In-Depth Survey Report

A Laboratory Evaluation of a Local Exhaust Ventilation System on a Roadtec Cold Milling Machine at Roadtec, Chattanooga, Tennessee

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

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Abstract

In April 2012, National Institute for Occupational Safety and Health (NIOSH) researchers and the Silica/Milling-Machines Partnership coordinated by the National Asphalt Pavement Association (NAPA) conducted laboratory testing of a local exhaust ventilation (LEV) system on a Roadtec RX600e cold milling machine. The testing was conducted indoors at the Roadtec manufacturing facility in Chattanooga, Tennessee.

All tests were conducted on a stationary milling machine with the cutter drum and conveyor belts moving, but without any reclaimed asphalt pavement (RAP) moving through the 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, an Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and a Miran SapphIRe infrared spectrometer.

Capture efficiency tests were conducted at a single flow rate on the Roadtec cold milling machine. The mean capture efficiency from the Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and Miran SapphIRe data were 98% and 99%, respectively. The lower 95% confidence limits were 97% for both the Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and Miran SapphIRe results. 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 actual field operation.

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 controls during asphalt pavement-milling operations. Pavement-milling is the process of removing the road surface for recycling. The 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 best practice guidelines for engineering controls on asphalt pavement milling machines.

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 study.

The large cold-milling machine evaluated during this study was a Roadtec RX600e with a 620 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 Roadtec RX600e cold-milling machine also had a local exhaust ventilation (LEV) system to capture dust generated in the cutter drum housing and remove the dust from worker locations.

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 and conveyor belts spinning, but without any reclaimed asphalt pavement (RAP) moving through the system.

This study was 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), the Laborers' International Union of North America (LIUNA), NIOSH, and other interested parties.

Methodology

Tracer Gas

Tracer gas is commonly used to evaluate capture efficiencies of LEV 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 LEV 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 an LEV 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 (<10µm in diameter) 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 titled *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 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 Roadtec RX600e cold-milling machine:

- Roadtec RX600e serial number 2010 cold milling machine with an LEV system
- Building with large opening (overhead door) to the outdoors and materials to seal off the conveyor around the opening.
- 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
    - Innova 1412 Photoacoustic Field Gas-Monitor Model 1412A, S/N 710-501 (California Analytical Instruments, Orange, California) (the Innova 1412A is a similar instrument to the B&K, just a newer generation)
    - Brüel & Kjær (B&K) multigas monitor type 1302
        - 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 (Aalborg, Orangeburg, New York) model GFC17, serial number 232901-1, range from 0-1000 ml/min, calibrated to SF_6
- Omega mass flow controller (Omega, Inc.,Stamford, Connecticut): Model: FMA5514, serial number 203906-1, with a range of 0-1000 ml/min, calibrated to nitrogen
- Sampling probe: Two 3 meter (10 foot) sections of polyethylene (PE) tubing: 6.35 mm (1/4-inch) outside diameter, seven 2.4 mm (3/32-inch) diameter holes drilled in a line every 6.35 mm (1/4 inch) on center starting 5.08 cm (2 inches) in from the end placed in each 10.1 cm (4 inch) diameter duct.
- Hot wire anemometer (Velocicalc Plus Anemometer, Model 8388, serial number 56080572, TSI Incorporated, St. Paul, Minnesota)

Process

The test consisted of three main parts. First, Roadtec engineers set up the machine to simulate the amount of open area that would be present during a milling job and positioned the machine for testing. Second, a smoke test and visual inspection of the machine was conducted to ensure there were no obvious leaks in the LEV duct system. Finally, tracer gas tests were conducted at a single flow rate.

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. For this testing, materials were placed under and around the drum housing to accommodate test equipment and fill in gaps that would normally be blocked by RAP during pavement milling operations. Foam was placed in between the rear floating moldboard and the ground. Foam was also 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 tape were used to fill in gaps under the edge plates, as shown in Figure 1.

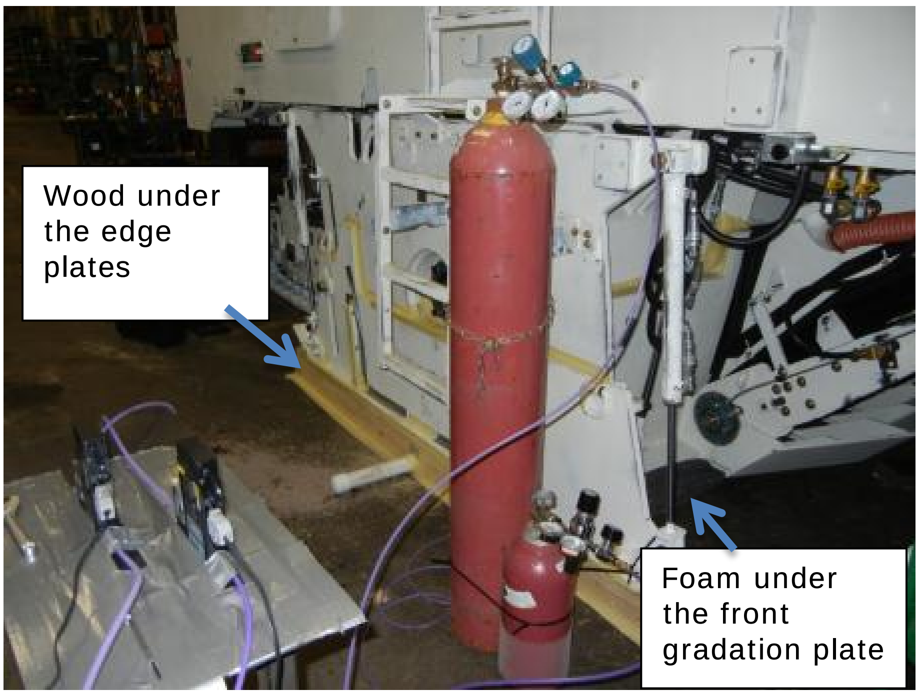

Figure 1: Wood, tape, and foam used to fill in gaps.

The LEV duct system consisted of a 7-HP Ilmeg hydraulic powered fan that drew air from two locations in the drum housing and two locations near the top of the primary conveyor of the cold milling machine. The fan was integrated into the machine in front of the operator location just before the conveyor. The outlet to the fan was connected to a single 6-inch diameter straight flexible duct that branched into two 4-inch diameter flexible ducts leading to rigid 4-inch diameter pipes that exhausted at the end of the secondary conveyor. The end of the secondary conveyor was placed through the opening of a large overhead door, and the remaining door opening was sealed off as shown in Figure 2 to prevent background levels of SF_6 from building up and affecting test results.

Figure 2: Outlet of the LEV system through the overhead door

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 through the PVC smoke distribution pipe under the cutter drum. The pipe system was positioned under the cutter drum with all of the holes inside the cutter drum housing.

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, SF_6 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 LEV hood, 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 1.0 L/m was connected with Swagelok® fittings to the tracer gas dosing line to help flush the tracer gas through the LEV duct system. A B&K multigas montior (similar to the Innova multigas monitor) was set up as an area monitor to check for any rise in background concentrations of SF_6 near the dosing area just outside of the cutter drum housing.

The flow was set using a speed controller on the fan and measuring the centerline velocity pressure of each 4-inch duct with a Dwyer pitot tube, applying a correction factor of 0.9, and multiplying by the resulting velocity and by the cross-sectional area based on the 3.75-inch inside diameter of each of the two pipes to calculate air flow. The right and left duct velocity pressure readings were 1.95 and 1.98 inches of water, respectively. The use of a centerline velocity pressure reading and the 0.9 correction factor was recommended in the instructions that were supplied with the Dwyer pitot tube and is a common industrial ventilation practice for an approximate estimation of duct velocity. The SF_6 mass flow controller was set so that the resulting duct concentration was below the Miran SapphIRe upper limit of 4 ppm. The SF_6 mass flow controller was set to 70 ml/min. This resulted in 100% capture concentrations of approximately 3.3 ppm.

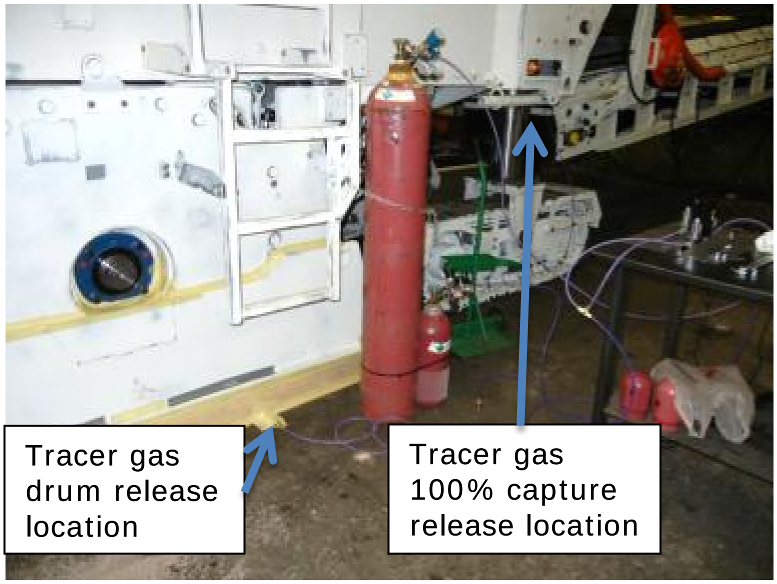

Figure 3: tracer gas injection locations

Sampling

Air sampling was performed by inserting the sampling probes perpendicular to the airflow downstream of the fan in each 4-inch diameter exhaust duct 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 Innova AirTech Instruments 1412 Photoacoustic field gas-monitor (similar instrument to the B&K). The exhaust ports on each instrument were released to the outdoors.

Figure 4: Tracer gas sampling location

Test Procedure

To determine the capture efficiency of the LEV duct system, SF_6 was released at one of two points; (1) directly into the LEV duct system to ensure 100% capture of the gas; and (2) into the cutter drum housing 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 SF_6 concentration released in the cutter drum housing by the 100% capture SF_6 concentration. Gas was released until five-minutes of steady state values were recorded on both the Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and Miran SapphIRe. The SF_6 gas was then shut off to allow the concentration in the LEV duct 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 study was a Roadtec RX600e cold milling machine with an 86-inch cutter drum and a diesel engine that provides 620 HP at 1850 rpm. The Roadtec RX600e was fitted with an LEV system consisting of a hydraulic powered 7 horsepower (hp) Ilmeg fan connected to a 6-inch diameter duct leading to a manifold that split the flow into two 4-inch diameter ducts that exhausted air at the top of the secondary conveyor. The LEV system was designed to create a negative pressure in the primary conveyor area and to exhaust the air away from any workers. The locations of the fan and ducts are shown in Figures 5 and 6.

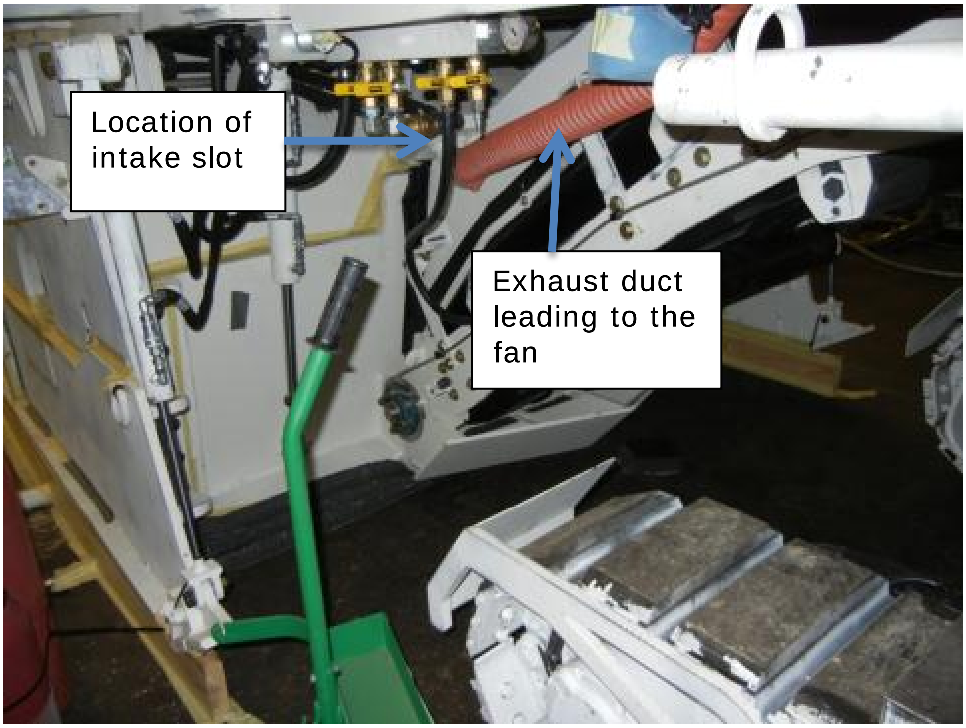

Figure 5: LEV air intake at the bottom of the primary conveyor

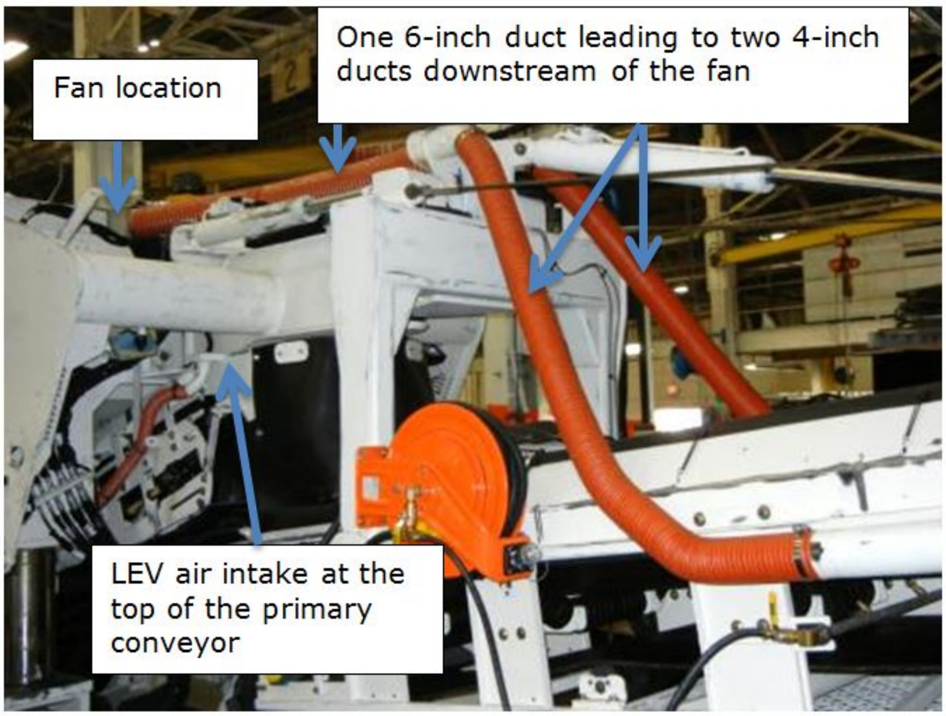

Figure 6: LEV air intake at the top of the primary conveyor.

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 LEV system operating. Smoke was observed leaking out of the front of the cutter drum housing when the LEV system was turned off.

Tracer Gas Results

Tracer gas capture efficiency results were calculated using both the Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and the Miran SapphIRe data. The tracer gas analyzers were both calibrated to SF_6. Results from the five individual capture efficiency trials with the average concentration and lower 95% confidence limit are provided in Table 1. 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% or less for all trials. The mean capture efficiency from the Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and Miran SapphIRe data were 98% and 99%, respectively. The lower 95% confidence limits were 97% for both the Innova AirTech Instruments 1412 Photoacoustic field gas-monitor and Miran SapphIRe results.

Table 1: Tracer gas capture efficiency.

Trial	Capture Efficiency (Photoacoustic monitor)	Capture Efficiency (Miran SapphIRe)
1	99%	100%
2	99%	99%
3	98%	99%
4	96%	95%
5	100%	100%
Average	98%	99%
Lower 95% confidence limit	97%	97%

Conclusions and Recommendations

Based on the laboratory test results, the LEV design on the Roadtec RX600e has the potential to significantly reduce worker exposure to respirable crystalline silica (originating from the cutter drum and primary conveyor areas) during 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 and airflow conditions inside the drum housing with RAP moving through the conveyor system, 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 potential improvements to the evaluated LEV design:

- The LEV system on the Roadtec RX600e cold milling machine was evaluated at a single flow rate. A higher flow rate may be feasible using the same fan by further reducing pressure losses through the system. The current transition from a single 6-inch duct to two 4-inch ducts downstream of the fan should be replaced with a smooth Y-transition. Also, consider if portions of the four flexible ducts on the inlet side of the fan, such as the one shown in Figure 7, could be replaced by smooth straight rigid duct to eliminate pressure losses from bends in flexible duct and losses due to added length of flexible duct.

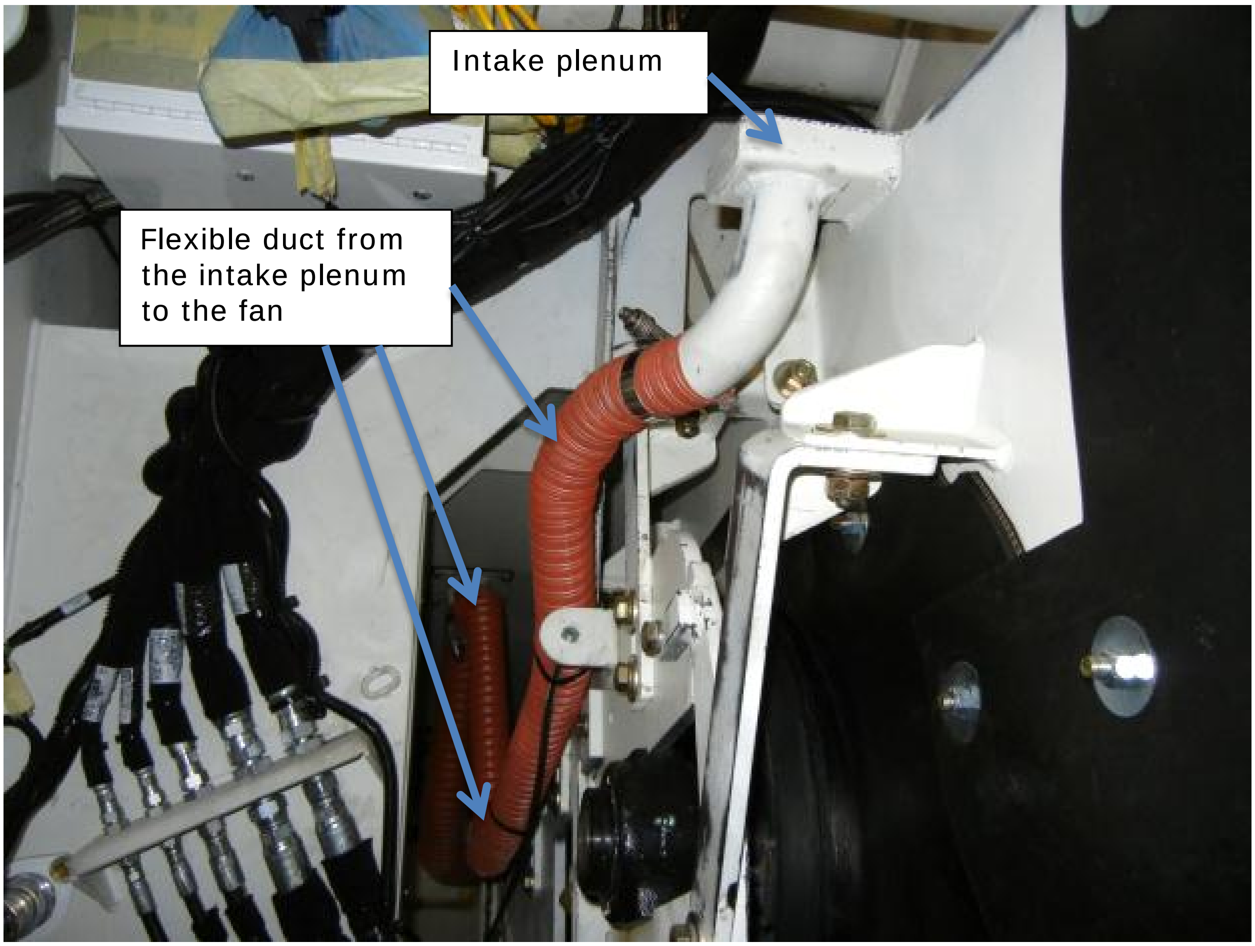

Figure 7: Flexible duct on the suction side of the fan

- Roadtec engineers designed the LEV system to have a minimum transport velocity to prevent dust from settling and plugging the flow. This design velocity is also within the range of minimum duct design velocities recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) (ACGIH 2010). However, velocities alone may not be enough to prevent plugging. It may also be important to prevent rocks and larger particles from entering the dust collection system. Consider placing a screen, wire mesh or other more suitable material at a distance around the intake slots (but not directly against the slots) to prevent larger particles from entering the dust collection system. It may also be necessary to increase the number, length, and/or open area of intake slots to reduce the capture velocity at the intake slots while still providing negative pressure to the enclosure and maintaining the minimum transport velocity in the ducts. A reduced capture velocity at the slot may help prevent larger particles from entering the slot and reduce pressure losses while still allowing for a minimum transport velocity once air enters the duct. Verify that any changes do not reduce the flow rate through the LEV duct system.

- The testing described in this report was performed on an LEV design indoors under ideal laboratory/factory conditions. Additional field testing is also recommended to verify the LEV performance results under actual asphalt milling operations.

Acknowledgements

The authors would like to thank management and staff at Roadtec for their gracious hospitality and assistance during this testing at the Roadtec manufacturing facility in Chattanooga, Tennessee. Their commitment to the development and testing of engineering controls to reduce occupational exposures to respirable crystalline silica is important to protect worker safety and health.

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