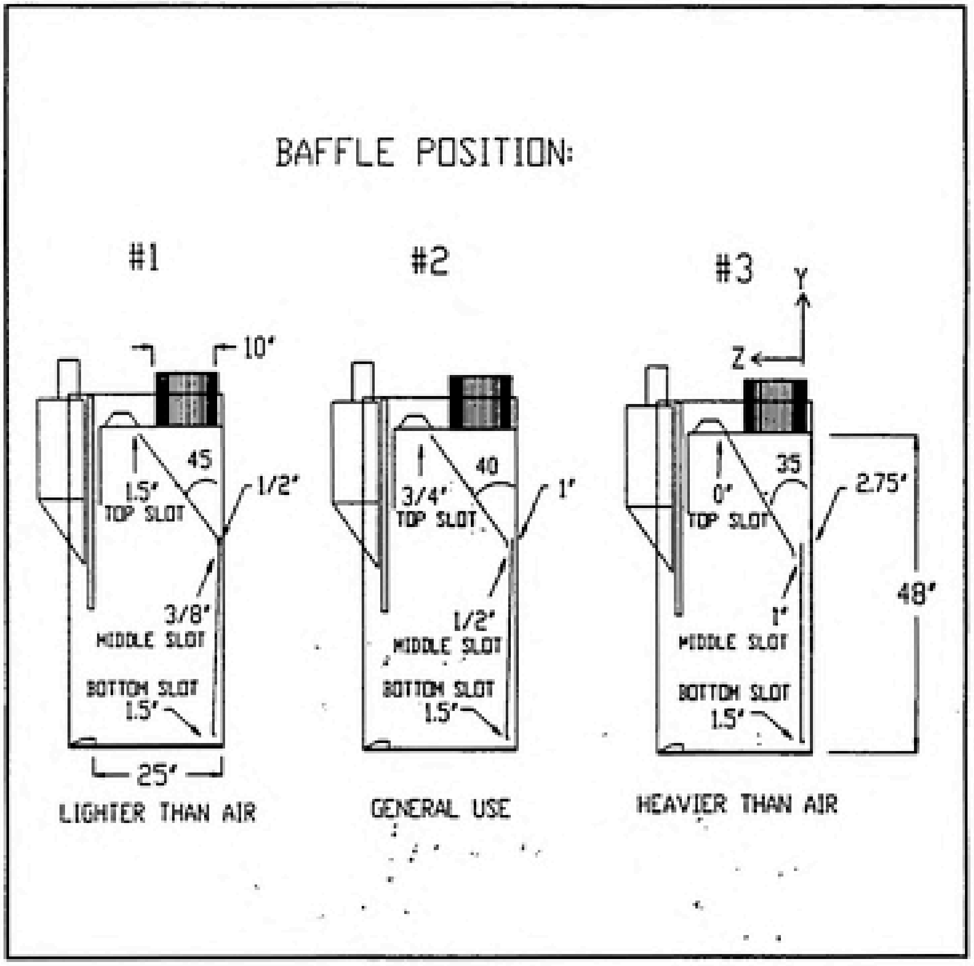


Figure 3. Baffle and slot configuration.

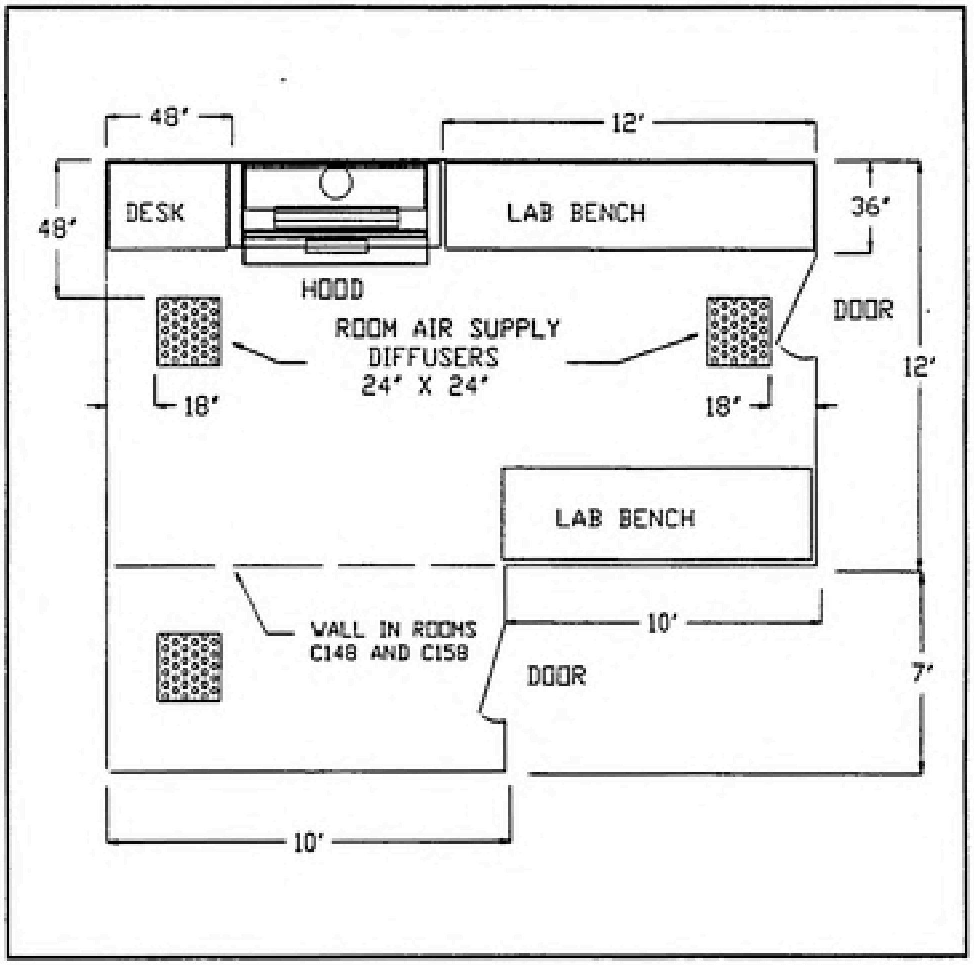


Figure 4. Location of laboratory hood in room D315

Experimental Apparatus

The test method was designed to provide a quantitative measurement of hood performance yet be flexible, mobile, easy to setup and use. The system was capable of providing reasonable simulation of actual use conditions. To some extent, the method was developed by adaptation and synthesis of the methods currently available and outlined in the literature review (1,10,21). See Figure 5. for a diagram of the experimental apparatus.

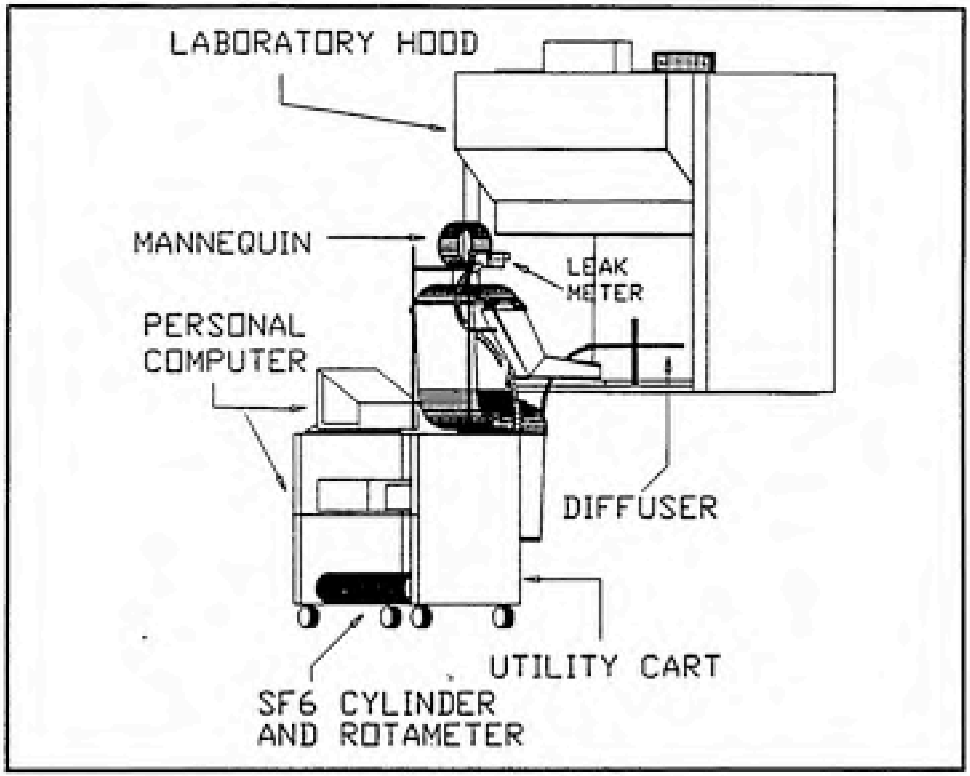


Figure 5. The Mobile, Quantitative Hood Testing System

The hood was challenged with a tracer gas, Sulfur Hexafluoride (SF_6), discharged through a rectangular diffusing manifold. The manifold was constructed of 1/2 inch I.D. copper tubing bent to form a rectangle 6" x 1'-6" with diffusion holes of 0.025" diameter spaced 1" apart around the perimeter (Figure 6.).

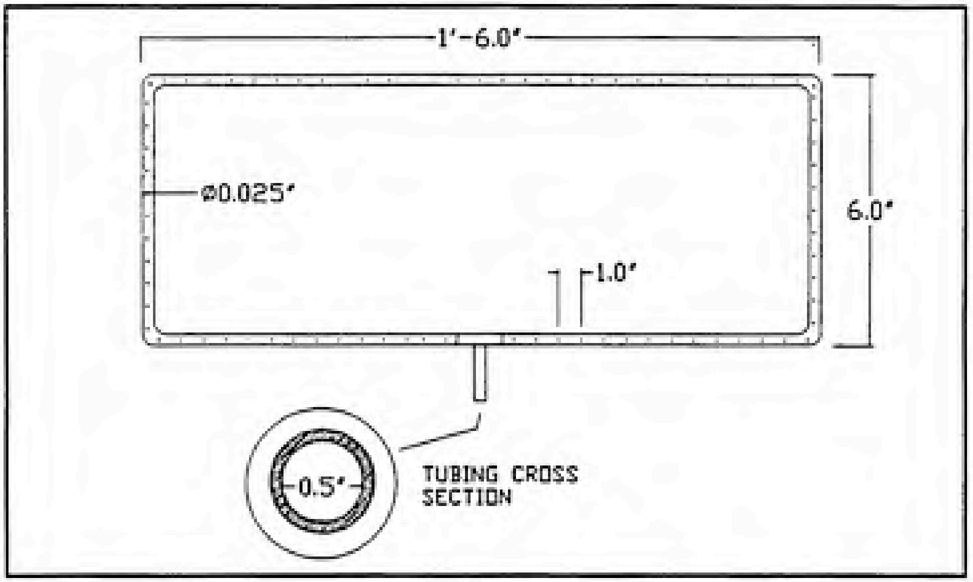


Figure 6. Sulfur Hexafluoride Diffusion Manifold

The diffuser is attached to a ring stand which allows variable height, positioning, and virtually any orientation for dispersal. A discharge flow of SF_6 was maintained at 4 liters/min as measured by a calibrated Air Products Rotameter, however, this flow could be changed depending on the need to simulate other contaminant generation rates. A flow of 1 liter/min simulates normal evaporation while 8 liter/min would be a generation rate due to rapid boiling (5,10,19). The tracer gas was dispersed at heights of two and eight inches from the bottom of the inside surface of the hood. The adjustable height diffuser was positioned eight inches from the hood face and ten inches from the side walls.

The rotameter, E29-R-150 MM4, regulating tracer gas flow was calibrated against a 133.2 cc/mm Warren E. Collins Chain Compensated Gasometer. The rotameter was calibrated with air and corrected for the density of SF_6, assuming pressure and velocity differences were negligible. The small rotameter, #210, used to measure the leakmeter inlet flow, was calibrated with a Gilian Minibuck Calibrator. Refer to Appendix IV for rotameter calibration data.

A stationary mannequin, Resusci Anne, was used to simulate a worker at the hood face. She was positioned with her nose 1" outside the plane of the hood opening with her arms projecting into the hood. The mannequin was positioned in the middle of the hood opening with the top of her head measuring 26 inches from the bottom of the hood. The mannequin's presence at the hood face resulted in approximately 36% blockage of the hood opening.

Leakage from the hood was measured in the breathing zone of the mannequin with an ITI Leakmeter Model 120 electron capture detector. The Leakmeter was calibrated before each hood test with known concentrations of SF_6 injected into a well mixed 3.69 liter dilution flask. The leakmeter was operated with a medium sensitivity probe having a 0.1 ppm detection limit. The leakmeter provided consistent and linear response over a range of 0.1 ppm to 100 ppm. Refer to

Appendix III for calibration data and plots.

Peak Breathing zone concentrations were measured and recorded every 30 seconds for ten minutes to arrive at an average peak concentration leaking from the hood. As opposed to using a time weighted average (TWA), measurement of maximum concentrations leaking from the hood would provide the most appropriate indication of overall performance. The primary objective of the laboratory hood is to contain contaminants, therefore control of peak leakages would inevitably control time weighted exposures. Furthermore, the problems associated with trying to simulate more than the presence of the worker combined with turbulent flow in the hood, would result in a misrepresentative or conservative TWA. The breathing zone concentration data was entered into a three dimensional Lotus Spreadsheet for data analysis and further analyzed statistically for variance.

Measurement of Exhaust Flow

Hood flow was determined by two methods. The first was determination of flow in the duct of the hood by an Air Monitor Corporation Volumetric Air Flow Control System. The system utilizes an array of Pitot tubes to measure air flow and has a constant volume regulator which actuates damper controls in the duct. The regulators are set for a specific air flow and pressure drop. The determined flow was then compared with values of flow computed from the average face velocity multiplied by the area of the hood opening.

Face Velocity Measurement

Values of hood face velocity were obtained by taking the average of a nine point traverse across the hood face with an Alnor Thermoanemometer Model 8500D-II. The Alnor Thermoanemometer was calibrated in a Kurz Instruments Model 400 Air Velocity Calibration System. Calibration data was obtained by measuring velocities in the wind tunnel downstream of a critical orifice over a range of pressure drops. Refer to Appendix II for results of anemometer calibrations.

The nine point face velocity traverse was performed by dividing the plane of the hood opening into nine equal area grids and measuring the velocity at a point located at the center of each grid. Refer to Figure 7. for a diagram of the face velocity traverse grid overlaid on the hood opening. The traverse was performed three times for each baffle position (Figure 3.) with the hood unobstructed and once again with the mannequin present. The face velocity traverse enabled the determination of air flow distribution across the hood opening.

Determination of Air Flow Patterns

Air flow patterns and hood containment were determined from observation of smoke patterns produced with MSA smoke tubes and 60 second smoke bombs. The observed patterns were compared with patterns suggested by the manufacturer in the hood installment and suggested practices literature. Photos

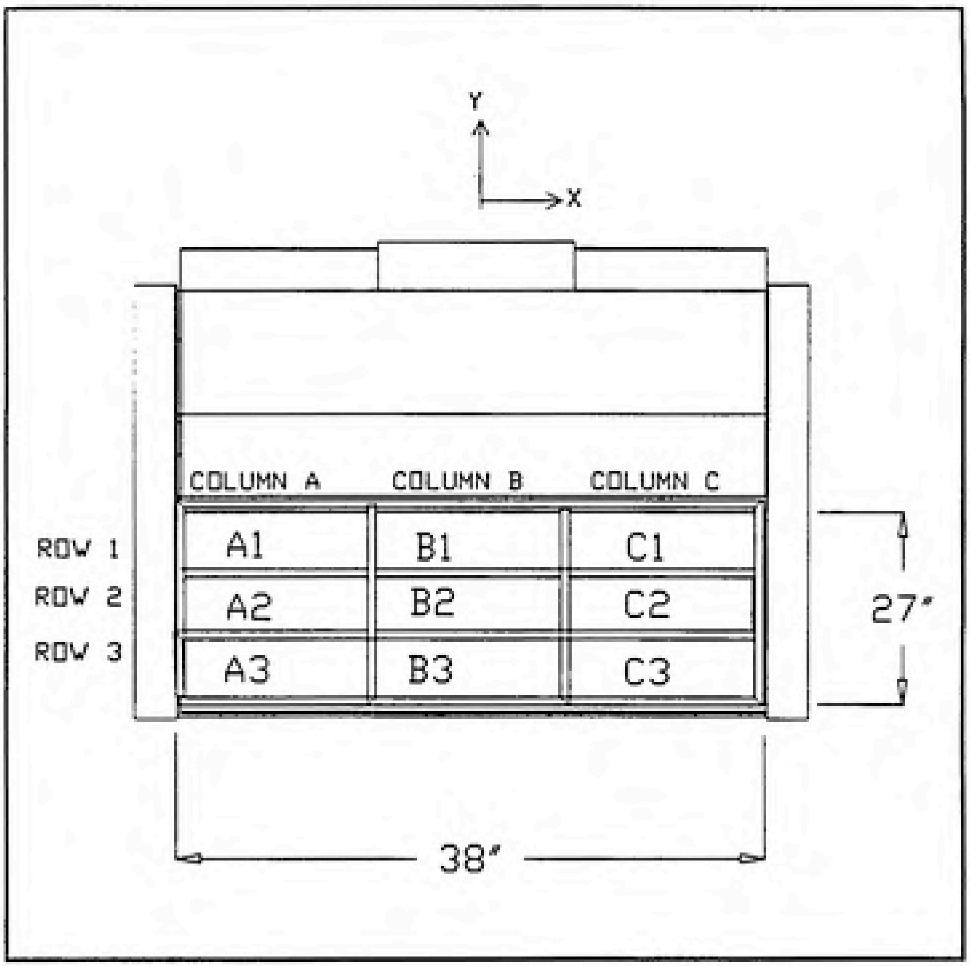


Figure 7. Nine Point Velocity Traverse Grid

were taken at each baffle setting and at different smoke generation locations. Successive photos were taken during the time of smoke generation to enable determination of pattern development. The photos were taken from various angles with and without the obstruction of the mannequin.

Measurement of Hood Performance

Each hood test consisted of collecting data corresponding to the fields on the sampling strategy form in Appendix VIII. The tests were performed at a fixed sash height of 27 inches and activity in the room was kept to a minimum during testing. The test procedures were as follows;

1.) Determine exhaust and auxiliary supply volumes,
2.) Adjust baffle for one of the three baffle positions,
3.) Perform face velocity traverse, unobstructed and with the mannequin present,
4.) Position diffuser in the hood at either the low or high generation heights, 2 inches and 8 inches respectively,
5.) Begin Discharge of SF_6,
6.) Wait for 1 minute and begin collecting the peak breathing zone concentration every 30 seconds for ten minutes,
7.) Change baffle position, allow 1 - 3 minutes for equilibrium and repeat data acquisition.

The procedure was continued until three separate trials had been performed at each baffle position and tracer gas release height. The process was then performed at two more hoods with different exhaust volumes.

Test of Slot Blockage

To evaluate the effects of storing materials within the hood, a hood was tested at 50% and 100% blockage of the bottom slot. The test conditions thought to be most and least influenced by bottom slot obstructions, baffle position #1 and baffle position #3, were tested at the 2 inch generation height. Blockage of the bottom slot was accomplished with 4000 ml. beakers, 9.5 inches tall and 7 inches in diameter, arranged side by side along the baffle. The 50% blockage test had the ends of the slot blocked with the middle 50% of the slot unblocked. The results were compared with tests repeated using a 36 inch wide by 8 inch deep by 2 inch high shelf positioned in front of the bottom slot. The beakers were stored on top of the shelf during shelf tests.

RESULTS

Three auxiliary supply hoods of the same type and dimensions were tested at different locations within NIEHS. The experimental results indicate the factors of baffle position, contaminant challenge height and flow have significant effects, $P < 0.0001$, on overall laboratory hood performance. These factors can be manipulated and combined with good laboratory hood work practices to arrive at optimum hood performance and reduced potential for employee exposures.

Hood Use Questionnaire

The survey results indicate that hood use and hood design are somewhat incompatible. The majority of the 50 hood users surveyed were either unaware, unwilling or simply unable to follow the guidelines for use provided by the hood manufacturer. Work practices, such as storage of materials within the hood and working with the sash fully open, are commonplace and necessary under many circumstances. Approximately 95% of the hood users questioned, stored materials in the hood for a variety of reasons, including containment of spills, control of fugitive emissions and to a small degree, lack of other space. Roughly 35% of hood users work with the sash fully open while the other 65% work with the sash half open or at varied height depending on the work being performed. As far as knowledge of hood functions were concerned, greater than 60% of the employees questioned were unaware of the function of the baffle and only 10% of these individuals had actually made any adjustments. These practices contradict the intended use for which these hoods were designed. The manufacturer suggests working with the sash half way closed at all times. The hood was also not designed to accommodate storage of materials such as equipment, chemical containers or beakers and flasks. Refer to Appendix I. for a copy of the hood survey questionnaire and response data.

Flow Measurements

Exhaust and auxiliary supply flow were obtained from the continuous flow monitors located on the interstitial floor above each laboratory. The flows ranged from 750 cfm to 1100 cfm. The hood in room D315 had an exhaust of 1100 cfm. The auxiliary supply flow was measured at 630 cfm, comprising approximately 57% of the exhausted air flow. The air flows through this hood fluctuated approximately +/- 20 cfm. Calculation of the average face velocity from the relationship of flow equaling velocity times hood face area, 7.125 ft^2, resulted in a predicted velocity of 152 fpm. The hood in room C158 had an exhaust flow of 850 cfm with variation of plus or minus 20 cfm. The auxiliary supply flow was 420 to 460 cfm, resulting in a minimum of 49% of the exhausted air flow. The predicted face velocity was 120 fpm. The hood in room C148 had the lowest flow of 750 cfm with an auxiliary supply flow of 350 cfm. The auxiliary supply was 47% of the exhausted air volume. The predicted average face velocity was 104 fpm. The exhaust flow on this hood fluctuated wildly about 750 cfm. Some mechanical difficulty with the flow measuring gauge was suspected.

Face Velocities

Adjustments to the baffle position had substantial effects on face velocities. The averages of the nine velocities of the traverse grid were found to be similar for each baffle position. However, the distribution and relative magnitudes of the velocities were substantially different from point to point on the grid. This data is summarized in Table I, where the average velocity was calculated from the mean of the velocities measured at each grid point and the maximum and minimum velocities were used to calculate the percent difference in point to point velocity values. For actual data corresponding to the locations and variance of the individual velocity measurements, refer to Appendix V - VII, containing velocity data for each hood test.

It is clear from the values calculated for percent difference, located in Table I., that velocity distributions were influenced by baffle positioning. The decrease in

Table I. Results of Face Velocity Traverse

Hood – Room D315
Flow – 1100 cfm

Predicted Average Velocity – fpm = 154

	Baffle Position #1	#2	#3
Average Velocity – fpm	150	146	151
Maximum Velocity – fpm	235	210	166
Minimum Velocity – fpm	131	124	142
Percent Difference – %	57	51	15

Hood – Room C158
Flow – 850 cfm

Predicted Average Velocity – fpm = 119

	Baffle Position #1	#2	#3
Average Velocity – fpm	111	109	104
Maximum Velocity – fpm	178	154	120
Minimum Velocity – fpm	82	94	91
Percent Difference – %	74	48	28

Hood – Room C148
Flow – 750 cfm

Predicted Average Velocity – fpm = 105

	Baffle Position #1	#2	#3
Average Velocity – fpm	74	72	73
Maximum Velocity – fpm	118	123	123
Minimum Velocity – fpm	24	28	39
Percent Difference – %	132	126	103

Notes: Baffle Position:
#1 – "Lighter Than Air"
#2 – "General Use"
#3 – "Heavier Than Air"

percent difference of point to point velocities from baffleposition #1 to baffle position #3 resulted in a more uniform velocity profile and thus better air distribution at the face of the hood. The following three-dimensional plots, Figures 8 - 16, display the velocity profiles over the face of the hood opening corresponding to each baffle position and for each hood flow. The graphs were generated using a graphical software package called Surfer. The plots provide a visual representation of velocity contours and differences between baffle settings. The data points plotted were the mean face velocities calculated at each traverse location.

For all hood tests, the velocity distribution is similar at each baffle position. In baffle position #1, the velocities are much higher in the areas A1 - C1 at the top of the hood. There is also a peak velocity located at the middle of the hood opening, region A2 - B2. Baffle position #2 has the same general distribution as position #1, however the velocities are not as extreme. The third baffle position, in which the bottom slot is being utilized, has the most uniform distribution of velocities and in some cases, such as hood C158 operating at 850 cfm (Figure 13) , the velocities are highest in magnitude along the bottom of the hood face.

The velocity traverse was also performed with the mannequin in place. The blockage of the hood opening resulted in an increase in velocities around the mannequin of approximately 70 percent. The velocities were nearly 20 - 30 percent lower in front of the mannequin. These results are as expected but somewhat difficult to quantify as the anemometer measures velocity unidirectionally and therefore would not represent the true direction of air flow around the mannequin.

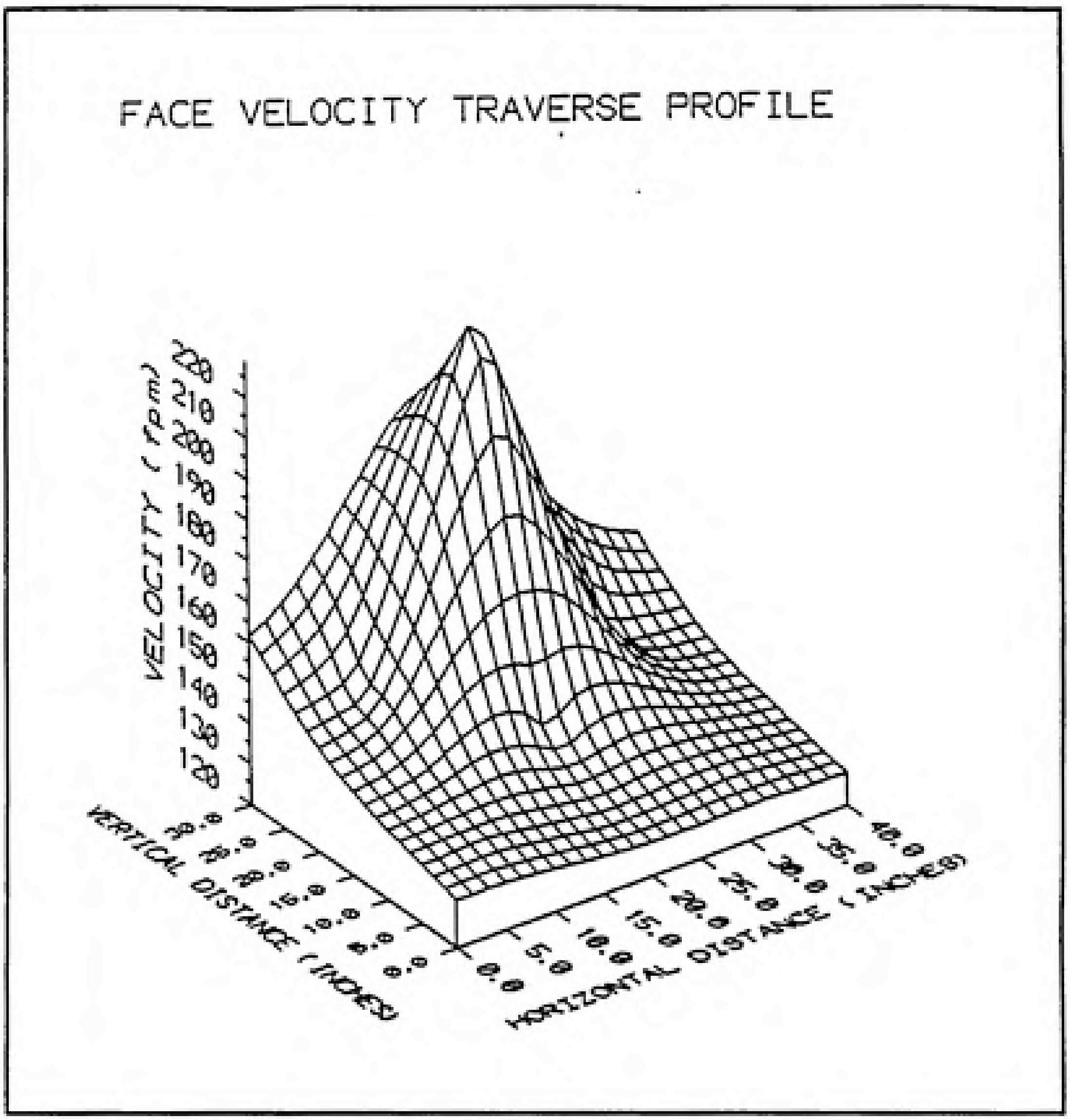


Figure 8. Face Velocity Traverse Profile for Baffle Position #1 at 1100 cfm in Room D315.

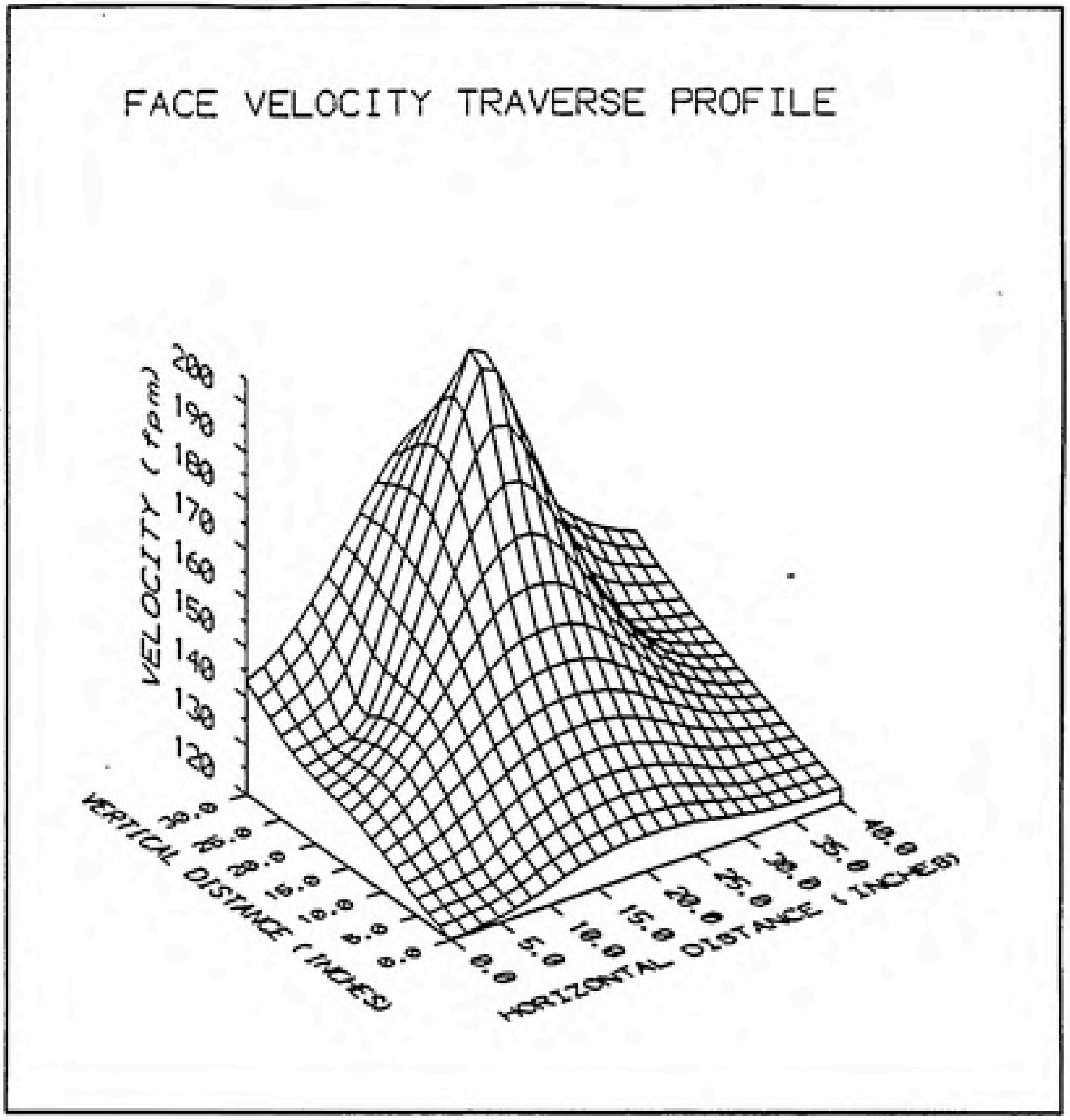


Figure 9. Face Velocity Traverse Profile for Baffle Position #2 at 1100 cfm in Room D315.

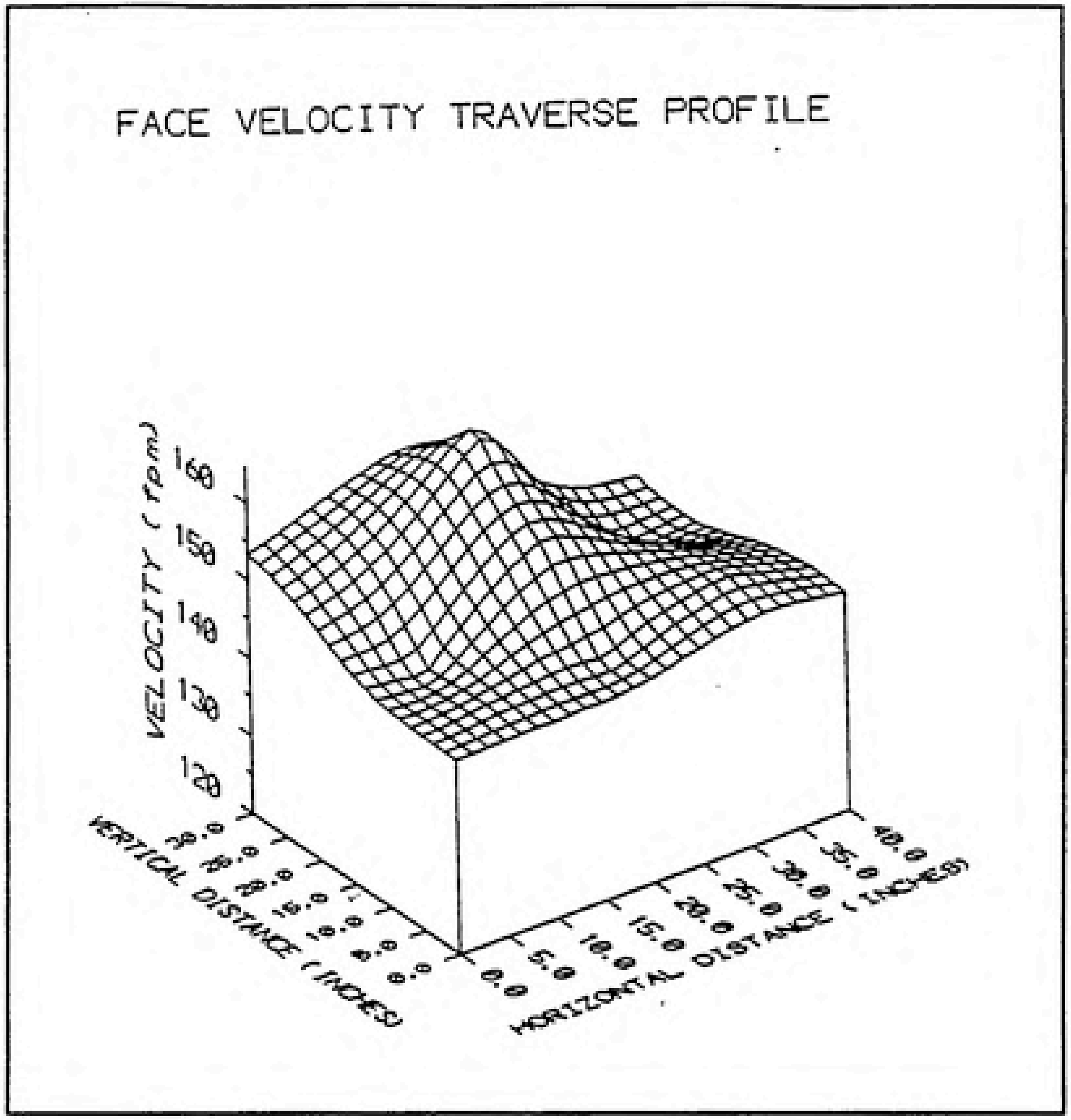


Figure 10. Face Velocity Traverse Profile for Baffle Position #3 at 1100 cfm in Room D315.

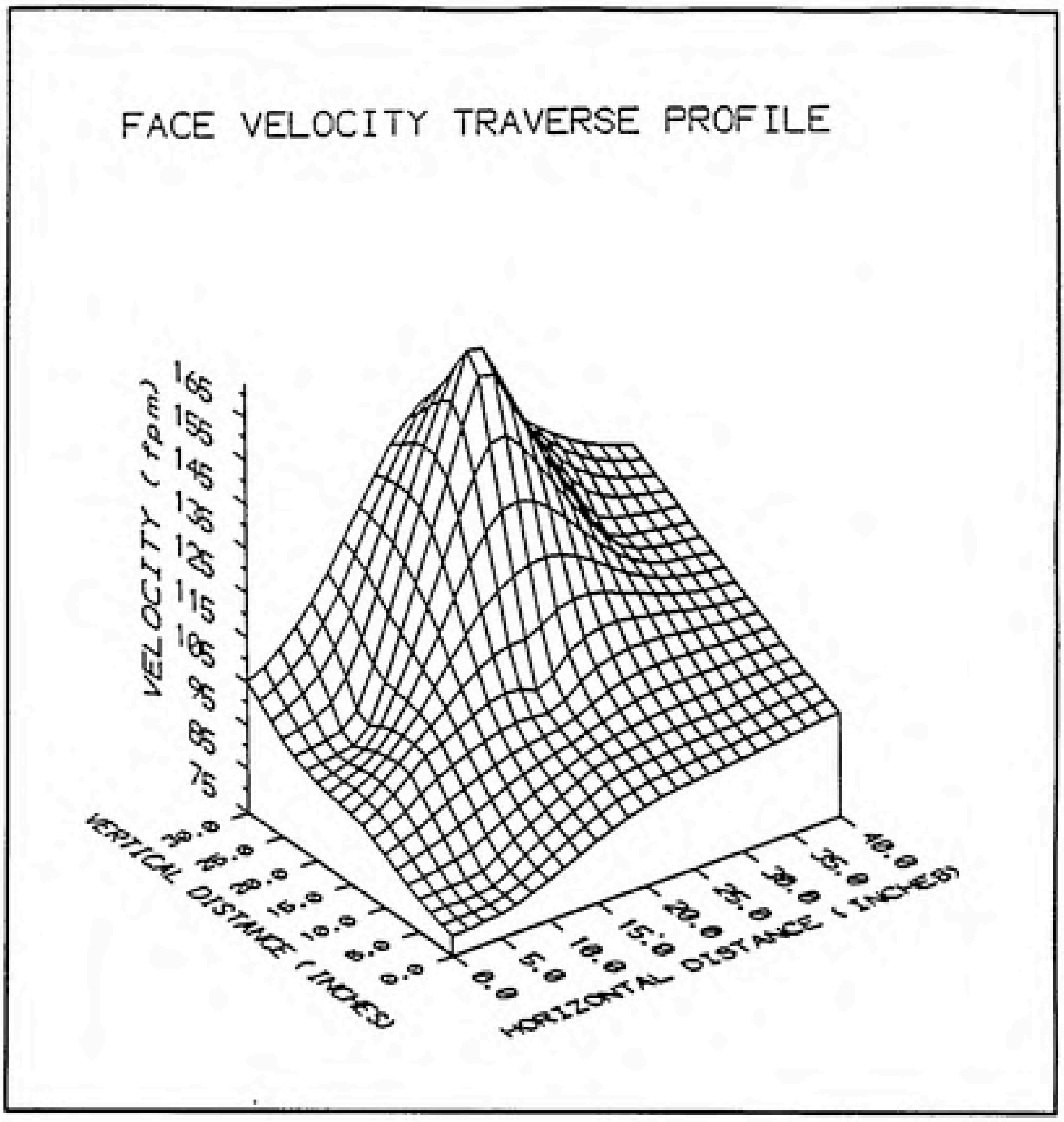


Figure 11. Face Velocity Traverse Profile for Baffle Position #1 at 850 cfm in Room C158.

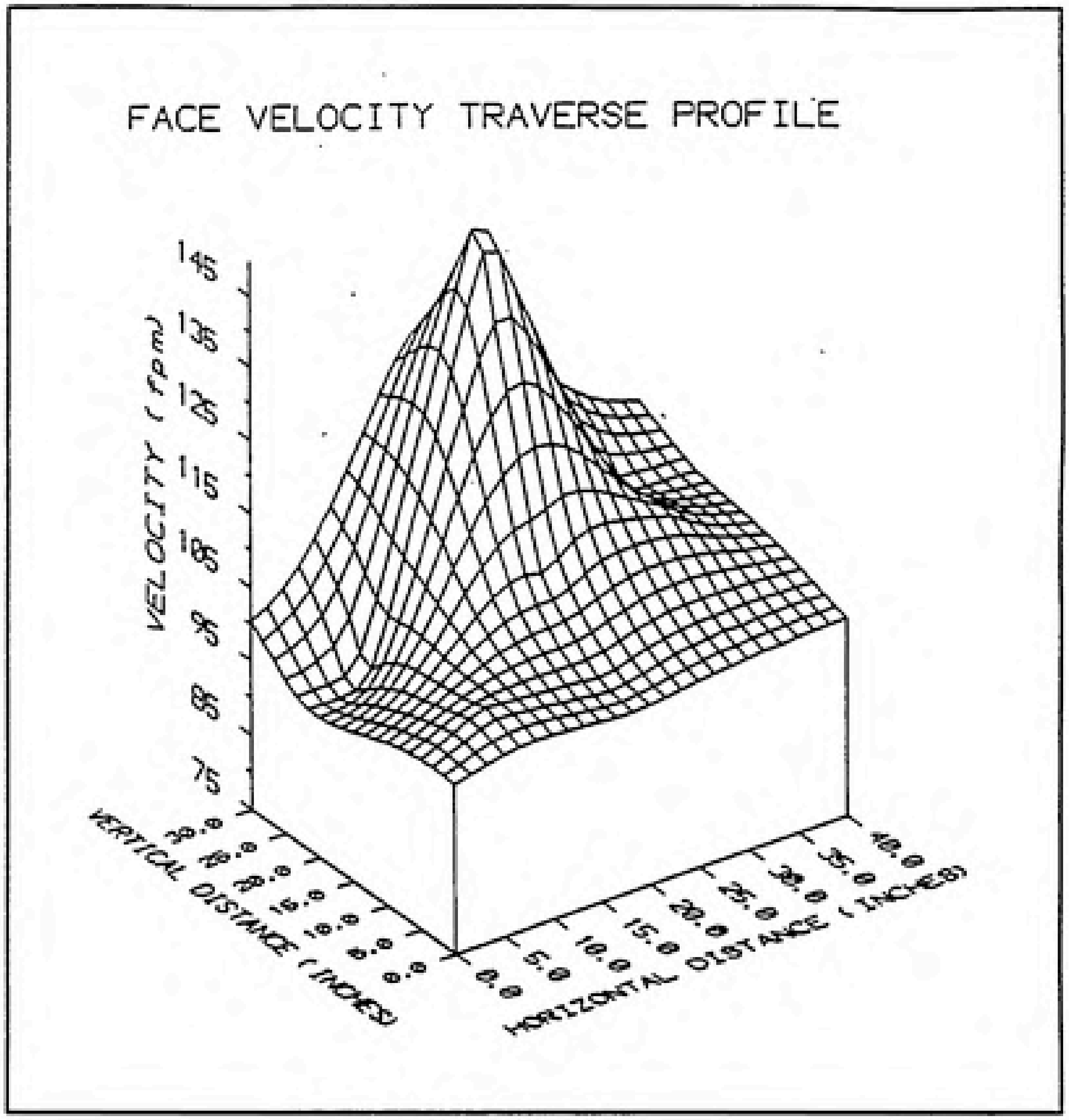


Figure 12. Face Velocity Traverse Profile for Baffle Position #2 at 850 cfm in Room C158.

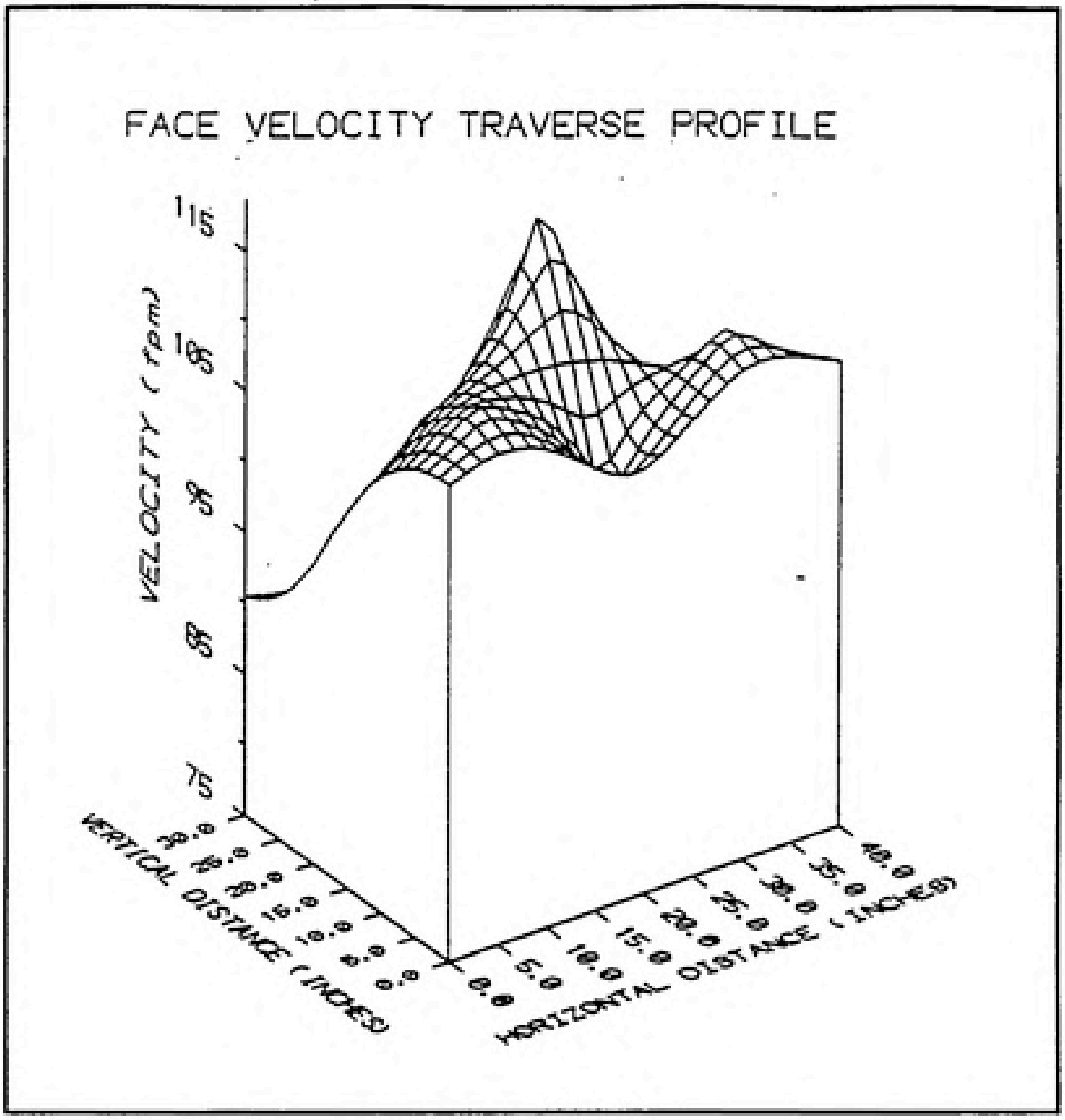


Figure 13. Face Velocity Traverse Profile for Baffle Position #3 at 850 cfm in Room C158.

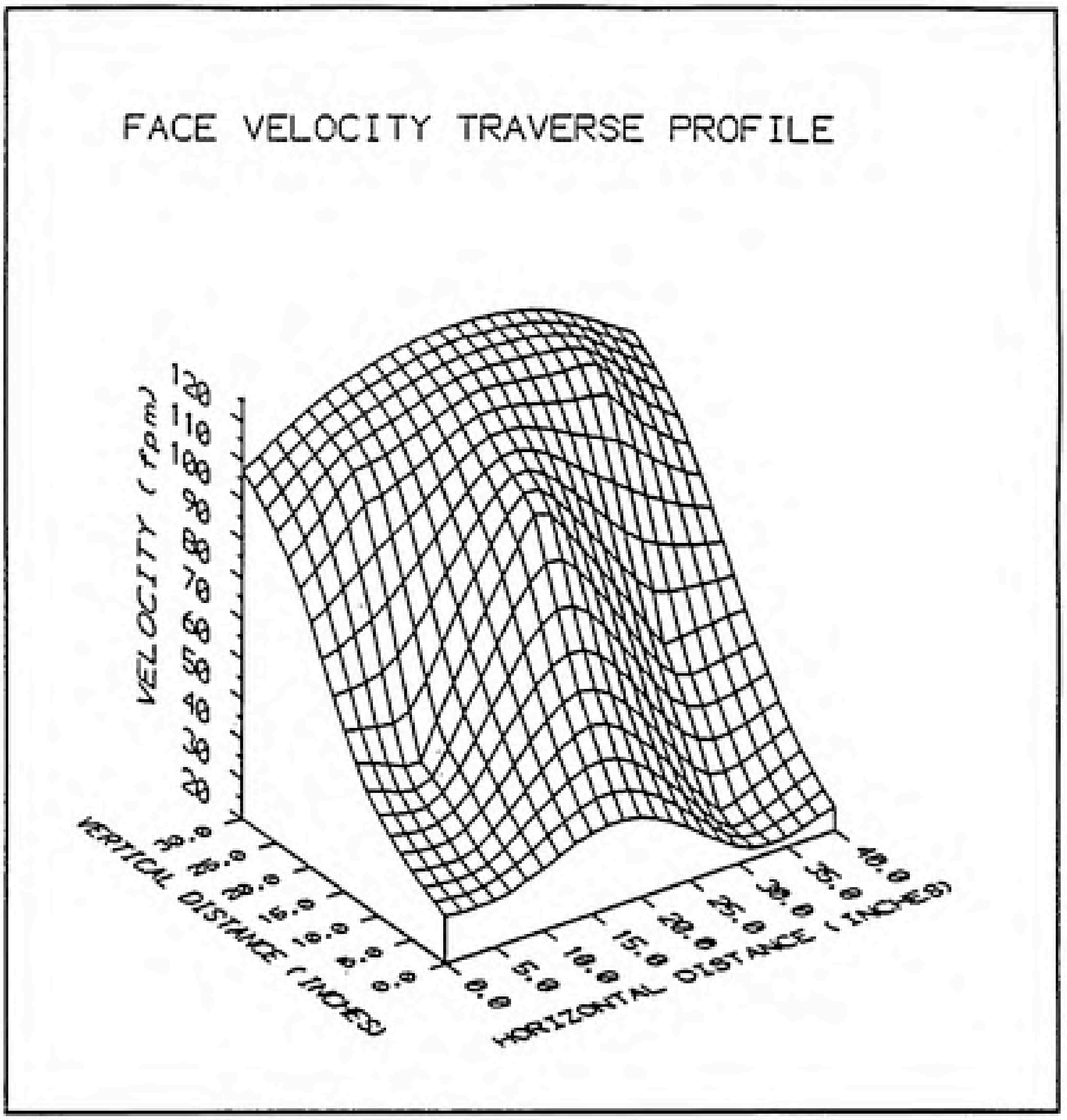


Figure 14. Face Velocity Traverse Profile for Baffle Position #1 at 750 cfm in Room C148.

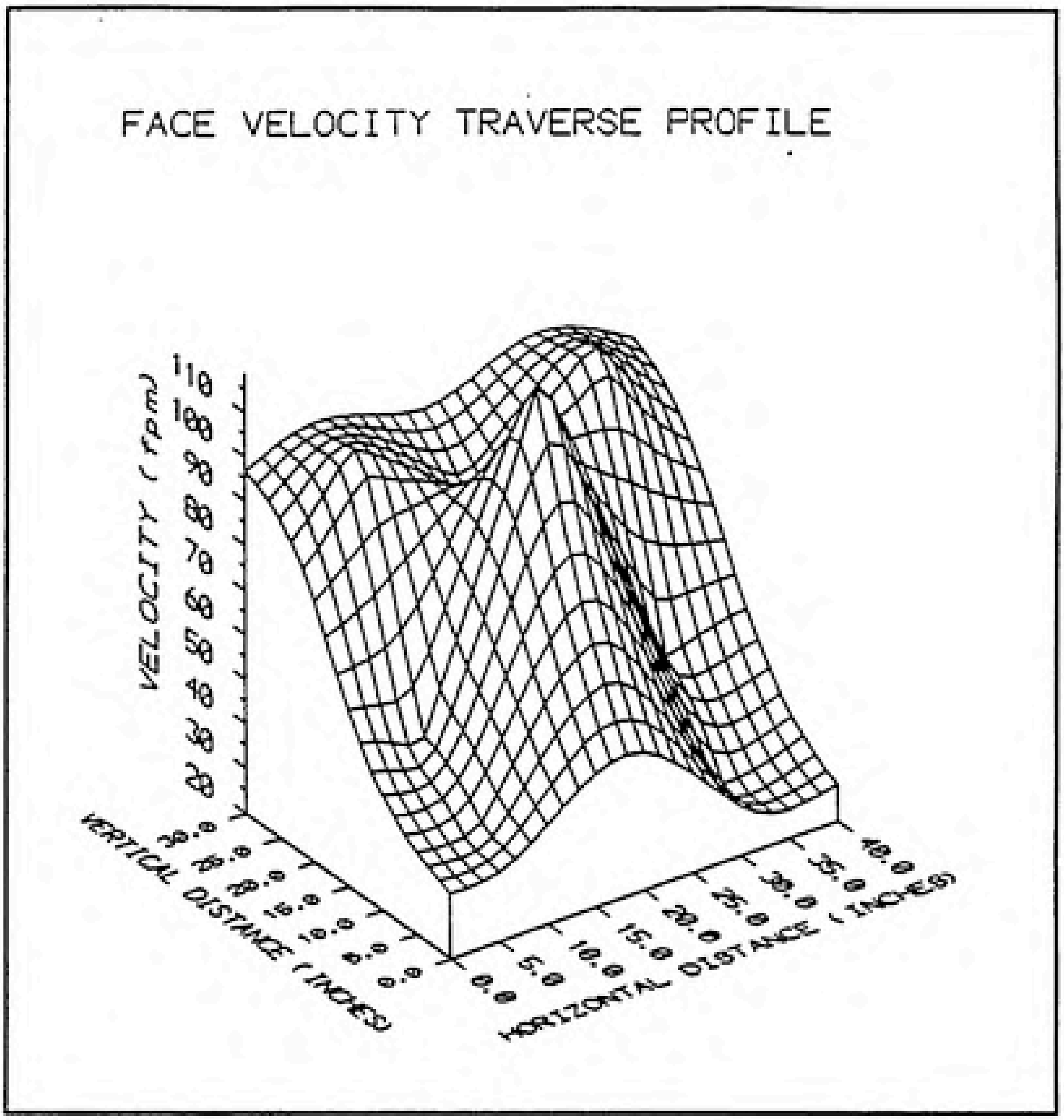


Figure 15. Face Velocity Traverse Profile for Baffle Position #2 at 750 cfm in Room C148.

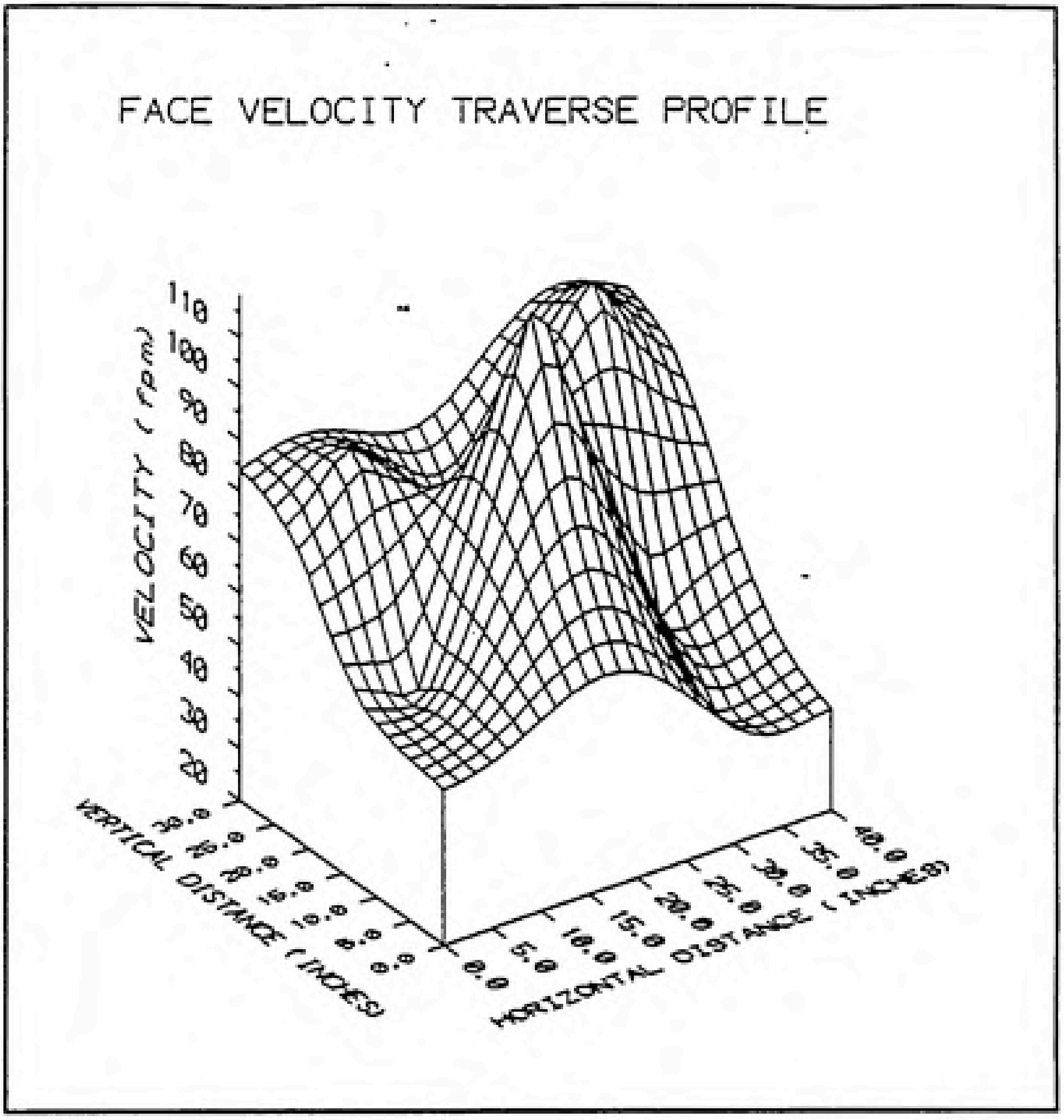


Figure 16. Face Velocity Traverse Profile for Baffle Position #3 at 750 cfm in Room C148.

Quantitative Leak Tests

Three hoods with different exhaust rates, were challenged with the SF_6 tracer gas. The average peak concentration of tracer gas escaping from the hood was measured in the breathing zone of the mannequin. The measurements were made at all three baffle settings and at two tracer gas release heights. All factors proved to have statistically significant effects on containment and hood performance.

The baffle and slot configuration were found to greatly influence the amount of leakage from the hood. Baffle position #1 had the most devastating effects on performance. This configuration with the top slot open, designed for "lighter than air" vapors, resulted in air flow distributions which provided little containment effectiveness. In all hood tests, the highest exposures were found in baffle position #1. The maximum average peak concentration was 67.5 ppm for the hood at the flow of 1100 cfm. The lowest exposures for all hood tests were found in Baffle position #3 where the average peak concentration was below the detection limit (BDL) measured in the breathing zone of the mannequin. This position utilized the bottom slot and had the top slot closed. Baffle position #2, which had all three slots partially open, resulted in leak rates which were somewhere between #1 and #2 for every hood test.

The height of tracer gas discharge also had a significant effect, P value less than 0.0001, on breathing zone exposures.

The lower height of 2 inches corresponded with the highest leakages. The release height of 8 inches was effectively controlled for all baffle positions with the exception of the hood with the highest flow. The average peak concentration still decreased, however, by 96 percent to 2.50 ppm. Hood tests at the lower flows displayed decreases in average peak concentrations of at least 50% by increasing tracer gas release height.

The effect of flow was somewhat difficult to quantify due to the influence of many variables, however the results indicate an optimum range of flow exists. The higher flow hood, 1100 cfm, had the most extreme peak leak rate of 67.5 ppm. The 850 cfm hood performed well for all hood trials with a maximum average peak leak concentration of 1.60 ppm in the worst baffle position. The lower air flow of 750 cfm had a higher leak rate than the 850 cfm hood with an average peak concentration of 3.40 ppm. Thus, the hood operating at 850 cfm exhibited the best overall performance of the flows tested.

Results of tracer gas tests are summarized in Table II. The mean peak concentration reported in the table is the mean of the three trials performed at each test condition. Figures 17. - 22. are plots of the average peak concentrations determined for each trial versus baffle position. Refer to Appendix VIII - X for actual concentration data corresponding to each test condition.

Table II. Summarized Results of Tracer Gas Tests

		Mean Peak Concentration ppm Hood Flow		
		1100 cfm	850 cfm	750 cfm
Challenge Position – low				
	#1	67.5	1.6	3.4
Baffle Position	#2	10.8	0.95	0.7
	#3	BDL	BDL	BDL
Challenge Position – high				
	#1	2.5	0.8	0.5
Baffle Position	#2	0.5	BDL	BDL
	#3	BDL	BDL	BDL

Notes: Tracer Gas Release Rate – 4.0 liters/minute

Baffle Position: #1 – "Lighter Than Air"

#2 – "General Use"

#3 – "Heavier Than Air"

BDL = Below Detection Limit – less than 0.1 ppm

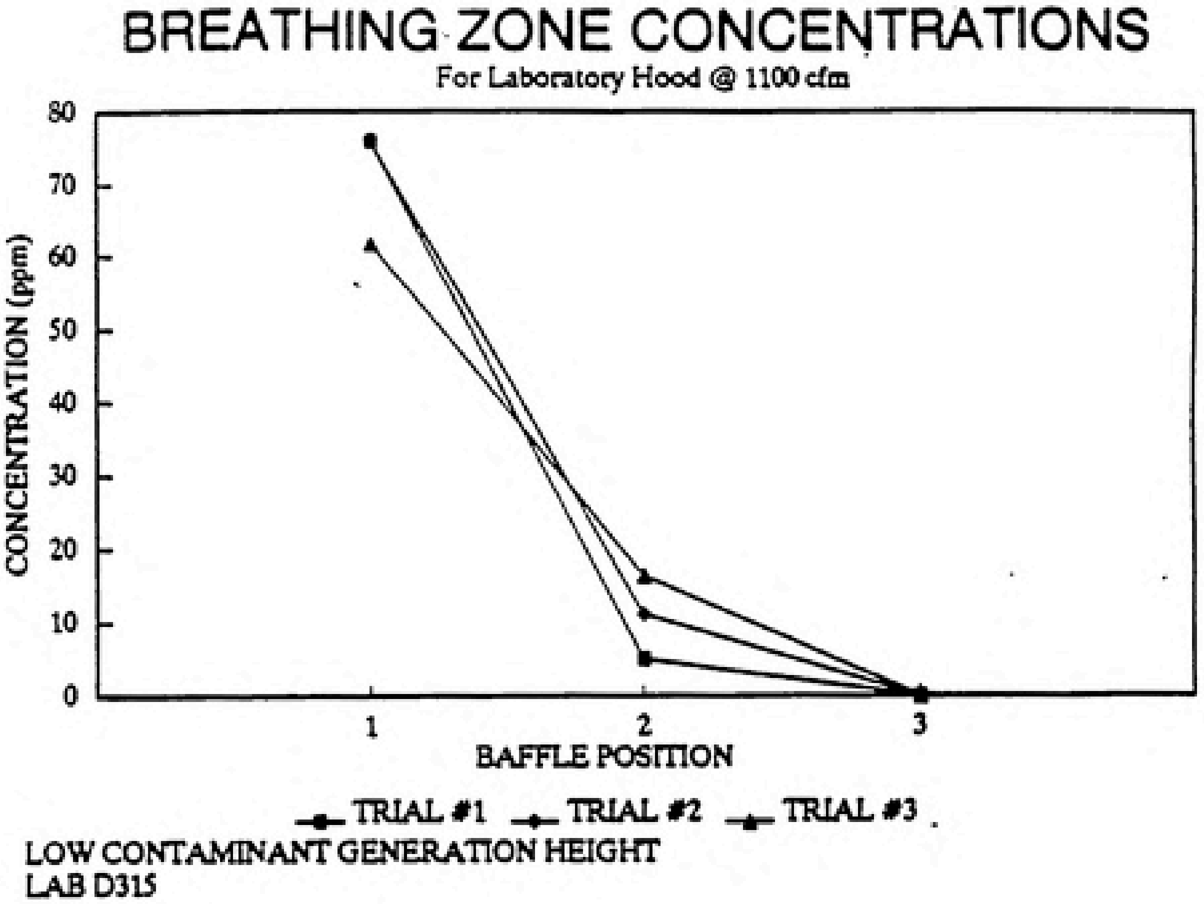


Figure 17. Average peak concentrations versus baffle position for 2" generation height and 1100 cfm.

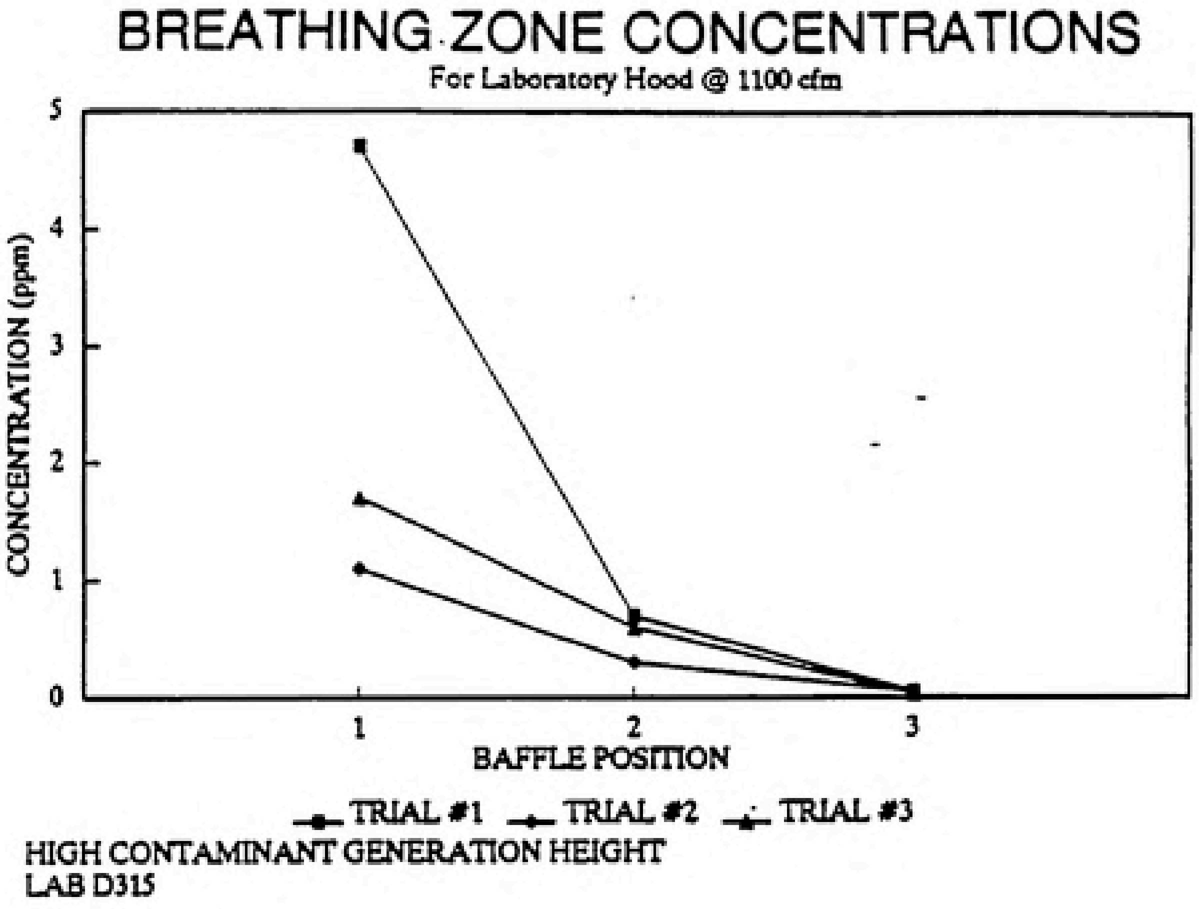


Figure 18. Average peak concentrations versus baffle position at 8" generation height and 1100 cfm.

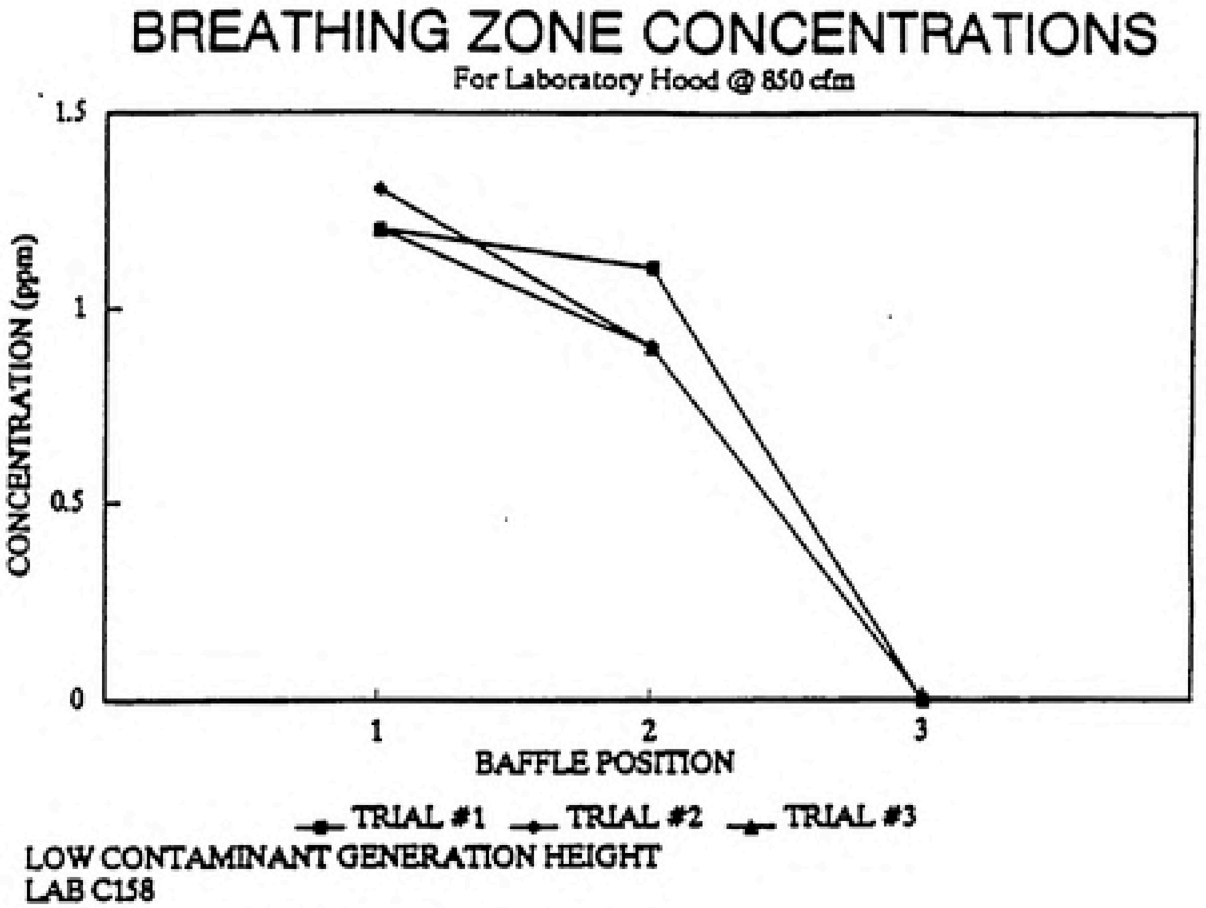


Figure 19. Average peak concentrations versus baffle position for 2" generation height and 850 cfm.

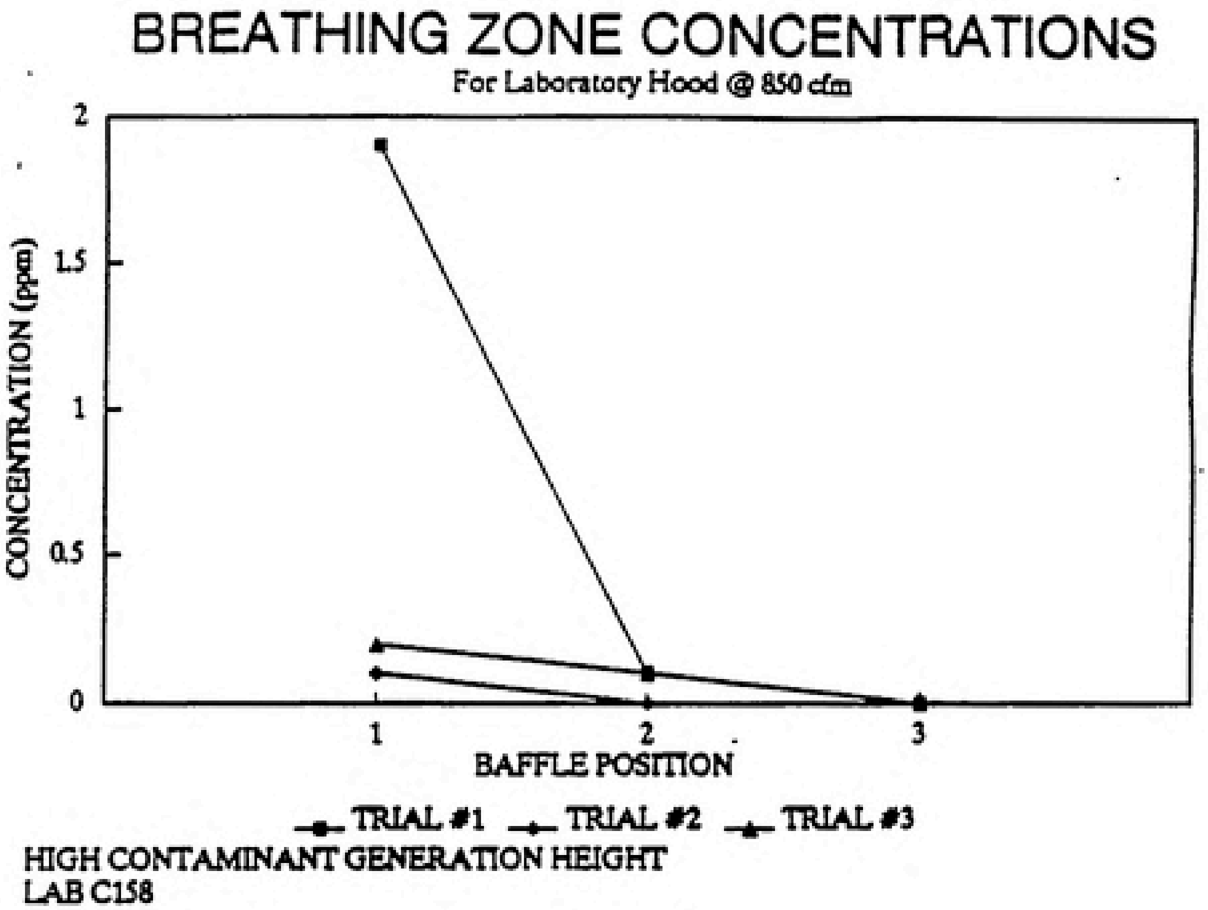


Figure 20. Average peak concentrations versus baffle position at 8" generation height and 850 cfm.

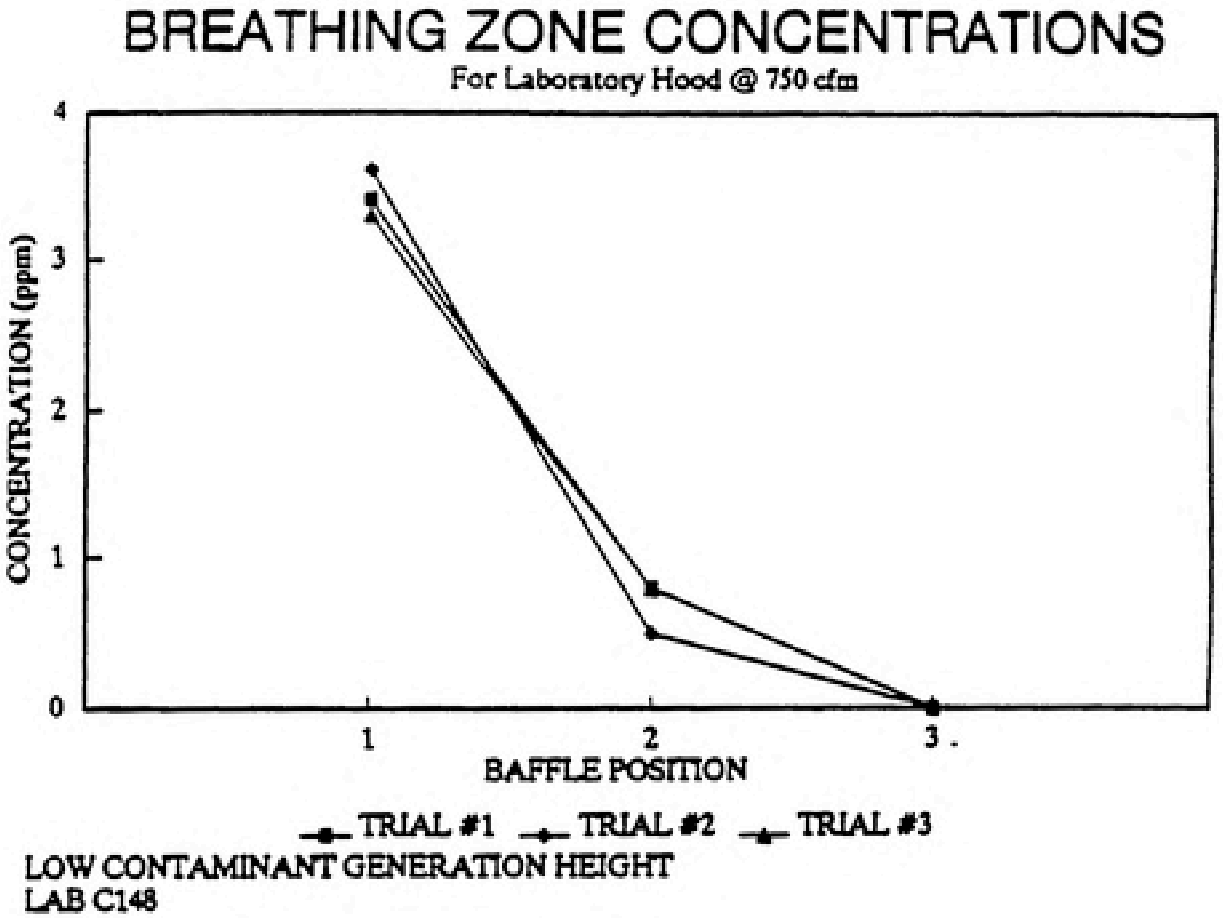


Figure 21. Average peak concentrations versus baffle position at 2" generation height and 750 cfm.

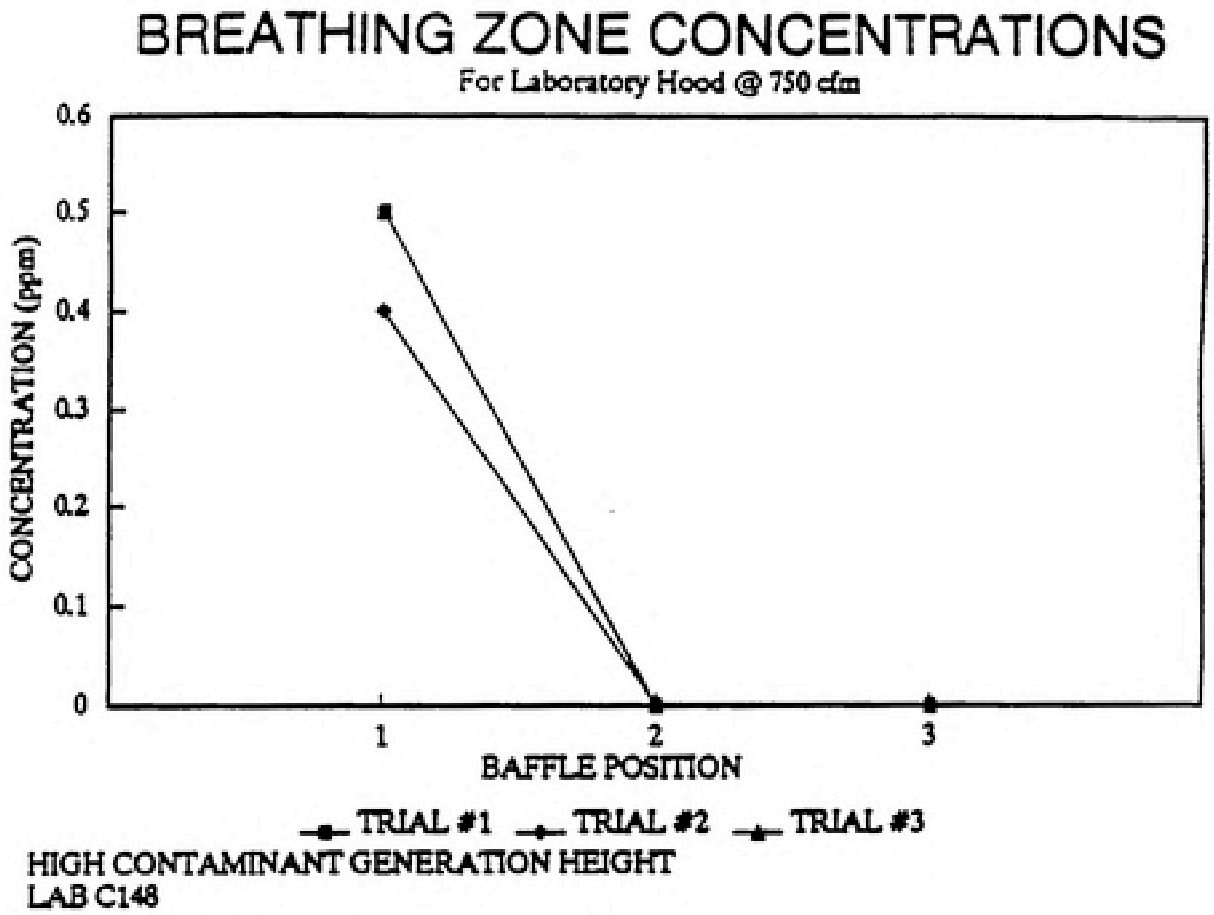


Figure 22. Average peak concentrations versus baffle position at 8" generation height and 750 cfm.

Results of Statistical Tests

A three way Analysis of Variance procedure (ANOVA), utilizing a general linear model, was applied to test the main effects of baffle position, height, and exhaust flow on breathing zone concentrations. The Three factors and their interactions were all found to be statistically significant ($P < 0.0001$). As a result of the high degree of heteroscedasticity in the concentration results, a square root transformation of the data was performed prior to the ANOVA.

Pairwise comparisons were made using the Fishers Least Significant Difference (LSD) test. This test is a multiple comparison procedure designed to control excessive error rates when doing multiple pairwise comparisons. The tests were performed at the 0.01 and 0.05 significance levels. Results are tabulated in Appendix XII.

Results of Blockage and Shelf Test

Blockage data were collected for only one hood, operating at 1100 cfm. Performance was measured in baffle position #1 and baffle position #3 with a tracer gas challenge height of 2 inches. These two positions corresponded to the best and worst cases from the above data. Face velocity and average breathing zone concentrations were measured at 0, 50%, and 100% blockage of the bottom slot. This data was then compared with results from data collected with a 36"x 8" x 2" shelf in place against the baffle.

The results indicate blockage of the bottom slot may have some influence on the laboratory hood performance, but not for expected reasons. Appendix XI contains the blockage data for average leak concentrations and velocity traverse data. In baffle position #3, where the bottom slot is most utilized, the average peak concentration was below the detection limit for all conditions accept for 100% blockage, where the value was 0.9 ppm. The face velocity data for this baffle position show a relatively consistent point to point percent difference of approximately 20% with the exception of the unblocked condition. The percent difference for this condition was 30% due to the high velocity measured at position B1 on the velocity traverse grid. In baffle position #1, where the bottom slot is utilized least, the average peak concentrations were found to increase with percent blockage of the bottom slot. The condition of 0% blockage resulted in 29 ppm leakage to 35 ppm for 50% blockage and a maximum of 61 ppm for 100% blockage. The shelf showed little or no benefits for this baffle position, as the average peak concentration measured was 59 ppm which was very similar to the 100% blockage case. Face velocity traverse data resulted in relatively the same profiles with an average percent difference of 59 percent.

DISCUSSION OF RESULTS

Hood Use Questionnaire

The results of the questionnaire indicate most hood users are unwilling or unable to use the hood as designed. The hood users explained their misuse by difficulties imposed by the poor ergonomic design. The vertical sash prevented performance of duties when the sash was at suggested operating heights. In order to maintain the six to eight inch working distance into the hood, the nose and forehead of the employee would be practically resting against the glass of the sash. Other complaints included lack of leg space beneath the hood and discomfort imposed by the flow of untempered auxiliary air.

Flow Measurements

The results gathered from the gauges of the continuous exhaust and auxiliary flow monitors provided good indication of the actual values of flow. The values of predicted velocity for the 1100 cfm and 850 cfm hoods were close to values obtained from the face velocity traverse. The predicted average velocities of 152 fpm and 120 fpm corresponded well with the average traverse velocities of 149 fpm and 109 fpm for the 1100 cfm and 850 cfm hoods respectively. The value of 750 cfm is questioned however, due to the low average face velocity of 73 fpm measured during repeated face velocity traverses. An average face velocity of 73 fpm with a 7.125 ft^2 face area would result in a flow of 520 cfm. In all three cases the measured face velocities were lower than predicted by the exhuast flow. This probably results from the influence of auxiliary air, unidirectional limitations of the anemometer, and nonuniformity and fluctuations in point to point face velocities.

Fluctuations in the supply and exhaust flows were as high as 20 - 30 cfm. These fluctuations are probably due to the turbulence in the duct. The ventilation system is rather poorly designed as branch entries of nearly 90 degrees are commonplace. The hoods also operate from a main duct line which might service multiple hoods and are therefore susceptible to system activity and operations in other hoods. System instability may also result from difficulties encountered in balancing the damper controls. System changes influence damper controls and may require time to equilibrate.

Hoods equipped with auxiliary supply are particularly susceptible to fluctuations in performance. The purpose of the auxiliary supply is to replace the amount of conditioned air being drawn from the laboratory. Consequently the supply air is drawn directly from the outdoors and undergoes little conditioning before reaching the hood face. The auxiliary air can experience a temperature gradient of a nearly 50 degrees fahrenheit. Although this gradient is not sufficient to cause serious ventilation system difficulties, it may cause turbulence in the hood due to the mixing of different temperature air streams. The untempered auxiliary air also causes worker discomfort at the hood face during seasons of extreme heat or in the cold of winter. The temperature extremes can also affect chemicals being used in the hood.

The auxiliary air flows through a rectangular duct where it enters a plenum above the hood. The plenum allows for even distribution and diffusion of air across the entire hood opening. These hoods however, do not have adequate plenum space and therefore result in an uneven air distribution. This was evident from the high velocity values consistently found in the middle of the hood opening as can be seen in nearly all the velocity profiles. The auxiliary supply has sufficient velocity upon exiting the duct to continue down the hood face in the form of a jet which can potentially cause reentrainment of contaminant into the room air. For this reason, the auxiliary flow must be monitored and controlled. For example, practice tests of hood leakage were performed prior to collecting data. The hood was operating at 1100 cfm with an auxiliary supply of 850 cfm or 77% of exhausted volume. It was noticed during the pre-test that the background concentration of SF_6 in the laboratory rose to greater than 100 ppm. The velocity of the auxiliary supply jet was sufficient to escape capture by the hood and entrain the tracer gas. The auxiliary flow was then reduced to less than 700 cfm or approximately 60% of exhausted air at which point no leakage was attributed to auxiliary flow reentrainment. In fact, the performance of the hood actually benefited from the influence of the auxiliary supply. This phenomenon will be discussed in detail later.

The effect of the auxiliary supply jet also complicated the measurement of face velocities. The method of measuring face velocities, relies on the assumption that air is flowing perpendicular to the hood face. This is not true of auxiliary air entering the hood. The trajectory of air from the auxiliary supply has a vertical component and thus is difficult to measure based on the unidirectional limitation of the hot wire anemometer.

Measurement of Velocity

The face velocity traverse data yielded surprisingly consistent results in light of the measurement difficulties. The influence of the auxiliary supply and air flow patterns resulting from baffle positioning and slot configuration had little effect on the average face velocities. The average values calculated from the traverse were consistent even at different baffle positions. However, the point to point face velocities were very different as can be seen in the velocity profile plots. Care was taken to insure the same orientation and position of the velocity probe for each velocity measurement. It was noticed that even a small change in the pitch angle of the probe resulted in much different velocities than for the probe parallel with the hood face. Variations as high as 50 - 80 fpm were recorded. This indicates the velocity vectors are often not perpendicular to the hood face.

Air flow patterns are influenced by the baffle positioning and actual patterns are observed to be different than stated by the manufacturer. The angle of the baffle and the slot configuration have significant impact on the formation of a vortex at the top of the hood. Figure 23. is a diagram of the flow patterns associated with each baffle position.

In baffle position #1, the top slot is open approximately 1.5" and the upper baffle is at an angle of 45 degrees from the vertical. In this position the plenum to the bottom slot is all but closed, resulting in relatively little air flow through the bottom slot. The face velocity traverse indicates high velocities at the top of the hood with correspondingly lower values at the bottom of the hood face. The manufacturers air flow diagram indicates the air flows along the angle of the baffle towards the top and then undergoes nearly a 90 to 180 degree turn before entering the slot.

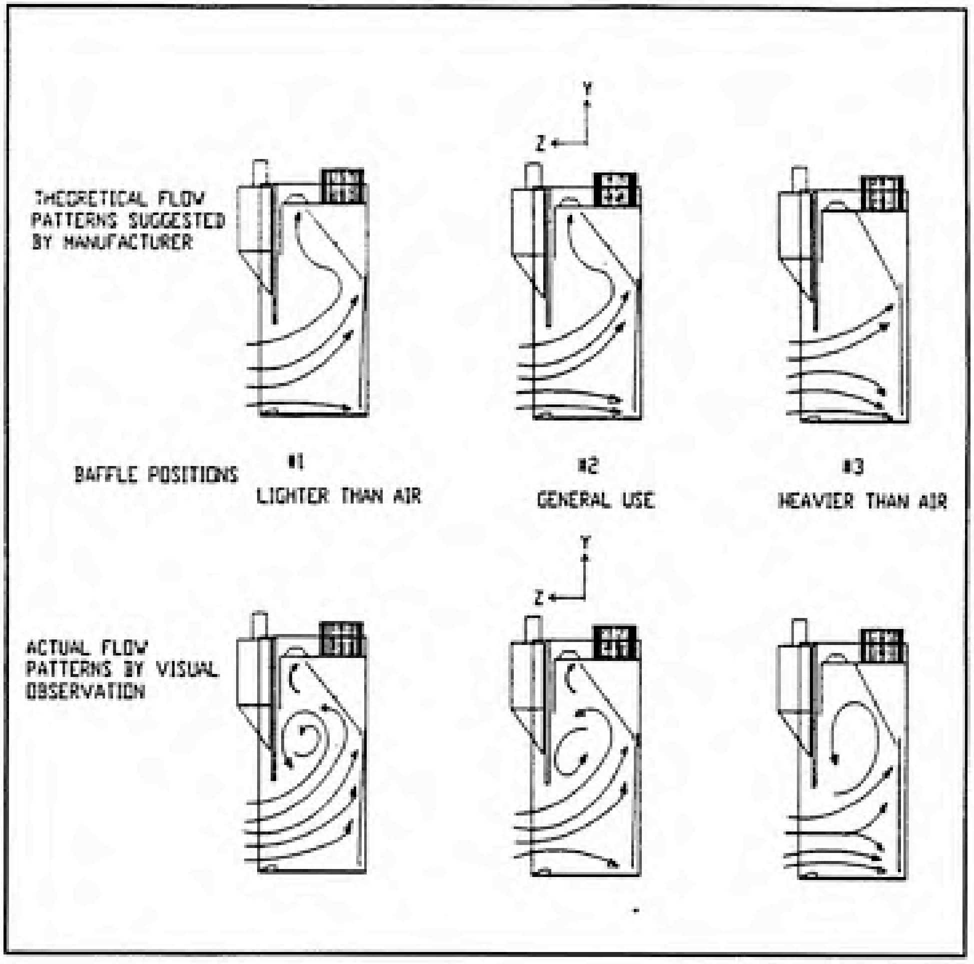


Figure 23. Air flow patterns suggested by manufacturer versus actual observed smoke patterns.

Observation of smoke patterns indicates this is not the case. The air does indeed flow towards the top slot. However, as it flows along the angle of the baffle it gains sufficient momentum to elude capture and form a vortex in the low pressure region just inside the sash. Although some air is drawn from the top of the enclosure, measurements, taken by placing the detector probe of the leakmeter in the vortex, resulted in concentrations over the maximum limit of the device. This indicates the existence of very high concentrations, greater than 1900 ppm, in close proximity to the breathing zone of the worker.

Baffle position #2 has the baffle at an angle of 40 degrees from the vertical with the top slot open only 3/4 inches. The middle slot is now open 1/2" and the plenum to the bottom slot is open 1 inch. The resulting air flow patterns are more favorable than baffle position #1, as some air does enter the bottom slot resulting in a more uniform velocity distribution. The top slot still forces the formation of the vortex but to a smaller degree than before.

Baffle position #3, has the top slot closed and the maximum plenum space open to service the bottom slot. The angle of the top baffle is 35 degrees and the middle slot is now 1" wide. This configuration resulted in the most uniform velocity distribution for all hood tests. Some contaminant does escape capture by the bottom and middle slot, however the quantity of air flowing to the top is removed by spaces around the edges of the baffle resulting in minimum vortex development.

The result of providing a more uniform velocity distribution across the hood opening is to increase the probability of perpendicular air flow and reduce the formation of the vortex at the top of the hood. The importance of the perpendicular air flow in reducing potential exposures will be discussed in following sections.

Auxiliary Air Flow

The auxiliary air supply can actually reduce the potential for leaks and improve the performance of the hood. If the auxiliary supply system has been designed and maintained properly, the auxiliary air flows across the breathing zone of the worker, thus reducing the potential for exposure. Figure 24. is the flow diagram of the auxiliary air flow distribution for baffle positions #1 and #3 at two sash positions.

The protection afforded by the auxiliary air is a result of displacing the vortex further into the hood and providing a clean air curtain which purges the breathing zone of the worker. In baffle position #1 and condition 1a., sash up, the auxiliary air flows out of the plenum and immediately turns 90 to 180 degrees into the hood. With the sash down, 1b, the auxiliary air is more diffuse over the breathing zone yet still exhibits the turn into the hood. In baffle position #3, the auxiliary air tends to split with some fraction flowing towards the bottom slot. When the sash is down, the air flows

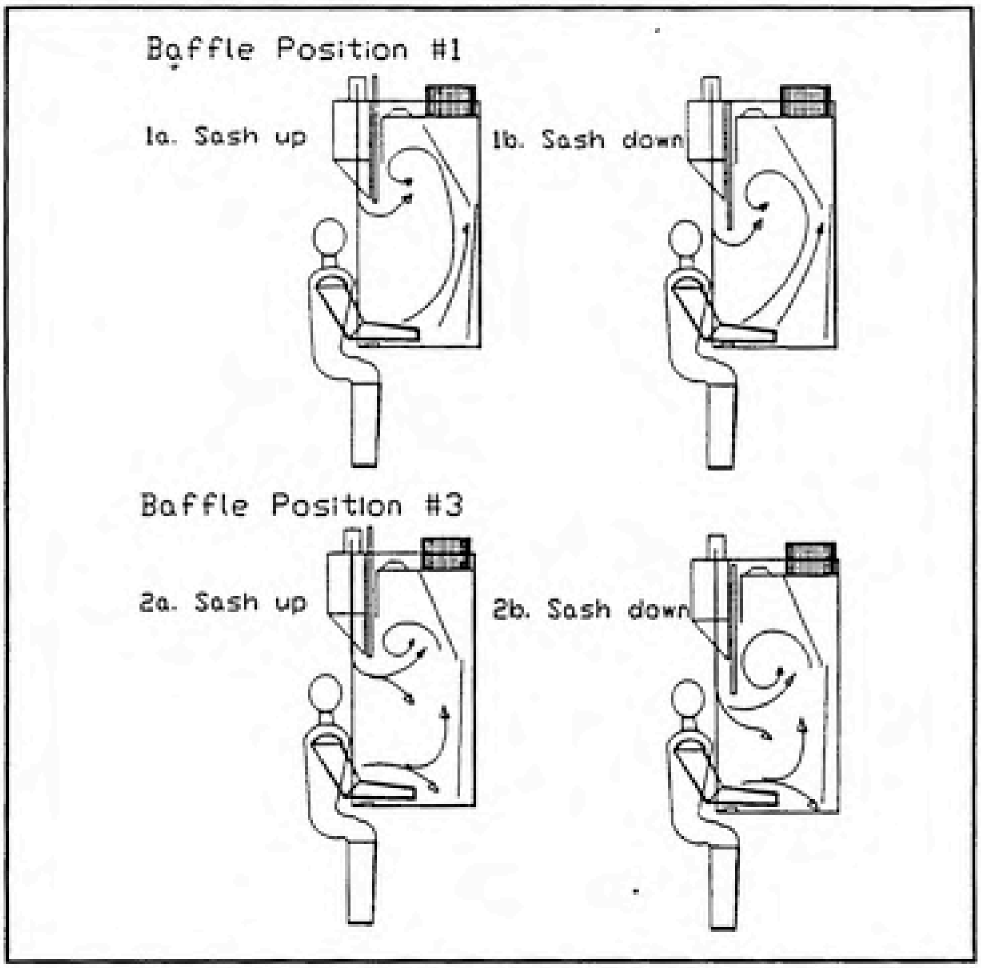


Figure 24. Auxiliary air flow patterns for baffle positions #1 and #3.

directly across the body and breathing zone of the user and the vortex does not have a substantial effect on breathing zone concentrations. Refer to Appendix XIII photos A - D for actual photographs of smoke flow.

Without the auxiliary supply, however, the vortex could pose a substantial threat to the employee. The presence of the employee in the path of the air flow would result in a low pressure zone immediately downstream of the person. The proximity of this low pressure zone to the vortex would enable the flow of contaminant into the breathing zone of the person. Visual observation of smoke patterns shows this to be true, although it was not quantified in this research.

Quantitative Leak Tests

The largest reason for leakage from the hood was the existence of the turbulence and backwash in the wake of the employee. The effect of a worker standing in the direction of air flow results in the phenomenon known in fluid dynamics as boundary layer separation. The boundary layer separation is characterized by formation of vortices in the low pressure zone immediately downstream of an obstacle. The vortices can entrain contaminant generated in the hood and through backwash allow its escape into the breathing zone of the employee. Refer to Figure 25, for a diagram of the flow separation and proximity of turbulent backwash resulting from the presence of an employee in the air flow.

Turbulence and boundary layer separation will significantly influence the amount of leakage from the hood. The separation of flow around an object results in the formation of a zone of low pressure. The flow separation and

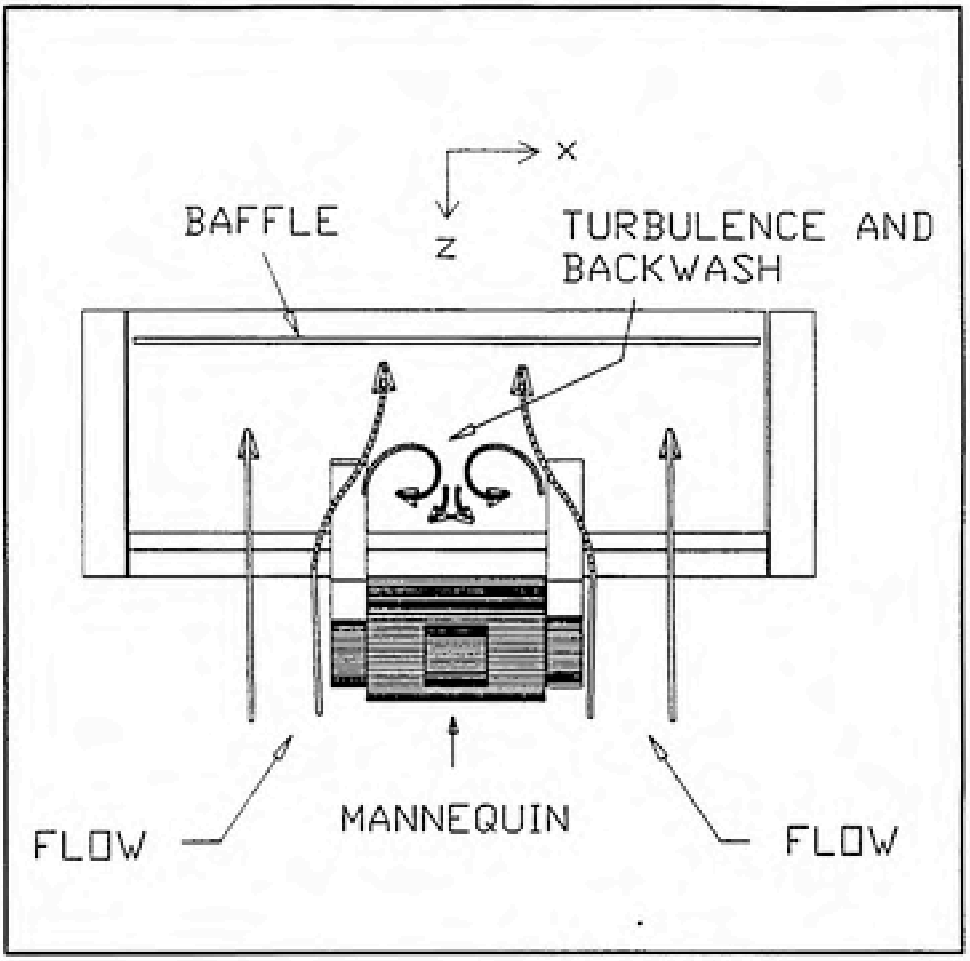


Figure 25. Top view of the hood displaying backwash resulting from obstruction of air flow into the hood.

low pressure area increases the potential for backwash and vortex formation. The existence of this low pressure zone and the proximity to the location of contaminant generation will influence the potential for employee exposure.

The highest average peak concentrations leaking from the hood were found at the highest flow of 1100 cfm. The resulting velocity of 150 fpm exceeds the maximum recommended velocity for this reason. The higher velocity resulted in a zone of low pressure which enabled turbulent diffusion of high concentrations of tracer gas into this zone. The lowest leakage was measured at 850 cfm. The boundary layer separation at the speed of 110 fpm was not sufficient to entrain a large concentration of tracer gas, therefore this flow offered the best protection. The lowest air flow of 750 cfm had higher concentrations, not due to the separation, but rather to its susceptibility to external influences such as room air currents and movements in and about the hood. An air speed of 70 fpm is not adequate to overcome air currents generated by external sources.

The importance of the air flow distribution now becomes important in establishing the effect of baffle position on hood containment. In baffle position #1, where air flow is greatest at the top of the hood, the velocity vectors along the bottom of the hood actually have a vertical component in the upward direction. This upward flow of air combined with contaminant in the low pressure zone in front of the mannequin, resulted in concentrations of contaminant passing through the breathing zone of the mannequin. In the baffle setting #3, the air flows are more perpendicular to the plane of the hood opening. The contaminant had less incentive to flow upward and was captured by the bottom slot. Average peak concentrations leaking from the hood were practically below detection for this position in all hood tests.

The effects of the boundary layer separation, combined with baffle position, can be clearly seen in the photographs of smoke flow located in Appendix XIII. The photos E. and F. display flow for baffle position #1 without the presence of the mannequin. The flow of smoke is upward to the top of the hood where it becomes entrained in the vortex. Photos G. and H. display the flow in baffle position #1 with the mannequin present. The entrainment of the smoke into the lower pressure zone is depicted in photo G.. Photo H. shows the actual leakage from the hood. Photographs I - L were taken in baffle position #3. Most air flow and smoke are captured by the bottom slot regardless of mannequin presence.

Blockage and Shelf Discussion

The blockage test results indicate blockage of the bottom slot has little effect on hood performance. The baffle position #3, which most utilizes the bottom slot, showed little performance degradation in the presence of slot obstructions. This results from the positive pressure gradient that exists regardless of slot blockage. Although direct flow into the slot is inhibited, the majority of contaminant will still be collected. The only measured leakage from the hood in baffle position #3 was 0.9 ppm in the case of 100% blockage. With the shelf in place the slot is again unblocked and leakage dropped to below the detection limit.

The increased leak concentrations resulting in baffle position #1 is not due to the blockage of the bottom slot. The decrease in the depth of the hood enabled the tracer gas to accumulate to higher concentrations at closer proximity to the mannequin. As the percentage of blockage increased the depth of the hood decreased. Breathing zone concentrations increased from 29 ppm for 0% blockage to 61 ppm at 100% blockage. The shelf in this case would have no effect, as no air flow is through the bottom slot. The same amount of surface area would, however, still be blocked.

RECOMMENDATIONS

Based on the results of the hood tests, the hoods found at NIEHS can be manipulated to perform in a very acceptable and safe manner. Optimum performance can be achieved through the coordination of the efforts of the laboratory employee, Health and Safety Branch personnel and facility engineers. The laboratory employee must be responsible for using the hood in a proper manner. The health and safety staff must be responsible for training the employees in proper hood use and inspecting the hoods to ensure safe operation. Facility engineers must be responsible for the monitoring and maintenance of the ventilation system.

Proper Hood Use

The laboratory employee can decrease the potential for exposures while working in the hood through the following:

a.) Adjusting baffle to position #3 for most hood applications

b.) Work with the sash pulled down as far as possible, c.) Keep the hood surface relatively free of obstructions. If storage of materials is necessary, try to align the items along side walls as opposed to along the back baffle,

d.) Try to elevate the contaminant source off the surface of the hood,

e.) Always work as far into the hood as possible, yet insure head remains outside the plane of the hood opening,

f.) Keep movements within the hood to a minimum,

g.) Try to discourage sudden movements in the laboratory especially the opening and closing of doors,

h.) To increase laboratory comfort, close the sash when hood is not in use to bypass auxiliary air into the hood.

These proper work practices are essential to reducing the probability of contaminant exposures. Many of the above suggestions can be achieved with little effort and inconvenience.

The Health and Safety Branch presently requires all laboratory employees to attend a safety course upon employment. Many violators of proper hood procedure are long time employees who are either unaware or have forgotten the safe hood practices. The Health and Safety Branch should promote a short course or issue a bulletin outlining hood use criteria.

The Health and Safety Branch also performs a quarterly laboratory hood inspection. Part of this inspection should incorporate the adjustment to baffle position #3 or that which yields the most uniform velocity profile. The average face velocity should be calculated from a nine point traverse and should be between 80 and 130 fpm for all hoods. Most recent literature by Hamilton Hoods (24) has stated that 100 fpm is the optimum performance velocity. Attempts should be made to determine excessive auxiliary supply. Upon observing unusually high traverse velocities along the top of the hood, notice should be given to the facilities engineers. NIEHS should develop a performance and acceptance criteria and also incorporate the quantitative hood test on a biannual basis to insure optimum hood performance and containment efficiency.

Facility engineers should develop a routine ventilation system inspection. The inspection should include recording of all hood exhaust and auxiliary supply volumes, measurement of ventilation system and filter house pressure drops and inspection of fan, motor and duct integrity. Problems encountered should be rectified with the notification and supervision of the Health and Safety Branch.

Further Research

Many hood advances have resulted from past research, however many elements affecting aerodynamic performance need to be evaluated on a quantitative basis. The baffle and slot configuration should be designed and tested to arrive at optimum slot widths, plenum depths and baffle angles. The present technology for modeling slot performance and capture effectiveness should be applied to laboratory hood design. Research should include development and analysis of ways to divert flow around the worker and insure adequate air flow in the breathing zone and areas most susceptible to acquiring concentrations of contaminant. This research could then be used to develop specific design criteria for laboratory hoods.

The benefits of auxiliary air should be analyzed in terms of improving hood performance. The auxiliary air supply system should be designed to provide safety and worker protection, not just diffused over the hood opening to reduce energy costs. The air supply system should be evaluated in order to eliminate unsafe supply velocities. The criteria for supply volume should not be based on a percentage of the exhaust but in relation to the competing velocities.

The hood must be evaluated in terms of ergonomic considerations. The hood should be designed so as to accommodate the employee. The sash could be angled into the hood to provide easier viewing and less strain. This adjustment would probably serve to better air flow by improving aerodynamics. The hood must also be reevaluated in terms of the type of processes and materials suitable for use. Processes which are not suited for laboratory hoods should be specified such as high temperature processes or those which require large amounts of hood space for equipment.

The laboratory hood is a very complicated contaminant control device. Performance is subject to many external factors which are difficult to control. The present hoods at NIEHS can be made to perform adequately; however, conscientious effort to insure proper operating parameters and hood use are necessary. The future of hood design should include measures designed to eliminate the need for extensive training and monitoring. The hood should be equipped with monitors and alarms to indicate potential performance difficulties and should be tested quantitatively on a routine basis.

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Appendix I. Laboratory Hood Questionnaire and Results

DEPARTMENT OF HEALTH & HUMAN SERVICES

National Institutes of Health
National Institute of
Environmental Health Sciences
P.O. Box 12233
Research Triangle Park, N C 27

Memorandum

Date June 20, 1989

From Thomas Smith, Industrial Hygienist

Subject Laboratory Hood Questionnaire

To Laboratory Hood Users

The purpose of this survey is to gain a better understanding of laboratory hood work practices. Your response would be greatly appreciated.

1.) How often do you use the Hood?
- ☐ Daily
- ☐ Weekly
- ☐ Monthly
- ☐ Never

Average length of time spent at the hood?
- ☐ 15 minutes
- ☐ 30 minutes
- ☐ 60 minutes

_____ hours/day

2.) What compounds do you normally work with in the hood?
- ☐ Chemical
- ☐ Radioactive
- ☐ Odorous

Please list any specific materials:

3.) What are the dimensions of your hood?
- ☐ 3 x 3
- ☐ 3 x 4
- ☐ 3 x 5
- ☐ 3 x 6
- ☐ 3 x 8

Do you feel there should be < less than or > greater than :

☐ < Height > ☐

☐ < Depth > ☐

4.) When working in the hood, what is the usual sash height?
- ☐ Fully Open
- ☐ Half Way Open
- ☐ Varies

5.) Do you store any materials in the hood?
☐ Yes ☐ No
If yes, ___ percentage of bottom slot obstructed
Reason for storage:
- ☐ Lack of other space
- ☐ For containment
- ☐ In case of spills

6.) Do you know how the baffle functions?
☐ yes ☐ no
Have you ever adjusted the baffle, if so, why?
☐ yes ☐ no
Why:

7.) Please list your complaints other than hot or cold auxiliary air. (ergonomics, noise, hood features, etc.)

8.) Please list any design modifications that would make the hood convenient to use or more efficient.

Thank you for your time and consideration in filling out this information. It is our desire to provide a safe yet convenient work atmosphere within the hood.

Thank you,

Thomas Smith

Results of Laboratory Hood Questionnaire

As of August 25, 1989, fifty employees were questioned concerning their laboratory hood work practices and their general knowledge of the design and operation of the hood. The results are as follows:

% of People Responding

A. Hood Use : Daily - 42.5%
Weekly - 46.8%
Monthly - 10.6%

Time of Use : 15 minutes - 42.5%
30 minutes - 25.5%
60 minutes - 31.9%

B. Compounds Used : Chemical - 75%
(e.g. solvents, ethers, formaldehyde, odorous)

Radioactive - 25%
(C-14, P-32, I-135)

C. Storage of Materials in Hood : Yes - 95% No - 5%

Reasons For Storage : Lack of other space - 12.5%
Control of emmissions - 62.5%
Containment of spills - 32.5%

D. Sash Working Height : Fully Open - 38.5%
Half Open - 38.5%
Varies - 22.8%

E. Baffle Function : Knowledge of purpose - 37.3%
Unaware of purpose - 62.7%

Baffle Adjustment : Adjusted - 10.2%
Never adjusted - 89.8%

Reasons for adjustment were detection of odors.

F. Satisfaction with Hood Design

Most hood users complained of variability in temperature due to supply of auxilliary air, noise, lack of leg room under hood, ergonomics (uncomfortable working while sash is lowered), lack of audible alarm for low flows, and lack of shelves or storage areas.

Appendix II. Calibration Data and Curves for Alnor Thermoanemometer

ALNOR THERMOANEMOMETER MODEL 8500D 3/7/90

TEMPERATURE = 25 C

BP = 29.56" Hg

WIND TUNNEL – KURZ INSTRUMENTS 400B AIR VELOCITY CALIBRATION SYSTEM

WIND TUNNEL		ALNOR ANEMOMETER	
PRESSURE DROP Inches.H2O	ACTUAL VELOCITY FPM	MEASURED VELOCITY FPM	LINEAR REGRESSION FPM
0	0	0	0
0.02	20	21	21
0.035	36	39	38
0.04	41	43	43
0.07	71	77	74
0.09	92	105	96
0.1	102	118	107
0.15	153	169	160
0.24	244	264	255
0.33	336	358	351
0.42	427	428	447

Regression Output:

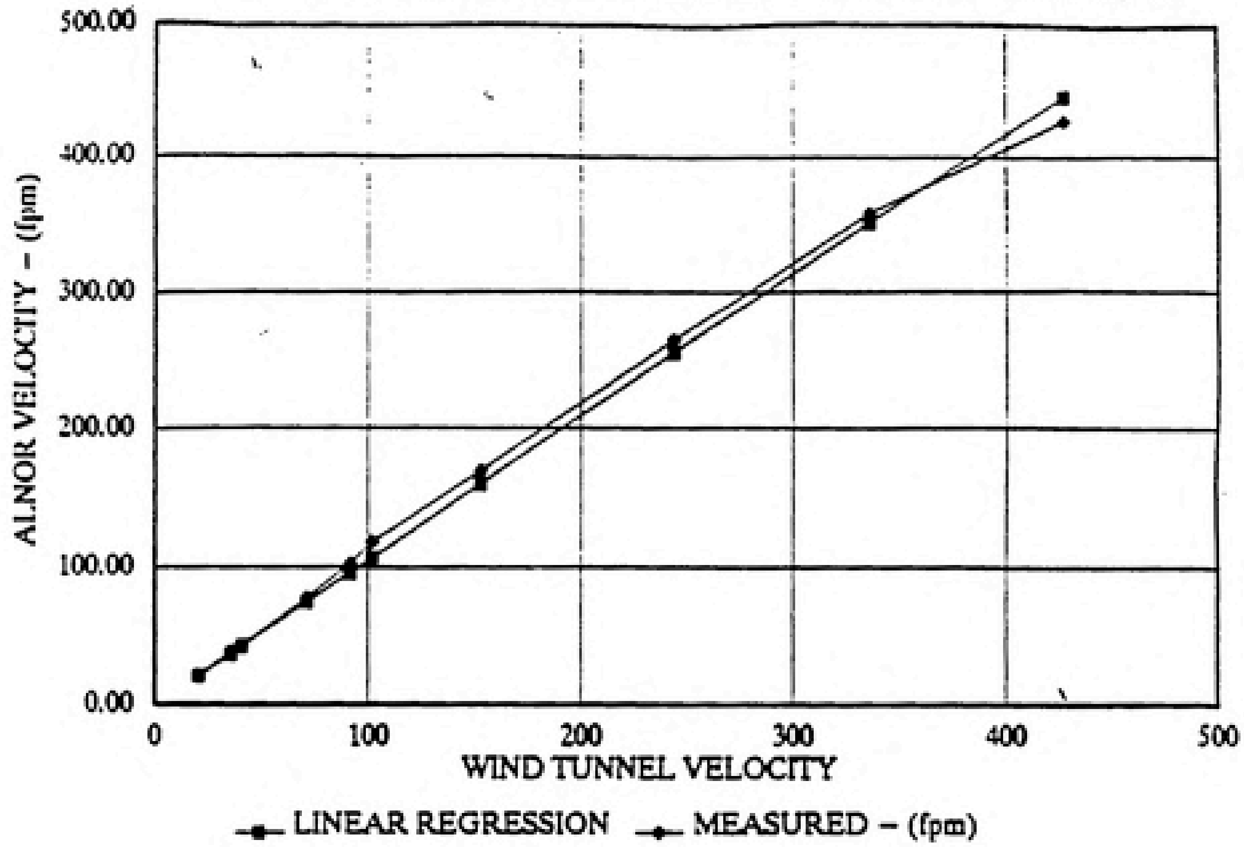
Constant		0
Std Err of Y Est		9.199812
R Squared		0.995796
No. of Observations		10
Degrees of Freedom		9
X Coefficient(s)	1.045901	
Std Err of Coef.	0.014447	

LINEAR REGRESSION

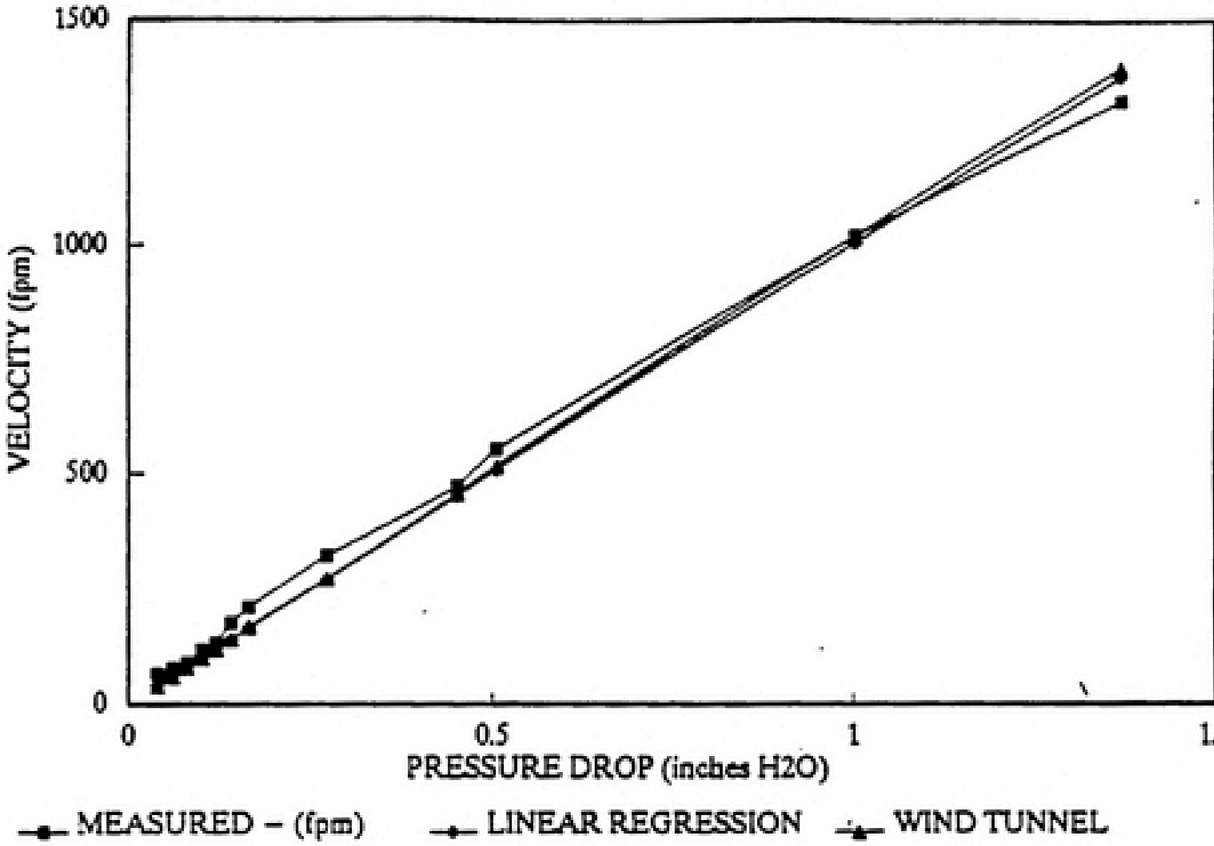
Computed with the actual velocity as the independent variable and with a zero intercept.

L.R. Velocity = Actual Velocity * 1.046

ALNOR ANEMOMETER CALIBRATION



ALNOR ANEMOMETER CALIBRATION



ALNOR THERMOANEMOMETER MODEL 8500D 1/25/90

TEMPERATURE = 25 C

BP = 29.1" Hg

WIND TUNNEL – KURZ INSTRUMENTS 400B AIR VELOCITY CALIBRATION SYSTEM

WIND TUNNEL		ALNOR ANEMOMETER	
PRESSURE DROP inches H_2O	ACTUAL VELOCITY FPM	MEASURED VELOCITY FPM	LINEAR REGRESSION FPM
0	0	0	0
0.04	41	66	45
0.06	61	78	66
0.08	81	90	88
0.1	102	118	111
0.12	122	133	133
0.14	142	175	154
0.165	168	211	183
0.27	275	325	299
0.45	458	471	498
0.505	514	550	559

Regression Output:

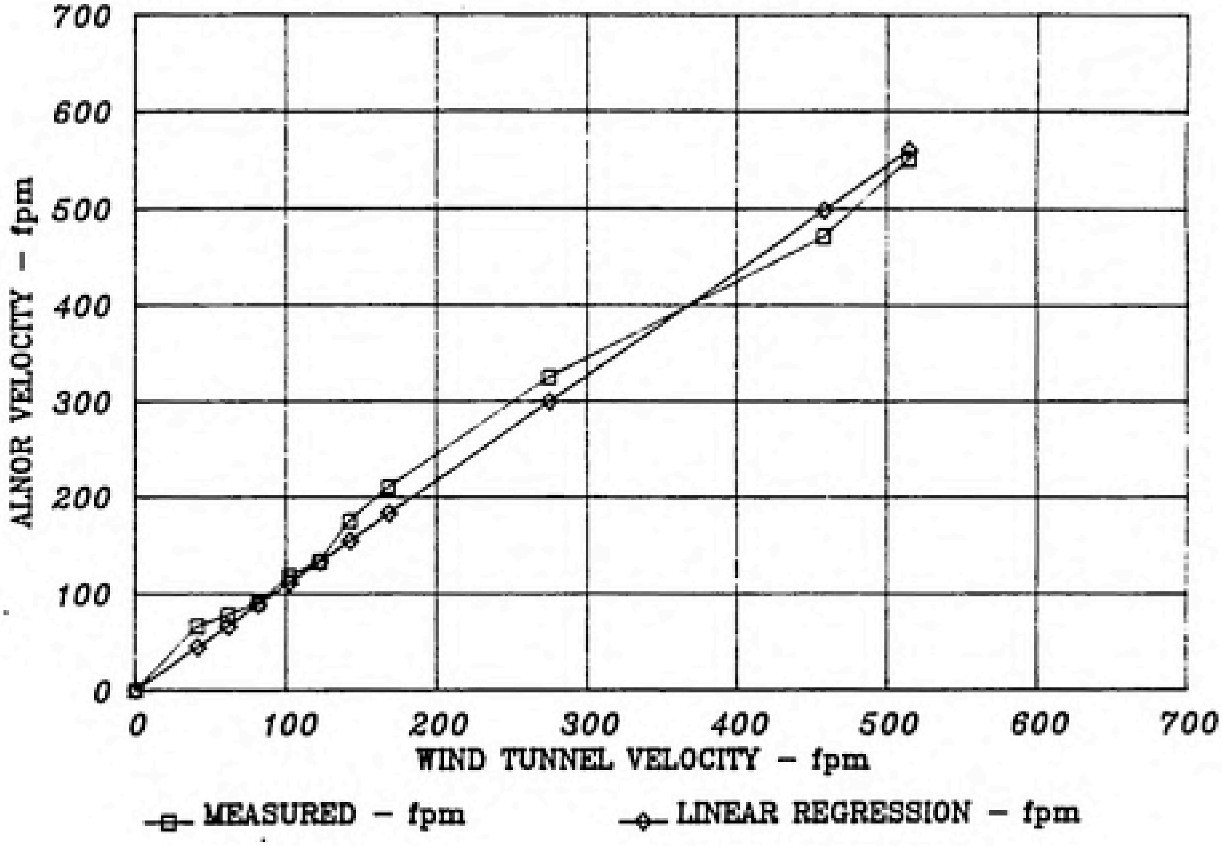
Constant		0
Std Err of Y Est		18.32693
R Squared		0.989110
No. of Observations		11
Degrees of Freedom		10
X Coefficient(s)	1.087973	
Std Err of Coef.	0.022994	

LINEAR REGRESSION

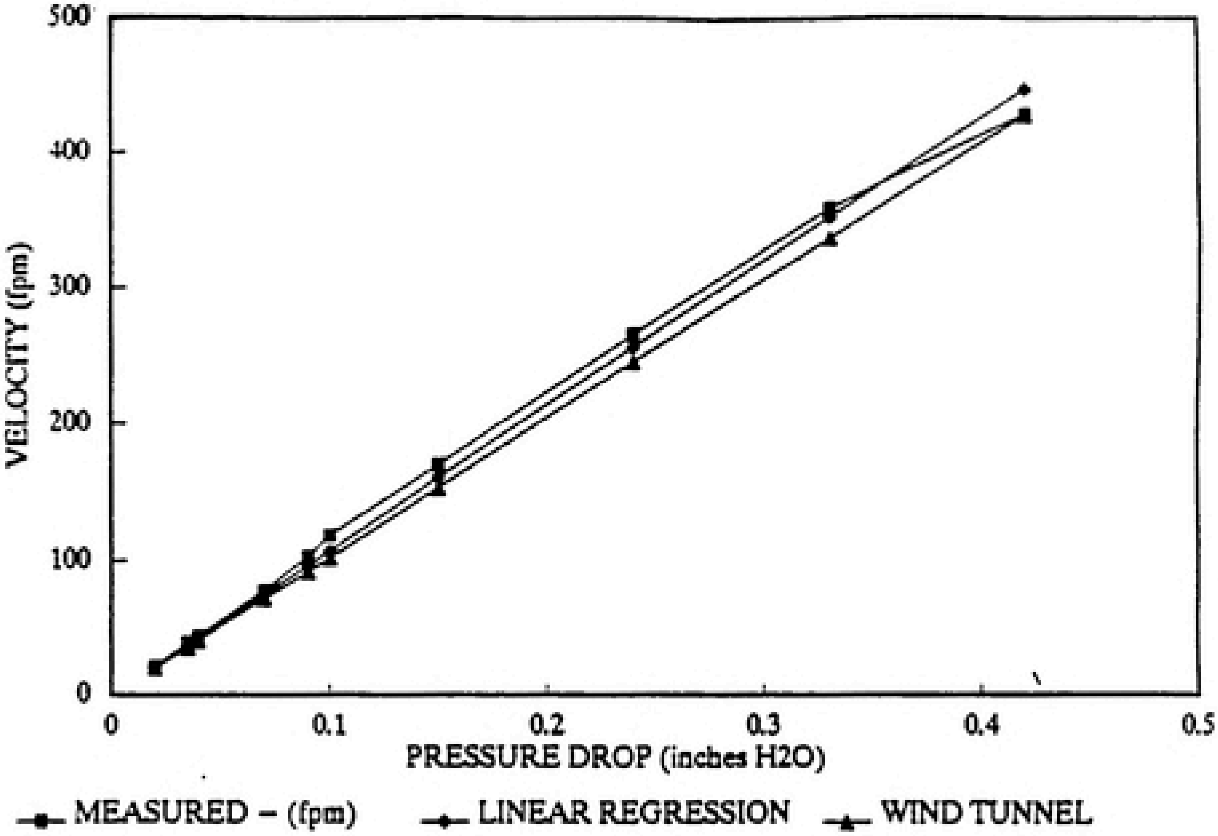
Computed with the actual velocity as the independent variable and with a zero intercept.

L.R. Velocity = Actual Velocity * 1.089

ALNOR ANEMOMETER CALIBRATION



ALNOR ANEMOMETER CALIBRATION



Appendix III. Calibration Data and Curves for ITI Leakmeter

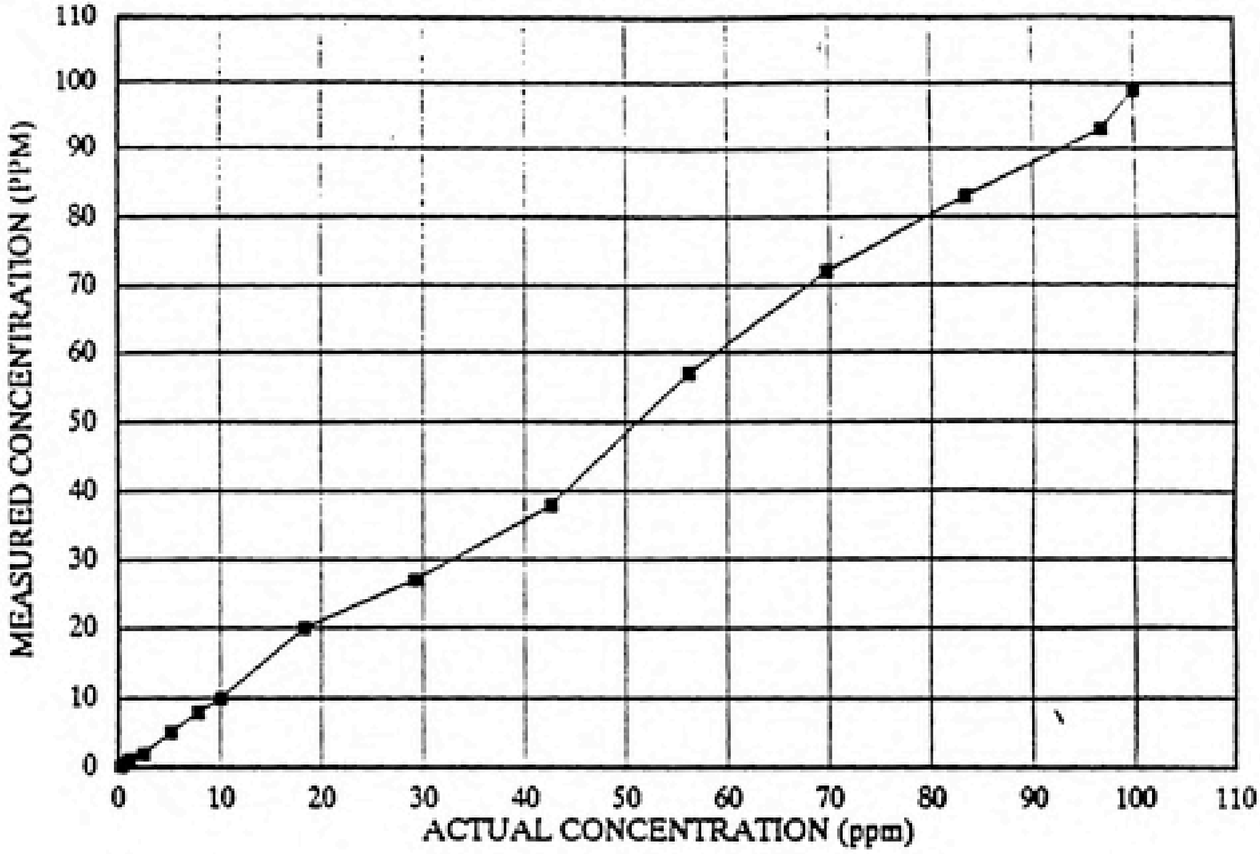
LEAKMETER CALIBRATION 2/19/90

LEAK METER FLOW (Q) = 100 cc/min

DILUTION FLASK VOLUME (V) = 3.69 L

VOLUME INJECTED uL	LEAKMETER CONCENTRATION ppm	CALCULATED CONCENTRATION ppm	LINEAR REGRESSION LEAK CONC.
1	0.2	0.3	0.27
2	0.4	0.5	0.53
4	1	1.1	1.07
9	1.9	2.4	2.41
19	5.1	5.1	5.08
29	8	7.9	7.76
37	9.9	10.0	9.90
67	20	18.2	17.92
107	27	29.0	28.62
157	38	42.5	42.00
207	57	56.1	55.37
257	72	69.6	68.75
307	83	83.2	82.12
357	93	96.7	95.50
369	99	100.0	98.71

LEAKMETER CALIBRATION 2/19/90



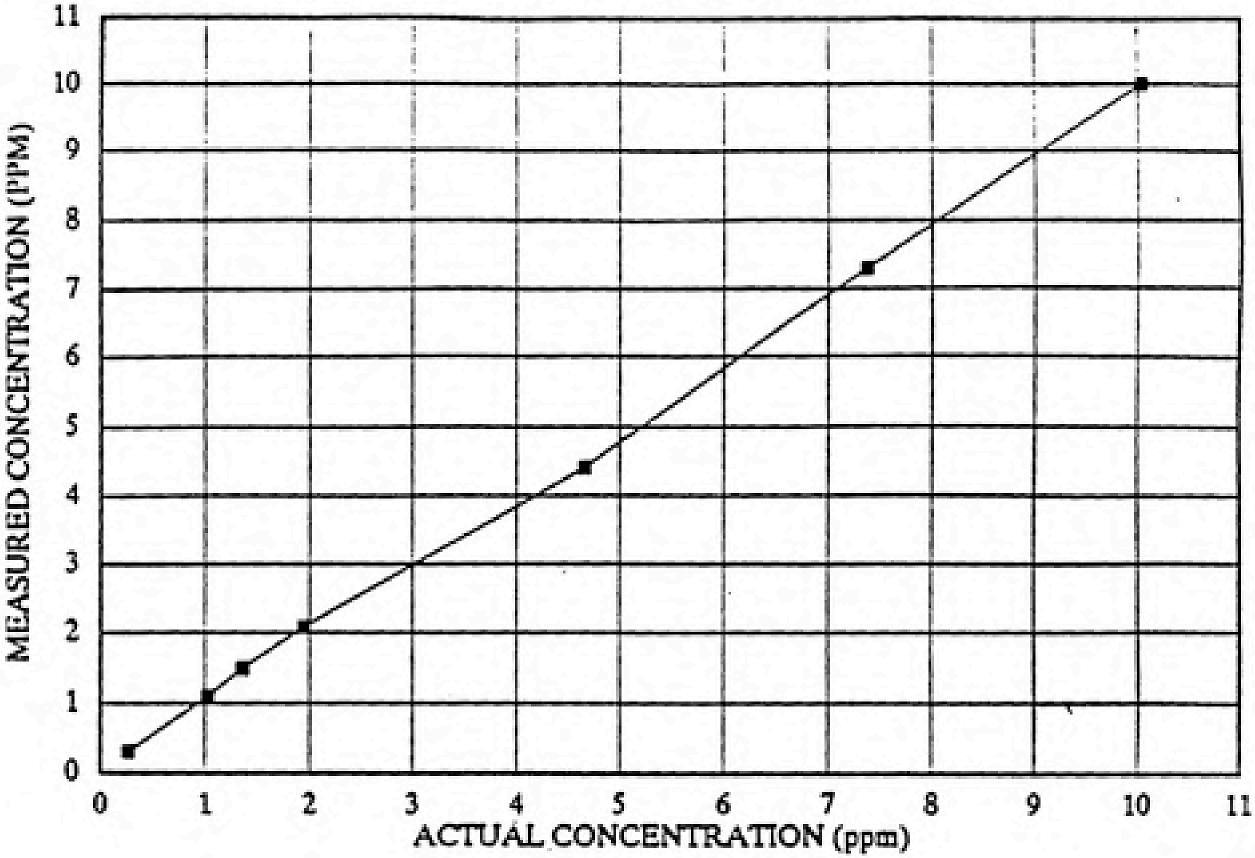
LEAKMETER CALIBRATION 2/26/90

LEAK METER FLOW (Q) = 100 cc/min

DILUTION FLASK VOLUME (V) = 3.69 L

VOLUME INJECTED uL	LEAKMETER CONCENTRATION ppm	CALCULATED CONCENTRATION ppm
1	0.3	0.3
3.8	1.1	1.0
5	1.5	1.4
7.2	2.1	2.0
17.2	4.4	4.7
27.2	7.3	7.4
37	10	10.0

LEAKMETER CALIBRATION 2/26/90



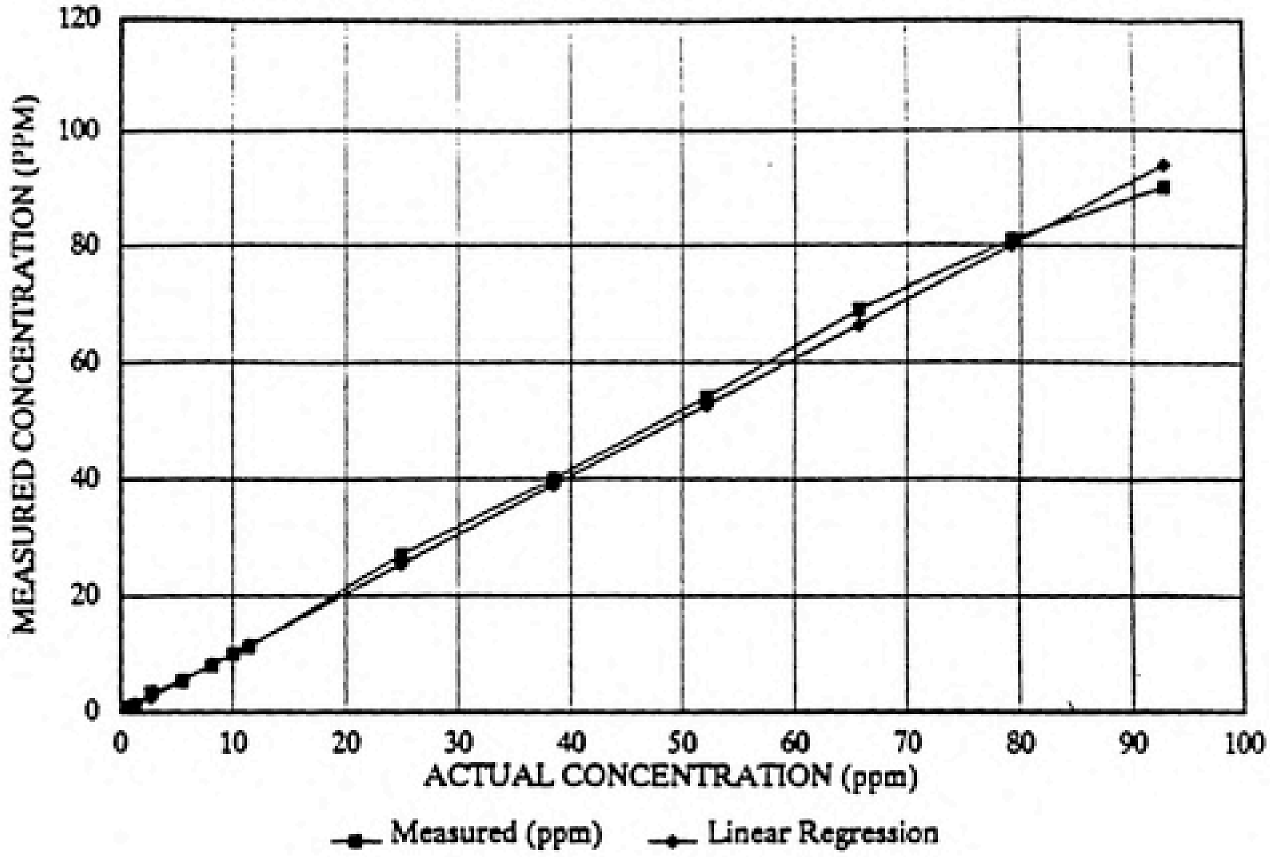
LEAKMETER CALIBRATION 3/8/90

LEAK METER FLOW (Q) = 110 cc/min

DILUTION FLASK VOLUME (V) = 3.69 L

VOLUME INJECTED uL	LEAKMETER CONCENTRATION ppm	CALCULATED CONCENTRATION ppm	LEAKMETER L.R.
3	0.9	0.8	0.8
5	1.3	1.4	1.4
10	3.4	2.7	2.7
20	5.4	5.4	5.5
30	8	8.1	8.2
37	10	10.0	10.2
42	11.2	11.4	11.5
92	35	24.9	25.2
142	55	38.5	39.0
192	54	52.0	52.7
242	69	65.6	66.4
292	81	79.1	80.1
342	90	92.7	93.8
392	100	106.2	107.6

LEAKMETER CALIBRATION 3/7/90



Appendix IV. Calibration Data and Curves for Rotameters

ROTAMETER CALIBRATION 1/4/90

AIR PRODUCTS E29 R 150 MM4

CALIBRATION STANDARD
Warren E. Collins
Chain Compensated Gasometer
2244
133.2 cc/mm

Top ball	Bottom ball		Distance mm	Time min		Flow L/min	Corrected Flow L/min
2.2	1.1		35	4.9023		0.95	0.4
3.9	2.1		40	2.4643		2.16	1.0
6.5	3.5		50	1.703		3.91	1.7
11.3	6		70	1.3407		6.95	3.1
15	7.9		115	1.6935		9.05	4.0
	11		80	0.8445		12.62	5.6
	13		110	0.963		15.21	6.7
	15		100	0.7573		17.59	7.8

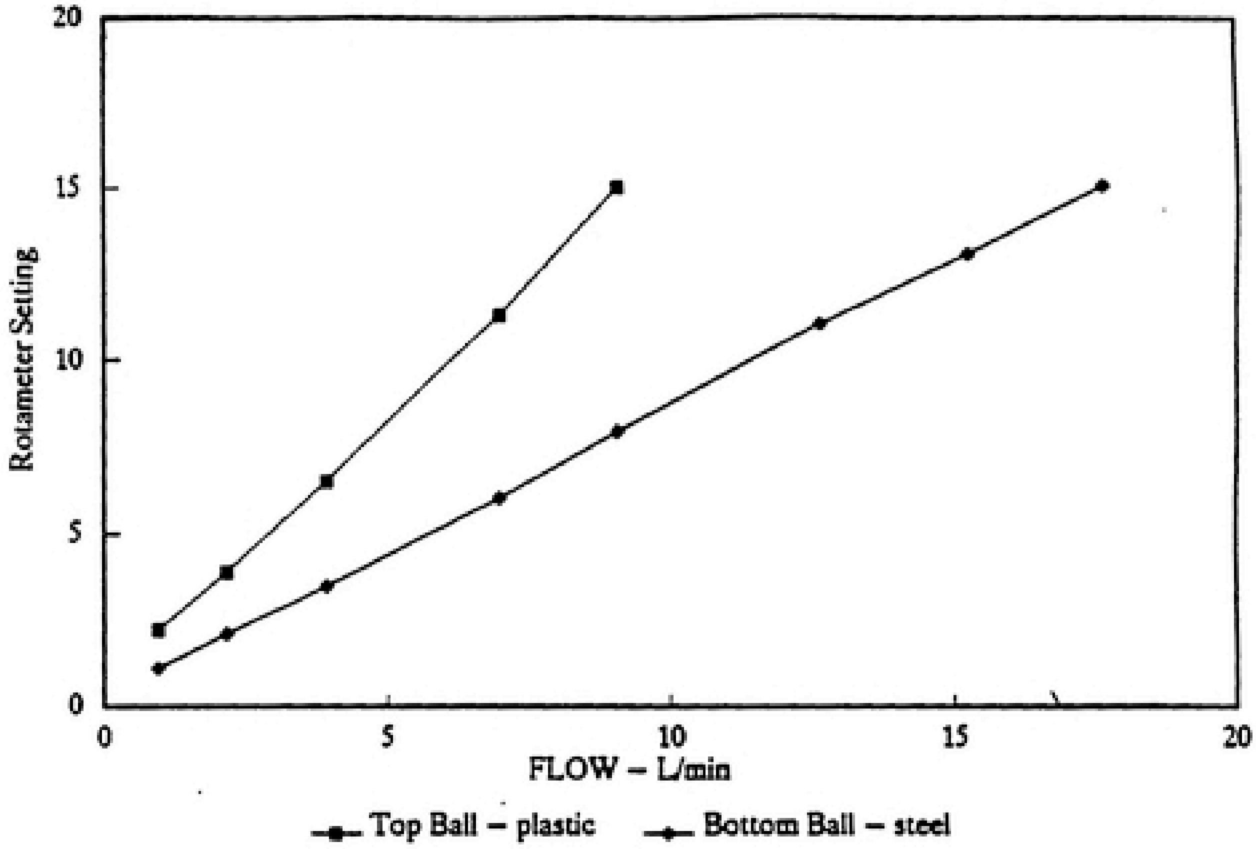
For Top ball
Regression Output:

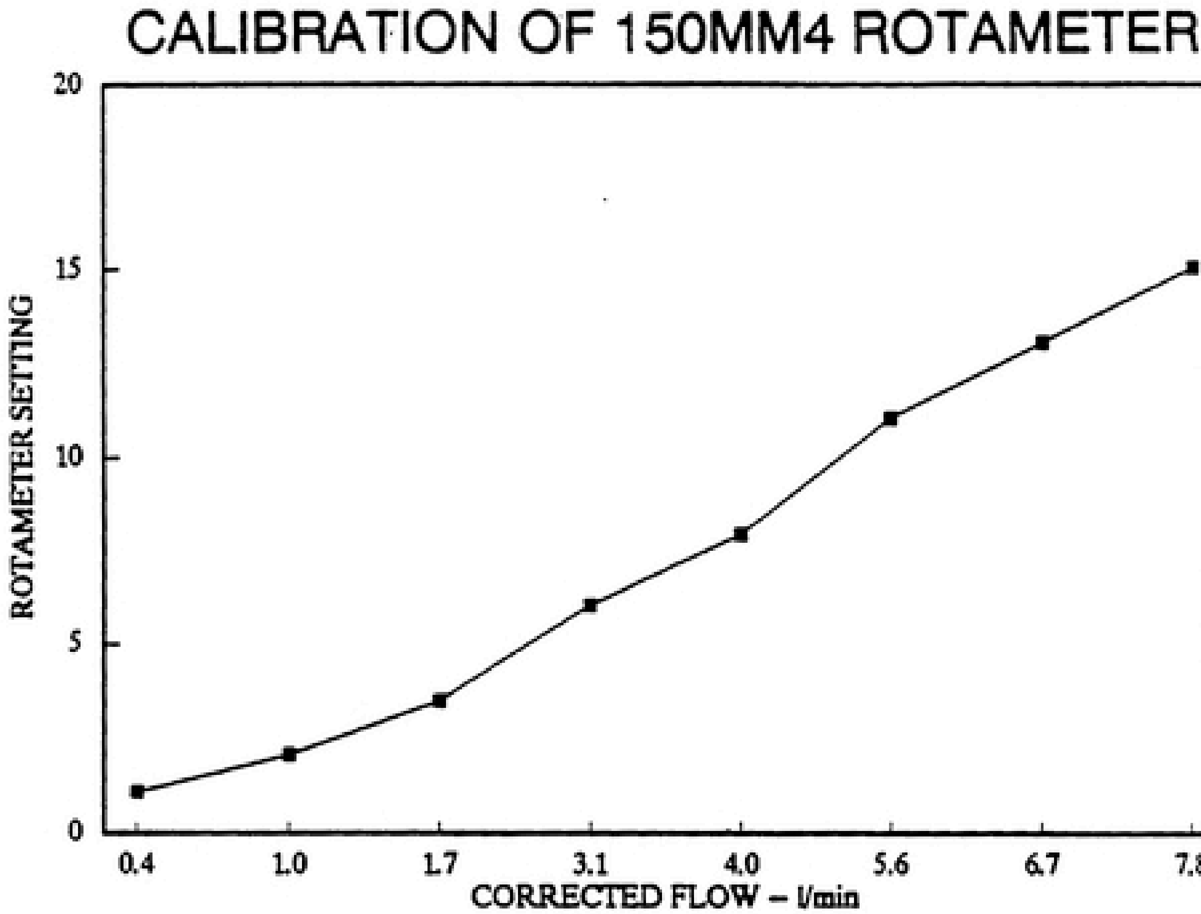
Constant		0.512109
Std Err of Y Est		0.223612
R Squared		0.998664
No. of Observations		5
Degrees of Freedom		3
X Coefficient(s)	1.578360	
Std Err of Coef.	0.033320	

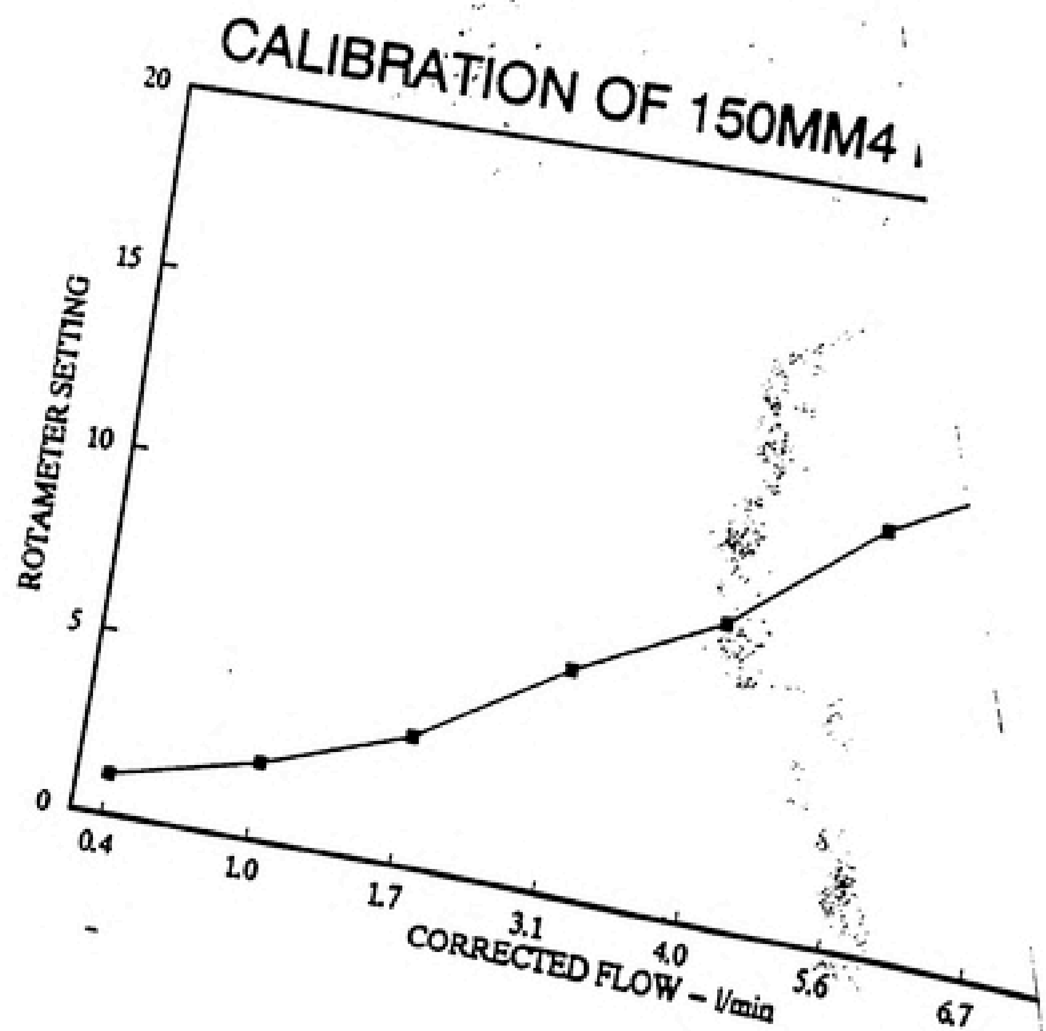
For Bottom ball
Regression Output:

Constant		0.265922
Std Err of Y Est		0.080606
R Squared		0.999791
No. of Observations		8
Degrees of Freedom		6
X Coefficient(s)	0.839685	
Std Err of Coef.	0.004946	

CALIBRATION OF 150MM4 ROTAMETER




CALIBRATION OF 150MM4 ROTAMETER
ROTAMETER SETTING
0
5
10
15
20
0.4
1.0
1.7
3.1
4.0
5.6
6.7
7.8
CORRECTED FLOW – l/min



CALIBRATION OF 150MM4
ROTAMETER SETTING
20
15
10
5
0
0.4
1.0
1.7
3.1
4.0
5.6
6.7
CORRECTED FLOW – l/min

CALIBRATION OF ROTAMETER #2

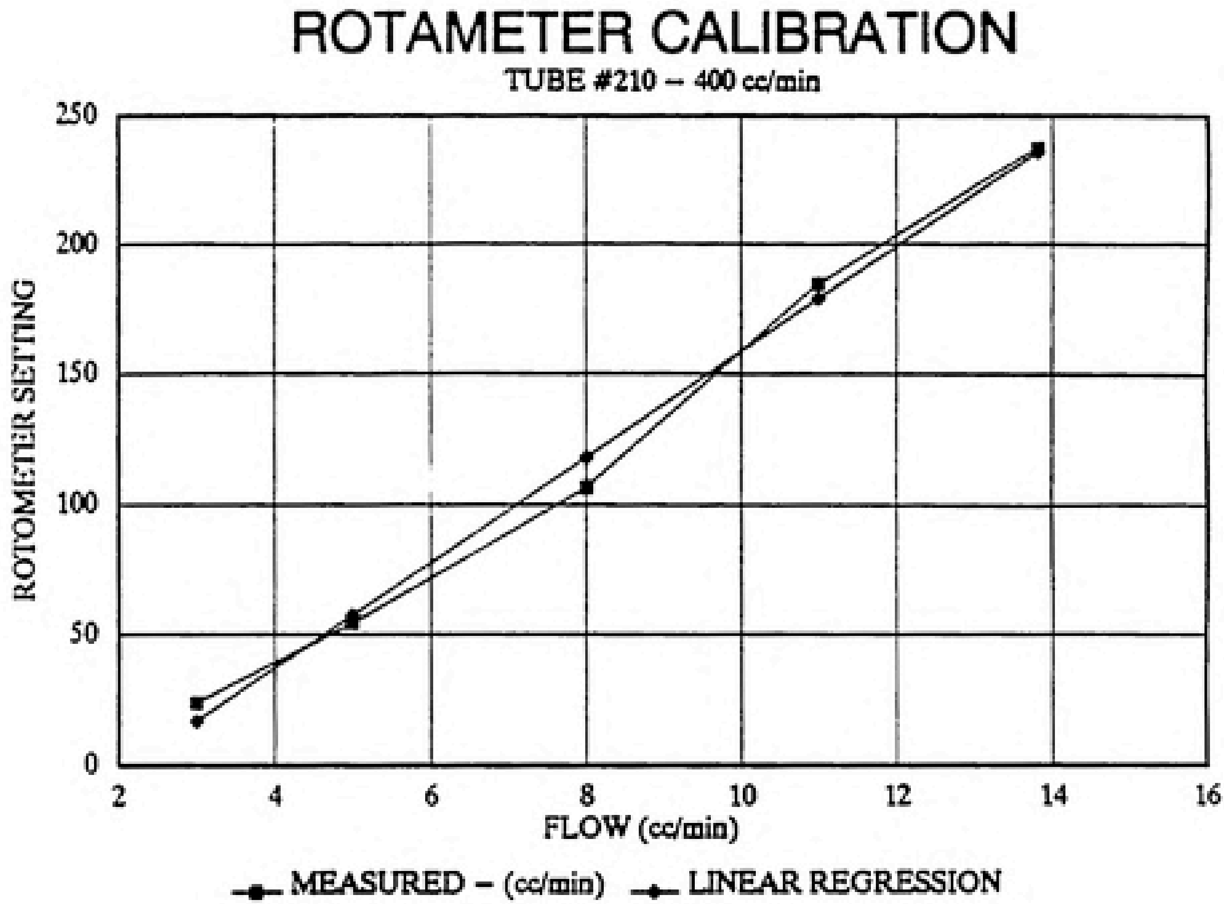
UPPER BALL
SMALL TUBE #210

GILIAN MINIBUCK CALIBRATOR

SETTING	FLOW cc/min	LINEAR REGRESSION cc/min	
=======	=======	=======	=======
3	23.7	16.9	
5	54.6	57.3	
8	106.7	118.1	
11	184.5	178.8	
13.8	237	235.5	

Regression Output:

Constant		-43.8751
Std Err of Y Est		8.533408
R Squared		0.993079
No. of Observations		5
Degrees of Freedom		3
X Coefficient(s)	20.24205	
Std Err of Coef.	0.975568	


ROTAMETER CALIBRATION
TUBE #210 – 400 cc/min
ROTOMETER SETTING
FLOW (cc/min)
MEASURED – (cc/min)
LINEAR REGRESSION
0
50
100
150
200
250
2
4
6
8
10
12
14
16

Appendix V.   Face Velocity Data for Hood at 1100 cfm in Room DJ15

FACE VELOCITY DATA - NINE POINT TRAVERSE   TEMP = 21.1 C
ALL VELOCITY VALUES HAVE UNITS - fpm

HOOD EXHAUST VOLUME -	1100	+/- 20 CFM		
HOOD AUXILLIARY VOLUME -	630	+/- 20 CFM	PERCENT	0.57
PREDICTED FACE VELOCITY =	152	V = Q/A		

A. BAFFLE POSITION #1 - TOP SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1		COLUMN 2		COLUMN 3
	140		224		141
ROW 1	159	ROW 1	240	ROW 1	146
	157		242		142
MEAN =	152	MEAN =	235	MEAN =	143
ST. DEV.=	8.52	ST. DEV.=	8.06	ST. DEV.=	2.16

	COLUMN 1		COLUMN 2		COLUMN 3
	138		140		135
ROW 2	144	ROW 2	147	ROW 2	143
	145		140		141
MEAN =	142	MEAN =	142	MEAN =	140
ST. DEV.=	3.09	ST. DEV.=	3.30	ST. DEV.=	3.40

	COLUMN 1		COLUMN 2		COLUMN 3
	140		133		126
ROW 3	133	ROW 3	130	ROW 3	135
	131		131		135
MEAN =	135	MEAN =	131	MEAN =	132
ST. DEV.=	3.86	ST. DEV.=	1.25	ST. DEV.=	4.24

AVERAGE FACE VELOCITY =	150		
POINT TO POINT		MAX VEL	MIN VEL
% DIFFERENCE =	56.73	235	131

B. BAFFLE POSITION #2 - MIDDLE SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

ROW 1	COLUMN 1	COLUMN 2	COLUMN 3
	139	218	146
	142	202	141
	131	210	138
MEAN =	137	210	142
ST. DEV.=	4.64	6.53	3.30

ROW 2	COLUMN 1	COLUMN 2	COLUMN 3
	138	158	144
	132	155	140
	149	159	135
MEAN =	140	157	140
ST. DEV.=	7.04	1.70	3.68

ROW 3	COLUMN 1	COLUMN 2	COLUMN 3
	130	136	138
	125	132	125
	118	135	119
MEAN =	124	134	127
ST. DEV.=	4.92	1.70	7.93

AVERAGE FACE VELOCITY = 146

POINT TO POINT
% DIFFERENCE = 51.25

MAX VEL	MIN VEL
210.00	124.33

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 1	164	ROW 1	164	ROW 1	149
	148		196		147
	149		138		131
MEAN =	154	MEAN =	166	MEAN =	142
ST. DEV.=	7.32	ST. DEV.=	23.72	ST. DEV.=	8.06

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 2	147	ROW 2	151	ROW 2	151
	145		159		150
	143		162		150
MEAN =	145	MEAN =	157	MEAN =	150
ST. DEV.=	1.63	ST. DEV.=	4.64	ST. DEV.=	0.47

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 3	135	ROW 3	144	ROW 3	150
	151		146		152
	153		148		152
MEAN =	146	MEAN =	146	MEAN =	151
ST. DEV.=	8.06	ST. DEV.=	1.63	ST. DEV.=	0.94

AVERAGE FACE VELOCITY = 151

		MAX VEL	MIN VEL
POINT TO POINT % DIFFERENCE =	15.35	166.00	142.33

Appendix VI. Face Velocity Data for Hood at 850 cfm in Room C158

FACE VELOCITY DATA - NINE POINT TRAVERSE
ALL VELOCITY VALUES HAVE UNITS - fpm

HOOD EXHAUST VOLUME -	870	+/- 20 CFM		
HOOD AUXILLIARY VOLUME -	460	+/- 20 CFM	PERCENT	0.53
PREDICTED FACE VELOCITY =	121	V = Q/A		

A. BAFFLE POSITION #1 - TOP SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 1	97 107 83	ROW 1	181 172 181	ROW 1	116 124 126
MEAN =	96	MEAN =	178	MEAN =	122
ST. DEV.=	9.84	ST. DEV.=	4.24	ST. DEV.=	4.32
ROW 2	107 97 100	ROW 2	105 105 107	ROW 2	116 111 115
MEAN =	101	MEAN =	106	MEAN =	114
ST. DEV.=	4.19	ST. DEV.=	0.94	ST. DEV.=	2.16
ROW 3	89 93 65	ROW 3	96 104 93	ROW 3	99 98 104
MEAN =	82	MEAN =	98	MEAN =	100
ST. DEV.=	12.36	ST. DEV.=	4.64	ST. DEV.=	2.62

AVERAGE FACE VELOCITY = 111

		MAX VEL	MIN VEL
POINT TO POINT % DIFFERENCE =	73.50	178	82

B. BAFFLE POSITION #2 - MIDDLE SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1	COLUMN 2	COLUMN 3
ROW 1	96	159	102
	88	153	116
	98	149	106
MEAN =	94	154	108
ST. DEV.=	4.32	4.11	5.89
ROW 2	96	112	110
	100	109	108
	105	106	116
MEAN =	100	109	111
ST. DEV.=	3.68	2.45	3.40
ROW 3	95	105	108
	109	93	102
	101	103	99
MEAN =	102	100	103
ST. DEV.=	5.73	5.25	3.74

AVERAGE FACE VELOCITY = 109

POINT TO POINT
% DIFFERENCE = 48.18

MAX VEL	MIN VEL
154	94

C. BAFFLE POSITION #3 - BOTTOM SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1	COLUMN 2	COLUMN 3
ROW 1	82 100 90	94 91 106	94 100 99
MEAN =	91	97	98
ST. DEV.=	7.36	6.48	2.62
ROW 2	108 107 107	117 118 124	93 104 99
MEAN =	107	120	99
ST. DEV.=	0.47	3.09	4.50
ROW 3	111 114 108	100 101 106	113 115 106
MEAN =	111	102	111
ST. DEV.=	2.45	2.62	3.86

AVERAGE FACE VELOCITY = 104

POINT TO POINT
% DIFFERENCE = 27.58

MAX VEL	MIN VEL
120	91

Appendix VII. Face Velocity Data for Hood at 750 cfm in Room C148

FACE VELOCITY DATA - NINE POINT TRAVERSE
ALL VELOCITY VALUES HAVE UNITS - fpm

HOOD EXHAUST VOLUME -	750	+/- 20 CFM		
HOOD AUXILLIARY VOLUME -	360	+/- 20 CFM	PERCENT	0.48
PREDICTED FACE VELOCITY =	104	V = Q/A		

A. BAFFLE POSITION #1 - TOP SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 1	115 104 106	ROW 1	143 111 100	ROW 1	117 110 119
MEAN =	108	MEAN =	118	MEAN =	115
ST. DEV.=	4.78	ST. DEV.=	18.24	ST. DEV.=	3.86

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 2	51 42 50	ROW 2	107 102 103	ROW 2	75 45 54
MEAN =	48	MEAN =	104	MEAN =	58
ST. DEV.=	4.03	ST. DEV.=	2.16	ST. DEV.=	12.57

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 3	32 36 41	ROW 3	51 58 61	ROW 3	23 27 23
MEAN =	36	MEAN =	57	MEAN =	24
ST. DEV.=	3.68	ST. DEV.=	4.19	ST. DEV.=	1.89

AVERAGE FACE VELOCITY =	74	MAX VEL	MIN VEL
POINT TO POINT % DIFFERENCE =	131.62	118	24

B. BAFFLE POSITION #2 - MIDDLE SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 1	104	ROW 1	75	ROW 1	114
	103		74		103
	106		91		106
MEAN =	104	MEAN =	80	MEAN =	108
ST. DEV.=	1.25	ST. DEV.=	7.79	ST. DEV.=	4.64

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 2	50	ROW 2	116	ROW 2	44
	42		121		52
	53		132		50
MEAN =	48	MEAN =	123	MEAN =	49
ST. DEV.=	4.64	ST. DEV.=	6.68	ST. DEV.=	3.40

	COLUMN 1		COLUMN 2		COLUMN 3
ROW 3	33	ROW 3	70	ROW 3	29
	41		72		27
	39		66		28
MEAN =	38	MEAN =	69	MEAN =	28
ST. DEV.=	3.40	ST. DEV.=	2.49	ST. DEV.=	0.82

AVERAGE FACE VELOCITY =	72		
POINT TO POINT		MAX VEL	MIN VEL
% DIFFERENCE =	125.83	123.00	28.00

C. BAFFLE POSITION #3 - BOTTOM SLOT OPEN

FACE VELOCITY - UNOBSTRUCTED

	COLUMN 1	COLUMN 2	COLUMN 3
ROW 1	87 85 100	66 63 59	107 110 108
MEAN =	91	63	108
ST. DEV.=	6.65	2.87	1.25
ROW 2	51 49 54	120 132 117	44 55 50
MEAN =	51	123	50
ST. DEV.=	2.05	6.48	4.50
ROW 3	50 57 57	73 79 69	36 42 40
MEAN =	55	74	39
ST. DEV.=	3.30	4.11	2.49

AVERAGE FACE VELOCITY = 73

POINT TO POINT
% DIFFERENCE = 103.08

MAX VEL	MIN VEL
123.00	39.33

Appendix VIII. Leakage Concentration Data Hood at 1100 cfm in Room D315

SAMPLING STRATEGY 2/23/90 TEMP = 21.1 C
D-315
HOOD EXHAUST VOLUME - 1100 +/- 20 CFM
HOOD AUXILLIARY VOLUME - 630 +/- 20 CFM PERCENT 0.57

I. CHALLENGE POSITION - LOW II. CHALLENGE POSITION - HIGH
BREATHING ZONE CONCENTRATIONS -
10 MINUTE PEAK AVERAGES - PPM
@ 30 SECOND INTERVALS
CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

A. BAFFLE POSITION #1 - TOP SLOT OPEN

FACE VELOCITY - UNOBS.

	1	2	3
1	140	224	141
2	138	140	135
3	140	133	126

AVERAGE VELOCITY = 146

FACE VELOCITY - OBS.

	1	2	3
1	158	254	189
2	185	70	169
3	175	53	165

AVERAGE VELOCITY = 158

TRIAL #	#1l	#2l	#3l			#1h	#2h	#3h	
1	43	57	27			0	0.7	0	
2	105	37	39			13.1	1.8	0.7	
3	70	100	74			10.4	0	0.3	
4	143	79	123			9.5	0	3	
5	94	46	118			8.4	1.7	3.8	
6	103	86	49			11.6	3.3	0	
7	85	38	41			0.4	0.7	3.7	
8	38	98	56			12.1	0	0.9	
9	100	39	82			1.2	1.8	0.6	
10	71	65	90			0	0.9	0.5	
11	46	96	93			0.7	0	2.4	
12	58	27	85			0	1.2	3	
13	48	65	52			6.8	0.5	0	
14	93	76	53			2.6	0.4	6	
15	68	88	9.9			8.9	3.6	3.4	
16	87	72	18.8			5.4	2	0	
17	59	89	14			0.3	0	0.2	
18	76	19.9	106			2.4	1.6	0.9	
19	43	93	43			0.3	1	2.2	
20	87	26	62			0.2	1.3	1.7	
				MEAN					MEAN
PEAK AVERAGES (ppm) =	75.9	64.8	61.8	67.5		4.7	1.1	1.7	2.5
				STD					STD
				6.0					1.5
MINIMUM	38.0	19.9	9.9		MINIMUM	0	0	0	
MAXIMUM	143.0	100.0	123.0		MAXIMUM	13.1	3.6	6.0	
STD. =	26.1	26.1	32.7		STD. =	4.7	1.0	1 7	

B. BAFFLE POSITION #2 - MIDDLE SLOT OPEN

I. CHALLENGE POSITION - LOW

II. CHALLENGE POSITION - HIGH

BREATHING ZONE CONCENTRATIONS -
10 MINUTE PEAK AVERAGES - PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY - UNOBS.

	1	2	3
1	139	218	146
2	138	158	144
3	130	136	138

AVERAGE VELOCITY = 150

FACE VELOCITY - OBS.

	1	2	3
1	165	205	145
2	200	41	199
3	187	58	191

AVERAGE VELOCITY = 155

TRIAL #	#1l	#2l	#3l			#1h	#2h	#3h	
1	2.6	5.4	11.5			0	0	0.4	
2	11.4	43	21			0	0	1.3	
3	0	30	38			0.2	0	0	
4	0.9	9.1	11.2			0	0	0	
5	24	1.5	14.1			0.9	0	0	
6	10.7	0.4	6.4			0.3	0	0.4	
7	11.2	2.2	6.9			7.1	0.3	0	
8	2.5	5.5	7.3			2	3.2	0.1	
9	2.9	26	3.7			0.1	0.2	4.3	
10	1.1	5.8	22			0	0.9	0.4	
11	5.1	7.1	10.5			0	0	1.2	
12	2.2	3.8	8.3			0.9	0	0	
13	2.4	11.2	2.2			0.2	0	0.5	
14	1.1	7.4	32			0	0	1	
15	1.5	8.2	16.9			0.2	0	0	
16	11.5	6.1	40			0.2	0	0.3	
17	2.7	30	44			1.1	0	0	
18	1.5	6.9	0.2			0.2	0.5	2	
19	0.5	1	13.1			0.5	0.3	0.3	
20	4.9	8.7	15.9			0.4	0.3	0.1	
				MEAN					MEAN
PEAK AVERAGES (ppm) =	5.0	11.0	16.3	10.8		0.7	0.3	0.6	0.5
				STD					STD
				4.6					0.2
MINIMUM	0.0	0.4	0.2		MINIMUM	0	0	0	
MAXIMUM	24.0	43.0	44.0		MAXIMUM	7.1	3.2	4.3	
STD. =	5.8	11.4	12.5		STD. =	1.5	0.7	1.0	

C. BAFFLE POSITION #3 - BOTTOM SLOT OPEN I. CHALLENGE POSITION - LOW II. CHALLENGE POSITION - HIGH

BREATHING ZONE CONCENTRATIONS -
10 MINUTE PEAK AVERAGES - PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY - UNOBS.

	1	2	3
1	164	164	149
2	147	161	151
3	135	144	150

AVERAGE VELOCITY = 151

FACE VELOCITY - OBS.

	1	2	3
1	171	139	167
2	193	68	193
3	191	39	195

AVERAGE VELOCITY = 151

TRIAL #	#1l	#2l	#3l			#1h	#2h	#3h	
1	0	0	0			0	0	0	
2	0	0	0			0.1	0	0	
3	0	0	0			0.1	0.4	0	
4	0	0	0			0	0	0.1	
5	0	0	0			0.2	0	0.2	
6	0	0	0			0.2	0	0	
7	0	0	0			0	0	0	
8	0	0	0			0	0	0.3	
9	0	0	0			0	0	0	
10	0	0	0			0	0	0	
11	0	0	0			0.1	0.1	0	
12	0	0	0			0	0	0	
13	0	0	0			0.1	0.1	0	
14	0	0	0			0	0.2	0	
15	0	0	0			0	0	0	
16	0	0	0			0	0	0	
17	0	0	0			0	0.1	0	
18	0	0	0			0.2	0	0.1	
19	0	0	0			0	0	0	
20	0	0	0			0	0	0	
				MEAN					MEAN
PEAK AVERAGES (ppm) =	0	0	0	0		0.05	0.05	0.04	0.04
				STD					STD
				0					0.01
MINIMUM	0	0	0		MINIMUM	0	0	0	
MAXIMUM	0	0	0		MAXIMUM	0.20	0.40	0.30	
STD. =	0	0	0		STD. =	0.07	0.10	0.08	

Appendix IX. Leakage Concentration Data for Hood at 850 cfm in Room C158

SAMPLING STRATEGY 2/24/90 TEMP = 21.1 C

C14B

HOOD EXHAUST VOLUME – 750 +/- 20 CFM

HOOD AUXILLIARY VOLUME – 350 +/- 20 CFM PERCENT 0.47

I. CHALLENGE POSITION – LOW II. CHALLENGE POSITION – HIGH

BREATHING ZONE CONCENTRATIONS –
10 MINUTE TWA – PPM
@ 30 SECOND INTERVALS

A. BAFFLE POSITION #1 – TOP SLOT OPEN

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY – UNOBS.

	1	2	3
1	95	111	102
2	55	106	54
3	15	60	30

AVERAGE VELOCITY = 70

FACE VELOCITY – OBS.

	1	2	3
1	100	118	116
2	64	59	70
3	35	40	28

AVERAGE VELOCITY = 70

TRIAL #	#1l	#2l	#3l		#1h	#2h	#3h	
1	1	2.4	2.1		0.9	0.4	0.3	
2	2.1	1.3	0.2		0.2	0.6	0.4	
3	1.1	0.1	3.5		0	0.9	0.1	
4	1.1	0.7	4.8		0	1.2	0	
5	0.1	2.5	0.3		0	0	0.2	
6	2.2	5.8	8.4		0	1.4	1.2	
7	7.7	0	0.6		0	0.1	0.5	
8	0.2	30	7.2		0.2	2.1	0	
9	3.7	0.2	0		0.5	0	0.5	
10	1.5	1.2	12		0.3	0	0	
11	3.4	0.1	4.2		0.2	0.2	0.4	
12	2.7	3.2	0.1		1.8	0.2	1.2	
13	23	1.1	2.9		0	0	0.6	
14	2.6	1.7	2.1		1.3	0	0.1	
15	0	2.9	1.5		0.1	0.2	0	
16	1.3	7	1.2		0.9	0	0.8	
17	3	1.1	0.6		1.9	0.1	1.5	
18	1.4	2.1	8		0.1	0	0.6	
19	0.4	8	5.5		0.5	0.5	0.8	
20	9.8	0.6	0.9		0.2	1	0.4	
				MEAN				MEAN
TIME WEIGHTED AVERAGE (ppm) =	3.4	3.6	3.3	3.4	0.5	0.4	0.5	0.5
				STD				STD
				0.12				0.017
MINIMUM	0	0	0	MINIMUM	0	0	0	
MAXIMUM	23.0	30.0	12.0	MAXIMUM	1.9	2.1	1.5	
STD. =	5.1	6.4	3.3	STD. =	0.6	0.6	0.4	

B. BAFFLE POSITION #2 – MIDDLE SLOT OPEN

I. CHALLENGE POSITION – LOW   II. CHALLENGE POSITION – HIGH

BREATHING ZONE CONCENTRATIONS –
10 MINUTE TWA – PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY – UNOBS.

	1	2	3
1	94	84	119
2	55	118	53
3	27	73	30

AVERAGE VELOCITY = 72

FACE VELOCITY – OBS.

	1	2	3
1	111	125	117
2	55	68	65
3	15	40	27

AVERAGE VELOCITY = 69

TRIAL #

	#1l	#2l	#3l			#1h	#2h	#3h	
1	0.2	0.1	0.3			0	0	0	
2	0.1	0.9	1			0.1	0.1	0	
3	0.4	0.1	0.5			0.3	0	0	
4	0.3	0	0.1			0	0	0	
5	0.1	0	0.4			0	0	0	
6	2.3	0.4	6			0	0	0	
7	0.1	0.9	0.5			0	0	0	
8	2.5	0.7	0			0	0	0	
9	0.3	0.4	0.5			0	0	0	
10	0.1	0	0			0	0	0	
11	0.6	2.1	0.1			0	0	0	
12	0.2	0.2	1			0	0	0	
13	7.4	0.2	2.1			0	0	0	
14	0	0.1	0.9			0	0	0	
15	0	0.3	0.5			0	0	0	
16	0.2	1.9	1.5			0	0	0	
17	0.3	2.4	0.6			0	0	0	
18	0.1	0.2	0.2			0	0	0	
19	0	0	0			0	0	0	
20	0.3	0	0.1			0	0	0	
				MEAN					MEAN
TIME WEIGHTED AVERAGE (ppm) =	0.78	0.55	0.82	0.71		0.02	0.005	0	0.008
				STD					STD
				0.12					0.008
MINIMUM	0	0	0		MINIMUM	0	0	0	
MAXIMUM	7.4	2.4	6		MAXIMUM	0.3	0.1	0	
STD. =	1.66	0.72	1.30		STD. =	0.07	0.02	0	

C. BAFFLE POSITION #3 - BOTTOM SLOT OPEN

I. CHALLENGE POSITION - LOW II. CHALLENGE POSITION - HIGH

BREATHING ZONE CONCENTRATIONS -
10 MINUTE TWA - PPM
@ 30 SECOND INTERVALS

CONCENTRATION. 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY - UNOBS.

	1	2	3
1	97	72	107
2	50	116	50
3	30	76	30

AVERAGE VELOCITY = 70

FACE VELOCITY - OBS.

	1	2	3
1	99	101	111
2	53	75	65
3	35	32	57

AVERAGE VELOCITY = 70

TRIAL #	#1l	#2l	#3l		#1h	#2h	#3h	
1	0	0	0		0	0	0	
2	0	0	0		0	0	0	
3	0	0	0		0	0	0	
4	0	0	0		0	0	0	
5	0	0	0		0	0	0	
6	0	0	0		0	0	0	
7	0	0	0		0	0	0	
8	0	0	0		0	0	0	
9	0	0	0		0	0	0	
10	0	0	0		0	0	0	
11	0	0	0		0	0	0	
12	0	0	0		0	0	0	
13	0	0	0		0	0	0	
14	0	0	0		0	0	0	
15	0	0	0		0	0	0	
16	0	0	0		0	0	0	
17	0	0	0		0	0	0	
18	0	0	0		0	0	0	
19	0	0	0		0	0	0	
20	0	0	0		0	0	0	
				MEAN				MEAN
TIME WEIGHTED AVERAGE (ppm) =	0	0	0	0	0	0	0	0
				STD				STD
				0				0
MINIMUM	0	0	0	MINIMUM	0	0	0	
MAXIMUM	0	0	0	MAXIMUM	0	0	0	
STD. =	0	0	0	STD. =	0	0	0	

Appendix X. Leakage Concentration Data for Hood at 750 cfm in Room C148

SAMPLING STRATEGY
C158
HOOD EXHAUST VOLUME – 850 +/- 20 CFM
HOOD AUXILLIARY VOLUME – 420 +/- 20 CFM

TEMP = 21.1 C

PERCENT 0.49

I. CHALLENGE POSITION – LOW

II. CHALLENGE POSITION – HIGH

BREATHING ZONE CONCENTRATIONS –
10 MINUTE AVERAGE PEAK VALUES – PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

A. BAFFLE POSITION #1 – TOP SLOT OPEN

FACE VELOCITY – UNOBS.

	1	2	3
1	114	196	125
2	105	115	112
3	92	88	100

AVERAGE VELOCITY = 116

FACE VELOCITY – OBS.

	. 1	2	3
1	140	163	143
2	127	78	157
3	126	35	115

AVERAGE VELOCITY = 120

TRIAL #

	#1l	#2l	#3l		#1h	#2h	#3h	
1	1.6	0.9	0		0	0	0.1	
2	0	2.6	2.1		0	0	0	
3	4	0.8	8.2		0	0	0	
4	0.1	0.8	2.1		0	0	0	
5	0.5	1.7	4.5		2.6	0.5	0	
6	0.3	0.6	0.5		0	0	0.5	
7	1.2	0.2	1.3		3.1	0	0	
8	0.5	0.3	0		2.8	0	0	
9	0.9	3.9	0.3		0.1	0.1	0.3	
10	0	1.2	5.3		2.4	0	0	
11	2.5	0.2	1.9		0	0.5	0	
12	2.4	2.6	2		2.9	0	0	
13	0.3	0	2.3		0.2	0	1.3	
14	1.3	4.8	1.5		7.3	0	0	
15	0.2	0	0.9		9	0	0	
16	0.2	0	5.3		0	0	0	
17	1.5	0	0.9		3.1	0.2	1	
18	0	0.3	1.7		1.3	0	1	
19	5.5	1.6	4		0	0.2	0.2	
20	0.3	2.6	0		4	0.6	0	
				MEAN				MEAN
AVERAGE PEAK VALUE (ppm) =	1.2	1.3	2.2	1.6	1.9	0.1	0.2	0.8
				STD				STD
				0.5				0.8
MINIMUM	0	0	0	MINIMUM	0	0	0	
MAXIMUM	5.5	4.8	8.2	MAXIMUM	9.0	0.6	1.3	
STD. =	1.4	1.4	2.1	STD. =	2.5	0.2	0.4	

SAMPLING STRATEGY
C158
HOOD EXHAUST VOLUME - 850 +/- 20 CFM
HOOD AUXILLIARY VOLUME - 420 +/- 20 CFM

TEMP = 21.1 C

PERCENT 0.49

I. CHALLENGE POSITION - LOW

II. CHALLENGE POSITION - HIGH

BREATHING ZONE CONCENTRATIONS -
10 MINUTE AVERAGE PEAK VALUES - PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

A. BAFFLE POSITION #1 - TOP SLOT OPEN

FACE VELOCITY - UNOBS.

	1	2	3
1	114	196	125
2	105	115	112
3	92	88	100

AVERAGE VELOCITY = 116

FACE VELOCITY - OBS.

	1	2	3
1	140	163	143
2	127	78	157
3	126	35	115

AVERAGE VELOCITY = 120

TRIAL #	#1l	#2l	#3l			#1h	#2h	#3h	
1	1.6	0.9	0			0	0	0.1	
2	0	2.6	2.1			0	0	0	
3	4	0.8	8.2			0	0	0	
4	0.1	0.8	2.1			0	0	0	
5	0.5	1.7	4.5			2.6	0.5	0	
6	0.3	0.6	0.5			0	0	0.5	
7	1.2	0.2	1.3			3.1	0	0	
8	0.5	0.3	0			2.8	0	0	
9	0.9	3.9	0.3			0.1	0.1	0.3	
10	0	1.2	5.3			2.4	0	0	
11	2.5	0.2	1.9			0	0.5	0	
12	2.4	2.6	2			2.9	0	0	
13	0.3	0	2.3			0.2	0	1.3	
14	1.3	4.8	1.5			7.3	0	0	
15	0.2	0	0.9			9	0	0	
16	0.2	0	5.3			0	0	0	
17	1.5	0	0.9			3.1	0.2	1	
18	0	0.3	1.7			1.3	0	1	
19	5.5	1.6	4			0	0.2	0.2	
20	0.3	2.6	0			4	0.6	0	
				MEAN					MEAN
AVERAGE PEAK VALUE (ppm) =	1.2	1.3	2.2	1.6		1.9	0.1	0.2	0.8
				STD					STD
				0.5					0.8
MINIMUM	0	0	0		MINIMUM	0	0	0	
MAXIMUM	5.5	4.8	8.2		MAXIMUM	9.0	0.6	1.3	
STD. =	1.4	1.4	2.1		STD. =	2.5	0.2	0.4	

B. BAFFLE POSITION #2 – MIDDLE SLOT OPEN

I. CHALLENGE POSITION – LOW

II. CHALLENGE POSITION – HIGH

BREATHING ZONE CONCENTRATIONS –
10 MINUTE AVERAGE PEAK VALUES – PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY – UNOBS.

	1	2	3
1	126	187	118
2	96	126	118
3	90	93	99

AVERAGE VELOCITY = 117

FACE VELOCITY – OBS.

	1	2	3
1	157	179	128
2	130	86	155
3	125	25	131

AVERAGE VELOCITY = 124

TRIAL #	#1l	#2l	#3l			#1h	#2h	#3h	
1	1.8	0.7	0.9			0	0	0	
2	0	0.3	1			0.1	0	0	
3	4.4	0.5	0			0	0	0	
4	0	0	0.5			0	0	0	
5	0	1.7	0.6			0	0	0	
6	0.4	1.3	0			0	0	0	
7	0.2	1.7	0.1			0	0.1	0	
8	1	0.6	0.4			0	0	0	
9	1.1	0	0			0	0	0	
10	0.5	1.5	1.1			1.1	0	0	
11	0	3.1	1.3			0	0	0	
12	1.2	0	0.4			0	0	0	
13	0	0.4	4.2			0	0	0	
14	0	3.1	0.5			0	0	0	
15	9.3	0.9	1.1			0	0.1	0	
16	0.3	0.7	2.2			0	0	0	
17	0.8	0.4	0.5			0	0	0	
18	0	0.6	0			0	0	0	
19	0	0.8	2.1			0	0	0	
20	0.7	0	0.1			0	0	0	
				MEAN					MEAN
AVERAGE PEAK VALUE (ppm) =	1.1	0.9	0.9	0.95		0.06	0.01	0	0.02
				STD					STD
				0.10					0.03
MINIMUM	0	0	0		MINIMUM	0	0	0	
MAXIMUM	9.3	3.1	4.2		MAXIMUM	1.1	0.1	0	
STD. =	2.13	0.89	1.00		STD. =	0.24	0.03	0	

C. BAFFLE POSITION #3 – BOTTOM SLOT OPEN

I. CHALLENGE POSITION – LOW

II. CHALLENGE POSITION – HIGH

BREATHING ZONE CONCENTRATIONS –
10 MINUTE AVERAGE PEAK VALUES – PPM
@ 30 SECOND INTERVALS

CONCENTRATION: 0 = < 0.1 ppm OR BELOW DETECTION LIMIT

FACE VELOCITY – UNOBS.

	1	2	3
	1	2	3
1	102	117	113
2	101	131	111
3	107	98	110

AVERAGE VELOCITY = 110

FACE VELOCITY – OBS.

	1	2	3
1	102	157	124
2	142	64	140
3	133	45	138

AVERAGE VELOCITY = 116

TRIAL #

	#1l	#2l	#3l		#1h	#2h	#3h	
1	0	0	0		0	0	0	
2	0.3	0	0		0	0	0	
3	0	0	0		0	0	0	
4	0	0	0		0	0	0	
5	0	0	0		0	0	0	
6	0	0	0		0	0	0	
7	0	0	0		0	0	0	
8	0	0	0		0	0	0	
9	0	0	0		0	0	0	
10	0	0	0		0	0	0	
11	0	0	0		0	0	0	
12	0	0	0		0	0	0	
13	0	0	0		0	0	0	
14	0	0	0		0	0	0	
15	0	0	0		0	0	0	
16	0	0	0		0	0	0	
17	0	0	0		0	0	0	
18	0	0	0		0	0	0	
19	0	0	0		0	0	0	
20	0	0	0		0	0	0	
				MEAN				MEAN
AVERAGE PEAK VALUE (ppm) =	0.02	0	0	0.005	0	0	0	0
				STD				STD
				0.007				0
STD. =	0.07	0	0	STD. =	0	0	0	

Appendix XI. Leakage and Velocity Data For Blockage Tests

HOOD EXHAUST VOLUME - 1100 +/- 20 CFM
HOOD AUXILLIARY VOLUME - 630 +/- 20 CFM PERCENT 0.57

A. BAFFLE POSITION #1 - TOP SLOT OPEN

BREATHING ZONE CONCENTRATIONS -
10 MINUTE AVERAGE PEAK VALUES - PPM
@ 30 SECOND INTERVALS

I. CHALLENGE POSITION - LOW

	BLOCKAGE				
	0 %	50 %	100 %	SHELF	
1	32	8.2	88	18.1	
2	65	13.5	7.6	8.4	
3	35	7.3	21	17.3	
4	4.5	62	93	29	
5	5.6	20	127	75	
6	32	27	33	26	
7	23	25	23	93	
8	7.8	52	46	57	
9	3.7	86	57	89	
10	28	3	34	60	
11	4.5	12.7	113	132	
12	7.5	50	35	29	
13	16.4	26	56	48	
14	86	29	105	97	
15	64	12.2	123	80	
16	29	45	41	129	
17	56	29	67	56	
18	44	13.2	79	31	
19	5.2	49	16.4	67	
20	25	135	57	40	
					MEAN
AVERAGE PEAK VALUE (ppm) =	28.7	35.3	61.1	59.1	41.69
					STD
					13.98
MINIMUM =	3.7	3	7.6	8.4	
MAXIMUM =	86	135	127	132	
STD. =	23.30	30.94	35.85	35.09	

FACE VELOCITY TRAVERSE DATA FOR HOOD @1100 cfm

UNOBSTRUCTED

FACE VELOCITY – fpm

	1	2	3
1	159	240	146
2	144	147	143
3	133	130	135

AVERAGE VELOCITY = 153

% DIFFERENCE = 58.98

50 % BLOCKAGE

FACE VELOCITY – fpm

	1	2	3
1	157	233	142
2	143	136	143
3	132	130	136

AVERAGE VELOCITY = 150

% DIFFERENCE = 56.44

100 % BLOCKAGE

FACE VELOCITY – fpm

	1	2	3
1	144	239	142
2	146	156	152
3	132	137	124

AVERAGE VELOCITY = 152

% DIFFERENCE = 61.99

SHELF

FACE VELOCITY – fpm

	1	2	3
1	157	242	142
2	145	140	141
3	131	131	135

AVERAGE VELOCITY = 152

% DIFFERENCE = 59.52

B. BAFFLE POSITION #3 - BOTTOM SLOT OPEN

BREATHING ZONE CONCENTRATIONS -
10 MINUTE AVERAGE PEAK VALUES - PPM
@ 30 SECOND INTERVALS

I. CHALLENGE POSITION - LOW

	BLOCKAGE 0 %	50 %	100 %	SHELF	
1	0	0	2	0	
2	0	0	0	0	
3	0	0	4	0	
4	0	0	1.1	0	
5	0	0	0	0	
6	0	0	2.8	0	
7	0	0	0	0	
8	0	0	1.4	0	
9	0	0	0	0	
10	0	0	0	0	
11	0	0	0	0	
12	0	0	0	0	
13	0	0	0	0	
14	0	0	0	0	
15	0	0	0	0	
16	0	0	0	0	
17	0	0	1.2	0	
18	0	0	0	0	
19	0	0	1.7	0	
20	0	0	3.1	0	
					MEAN
AVERAGE PEAK VALUE (ppm) =	0.0	0.0	0.9	0.0	0.29
					STD
					0.41
MINIMUM =	0	0	0	0	
MAXIMUM =	0	0	4	0	
STD. =	0	0	1.22	0.00	

FACE VELOCITY TRAVERSE DATA FOR HOOD @1100 cfm
BAFFLE POSITION #3

UNOBSTRUCTED
FACE VELOCITY - fpm

	1	2	3
1	148	196	147
2	145	159	150
3	151	146	152

AVERAGE VELOCITY = 155
% DIFFERENCE = 29.91

50 % BLOCKAGE
FACE VELOCITY - fpm

	1	2	3
1	145	170	145
2	145	155	150
3	144	142	149

AVERAGE VELOCITY = 149
% DIFFERENCE = 17.83

100 % BLOCKAGE
FACE VELOCITY - fpm

	1	2	3
1	150	170	147
2	148	165	144
3	139	150	150

AVERAGE VELOCITY = 151
% DIFFERENCE = 20.06

SHELF
FACE VELOCITY - fpm

	1	2	3
1	149	138	131
2	143	162	150
3	153	148	152

AVERAGE VELOCITY = 147
% DIFFERENCE = 20.33

Appendix XII. Statistical Results and Tables

COUNT	TRIAL	BAFFLE	HEIGHT	FLOW	BZCONC
1	1	TOP SLOT OPEN	LOW - 2"	1100 CFM	75.90
2	2	TOP SLOT OPEN	LOW - 2"	1100 CFM	64.80
3	3	TOP SLOT OPEN	LOW - 2"	1100 CFM	61.80
4	1	MIDDLE SLOT OPEN	LOW - 2"	1100 CFM	5.00
5	2	MIDDLE SLOT OPEN	LOW - 2"	1100 CFM	11.00
6	3	MIDDLE SLOT OPEN	LOW - 2"	1100 CFM	16.30
7	1	BOTTOM SLOT OPEN	LOW - 2"	1100 CFM	0.00
8	2	BOTTOM SLOT OPEN	LOW - 2"	1100 CFM	0.00
9	3	BOTTOM SLOT OPEN	LOW - 2"	1100 CFM	0.00
10	1	TOP SLOT OPEN	HIGH - 8"	1100 CFM	4.70
11	2	TOP SLOT OPEN	HIGH - 8"	1100 CFM	1.10
12	3	TOP SLOT OPEN	HIGH - 8"	1100 CFM	1.70
13	1	MIDDLE SLOT OPEN	HIGH - 8"	1100 CFM	0.70
14	2	MIDDLE SLOT OPEN	HIGH - 8"	1100 CFM	0.30
15	3	MIDDLE SLOT OPEN	HIGH - 8"	1100 CFM	0.60
16	1	BOTTOM SLOT OPEN	HIGH - 8"	1100 CFM	0.05
17	2	BOTTOM SLOT OPEN	HIGH - 8"	1100 CFM	0.05
18	3	BOTTOM SLOT OPEN	HIGH - 8"	1100 CFM	0.04
19	1	TOP SLOT OPEN	LOW - 2"	850 CFM	1.20
20	2	TOP SLOT OPEN	LOW - 2"	850 CFM	1.30
21	3	TOP SLOT OPEN	LOW - 2"	850 CFM	2.20
22	1	MIDDLE SLOT OPEN	LOW - 2"	850 CFM	1.10
23	2	MIDDLE SLOT OPEN	LOW - 2"	850 CFM	0.90
24	3	MIDDLE SLOT OPEN	LOW - 2"	850 CFM	0.90
25	1	BOTTOM SLOT OPEN	LOW - 2"	850 CFM	0.00
26	2	BOTTOM SLOT OPEN	LOW - 2"	850 CFM	0.00
27	3	BOTTOM SLOT OPEN	LOW - 2"	850 CFM	0.00
28	1	TOP SLOT OPEN	HIGH - 8"	850 CFM	1.90
29	2	TOP SLOT OPEN	HIGH - 8"	850 CFM	0.10
30	3	TOP SLOT OPEN	HIGH - 8"	850 CFM	0.20
31	1	MIDDLE SLOT OPEN	HIGH - 8"	850 CFM	0.10
32	2	MIDDLE SLOT OPEN	HIGH - 8"	850 CFM	0.00
33	3	MIDDLE SLOT OPEN	HIGH - 8"	850 CFM	0.00
34	1	BOTTOM SLOT OPEN	HIGH - 8"	850 CFM	0.00
35	2	BOTTOM SLOT OPEN	HIGH - 8"	850 CFM	0.00
36	3	BOTTOM SLOT OPEN	HIGH - 8"	850 CFM	0.00
37	1	TOP SLOT OPEN	LOW - 2"	750 CFM	3.40
38	2	TOP SLOT OPEN	LOW - 2"	750 CFM	3.60
39	3	TOP SLOT OPEN	LOW - 2"	750 CFM	3.30
40	1	MIDDLE SLOT OPEN	LOW - 2"	750 CFM	0.80
41	2	MIDDLE SLOT OPEN	LOW - 2"	750 CFM	0.50
42	3	MIDDLE SLOT OPEN	LOW - 2"	750 CFM	0.80
43	1	BOTTOM SLOT OPEN	LOW - 2"	750 CFM	0.00
44	2	BOTTOM SLOT OPEN	LOW - 2"	750 CFM	0.00
45	3	BOTTOM SLOT OPEN	LOW - 2"	750 CFM	0.00
46	1	TOP SLOT OPEN	HIGH - 8"	750 CFM	0.50
47	2	TOP SLOT OPEN	HIGH - 8"	750 CFM	0.40
48	3	TOP SLOT OPEN	HIGH - 8"	750 CFM	0.50
49	1	MIDDLE SLOT OPEN	HIGH - 8"	750 CFM	0.00
50	2	MIDDLE SLOT OPEN	HIGH - 8"	750 CFM	0.00
51	3	MIDDLE SLOT OPEN	HIGH - 8"	750 CFM	0.00
52	1	BOTTOM SLOT OPEN	HIGH - 8"	750 CFM	0.00
53	2	BOTTOM SLOT OPEN	HIGH - 8"	750 CFM	0.00
54	3	BOTTOM SLOT OPEN	HIGH - 8"	750 CFM	0.00

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
THREE TRIALS WERE PERFORMED UNDER EACH CONDITION

GENERAL LINEAR MODELS PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
BAFFLE	3	B1 B2 B3
HEIGHT	2	H1 H2
FLOW	3	F1 F2 F3

NUMBER OF OBSERVATIONS IN DATA SET = 54

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
THREE TRIALS WERE PERFORMED UNDER EACH CONDITION

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: BZCONC

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	17	12757.89861481	750.46462440	146.36
ERROR	36	184.59340000	5.12759444	PR > F
CORRECTED TOTAL	53	12942.49201481		0.0001

R-SQUARE	C.V.	ROOT MSE	BZCONC MEAN
0.985737	45.6707	2.26441923	4.95814815

SOURCE	DF	TYPE I SS	F VALUE	PR > F
BAFFLE	2	1660.22650370	161.89	0.0001
HEIGHT	1	1083.26406667	211.26	0.0001
FLOW	2	1997.17050370	194.75	0.0001
BAFFLE*HEIGHT	2	1353.86591111	132.02	0.0001
BAFFLE*FLOW	4	2589.63167407	126.26	0.0001
HEIGHT*FLOW	2	1751.53613333	170.80	0.0001
BAFFLE*HEIGHT*FLOW	4	2322.20382222	113.22	0.0001

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
Pairwise comparisons within HEIGHT and BAFFLE POSITION
between FLOW

HEIGHT HIGH - 8"

	BAFFLE								
	BOTTOM SLOT OPEN			MIDDLE SLOT OPEN			TOP SLOT OPEN		
	BZCONC			BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
FLOW									
750 CFM	3	0.00	0.000	3	0.00	0.000	3	0.47	0.033
850 CFM	3	0.00	0.000	3	0.03	0.033	3	0.73	0.584
1100 CFM	3	0.05	0.003	3	b 0.53	0.120	3	a 2.50	1.114

HEIGHT LOW - 2"

	BAFFLE								
	BOTTOM SLOT OPEN			MIDDLE SLOT OPEN			TOP SLOT OPEN		
	BZCONC			BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
FLOW									
750 CFM	3	0.00	0.000	3	0.70	0.100	3	3.43	0.088
850 CFM	3	0.00	0.000	3	0.97	0.067	3	c 1.57	0.318
1100 CFM	3	0.00	0.000	3	a10.77	3.264	3	a67.50	4.288

a) $P < .01$ vs. both 750 and 850 cfm.
b) $P < .01$ vs. 750 cfm and $P < .05$ vs. 850 cfm.
c) $P < .05$ vs. 750 cfm

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
Pairwise comparisons within FLOW and HEIGHT
between BAFFLE POSITIONs

FLOW 750 CFM

	HEIGHT					
	HIGH - 8"			LOW - 2"		
	BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR
BAFFLE						
BOTTOM SLOT OPEN	3	0.00	0.000	3	0.00	0.000
MIDDLE SLOT OPEN	3	0.00	0.000	3	b 0.70	0.100
TOP SLOT OPEN	3	c 0.47	0.033	3	a 3.43	0.088

FLOW 850 CFM

	HEIGHT					
	HIGH - 8"			LOW - 2"		
	BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR
BAFFLE						
BOTTOM SLOT OPEN	3	0.00	0.000	3	d 0.00	0.000
MIDDLE SLOT OPEN	3	e 0.03	0.033	3	0.97	0.067
TOP SLOT OPEN	3	b 0.73	0.584	3	1.57	0.318

a) $P < .01$ vs. both BOTTOM and MIDDLE
b) $P < .01$ vs. BOTTOM
c) $P < .05$ vs. both BOTTOM and MIDDLE
d) $P < .01$ vs. both TOP and MIDDLE
e) $P < .05$ vs. TOP

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
Pairwise comparisons within FLOW and HEIGHT
between BAFFLE POSITIONs (cont'd)

FLOW 1100 CFM

	HEIGHT					
	HIGH - 8"			LOW - 2"		
	BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR
BAFFLE						
BOTTOM SLOT OPEN	3	0.05	0.003	3	0.00	0.000
MIDDLE SLOT OPEN	3	0.53	0.120	3	b10.77	3.264
TOP SLOT OPEN	3	a 2.50	1.114	3	a67.50	4.288

a) P < .01 vs. both BOTTOM and MIDDLE
b) P < .01 vs. BOTTOM

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
Pairwise comparisons within BAFFLE POSITION and FLOW
between HEIGHTs

BAFFLE BOTTOM SLOT OPEN

	FLOW								
	750 CFM			850 CFM			1100 CFM		
	BZCONC			BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
HEIGHT									
LOW - 2"	3	0.00	0.000	3	0.00	0.000	3	0.00	0.000
HIGH - 8"	3	0.00	0.000	3	0.00	0.000	3	0.05	0.003

BAFFLE MIDDLE SLOT OPEN

	FLOW								
	750 CFM			850 CFM			1100 CFM		
	BZCONC			BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
HEIGHT									
LOW - 2"	3	a 0.70	0.100	3	a 0.97	0.067	3	a10.77	3.264
HIGH - 8"	3	0.00	0.000	3	0.03	0.033	3	0.53	0.120

a) P < .01 vs. HIGH.

STATISTICAL ANALYSIS FOR LABORATORY HOOD EXPERIMENT
Pairwise comparisons within BAFFLE POSITION and FLOW
between HEIGHTs (cont'd)

BAFFLE TOP SLOT OPEN

	FLOW								
	750 CFM			850 CFM			1100 CFM		
	BZCONC			BZCONC			BZCONC		
	N	MEAN	STDERR	N	MEAN	STDERR	N	MEAN	STDERR
HEIGHT									
LOW - 2"	3	a 3.43	0.088	3	1.57	0.318	3	a67.50	4.288
HIGH - 8"	3	0.47	0.033	3	0.73	0.584	3	2.50	1.114

a) P < .01 vs. HIGH.

Appendix XIII. Photographs of Air Flow

Figure 26 - Photo A. Auxiliary supply flow for baffle position #3 with the sash up.

Figure 27 - Photo B. Auxiliary supply flow for baffle position #3 with the sash down.

Figure 28 - Photo C. Auxiliary supply flow for baffle position #1 with the sash up.

Figure 29 - Photo D. Auxiliary supply flow for baffle position #1 with the sash down.

Figure 30 - Photo E. Unobstructed flow for baffle position #1.

Figure 31 - Photo F. Unobstructed flow after time for baffle position #1.

Figure 32 - Photo G. Flow for baffle position #1 with mannequin present.

Figure 33 - Photo H. Flow after time for baffle position #1 with mannequin present.

Figure 34 - Photo I. Unobstructed flow for baffle position #3.

Figure 35 - Photo J. Unobstructed flow after time for baffle position #3.

Figure 36 - Photo K. Flow for baffle position #3 with mannequin present.

Figure 37 - Photo L. Flow after time for baffle position #3 with mannequin present.