Applied Occupational and Environmental Hygiene
Volume 14(8): 565–573, 1999

1047-322X/99 $12.00 + .00

Factory Performance Evaluations of Engineering Controls for Asphalt Paving Equipment

Kenneth R. Mead,[1] R. Leroy Mickelsen,[1] and Thomas E. Brumagin[2]
[1] Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Cincinnati, Ohio; [2] National Asphalt Pavement Association, Lanham, Maryland

This article describes a unique analytical tool to assist the development and implementation of engineering controls for the asphalt paving industry. Through an agreement with the U.S. Department of Transportation, the National Asphalt Pavement Association (NAPA) requested that the National Institute for Occupational Safety and Health (NIOSH) assist U.S. manufacturers of asphalt paving equipment with the development and evaluation of engineering controls. The intended function of the controls was to capture and remove asphalt emissions generated during the paving process. NIOSH engineers developed a protocol to evaluate prototype engineering controls using qualitative smoke and quantitative tracer gas methods. Video recordings documented each prototype's ability to capture theatrical smoke under "managed" indoor conditions. Sulfur hexafluoride (SF_6), released as a tracer gas, enabled quantification of the capture efficiency and exhaust flow rate for each prototype. During indoor evaluations, individual prototypes' capture efficiencies averaged from 7 percent to 100 percent. Outdoor evaluations resulted in average capture efficiencies ranging from 81 percent down to 1 percent as wind gusts disrupted the ability of the controls to capture the SF_6. The tracer gas testing protocol successfully revealed deficiencies in prototype designs which otherwise may have gone undetected. It also showed that the combination of a good enclosure and higher exhaust ventilation rate provided the highest capture efficiency. Some manufacturers used the stationary evaluation results to compare performances among multiple hood designs. All the manufacturers identified areas where their prototype designs were susceptible to cross-draft interferences. These stationary performance evaluations proved to be a valuable method to identify strengths and weaknesses in individual designs and subsequently optimize those designs prior to expensive analytical field studies.

Keywords Asphalt Fume, Asphalt Paving, Engineering Controls, Asphalt Paving Equipment, Tracer Gas, Sulfur Hexafluoride (SF_6), Ventilation Testing

The objective of this National Institute for Occupational Safety and Health (NIOSH) study was to facilitate the development of engineering controls for asphalt paving equipment and evaluate their performance under stationary conditions. The intended function of the controls was to capture and remove asphalt emissions generated during the paving process. A protocol was developed to conduct stationary performance evaluations at the manufacturing plant of each of the five participating paver manufacturers. The manufacturers were to use the results and recommendations of the plant-site evaluations to optimize their prototype designs prior to further evaluations during actual paving operations.

BACKGROUND

Populations at increased risk for exposure to asphalt fumes are those listed under the Standard Industrial Classification Code 1611: (1) Highway and Street Construction Workers (except elevated highways), and (2) Asphalt Paving: roads, public sidewalks, and streets. An estimated 300,000 workers perform these jobs annually.(1)

The actual asphalt content in asphalt pavements is relatively low. Hot mix asphalt (HMA) paving material typically consists of 95 percent mineral aggregate (rock, sand, and gravel) and 5 percent asphalt cement, which is the glue that holds the rocks together. Asphalt cement is a thermoplastic material that is solid at ambient temperatures and becomes pliable or plastic at elevated temperatures. The chemical composition of asphalt cement depends on the source of the crude oil used to manufacture and refine the asphalt plus any additives required for the finished product to meet performance specifications. The major constituents of asphalt are asphaltenes, resins, and oils which consist of saturated and unsaturated hydrocarbons. Limited data exist concerning the individual chemical constituents and their resulting exposure levels during asphalt paving operations.

EXPOSURE CRITERIA

For many of the chemical constituents present in asphalt emissions, there are no relevant exposure criteria. The NIOSH-recommended exposure limit (REL) for asphalt fume is 5 milligrams per cubic meter (mg/m^3) for a 15-minute ceiling value. However, NIOSH is investigating the need to revise the existing REL for asphalt fume. A Threshold Limit Value (TLV®) of 5 mg/m^3 for an 8-hour time-weighted average (TWA) has been set by the American Conference of Governmental Industrial Hygienists (ACGIH®). The Occupational Safety and Health Administration (OSHA) does not have a regulation specifically for exposures to asphalt emissions. However, in 1996, OSHA listed asphalt fume exposures as a top non-regulatory initiative.(2) OSHA does regulate some components (benzene, toluene, xylene, respirable particulate) found in asphalt emissions, but daily exposure levels to these components are generally below their regulated exposure limits.

The investigation of worker exposures to HMA and its various components is the subject of multiple research activities inside and outside NIOSH. Engineering control implementation is seen as a proactive measure to minimize worker exposures until the exposure and toxicology research efforts are concluded. In support of this effort, the stationary engineering control evaluations reported in this manuscript focused exclusively on maximizing the engineering performance of the prototype engineering control systems.

PAVING PROCESS DESCRIPTION

At the HMA plant, mineral aggregates are proportioned according to a mix design or recipe, then heated and coated with asphalt cement to form a hot, homogeneous, asphalt paving mixture. Other additives such as fibers, polymers, and antistrip agents may be included in the mix recipe based on the desired pavement characteristics.(3)

Prior to paving, the road surface is physically prepared to create a durable bond between the existing surface and the new HMA surface material. The HMA is transported from the mixing plant by dump truck. Before loading, a release agent may be sprayed onto the bed of the trucks to reduce sticking of the HMA. The HMA is transferred to the receiving hopper of the paving machine directly from the trucks or via an optional material transfer vehicle. When used, the material transfer vehicle allows the paving crew to pave continuously by eliminating the need to stop between each HMA truck delivery.

The asphalt paving machine consists of two primary components: the tractor unit and the screed unit (see Figure 1). The tractor unit provides the locomotion for the paver. A receiving hopper on the front of the tractor receives the HMA from the material transfer vehicle. Two slat-conveyors transfer the HMA from the receiving hopper through conveyor tunnels and to the rear of the tractor where it falls to the prepared road surface. Screw augers, located at the back of the tractor, distribute the HMA across the width of the paving surface. The second component of the paving machine, the screed unit, follows directly after the screw augers and is similar to a heavy sled. The screed is pulled by two long towing arms that attach to both sides of the tractor via adjustable tow points. This allows the screed to float on and level the HMA material while providing initial

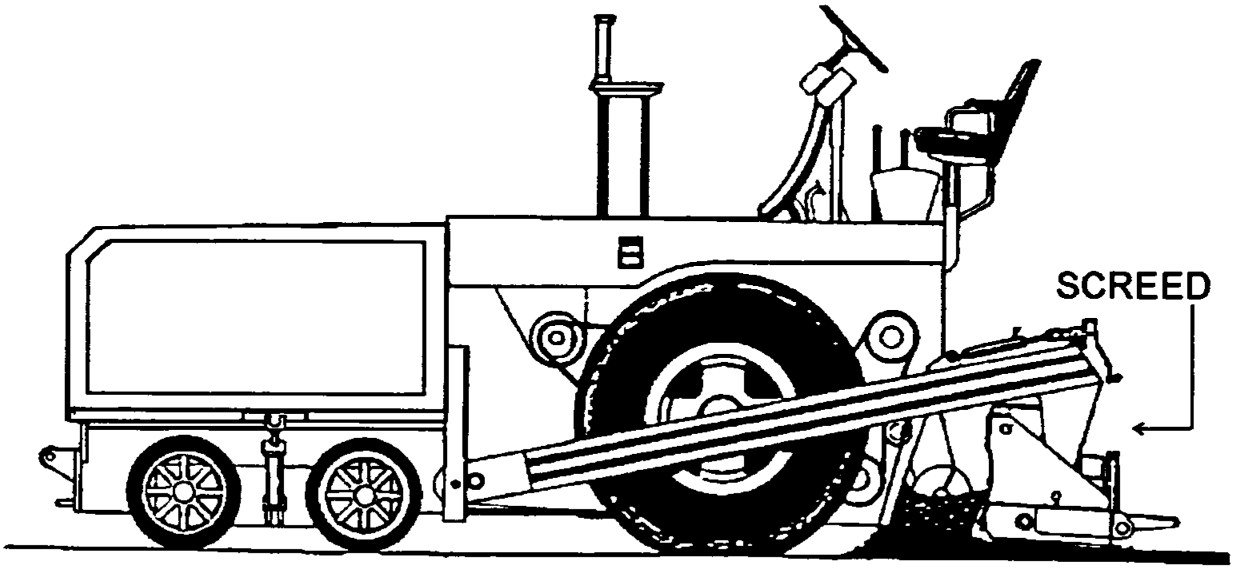

FIGURE 1
Diagram of an asphalt paving tractor with screed. The screed unit, which resembles a large sled, is pulled behind the tractor through the use of height-adjustable towing arms.

compaction and texture to the paving surface. After initial compaction by the screed, a machine called the compaction roller applies the additional compaction to the freshly laid surface.

Usually, HMA arrives at the paving site at temperatures between 250°–320°F. When some modifiers are used, they increase the HMA's stiffness, thus requiring higher application temperatures for workability. The higher the temperature of the HMA, the greater the generation of fumes and vapors. During transport, the exposed HMA surface cools, creating a skin which encapsulates the truckload of HMA and inhibits the release of fumes and vapors. During agitation of the HMA, the skin is disrupted, greatly enlarging the hot surface area exposed to ambient air and increasing the release of fumes and vapors. There are two primary opportunities for HMA agitation to occur during the paving process: (1) within the hopper as the HMA is transferred to the paver, and (2) within the auger area (between the back of the tractor and the screed) as the HMA falls from the slat conveyors and is laterally distributed by the screw augers. Preliminary field evaluations revealed that the HMA agitation and resulting fume generation within the hopper was markedly less than that of the auger area. In addition, the paver-mounted workstations are directly above and directly behind the auger area. These two criteria, prevailing fume generation and worker proximity, identified the auger area as the predominant contributor to paver-mounted worker exposures, and thus, was targeted as the primary focus of engineering control efforts.(4)

EMERGENCE OF ENGINEERING CONTROLS STUDY

The effort to develop engineering controls for HMA paving equipment originated in February 1993 at the annual convention of the National Asphalt Pavement Association (NAPA). A paving contractor asked several paver manufacturers what could be done with the paving equipment to eliminate workers' exposure to fumes during HMA paving operations. In May 1993, NAPA formed an Engineering Controls Task Force comprised of paving contractors, equipment manufacturers, asphalt suppliers, and other interested parties. The task force established the goal, "To improve the overall working environment and conditions during HMA paving operations by reducing or eliminating worker exposures to asphalt fumes through the implementation of engineering controls on HMA pavers."(5) NAPA's task force coordinated an engineering control field study which investigated two general approaches for reducing worker exposures to fumes during HMA paving operations: (1) diluting worker exposures with filtered showers of clean air, and (2) incorporating industrial exhaust ventilation methods to capture asphalt emissions at their predominant points of generation. The NAPA evaluation protocol incorporated industrial hygiene sampling methods for total particulate and the benzene-soluble fraction of total particulate (asphalt fume). Both general area and breathing zone samples were collected during controlled (with ventilation) and uncontrolled (without ventilation) paving operations. Many of the samples collected by NAPA were at or below the analytical limit of detection, indicating a need for analytical methods with increased sensitivity to determine worker exposure to asphalt fumes during paving. However, of the two control techniques tested (clean air showers and local exhaust ventilation), the study results showed some indication that the Local Exhaust Ventilation (LEV) techniques could potentially reduce workers' exposure to asphalt fumes.(6)

The task force recognized the need for outside assistance to (1) optimize the engineering controls' performance capabilities, and (2) conduct a thorough performance evaluation of final prototype designs. NAPA approached the Federal Highway Administration (FHWA) with a project proposal and a request for funding under the Applied Research and Technology Program of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). In the proposal, NAPA requested that NIOSH assist each participating manufacturer with the design optimization of their prototype engineering control systems. At the conclusion of the design optimization phase, NIOSH would conduct a field phase (Phase II) to evaluate each engineering control during actual paving operations. Five paver manufacturers, representing more than 80 percent of highway-class paver sales, volunteered to participate in the study.

METHODS

NIOSH engineers developed a protocol that divided the project into two phases. Phase I evaluations, the focus of this article, were conducted at each participating paver manufacturing plant. Each of the manufacturers developed its own prototype design(s) for evaluation. Although each manufacturer's design was unique, all of the engineering control designs incorporated local exhaust hoods above the auger (see Figure 2), exhaust fans, vertical exhaust stacks, and the associated duct material. Some of the prototype designs provided additional enclosure around the auger area. The Phase I evaluation used surrogate "contaminants" to evaluate each prototype design under prescribed indoor and outdoor stationary conditions. NIOSH engineers used results from these evaluations to provide design optimization recommendations to the manufacturers. The participating manufacturers used the evaluation reports and accompanying recommendations to modify their prototype designs prior to the Phase II field evaluations. Results from the Phase II evaluations, which were conducted in the field during actual paving operations, will be published in a future article.

INDOOR EVALUATIONS

To prevent infiltration of captured contaminant back into the testing environment, the indoor evaluation protocol required a barrier to separate the contaminant capture region of the paver from the engineering control's exhaust discharge. To achieve this condition, the paver was positioned beneath an overhead door, with the auger and screed on the interior side of the doorway and the paver exhaust and engineering control exhaust on the exterior side. Next, the barrier was established by lowering the overhead door to the paver deck and sealing the remaining open areas. Figures 3a and 3b illustrate the setup requirements.

The evaluation protocol included qualitative smoke and quantitative tracer gas analysis methods. For the qualitative evaluations, a theatrical smoke generator supplied the smoke. A 2-inch by 10-foot polyvinyl chloride (PVC) pipe, with a linear distribution of 3/8-inch holes, distributed the theatrical smoke across the full length of the augers. Video recordings documented each prototype's ability to capture the smoke under managed indoor conditions. The smoke tests were useful to verify proper operation of the engineering controls prior to the quantitative evaluation. Minor problems could be identified and eliminated during this stage of the evaluation. In addition to providing a visual picture of each engineering control's effectiveness, the smoke tests also provided information regarding room-air currents and the integrity of the separation barrier.

The quantitative evaluations were conducted using sulfur hexafluoride (SF_6) as a tracer gas and surrogate contaminant. This evaluation was designed to quantify the prototype control's exhaust flow rate and to measure each control's ability to capture the SF_6 when released into the auger area. The SF_6 release was regulated by two mass flow controllers, each calibrated to a predetermined flow rate of SF_6. Discharge tubes carried the SF_6 from the mass flow controllers to the engineering control. A schematic of the SF_6 distribution system is shown in Figure 4.

A hole drilled into the engineering control's exhaust duct (exterior side of the overhead garage door), allowed access for a multipoint monitoring wand to be inserted into the exhaust stream. This sampling location was chosen to maximize the opportunity for thorough mixing of the SF_6 within the exhaust stream. The monitoring wand was oriented with the perforations perpendicular to the moving exhaust stream. A sampling tube connected the wand to a multi-gas monitor positioned on the exterior side of the overhead garage door. During each test, the gas monitor analyzed and recorded the SF_6 concentration (in parts per million [ppm]) within the engineering control's exhaust stream. Sample frequency was approximately once every 30 seconds. Exhaust stream monitoring continued until SF_6 concentrations reached approximate steady-state conditions.

To determine the exhaust flow rate of the engineering control system, the discharge hose from a single mass flow controller was positioned to feed directly into the intake duct for the engineering control exhaust system, thus creating 100 percent capture of the released SF_6. The mean concentration of SF_6 measured in the exhaust stream was then used to calculate the

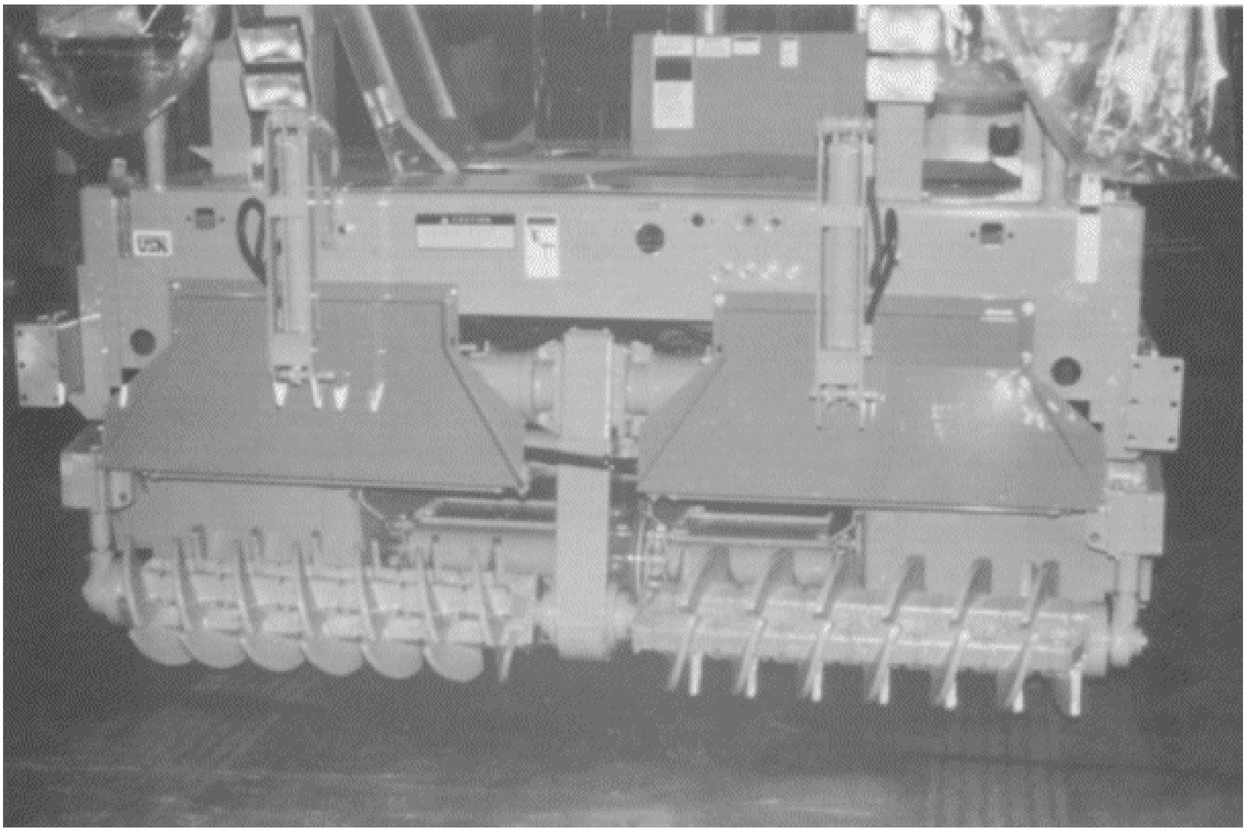

FIGURE 2

Photograph of two local exhaust hoods mounted on the rear of a paving tractor and located above the distribution augers. Exhaust ducts connect the two exhaust hoods to a single exhaust fan (fan and ducts are located beneath the paver deck). The screed is not pictured.

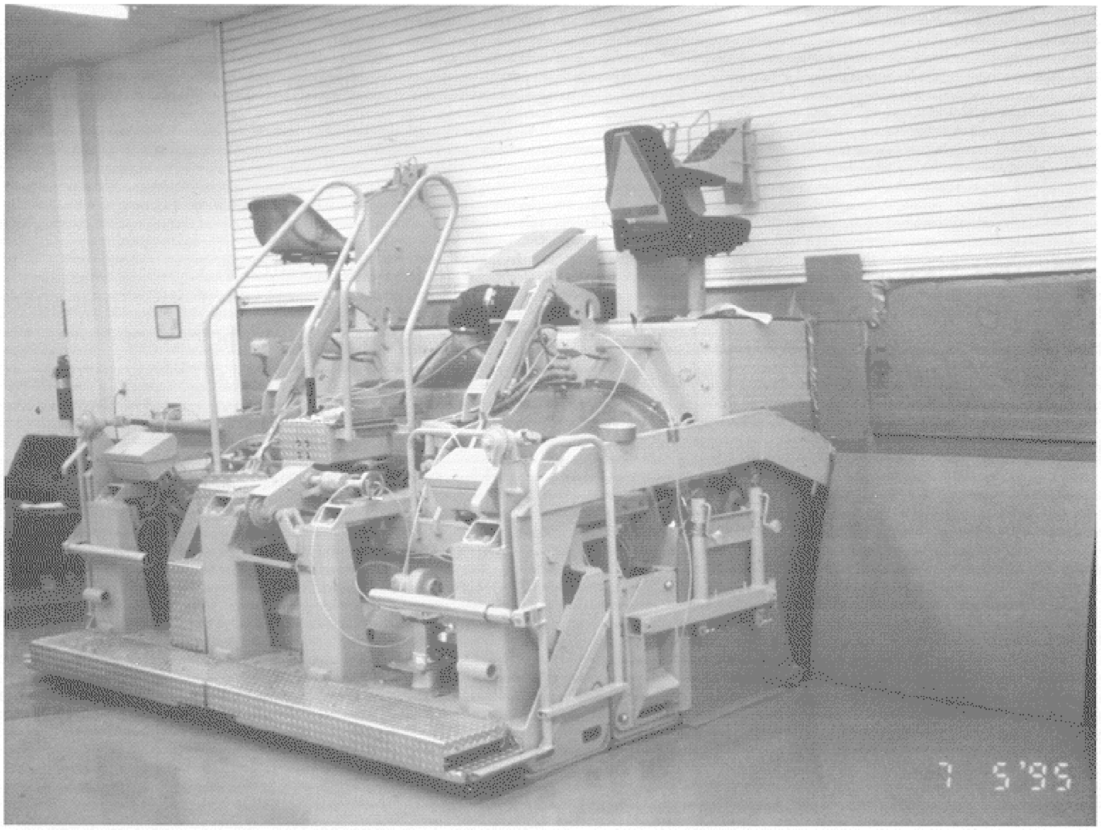

FIGURE 3a
Photograph of the indoor portion of an asphalt paving machine undergoing engineering control performance evaluations. The contaminant generation area (the auger area) is separated from the engineering control's exhaust stack.

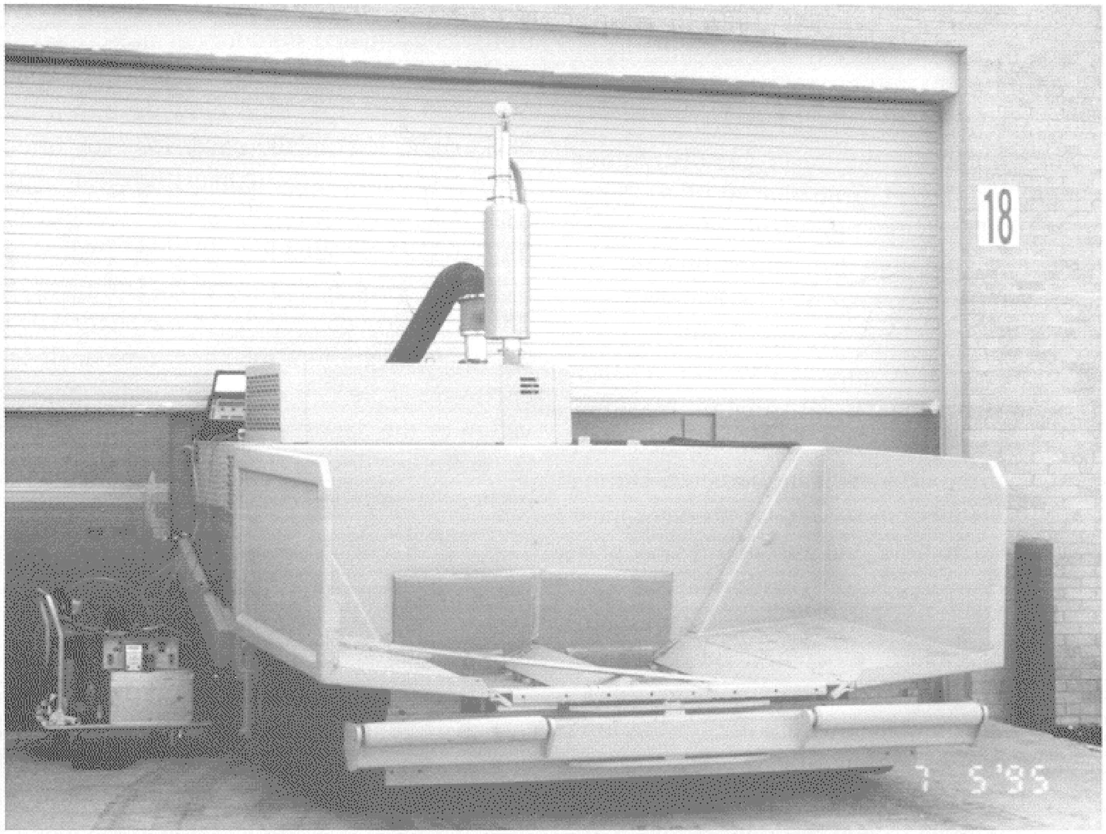

FIGURE 3b
Outdoor photograph of an asphalt paving machine positioned for engineering control performance evaluations. Exhausted contaminant and SF_6 supply bottle are kept outside.

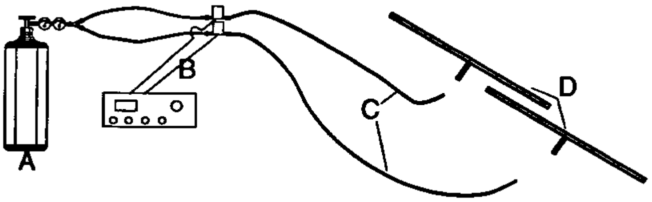

FIGURE 4
A schematic diagram of the SF_6 distribution equipment. The mass-flow controllers allowed precise dosing of tracer gas to the engineering control testing area. A = tracer gas cylinder with regulator; B = mass flow control system; C = PTFE distribution tubes; D = tracer gas distribution plenums.

flow rate. The equation for determining the exhausted flow rate is:

$$Q_{(exh)} = \left[Q_{(SF_6)}/C^*_{(SF_6)}\right] \times 10^6 \qquad [1]$$

where $Q_{(exh)}$ = Volumetric flow rate of air exhausted through the engineering control [liters per minute (lpm)]**

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

$C^*_{(SF_6)}$ = Concentration of SF_6 (ppm) detected by the multi-gas monitor with 100 percent capture conditions.

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

To verify our results, the above process was repeated using two mass flow controllers, thus, doubling the dose of SF_6 introduced into the exhaust system.

To determine capture efficiency, the tracer gas distribution configuration was slightly different from that used to determine the exhaust flow rate. Discharge tubes from the two mass flow controllers supplied SF_6 into two distribution plenums located within the paver's auger area. One plenum supplied SF_6 to the right auger area and the second plenum supplied SF_6 to the left auger area. Cold-water PVC pipe (CPVC) of 1/2-inch diameter was used to construct the SF_6 distribution plenums. Each T-shaped plenum was 4 feet wide and contained four evenly spaced holes measuring 1/64 inch in diameter. During the plenum design at NIOSH laboratories, static pressure measurements were taken at each hole and infrared video photography was used to verify even SF_6 distribution across each plenum.

To determine the indoor capture efficiency, the multi-gas monitor was initially used to verify that no significant background levels of SF_6 had accumulated within the testing area during the experimental setup. After initiating SF_6 flow through both distribution plenums, the multi-gas monitor sampled the exhaust stream until approximate steady-state conditions were achieved. Once this occurred, the SF_6 supply was stopped and background concentrations were monitored to identify the extent to which general area concentrations of noncaptured SF_6 contributed to the exhaust concentration. The engineering control capture efficiency was calculated with the following equation:

$$\eta = 100 \times \left(C_{(SF_6)}/C^*_{(SF_6)}\right) \qquad [2]$$

where η = capture efficiency

$C_{(SF_6)}$ = Concentration of SF_6 (ppm) measured during the capture efficiency evaluations

$C^*_{(SF_6)}$ = Concentration of SF_6 (ppm) measured during 100 percent capture conditions using both mass flow controllers

The above procedures for determining the exhaust flow rate and the capture efficiency were repeated at least three times. Calculated exhaust flow rates were compared for consistency and capture efficiency results were averaged. If a calculated exhaust flow rate was more than 5 percent different from previous readings, a troubleshooting evaluation of the equipment and setup was initiated. In this respect, $Q_{(exh)}$ calculations helped to ensure proper equipment operation prior to each capture efficiency determination. Sufficient time was allowed between test runs for area concentrations of SF_6 to decay below 0.1 ppm. Exhaust stream concentrations of SF_6 ranged from 15–80 ppm during the tracer gas evaluations.

OUTDOOR EVALUATIONS

After each indoor evaluation, the prototype engineering control was evaluated outdoors at prescribed stationary positions relevant to the prevailing winds. Up to four orientations were evaluated with the wind blowing into a different side (front, back, right, left) of the paver for each orientation. At each of these orientations, the exhaust flow rate and capture efficiency were determined using the same tracer gas techniques described for the indoor evaluations. A third evaluation criterion, the *enclosure score*, was also appraised during the outdoor evaluations. The geometric complexity of the auger area prohibited a scientific quantification of the auger-area enclosure. As a result, the enclosure score is a subjective value based on a visual observation of the degree of auger-area enclosure incorporated into the prototype design. The more the auger area was enclosed, the higher the assigned enclosure score.

RESULTS AND INTERPRETATION

Indoor Evaluations

After using the smoke test procedure to optimize the testing environment, the engineering controls' tracer gas capture efficiencies were determined. Figure 5 shows a graph of the mean indoor capture efficiencies for all of the evaluated prototype engineering controls. (Two of the manufacturers submitted more than one prototype design for evaluation.) The individual

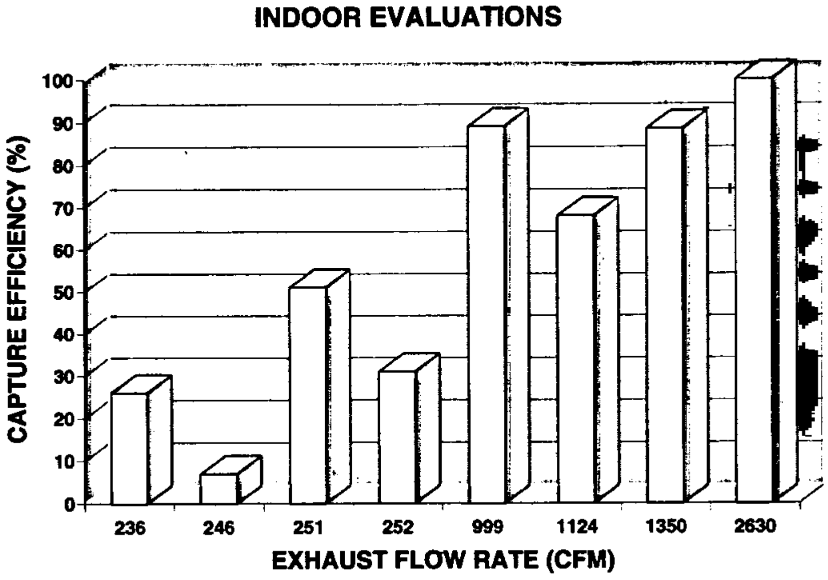

FIGURE 5
A graph of mean capture efficiencies, measured during the indoor engineering control performance evaluations. Each evaluated engineering control is identified by its measured exhaust flow rate.

engineering controls are identified by their measured exhaust flow rates as determined using the tracer gas protocol. Figure 5 reveals an expected trend: as the flow rates increased, so did the engineering controls' collection efficiencies. At exhaust flow rates below 255 cfm, each prototype's indoor capture efficiency appears to be increasingly influenced by physical design and environmental factors (e.g., room currents) as opposed to any induced capture velocity. This indicates that even in the managed environment, there is a minimum exhaust flow requirement to capture the tracer gas.

Outdoor Evaluations

Open locations with minimal wind blockage were sought for the stationary outdoor evaluations. Frequently, the selected site was an open parking lot. During the outdoor evaluations, the same protocol described for the indoor evaluations (minus the separating barrier) was used to determine the exhaust flow rate and capture efficiency for each paver orientation. Only one prototype per manufacturer was evaluated during the outdoor evaluations. Incorporating data from all paver orientations, Figure 6 shows a graph of the mean outdoor capture efficiency

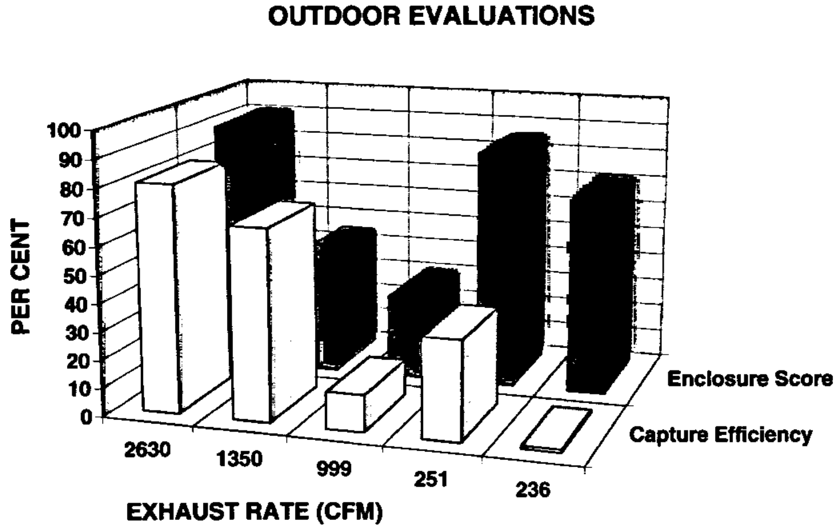

FIGURE 6
A graph showing mean capture efficiencies and enclosure scores for each prototype control evaluated during outdoor stationary evaluations. The outdoor evaluation results emphasized the importance of a good enclosure.

as well as the identified enclosure score for each prototype's outdoor evaluation.

Although it is not a quantitative relationship, Figure 6 clearly reveals the importance of hood enclosure as it relates to the capture efficiencies measured during the outdoor stationary evaluations. The prototype with the highest capture efficiency during indoor evaluations (Exhaust = 2630 cfm) also had a high enclosure score, resulting in an outdoor capture efficiency greater than 80 percent. However, the prototype with the second-highest indoor capture efficiency (Exhaust = 999 cfm) had a much lower enclosure score, resulting in dramatically reduced outdoor capture efficiency. The data for the prototype with the lowest outdoor capture efficiency is slightly misleading. Although there was good enclosure in this prototype design, air from the paver engine's cooling fan leaked from the engine compartment into the auger area. This disrupted the minimal capture velocity generated by the engineering control's 236 cfm exhaust system.

DISCUSSION AND CONCLUSIONS

Designing engineering controls for mobile HMA paving equipment is a unique challenge. Strict adherence to the traditional tenets of industrial ventilation design is impractical due to a changing physical environment and a hot, churning control area that requires worker access. This challenge evolves into a compromise between the ideal design of an engineering control system and a workable design which succeeds despite the process-inherent limitations. Once the designer attempts to overcome this challenge, he or she require some method of testing the prototypes' performance. When the worksite is outdoors, and in this case mobile, the myriad of uncontrollable environmental variables can make performance assessment difficult, timely, and expensive. In these circumstances, performance evaluations which use surrogate contaminants within a controlled environment are valuable assessment tools. The testing and evaluation protocol described in this article proved to be such a tool through the concise, cost-effective identification of underperforming control designs early in the design stage. Although such evaluations do not replace the need for real-world performance assessments, the designing engineer receives a much better idea of the expected performance prior to initiating the real-world evaluation.

Results and recommendations from the stationary evaluations provided paver manufacturers with the critical information needed to optimize their engineering control designs. Several manufacturers increased their exhaust flow rate after they discovered that they had insufficient exhaust capacity to capture and remove the contaminants. One manufacturer used the Phase I evaluation to select the best performing hood from among three prospective designs. Another manufacturer redesigned their engine compartment after the evaluation revealed that engine cooling air was blowing into the auger area and disrupting the control's capture effectiveness. From the stationary outdoor evaluations, all the manufacturers identified areas where their initial designs were susceptible to cross-draft interference from the wind. Based on the Phase I evaluation data, the manufacturers were able to refine their prototype designs in preparation for performance evaluations conducted during actual paving operations (Phase II).

In addition to the individual benefits the tracer gas protocol afforded the asphalt paver manufacturers, the protocol promises to provide a positive impact to an entire industry of asphalt paving workers. In January 1997, a modification of the tracer gas testing protocol was incorporated into the NIOSH document, *Engineering Control Guidelines for Hot Mix Asphalt Pavers, Part 1: New Highway-Class Pavers* (NIOSH 97-105).(7) Coinciding with the release of the NIOSH document, representatives from the paving industry, organized labor, and OSHA teamed together to formulate and sign the *Voluntary Initiative to Reduce Worker Exposure to Paving Asphalt Fumes.*(8) This voluntary initiative calls for each paver manufacturer to design and install engineering control ventilation systems as standard equipment on each highway-class asphalt paving machine manufactured after July 1, 1997. In addition, each signatory manufacturer agreed that the engineering control design will have a capture efficiency of 80 percent or greater based on the indoor tracer gas evaluation protocol identified in the NIOSH guidelines. This voluntary initiative received former OSHA director Joseph Dear's signature on January 9, 1997, as one of his last official acts before leaving OSHA.

ACKNOWLEDGMENTS

The development of engineering controls for HMA paving equipment is a cooperative effort that defies the many stereotypical roles expected in ventures between government and industry. The paver equipment manufacturers who collaborated in the Phase I evaluation included: Barber-Greene/Caterpillar Inc., Blaw-Knox/Ingersoll Rand, Cedarapids Inc., Champion Road Machinery, and Roadtec Inc. Along with the National Asphalt Pavement Association, these manufacturers should be applauded for their proactive initiative to improve the asphalt paving working environment. Special thanks are also due to the Federal Highway Administration for its role in supporting this meaningful research. The authors would also like to thank Stanley Shulman, Scott Earnest, Ronald Kovein, Walter Haag, Daniel Watkins, Robin Smith, and Bernice Clark for their key contributions to this research effort. Their participation was an important component of the successful outcome of this project.

DISCLAIMER

Mention of company or product names does not constitute endorsement by the Centers for Disease Control and Prevention (CDC) or the National Asphalt Pavement Association (NAPA).

REFERENCES

1. Asphalt Institute: Report to OSHA and NIOSH: Status of Asphalt Industry Steering Committee Research Program on the Health

Effects of Asphalt Fumes and Recommendation for a Worker Health Standard. Asphalt Institute, Lexington, KY (1990).

2. Occupational Safety and Health Administration (OSHA): The OSHA Priority Planning Process. OSHA, Washington, D.C. (1995).
3. U.S. Army Corps of Engineers (USACE): Handbook: Hot-Mix Asphalt Paving. Document Number UN-13 (CEMP), USACE, Washington, D.C. (1991).
4. National Institute for Occupational Safety and Health (NIOSH): Trip Report: Florida Field Study of Asphalt Paving Processes by R.L. Mickelsen, Document Number ECTB 208. NIOSH, Cincinnati, OH (1995).
5. Brumagin, T.: Engineering Control for HMA Paving Equipment. An Update for Members of the National Asphalt Pavement Association. NAPA, Lanham, MD (1996).
6. National Asphalt Pavement Association (NAPA): 1993 Activities Report—NAPA's Paver Modification Task Force. NAPA, Lanham, MD (1994).
7. NIOSH: Engineering Control Guidelines for Hot Mix Asphalt Pavers, Part 1: New Highway-Class Pavers (NIOSH 97-105) NIOSH, Cincinnati, OH (1995).
8. OSHA: Voluntary Initiative to Reduce Worker Exposure to Paving Asphalt Fumes. OSHA, Washington, D.C. (1997).