In-Depth Survey Report

An Evaluation of Local Exhaust Ventilation Systems for Controlling Hazardous Exposures in Nail Salons

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) conducted a laboratory research project to evaluate the effectiveness of local exhaust ventilation controls for preventing worker exposure to chemicals in nail salons. Nail salon employees are potentially exposed to dozens of hazardous chemicals including acrylates, solvents, and biocides in the form of dusts or vapors. Exposure to these chemicals on the job have been examined by a small but growing number of studies that have found possible links between nail technicians' work and adverse health outcomes including respiratory, neurological, and musculoskeletal disorders, as well as other health conditions including cancer.

NIOSH asked prototype designers, commercial manufacturers, and vendors of downdraft ventilated nail tables (VNT) and portable nail salon source capture ventilation systems (SCV) that featured local exhaust recirculation to provide new, unused, downdraft units to be evaluated in this project. The NIOSH research project included an evaluation of airflow and capture characteristics of the units as well as noise levels around them. Three different exhaust systems and four different collecting hoods were provided to NIOSH for this study. To quantitatively evaluate the capture efficiency of the ventilation system, a tracer gas method was used.

Results of the tracer gas capture efficiency measurements for the various configurations showed the potential to reduce exposures by at least 50% - 60%. Exhaust system 2 (the silver shop vacuum) was the most efficient at removing potentially harmful chemicals during these tests. Results from the sound level readings also revealed that system 2 was the loudest of the three.

Additional testing could be conducted to determine configurations that would improve collection efficiency. Practical testing in salons is necessary to determine if this arrangement would be accepted by nail technicians. From the results of this research as well as stated industry needs, the following recommendations are made:

- Conduct additional studies with the nail table and exhaust hoods to determine optimum flow rates for increased capture efficiencies.
- Provide training to nail salon operators and employees about the importance of using engineering controls for processes that involve potentially hazardous chemicals.
- Investigate the requirements for salon ventilation to determine if current recommendations are adequate or if higher flows are more protective.
- Conduct CFD simulations of the various ventilation system and hood configurations to determine which provide the most protection for the worker.
- Conduct research on the filtration used in the ventilation units.
- Produce this information in easy to understand documents that will be made available to nail salon owners and workers.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC) is the primary Federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Engineering and Physical Hazards Branch (EPHB) of the Division of Applied Research and Technology has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, EPHB has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

Background for this Study

NIOSH researchers are conducting initial laboratory studies to determine the effectiveness of several control technologies for reducing worker exposure to chemicals in nail salons. According to industry estimates, approximately 375,000 people are employed in nail salons and other personal care services in the United States [Drummey 2011]. The workforce in this industry is mostly female (96%) and also includes a large number of minority workers (63%). Nail salon employees are potentially exposed to dozens of hazardous chemicals including acrylates, solvents, and biocides in the form of dusts or vapors. Exposure to these chemicals on the job has been examined by a small but growing number of studies that have found possible links between nail technicians' work and adverse health outcomes including respiratory, neurological, and musculoskeletal disorders, as well as other health conditions including cancer.

Nail technicians typically perform manicures and apply artificial fingernails over a workstation – or "nail table" – with the client's hands resting on the table top as the technician completes the work. Due to the proximity of the technicians' breathing zone to the chemicals used in the manicure process, exposure to these chemicals represents a reason for concern. To protect nail salon workers from these chemical exposures, various types of engineering controls may be employed. These may include downdraft ventilated tables, portable source capture exhaust ventilation systems, and ventilation systems that remove contaminants before they cross the breathing zone. Down- or side-draft nail ventilation pulls contaminated air from near the area where products are placed or used to prevent it from reaching the face and being inhaled as the contaminated air crosses the breathing zone. A downdraft table uses ventilation pulled through the table's top to remove particulate and vapor contaminants. A portable SCV system is a device that hooks to a source of ventilation to provide local ventilation, typically to the area where products are placed or used. These engineering control systems provide the means to remove potentially harmful exposures from the workplace. Because it is desirable to remove contaminated air before it crosses the breathing zone, ventilation systems that do not feature down- or side-draft ventilation were not included in this evaluation.

There are a number of commercially available sources of engineering control solutions for nail salon applications. NIOSH undertook a unique research project to examine the effectiveness of different local exhaust ventilation systems in removing potential exposures from the work area. NIOSH asked prototype designers, commercial manufacturers, and vendors of downdraft VNT's and portable SCVs to provide new, unused, downdraft systems to be evaluated in this project. Only SCVs were received in response. The NIOSH research project included an evaluation of airflow and capture characteristics of the SCVs connected to a standard nail table as well as noise levels around the SCVs. Results and recommendations from this research project will be distributed to the participating suppliers. NIOSH may also use research findings to develop educational materials for nail technicians and other publications.

Methodology

To evaluate the different VNT local exhaust ventilation systems an enclosure was constructed using 1.25 inch diameter schedule 40 polyvinyl chloride (PVC) pipes that were covered with 6 mil plastic sheeting. The dimensions of the room were approximately 8 x 10 x 7.5 feet for an approximate room volume of 600 cubic feet (ft^3). The enclosure was fitted with a standard ceiling diffusor (2 x 2 feet) in the center of the ceiling connected to a variable speed exhaust system (Yaskawa Varispeed E7 model CIMR- E7U4024). The PVC frame of the enclosure is shown in Figure 1.

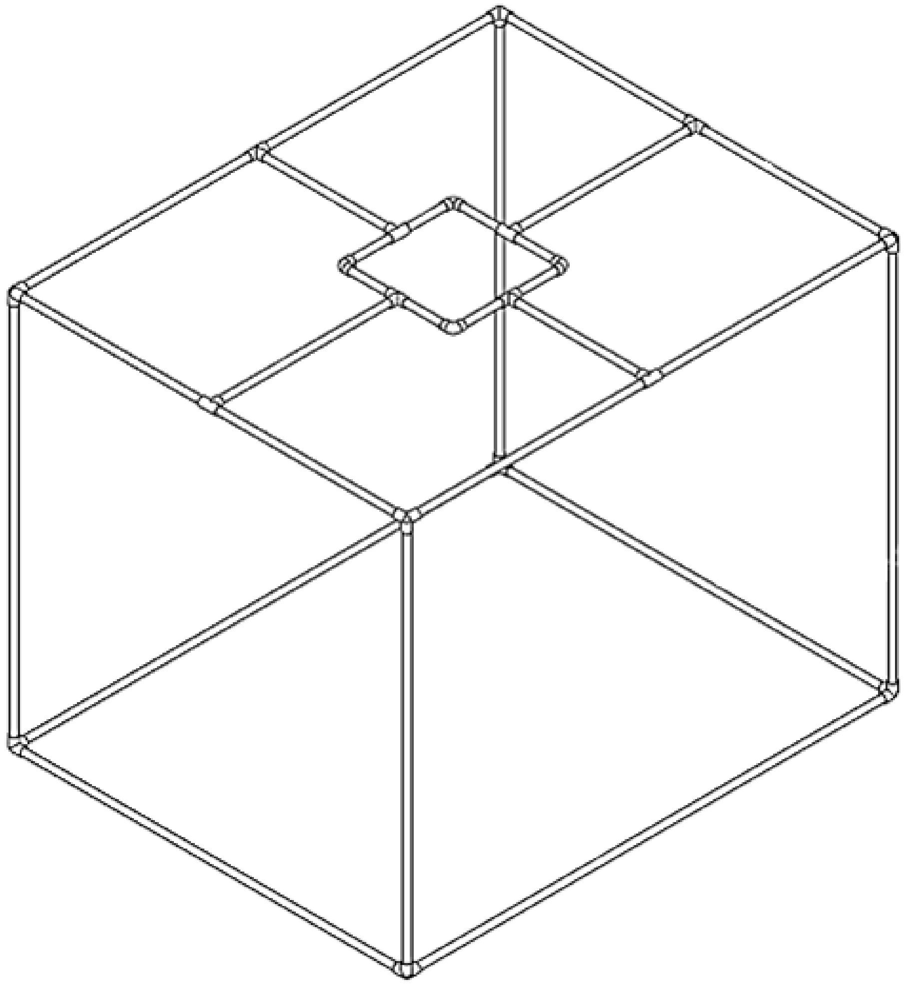

Figure 1: PVC frame layout for testing enclosure

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc. (ASHRAE) Standard 62.1 recommends a minimum ventilation supply rate of 20 cubic feet of per minute (cfm) of outdoor air with a minimum exhaust rate of 0.6 cfm/ft^2 for beauty and nail salons [ASHRAE 2010]. The general air exhaust flow rate in the testing enclosure was set at 65 cfm.

The VNT used for this evaluation was a nail salon table exhaust ventilation system as shown in Figure 2. The table has a surface area of 4.75 square feet (ft^2) and a height of approximately 3 feet. The VNT was placed inside of the enclosure directly under the ceiling exhaust diffuser. Manikins were seated on either side of the table representing the technician and the client.

Figure 2: Nail Salon Table

To quantitatively evaluate the capture efficiency of the ventilation system, a tracer gas method was used. Tracer gas is commonly used to evaluate capture efficiencies of local exhaust ventilation systems. One of the most common applications of tracer gas testing occurs in fume hood testing for local exhaust ventilation hoods that are designed to capture both gases and particles [ANSI/ASHRAE 1985].

To evaluate the collection efficiencies of the different local exhaust ventilation systems connected to the nail salon table, tracer gas was released from a location on the VNT top where nail products (such as polish remover or acrylic nail liquid) would normally be placed. The tracer gas used was a 1% concentration of gravimetric grade sulfur hexafluoride (SF_6) in air. The gas was delivered to the release point at a mass flow rate of 0.5 liters per minute (lpm) using an Omega mass flow meter (model FMA5528 0-50 lpm, Omega Engineering, Inc., Stamford, Connecticut). SF_6 concentrations were measured near the technician's breathing zone using a MIRAN® Sapphire Specific Vapor Analyzer (model 205B-XL2A351, Thermo Environmental Instruments, Franklin, Massachusetts). The MIRAN® has a sensitivity of +/- 2 parts per billion (ppb). A photo of the experimental set-up is shown in Figure 3.

To prevent SF_6 from being re-entrained into the enclosure, the discharge from the local exhaust ventilation system was routed to an exhaust box that was then vented to the enclosure's ceiling exhaust. The exhaust box was constructed of Plexiglas with the dimensions of 3.04 x 2.56 x 5.06 feet.

Figure 3: Experimental Arrangement

During the evaluation, the analyzer was set to measure and record data at a one second interval. A typical sample run involved generating a known concentration of SF_6 within the enclosure for 15 minutes, then running the local exhaust ventilation system for 15 minutes followed by another 15 minutes with the exhaust ventilation system off. Data from the first 5 minutes of each interval (system off or on) were not used to calculate the mean SF_6 concentration as the readings in this initial interval are typically unstable and will not accurately represent the capture efficiency. Mean concentrations of SF_6 for the remaining 10 minutes for each run (system on and off) were calculated. Collection efficiency was calculated by comparing the mean SF_6 concentration while the local exhaust ventilation system was off to the mean SF_6 concentration while the system was on.

Control Technology

Description of the Evaluated Systems

Three commercially available exhaust ventilation systems were provided to NIOSH for evaluation. Each of these systems was connected to different local exhaust ventilation hoods on top of the VNT for testing. The following is a brief description of each exhaust ventilation system:

<u>Exhaust ventilation system #1:</u>

Specifications:

- Variable speed control (for this study the speed was set at maximum speed)
- Weight: Approximately 30 lbs.
- Noise level 58-60 dBA at 6 ft.
- Height: 30 inches
- Length: 12.5 inches
- Width: 12.5 inches
- Filtration: Activated charcoal system for organic vapors

Figure 4: Exhaust system #1

<u>Exhaust ventilation system #2:</u>

Specifications:

- Single speed exhaust (on/off)
- Noise level: N/A
- Weight: Approximately 40 lbs.
- Height: 30 inches
- Diameter: 19 inches
- Filtration: Not specified

Figure 5: Exhaust system #2

Exhaust ventilation system #3:

Specifications:

- Single speed exhaust (on/off)
- Noise level: N/A
- Weight: Approximately 50 lbs.
- Height: 19.5 inches
- Length: 16 inches
- Width: 12 inches
- Filtration: Not specified

Figure 6: Exhaust system #3

Four (4) collecting hoods were evaluated in conjunction with the three exhaust ventilation systems. The combination of the three exhaust systems and the four collecting hoods resulted in a test matrix of twelve tests. A brief description of each collecting hood is provided below:

A. Downdraft exhaust hood centered on the table top
Hood face inlet area: 0.0575 ft^2

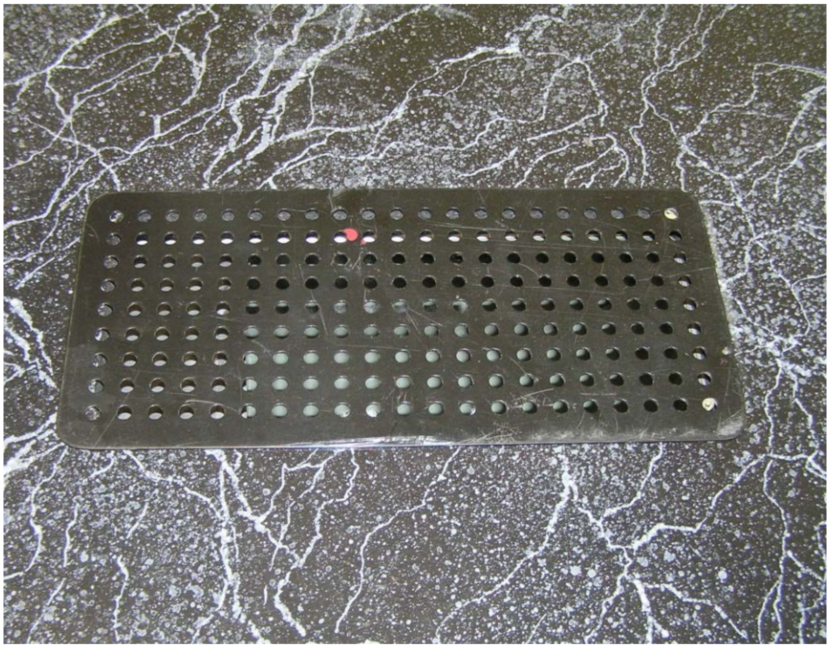

Figure 7: Downdraft exhaust hood built into the table

<u>B. Plain Opening Side draft exhaust</u>
Hood face inlet area of 0.0476 ft^2

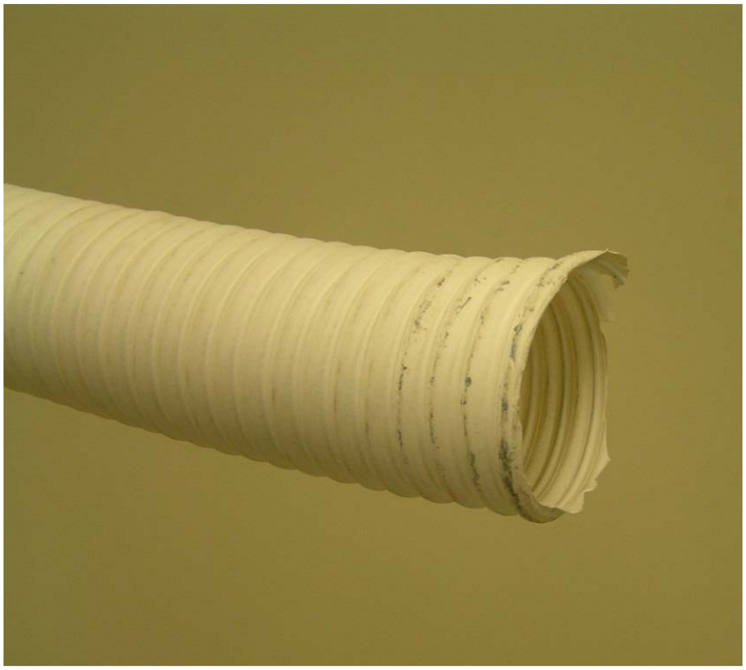

Figure 8: Plain opening side exhaust hood

<u>C. Rectangular side draft exhaust hood (6” x 6” x 1.5”)</u>
Hood face inlet area of 0.0525 ft^2

Figure 9: Rectangular side exhaust hood

D. Hand rest with an exhaust hood for nail products
Hand rest dimensions (1.33 ft. x 0.42 ft.)
Hood face inlet area of 0.0104 ft^2.


Figure 10: Hand rest exhaust

In addition to evaluating the capture efficiency of each local exhaust ventilation system, sound level measurements were also collected. A Quest sound level meter (model 2400, Quest Technologies, Oconomowoc, Wisconsin) with fast response and A-weighting scale was used to collect the noise readings. Measurements were made near the system (within two inches) and six feet away from the system.

Results

One percent SF_6 was delivered to the test enclosure at a mass flow rate of 0.5 lpm to generate a uniform SF_6 mix inside of the enclosure. The room exhaust rate was set at 65 cfm. A mean SF_6 concentration of approximately 30 ppb (SD= 0.009 ppb) was generated during eight, ten-minute test runs (n=600) as shown in Table 1.

Table 1: SF_6 steady-state concentrations inside of test enclosure

Test Run	Mean SF_6 Conc. (ppb)	Std. Dev.
1	43	0.018
2	37	0.011
3	27	0.010
4	48	0.031
5	36	0.009
6	15	0.006
7	13	0.007
8	17	0.005
Mean	29	0.009

As a result of these test runs, a room SF_6 concentration between 25 and 85 ppb was used as test concentrations when the exhaust ventilation system being evaluated was off. The flow rates and inlet area for each of the exhaust ventilation systems were measured using a TSI VelociCalc (TSI Incorporated, Shoreview, Minnesota) hot-wire anemometer model 9545-A and is reported below:

1. Exhaust Ventilation System # 1
   Inlet area = 0.0451 ft^2
   Flow rate = 110 cfm
2. Exhaust Ventilation System # 2
   Inlet area= 0.0308 ft^2
   Flow rate =108 cfm
3. Exhaust Ventilation System #3
   Inlet area = 0.0042 ft^2
   Flow rate = 17.7 cfm

Average face velocities were collected for each combination of the evaluated exhaust ventilation systems and collecting hoods. The average face velocity was the result of the collection of five measurements for each combination. The average flow rate was calculated by multiplying the average face velocity and the area of the open face for each hood. Results of these measurements are shown in Table 2 below.

Table 2: Ventilation Summary Table

Exhaust Ventilation System	Hood	Face Velocity (fpm)	Face Area (ft^2)	Flow Rate (cfm)
1	A	208	0.0574	11.9
1	B	1431	0.0476	68.1
1	C	157	0.0525	8.24
1	D	674	0.0104	7.01
2	A	182	0.0574	10.4
2	B	1680	0.0476	80.0
2	C	282	0.0525	14.8
2	D	4375	0.0104	45.5
3	A	37.3	0.0574	2.14
3	B	202	0.0476	9.60
3	C	131	0.0525	6.86
3	D	1794	0.0104	18.7

Each test configuration was evaluated by conducting two trials. Each trial involved five sequences of control off and control on. For each sequence, the collection efficiency was calculated and the average mean efficiency was calculated per trial. Appendices A, B, and C contain tables including all the collected experimental data segregated by trial. Mean SF_6 concentrations were determined using 600 measurements (for both, control on and off). Table 3 shows the mean collection efficiencies for each trial and the overall mean efficiency for each test configuration.

Table 3: Collection efficiency results by trial

Exhaust Ventilation System	Hood	Test Run #1 Collection Efficiency (%)	Test Run #2 Collection Efficiency (%)	Mean Collection Efficiency (%)
1	A	51.7	53.7	52.7
1	B	52.9	53.6	53.3
1	C	52.4	52.3	52.4
1	D	52.9	53.0	53.0
2	A	51.5	50.2	50.9
2	B	51.4	51.2	51.3
2	C	64.3	52.7	58.5
2	D	60.1	63.2	61.7
3	A	50.8	50.8	50.8
3	B	51.4	50.7	51.1
3	C	50.0	51.6	50.8
3	D	55.9	52.4	54.2

Sound level measurements were collected for the three evaluated exhaust ventilation systems. The results from the noise evaluation are shown in Table 4.

Table 4: Sound level measurements for the exhaust ventilation systems

Exhaust Ventilation System	Sound Level Near (dBA)	Sound Level 6' Away (dBA)
1	85.1	64.4
2	87.0	69.2
3	84.1	68.0

Discussion

On average, the different exhaust configurations evaluated in this project showed the potential to reduce exposures by at least 50%. The highest collection efficiency was achieved by using the exhaust ventilation system 2 connected to the hand rest hood (D) at 61.7%. The hand rest hood (D) seemed to be (overall) the most efficient hood with a mean collection efficiency of 56.3%. Combining the four different hood configurations with each exhaust ventilation system, exhaust system 1 resulted in an overall collection efficiency of 52.9%, system 2 of 55.6%, and system 3 of 51.7%. The lowest mean collection efficiency was noted when using exhaust system 3 with hood configurations A and C with an average efficiency of 50.8%.

During the completion of this project, it was noted that all the evaluated exhaust systems and collecting hoods had similar capture efficiencies. However, the hand rest hood (D) seemed to perform slightly better than the other evaluated hoods. This hood provides a soft hand rest surface for the client as well as a ventilated product holder for the technician.

A typical practice in nail salons is for the technician to place a towel on the table under the client's hands. This was taken into account during the testing although it should not have a significant impact on the performance of the controls. However, the use of the downdraft control would be compromised if the towel covered all or part of the exhaust surface.

Sound level readings collected near the three evaluated systems were 85.1, 87.0, and 84.1 dBA for systems 1, 2, and 3, respectively. The sound level readings collected 6 feet away from the three exhaust systems were 64.4, 69.2, and 68.0 dBA, for systems 1, 2, and 3, respectively. The sound levels readings near the systems (within two inches) are potentially high for long term exposure. Provisions should be made to place the fan unit away from the workers to reduce potential noise exposures.

Conclusions and Recommendations

The results of this laboratory testing indicate that the evaluated exhaust ventilation systems have the potential to reduce worker chemical exposure in nail salons by at least 50%. The efficiency measurements for the various configurations produced very similar results. Exhaust system 2 was the most effective at removing potential harmful chemicals during these tests. Results from the sound level readings also indicate that system 2 was the loudest of the three evaluated systems.

Additional testing could be used to determine configurations that would improve collection efficiency. Practical testing in nail salons is necessary to determine if this arrangement would be accepted by nail technicians. From the results of this research as well as stated industry needs, the following recommendations are made:

•Conduct additional studies with the nail table and exhaust hoods to determine optimum flow rates for increased capture efficiencies and reduce noise.

•Provide training to nail salon operators and employees about the importance of using engineering controls for processes that involve potentially hazardous chemicals.

•Investigate the requirements for general and local salon ventilation to determine if current recommendations are adequate or if higher flows are more protective.

•Conduct CFD simulations of the various ventilation system and hood configurations to optimize design parameters and improve capture efficiency.

•Conduct research to evaluate the effectiveness of the filtration systems used in the ventilation units.

•Produce this information in easy to understand documents that will be made available to nail salon owners and workers.

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Appendix A: Collection Efficiency Results for Exhaust Ventilation System 1

- **1st Run, Hood A:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	A	1	56.6	52.3	25.9	52.50
1	A	2	52.3	52.6	24.3	53.70
1	A	3	52.6	47.2	23.1	53.70
1	A	4	47.2	48.7	22.2	53.60
1	A	5	48.7	44	20.8	55.10
					Mean	53.70

- **2nd Run, Hood A:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	A	1	30.3	42.9	16.7	54.50
1	A	2	42.9	43.7	20.8	51.90
1	A	3	43.7	49.6	22.2	52.40
1	A	4	49.6	51.3	25.6	49.20
1	A	5	51.3	54.6	26.2	50.50
					Mean	51.70

- **1st Run, Hood B:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	B	1	87.6	82.4	41.4	51.30
1	B	2	82.4	88.4	41.2	51.80
1	B	3	88.4	90.9	40.6	54.70
1	B	4	90.9	89.3	41.7	53.70
1	B	5	89.3	90.1	42.2	53.00
					Mean	52.90

- **2nd Run, Hood B:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	B	1	30	46.1	17	55.40
1	B	2	46.1	52.3	21.9	55.40
1	B	3	52.3	57.7	25.5	53.60
1	B	4	57.7	61.5	28.5	52.20
1	B	5	61.5	69.4	31.8	51.40
					Mean	53.60

- **1st Run, Hood C:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	C	1	37.6	50.7	20.8	52.90
1	C	2	50.7	66.1	27	53.80
1	C	3	66.1	65.9	30.9	53.20
1	C	4	65.9	72.5	33.8	51.20
1	C	5	72.5	83.6	38.6	50.60
					Mean	52.40

- **2nd Run, Hood C:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	C	1	35	41.2	18.1	52.50
1	C	2	41.2	53.1	22.4	52.60
1	C	3	53.1	61.8	26.8	53.30
1	C	4	61.8	66.4	30.6	52.20
1	C	5	66.4	66.8	32.8	50.70
					Mean	52.30

- **1st Run, Hood D:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	D	1	33.4	46.8	18.9	52.80
1	D	2	46.8	54.7	23.8	53.10
1	D	3	54.7	61.7	27	53.60
1	D	4	61.7	61.8	29.3	52.50
1	D	5	61.8	68.1	30.9	52.40
					Mean	52.90

- **2nd Run, Hood D:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
1	D	1	40.2	47.1	19.5	55.50
1	D	2	47.1	60	24.1	55.00
1	D	3	60	55.3	26.4	54.20
1	D	4	55.3	58.4	28.2	50.40
1	D	5	58.4	59.5	29.5	50.00
					Mean	53.00

Appendix B: Collection Efficiency Results for Exhaust Ventilation System 2

- **1st Run, Hood A:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	A	1	33.9	41.9	18.6	50.90
2	A	2	41.9	51.2	22.8	50.90
2	A	3	51.2	58.6	26.8	51.10
2	A	4	58.6	63.7	29.3	52.10
2	A	5	63.7	66.5	31.1	52.30
					Mean	51.50

- **2nd Run, Hood A:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	A	1	28.6	35.3	16.1	49.70
2	A	2	35.3	41.3	19.1	50.10
2	A	3	41.3	46.9	21.6	51.10
2	A	4	46.9	51.1	24.4	50.30
2	A	5	51.1	54.7	26.5	49.80
					Mean	50.20

- **1st Run, Hood B:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	B	1	48	45.4	22.8	51.10
2	B	2	45.4	43.2	21.9	50.60
2	B	3	43.2	41.4	21	50.40
2	B	4	41.4	41.3	19.1	53.80
2	B	5	41.3	46.9	21.6	51.10
					Mean	51.40

- **2nd Run, Hood B:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	B	1	31.5	37.7	17	50.90
2	B	2	37.7	45.4	20.5	50.60
2	B	3	45.4	53.3	24.3	50.70
2	B	4	53.3	58.8	27.1	51.50
2	B	5	58.8	60.8	28.7	52.10
					Mean	51.20

- **1st Run, Hood C:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	C	1	42.3	41.6	11.1	73.50
2	C	2	41.6	23.9	11.1	66.20
2	C	3	23.9	37.5	11.1	63.90
2	C	4	37.5	22.3	11.1	62.90
2	C	5	22.3	26.2	10.9	55.20
					Mean	64.30

- **2nd Run, Hood C:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	C	1	46.6	61.5	23.3	56.90
2	C	2	61.5	68.2	30.9	52.30
2	C	3	68.2	75.8	34.8	51.70
2	C	4	75.8	82.3	38.4	51.40
2	C	5	82.3	85.5	41	51.10
					Mean	52.70

- **1st Run, Hood D:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	D	1	27.3	40.8	15	56.00
2	D	2	40.8	56.2	17.9	63.10
2	D	3	56.2	47.4	19	63.30
2	D	4	47.4	45	18.7	59.50
2	D	5	45	39.3	17.5	58.50
					Mean	60.10

- **2nd Run, Hood D:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
2	D	1	24.8	22.1	9.6	59.30
2	D	2	22.1	29.3	8.4	67.40
2	D	3	29.3	25.9	9.2	66.60
2	D	4	25.9	28.3	10.3	62.20
2	D	5	28.3	25.2	10.6	60.50
					Mean	63.20

Appendix C: Collection Efficiency Results for Exhaust Ventilation System 3

- **1st Run, Hood A:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	A	1	35.4	43.2	19.3	50.90
3	A	2	43.2	52.8	24.2	49.50
3	A	3	52.8	58.1	27.4	50.50
3	A	4	58.1	66.1	30	51.70
3	A	5	66.1	68.3	32.8	51.20
					Mean	50.80

- **2nd Run, Hood A:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	A	1	43.5	48.9	21.2	54.20
3	A	2	48.9	60.1	27.6	49.30
3	A	3	60.1	67.6	32.1	49.80
3	A	4	67.6	73.5	35	50.40
3	A	5	73.5	80.5	38.3	50.20
					Mean	50.80

- **1st Run, Hood B:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	B	1	43.8	55.4	23.2	53.20
3	B	2	55.4	65.4	29.6	51.00
3	B	3	65.4	71.8	32.8	52.20
3	B	4	71.8	75	36.6	50.20
3	B	5	75	77.4	37.7	50.60
					Mean	51.40

- **2nd Run, Hood B:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	B	1	77.4	80.1	39.6	49.80
3	B	2	80.1	80	39.6	50.50
3	B	3	80	83.5	39.4	51.80
3	B	4	83.5	76.8	39.8	50.40
3	B	5	76.8	70.9	36.1	51.20
					Mean	50.70

- **1st Run, Hood C:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	C	1	26.3	31.3	14.1	50.90
3	C	2	31.3	35.3	16.9	49.30
3	C	3	35.3	38	18.4	49.70
3	C	4	38	40.6	19.6	50.10
3	C	5	40.6	38.5	19.7	50.20
					Mean	50.00

- **2nd Run Hood C:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	C	1	32.6	31.1	14.4	54.80
3	C	2	31.1	28.3	14.1	52.40
3	C	3	28.3	28.5	13.8	51.40
3	C	4	28.5	22.1	12.8	49.30
3	C	5	22.1	22.6	11.1	50.10
					Mean	51.60

- **1st Run, Hood D:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	D	1	28.9	27.6	12.7	55.10
3	D	2	27.6	37.1	14.1	56.40
3	D	3	37.1	35.7	16.1	55.70
3	D	4	35.7	35.4	15.9	55.30
3	D	5	35.4	30.5	14.1	57.20
					Mean	55.90

- **2nd Run, Hood D:**

Exhaust System	Hood	Test	SF_6 Before (ppm)	SF_6 After (ppm)	SF_6 Control On (ppm)	% Reduction
3	D	1	56.8	51.5	27.5	49.20
3	D	2	51.5	48.1	22.9	54.10
3	D	3	48.1	45.1	22.9	50.90
3	D	4	45.1	54.1	23.3	53.00
3	D	5	54.1	52.8	24.2	54.70
					Mean	52.40

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