In-Depth Survey Report

A Laboratory Evaluation of a Prototype Local Exhaust Ventilation System on a Terex Cold Milling Machine at Terex Roadbuilding, Oklahoma City, Oklahoma

Conducted with assistance from the Silica/Milling-Machines Partnership, affiliated with and coordinated through The National Asphalt Pavement Association (NAPA)

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NAICS Code: 237310 (Highway, Street, and Bridge Construction)

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Abstract

In August 2011, NIOSH researchers and the Silica/Milling-Machines Partnership coordinated by the National Asphalt Pavement Association (NAPA) conducted laboratory testing of a prototype local exhaust ventilation (LEV) system on a Terex PR600c cold milling machine. The testing was conducted indoors at the Terex Roadbuilding manufacturing facility in Oklahoma City, Oklahoma.

All tests were conducted on a stationary milling machine with the cutter drum spinning and belts stationary, and without any reclaimed asphalt pavement (RAP) moving through the system. Terex engineers used cardboard and plastic to simulate the level of gap-seal to be provided in a true production machine factory-equipped with an LEV control system. Smoke and tracer gas were used as surrogates for silica dust to evaluate capture efficiencies of the dust emission-control system in the cutter drum housing of the machine. Smoke was used as an initial qualitative test to visually check for leaks. Sulfur Hexafluoride (SF_6) was used to quantitatively evaluate capture efficiency of tracer gas released in the cutter drum housing of the machine. Two independent analytical instruments were used to measure the resulting SF_6 concentrations in the LEV exhaust duct, a Bruel & Kjaer (B&K) photoacoustic analyzer and a Miran SapphIRe infrared spectrometer.

Capture efficiency tests were conducted at flow rates of 1300 actual cubic feet per minute (acfm), 900 acfm, and 600 acfm on the Terex cold milling machine. Capture efficiency results from the two trials conducted at 600 acfm were 97.1% and 97.0% for the B&K data and 98.2% and 97.4% for the Miran SappIRe data. The mean capture efficiency from the four trials conducted at 900 acfm from the B&K and Miran SapphIRe data were 99.7% and 99.9%, with lower 95% confidence limits of 99.3% and 99.7%, respectively. Results from the two trials conducted at 1300 acfm were 100% for both trials as measured by both instruments. Additional testing during actual milling activities is recommended to document capture efficiency under true field conditions. The testing reported here only evaluated capture efficiency within the cutter drum housing. Other potential dust release locations on the machine such as the transition between the primary and secondary conveyor and the top of the secondary conveyor were not evaluated during this testing but could contribute to silica exposures during field testing.

Introduction

Background for Control Technology Studies

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

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

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

NIOSH is studying the effectiveness of dust-emission control measures during asphalt pavement-milling operations. The initial aim of this project is to determine if the dust emission-control systems installed on new pavement-milling machines and operated according to the manufacturers' recommendations are adequate to control worker exposures to respirable dust, especially that containing crystalline silica, a long-recognized occupational respiratory hazard. Chronic over-exposures to such dust may result in silicosis, a chronic progressive lung disease that eventually may be disabling or even fatal, and an increased risk of lung cancer

[NIOSH 2002]. The long term goal of this project is to adequately control worker exposures to respirable dust and crystalline silica by providing data to support the development of a set of best practice guidelines for the equipment if the engineering controls are adequate, or to develop a set of recommendations to improve the performance of controls if they are not adequate.

Many construction tasks have been associated with overexposure to crystalline silica [Rappaport et al. 2003]. Among these tasks are tuck pointing, concrete sawing, concrete grinding, and abrasive blasting [NIOSH 2000; Thorpe et al. 1999; Akbar-Kanzadeh and Brillhart 2002; Glindmeyer and Hammad 1988]. Road milling has also been shown to result in overexposures to respirable crystalline silica [Linch 2002; Rappaport et al. 2003; Valiante et al. 2004]. However, all three of those road-milling studies are limited because they do not provide enough information about the operating parameters and engineering controls present on the milling machines to determine if the overexposures were due to a lack of effective controls or poor work practices. The current study is helping to fill that knowledge gap.

A variety of machinery are employed in asphalt pavement recycling, including cold-planers, heater-planers, cold-millers, and heater-scarifiers [Public Works 1995]. Cold-milling, which uses a toothed, rotating cutter drum to grind and remove the pavement to be recycled, is primarily used to remove surface deterioration on both petroleum-asphalt aggregate and Portland-cement concrete road surfaces [Public Works 1995]. The milling machines used in cold-milling are the focus of this investigation.

The large cold-milling machine evaluated during this evaluation was a Terex PR600c with a 600 horsepower (HP) diesel engine and a 2185 mm (86 inch) wide cutter drum. Most half-lane cold-milling machines have a spinning cutter drum with teeth to remove pavement from the road surface and transfer it onto a primary conveyor. From the primary conveyor, the reclaimed pavement is transferred to a secondary conveyor and into a dump truck. All production milling machines are also equipped with water-spray systems to cool the cutting teeth and suppress dust. The evaluated Terex PR600c cold-milling machine also had a prototype local exhaust ventilation (LEV) system to capture dust generated in the cutter drum housing and along the primary conveyor of the machine.

This laboratory/factory research evaluated the performance of the LEV using smoke and tracer gas testing to simulate the emission of respirable dust. Tracer gas tests were conducted on a stationary machine with the cutter drum spinning and the belts stationary without any reclaimed asphalt pavement moving through the system. Terex engineers used cardboard and plastic to simulate the level of gap-seal expected in an actual production machine that will be factory-equipped with an LEV control system.

This study is facilitated by the Silica/Milling-Machines Partnership, which is affiliated with and coordinated through the National Asphalt Pavement Association (NAPA). The partnership includes NAPA, the Association of Equipment Manufacturers (AEM), the manufacturers of almost all pavement-milling machines sold in the U.S., numerous construction contractors, the International Union of Operating Engineers (IOUE), NIOSH, and other interested parties.

Previous Silica/Milling Machines Studies

NIOSH researchers collaborated with the Silica/Milling-Machines Partnership to conduct field research on respirable-dust and crystalline-silica exposures and exposure controls from 2003 through 2010. The studies were performed with five of the largest domestically-marketed manufacturers of cold-milling machines. With the assistance of the Partnership in identifying pavement-milling job sites appropriate for study and in arranging for the field work, NIOSH researchers completed a pilot field survey in 2003 [Echt et al. 2004], four in-depth field surveys with different manufacturers from 2004 to 2006 [Echt et al. 2007; Blade et al. 2009a; Blade et al. 2009b; Blade et al. 2009c], a large study of milling machines from four different manufacturers in 2008 [Blade et al. 2011], and a second large study of milling machines from five different manufacturers in 2010 [Hammond et al. 2011].

The following observations are based on the research conducted on controls from five different manufacturers from 2003 to 2010:

(1) During the first four studies, NIOSH researchers collected personal breathing zone samples by hanging personal sampling pumps and sampling media on operators and ground crew from multiple manufacturers of cold-milling machines with water-flow dust suppression controls operated at normal and maximum water flow rates. When using water-flow dust suppression, personal breathing zone sampling results from the studies conducted between 2004 and 2006 for respirable crystalline silica varied dramatically by manufacturer, by study site, and within study site. Between 2004 and 2006, 56 personal breathing zone samples of respirable crystalline silica exposures were collected at four different highway sites from four different cold-milling machine manufacturers. Three of the 12 personal breathing zone samples from the 2004 study in Wisconsin were below the limit of detection and the remaining nine ranged from 0.04 to 0.17 milligrams (mg) of respirable crystalline silica per cubic meter (m^3) of air [Echt et al. 2007]. Five of the 12 personal breathing zone samples from the 2006 study in Minnesota were below the limit of detection while the remaining 7 samples ranged from 0.02 to 0.06 mg/m^3 [Blade et al. 2006a]. All 22 personal breathing zone samples from the 2006 testing in South Dakota were below the limit of detection [Blade et al. 2009b]. The 10 personal breathing zone samples from the 2006 study in New York ranged from 0.016 to 0.36 mg/m^3 [Blade et al. 2009c].

(2) In addition to evaluating worker exposures using personal breathing zone sampling, controls were evaluated by measuring the reduction in respirable dust in area samples mounted to the cold-milling machines of five manufacturers. Between 2003 and 2010, testing of water-spray dust suppression controls indicated that raising the water flow rate of the milling-machine water-spray systems from

the “normal” rate to the maximum rate did not consistently reduce respirable dust concentrations by an appreciable and statistically significant amount. The data revealed appreciable reductions in some cases but not in others.

(3) The LEV control tested in 2008 resulted in reduction in respirable dust concentrations of approximately 60% when compared to the baseline respirable dust concentration on the same machine [Blade et al. 2011]. The LEV control tested in 2010 resulted in reduction in respirable dust concentrations of 80% at the medium air flow rate and 69% at the low air flow rate when compared to the baseline respirable dust concentration on the same machine [Hammond et al. 2011].

After the 2010 testing in Wisconsin, the Silica/Milling-Machines Partnership members decided to further develop and test LEV controls to achieve more consistent and statistically significant reductions in emissions of respirable dust and crystalline silica. The 2011 testing phase began with initial laboratory testing of the ventilation controls with future plans to conduct field testing to verify the laboratory results.

Methodology

Tracer Gas

Tracer gas is commonly used to evaluate capture efficiencies of local exhaust ventilation systems even when those systems are designed to control a hazard in particulate form. Tracer gas has been used to evaluate local exhaust on asphalt paving machines [Mickelson et. al. 1999], and to evaluate hoods designed to capture particles generated from grinding wheels [Fletcher, 1995]. Probably the most common application of tracer gas occurs in performance testing for laboratory fume hoods [ANSI/ASHRAE 1985] that are designed to capture both gases and particles.

Past NIOSH testing has resulted in the application of a model that uses tracer gas to evaluate local exhaust ventilation of mail-processing equipment [Beamer B, 2004]. The model for using tracer gas followed a thorough literature review which found multiple sources that indicated tracer gas is an appropriate evaluation method to test the capture efficiency of a hazard in particulate form. In ANSI/ASHRAE Standard 110-1985 the point is made that “fine dust, small enough to be of health significance will be carried along with the hood air currents in a fashion similar to the transport of a gas.” Hemeon, in “Plant and Process Ventilation,” states that “to control small particle motion, one must control the motion of the air in which the small particles are suspended [Hemeon, 1999].” In “Risk Assessment of Chemicals,” Leeuwen describes how “small particles tend to behave like gases [Leeuwen et al. 2007].” The most compelling study compared capture efficiencies measured by tracer gas and aerosol tracer techniques and concluded that the transfer of aerosol to a local exhaust system was “nearly identical to that of a gas” for particles with diameters less than 30 µm [Beamer D, 1998]. This indicates that tracer gas is a reasonable substitute for respirable crystalline silica particles that are capable of being inhaled deep into the lungs.

The tracer gas laboratory/factory methods used in this report were adopted from a document entitled *Engineering Control Guidelines for Hot Mix Asphalt Pavers* [NIOSH, 1997] and modified for asphalt milling machines. The test procedures are the result of a collaborative effort by industry, government, and labor to improve worker safety and health through the testing and implementation of engineering controls to prevent worker exposures. The procedures were adopted for use in the current study to evaluate the effect of different flow rates on tracer gas capture efficiency for the evaluated prototype LEV system. This was not a certification test.

Materials Equipment and Facilities

The following list describes the materials, equipment, and facilities used to conduct a laboratory/factory tracer gas test of the Terex PR600c cold-milling machine:

- Terex PR600c asphalt milling machine fitted with an LEV system
- Building with large opening (overhead door) to the outdoors and house exhaust ventilation system
- Smoke generator
    - Category 2 Hurricane Fog Machine, Chauvet USA, Hollywood, FL
- Smoke distribution pipe: 5.08 cm (2-inch), schedule 40 PVC, 2.4 meter (m) (8 feet) long, capped on one end, 6.35 millimeter (mm) (1/4-inch) diameter holes drilled in a line every 15.24 centimeters (cm) (6 inches) on center
- Tracer gas cylinder: Sulfur Hexaflouride (SF_6) CP-grade, 99.8% pure, with a Compressed Gas Association (CGA) 590 pressure regulator
- Zero air cylinder connected to a CGA-590 regulator
- SF_6 detectors: Required detection limit as low as 0.01 ppm and calibration curve as high as 15 ppm SF_6 with an accuracy of at least ± 0.01 ppm
    - Brüel & Kjær (B&K) multigas monitor type 1302
        - Sampling S/N: 1804892
        - Background S/N: 171524
    - Miran SapphIRe Model:205B-XL2A3S S/N: 205B80183-453
- Teflon tubing: 3.175 mm (1/8-inch) outside diameter, 6 m (20 feet) long
- Tracer gas distribution pipe: Copper pipe, 12.7 mm (1/2-inch) inside diameter, the same length as the cutter drum width, 0.8 mm (1/32-inch) diameter holes drilled in a line every 30.5 cm (12 inches) on center
- Polyethylene (PE) tubing: 6.35 mm (1/4-inch) outside diameter, 30.5 m (100 feet) long
- Aalborg mass flow controller: model GFC17, serial number 232901-1, range from 0-1000 ml/min, calibrated to SF_6
- Omega mass flow controller: Model: FMA5523, serial number 142242-2, with a range of 0-15 L/min, calibrated to nitrogen
- Sampling probe: Copper tubing, 6.35 mm (1/4-inch) outside diameter, 30.5 cm (12 inches) long , sealed at one end, 1.6 mm (1/16-inch) diameter holes drilled in a line every 2.54 cm (1 inch) on center starting 2.54 cm (1 inch) in from the sealed end (the number of holes depends on the diameter of the ventilation exhaust duct: a 20.32 cm (8-inch) exhaust duct would require the use of a sampling probe with seven 1.6 mm (1/16-inch) holes)
- Hot wire anemometer (Velocicalc Plus Anemometer, Model 8388, serial number 56080572, TSI Incorporated, P.O. Box 64394, St. Paul, Minnesota, 55164)

Process

The tracer gas evaluation of the prototype LEV system on a Terex PR600c asphalt milling machine was conducted on August 16-17, 2011 at the Terex Roadbuilding manufacturing facility in Oklahoma City, Oklahoma. The test was designed as a first step in determining the capture efficiency at different LEV flow rates of the prototype system. The test consisted of three main parts. First, Terex engineers used cardboard and plastic to simulate the level of gap-seal expected in a future production machine factory-equipped with an LEV control system. Second, a smoke test and visual inspection of the machine was conducted to ensure there were no obvious leaks in the system. Finally, tracer gas tests were conducted at the three LEV flow rates of 1300 actual cubic feet per minute (acfm), 900 acfm, and 600 acfm.

Environment Preparation

The milling machine was equipped with a front gradation plate, rear floating moldboard, and edge plates that are flush with the ground during normal milling operations. During this testing, wood blocks, cardboard, and plastic were placed inbetween the rear floating moldboard and the ground. Cardboard was placed between the front gradation plate and the ground. The edge plates were several inches above the ground to allow for the smoke and tracer gas test equipment to be positioned inside the cutter drum housing. Wood blocks and cardboard were used to fill in gaps under the edge plates, as shown in Figure 1.

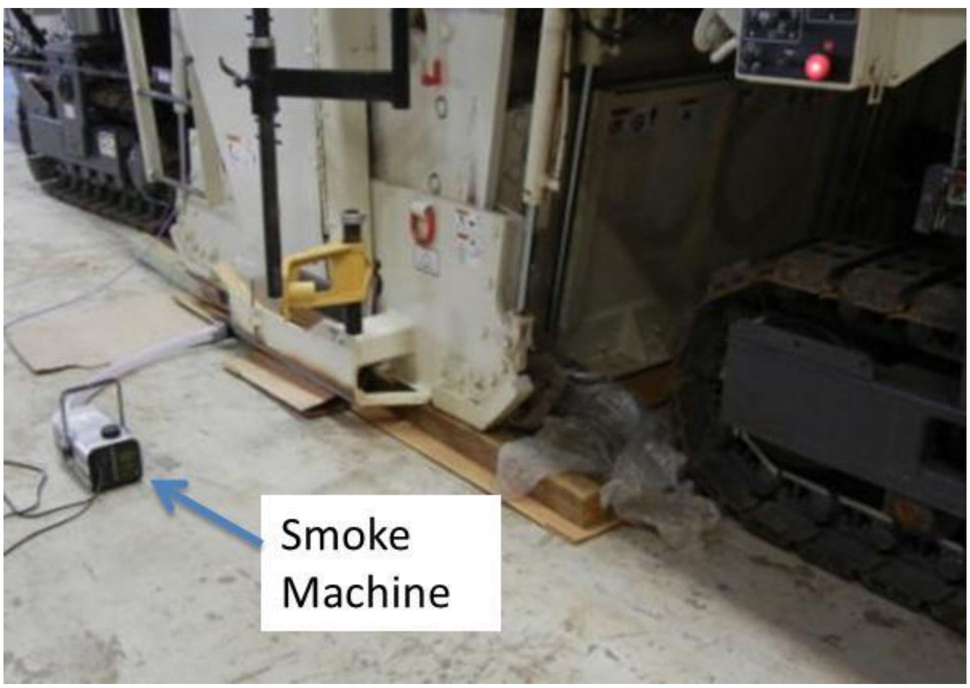

Figure 1: Wood blocks, cardboard, and plastic used to fill in gaps.

The prototype LEV system consisted of a gasoline powered fan connected to four 6-inch diameter flexible ducts that drew air from the cutter drum housing and primary conveyor locations of the Terex PR600c cold milling machine. The fan was located on the ground outside of the building to prevent researcher exposure to carbon monoxide from the gasoline engine. Terex engineers cut a hole in the wall of the building to route the flex duct to the fan as shown in Figure 2. A different fan will be mounted to the milling machine for the production version of the LEV design. The diesel exhaust from the milling machine was routed to the outside of the building using a building local exhaust system. Large open overhead doors and a building exhaust ventilation system provided general ventilation to prevent background levels of SF_6 from building up and affecting test results.

Figure 2: Fan and ductwork for prototype LEV testing.

Smoke Test

A smoke test was performed prior to the tracer gas test to visually check the system for leaks. Smoke was released from a Category 2 Hurricane fog machine under the cutter drum. The smoke was released through the PVC smoke distribution pipe. The pipe system was positioned just in front of the cutter drum with all of the holes inside the cutter drum housing. The configuration of the fog machine can be seen in Figure 1.

Smoke was released into the cutter drum housing with the cutter drum, and LEV system active. The system was visually inspected to determine if there were any visible leaks from within the cutter drum housing and primary conveyor areas or from the LEV exhaust system.

The sequence of the smoke test is outlined below:

- Verify that the smoke test will not set off a fire alarm or fire-suppression system.
- Place the smoke distribution pipe directly beneath the cutter drum and secure in a horizontal position.
- Connect the smoke generator to the distribution pipe.
- Clear the cutter drum area of any extraneous materials.
- Activate the LEV system, cutter drum and smoke generator.
- Ensure that smoke is not being re-entrained into the building.
- Inspect the LEV for unintended leaks at all fittings.
- Deactivate the LEV for a short time to simulate a no-control condition for comparison purposes.
- Deactivate the smoke generator and wait for smoke levels to subside. If desired, turn on additional exhaust ventilation to clear the room more quickly.
- Disassemble the test equipment.

Tracer Gas Test

Dosing

For the LEV efficiency test, sulfur hexaflouride tracer gas (minimum purity 99.8%) was released within the cutter drum housing of the milling machine via the tracer gas distribution pipe. One end of the pipe was capped and the other end had a quick-connect fitting. To represent 100% capture of the released tracer gas, a section of Teflon tubing with a quick-connect fitting on one end was placed directly into the duct system, as shown in Figure 3. The flow of tracer gas was controlled using an Aalborg mass flow controller calibrated for SF_6 and connected to a CGA-590 regulator and tracer gas cylinder using 6.35 mm (¼-inch) Teflon tubing and Swagelok® connections. A section of 6.35 mm (¼-inch) Teflon tube with Swagelok® fittings and a quick-connect fitting joined the outlet of the mass flow controller and the tracer gas release location in the duct representing 100% capture injection location in the cutter drum housing. A zero air cylinder connected to a regulator and controlled using an Omega mass flow controller set to 2.0 L/m was connected with Swagelok® fittings to the tracer gas dosing line to help flush the tracer gas through the system. A B&K multigas monitor was set up as an area monitor to check for any rise in background levels of SF_6 near the dosing area just outside of the cutter drum housing.

The SF_6 mass flow controller was set so that the resulting duct concentration was below the Miran SapphIRe maximum recommended upper limit of 4 ppm. The SF_6 mass flow controller was set to 130 ml/min, 100 ml/min, and 60 ml/min, for LEV flow rates of 1300 acfm, 900 acfm, and 600 acfm, respectively. This resulted in 100% capture concentrations of approximately 3.9 ppm at the 900 acfm flow setting and approximately 3.5 ppm for both the 1300 acfm and 600 acfm flow settings.

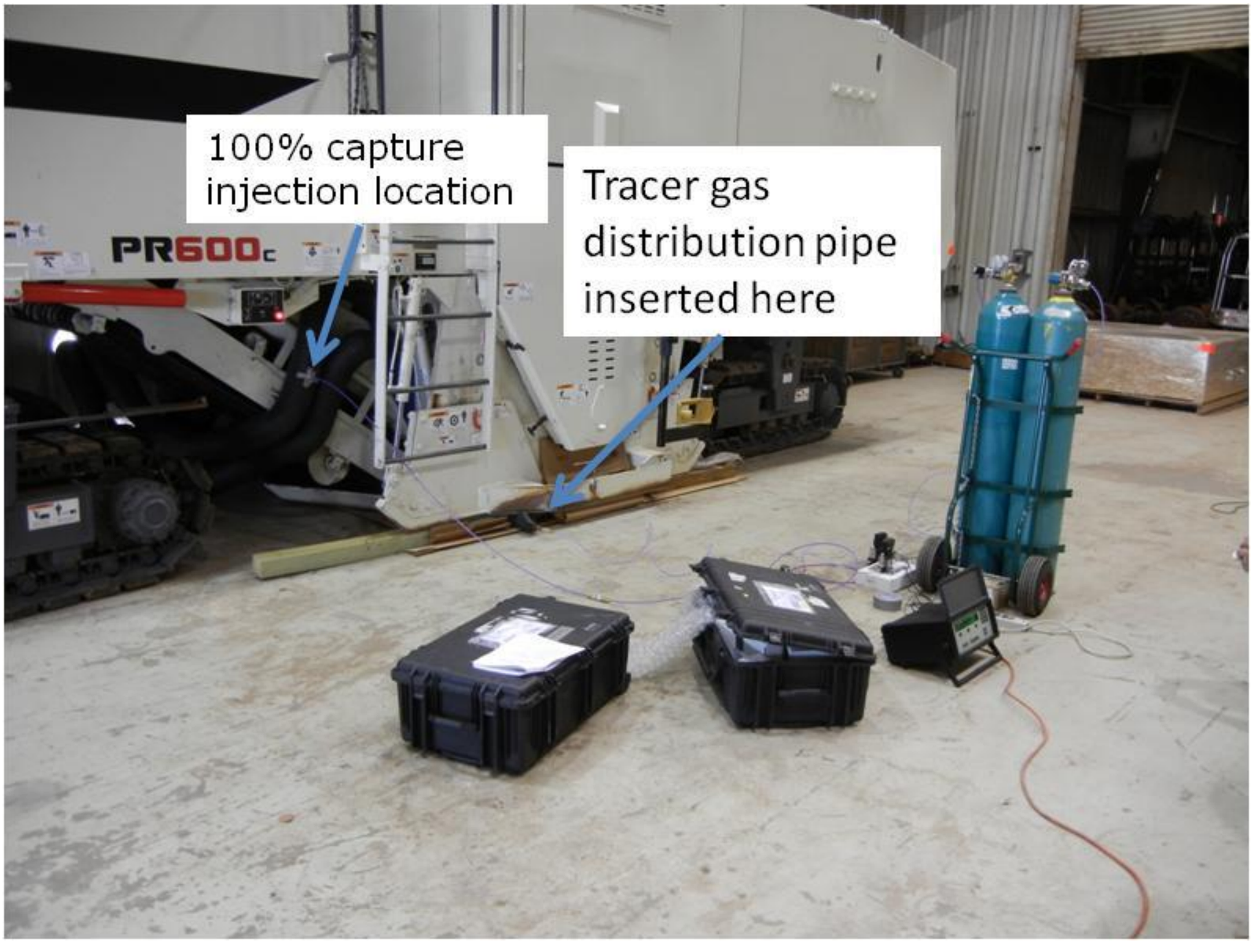

Figure 3: Tracer gas injection locations.

Sampling

Air sampling was performed by inserting the sampling probe perpendicular to the exhaust duct airflow downstream of the fan as shown in Figure 4. The air sample was drawn through the sampling probe to a tee-fitting where the sample was delivered through separate Teflon tubes to both the Miran SapphIRe and the B&K multigas monitor. The exhaust ports on each instrument were released to the outdoor atmosphere.

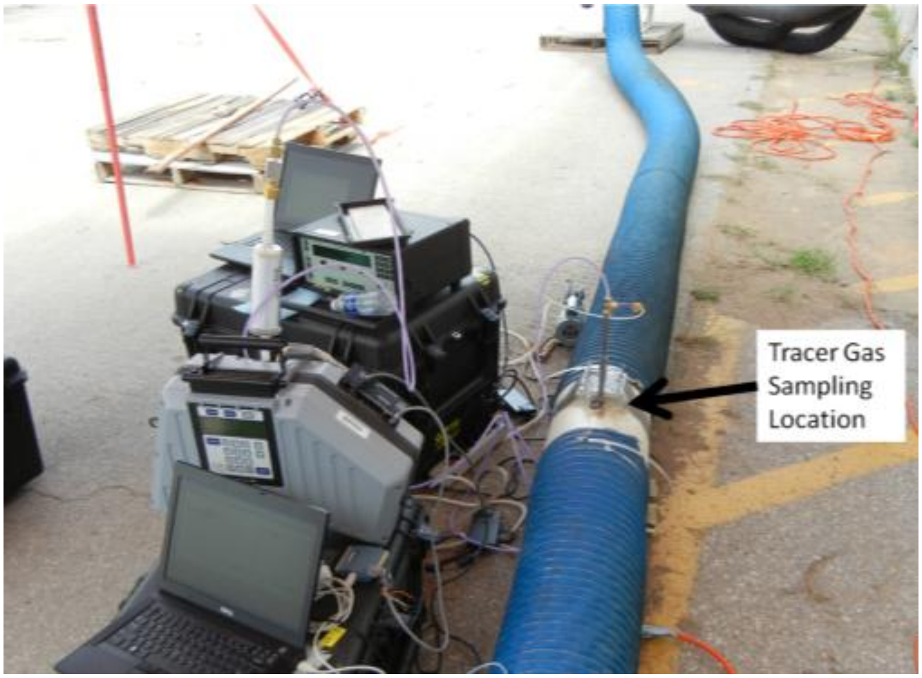

Figure 4: Sampling probe placement.

Test Procedure

To determine the capture efficiency of the system, sulfur hexafluoride was released into the ventilation system at one of two points; (1) directly into the exhaust duct system to ensure 100% capture of the gas; and (2) into the cutter drum housing area to simulate small dust particles generated during milling. The tracer gas concentration during each condition was measured downstream of the fan and a capture efficiency ratio was calculated by dividing the cutter drum housing release SF_6 concentration by the 100% capture SF_6 concentration. Gas was released until five-minutes of steady state values were recorded on both the B&K and Miran SapphIRe. The SF_6 gas was then shut off to allow the concentration in the system to decay between each release condition. The 100% capture and cutter drum housing release measurements were adjusted for any change in average background SF_6 concentration by subtracting the average five minute steady state background SF_6 measurement that immediately followed each test. The capture efficiency was determined from the background-adjusted average of the five-minute samples for each test using Equation 1.

$$\eta = \frac{C_{SF_6}}{C^*_{SF_6}} \times 100\% \qquad (1)$$

Where

η = the capture efficiency,
C_{SF_6} = the background-adjusted average concentration of SF_6 (parts per million) detected in the duct, and

$C^*_{SF_6}$ = the background-adjusted average concentration of SF_6 from the 100% capture test.

Control Technology

Description of tested dust-emission control configuration

The equipment evaluated during this laboratory study was a 600 hp Terex PR600c cold milling machine with a prototype LEV system consisting of a gas powered fan and four 6-inch diameter flex ducts. The LEV system was designed to create a negative pressure in the cutter drum housing and primary conveyor area and to exhaust the air away from any workers. The locations of the flexible duct systems are shown in Figures 5 and 6. Terex engineers placed cardboard and plastic in multiple locations around the cutter drum housing and primary conveyor of this prototype LEV design to simulate the amount of open area anticipated in a future production LEV design. A significant cardboard and plastic obstruction was also placed into the area at the top of the primary conveyor where reclaimed asphalt pavement (RAP) would normally dump onto the secondary conveyor. The obstruction (shown in Figure 7) was intended to simulate a check valve or hard rubber seal that Terex engineers are designing to fill in the air gap around the flow of RAP in the primary conveyor for the production LEV design. A small piece of cardboard was removed during the final test to simulate a worn check valve.

Figure 5: LEV exhaust locations along the left side of the primary conveyor.

Figure 6: LEV exhaust locations along the right side of the primary conveyor.

Figure 7: Obstruction stuffed in the outlet of the primary conveyor.

Results

Smoke Evaluations

The smoke test evaluation provided qualitative information about the integrity of the test set up and to check for any obvious leaks in the cutter drum housing before conducting tracer gas capture tests. No smoke was observed around the machine when smoke was released in the cutter drum housing area with the prototype LEV system operating. Smoke was observed leaking out of the cutter drum housing when the prototype LEV system was turned off.

Tracer Gas Results

Tracer gas capture efficiency results were calculated using both the B&K and the Miran SapphIRe data. The two tracer gas analyzers were both calibrated to SF_6. Results from the four individual capture efficiency trials at 900 acfm along with the average and lower 95% confidence limit are provided in Table 1. Confidence limits were not calculated for the remaining data presented in Table 2 since only two trials were performed at 1300 acfm and 600 acfm and only one trial was performed with a simulated worn check valve at 900 acfm. Every effort was made to hold all conditions constant from trial to trial. Results using the two instruments were very similar and differences were 1.1% or less for all trials. The mean capture efficiency at the 900 acfm flow rate from the B&K and Miran SapphIRe data were 99.7% and 99.9%, respectively. The lower 95% confidence limits at the 900 acfm flow rate were 99.3% and 99.7% for the B&K and Miran SapphIRe results, respectively.

Table 1: Tracer gas capture efficiency at 900 acfm.

Trial	Capture Efficiency (B&K)	Capture Efficiency (Miran SapphIRe)
1 (900 acfm)	99.5%	100%
2 (900 acfm)	99.3%	99.6%
3 (900 acfm)	99.8%	100%
4 (900 acfm)	100%	100%
Average	99.7%	99.9%
Lower 95% confidence limit	99.3%	99.7%

Table 2: Tracer gas capture efficiency data at 1300 acfm, 600 acfm, and 900 acfm.

Trial	Capture Efficiency (B&K)	Capture Efficiency (Miran SapphIRe)
1 (1300 acfm)	100%	100%
2 (1300 acfm)	100%	100%
1 (600 acfm)	97.1%	98.2%
2 (600 acfm)	97.0%	97.4%
1 (900 acfm)*	99.2%	100%

*A worn check valve was simulated during this test by removing a small piece of cardboard from the outlet of the primary conveyor.

Conclusions and Recommendations

Based on the laboratory test results, the Terex PR600c prototype LEV design has potential to significantly reduce worker exposure to respirable crystalline silica (originating from the cutter drum and primary conveyor areas) during asphalt pavement milling operations. The wind speed, silica dust emission rate, work practices of individuals, dust emissions from sources other than the evaluated cutter drum housing, percent open area of the final production design, and other factors may affect actual reductions in occupational exposures outside of the laboratory/factory setting.

The following general recommendations are provided for consideration as improvements to the evaluated prototype LEV design:

- The prototype LEV system on the Terex PR600c cold milling machine was evaluated at three flow rates of 1300 acfm, 900 acfm, and 600 acfm. Engineers should consider the pressure drop through the flex duct and LEV system when sizing the fan for the production version of the machine. A fan nominally rated at 1300 acfm might produce appreciably less air flow when connected to long runs of flex duct which creates a high pressure drop. It is recommended to use smooth rigid duct work and eliminate elbows and long runs wherever possible to reduce the pressure drop through the LEV system.
- This testing only evaluated prototype LEV capture efficiency from the cutter drum housing area of the Terex PR600C cold milling machine. The check valve design concept at the top of the primary conveyor likely increased capture in the drum housing but may potentially decrease capture from the transition between the two conveyors. Based upon qualitative observations made in the field, it is recommended that Terex engineers consider adding LEV controls to the transition area between the primary and secondary conveyor of the production LEV design since this transition area is near the operator and may present a secondary source of dust generation. Transition area covering and sealing varies between manufacturers. Field testing should help determine if ventilation is required in this area for various milling machine manufacturers.
- Dust will also be released at the outlet of the LEV system. It is recommended that the discharge outlet of the production LEV design be oriented and located far away from operator and worker locations. Engineers should also consider the feasibility of adding cyclonic or other filtration provisions to remove dust from the LEV airstream.
- The testing described in this report was performed on a prototype LEV design indoors under ideal laboratory/factory conditions. Additional NIOSH laboratory testing is recommended on the actual production version of the LEV design. After the additional laboratory/factory testing is performed, field testing is also recommended to benchmark the LEV performance results under actual asphalt milling operations.

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