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IN-DEPTH SURVEY REPORT:

A LABORATORY EVALUATION OF PROTOTYPE ENGINEERING CONTROLS DESIGNED TO REDUCE OCCUPATIONAL EXPOSURES DURING ASPHALT PAVING OPERATIONS

AT

Dynapac Compaction and Paving
Selma, Texas

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DISCLAIMER

Mention of company names or products does not constitute endorsement by the Centers for Disease Control and Prevention (CDC).

EXECUTIVE SUMMARY

On August 12-13, 1997, researchers from the National Institute for Occupational Safety and Health (NIOSH) evaluated prototype engineering controls designed for the control of fugitive asphalt emissions during asphalt paving. The Dynapac engineering control evaluation was completed as a supplement to an existing Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment. NIOSH researchers are conducting the research through an interagency agreement with DOT's Federal Highway Administration (FHWA). The National Asphalt Pavement Association continues to play a critical role in coordinating the paving manufacturers' and paving contractors' voluntary participation in the study.

The study protocol for the original FHWA project included two major phases. During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions. The indoor evaluation incorporated tracer gas analysis techniques to quantify the control's exhaust volume and to determine the capture efficiency. Results from the indoor evaluations provided equipment manufacturers with the necessary information to maximize engineering control performance prior to the second phase of the study, a performance evaluation of the prototype engineering controls under "real-life" outdoor conditions during an actual paving operation. In March of 1997, the FHWA agreed to fund the evaluation of prototype engineering controls on Dynapac Paving equipment. This report signifies the culmination of the phase I evaluation and includes specific design recommendations to improve the Dynapac prototype engineering control design. Results and discussion from the Dynapac phase II evaluation will be published in a separate report.

The Dynapac evaluation studied the performance of one engineering control design. During the testing process, slight modifications to the design were also evaluated to identify their influence on prototype performance. The prototype design consisted of a slot hood mounted above the full length of the paver's auger area. A partition located inside the plenum at its midpoint, separated the left and right sides of the exhaust plenum. Two hydraulically-driven exhaust fans, one at each end of the plenum, provided the exhaust source for the prototype design.

During the performance tests, the control system exhaust volume averaged 1476 cubic feet per minute (cfm). The average indoor capture efficiency was 70.5 percent for the stock configuration and 79.6 percent for a modified configuration which included the addition of baffles between the exhaust hood and the rear of the tractor. During outdoor stationary performance evaluations, the paver was positioned at varying orientations to the prevailing wind direction. Under these conditions, the average capture efficiency reduced to 33.5 percent as wind gusts hampered the control's ability to capture the surrogate contaminant.

A design feature requiring further consideration is the position and direction of the engineering

control's exhaust stack. The current design has the potential to expose workers located behind the paver to the contaminants captured by the engineering control. In their final design, Dynapac engineers should consider redirecting the exhausted contaminant in order to minimize this potential hazard.

The Dynapac engineering control design reveals a creative and promising approach to the difficult task of controlling asphalt-generated contaminants. However, marginal test results and concerns over exhaust discharge orientation reveal that some limitations exist in the current engineering control design scheme. Recommendations to Dynapac design engineers include:

- Redirect engine cooling air away from auger area
- Move the exhaust hood closer to the auger-area capture region
- Seal the open area between the front of the exhaust hood and the rear of the tractor
- Extend the rear flange (closest to the screed) to a minimum width of eight inches.
- Increase the enclosure surrounding the auger area to minimize wind disruption of the engineering control's capture velocity.
- Reorient and extend the exhaust stack to minimize the potential for worker exposure to exhausted contaminant.
- Identify the operating specifications of the existing hydraulic fans. Depending upon Dynapac's ability to incorporate the previous recommendations, additional exhaust volume may be necessary. NIOSH engineers are available to assist Dynapac with their fan specification requirements.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH), a Federal agency located in the Centers for Disease Control and Prevention under the Department of Health and Human Services, was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct research and educational programs separate from the standard setting and enforcement functions conducted 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 Control Technology Branch (ECTB) of the Division of Physical Sciences and Engineering (DPSE), has the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness. Since 1976, ECTB has conducted a large number of studies to evaluate engineering control technology based upon industry, process, or control technique. The objective of each of these studies has been to document and evaluate control techniques and to determine their effectiveness in reducing potential health hazards in an industry or at specific processes.

BACKGROUND

On August 12-13, 1997, researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted an evaluation of a prototype engineering control designed for the control of fugitive asphalt emissions during asphalt paving. The NIOSH researchers included Leroy Mickelsen, Chemical Engineer; Ken Mead, Mechanical Engineer; and Charles Hayden, Mechanical Engineer; all from the NIOSH Engineering Control Technology Branch (ECTB), Division of Physical Sciences and Engineering (DPSE). The DPSE researchers were assisted by Mr. Tom Brumagin of the National Asphalt Pavement Association and Mr. David Emerson, Product Manager-Pavers, Dynapac Compaction and Paving.

The Dynapac engineering control evaluation was completed as an addendum to an existing Department of Transportation (DOT) project which is evaluating the effectiveness of engineering controls on asphalt paving equipment. The NIOSH/DPSE researchers are conducting the research through an interagency agreement with DOT's Federal Highway Administration (FHWA). Additionally, the National Asphalt Pavement Association (NAPA) continues to play a critical role in coordinating the paving industry's voluntary participation in the study. The original DOT study consisted of two major phases. During the primary phase, NIOSH researchers visited each participating manufacturer and evaluated their engineering control designs under managed environmental conditions. General protocols for the indoor evaluations are located in Appendix A. Minor deviations from the protocols could occur depending upon available time, prototype design, equipment performance, and available facilities. Results from the indoor evaluations are intended to provide equipment manufacturers with the necessary information to maximize engineering control performance prior to their implementation at actual paving sites.

DESIGN REQUIREMENTS

When designing a ventilation control, the designer must consider three underlying factors; the level of enclosure, the hood design, and the airflow capacity. When possible, the ideal approach is to maximize the level of enclosure in order to isolate and contain the contaminant emissions. With a total or near-total enclosure approach, hood design is less critical and the required airflow exhaust rate is reduced. Many times, worker access or other process requirements limit the amount of enclosure allowed. Under these constraints, the designer must compromise on the level of enclosure and increase attention toward hood design and increased air flow.

In the absence of a totally enclosed system, the hood design plays a critical role in determining a ventilation control's capture efficiency. Given a specified exhaust volume, the hood shape and configuration affect the ventilation control's ability to capture the contaminant, pull it into the hood, and direct it toward the exhaust duct. A well-engineered hood strives to achieve a uniform velocity profile across the open hood face. When effective hood design is combined with proper enclosure techniques, cross drafts and other airflow disturbances are less likely to reduce the ventilation control's capture efficiency.

In addition to process enclosure and hood design, a third area of consideration when designing a ventilation control is the airflow required to remove the contaminant from the working area. For most work processes, the contaminant must be "captured" and directed into the contaminant removal system. For ventilation controls, this is achieved with a moving airstream often referred to as a capture velocity. The designed capture velocity must be sufficient to overcome process-inherent contaminant velocities, convective currents, cross drafts, or other potential sources of airflow interference in order to maintain a protected environment. The minimum required exhaust volume (Q) is easily calculated by inputting the selected capture velocity and process geometry information into the design equations specific to the selected hood design. Combining Q with the calculated pressure losses within the exhaust system, the designer can appropriately select the system's exhaust fan.

For most ventilation controls, including the asphalt paving controls project, these three fundamentals, process enclosure, hood design, and airflow capacity, are interdependent. A design which lacks process enclosure can overcome this shortcoming with effective hood design and increased air flow. Similarly, lower capture velocities may be adequate if increased enclosure and proper hood design techniques are followed. When process geometries do not allow proper hood designs, increased exhaust flow and increased enclosure can compensate for the hood design shortcomings. Additional information on designing ventilation controls can be found in the American Conference of Governmental Industrial Hygienists' (ACGIH) ***"INDUSTRIAL VENTILATION: A Manual of Recommended Practice"*** [ACGIH, 6500 Glenway Avenue, Building D-7, Cincinnati, Ohio 45211.]

EVALUATION PROCEDURE

The Dynapac engineering control design was evaluated in a large bay area within the Dynapac production facility. The evaluation protocol (Appendix A) required the auger area of the paver, also referred to as the capture area, to be separated from the engineering control exhaust and the paver's engine exhaust. To accomplish this separation, the paver was parked underneath a large overhead door. The screed and rear half of the tractor were positioned within the bay area (referred to as the testing area) and the front half of the tractor was positioned outside the building. While this configuration successfully located the engine exhaust outside of the testing area, the engineering control's exhaust was still located within the testing area. For testing purposes, each of the engineering control's exhaust ducts were rotated 180 degrees and extended approximately six-feet in order to direct the captured "contaminant" outside of the testing area. The overhead garage door was lowered to rest on top of the two duct extensions and the remaining doorway openings were sealed to isolate the front and rear halves of the tractor. This setup proved effective at preventing the engine exhaust and the captured surrogate contaminants from reentering the testing area.

The first surrogate contaminant used in the evaluation was theatrical smoke produced by a Rosco® smoke generator and released through a perforated distribution tube. The tube placement traversed the width of the auger area between the tractor and the screed and rested on the ground under the augers. The general smoke test protocol is in Appendix A. Initially, this test helped to identify failures in the integrity of the barrier separating the front and rear portions of the tractor. After sealing leaks within the barrier, smoke was again released to identify airflow patterns within the test area and to visually observe the control system's performance.

The second method of evaluation was the tracer gas evaluation. This evaluation was designed to: (1) Calculate the total volumetric exhaust flow of the engineering control; and (2) Evaluate the engineering control's effectiveness in controlling and capturing a surrogate contaminant under the "controlled" indoor scenario. Sulfur hexafluoride (SF_6) was the tracer gas selected to act as the second surrogate contaminant. The tracer gas evaluation procedure is also included in the protocol in Appendix A.

The real-time SF_6 detector (Bruel & Kjaer Model 1302) was calibrated in the NIOSH laboratories prior to the evaluation. Known amounts of reagent grade SF_6 were injected into 12-liter Milar sampling bags and diluted with nitrogen to predetermined concentrations. Seven concentrations, ranging from zero (0) to 100 parts per million SF_6/nitrogen were generated. A curve was fit to the data and used to convert detector response to SF_6 concentration. Calibration data are included with the testing data in Appendix B.

The tracer gas evaluation protocol was originally written for an exhaust system composed of a single fan with one exhaust stack. As previously described, the Dynapac engineering control used two fans and each fan had its own exhaust stack. Using the protocol listed in Appendix A, the NIOSH engineers evaluated the performance characteristics of the two fans independently and then collectively reported the overall results. This entailed adding the two individual fan exhaust volumes together for an overall exhaust volume and averaging the two captured SF_6 concentrations in order to determine an overall capture efficiency.

To quantify exhaust volume, a tracer gas discharge tube was placed directly into the suction side of the exhaust duct connected to the fan under evaluation. A known volumetric flow rate of SF_6 was released into the duct and the SF_6 detector measured the diluted concentration of SF_6 within the discharge stack of the fan. The fan's exhaust volume flow rate was calculated using the following equation:

$$Q_{(exh)} = \frac{Q_{(SF6)}}{C_{(SF6)}} X\ 10^6$$

where $Q_{(exh)}$ = airflow rate exhausted through the fan (lpm or cfm)*
$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm)* introduced into the duct
$C_{(SF6)}$ = Concentration of SF_6 (parts per million (ppm)) detected in the exhaust

* The flow rate in liters per minute (lpm) must be divided by 28.3 liters/cubic-feet to convert the units to cfm.

To quantify capture efficiency, SF_6 was released through a ten-foot distribution plenum. Each discharge hose fed SF_6 from the tank regulator, through a mass flow controller, and into one side of a single T-shaped pipe fitting. The stem of the tee fitting was connected to the end of a ten-foot copper distribution plenum designed to release the SF_6 evenly throughout its length. During the capture efficiency test, the discharge plenum was placed directly underneath the screw augers with the discharge holes pointed upwards. A known quantity of SF_6 was released through the plenum into the auger area. (This quantity was equal to the sum quantity of SF_6 introduced during the two fans' individual exhaust volume evaluations.) Moving air, induced by the engineering control system, captured a portion of the SF_6 and carried it through the exhaust system where it was discharged to the outside. On the discharge side of the control (downstream of the exhaust fans), the SF_6 detector measured the concentration of SF_6 in each fan's exhaust air stream. The capture efficiency was calculated using the following equation:

$$\eta = \frac{C_{(SF6_1+SF6_2)}}{10^6} X \frac{Q_{(exh)}}{Q_{(SF6)}} X\ 100$$

where: η = capture efficiency
$C_{(SF61 + SF62)}$ = The average concentration of SF_6 (parts per million (ppm)) detected in the two exhaust stacks
$Q_{(exh)}$ = Total airflow rate exhausted through the engineering control (lpm or cfm)*
$Q_{(SF6)}$ = Volume flow rate of SF_6 (lpm or cfm)* introduced into the plenum

* The flow rate in lpm must be divided by 28.3 liters/cubic-feet to convert the units to cfm.

The flow rate and capture efficiency tests were repeated four times for a total of five indoor performance tests. Two of the five tests evaluated a modified plenum which was created by inserting strips of cardboard to fill the gap between the rear of the tractor and the exhaust plenum.

In addition to the indoor evaluation, an outdoor evaluation was also completed. With the duct extensions removed and the exhaust orientation returned to the original position, the paver was tested at different orientations relative to the prevailing wind.

EQUIPMENT

Smoke Tests

Rosco® Smoke Generator
2" x 10' Schedule-40 PVC perforated distribution pipe

Tracer Gas Tests

Compressed cylinder of 99.98% SF_6 with regulator
MKS Mass Flow controllers with control box
1/8" ID x 20' Teflon tubing and snap valves for SF_6 distribution
Gilian Primary Flow Calibrator
SF_6 distribution plenum (½" x 10' copper pipe w/1/32" dia. holes drilled 12" on center)
Bruel & Kjaer Model 1302 Multi-gas Monitor calibrated for SF_6

Ventilation System Evaluation

TSI Air Velocity Meter
Pacer HTA 4200 Hygrothermo Anemometer
Neotronics Micromanometer w/Pitot Tube
8-mm Camcorder
Tape Measure
35-mm Camera

ENGINEERING CONTROL DESIGN DESCRIPTION

The Dynapac asphalt paver engineering control was a local exhaust ventilation system consisting of a hood, two exhaust fans, duct work, and two exhaust stacks. The local exhaust ventilation system was designed and installed by engineers at Svedala Compaction and Paving in Wardenburg, Germany. The evaluated control system was incorporated into the design of a Dynapac Model F30W Wheeled Paver with screed model VB 1000 V.

The exhaust hood measured ninety-four inches long and was centered behind the paver such that 50 percent of the exhaust hood served the right half of the auger area and 50 percent served the left half. The plenum inlet was a one-inch slot, located on the bottom of the plenum and running the approximate length of the hood. The eight-inch wide plenum varied in height from eleven inches at the two ends to five inches at the center to allow clearance for the auger assembly. Five-inch flanges extended from the leading and trailing edges of the exhaust hood across the full length of the hood. The open space between the leading flange and the rear of the paver measured five inches.

The hood position was fixed. With the augers placed in a typical paving height (position #4), the bottom of the hood measured forty-six inches above the floor and approximately twenty-six inches above the top of the augers.

A partition, located within the exhaust plenum, separated the right and left halves of the plenum. Two hydraulically-driven exhaust fans, one for each half of the plenum, provided the negative pressure and exhaust capacity to the exhaust hood. These fans were of German manufacture with German specification plates. The nomenclature on the specification plates was unconventional, by U.S. standards, and was recorded for further inquiry. NIOSH engineers forwarded the specification plate information to a Swedish engineering firm which does business throughout Europe. Results of this inquiry (see Appendix C) indicate that under the circumstances indicated on the specification plate, each fan is rated at approximately 590 cubic feet per minute (cfm) [1000 cubic meters per hour]. The exhaust volumes indicated by the tracer gas tests were moderately higher than this value (ave.=729 cfm). To clarify the discrepancy, NIOSH recommends that the German design engineers at Svedala verify the interpretation of the fan specification plates, identify the fans' current operating parameters (fan pressure & rpm), and compare the measured exhaust volumes to a manufacturer-supplied fan curve in order to characterize current & potential fan performance.

DATA RESULTS

FLOW VELOCITIES

A hot-wire anemometer was used to measure slot and capture velocities induced by the engineering control's exhaust hood. Due to the symmetry of design, these values were averaged across the full length of the hood.

TABLE 1. SLOT & CAPTURE VELOCITIES

LOCATION	AVERAGE VELOCITY
Slot Face	1625 feet per minute (fpm)
8" from hood	50 fpm
Top of auger axle	35 fpm
Near Copper Plenum	20 fpm*

*(Note: Flow measurements below 30 fpm are below the instrument's specified operating range.)

SMOKE EVALUATIONS

The smoke evaluation provided only qualitative information. This information assisted the researchers in sealing the separation barrier and reducing air flow around the test area in preparation for the quantitative tracer gas evaluation of the engineering control designs.

In a deviation from the smoke evaluation protocol, the theatrical smoke generator was moved to the outdoor side of the separation barrier and positioned such that the smoke discharge fed into the intake of the paver engine's cooling fan. Within a matter of seconds, a substantial amount of smoke was visible within the testing area on the indoor side of the separating barrier. This test verified that large volumes of cooling air from the paver's engine compartment was escaping back into the auger area.

TRACER GAS EVALUATION

(A copy of the tracer gas evaluation data files and associated calculations are included in Appendix B).

INDOOR EVALUATIONS

The indoor evaluations were conducted with the testing area located indoors under semi-controlled conditions. In order to meet these protocol requirements, the discharge for each exhaust stack was rotated 180 degrees and duct extensions were added to relocate the exhaust point on the outdoor side of the barrier. Since this modification could have potentially altered the exhaust characteristics of the fans, a baseline test was conducted, prior to modification, to identify a baseline exhaust flow. The results of this individual test indicated a total system exhaust volume of 1384 cfm. There were a total of five indoor tests. Three tests evaluated the stock hood/plenum design as delivered from Svedala in Germany. The remaining two tests evaluated a modified hood design where strips of cardboard were inserted to fill the gap between the rear of the tractor and the leading hood flange. Measured performance results for the stock and modified indoor tests are presented in Tables II and III.

TABLE II. INDOOR TRIALS, STOCK HOOD DESIGN

Test	$Q_{(exh)}$	Efficiency
Indoor-2	1484 cfm	66.4%
Indoor-3	1447 cfm	75.3%
Indoor-4	1484 cfm	69.9%
Average	1472 cfm	70.5%

TABLE III. INDOOR TRIALS, MODIFIED HOOD DESIGN

Test	$Q_{(exh)}$	Efficiency
Indoor-1	1484 cfm	83.1%
Indoor-5	1480 cfm	76.0%
Average	1482 cfm	79.6%

OUTDOOR EVALUATIONS

The outdoor evaluation occurred in an open parking area. The duct extensions were removed and the exhaust orientation returned to stock configuration. The protocol called for four paver orientations to be evaluated however, the paver ran out of fuel during the end of the third orientation. Due to refueling constraints, we evaluated the existing data and determined it sufficient to bring the outdoor evaluation to an end. The three tests conducted included paver orientations with the wind into the rear, front, and left side. Results of these tests are in Table IV.

TABLE IV. OUTDOOR TRIALS (Stock Hood Design w/o Duct Extensions)

Wind Into	$Q_{(exh)}$	Efficiency
Rear	1441 cfm	15.8%
Front	1468 cfm	41.6%
Left Side	1369 cfm	43.0%
Average	1426 cfm	33.5%

DISCUSSION

FLOW VELOCITIES

The ACGIH Industrial Ventilation Manual provides guidance to facilitate the selection and design of minimum capture velocities. Additionally, NIOSH assistance can be provided in selecting a capture velocity based upon your intended control design. In the absence of total enclosure and given the physical properties of the paving process and the generated contaminants, a minimum design capture velocity of 100 feet per minute across the top of the auger area's horizontal plane is recommended. This recommendation assumes very good enclosure to minimize wind interference during paving operations.

Based upon the current design parameters, the 100 fpm capture velocity recommendation would be required approximately 20 inches away from the face of the hood. The velocity measurements shown in Table I indicate an average capture velocity of only 50 fpm at less than half of this distance. Thus, using the current hood design, a significantly higher exhaust capacity is required in order to generate the desired capture velocity at the top of the augers

EXHAUST VOLUME MEASUREMENTS

Since the two duct extensions and the 180-degree discharge rotation required by the indoor testing protocol could potentially alter the engineering control's exhaust flow rate, a preliminary baseline test was conducted to measure the engineering control's exhaust flow prior to the duct system modifications. As previously reported, the measured exhaust volume was 1384 cfm. This individual measurement is approximately 6 percent smaller than the average exhaust volume recorded during the indoor evaluations (Ave.= 1476 cfm). This discrepancy is most likely explained by experimental error, cold hydraulic fluid supplying less energy to the hydraulic fans, an improvement in exhaust capacity due to improved discharge characteristics (created by the duct extensions), or any combination of the three. Further analyses of this issue can be made by comparing the measured exhaust volumes during the outdoor trials (Table IV - These tests were performed with the exhaust stacks in their stock configuration) with those measured during the indoor trials (Tables II & III). The third outdoor test (wind into left side) shows a lower exhaust volume than the previous two. Since this is the test during which the paver ran out of fuel, we speculate that this 6 percent reduction may be related to the low-fuel condition reducing tractor engine performance. Comparing the average exhaust volume for the first two outdoor tests (ave.=1455 cfm) with the average value for the indoor tests (ave.=1476 cfm) reveals that the exhaust volumes for the two exhaust configurations were within two percent of each other. Based upon these evaluations, it is clear that the exhaust stack modifications did not negatively affect the exhaust volume capacity of the Dynapac engineering control.

INDOOR CAPTURE EFFICIENCY

Test results from the Dynapac engineering control evaluations show that the stock design, as delivered from Svedala Compaction and Paving in Wardenburg, Germany, will not meet the indoor collection efficiency criteria of 80 percent which is recommended in the NIOSH Engineering Control Guidelines for Hot Mix Asphalt Pavers. A modified design, which added cardboard baffles to seal the open area between the exhaust hood and the rear of the paver, improved the average indoor capture efficiency from 70.5 percent up to 79.6 percent. While the modified flange extensions did improve collection efficiency performance, the average collection efficiency remained slightly less than the recommended 80 percent criterion. However, the 80 percent minimum collection efficiency criterion appears clearly within reach after incorporating minimal design improvements. Some recommended improvements are identified in the ***Conclusions And Recommendations*** section of this report.

OUTDOOR CAPTURE EFFICIENCY

Test results from the outdoor evaluations reveal that the Dynapac prototype's design performance is significantly hampered by the lack of enclosure around the auger area, an insufficient exhaust volume, an excessive distance between the face of the hood and the capture region, and the presence of engine cooling air blowing back into the capture region. These factors collectively allowed the ambient wind to play a predominant role in determining contaminant dispersion and resulted in an average outdoor capture efficiency of only 33.5 percent.

Interpretation of the outdoor results is somewhat difficult. There are no recommended or consensus criteria for the outdoor tracer gas capture efficiency evaluations. Admittedly, some of the wind which disrupts the engineering control's capture efficiency may also carry airborne contaminant away from the occupied work area but in other cases, the escaped contaminant may collect within a working area, creating an increased opportunity for elevated exposure. Thus, the safest solution is to remove as much contaminant as is reasonably possible at the source (the auger, in this case) and not allow it to enter the working areas. The recommendations forwarded in the ***Conclusions And Recommendations*** section of this report aim to reach this goal.

EXHAUST DISCHARGE

One final consideration is the position and direction of the engineering control's exhaust stack. The current design incorporates a horizontal discharge which has the potential to expose workers located behind the paver to the contaminants captured by the engineering control. This potential could be greatly reduced by reorienting the exhaust stacks to a vertical discharge and extending them to a discharge height at least three feet above the paver operator's breathing zone.

CONCLUSIONS AND RECOMMENDATIONS

The Dynapac engineering control evaluation was completed as a supplement to an existing Department of Transportation (DOT) project to evaluate the effectiveness of engineering controls on asphalt paving equipment. The study protocol for this evaluation was based upon that used in the original DOT study. The intent of the phase I evaluation protocol was to evaluate engineering control performance characteristics and identify potential areas for improvement. This evaluation was performed within a controlled environment, void of the many interfering variables which frustrate performance evaluations during typical paving operations. The Dynapac study has been successful in this regard. Implementation of the provided recommendations will improve the performance of the Dynapac engineering control prior to field implementation and testing.

The Dynapac engineering control design reveals a creative and promising approach to the difficult task of controlling asphalt-generated contaminants. However, indoor capture efficiencies below 80 percent and outdoor capture efficiencies as low as 16 percent reveal some limitations in the tested engineering control design scheme. Recommendations to Dynapac design engineers include: (1) Redesigning the engine compartment such that engine cooling air is not discharged back into the auger region; (2) Evaluate the exhaust hood and exhaust duct configuration to identify how the exhaust hood can be lowered closer to the auger-area capture region; (3) Extend the width of the exhaust hood's leading flange in order to seal off the open area between the front of the exhaust hood and the rear of the tractor; (4) Extend the rear flange (located between plenum hood and front of screed) width to a minimum of 8 inches; (5) Increase the enclosure surrounding the auger area to minimize the wind effects, especially near the ends of the auger area and under extended-screed conditions; (6) Reorient and extend the exhaust stack to reduce the potential for worker exposure to exhausted contaminant; (7) Identify the operating specifications of the existing hydraulic fans. Depending upon Dynapac's ability to incorporate the previous recommendations, additional exhaust volume may be necessary. If additional exhaust volume is necessary and the operating parameters of the existing fans are known, design engineers can determine if the existing fans can be modified to meet the new performance requirements. NIOSH engineers are available to assist Dynapac with their fan specification requirements.

ACKNOWLEDGMENTS

We would like to thank the Dynapac management and staff for their gracious hospitality and assistance during our visit to the Dynapac facility. Their commitment to the design and implementation of engineering controls to reduce occupational exposures is an admirable pledge which will benefit workers throughout the asphalt paving industry.

APPENDIX A

ENGINEERING CONTROLS FOR ASPHALT PAVING EQUIPMENT

STATIONARY EVALUATION PROTOCOL

PURPOSE: To evaluate the efficiency of ventilation engineering controls used on highway-class hot mix asphalt (HMA) pavers in an indoor stationary environment.

SCOPE OF USE: This test procedure was developed to aid the HMA industry in the development and evaluation of prototype ventilation engineering controls with an ultimate goal of reducing worker exposures to asphalt fumes. This test procedure is a first step in evaluating the capture efficiency of paver ventilation systems and is conducted in a controlled environment. The test is not meant to simulate actual paving conditions. The data generated using this test procedure have not been correlated to exposure reductions during actual paving operations.

For the laboratory evaluation, we will conduct a two-part experiment where the surrogate "contaminant" is injected into the auger region behind the tractor and in front of the screed. For part A of the evaluation, smoke from a smoke generator is the surrogate contaminant. For part B, the surrogate contaminant is sulfur hexafluoride, an inert and relatively safe (when properly used) gas, commonly used in tracer gas studies.

SAFETY: In addition to following the safety procedures established by the host facility, the following concerns should be addressed at each testing site:

1. The discharge of the smoke generating equipment can be hot and should not be handled with unprotected hands.
2. The host may want to contact building and local fire officials in order that the smoke generators do not set off fire sprinklers or create a false alarm.
3. In higher concentrations, smoke generated from the smoke generators may act as an irritant. Direct inhalation of smoke from the smoke generators should be avoided.
4. All compressed gas cylinders should be transported, handled, and stored in accordance with the safety recommendations of the Compressed Gas Association.
5. The Threshold Limit Value for sulfur hexafluoride is 1000 ppm. While the generated concentrations will be below this level, the concentration in the cylinder is near 100 percent. For this reason, the compressed cylinder will be maintained outdoors whenever possible. Should a regulator malfunction or some other major accidental release occur, observers should stand back and let the tank pressure come to equilibrium with the ambient environment.

Laboratory Setup: The following laboratory setup description is based on our understanding of the facilities available at the asphalt paving manufacturing facilities participating in the study. The laboratory evaluation protocol may vary slightly from location to location depending upon the available facilities.

Paver Position: The paving tractor, with screed attached, will be parked underneath an overhead garage door such that both the tractor exhaust and the exhaust from the engineering controls exits into the ambient air. The garage door will be lowered to rest on top of the tractor and plastic or an alternative barrier will be applied around the perimeter of the tractor to seal the remainder of the garage door opening.

Laboratory Ventilation Exhaust: For this evaluation, smoke generated from Rosco Smoke Generators (Rosco, Port Chester, NY) is released into a perforated plenum and dispersed in a quasi-uniform distribution along the length of the augers. Due to interferences created by the auger's gear box, this evaluation may require a separate smoke generator and distribution plenum on each side of the auger region. Releasing theatrical smoke as a surrogate contaminant within the auger region provides excellent qualitative information concerning the engineering control's performance. Areas of diminished control performance are easily determined and minor modifications can be incorporated into the design prior to quantifying the control performance. Additionally, the theatrical smoke helps to verify the barrier integrity separating the front and rear halves of the asphalt paver. A video camera will be used to record the evaluation. The sequence from a typical test run is outlined below:

1. Position paving equipment within door opening and lower overhead door.
2. Seal the remaining door opening around the tractor.
3. Place the smoke distribution tube(s) directly underneath the auger.
4. Connect the smoke generator(s) to the distribution tube(s).
5. Activate video camera, the engineering controls, and the smoke generator(s).
6. Inspect the separating barrier for integrity failures and correct as required.
7. Inspect the engineering control and exhaust system for unintended leaks.
8. De-activate the engineering controls for comparison purposes.
9. De-activate smoke generators and wait for smoke levels to subside.
10. End the smoke test evaluation.

Evaluation Part B (Tracer Gas): The tracer gas test is designed to: (1) Calculate the total exhaust flow rate of the paver ventilation control system; and (2) Evaluate the effectiveness in capturing and controlling a surrogate contaminant under a "controlled" indoor conditions. SF_6 will be used as the surrogate contaminant.

Quantify Exhaust Volume: To determine the total exhaust flow rate of the engineering control, a known quantity of sulfur hexafluoride (SF_6) is released directly into the engineering control's exhaust hood, thus creating a 100 percent capture condition. The SF_6 release is controlled by two Tylan Mass Flow controllers (Tylan, Inc., San Diego, CA). Initially, the test will be performed using a single flow controller calibrated at 0.35 lpm. A hole drilled into the engineering control's exhaust duct allows access for a multi-point monitoring wand into the exhaust stream. The monitoring wand is oriented such that the perforations are perpendicular to the moving air stream. A sample tube connects the wand to a Bruel & Kjaer (B&K) Model 1302 Photo acoustic Infra-red Multi-gas Monitor (California Analytical Instruments, Inc., Orange, CA) positioned on the exterior side of the overhead door. The gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream. The B&K 1302 will be programmed to repeat this analysis approximately once every 30 seconds. Monitoring will continue until approximate steady-state conditions are achieved. The mean concentration of SF_6 measured in the exhaust stream will be used to calculate the total exhaust flow rate of the engineering control. The equation for determining the exhaust flow rate is:

$$Q_{(exh)} = \frac{Q_{(SF_6)}}{C^*_{(SF_6)}} \times 10^6 \qquad \textbf{Equation 1}$$

where: $\mathbf{Q_{(exh)}}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$\mathbf{Q_{(SF6)}}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

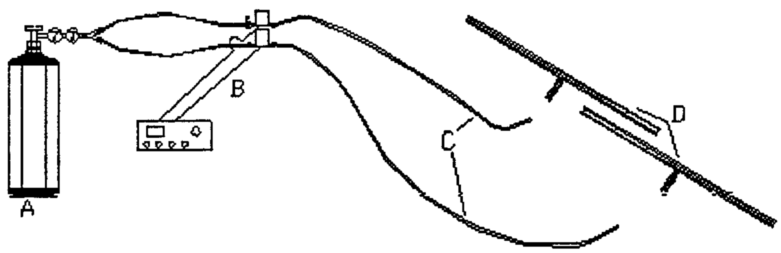
$\mathbf{C^*_{(SF6)}}$ = concentration of SF_6 (parts per million) detected in exhaust

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

In order to increase accuracy, the exhaust flow rate will be calculated a second time using two mass flow controllers, each calibrated at approximately 0.35 lpm of SF_6. Sufficient time will be allowed between all test runs to allow area concentrations to decay below 0.1 ppm before starting subsequent test runs.

Quantitative Capture Efficiency: The test procedure to determine capture efficiency is slightly different than the exhaust volume procedure. The mass flow controllers will each be calibrated for a flow rate approximating 0.35 liters per minute (lpm) of 99.8 percent SF_6. The discharge tubes from the mass flow controllers will each feed a separate distribution plenum, one per side, within the paver's auger area. The distribution plenums are designed to distribute the SF_6 in a uniform pattern along the length of the auger area. (See Figure 1.) The B&K multi-gas monitor analyzes the air sample and records the concentration of SF_6 within the exhaust stream until approximate steady-state conditions develop. Once this occurs, the SF_6 source will be discontinued and the decay concentration of SF_6 within the exhaust stream will be monitored to indicate the extent in which general area concentrations of non-captured SF_6 contributed to the concentration measured in the exhaust stream.

FIGURE 1



A capture efficiency can be calculated for the control using the following equation:

$$\eta = 100 \times \frac{\frac{C_{(SF_6)} \times Q_{(exh)}}{10^6}}{Q_{(SF_6)}} \qquad \text{Equation 2A}$$

where: η = capture efficiency

$C_{(SF6)}$ = concentration of SF_6 (parts per million) detected in exhaust

$Q_{(exh)}$ = flow rate of air exhausted through the ventilation system (lpm or cfm)

$Q_{(SF6)}$ = flow rate of SF_6 (lpm or cfm) introduced into the system

[To convert from liters per minute (lpm) to cubic feet per minute (cfm), divide lpm by 28.3.]

NOTE: When the flow rate of SF_6 [$Q_{(SF6)}$] used to determine the engineering control's capture efficiency is the same as that used to quantify the exhaust flow rate, equation 2A may be simplified to:

where the definitions for $C^*_{(SF6)}$, η, and $C_{(SF6)}$ remain the same as in equations 1 and 2A.

$$\eta = \frac{C_{(SF_6)}}{C^*_{(SF_6)}} \times 100 \qquad \text{Equation 2B}$$

The sequence from a typical test run is outlined below:

1. Position paving equipment and seal openings as outlined above.
2. Calibrate (outdoors) both mass flow meters at approximately 0.35 lpm of SF_6.
3. Drill an access hole in the engineering control's exhaust duct on the outdoor side of the overhead door, and position the sampling wand into the hole.
4. While maintaining the SF_6 tanks outdoors, run the discharge hoses from the mass flow meters to well-within the exhaust hood(s) to create 100 percent capture conditions.
5. With the engineering controls activated, begin monitoring with the B&K 1302 to determine background interference levels.
6. Initiate flow of SF_6 through a single mass flow meter.
7. Continue monitoring with the B&K for five minutes or until three repetitive readings are recorded.
8. Deactivate flow of the SF_6 and calculate exhaust flow rate using the calculation identified above.
9. Repeat steps #2 through #8 using both mass flow controllers.
10. Allow engineering control exhaust system to continue running until SF_6 has ceased leaking from the discharge hoses then remove the hoses from the hoods.
11. End the exhaust flow rate test.
12. Locate an SF_6 distribution plenum on each side of the auger area, and connect each plenum to the discharge hose of a mass flow meter.
13. Initiate B&K monitoring to establish background interference levels until levels reach 0.1 ppm or below.
14. Initiate SF_6 flow through the mass flow meters and monitor with the B&K until approximate steady state conditions appear.
15. Once steady state is achieved, discontinue SF_6 flow and quickly remove the distribution plenums and discharge hoses from the auger area.
16. Continue monitoring with the B&K to determine the general area concentration of SF_6 which escaped auger area into the laboratory area.
17. Discontinue B&K monitoring when concentration decay is complete.
18. Calculate the capture efficiency.
19. Repeat steps 11 - 18 as time permits.

APPENDIX B

TRACER GAS EVALUATION :

B&K Calibration Data, Data Files, And Calculation Results

DYNAPAC SHOP TEST
12-13 August 1997

EXHAUST FLOW TEST

(Stationary Outdoor Test: No duct extension)

Left Fan	693 cfm
Right Fan	691 cfm
Total	1384 cfm

Indoor Performance Test Summary

(All tests incorporated duct extensions to meet protocol requirements)

MODIFIED ENCLOSURES (Cardboard Baffles added between back of paver and front of hood)

TEST	Efficiency	Exhaust Flow (cfm)
Indoor-1	83.13%	1484
Indoor-5	75.96%	1480
Average	79.55%	1482

STOCK ENCLOSURES (As delivered from Germany)

TEST	Efficiency	Exhaust Flow (cfm)
Indoor-2	66.44%	1484
Indoor-3	75.29%	1447
Indoor-4	69.85%	1484
Average	70.53%	1472

Outdoor Performance Test Summary

(All tests were with stock enclosures & no duct extensions)

Wind Into:	Efficiency	Exhaust Flow (cfm)
Rear	15.77%	1441
Front	41.63%	1468
Left Side	43.00%	1369
Average	33.47%	1426

BASELINE EXHAUST VOLUME CALCULATION

(Measured Outdoors without duct extensions)

[x=(y+0.00093)/0.964051]

Sample #	Time	BnK Positio	Comment	BnK Response	Calculations	Average
1	11:09:10	Open air	*Background*	-0.003	-0.011	Background
2	11:10:16			-0.005	-0.010	Calib. Corrected
3	11:11:10			-0.011		
4	11:12:04			-0.011		
	11:12:04		*User Event Number 1.*			
5	11:12:58	LHS	100% SF6 - 219.4 cc/min	10.800	10.780	Average (ppm)
6	11:13:54	LHS		10.800	11.183	Calib. Corrected
7	11:14:48	LHS		10.800	11.193	BG Corr.
8	11:15:42	LHS		10.800	693	CFM
9	11:16:35	LHS		10.700		
	11:17:40		*User Event Number 2.*			
10	11:17:40			0.258		
11	11:18:37			0.026	0.007	Background
12	11:19:30			-0.008	0.009	Calib. Corrected
13	11:20:24			0.007		
	11:21:18		*User Event Number 3.*			
14	11:21:18	RHS	Transition point	10.500		
15	11:22:15	RHS	100% SF6 - 219.4 cc/min	10.800	10.820	Average (ppm)
16	11:23:08	RHS		10.800	11.224	Calib. Corrected
17	11:24:02	RHS		10.900	11.216	BG Corr.
18	11:24:56	RHS		10.700	691	CFM
19	11:25:50	RHS		10.900		
	11:26:44		*User Event Number 4.*			
20	11:26:44		(End of test)	11.200		
21	11:28:09			0.027		
22	11:29:06			-0.007		

Total Exh.(cfm)= 1384

Performance Test #1 (Modified Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
1	16:57:09	0.008	Background	-0.003	Background
2	16:58:15	0.003		-0.002	Calib. Corrected
3	16:59:09	-0.006			
4	17:00:03	0.003			
5	17:00:57	-0.001			
6	17:01:51	-0.006			
7	17:02:44	-0.015	-0.003		
8	17:03:38	-0.007			
9	17:04:43	-0.006			
10	17:05:37	-0.003			
Event 1	17:05:37				
11	17:06:31	10.300	100% Capture: LHS	10.250	Average (ppm)
12	17:07:27	10.300		10.633	Calib. Corrected
13	17:08:21	10.200		10.635	BG Corr.
14	17:09:15	10.200		741	CFM
15	17:10:09	10.200			
16	17:11:02	10.300			
Event 2	17:11:02				
Event 3	17:11:56				
17	17:11:56	10.400	100% Capture RHS	10.457	Average (ppm)
18	17:12:50	10.400		10.848	Calib. Corrected
19	17:13:45	10.500		10.850	BG Corr.
20	17:15:10	10.500		743	CFM
21	17:16:04	10.400			
22	17:16:58	10.500			
23	17:17:52	10.500			
Event 4	17:18:46				
24	17:18:46	0.064	BG in RH Duct	0.004	Background
25	17:19:42	-0.003		0.005	Calib. Corrected
26	17:20:36	0.005			
27	17:21:30	0.004			
Event 5	17:22:24				
28	17:22:24	0.006	Transition points	8.470	Average (ppm)
29	17:23:18	0.043		8.787	Calib. Corrected
30	17:24:12	2.160	% Capture RHS	8.782	BG (duct) Corr.
31	17:25:25	6.270			
32	17:26:21	10.400			
33	17:27:15	10.200			
34	17:28:09	10.400			
35	17:29:03	8.990			
36	17:29:57	11.100			
37	17:30:51	8.240			
Event 6	17:30:51				
38	17:31:45	9.580			
Event 7	17:32:39				
39	17:32:39	7.720	Wand Orientation Problem		
40	17:33:33	10.600			
41	17:34:37	6.490			
42	17:35:32	9.050	% Capture LHS	8.756	Average (ppm)
43	17:36:26	9.460		9.083	Calib. Corrected
44	17:37:19	7.730		9.078	BG (duct) Corr.
45	17:38:13	8.120			
46	17:39:07	9.420			
Event 8	17:39:07				

Capture Eff. = **83.13%**

Performance Test #2 (Stock Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
Event 9	17:40:01				
47	17:40:01	6.340	% Capture LHS	6.428	Average (ppm)
48	17:40:55	9.790		6.669	Calib. Corrected
49	17:41:49	9.090		6.354	BG Corr. (Post-sample Ave.
50	17:42:43	5.410			
51	17:43:37	0.824			
52	17:45:04	4.360			
53	17:46:00	7.000			
54	17:46:54	7.210			
55	17:47:48	5.170			
56	17:48:42	5.630			
57	17:49:36	3.070			
58	17:50:30	5.690			
59	17:51:23	11.400			
60	17:52:17	9.010			
Event 10	17:53:11				
61	17:53:11	6.940			
62	17:54:05	0.206			
Event 11	17:55:21		% Capture RHS		
63	17:55:21	10.700		7.939	Average (ppm)
64	17:56:17	10.500		8.236	Calib. Corrected
65	17:57:11	7.990		7.921	BG Corr. (Post-sample BG)
66	17:58:05	5.180			
67	17:58:59	7.140			
68	17:59:53	6.080			
69	18:00:47	7.980			
Event 12	18:00:47		Background in RH Duct		
70	18:01:41	11.900		0.302	Average (ppm)
71	18:02:35	0.540		0.314	Calib. Corrected
72	18:03:31	0.243			
73	18:04:36	0.356			
74	18:05:30	0.282			
75	18:06:24	0.325			
76	18:07:17	0.270			
77	18:08:11	0.099			
Event 13	18:09:05				

From Test #1: C (RHS) @ 100% Capture = 10.850

From Test #1: C (LHS) @ 100% Capture = 10.635

Capture Eff. = 66.44%

Performance Test #3 (Stock Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
Event 12	18:00:47		Background in RH Duct		
74	18:05:30	0.282		0.099	Background
75	18:06:24	0.325		0.104	Calib. Corrected
76	18:07:17	0.270			
77	18:08:11	0.099			
Event 13	18:09:05		100% Capture RHS		
78	18:09:05	0.217			
79	18:09:59	15.700			
80	18:10:55	11.100		10.957	Average (ppm)
81	18:11:49	11.000		11.367	Calib. Corrected
82	18:12:43	10.900		11.263	BG Corrected
83	18:13:37	10.900		715	CFM
84	18:15:02	11.100			
85	18:15:56	10.800			
86	18:16:50	10.900			
Event 14	18:17:44				
87	18:17:44	10.700			
88	18:18:37	0.209			
89	18:19:34	0.155			
Event 15	18:20:28		100% Capture LHS		
90	18:20:28	0.096			
91	18:21:22	9.460			
92	18:22:18	10.400		10.478	Average (ppm)
93	18:23:12	10.400		10.869	Calib. Corrected
94	18:24:06	10.400		10.766	BG Corrected
95	18:25:19	10.100		732	CFM
96	18:26:13	10.400			
97	18:27:07	10.700			
98	18:28:01	10.700			
99	18:28:54	10.700			
100	18:29:48	10.500			
Event 16	18:29:48				
101	18:30:42	5.000			
Event 17	18:31:36		% Capture LHS		
102	18:31:36	6.170		7.335	Average (ppm)
103	18:32:30	8.490		7.609	Calib. Corrected
104	18:33:24	5.970		7.506	BG Corr.
105	18:34:17	6.870			
106	18:35:23	8.560			
107	18:36:17	7.950			
Event 18	18:36:17				
108	18:37:11	0.052			
Event 19	18:38:07				
109	18:38:07	7.710			
Event 20	18:39:03				
110	18:39:03	8.800	% Capture RHS	8.853	Average (ppm)
111	18:39:57	8.010		9.184	Calib. Corrected
112	18:40:51	11.500		9.080	BG Corr.
113	18:41:45	9.010			
114	18:42:39	8.590			
115	18:43:33	7.250			
116	18:44:58	8.810			
Event 21	18:44:58		Background (Meas. in RHS)		
117	18:45:52	0.221		0.286	Average (ppm)
118	18:46:48	0.324		0.298	Calib. Corrected
119	18:47:42	0.313			
120	18:48:36	0.337			
121	18:49:30	0.245			
122	18:50:24	0.102			
123	18:51:17	0.515			
124	18:52:11	0.197			
125	18:53:05	0.329			
126	18:53:59	0.278			

Capture Eff. = 75.29%

Performance Test #4 (Stock Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
124	18:52:11	0.197	BG (Meas. In RHS)	0.278	Background
125	18:53:05	0.329		0.289	Calib. Corrected
126	18:53:59	0.278			
Event 22	18:55:12		100% in RHS		
127	18:55:12	0.306		10.880	Average (ppm)
128	18:56:06	10.900		11.287	Calib. Corrected
129	18:57:02	11.000		10.997	BG Corr.
130	18:57:56	10.900		733	CFM
131	18:58:50	10.800			
132	18:59:44	10.800			
Event 23	18:59:44				
133	19:00:38	0.047			
Event 24	19:01:34		100% in LHS		
134	19:01:34	10.300		10.400	Average (ppm)
135	19:02:30	10.500		10.789	Calib. Corrected
136	19:03:24	10.300		10.499	BG Corr.
137	19:04:29	10.300		751	CFM
138	19:05:23	10.600			
139	19:06:17	10.400			
140	19:07:11	10.400			
Event 25	19:07:11				
141	19:08:05	2.770			
Event 26	19:09:01		% Capture LHS		
142	19:09:01	3.360			
143	19:09:57	5.100		5.493	Average (ppm)
144	19:10:51	4.330		5.699	Calib. Corrected
145	19:11:45	8.220		5.410	BG Corr.
146	19:12:39	4.700			
147	19:13:33	4.290			
148	19:14:58	6.320			
Event 27	19:14:58				
149	19:15:52	0.283			
Event 28	19:16:48		% Capture RHS		
150	19:16:48	11.100		9.539	Average (ppm)
151	19:17:45	7.700		9.895	Calib. Corrected
152	19:18:39	9.820		9.606	BG Corr.
153	19:19:32	8.820			
154	19:20:26	11.500			
155	19:21:20	6.630			
156	19:22:14	11.200			
Event 29	19:22:14		BG (Meas. In RHS)		
157	19:23:08	0.504		0.359	Average (ppm)
158	19:24:04	0.525		0.374	Calib. Corrected
159	19:25:17	0.467			
160	19:26:11	0.350			
161	19:27:05	0.263			
162	19:27:59	0.311			
163	19:28:55	0.275			
164	19:29:51	0.180			
Event 30	19:30:45				

Capture Eff. = 69.85%

Performance Test #5 (Modified Enclosure)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Calculations	
Event 29	19:22:14				
157	19:23:08	0.504			
158	19:24:04	0.525			
159	19:25:17	0.467			
160	19:26:11	0.350	Background in RHS		
161	19:27:05	0.263		0.250	Background
162	19:27:59	0.311		0.260	Calib. Corrected
163	19:28:55	0.275			
164	19:29:51	0.180			
165	19:30:45	0.250			
Event 30	19:30:45		100% Capture RHS		
166	19:31:39	10.900		10.850	Average (ppm)
167	19:32:35	10.800		11.256	Calib. Corrected
168	19:33:29	10.800		10.995	BG Corr.
169	19:34:34	10.900		733	CFM
Event 31	19:34:34		Transition		
170	19:35:28	9.590			
171	19:36:22	0.215			
Event 32	19:37:18		100% LHS		
172	19:37:18	10.300		10.417	Average (ppm)
173	19:38:14	10.400		10.806	Calib. Corrected
174	19:39:08	10.400		10.546	BG Corr.
175	19:40:02	10.400		747	CFM
176	19:40:56	10.500			
177	19:41:50	10.500			
Event 33	19:41:50		Transition		
178	19:42:44	4.850			
Event 34	19:43:38		% Capture LHS		
179	19:43:38	5.070		5.183	Average (ppm)
180	19:45:03	8.060		5.377	Calib. Corrected
181	19:45:57	3.330		5.117	BG Corr.
182	19:46:50	7.440			
183	19:47:44	4.620			
184	19:48:38	5.660			
185	19:49:32	4.330			
186	19:50:26	5.490			
187	19:51:20	6.110			
188	19:52:13	3.310			
189	19:53:07	3.140			
190	19:54:01	4.730			
191	19:55:14	6.090			
Event 35	19:55:14		Transition		
Event 36	19:56:08		% Capture RHS		
192	19:56:08	10.100		11.092	Average (ppm)
193	19:57:02	12.100		11.507	Calib. Corrected
194	19:57:56	13.700		11.247	BG Corr.
195	19:58:50	10.200			
196	19:59:44	8.040			
197	20:00:37	12.700			
198	20:01:31	13.200			
199	20:02:25	11.000			
200	20:03:19	8.790			
Event 37	20:04:13		BG (Meas. in RHS)		
201	20:04:13	1.030		0.853	Average (ppm)
202	20:05:20	0.671		0.885	Calib. Corrected
203	20:06:14	1.530			
204	20:07:08	0.179			

Capture Eff. = 75.96%

Outdoor Performance Test (13 Aug 97)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Wind Into..	Calculations	
1	11:35:21	-0.003	Background	Rear	-0.009	Background
2	11:36:27	-0.001			-0.008	Calib. Corrected
3	11:37:32	-0.009				
4	11:38:26	-0.011				
5	11:39:19	-0.009				
6	11:40:13	-0.011				
7	11:41:07	-0.003				
8	11:42:01	-0.007				
9	11:42:55	-0.008				
10	11:43:48	-0.010				
11	11:44:42	-0.011				
12	11:45:36	-0.016				
13	11:46:30	-0.014				
14	11:47:55	-0.009				
Event 01	11:47:55		100% Capture LHS		10.100	Average (ppm)
15	11:48:49	2.690			10.478	Calib. Corrected
16	11:49:45	10.000			10.486	BG Corr.
17	11:50:39	10.100			732	CFM
18	11:51:33	10.200				
19	11:52:27	10.100				
Event 02	11:53:20					
20	11:53:20	0.167				
Event 03	11:54:17		100% Capture RHS		10.650	Average (ppm)
21	11:54:17	10.700			11.048	Calib. Corrected
22	11:55:13	10.700			11.056	BG Corr.
23	11:56:07	10.600			709	CFM
24	11:57:20	10.600				
Event 04	11:57:20		% Capture RHS		2.663	Average (ppm)
25	11:58:15	0.276			2.763	Calib. Corrected
26	11:59:11	3.040			2.771	BG Corr.
27	12:00:07	0.370				
28	12:01:04	0.085				
29	12:01:57	1.060				
30	12:02:51	5.970				
31	12:03:48	7.840				
Event 05	12:04:42					
32	12:04:42	0.591				
33	12:05:38	0.065				
Event 06	12:06:32		% Capture LHS		0.595	Average (ppm)
34	12:06:32	1.610			0.618	Calib. Corrected
35	12:07:37	-0.003			0.626	BG Corr.
36	12:08:31	0.035				
37	12:09:25	0.737				
			Capture Eff. = (Wind into rear of paver)	**15.77%**		

Outdoor Performance Test (13 Aug 97)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Wind Into..	Calculations	
Event 07	12:10:18		Transition Data			
38	12:10:18	0.097				
39	12:11:13	-0.008				
40	12:12:07	0.101				
41	12:13:01	0.035				
42	12:13:55	-0.008				
43	12:14:48	0.044				
44	12:15:42	-0.005				
45	12:17:07	0.075				
46	12:18:01	0.203				
47	12:18:55	0.335				
Event 08	12:18:55		100% Capture LHS	Front	10.325	Average (ppm)
48	12:19:49	10.300			10.711	Calib. Corrected
49	12:20:45	10.400			10.594	BG Corr.
50	12:21:39	10.400			724	CFM
51	12:22:33	10.200				
Event 09	12:22:33		Background LHS		0.112	Background
52	12:23:27	0.239			0.117	Calib. Corrected
53	12:24:23	0.205				
54	12:25:17	0.122				
55	12:26:11	0.141				
56	12:27:24	0.112				
Event 10	12:27:24		% Capture LHS		6.048	Average (ppm)
57	12:28:18	1.380			6.274	Calib. Corrected
58	12:29:12	7.580			6.157	BG Corr.
59	12:30:08	3.590				
60	12:31:02	6.860				
61	12:31:55	5.410				
62	12:32:49	6.800				
Event 11	12:32:49					
63	12:33:43	2.490				
Event 12	12:33:43		% Capture RHS		2.785	Average (ppm)
64	12:34:38	0.390			2.890	Calib. Corrected
65	12:35:34	2.560			2.642	BG Corr.
66	12:36:28	2.920				
67	12:37:35	2.980				
68	12:38:29	2.680				
Event 13	12:39:23		Background RHS		0.238	
69	12:39:23	1.180			0.248	
70	12:40:19	0.200				
71	12:41:13	0.238				
Event 14	12:42:07		100% Capture RHS		10.400	Average (ppm)
72	12:42:07	0.274			10.789	Calib. Corrected
73	12:43:01	10.500			10.541	BG Corr.
74	12:43:57	10.400			744	CFM
75	12:44:51	10.400				
76	12:45:45	10.300				
Event 15	12:45:45		Background Decay			
77	12:47:10	0.126				
78	12:48:06	0.128				
			Capture Eff. = (Wind into front of paver)	**41.63%**		

Outdoor Performance Test (13 Aug 97)

(All values are ppm)

Sample #	Time	BnK Response	Test Condition	Wind Into..	Calculations	
Event 16	12:49:00		Transition Data	Left Side		
79	12:49:00	0.240				
80	12:49:54	0.009	Background		-0.003	Average (ppm)
81	12:50:48	0.009			-0.002	Calib. Corrected
82	12:51:42	-0.003				
Event 17	12:52:35		100% Capture RHS		10.733	Average (ppm)
83	12:52:35	0.073			11.135	Calib. Corrected
84	12:53:29	10.800			11.137	BG Corr.
85	12:54:25	10.900			704	CFM
86	12:55:19	10.800				
87	12:56:13	10.900				
88	12:57:26	10.500				
89	12:58:20	10.500				
Event 18	12:58:20		% Capture RHS		4.275	Average (ppm)
90	12:59:14	2.820			4.435	Calib. Corrected
91	13:00:08	3.130			4.437	BG Corr.
92	13:01:02	0.639				
93	13:01:58	9.920				
94	13:02:54	4.240				
95	13:03:48	4.900				
Event 19	13:03:48					
Event 20	13:04:42		% Capture LHS		5.120	Average (ppm)
96	13:04:42	7.120			5.312	Calib. Corrected
97	13:05:36	2.230			5.314	BG Corr.
98	13:06:32	1.220				
99	13:07:37	5.590				
100	13:08:33	8.260				
101	13:09:27	6.670				
102	13:10:21	4.750				
Event 21	13:10:21		100% Capture LHS		11.125	Average (ppm)
103	13:11:15	11.700			11.541	Calib. Corrected
104	13:12:09	11.300			11.543	BG Corr.
105	13:13:02	11.100			665	CFM
106	13:13:56	11.200				
107	13:14:50	11.000				
108	13:15:44	11.200				
Event 22	13:17:09		Paver ran out of fuel			
109	13:17:09	10.700				
Event 23	13:18:03		Background Decay			
110	13:18:03	0.051				
111	13:18:59	0.332				
112	13:19:53	0.196				
113	13:20:47	0.120				
114	13:21:41	0.119				
			Capture Eff. =	**43.00%**		
			(Wind into left side of paver)			

Overall Average Outdoor Capture Eff. = 33.47%

APPENDIX C

DYNAPAC ENGINEERING CONTROL FAN SPECIFICATIONS: CORRESPONDENCE AND CALCULATIONS

The Dynapac engineering control design used two exhaust fans to supply the negative pressure to the exhaust hood. Each of the fans was hydraulically driven, appeared to be of German manufacturer, and appeared to be of the same model.

A fan specification plate was mounted to the fan housing on each of the two fans. The information on each plate was identical and is shown below.

Hubert Vogel	Typ:	HBC 200/D	Fabr Nr	970139
Lufttechnische Anlagen	V	1 200 kg/m³	ΔP_{ges}	60 Pa
42279 Wuppertal	n	2840 Upm	γ	1,2 kg/m³
RUF 0202/642097/99	N_w	0,4 kW	η	80%

During an internet search to identify the Hubert Vogel fan manufacturer. NIOSH engineers identified a Swedish Engineering Design firm operations throughout the European Union. In response to our inquiry, the interpretation of the fan specification information was provided via an email message. A copy of the reply is included in this appendix.

(Copy of text from email message)
Dear Mr. Kenneth,

Thank you for your inquiry. I hope my following information will help you.

Typ HBC 200/D: means an internal name for the fan with in- or outlet of 200 mm diameter

Fabr Nr. 970139: this is the fabrication number from the manufacturing company

V: normally it means the volumen to transport but 1200 kg/m**3 is an old description for the volume today it is specified by m**3/h (cubicmeter per hour) if we divide that with Gamma with should have a transport volume of 1000 m**3/h (can be possible)

Delta Pges: this is the total pressure difference Pascal (difference between the dynamic (environment) and static (pressure in the system) pressure

n 2840 Upm: are the turns per minute --> rpm = upm

Gamma: is the specific weight of air

Nw 0,4kW : is the old description of power, your fan has an input power of 0,4 kiloWattage

Efficiency 80%: is the economical value for the fan, this means form 100% inputed energy, 80% is used by the fan and 20% are lost (more for figures and statistics)

Again, I hope this information will be helpful, if you could tell me the manufacturer there is maybe more information available. If you have an further questions, please do not hesitate to contact me. (did you already visit our homepage at http://www.kncag.com)

Yours sincerely,

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