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Effects of face velocity, cross-draft velocity and interventions on the performance of a benchtop enclosing hood

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Effects of Face Velocity, Cross-Draft Velocity and Interventions on the Performance of A Benchtop Enclosing Hood

By
Xinjian He

Thesis submitted to
The College of Engineering and Mineral Resources
at West Virginia University

In partial fulfillment of the requirements for the degree of
Master of Science
In
Industrial Hygiene and Safety

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2010

Keywords: Tracer gas study, Ventilation, Manikin, Exposure assessment

Abstract

“Effects of Face Velocity, Cross-Draft Velocity and Interventions on the Performance of A Benchtop Enclosing Hood”

Xinjian He

In industry, benchtop enclosing hoods are critical in protecting workers from airborne contaminants, but there is little research published about industrial enclosing hoods. Almost all hood research has been done on laboratory fume hoods.

A tracer gas method was used to study the performance of a single benchtop enclosing hood tested inside a 9 *ft* high, 12 *ft* wide and 40 *ft* long wind tunnel. Freon-134a concentrations were measured on an anthropometrically scaled, heated, breathing manikin holding a source between its hands while standing at the enclosing hood's face. Samples were taken at the nose (C_{nose}), mouth (C_{mouth}), inlet of the wind tunnel ($C_{ambient}$), downstream of the wind tunnel ($C_{downstream}$) and the exhaust duct (C_{duct}). Each location was sampled at 0.15 *LPM* for 20 minutes.

The work was divided into two studies, each having a complete factorial design and two replicates of each treatment combination. Study-I tested the effects of hood face velocity at five levels (111, 140, 170, 200 and 229 *fpm*) and wind tunnel cross-draft velocity at five levels (14, 26, 36, 46 and 57 *fpm*) on the plain enclosing hood performance. Study-II determined the effects of different interventions added to the face of the same enclosing hood.

The results showed that hood face velocity, wind tunnel cross-draft velocity and different interventions had significant effects on the concentrations at C_{nose} and C_{mouth} . Flanges, cowls, and most other interventions failed to consistently reduce exposures and often exacerbated them. However, the customized sash reduced exposures to nearly zero. It is also found that higher face velocity and cross-draft velocity were associated with lower C_{nose} and C_{mouth} .

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Abbreviations

WT	Wind tunnel
V_{face}	Enclosing hood face velocity
V_{cross}	Wind tunnel cross-draft velocity
$C_{ambient, L}$	Concentration at left entrance location of WT
$C_{ambient, R}$	Concentration at right entrance location of WT
$C_{downstream}$	Concentration at downstream of inside WT
C_{nose}	Concentration at manikin nose location
C_{mouth}	Concentration at manikin mouth location
C_{duct}	Concentration at exhaust duct location
LPM	Liter per minute
fpm	feet per minute
ppm	parts per million
η_{pro}	Hood protection efficiency
η_{cap}	Hood capture efficiency

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Chapter 1: Introduction

In industry, benchtop enclosing hoods are critical for protecting workers from airborne contaminants. Generally, these hoods are boxes with a plenum in the back leading to a tapered takeoff, (see Figure 1.1). The performance of an enclosing hood represents its ability to capture, contain, and remove the airborne contaminants generated inside the hood. In this study, performance was determined from tracer gas concentrations at a manikin's mouth and nose.

1.1 Background and Significance

Benchtop enclosing hoods are widely used to control airborne contaminants in industrial processes, since they can effectively reduce worker exposure if the hood performs well.

Many factors affect the performance of enclosing hoods (Brent A. Altemose, 1998). Some are dependent on work practices, such as arm movements of the user, and the source characteristics. Physical characteristics, such as the shape of the hood

Figure 1.1: Benchtop Enclosing Hood

opening and baffle locations, also can affect the effectiveness of the hood. Furthermore, the location of a hood can expose it to disruptive cross drafts across the face, especially if it is near air supply diffusers, doorways, windows, or aisles. Finally, operating parameters, such as exhaust flow rate and face velocity, have long been thought to be very important to hood performance (Kwangseog Ahn et al., 2008).

However, opinions have been supported by very little published research on the effectiveness of the simple enclosing hoods that are used so commonly in industry (Guffey, 1994). Almost all hood research has been conducted on laboratory fume hoods. Due to the differences in airflow patterns induced by the sash of laboratory fume hoods, results from lab hood studies could be very misleading if applied to plain enclosing hoods.

Given the complete lack of published surveys of hood performance and lack of predictive models of their performance, practitioners have little solid guidance in designing small enclosing hoods.

1.2 Research Goals and Approach

This research investigated factors affecting the performance of one benchtop enclosing hood. The following factors are involved in this research:

- Hood face velocity (V_{face})
- Wind tunnel cross-draft velocity (V_{cross})
- Interventions, including: collar flange, bottom flange, cowling and a custom sash.

Since enclosing hoods are intended to minimize exposure of individuals working at the hood, testing should measure exposure. Accordingly, tracer gas tests were used on this study, with a heated, breathing manikin standing at the face of the enclosing hood (see Figure 1.2). The objectives of this research effort include the following:

1. Determine the effects of face velocity combined with wind tunnel cross-draft velocity for a plain, benchtop enclosing hood on C_{nose} and C_{mouth} .

2. Determine hood performance for the same hood with either a flange, cowl, or sash added.

Figure 1.2: Bench-Top Hood with A Manikin In The “Working” Position At The Hood Face

To achieve these goals, a full sized mannequin was used while it was in a “working” posture standing at the face of the hood (see Figure 1.2). The mannequin was heated and “breathed”. A tracer gas, Freon-134a mixed with helium, was released from a 9 in. circular pan placed at the front of the enclosing hood. The mannequin and hood were placed so that the hood was perpendicular to the flow of air through the wind tunnel. Samples were taken at the nose (C_{nose}), mouth (C_{mouth}), outside the wind tunnel ($C_{ambient}$), downstream of the wind tunnel ($C_{downstream}$), and from the exhaust duct (C_{duct}). Samples were analyzed by a Gasmet Fourier transform infrared (FT-IR) gas analyzer to determine concentrations. By comparing the results of all tests, the effects of different factors on the effectiveness of the enclosing hood were determined.

Chapter 2: Literature Review

Forty-three studies found in the literature reported on experimental investigations of the effects of various factors on lab hood performance. Each used either a tracer gas or aerosols as the contaminant source (Ahn et al., 2008). Only one study involved a plain benchtop enclosing hood (Guffey and Barnea, 1994). Clearly, there is a need for additional studies of plain enclosing hood effectiveness.

2.1 Effects of Hood Face Velocity (V_{face})

Historically, evaluating hood performance has focused on measuring face velocity and its distribution across the face. Many papers and organizations have recommended acceptable ranges for average face velocity and its spatial distribution across a laboratory fume hood. ^(2-5,15) Much evidence supports the commonly recommended range of 80 to 120 ft/min inflow velocity into laboratory hoods.

For all enclosing hoods the operational assumption is that the inward movement of air must overcome competing air currents induced by cross-drafts, diffusers, traffic, operator motions, etc. For very large hoods, the 2010 ACGIH Industrial Ventilation (IVM) recommends 75-125 *ft/min*, depending on the perceived strength of competing motions. For “small” hoods, the recommended range is 100-150 *ft/min*. It is also assumed that the performance of a hood is best when the hood face velocity is uniform (ACGIH, 2010).

Altemose (1998) found that face velocity (V_{face}) and its variability are important in determining whether a laboratory hood will leak. They also found that the temporal variation of face velocity was more strongly related to tracer gas test results than spatial variation. However, in that research, the complex interaction of cross drafts with face velocity and their relationship to hood performance were described as not well understood and warranting further study.

Guffey and Barnea (1994), in a study of the effectiveness of a plain benchtop enclosing hood, found that hood face velocity was the dominant factor affecting exposure at the breathing zone of a manikin standing at the face of the hood. At face velocities above 0.51 *m/sec* (100 *ft/min*), exposures were low for all cases. Increasing face velocities always decreased concentrations, even at the highest face velocities. They also concluded that exposures generally were substantially higher when the manikin's head and arms intruded into the hood than when they did not, especially when velocities were low.

2.2 Effects of Cross-Draft Velocity (V_{cross})

Existing standards for laboratory fume hoods focus on the face velocity. The influence of room air currents is as important as face velocity in capturing contaminants when a manikin is standing at the hood face. Further, face velocity standards are not very meaningful for auxiliary air hoods⁽⁵⁾. Cross-drafts caused by external airflows, pumping doors, or by walking past a hood, are believed to affect the performance of lab hoods (Rota, 2000). However no guidance is available as to what level of cross-draft is acceptable (DiBerardinis, 2003). The effects of cross-drafts on the performance of lab hood can be dramatic and complex. One suggestion is that the cross-draft velocity should be less than 25% of the hood face velocity (i.e., < 25 *ft/min*) (Caplan, 1982).

Two studies reported that high cross-draft velocities reduced the performance of a laboratory fume hood (Caplan, 1982; Altemose, 1998). Recommendations for acceptable cross draft velocities vary from one-fifth to two-thirds of the average face velocity.^(6,17,23)

Rake (1978) found that as the crossflow velocity exceeded 100 fpm, the ability of a biological safety cabinet to protect either experiments or investigators decreased logarithmically with increasing crossdraft speed. She also indicated that because 100 *fpm* is an airspeed easily achieved by some air conditioning and heating vents (open windows and doorways may create velocities far in excess of 200 *fpm*), the proper placement of a biological safety cabinet within the laboratory (i.e., away from such disruptive air currents) is essential to satisfactory cabinet performance.

2.3 Benchtop Enclosing Hoods: Interventions

There is also wide agreement that airfoil sills are important to lab hood performance (Ljungvist, 1991). Only one published article reported results from an experimental study of effectiveness of a benchtop enclosing hood (Guffey, 1994). That study reported that the presence of a manikin dramatically increased concentrations at the hood face. It also reported that attaching flanges and tapered entries to the plain hood increased the exposures. However that research was conducted in the absence of cross-drafts and the manikin was neither heated nor breathing.

Furthermore, that result may have occurred because: 1) the tapered inlets pushed the worker partially out of the hood, and moved the source closer to the hood face, and (2) the flange and tapers were in direct contact with the manikin's thighs, effectively blocking upward flow between its belly and the hood.

2.4 Summary

In short, the nearly complete lack of published studies of plain enclosing hood performance makes guidance to practitioners a matter of perceived plausibility rather than empirical science. This thesis focuses on the effects of face velocity, cross-drafts, and different interventions on the performance of a small plain enclosing hood. The author hopes that this study will provide information useful to practitioners and lead them to more effective hood designs and more certain selection of hood airflows.

Chapter 3: Research Design and Methods

3.1 Research design

The experiments were carried out in a wind tunnel that is 40 ft long, 9 ft high and 12 ft wide. A tracer gas (Freon 134a) was released at a fixed rate from a fixed position in the hood and monitored in the breathing zone of a mannequin “working” at the face of the hood. The wind tunnel is shown as Figure 3.1.

Figure 3. 1: The overall view of the Wind Tunnel

Samples were taken at the nose (C_{nose}), mouth (C_{mouth}), outside the wind tunnel ($C_{ambient}$), downstream of the wind tunnel ($C_{downstream}$), and from the exhaust duct (C_{duct}). The sampling locations for the study are shown in Table 3.1.

Each sample was collected for 20 minutes and all locations were sampled concurrently by drawing sampled air into plastic bags (see Appendices B & C). Sampling volumes were 3 liters each. After sample collection, each sample was analyzed by a Gasmet Fourier transform infrared (FT-IR) gas analyzer (see Appendix A) to determine its concentration.

The dependent variables for this study were concentrations measured simultaneously at five designated different locations as shown (see Table 3.1).

Table 3.1: Description of sampling sites (see Fig. 3.1)

Description	Location	Abrev.
0.5 cm laterally from nasal orifice	Nose	C_{nose}
At the mouth 3 cm from the right of the lip	Mouth	C_{mouth}
At 2m in front of the outlet of the wind tunnel, between the hood face and wind tunnel outlet	Downstream	$C_{downstream}$
At 2 m downstream of the exhaust duct fan	Duct	C_{duct}
2 m at the wind tunnel inlet	Ambient Left & Right	$C_{ambient}$

The independent variables were enclosing hood face modifications, as well as several pre-determined levels of hood face velocity (V_{face}) and wind tunnel cross-draft velocity (V_{cross}).

This study consisted of two parts: Study I and Study II.

- Study I tested the plain hood's performance without any intervention. Two factors were investigated: hood face velocities and wind tunnel cross-draft velocities. Test conditions included every combination of five pre-determined hood velocities: 111, 140, 170, 200 and 229 *ft/min*, and five

cross-draft velocities: 14, 26, 36, 46 and 57 *ft/min*. Roughly 45 minutes were required for each test (30 min. for sampling, and 15 min. for FT-IR sampling analysis). Each condition test was done twice (see Table 3.2). The total number of tests was 50.

- Study II was done to determine the effects of flanges, cowling, and sashes added to a plain enclosing hood. The test methods were the same as Study I. Test conditions included every combination of the three hood velocities (111, 170 and 229 *ft/min*), two cross-draft velocities (14 and 46 *ft/min*), and five intervention conditions (no intervention, collar flange, bottom flange, cowling, and sash). Fifty minutes was required for each test (35 min. for sampling, and 15 min. for FT-IR sampling analysis). Each condition test was repeated once. (see Table 3.3)

Table 3.2: Levels for independent variables for study I

Independent Variables	Levels
Hood face velocity (<i>ft/min</i>), V_{face}	111, 140, 170, 200, 229
Cross-draft velocity (<i>ft/min</i>), V_{cross}	14, 26, 36, 46, 57

Table 3.3: Levels for independent variables for study II

Independent Variables	Levels
Hood face velocity (<i>ft/min</i>), V_{face}	111, 170, 229
Cross-draft velocity (<i>ft/min</i>), V_{cross}	14, 46
Intervention	Collar flange
	Bottom flange
	Cowling
	Sash
	Plain Hood (No Intervention)

There were two replicates for each combination of independent variables. The significance of the independent variables and their interactions for each study was analyzed using the Data Desk (Data Description, Cornell, NY) statistical package.

The fixed conditions for this study included the use of one anthropometrically proportioned manikin wearing summer clothes (see Figure 3.2). The manikin was stationary and was posed in a fixed “working” posture for all tests. During each test, the manikin’s hands were placed on each side of the tracer gas source (a 9 inch pie-pan) in a manner intended to simulate a “working” posture at the hood face.

Figure 3. 2: Test manikin standing in front of the enclosing with a “working” posture

3.2 Apparatus

3.2.1 Wind Tunnel

The study was done in the Ventilation Laboratory in the Mineral Resources Building (MRB) at CEMR, West Virginia University. The dimensions of the wind tunnel are 40 ft long, 9 ft high and 12 ft wide. The uniformity of velocities in the wind tunnel is improved by the upstream and downstream HEPA filters. Constant Temperature Anemometry (CTA) measurements taken at 6" intervals vertically and 12" intervals horizontally showed a coefficient of variation of 10%. The turbulent intensity was generally around 10%. It was 3-5% in the middle where the manikin stands. The wind tunnel fan is controlled by a variable frequency drive, allowing a range of wind tunnel velocities of 10 to 155 *ft/min*.

The combined cross-section of the full-sized enclosing hood and the manikin was less than 15% of the wind tunnel cross-section. To reduce thermal buoyancy effects due to different temperatures at floor and ceiling, the concrete floor of the building was covered with 0.75" styrene foam insulating sheets, which was overlaid with 1" plywood sheets and a linoleum floor covering. Infrared thermometry showed temperatures in the air and at the walls, ceiling and floor to be within 2°C winter and summer.

3.2.2 Experimental Enclosing Hood

The enclosing hood has a transparent plastic glass side and top to allow inside observation (see Figure 3.2). The hood dimensions are 36 inch wide and 30 inch high. To enhance spatial velocity uniformity, a perforated sheet face with 95% opacity was installed in the back of the hood. The takeoff is tapered 45 degrees in a typical square to round transition. The enclosing hood was located such that the subject is near the center of the width of the wind tunnel (see Figure 3.3).

Figure 3. 3: The experimental enclosing hood and its location in a wind tunnel

For testing the effects of interventions on the plain hood's performance, the following modifications were made at the hood inlet (see Table 3.4):

Table 3.4: Description of interventions

Description	Interventions
Attached a 12 inch, 90 degree flange to the sides and top to the hood (see Figure 3.4)	Collar flange
Attached a 12 inch, 90 degree flange to the bottom of the hood (see Figure 3.5)	Bottom flange
Attached a cowling, which is 12 inch straight extension of the two sides and top (see Figure 3.6)	Cowling
Installed a custom sash inside of the hood (see Figure 3.7)	Sash

Figure 3. 4: Collar flange

Figure 3. 5: Bottom flange

Figure 3. 7: Cowling

Figure 3. 6: Sash

3.2.3 Manikin

The test manikin is a 66" high, anthropometrically-scaled (including facial features and short hair) male with hollow cavities in the head, torso, legs and arms. It has a rubber skin that feels reasonably like real skin. The manikin has joints in shoulders, hips and knees. This enables it to stand, sit and to pose in lifelike postures. Measuring 66 inches in height, the manikin dimensions match with 50th percentile for women and 5th percentile for men.

Heating the manikin head and torso to simulate the body heat of humans was done by placing strings of 1.5 watt lights within the torso and the head, for a total of 90 watts of power (see Figure 3.8). This produced the manikin's face temperatures (24 – 28 °C) and back temperatures (34 - 38 °C).

Figure 3. 8: Manikin heating system

The manikin was clothed with loose-fitting pants and a summer-weight short-sleeved shirt. Breathing by the manikin was simulated by using a bellows device (see Figure 3.9). Air was drawn in and expelled the same air through the nasal openings,

which was connected to 1" diameter Teflon tubing. This air was heated to 98°F as it passing through the torso. A motorized bellows outside the wind tunnel provided a sinusoidal pattern at roughly 0.4 – 0.5 Liter per breath and 30 – 39 breathes per minute.

Figure 3. 9: Bellows breathing mechanism

3.2.4 Temperature, Humidity and Barometric Measurements

Temperatures of surfaces were measured with an infrared thermometer (Oakton, model number EW-35629, see Appendix D). Multiple points were measured on the manikin's cheek and torso, along with multiple points on the wind tunnel walls, ceiling, and floor. Air temperatures were measured with a calibrated dry bulb thermometer. Humidity was determined from a standard sling psychrometer, and barometric pressure was measured with a standard laboratory mercury barometer.

3.2.5 Tracer Gas Release System

A tracer gas was utilized in this study to determine the performance of the enclosing hood. Freon-134a was mixed with helium in a roughly neutrally buoyant mixture. Tracer gas was released through a 9" pie-pan into the enclosing hood front face. The pie-pan was covered by a plastic glass with 99 uniformly spaced drilled holes, each 0.05 in. in diameter. The system is shown as Figures 3.10 – 3.11.

Figure 3. 10: Tracer gas release system part I

Figure 3. 11: Tracer gas release system part II

3.2.6 Gas Analyses

Analysis of Freon-134a / air mixtures was performed using a Gasmet Fourier transform infrared (FT-IR) gas analyzer (Model: DX-4015) (see Figure 3.12). The FT-IR was frequently calibrated using 2 ppm, 10 ppm, 100 ppm and 200 ppm span gases (Air-Gas, Morgantown, WV).

Figure 3. 12: Gas analysis system

3.3 Procedure

The procedure for this study is shown in flow-chart form in Figure 3.13.

Figure 3.13: Experiment procedure

3.3.1 Sampling System Preparation Prior To Experiment Runs

1. Manikin heat turned on at least three hours prior to sampling.
2. Calibrate Low flow pumps.
3. Purge TeflonTM sampling bags with ambient air.

4. Purge the ventilation laboratory before sampling.
5. Turn on wind tunnel fan and exhaust hood fan and adjust the fan controllers to desired airflows.
6. Turn on the manikin breathing system.
7. Connect Teflon™ bag to the sampling pumps according to the labels identifying sampling location.
8. Record wind tunnel environmental conditions (temperature, humidity, barometric pressure).
9. Install intervention onto the enclosing hood, if required.
10. Check manikin posture, location of its head in the plane of the hood face, locations of hands to each side of the source, heating and breathing.

3.3.2 Tracer Gas Release System

1. Open valves for helium & freon cylinders.
2. Turn on mass flow controllers (gas flow meters) for Freon-134a and helium to release tracer gas mixture.
3. Adjust the flow rate for each mass flow controller to 3 *LPM* for Freon-134a and 9 *LPM* for helium.

(Note: Tracer gas was released into the hood through a 9" pie-pan placed between the manikin's hands.)

3.3.3 Sampling Procedure

1. Switch all sampling pumps to "ON".
2. Close wind tunnel doors tightly.

3. Wait five minutes before starting the sampling to allow equilibration of the concentration in the wind tunnel.
4. Do pitot traverses at the exhaust hood duct to determine V_{duct} and V_{face} .
5. Wait 20 minutes as the sampling bags are filled by sampling pumps.
6. At the end of the 20 minutes of sampling, disconnect the bags from the pumps and close their valves
7. Take bags to the FT-IR gas analyzer.

3.3.4 Analysis of Sampling Bags

1. Run pure nitrogen through the gas analyzer until desired background achieved.
2. Connect a sample bag to the gas analyzer inlet port.
3. Draw sample into the analyzer for 1 min.
4. Analyze sample and note Feron-134a concentration on screen (same value is logged to an ongoing database).
5. Record sampling bag, Freon-134a concentration, residual concentration, and sampling time.
6. Repeat for the next sample bag.

3.4 Hypotheses Tested

The first hypothesis of this research is that enclosing hood face velocity and cross-draft velocity will affect the concentrations at the nose and mouth sampling locations:

$$H_0: \mu = \text{Constant};$$

$$H_1: \mu \neq \text{Constant}.$$

$$\text{Expectation: } \mu = f\{\text{hood face velocity, cross-draft velocity}\}.$$

Where: μ = mean concentrations at nose or mouth sampling location.

The second hypothesis tests whether certain interventions reduce the manikin's exposures compared to the plain hood:

$$H_0: \mu = \text{Constant};$$

$$H_1: \mu \neq \text{Constant}.$$

$$\text{Expectation: } \mu = f\{\text{Intervention, hood face velocity, cross-draft velocity}\}$$

Chapter 4: Results of Study I — Effects of V_{cross} and V_{face} on Concentrations for the Plain Hood

This study tested performance of a plain hood. This study was a complete factorial design, which included 5 levels of hood face velocity (V_{face}) and 5 levels of wind tunnel cross-draft velocity (V_{cross}). Each test condition was replicated twice in random order. The goal of this study was to find the effects of V_{face} and V_{cross} on concentrations measured at different locations. Concentrations were measured at 5 locations: nose (C_{nose}), mouth (C_{mouth}), outside the wind tunnel ($C_{ambient}$), downstream of the wind tunnel ($C_{downstream}$) and the exhaust duct (C_{duct}). Only C_{mouth} and C_{nose} are analyzed here. All values of $C_{ambient}$ were near zero, so it was not necessary to “correct” for ambient concentration. $C_{downstream}$ was also found to be zero or trivial in all cases.

4.1 Comparison of C_{mouth} to C_{nose}

Two samples were taken simultaneously at the manikin’s mouth and nose locations. Plausibly, there would be only small differences between C_{mouth} and C_{nose} because they are close to each other. As shown in Figure 4.1.1, it is very clear that the two dependent variables were highly correlated ($R^2 = 0.91$) with a linear regression slope of 0.9986.

Figure 4.1.1: C_{mouth} Versus C_{nose}

4.2 Effects of Hood Face Velocity (V_{face}) on Concentration at Mouth (C_{mouth})

Figures 4.2.1 to 4.2.5 show the effects of hood face velocity on C_{mouth} . Five levels of hood face velocity were investigated: 111, 140, 170, 200 and 229 *ft/min*. As expected, V_{face} appeared to have strong effects on C_{mouth} , with higher C_{mouth} levels associated with lower V_{face} values. This result is consistent with published research for lab hoods.

Figure 4.2.1- a: Mouth concentration versus hood face velocity for plain hood ($V_{cross} = 14$ fpm)

Figure 4.2.1- b: log C_{mouth} versus hood face velocity for plain hood ($V_{cross} = 14$ fpm)

Figure 4.2.2- a: Mouth concentration versus hood face velocity for plain hood ($V_{cross} = 26 \text{ fpm}$)

Figure 4.2.2- b: log C_{mouth} versus hood face velocity for plain hood ($V_{cross} = 26 \text{ fpm}$)

Figure 4.2.3- a: Mouth concentration versus hood face velocity for plain hood ($V_{cross} = 36$ fpm)

Figure 4.2.3- b: log C_{mouth} versus hood face velocity for plain hood ($V_{cross} = 36$ fpm)

Figure 4.2.4- a: Mouth concentration versus hood face velocity for plain hood ($V_{\text{cross}} = 46 \text{ fpm}$)

Figure 4.2.4- b: $\log C_{\text{mouth}}$ versus hood face velocity for plain hood ($V_{\text{cross}} = 46 \text{ fpm}$)

Figure 4.2.5- a: Mouth concentration versus hood face velocity for plain hood ($V_{cross} = 57 \text{ fpm}$)

Figure 4.2.5- b: log C_{mouth} versus hood face velocity for plain hood ($V_{cross} = 57 \text{ fpm}$)

4.3 Effects of Wind Tunnel Cross-Draft (V_{cross}) on Concentration at Mouth (C_{mouth})

Wind tunnel cross-draft velocity was another factor which could affect the performance of an enclosing hood. Five levels of cross-draft velocity were studied: 14, 26, 36, 46 and 57 *ft/min* at five levels of V_{face} : 111, 140, 170, 200 and 229 *ft/min*.

Many researchers studying laboratory fume hoods state that cross-draft velocity made the hood performance worse and should be reduced as low as possible (Brent A. Altemose, 1998) (Caplan, 1982).

However, the results of this study do not support that assumption. As shown in Figures 4.3.1 to 4.3.5, the lower values of V_{cross} are associated with the higher C_{mouth} values in every case. The lowest C_{mouth} values were found in the middle range of cross-draft, $V_{cross}=36$ *fpm*.

One reason is perhaps that previous studies investigated laboratory fume hoods, whose sash profoundly affects flow into the hood.

Figure 4.3- a: Mouth concentration versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 111 \text{ fpm}$)

Figure 4.3- b: log C_{mouth} versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 111 \text{ fpm}$)

Figure 4.3- c: Mouth concentration versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 140$ fpm)

Figure 4.3- d: $\log C_{mouth}$ versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 140$ fpm)

Figure 4.3- e: Mouth concentration versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 170$ fpm)

Figure 4.3- f: log C_{mouth} versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 170$ fpm)

Figure 4.3- g : Mouth concentration versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 200$ fpm)

Figure 4.3- h: log C_{mouth} versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 200$ fpm)

Figure 4.3- i: Mouth concentration versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 229 \text{ fpm}$)

Figure 4.3- j: $\log C_{mouth}$ versus wind tunnel cross-draft velocity for plain hood ($V_{face} = 229 \text{ fpm}$)

Chapter 5: Discussions of Study I

5.1 Effects of Independent Variables on Mouth Concentration

In this study, there were two independent variables, V_{face} and V_{cross} . As shown in Figures 5.1 to 5.4, each affects C_{mouth} . The lowest C_{mouth} occurred at $V_{face} = 170$ fpm and $V_{cross} = 36$ fpm.

Figure 5. 1: Hood face velocity versus mouth concentration for plain hood regardless of the levels of wind tunnel cross-draft velocity

Figure 5. 2: Hood face velocity versus log C_{mouth} for plain hood regardless of the levels of wind tunnel cross-draft velocity

Figure 5. 3: Wind tunnel cross-draft velocity versus moth concentration for plain hood regardless of the levels of hood face velocity

Figure 5. 4: Wind tunnel cross-draft velocity versus $\log C_{\text{mouth}}$ for plain hood regardless of the levels of hood face velocity

5.2 Simple Regression Analysis

Regression analysis was performed on log transformed concentrations at the mouth location with hood face velocity (V_{face}) and wind tunnel cross-draft velocity (V_{cross}) separately. Table 5.2.1 and 5.2.2 each summarizes adjusted R^2 , regression coefficients, and P -values obtained from regression analysis for each sample treatment (see Appendix J).

Table 5.2. 1: Simple Regression Analysis Results for log C_{mouth} with Hood Face Velocity (V_{face})

Dependent Variable log C_{mouth}	P -value	Adj_ R^2 (%)	C_0	C_1
@ $V_{cross}=14$ fpm	0.0029	60.6	2.0156	-0.00669
@ $V_{cross}=26$ fpm	0.0274	37.2	1.4485	-0.00433
@ $V_{cross}=36$ fpm	0.0001	79.9	1.2067	-0.00415
@ $V_{cross}=46$ fpm	0.0006	76.4	1.1382	-0.00365
@ $V_{cross}=57$ fpm	0.0010	73.3	1.4258	-0.00513

*Model: $Log C_{mouth} = C_0 + C_1 * V_{face} + \varepsilon$

Table 5.2. 2: Simple Regression Analysis Results for log C_{mouth} with Cross-draft Velocity (V_{cross})

Dependent Variable log C_{mouth}	P -value	Adj_ R^2 (%)	C_0	C_1
@ $V_{face}=111$ fpm	0.0040	62.3	1.5814	-0.01740
@ $V_{face}=140$ fpm	0.0479	27.0	1.0371	-0.00655
@ $V_{face}=170$ fpm	0.3211	1.30	0.5508	-0.00128
@ $V_{face}=200$ fpm	0.0270	3.70	0.6060	-0.00253
@ $V_{face}=229$ fpm	0.0091	54.3	0.8590	-0.01341

*Model: $Log C_{mouth} = C_0 + C_1 * V_{cross} + \varepsilon$

As can be inferred from Tables 5.2.1 and 5.2.2, for most values of V_{face} , V_{cross} is not quite linearly related to $\log C_{mouth}$; meanwhile, for each level of V_{cross} , V_{face} is moderately linearly proportional to $\log C_{mouth}$. Since the regression slopes are negative in every case, C_{mouth} declines exponentially with both V_{face} and V_{cross} .

5.3 Analysis of Variance (ANOVA)

The independent variables for this study were the V_{face} (five levels, 111, 140, 170, 200 and 229 *fpm*) and V_{cross} (five levels, 14, 26, 36, 46, 57 *fpm*). The dependent variables were the concentrations at the mouth and nose locations.

Data Desk[®] (Data Description, Cornell, NY) software was used for ANOVA. The results are listed in Tables 5.4.1.

Table 5.3. 1: The ANOVA table for C_{mouth} on the plain hood

Analysis of Variance For		Log C_{mouth}			
Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	22.0817	22.0817	1531.7	< 0.0001
Vface	4	2.10098	0.525244	36.433	< 0.0001
Vcross	4	1.08876	0.27219	18.88	< 0.0001
Vface*Vcross	16	0.558423	0.0349015	2.4209	0.0207
Error	27	0.38925	0.0144167		
Total	51	4.20092			

We can see that both the V_{face} and V_{cross} have highly significant statistically effects ($p < 0.005$) on concentrations at both the mouth and nose locations. It should be noted that all velocities were pre-determined, and the ANOVA model is a fixed effect one. Consequently, the results obtained are good only for these specific velocities.

Chapter 6: Results of Study II—Flange, Cowl and Sash Tests

Study I established that hood face velocity (V_{face}) and wind tunnel cross-draft velocity (V_{cross}) were important factors affecting hood performance. Study I only focused on the plain enclosing hood (without any intervention added). Study II tested the effects on the hood performance of adding different interventions at the hood face or just inside the hood (sashes). This study was a complete factorial design. Each test condition was done twice in random order.

The apparatus and methods were identical to Study I except for adding the specific modifications to the hood. The goal for Study II was to determine whether interventions (see Table 6.1) to the hood improved its performance.

Table 6. 1: Levels for independent variables for study II

Independent Variables	Levels
Hood face velocity (<i>ft/min</i>)	111, 170, 229
Cross-draft velocity (<i>ft/min</i>)	14, 46
Intervention	Collar flange
	Bottom flange
	Cowling
	Sash
	Plain Hood (No Intervention)

6.1 Comparison of Effects of Different Interventions on Concentration at Mouth and Nose Locations

Table-6.2 lists Concentrations at C_{mouth} and C_{nose} for each intervention (no intervention is treated as an intervention here).

Table 6. 2: Results of C_{mouth} and C_{nose} by giving different interventions

Interventions	V_{face} , fpm	V_{cross} , fpm	C_{nose_Ave} , ppm	C_{mouth_Ave} , ppm
No Intervention	111	14	96.0	91.4
No Intervention	111	46	10.7	18.8
No Intervention	170	14	53.3	43.6
No Intervention	170	46	42.0	46.8
No Intervention	229	14	25.6	17.1
No Intervention	229	46	23.8	22.2
FlangeTopSides12in	111	14	156.7	208.4
FlangeTopSides12in	111	46	36.3	43.7
FlangeTopSides12in	170	14	71.9	130.7
FlangeTopSides12in	170	46	34.9	28.4
FlangeTopSides12in	229	14	47.0	39.6
FlangeTopSides12in	229	46	136.0	107.1
FlangeBottom 12in	111	14	36.1	63.3
FlangeBottom 12in	111	46	61.9	88.7
FlangeBottom 12in	170	14	64.1	127.4
FlangeBottom 12in	170	46	79.9	129.6
FlangeBottom 12in	229	14	89.6	141.5
FlangeBottom 12in	229	46	197.4	227.2
CowlTopSides12in	111	14	75.6	220.9
CowlTopSides12in	111	46	214.6	383.2
CowlTopSides12in	170	14	197.6	249.8
CowlTopSides12in	170	46	230.3	196.4
CowlTopSides12in	229	14	167.4	147.8
CowlTopSides12in	229	46	389.1	497.3
Sash 17in	111	14	-0.01	-0.02
Sash 17in	111	46	-0.01	-0.01
Sash 17in	170	14	-0.01	-0.01
Sash 17in	170	46	-0.02	-0.03
Sash 17in	229	14	-0.03	-0.03
Sash 17in	229	46	-0.01	-0.02

6.2 Results of C_{mouth} for each Intervention

In order to see the effects of the interventions added on the hood, the results were plotted in Figures 6.2.1 – 6.2.3. Through these figures, we can clearly see that the sash dramatically reduced concentrations in all cases. Flanges and Cowl performed worse than no intervention.

Figure 6.2. 1: C_{mouth} versus four different interventions ($V_{face}=111$ fpm; $V_{cross}=14, 46$ fpm)

Figure 6.2.2: C_{mouth} versus four different interventions ($V_{face}=170$ fpm; $V_{cross}=14, 46$ fpm)

Figure 6.2. 3: C_{mouth} versus four different interventions ($V_{face}=229$ fpm; $V_{cross}=14, 46$ fpm)

Chapter 7: Discussions of Study II

7.1 Comparison of C_{mouth} to C_{nose}

As with Study I, two samples were taken simultaneously at the manikin's mouth and nose. Figure 7.1 plots C_{mouth} against C_{nose} with all conditions included. It is clear that the two dependent variables were highly correlated ($R^2 = 0.87$) with a linear regression slope of 1.229.

Figure 7. 1: C_{mouth} Versus C_{nose}

7.2 Effects of Intervention Variables on Mouth and Nose Concentration

Intervention variables included: no intervention, collar flange, bottom flange and cowl. Regardless of the levels of hood face velocity and wind tunnel cross-draft velocity, the effects of interventions on C_{mouth} and C_{nose} are shown as Figure 7.2.1 and Figure 7.2.2.

Figure 7. 2.1: Effects of interventions on C_{mouth} regardless of V_{face} and V_{cross}

Figure 7. 2.2: Effects of interventions on C_{nose} regardless of V_{face} and V_{cross}

7.3 Analysis of Variance (ANOVA)

ANOVA was performed to answer the question, “Do all the five groups (five different interventions) have the same mean?”

Null Hypothesis, $H_0: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$;

Alternative Hypothesis, H_1 : *At least one mean is not equal to the others.*

Data Desk[®] (Data Description, Cornell, NY) software was used to do analysis of variance (ANOVA) for log C_{mouth} and log C_{nose} . The analysis results are listed on Table 7.3.1 and 7.3.2.

Table 7.3. 1 The ANOVA table for log C_{mouth} on intervention tests

Analysis of Variance For		Log C_{mouth}			
Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	179.582	179.582	2581.2	< 0.0001
Vface	2	0.0194982	0.00974912	0.1401	0.8698
Vcross	1	0.00683852	0.00683852	0.0983	0.7561
Vface*Vcross	2	0.721652	0.360826	5.1863	0.0116
Intervention	3	5.00621	1.66874	23.986	< 0.0001
Vface*Intervention	6	0.816875	0.136146	1.9569	0.1038
Vcross*Intervention	3	0.464231	0.154744	2.2242	0.1058
Error	30	2.08717	0.0695724		
Total	47	9.12248			

Since the velocities and intervention methods were fixed, the ANOVA model is a fixed effect model, and the results apply only for these fixed values.

Table 7.3. 2: The ANOVA table for log C_{nose} on intervention tests

Analysis of Variance For		Log C_{nose}			
Source	df	Sums of Squares	Mean Square	F-ratio	Prob
Const	1	165.041	165.041	2753.8	< 0.0001
Vface	2	0.200233	0.100116	1.6705	0.2052
Vcross	1	0.000271219	0.000271219	0.0045	0.9468
Vface*Vcross	2	0.453926	0.226963	3.7869	0.0342
Intervention	3	3.37685	1.12562	18.781	< 0.0001
Vface*Intervention	6	0.68634	0.11439	1.9086	0.112
Vcross*Intervention	3	0.798193	0.266064	4.4394	0.0107
Error	30	1.79799	0.0599329		
Total	47	7.3138			

Surprisingly, P -values are very large for all variables except Intervention. However, some of the interventions between variables had small P -values. It is critical to know that all the sash tests produced zero mouth and nose concentrations, meanwhile the cowling produced extremely high concentration (>300ppm), which played tremendous effects in the above ANOVA analysis. It is very clear that the interventions didn't all have the same mean for both C_{mouth} and C_{nose} .

Chapter 8: Conclusions and Recommendations

The main purpose of this research was to investigate the effects of face velocity, cross-draft velocity, flanges, cowling, and a custom sash on the performance of a specific benchtop enclosing hood. This study consisted of two parts: 1) studying the effects of hood face velocity and wind tunnel cross-draft velocity on a plain, benchtop enclosing hood, and 2) studying the effects of specific interventions -+on the performance of the same enclosing hood.

8.1 Conclusions for Plain Enclosing Hood Study

Five levels of hood face velocity ($V_{face} = 111, 140, 170, 200 \text{ and } 229 \text{ fpm}$) and five levels of cross-draft velocity ($V_{cross} = 14, 26, 36, 46 \text{ and } 57 \text{ fpm}$) were studied in the experiment to determine the effects of V_{face} , V_{cross} , and their interactions on the performance of a benchtop enclosing hood. Concentrations were measured at a heated, “breathing” anthropometrically scaled manikin’s mouth and nose. Results from this study indicate that:

- Enclosing hood face velocity (V_{face}), wind tunnel cross-draft velocity (V_{cross}) and their interactions all had statistically significant effects on log-transformed concentrations ($\text{Log } C_{mouth} \text{ and } \text{Log } C_{nose}$), ^(2-5, 6, 12) which is in agreement with many published papers. However, V_{cross} at the lowest level (14fpm) increased concentrations at the manikin’s mouth and nose, which is not consistent with common recommendations^(6, 7, 23) that the cross-draft velocity has negative effect and should be kept as low as possible. One possible reason is that the differences between a lab hood and the plain hood. Lab hoods have aerodynamically-shaped entries, while typical benchtop enclosing hoods generally have plain sides. As we have observed with smoke tests on an enclosing hood in our wind tunnel, the wake from the wall can extend nearly to the hood user when the cross-draft is from the side.

- Higher face velocity and higher cross-draft velocity were associated with lower C_{nose} and C_{mouth} . Once V_{face} exceeded 170 fpm and V_{cross} exceeded 36 fpm, the concentrations no longer declined substantially.

8.2 Conclusions for the Interventions Study

Five interventions: no intervention, collar flange, bottom flange, cowl and sash, along with three levels of V_{face} (111, 170, 229 fpm) and two levels of V_{cross} (14, 46 fpm) were studied to determine the effects of interventions on the performance of the same enclosing hood. It was found that:

- All interventions were found to significantly affect on the performance of the enclosing hood.
- TopSides12in Cowl produced the highest mouth and nose concentrations compare to other interventions. A possible reason is that the 12in cowl induced a substantial region of separation that enlarged the manikin's wake zone. This could have increased flow from the source to the manikin.
- The flanges at best were not better than having no intervention. The average concentration values with flanges were greater than with no intervention, which is consistent with Guffey and Barnea (1994).
- The most important finding is that the sash reduced the concentrations dramatically. Zero exposures were achieved at all combinations of V_{face} and V_{cross} . The reason for it could possibly be that the custom sash reshaped the manikin's wake zone, thus keeping manikin's breathing zone out of its wake zone. On the other hand, the sash keeps the worker's face separated from the contaminant, so it is unlikely that the manikin would be over exposed.

8.3 Recommendations

- A similar sash should be used when feasible.
- The hood face velocity should be at least 170 fpm.
- Neither external flanges nor cowls should be used.

8.4 Caveats and Limitations

- The results may have been sensitive to the position of the manikin's face, suggesting that even minor changes in posture could have substantial effects.
- This study was done in a wind tunnel with airflows that are more uniform than would exist in a work place, also this study examined only a few of levels of V_{face} , V_{cross} , and interventions. The results found apply only to the conditions investigated. More levels of V_{face} and V_{cross} combinations to be studied.
- Results may differ from results found with human subjects. The manikin did not move, and its arms and legs were not heated.

References

1. AIHA (2004). Industrial Ventilation A Manual of Recommended Practice. Cincinnati, Ohio: ACGIH®.
2. Abrams, DS, Reist, PC, Derment, JM, (1986). An Evaluation of a Receive Lab Hood, AIHAJ 47 (1): 22– 26.
3. Altemose, BA, Flynn, MR, Sprankle, J, (1998), Application of a Tracer Gas Challenge with a Human Subject to Investigate Factors Affecting the Performance of Lab Hoods; AIHAJ 59: 321– 327.
4. Brent A. Altemose, M. R. (1998). Application of a Tracer Gas Challenge with a Human Subject to Investigate Factors Affecting the Performance of Laboratory Fume Hoods. American Industrial Hygiene Association Journal, 59:321-327.
5. Caplan, K.J. and Knutson, G.W., (1982), A Performance Test for Laboratory Fume Hoods; Am. Ind. Hyg. Assoc. 43:722-737.
6. Caplan, K.J. and Knutson, G.W., (1982), Influence of Room Air Supply on Laboratory Hoods; Am. Ind. Hyg. Assoc. 43:738-746.
7. DiBerardinis, LJ [and 20 others], (2003), Report of the Howard Hughes prod inst. Workshop on the performance of lab hood, AIHAJ 64:228-237.
8. DiBerardinis, LJ, First, MW, and Ivany, RE, (1991) Field results of an in-place, quantified performance test of lab hoods, AOEH 6:227-231.
9. Greenley, PL, Billings CE, Diberardinis, LJ, (1999), Containment testing of lab hoods on as-used conditions ANSI 110 manikin & human not compared, ASHRAE Transactions Vol. 105, Part I.
10. Guffey SE and Barnea N (1994). "Effects of Face Velocity, Flanges, and Manikin Position on the Effectiveness of a Benchtop Enclosing Hood in the Absence of Cross-Drafts". Am. Ind. Hyg. Assoc. J., 55(2):132-139.
11. Guffey SE, Flanagan ME and van Belle G, (2001). Air Sampling at the Chest and Ear As Representative of the Breathing Zone. AIHA Journal: Vol. 62, No. 4, pp. 416–427.
12. Hitchings, DT (1995), "ANSI/ ASHRAE 110 fume hood performance testing", Lab Safety Environment Man 3(6):4.
13. Ivany, RE, First, MW and DiBerardinis (1989), A new method for quantitative in-use testing of fume hoods, AIHAJ 50 (5) 275– 280.
14. Jon L. BARNETT, MAX L. RICHARD (1983), "A tracer Method for Quantifying Contamination of Building Supply Air: Reentrainment of Laboratory Hood Exhausts", Am. Ind. Hyg. Assoc. J. 44(8): 580-582
15. Johnson, A.E. and Fletcher, B. (1992) "Containment Testing of Fume Cupboards – I: Methods." Ann. Occup. Hyg. 36: 239-252.

16. Johnson, A.E. and Fletcher, B. (1992) "Containment Testing of Fume Cupboards – II: Test Room Measurements." *Ann. Occup. Hyg.* 36: 395-40.
17. Knutson, G.W. (1987): Testing containment of laboratory hoods: a field study. *ASHRAE Trans.* 93:1801-1912
18. Kwangseog Ahn, S. W. (2008). A Review of Published Quantitative Experimental Studies on Factors Affecting Laboratory Fume Hood Performance. *Journal of Occupational and Environmental Hygiene*, 5: 735-753.
19. Kulmala, I, Saamanen, A. and Enbom, S. (1996) "The Effect of Contaminant Source Location on Worker Exposure in the Near-Wake Region." *Ann. Occup. Hyg.* Vol. 40, pp. 511-523.
20. Ljungvist, B, (1991) "Aerodynamic design of fume cupboards", *Safety Health Practices*, 36-40.
21. Maupins, K & Hitchings, DJ. (1998) Reducing employees' exposure potential using ANSI (10 method of testing performance of lab fume hoods as a diagnostic tool; *AIHA* 59: 133- 138.
22. Pathanjali, C. and Rahman, M.M. (1996) "Study of Flow Patterns in Fume Hood Enclosures." *IEEE J.* 36:2003-2008.
23. Rake, B.W. (1978): Influence of cross drafts on the performance of a biological safety cabinet. *App. Env. Microbiol.* 36:278-283.
24. Rota, R.; Canossa, L. and Nano, G. (2000) "Analysis of Air Draught Influence on the Local Ventilation Efficiency through CFD Modeling." 6th International Symposium on Ventilation for Contaminant Control 4-7 June 2000, Helsinki, Finland.
25. Saamanen, A., Kulmala, I., Welling, I., Rosen, G., Andersson, I.M. (2000) "Person in a Uniform Airflow - Effects of Freestream Air Velocity and Body Convection," *Proceedings of the Ventilation 2000, 6th International Symposium on Ventilation for Contaminant Control 4-7 June 2000, Helsinki, Finland*
26. Smith, T.C., M.R. Flynn, and J.M. Dement (1994): A design and performance analysis of laboratory fume hoods. *Appl. Occup. Environ. Hyg.* 9:117-124.
27. Trevelyan P.M.J.; Ingham, D.B. and Elliott, L. (2000) "The effect of Ventilation and Sash Handles on the Flow in Fume Cupboards." 6th International Symposium on Ventilation for Contaminant Control 4-7 June 2000, Helsinki, Finland.
28. Wood, J.D., and J.L.Birkett (1979): External Airflow Effects on Personal Brit. *Occup. Hyg.* 22: 299-310.
29. William A. Burgess, M. J. (2004). *Ventilation for control of the work environment.* Hoboken, N.J.: Wiley-Interscience, c2004.
30. El Nahass W. (2005): Effects of Heating, Breathing, Hair Style, Posture, and air Velocity on breathing zone concentrations for an Anthropometrically-correct Manikin in a Wind Tunnel. Doctoral Dissertation, West Virginia University.
31. Santosh Kulkarni (2003): Comparison of Concentrations in the Breathing Zone. Master Thesis, West Virginia University.

Appendix A

Gasmet® Fourier Transform Infrared (FT-IR) Gas Analyzer

Gasmet™ DX-4015

Multicomponent FTIR Gas Analyzer

GASMET ON-SITE SERIES includes portable multicomponent gas analyzers for demanding applications. The GASMET DX - 4015 features a Fourier Transform Infrared (FTIR) spectrometer, a temperature controlled sample cell with a built-in pump, and signal processing electronics. The sample cell can be heated to 50 °C. Sample cell absorption path length is selected according to the application. This analyzer offers versatility and high performance for different applications.

The GASMET DX-4015 is designed for on site measurements at low concentrations in ambient air. Typical usage areas include industrial hygiene and emergency response situations.

The GASMET DX-4015 is factory calibrated using certified single component calibration gases. There is no need for the user to do any span calibrations after that. The user can also easily configure the analyzer for a new set of compounds.

General parameters

Measuring principle:	Fourier Transform Infrared, FTIR
Performance:	Simultaneous analysis of up to 50 gas compounds
Response time, T ₉₀ :	Typically < 120 s, depending on the gas flow and measurement time
Operating temperature:	Short term 20 ± 20°C long term 15 - 25°C non condensing
Storage temperature:	-20 - 60°C, non condensing
Power supply:	100-115 or 230 V / 50 -60 Hz 12 VDC
Power consumption:	300 W

Spectrometer

Resolution:	8 cm ⁻¹ or 4 cm ⁻¹
Scan frequency:	10 scans / s
Detector:	Peltier cooled MCT
Source:	SiC, 1550 K
Beamsplitter:	ZnSe
Window material:	ZnSe
Wavenumber range:	900 - 4 200 cm ⁻¹

GASMET-USA Tel: 512.331.0073 Fax: 512.331.5353 sales@Gasmet-USA.com www.Gasmet-USA.com

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TEL: +358 9 759 00 400
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WEB: www.gasmet.fi
VAT NO: FI19526395

Sample Cell

Structure:	Multi-pass, fixed path length 9.8 m
Material:	100 % Rhodium coated aluminium
Mirrors:	Fixed, protected gold coating
Volume:	0.4 l
Connectors:	Inlet Swagelok 6 mm Outlet Swagelok 8 mm
Gaskets:	Viton® O-rings
Temperature:	50 °C, maximum
Valve:	Manual Swagelok
Window material:	Ar coated ZnSe

Measuring parameters

Zero point calibration:	24 hours, calibration with nitrogen (4.0 or higher N ₂ recommended)
Zero point drift:	< 2 % of measuring range per zero point calibration interval
Sensitivity drift:	none
Linearity deviation:	< 2 % of measuring range
Temperature drifts:	< 2 % of measuring range per 10 K temperature change
Pressure influence:	1 % change of measuring value for 1 % sample pressure change. Ambient pressure changes measured and compensated

Electrical Connectors:

Digital Interface:	9-pole D-Connector for RS-232 Analyzer is connected to an external computer via RS-232C cable. The external computer controls the GASMET.
Power connection:	Standard plug CEE-22

Gas Inlet and Outlet Conditions

Gas temperature:	Non-condensing, the sample gas temperature should be the same as the sample cell temperature
Flow rate:	120 - 800 l per hour
Gas filtration:	Filtration of particulates (2µ) required
Sample gas pressure:	Ambient
Sample pump:	Internal, for ambient air only

Electronics

A/D Converter:	Dynamic range 95 dB
Signal Processor:	32-bit floating point DSP 120 MFLOPS speed
Computer:	External, not included

Analysis Software (for external PC)

Operating system:	Windows XP
Analysis software:	CALCMET 2005 for Windows

Options

Sample Cell:	Multi-pass, fixed path 2.5m or 5.0 m
Analog Signals (ext PC):	PCMCIA card for 8 analog inputs
Sample cell gaskets:	Teflon® coated Viton® or Kalrez®
Power supply cables:	12V cables with battery clips or cigarette lighter connector
Trolley:	Wheeled cart for the analyzer and laptop computer

Enclosure

Material:	Aluminium
Dimensions (mm):	438 * 184 * 445
Weight:	14.9 kg
CE - Label:	According to EMI guideline 89/336/EC

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Appendix B

SKC® Quality Sample Bag

Operating Instructions

863 Valley View Road, Eighty Four PA 15330 USA
Tel: 724-941-9701 Fax: 724-941-1369 www.skcinco.com

Dual Stainless Steel Fitted Bags 231 and 237 Series Sample Bags

The 231 and 237 Series sample bags feature dual stainless steel fittings – an inlet valve for flushing and filling and a Teflon-lined septum fitting for removing samples.

Guidelines for Bag Sampling

1. Ensure that the bag material and fittings are appropriate for the compounds to be sampled.
2. Use only Teflon® tubing to connect the sample bag to the pump to prevent sample loss by adsorption on tubing walls.
3. Before using, flush the bag thoroughly with purified air or nitrogen.
4. Analyze the sample within 24 to 48 hours. Long-term storage of air-contaminant mixtures in bags is not recommended.
5. Do not ship sample bags by air unless the cargo cabin is pressurized.

Cautions

- ❗ The O-rings inside the bag fittings resist heat to 225 F (107 C). Do not sample compounds that exceed this specification.
- ❗ 237 Series FlexFilm bag material can withstand temperatures up to 140 F (60 C). Do not exceed this specification.
- ❗ Do not use sample bags to sample compounds with boiling points > 249.8 F (121 C).
- ❗ SKC sample bags are designed for sampling air at atmospheric pressure only. Attempting to pressurize the bag can result in bag rupture and sample loss. Do not ship bag samples by air freight in a non-pressurized cargo cabin. Bags can burst under such conditions.
- ❗ All federal and state packaging and transporting regulations apply.
- ❗ Failure to follow warnings and cautions voids any warranty.
- ❗ Sample bags are designed for single use only.

Operation

1. Flush the bag at least 3 times with purified air or nitrogen before use.
2. To fill a bag, connect Teflon tubing from the exhaust port of an air sample pump to the hose connection on the bag (stem protruding from the top of the inlet fitting).

3. To unlock the valve, loosen the knurled thumb screw on the side of the inlet fitting by turning it counterclockwise.

4. Push the stem of the valve down to open the inlet fitting for sampling.

5. To lock the valve open, re-tighten the knurled thumbscrew on the side of the inlet fitting by turning it clockwise. Turn on the sample pump to fill the bag (*see Proper Bag Inflation*).

⚠ Do not sample compounds that exceed the 225 F (107.2 C) temperature rating of the fitting O-rings.

⚠ When using 237 Series FlexFilm bags, do not sample compounds that exceed 140 F (60 C) temperature.

⚠ Do not use sample bags to sample compounds with boiling points > 249.8 F (121 C).

6. When sampling is complete, turn off the pump and loosen the knurled thumbscrew.

7. Close the shut-off valve by pulling up on the valve stem (Note: Ensure the Teflon tubing is not pulled off while pulling up on the valve stem). Tighten the knurled screw to lock the valve closed.

8. To withdraw samples using a needle and syringe, carefully insert the needle into the port in the septum fitting and pierce the septum.

⚠ Do not allow the needle to puncture the bag material when piercing the septum.

Proper Bag Inflation

Avoid filling any bag more than 80% of its maximum volume. At the end of the sampling period, turn the pump off and close the valve on the bag. Tighten the knurled screw to lock the valve closed.

*Incorrect
Inflation*

*Correct
Inflation*

Silicone Background

All SKC fittings are lubricated with grease that contains silicone. This may produce high peaks for silicone in a GC-MS analysis.

SKC sample bags are available in Tedlar®, black Tedlar, Teflon, SamplePro® FlexFilm, and FlexFoil® with fittings made of stainless steel, polypropylene, or Teflon in sizes ranging from 10 milliliters to 100 liters. SKC also manufactures custom sample bags. Contact SKC at 724-941-9701 or skctech@skcinc.com.

Appendix C

SKC® Low Flow Sample Pump 222 Series

Description

SKC 222 Series Low Flow Pumps are miniature diaphragm-type pumps for personal or area sampling of gases and vapors in air using sorbent tubes or sample bags. These reliable lightweight pumps are motor-operated and powered by a rechargeable battery pack. Featuring reliable stroke counter technology, the pump's stroke counter indicates the number of times the pump's diaphragm has pulsed (or stroked) during the sampling period. By multiplying this stroke number by the volume of air per stroke, an accurate determination of air volume can be made. SKC sample pumps have special patented valves that close positively, ensuring zero leaks. All working parts are housed in a sturdy, shock-resistant case with belt clip. Model 222-3 pumps provide flows from 50 to 200 ml/min; Model 222-4 pumps provide flows from 20 to 80 ml/min.

222-3 Low Flow Pump

Performance Profile

Flow Rate:	222-3:	50 to 200 ml/min
	222-4:	20 to 80 ml/min
Operation Time:	10 hrs per battery charge	
Case:	Sturdy, lightweight plastic	
Battery:	Rechargeable NiCad, 2.4 V	
Charge Time: <i>(varies with capacity and level of charge)</i>	6 to 8.5 hrs with PowerFlex charger	
Battery Regulator:	Holds voltage constant	
Counter Readout:	Shows pump strokes up to six digits	
Valves:	Zero-leak valves	
Pumping Action:	Diaphragm	
Temperature Ranges:	Operating:	32 to 113 F (0 to 45 C)
	Charging:	32 to 113 F (0 to 45 C)
	Storing:	-4 to 113 F (-20 to 45 C)

Protect sample pump from weather when in use outdoors.

Size:	5.1 x 2.5 x 1.25 in (13 x 6.4 x 3.2 cm)
Weight:	12 oz (340 gm)
Approvals:	UL Listed for intrinsic safety; Class I, Groups A, B, C, and D CE marked

Use only the SKC-approved battery and charger for this model to ensure reliable performance and to maintain the UL Listing for intrinsic safety. Failure to do so voids any warranty.

Appendix D

Oakton® Infrared Thermometer

• Specifications •

Catalog number	WD-35629-00	WD-35629-10	WD-35629-20	WD-35629-30	WD-35629-40
Description	Infrapro® 1	Infrapro 2	Infrapro 3	Infrapro 4	Infrapro 5
Range	-32 to 400°C (-25 to 750°F)	-32 to 545°C (-25 to 950°F)	-32 to 600°C (-25 to 1100°F)	-32 to 760°C (-25 to 1400°F)	-32 to 760°C (-25 to 1400°F)
Resolution	0.2°C (0.5°F)				
Accuracy	±1% of the reading or ±1°C (±2°F) whichever is greater				
Repeatability	±0.5% of reading or ±1°C (±2°F) whichever is greater				
Spectral range	8 to 14 μm				
Response time	500 msec				
Emissivity	Fixed at 0.95	Fixed at 0.95	0.10 to 1.00	0.10 to 1.00	0.10 to 1.00
Laser sighting	Single spot, class II laser	Offset circle, class II laser	Offset circle, class II laser	Offset circle, class II laser	Offset circle, class II laser
Distance-to-target ratio	12:1	12:1	30:1	50:1	50:1
HOLD function	Yes	Yes	Yes	Yes	Yes
Maximum reading	Yes	Yes	Yes	Yes	Yes
Minimum reading	—	—	Yes	Yes	Yes
Differential reading	—	—	Yes	Yes	Yes
Average reading	—	—	Yes	Yes	Yes
High/low alarms	—	—	Yes	Yes	Yes
Datalogging	—	—	up to 12 points	up to 12 points	up to 12 points
External RTD probe	—	—	Optional	Optional	Included
Trigger lock (for long-term monitoring)	—	—	Yes	Yes	Yes
Intrinsically safe	—	—	—	—	Yes
Operating range	0 to 50°C (32 to 120°F)				
Power	9 V battery; display features low battery indicator				
Battery life	10 hours continuous	10 hours continuous	14 hours continuous	14 hours continuous	14 hours continuous
Dimensions	8" L x 6" W x 2" H				
Weight	11 oz (320 g) unit only; 2 lbs (1 kg) boxed				

Appendix E

Bios® Defender 510-M DryCal®

Flow Ranges	Low (L) 5 mL – 500 mL/min Medium (M) 50 mL – 5,000 mL/min High (H) 300 mL – 30,000 mL/min
Accuracy	1% Volumetric
Size	Small enough to fit easily in your hand; slim enough to slide into a briefcase or tote
Weight	29 oz / 820 g
Dimensions (H x W x D)	5.5 x 6 x 3 in / 140 x 150 x 75 mm

User-Selectable Measurement Units				
Volumetric Flow	mL/min	L/min	cc/min	cf/min
Pressure (Defender 520 only)	mmHg	PSI	kPa	
Temperature (Defender 520 only)	°C	°F		

Defender 500 Series Specifications	
Approximate Time per Reading:	1–15 seconds
Gas Compatibility:	Use with non-corrosive, non-condensing, non-combustible gases, less than 70% humidity
Flow Modes:	Suction or Pressure
Measurement Cell Style:	Integrated
Temperature and Pressure Sensors:	In the flow stream Press. Accuracy: 3.5 mmHg (typical), 7.0 mm (max); Temp. Accuracy: 0.8° C (typical), 1.3° C (max)
Reading Styles:	Single (manual), Continuous or Burst, with averaging function user-selectable from 1 to 100 measurements
AC Adapter/Charger:	12V DC, >250ma, 2.5 mm, center positive
Battery System:	6V rechargeable, sealed lead-acid, 6–8 hrs typical operation
Battery Operational Time (5 cycles/min):	3 hrs backlight on, 8 hrs backlight off
Pressure and Suction Fittings:	¼" ID Hose Barb
Warranty:	1 year; battery 6 months
Storage Temperature:	0–70° C
Ambient Humidity:	0–70%, non-condensing
Operating Pressure (Absolute):	15 PSI
Display:	Backlit graphical LCD
Data Port (for use with Optimizer software):	Serial (RS-232)
Data Cable (for use with Optimizer software):	1 meter (Defender Data Port to PC serial port)
Protective Case:	Soft side or Pelican case available
RoHS- and CE-compliant	

Appendix F

Experimental Data Collection Sheet

Parameters		Present		Temp, C		Pbar/Vel		Time	
TN		Manik		EntryWall		BarmmHg		GasOn:	
Date		ManBreath		CoalWall		VPcl_1		BagOn:	
SubjectID		Table		SamplWall		VPcl_2			
HoodFanHz		Clutter		Floor		VductTran		BagOff:	
WTrpm		Heated		Ceiling		~Vface		GasOff:	
HoodHeight		Source		Air,T db		Initials			
HoodWidth		PanToFace		Air, T wb		InitTravser		FatalError	
CrossOrient		Freon, lpm		ManFace		Sampler		MatchConfi	
Intervention		He, lpm		M. Torso		FTIR anal			
Face Loc.									
Location	Freon 134a	Residual	Time	RefNo	Comments & Errors				
Ambient Left									
AmbientRight									
Downstream									
Nose									
Mouth									
Duct									
Other									

Appendix G

Experimental Data Collection Software – Heavent[®] Measurement

FTIR

Files Add ID Who did what defaults Man Face Angle Hood defaults FTIR data input Units PitotTraverse

Experimental Conditions

Number	Time Traverse		Date Traverse			Duct	Windtunnel				Hood					Interv
Test	Long	Hour	Long	Day	Month	Vavg	RPM	CrossOrnt*	Vcross	Vface	FreqHz	Height	Width	FlangW	ElvMid-Table	Interv
68	00:00	0	03-24-08	24	Mar	3900	930	right	57.1	176	47.1	30.0	36.0	0	0	?
73	00:00	0	03-25-08	25	Mar	1872	300	right	15.1	84.4	23.5	30.0	36.0	0	0	No
74	00:00	0	03-25-08	25	Mar	3217	930	right	57.1	145	43.0	30.0	36.0	0	0	No
75	00:00	0	03-25-08	25	Mar	3885	300	right	15.1	175	45.3	30.0	36.0	0	0	No
76	00:00	0	03-25-08	25	Mar	3823	300	right	15.1	172	45.3	30.0	36.0	0	0	No

Sample

Seq = 352 (TN = 436)

Freon Location

Transfer FTIR Temp

Update

Set of conditions

Parameters		Present	Temp,C		Pbar/Vel		Time		Location	
TN	436	Manik	Y	EntryWall	23.4	BarmHg	743.7	GasOn:	14:11	Ambient Le
Date	07-09-09	ManBreath	Y	CoalWall	24.6	VPcL1	0.86	Bag on:	14:14	AmbientRigt
Subject ID		Table	Y	SamplWall	24.8	VPcL2	0.835			Downstrear
HoodFanHz	45	Clutter	n	Floor	24.6	VductTran	3702	Bag off:	14:34	Nos
W/Tpm	300	Heated	Y	Ceiling	24.8	Vface	167	Gas off:	14:34	Mout
HoodHeight	30.0	Source		Air,Tdb	23.0	Initials				Duc
HoodWidth	36.0	PanToFace	1.125	Air,Twb	16.5	InitTravser	BVL	FatalError	n	Othe
CrossOrient	90	Freon, lpm	3	ManFace	27.2	Sampler	BVL	MatchConf	10	
Intervention	None	He, lpm	9.5	M.Torso	32.0	FTIR anal	BVL			
Face loc.	Sideburn									

Number	Time, Min	Time	Date	Status	Freon134a		Others, ppm			Residuals			File No
Refer	SinceBagOff	Long	Long		ppm	Residuals	H2Oppm	CO2ppm	CO ppm	H2O	CO2	CO	Ref No
536	-284	09:50	07-09-09	warning	0	0.01	1.18	1335	0	0.01	0.0	0.0	c:\calcm
537	-282	09:52	07-09-09	warning	0	0.0	1.2	-574	0	0.01	0.0	0.0	c:\calcm
538	-280	09:54	07-09-09	warning		0.01	1.17	24.8	0	0.01	0.0	0.0	c:\calcm
539	-278	09:56	07-09-09	warning	2.75	0.01	1.14	371	0	0.01	0.0	0.0	c:\calcm
540	-276	09:58	07-09-09	warning	4.07	0.01	1.14	23.1	0	0.01	0.0	0.0	c:\calcm
541	-274	10:00	07-09-09	warning	82.2	0.02	1.16	36.4	0.02	0.01	0.0	0.0	c:\calcm

Update

Appendix H

All Experimental Data for Study I

TestNo	DateTraverse	HoodFanHz	WTrpm	Intervention	SubjectFacelocation With Hood Face	FreonGenLPM	HeliumGenLPM	SourceXface, inch	CambLeft, ppm	CambRight, ppm	Cdown, ppm	Cnose, ppm	Cmouth, ppm	Cduct, ppm
319	04-08-09	60	480	None	Sideburn	3	9.5	1.125	0	0.01	0.01	7.98	7.7	39.17
320	04-08-09	30	300	None	Sideburn	3	9.5	1.125	0	0	0	34.02	34.64	79.77
321	04-08-09	60	300	None	Sideburn	3	9.5	1.125	0.01	0.01	0	5.86	4.33	38.8
322	04-08-09	30	480	None	Sideburn	3	9.5	1.125	0	0	0	18.23	20.69	79.66
323	04-08-09	30	930	None	Sideburn	3	9.5	1.125	0.01	0	0	3.66	5.69	83.24
324	04-08-09	60	780	None	Sideburn	3	9.5	1.125	0.01	0.01	0.01	2.71	2.12	39.72
325	04-08-09	30	480	None	Sideburn	3	9.5	1.125	0.01	0.01	0.01	9.87	10.42	80.18
326	04-08-09	30	930	None	Sideburn	3	9.5	1.125	0.01	0.01	0.01	4.41	6.78	83.45
327	04-08-09	30	780	None	Sideburn	3	9.5	1.125	0.01	0.01	0	3.02	4.8	82.79
328	04-09-09	30	630	None	Sideburn	3	9.5	1.125	0	0	0	3.56	4.37	79.86
329	04-09-09	30	300	None	Sideburn	3	9.5	1.125	0	0	0	18.84	23.76	77.06
330	04-09-09	60	930	None	Sideburn	3	9.5	1.125	0	0	0	1.76	1.81	39.74
331	04-09-09	60	480	None	Sideburn	3	9.5	1.125	0	-0.01	0	3.04	2.21	39.44

332	04-09-09	60	930	None	Sideburn	3	9.5	1.125	0	0	0	1.75	-0.196	39.68
333	04-09-09	30	780	None	Sideburn	3	9.5	1.125	0	0	0	2.56	4.31	81.66
334	04-09-09	30	630	None	Sideburn	3	9.5	1.125	0	0	0	4.06	5.9	80.46
335	04-10-09	60	780	None	Sideburn	3	9.5	1.125	0	0	0	1.56	1.61	39.99
336	04-10-09	60	300	None	Sideburn	3	9.5	1.125	0	0	0	7.79	4.98	39.56
337	04-10-09	60	630	None	Sideburn	3	9.5	1.125	0	0	0	2.45	1.74	39.79
338	04-10-09	60	630	None	Sideburn	3	9.5	1.125	0	0	0	2.19	1.51	39.7
339	04-15-09	45	300	None	Sideburn	3	9.5	1.125	-0.01	-0.01	-0.01	4.39	3.7	51.53
340	04-15-09	45	780	None	Sideburn	3	9.5	1.125	-0.01	-0.01	-0.01	2.71	2.86	53.57
341	04-15-09	45	930	None	Sideburn	3	9.5	1.125	-0.01	-0.02	-0.01	3.54	3.37	54.32
342	04-16-09	45	630	None	Sideburn	3	9.5	1.125	0	-0.01	0	2.87	2.94	53.1
343	04-16-09	45	930	None	Sideburn	3	9.5	1.125	0	0	0	1.68	3.13	53.4
345	04-17-09	45	480	None	Sideburn	3	9.5	1.125	0.01	0	0	4.18	3.22	52.58
346	04-17-09	45	630	None	Sideburn	3	9.5	1.125	0	-0.01	0	2.94	2.47	52.59
347	04-17-09	45	300	None	Sideburn	3	9.5	1.125	0	0	0	9.74	3.92	51.92
348	04-17-09	45	480	None	Sideburn	3	9.5	1.125	0	0	0	4.51	3.06	53.01
349	04-17-09	45	780	None	Sideburn	3	9.5	1.125	0	-0.01	0	3.2	3.48	53.97
350	04-20-09	52.5	480	None	Sideburn	3	9.5	1.125	0	0	0	4.53	3.11	45.5
351	04-20-09	37.5	930	None	Sideburn	3	9.5	1.125	0	0	0	4.51	5.29	64.68
352	04-20-09	52.5	780	None	Sideburn	3	9.5	1.125	-0.01	0	-0.01	3.19	2.55	45.8
353	04-21-09	52.5	300	None	Sideburn	3	9.5	1.125	0	0	0	5.29	3.71	45.03
354	04-21-09	37.5	300	None	Sideburn	3	9.5	1.125	-0.01	-0.01	0	7.57	6.21	63.85

355	04-21-09	37.5	780	None	Sideburn	3	9.5	1.125	0	-0.01	0	5.5	6.5	64.72
356	04-21-09	37.5	630	None	Sideburn	3	9.5	1.125	0	0	-0.01	5.38	5.48	64.19
357	04-22-09	52.5	780	None	Sideburn	3	9.5	1.125	0	-0.08	0	3.23	2.75	45.93
358	04-22-09	52.5	630	None	Sideburn	3	9.5	1.125	0	0	0	3.22	2.37	45.21
359	04-22-09	52.5	300	None	Sideburn	3	9.5	1.125	0	0	0	7.23	5.13	45.02
360	04-22-09	37.5	930	None	Sideburn	3	9.5	1.125	0	-0.01	-0.01	4.73	6.32	66.12
361	04-22-09	37.5	630	None	Sideburn	3	9.5	1.125	0	0	0	4.99	4.55	64.19
362	04-22-09	37.5	480	None	Sideburn	3	9.5	1.125	0	0	0	7.31	6.31	62.99
363	04-22-09	37.5	780	None	Sideburn	3	9.5	1.125	0	-0.01	0	2.88	4.61	64.41
364	04-22-09	52.5	480	None	Sideburn	3	9.5	1.125	0	0	0	4.23	4.08	44.86
365	04-23-09	52.5	630	None	Sideburn	3	9.5	1.125	0	0	0	4.13	3.35	45.47
366	04-23-09	37.5	300	None	Sideburn	3	9.5	1.125	0	0	0	15.44	16.13	63.4
367	04-23-09	37.5	480	None	Sideburn	3	9.5	1.125	0	0	0	6.93	5.62	64.05
368	04-23-09	37.5	480	None	Sideburn	3	9.5	1.125	0	0	0	6.82	5.46	55.58
369	04-29-09	52.5	930	None	Sideburn	3	9.5	1.125	-0.01	2.54	-0.01	3.84	3.6	47.76
370	04-29-09	52.5	630	None	Sideburn	3	9.5	1.125	-0.01	0	-0.01	3.82	2.49	45.57
371	04-29-09	52.5	930	None	Sideburn	3	9.5	1.125	0	0	0	4.02	3.84	46.11
372	04-29-09	37.5	300	None	Sideburn	3	9.5	1.125	0	0	-0.01	20.23	14.47	63.2

Appendix I

All Experimental Data for Study II

TestNo	DateTraverse	HoodFanHz	WTrpm	Intervention	Subject FaceLocation WithHoodFace	Cambleft, ppm	CambRight, ppm	Cdown, ppm	Cnose, ppm	Cmouth, ppm	Cduct, ppm	Confidence InInput dData
378	05-21-09	30	300	CowlTopSides12in	Sideburn	-0.01	-0.01	-0.01	82.96	213.74	75.17	10
379	05-21-09	30	780	CowlTopSides12in	Sideburn	-0.01	-0.09	-0.01	68.24	228.06	81.74	10
380	05-21-09	45	780	CowlTopSides12in	Sideburn	0	-0.01	-0.01	95.74	183.34	54.63	10
391	05-26-09	30	780	CowlTopSides12in	Sideburn	0	0	-0.01	333.48	582.98	81.48	10
392	05-27-09	45	300	CowlTopSides12in	Sideburn	-0.03	0	-0.04	222.84	294.46	53.61	10
393	06-01-09	60	300	CowlTopSides12in	Sideburn	0	0	-0.02	172.26	205.18	34.33	10
409	06-15-09	45	780	CowlTopSides12in	Sideburn	-0.01	0	-0.01	280.56	256.98	54.54	10
410	06-15-09	60	780	CowlTopSides12in	Sideburn	0	0	-0.01	179.98	135.84	40.52	10
411	06-15-09	60	300	CowlTopSides12in	Sideburn	0	0	-0.01	159.88	143.6	40.09	10
418	06-17-09	60	780	CowlTopSides12in	Sideburn	-0.01	0	0.6	174.84	151.91	40.37	10
419	06-17-09	45	300	CowlTopSides12in	Sideburn	-0.01	0	-0.34	244.14	304.86	53.89	10
420	06-17-09	30	300	CowlTopSides12in	Sideburn	-0.03	0	-0.01	534.09	689.78	80.46	10
376	05-15-09	60	780	FlangeBottom 12in	Sideburn	0	-0.01	-0.01	15.1	25.6	34.5	10

377	05-15-09	30	300	FlangeBottom 12in	Sideburn	-0.01	0	-0.01	57	101	69.31	10
381	05-21-09	45	780	FlangeBottom 12in	Sideburn	-0.01	-0.01	-0.01	72.37	118.78	55.08	10
382	05-21-09	60	300	FlangeBottom 12in	Sideburn	-0.01	-0.01	-0.04	51.36	58.64	39.13	10
383	05-21-09	45	300	FlangeBottom 12in	Sideburn	-0.01	0	-0.01	72.79	89.44	53.73	10
384	05-22-09	30	780	FlangeBottom 12in	Sideburn	-0.01	-0.01	-0.01	55.35	165.33	82.22	10
400	06-02-09	45	300	FlangeBottom 12in	Sideburn	-0.01	0	-0.02	82.08	96.92	53.51	10
401	06-02-09	45	780	FlangeBottom 12in	Sideburn	-0.01	0	-0.01	77.65	162.22	55.13	10
402	06-02-09	60	300	FlangeBottom 12in	Sideburn	-0.01	0	-0.01	53.96	58.94	39.88	10
415	06-16-09	30	780	FlangeBottom 12in	Sideburn	-0.01	0	-0.01	125.24	224.15	83.35	10
416	06-16-09	60	780	FlangeBottom 12in	Sideburn	-0.01	0	-0.01	76.32	115.65	40.88	10
417	06-16-09	30	300	FlangeBottom 12in	Sideburn	0	0	-0.01	318.48	338.7	80.51	10
388	05-25-09	30	300	FlangeTopSides12in	Sideburn	-0.01	-0.01	-0.01	189.9	169.95	78.85	10
389	05-25-09	30	780	FlangeTopSides12in	Sideburn	-0.01	0	-0.01	123.51	246.94	82.22	10
390	05-26-09	45	780	FlangeTopSides12in	Sideburn	-0.01	0	0	39.93	59.59	54.16	10
394	06-01-09	45	300	FlangeTopSides12in	Sideburn	-0.01	0	-0.01	32.67	27.83	51.87	10
395	06-01-09	30	780	FlangeTopSides12in	Sideburn	-0.06	0	-0.01	111.11	227.38	83.15	10
396	06-01-09	60	780	FlangeTopSides12in	Sideburn	-0.01	0	-0.02	32.76	34.06	40.73	10
403	06-02-09	60	300	FlangeTopSides12in	Sideburn	-0.01	0	-0.03	39.27	32.71	40.15	10
404	06-03-09	60	300	FlangeTopSides12in	Sideburn	-0.01	0	-0.01	30.6	24.04	39.55	10
405	06-03-09	45	300	FlangeTopSides12in	Sideburn	-0.03	0	-0.01	39.96	33.71	53.32	10
412	06-15-09	60	780	FlangeTopSides12in	Sideburn	-0.01	0	-0.01	54	45.47	40.17	10
413	06-16-09	45	780	FlangeTopSides12in	Sideburn	-0.01	0	0	62.54	52.46	54.15	10

414	06-16-09	30	300	FlangeTopSides12in	Sideburn	-0.19	0	-0.01	209.43	161.77	80.4	10
373	05-14-09	30	780	None	Sideburn	-0.01	-0.02	-0.01	11.2	17.3	82.33	10
374	05-14-09	30	780	None	Sideburn	0	-0.01	-0.01	10.2	20.3	82.73	10
375	05-14-09	30	300	None	Sideburn	-0.01	-0.01	-0.01	90	100	79.65	10
385	05-22-09	45	300	None	Sideburn	-0.02	-0.03	-0.02	39.21	30.63	53.28	10
386	05-24-09	60	780	None	Sideburn	0	0	-0.01	26.63	26.04	40.74	10
387	05-24-09	45	780	None	Sideburn	-0.01	-0.01	-0.01	38.64	48.44	55.22	10
397	06-01-09	45	300	None	Sideburn	-0.01	0	-0.01	67.47	56.59	53.06	10
398	06-02-09	30	300	None	Sideburn	-0.02	0	-0.01	102.08	82.76	79.82	10
399	06-02-09	60	780	None	Sideburn	0	0	-0.02	21.05	18.29	40.72	10
406	06-03-09	60	300	None	Sideburn	-0.01	0	-0.02	16.26	8.59	39.77	10
407	06-15-09	60	300	None	Sideburn	0	0	-0.01	35.01	25.64	39.97	10
408	06-15-09	45	780	None	Sideburn	0	0	-0.01	45.37	45.25	54.73	10

Appendix J

Regression Analysis for Study I – Plain Hood Study

Table J.1-a: Regression of Log C_{mouth} with Hood Face Velocity (V_{face}) at $V_{cross} = 14$ fpm

Dependent variable is: Log C_{mouth}				
No Selector				
R squared = 64.5% R squared (adjusted) = 60.6%				
s = 0.2241 with 11 - 2 = 9 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.821191	1	0.821191	15.3
Residual	0.452064	9	0.0502293	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	2.0156	0.2849	7.07	≤ 0.0001
Vface	-0.00669108	0.001655	-4.04	0.0029

Table J.1-b: Regression of Log C_{mouth} with Hood Face Velocity (V_{face}) at $V_{cross} = 26$ fpm

Dependent variable is: Log C_{mouth}				
No Selector				
R squared = 43.4% R squared (adjusted) = 37.2%				
s = 0.2232 with 11 - 2 = 9 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.344409	1	0.344409	6.91
Residual	0.448445	9	0.0498273	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.44847	0.2838	5.1	0.0006
Vface	-0.00433323	0.001648	-2.63	0.0274

Table J.1-c: Regression of Log C_{mouth} with Hood Face Velocity (V_{face}) at $V_{cross} = 36$ fpm

Dependent variable is: Log C_{mouth}				
No Selector				
R squared = 81.9% R squared (adjusted) = 79.9%				
s = 0.08793 with 11 - 2 = 9 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.315815	1	0.315815	40.8
Residual	0.0695852	9	0.00773169	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.20672	0.1152	10.5	≤ 0.0001
Vface	-0.00414945	0.0006492	-6.39	0.0001

Table J.1-d: Regression of Log C_{mouth} with Hood Face Velocity (V_{face}) at V_{cross} = 46 fpm

Dependent variable is: Log C_{mouth}				
No Selector				
R squared = 79.0% R squared (adjusted) = 76.4%				
s = 0.08807 with 10 - 2 = 8 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.233956	1	0.233956	30.2
Residual	0.0620542	8	0.00775678	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.13815	0.1165	9.77	≤ 0.0001
Vface	-0.00365385	0.0006653	-5.49	0.0006

Table J.1-e: Regression of Log C_{mouth} with Hood Face Velocity (V_{face}) at V_{cross} = 57 fpm

Dependent variable is: Log C_{mouth}				
No Selector				
R squared = 76.3% R squared (adjusted) = 73.3%				
s = 0.1339 with 10 - 2 = 8 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.460889	1	0.460889	25.7
Residual	0.143351	8	0.0179189	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.42583	0.177	8.05	≤ 0.0001
Vface	-0.0051284	0.001011	-5.07	0.0010

Table J.2-a: Regression of Log C_{mouth} with Cross-draft Velocity (V_{cross}) at $V_{face} = 111$ fpm

Dependent variable is: logCmouth				
No Selector				
R squared = 66.5% R squared (adjusted) = 62.3%				
s = 0.2074 with 10 - 2 = 8 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.684328	1	0.684328	15.9
Residual	0.344282	8	0.0430353	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.5814	0.1698	9.32	≤ 0.0001
Vcross	-0.0174413	0.004374	-3.99	0.0040

Table J.2-b: Regression of Log C_{mouth} with Cross-draft Velocity (V_{cross}) at $V_{face} = 140$ fpm

Dependent variable is: logCmouth				
No Selector				
R squared = 33.7% R squared (adjusted) = 27.0%				
s = 0.152 with 12 - 2 = 10 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.117299	1	0.117299	5.08
Residual	0.231101	10	0.0231101	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	1.0371	0.1059	9.79	≤ 0.0001
Vcross	-0.00654572	0.002905	-2.25	0.0479

Table J.2-c: Regression of Log C_{mouth} with Cross-draft Velocity (V_{cross}) at $V_{face} = 170$ fpm

Dependent variable is: logCmouth				
No Selector				
R squared = 12.3% R squared (adjusted) = 1.3%				
s = 0.05741 with 10 - 2 = 8 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.00368706	1	0.00368706	1.12
Residual	0.0263629	8	0.00329537	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.550832	0.04698	11.7	≤ 0.0001
Vcross	-0.00128023	0.00121	-1.06	0.3211

Table J.2-d: Regression of Log C_{mouth} with Cross-draft Velocity (V_{cross}) at $V_{face} = 200$ fpm

Dependent variable is: logCmouth				
No Selector				
R squared = 13.3% R squared (adjusted) = 3.7%				
s = 0.102 with 11 - 2 = 9 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.0143871	1	0.0143871	1.38
Residual	0.0936856	9	0.0104095	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.606035	0.08296	7.3	≤ 0.0001
Vcross	-0.00252889	0.002151	-1.18	0.2699

Table J.2-e: Regression of Log C_{mouth} with Cross-draft Velocity (V_{cross}) at $V_{face} = 229$ fpm

Dependent variable is: logCmouth				
No Selector				
R squared = 59.3% R squared (adjusted) = 54.3%				
s = 0.1861 with 10 - 2 = 8 degrees of freedom				
Source	Sum of Squares	df	Mean Square	F-ratio
Regression	0.404404	1	0.404404	11.7
Residual	0.277086	8	0.0346358	
Variable	Coefficient	s.e. of Coeff	t-ratio	prob
Constant	0.858996	0.1523	5.64	0.0005
Vcross	-0.0134077	0.003924	-3.42	0.0091