In-Depth Survey Report

A Laboratory Evaluation of a Local Exhaust Ventilation System on a Caterpillar Cold Milling Machine at Caterpillar, Minnesota

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 August 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 Caterpillar PM200 cold milling machine. The testing was conducted indoors at a Caterpillar facility in Minnesota.

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 the capture efficiency of tracer gas released in the cutter drum housing of the machine. A Miran SapphIRe infrared spectrometer was used to measure the resulting SF_6 concentrations in the LEV exhaust duct.

Capture efficiency tests were conducted at four flow rates of 1,675 actual cubic feet per minute (acfm), 1,450 acfm, 1,250 acfm, and 980 acfm with mean capture efficiency results of 98.1%, 97.5%, 94.7%, and 88.6%, respectively. Additional testing during actual milling activities is recommended to document capture efficiency under true field conditions.

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. Pavement-milling is the process of removing the road surface for recycling. 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 dust 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-Khanzadeh 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. The current study is helping to fill that knowledge gap.

A variety of machinery is 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 Caterpillar PM200 with a 575 horsepower (HP) diesel engine and a 2 m (79-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 Caterpillar PM200 cold-milling machine also had a LEV system to capture dust generated in the cutter drum housing and in the conveyor transition area of the machine.

This laboratory/factory research evaluated the performance of the local exhaust ventilation (LEV) system 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 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), 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 LEV 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 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 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 *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 Caterpillar PM200 cold-milling machine:

- Caterpillar PM200 cold milling machine with an LEV system
- Large building with building exhaust ventilation system
- Smoke generator
    - Regin Smoke Emitters (90 Second- Part# S103, 3-min- Part# S104, Regin HVAC Products, Inc., Oxford, CT)
- Tracer gas cylinder: Sulfur hexafluoride (SF_6) Chemically Pure (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
    - Miran SapphIRe (model 205B-XL2A3S, Thermo Environmental Instruments, Franklin, MA)
- High efficiency particulate air (HEPA) capsule filter (model 12127, Gelman Sciences, Inc., Ann Arbor, MI).
- External pump: high-volume rotary vane pump (model ZHV00, Zefon International, Inc. Ocala, FL)
- Teflon tubing: 3.175 mm (1/8-inch) outside diameter, 6 meters (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
- Teflon tubing: 6.35 mm (1/4-inch) outside diameter, 30.5 m (100 feet) long
- Mass flow controller (model GFC17, Aalborg, Orangeburg,NY), range from 0-5,000 milliliter/minute (ml/min), calibrated to nitrogen, K Factor for SF_6 relative to nitrogen of 0.2635
- Mass flow controller (model GFC37, Aalborg, Orangeburg,NY) range of 0-20,000 mL/min, calibrated to nitrogen
- Sampling probe: Two 3 m(10 foot) sections of 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 duct
- Hot wire anemometer (Velocicalc Plus Anemometer, Model 8388, TSI Incorporated, St. Paul, MN)

Process

The test consisted of three main parts. First, Caterpillar 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 (SF_6) tests were conducted at four fan speeds.

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 the drum housing to accommodate test equipment. Wooden boards were placed in between the rear floating moldboard and the ground. Wooden boards were also placed between the front gradation plate and the ground. The edge plates were several inches above the ground to allow for tracer gas test equipment to be positioned inside the cutter drum housing. Wooden boards were used to fill in gaps under the edge plates, as shown in Figure 1.

Smoke Test
A qualitative smoke test was performed prior to the tracer gas test to visually check the system for leaks. Smoke was released from smoke bombs in 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 the cutter drum housing and primary conveyor areas or from the LEV 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
- Activate the LEV system, cutter drum and belts
- Light and place the smoke bombs directly beneath the cutter drum
- Inspect the LEV system for unintended leaks at all fittings
- Deactivate the LEV system for a short time to simulate a no-control condition for comparison purposes

Tracer Gas Test

Dosing
To test the efficiency of the LEV system, SF_6 tracer gas 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 duct, as shown in Figure 2. The flow of tracer gas was controlled using a mass flow controller 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. A zero air cylinder connected to a regulator and controlled using a mass flow controller set to 2 L/min was connected with Swagelok® fittings to the tracer gas dosing line to help flush the tracer gas through the tracer gas distribution pipe.

Testing was conducted at four fan speeds of 3,500, 3,000, 2,500, and 2,000 revolutions per minute (rpm) roughly corresponding to volumetric flow rates through the LEV system of 1,675, 1,450, 1,250, and 980 acfm, respectively. The flow rates were determined by releasing a known mass flow of tracer gas directly into the duct and measuring the concentration of tracer gas at a well-mixed location downstream in the same duct. Duct velocities were also calculated by dividing the flow rate by the by the cross-sectional area of each of the two pipes. The mass flow controller for the SF_6 was set so that the resulting duct concentration was below the Miran SapphIRe upper limit of 4 ppm for each evaluated fan speed.

Sampling

Air sampling was performed by inserting the probes perpendicular to the airflow upstream of the fan in each duct as shown in Figure 2. The air sample was drawn through Teflon tubes from each duct to a tee-fitting then to a single Teflon tube. The air was then filtered to remove dust and then pulled through a Miran SapphIRe, using an external pump at approximately 30 L/min. The exhaust port on the instrument was released to the outdoors.

Velocity Measurements

Approximate air velocities through each section of flexible duct were measured using a hot-wire anemometer (Velocicalc Plus Anemometer, Model 8388, TSI Incorporated, P.O. Box 64394, St. Paul, Minnesota, 55164). Air velocities through the duct were also calculated using the volumetric flow rate based on the dilution concentration of SF_6 in the duct and dividing by the cross-sectional area.

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 just upstream 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 three-minutes of steady state values were recorded on 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 steady state background SF_6 measurement that immediately followed each test from the average steady state capture concentration. The capture efficiency was determined from the background-adjusted average of the three-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 (ppm) 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 Caterpillar PM200 cold milling machine with a 2 m (79-inch) cutter drum and a diesel engine that provides 429 kilowatt (kW) (575 horsepower (hp)) at 1900 rpm. The Caterpillar PM200 was fitted with an LEV system consisting of a hydraulic powered fan located on the secondary conveyor. The suction side of the fan was connected to two ducts each connected to a manifold that further split the flow and drew air from the drum housing and the conveyor transition area. The outlet to the fan was not connected to any duct and exhausted air into the room. A house LEV system was placed several feet away from the fan outlet to prevent the tracer gas concentration from building up in the room. The LEV system was designed to create a negative pressure in the drum housing and conveyor transition areas and to exhaust the air away from any worker locations.

Results

Smoke Evaluations

The smoke test evaluation provided qualitative information about the integrity of the test set up and checked for any obvious leaks in the cutter drum housing before tracer gas capture tests were conducted. No smoke was observed around the machine when a single smoke bomb was released in the cutter drum housing area with the LEV system operating. A very small smoke leak was observed from the side of the cutter drum housing when three larger smoke bombs were released in the cutter drum housing. Smoke release observations indicated very good containment by the LEV system of the PM200.

Tracer Gas Results

Results from the individual capture efficiency trials at each evaluated flow rate along 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. Mean capture efficiency results at flow rates of 1,675 acfm, 1,450 acfm, 1,250 acfm, and 980 acfm were 98.1%, 97.5%, 94.7%, and 88.6%, respectively.

Conclusions and Recommendations

Based on the laboratory test results, the LEV design on the Caterpillar PM200 has the potential to significantly reduce worker exposure to respirable crystalline silica (originating from the cutter drum and conveyor transition areas) during pavement milling operations. The wind speed, silica dust emission rate, work practices of individuals, and dust emissions from sources other than the evaluated milling machine 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 Caterpillar PM200 cold milling machine was evaluated at four fan speeds and flow rates. A higher flow rate may be achievable at each fan speed by further reducing static pressure losses through the system. Use smooth-walled fixed duct where possible and eliminate any unnecessary elbows or duct length. Use flexible duct only where necessary and use duct with a smooth interior wall for minimal air flow resistance.
- Minimum duct design velocities are recommended by the American Conference of Governmental Industrial Hygienists (ACGIH®) in Table 5-1 of the Industrial Ventilation Manual. Duct velocities of “4500 fpm and up” are recommended for heavy or moist dusts [ACGIH® 2010].
- Velocities alone may not be enough to prevent plugging. It may also be important to provide a clean-out door or other means to periodically clean dirt from elbows or other locations that are likely to plug.
- 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

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Table 1: Capture efficiency at different fan speeds and flow rates

Fan Speed (RPM)	Air Flow (CFM)	Trial 1	Trial 2	Trial 3	Mean	Lower 95% confidence limit
3,500	1,675	100.0%	97.0%	97.4%	98.1%	95.7%
3,000	1,450	99.4%	99.4%	93.8%	97.5%	95.1%
2,500	1,250	95.6%	93.3%	95.3%	94.7%	92.3%
2,000	980	87.5%	91.3%	87.0%	88.6%	86.2%

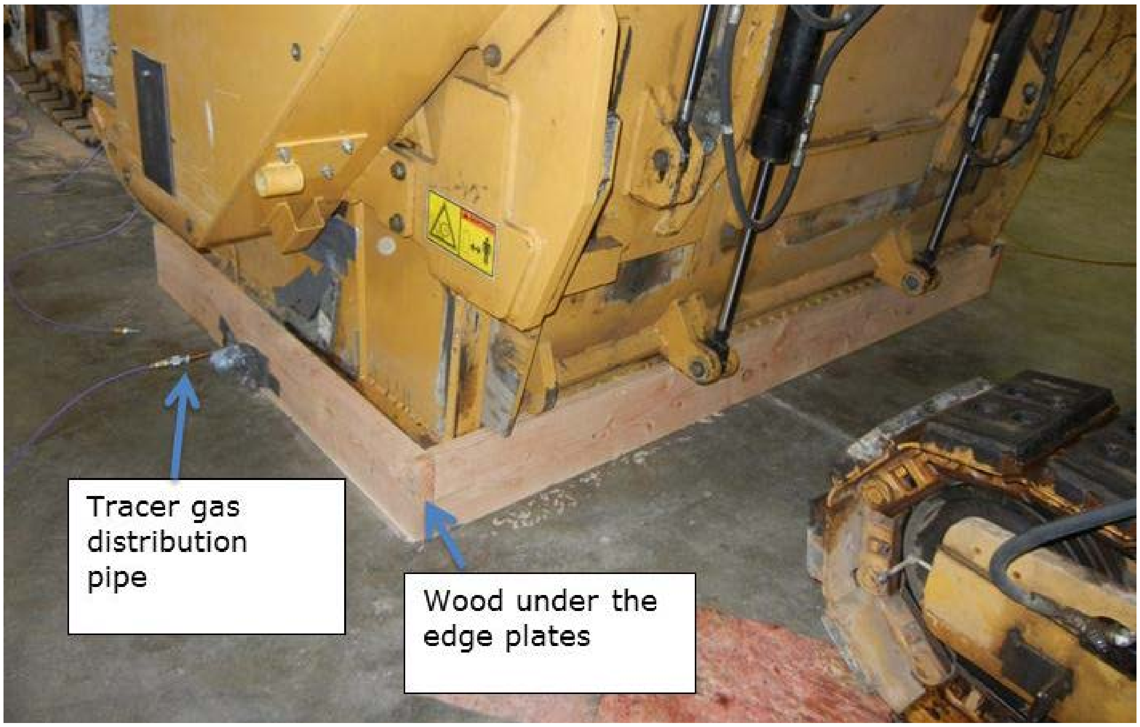

Figure 1: Wood used to fill in gaps for test.

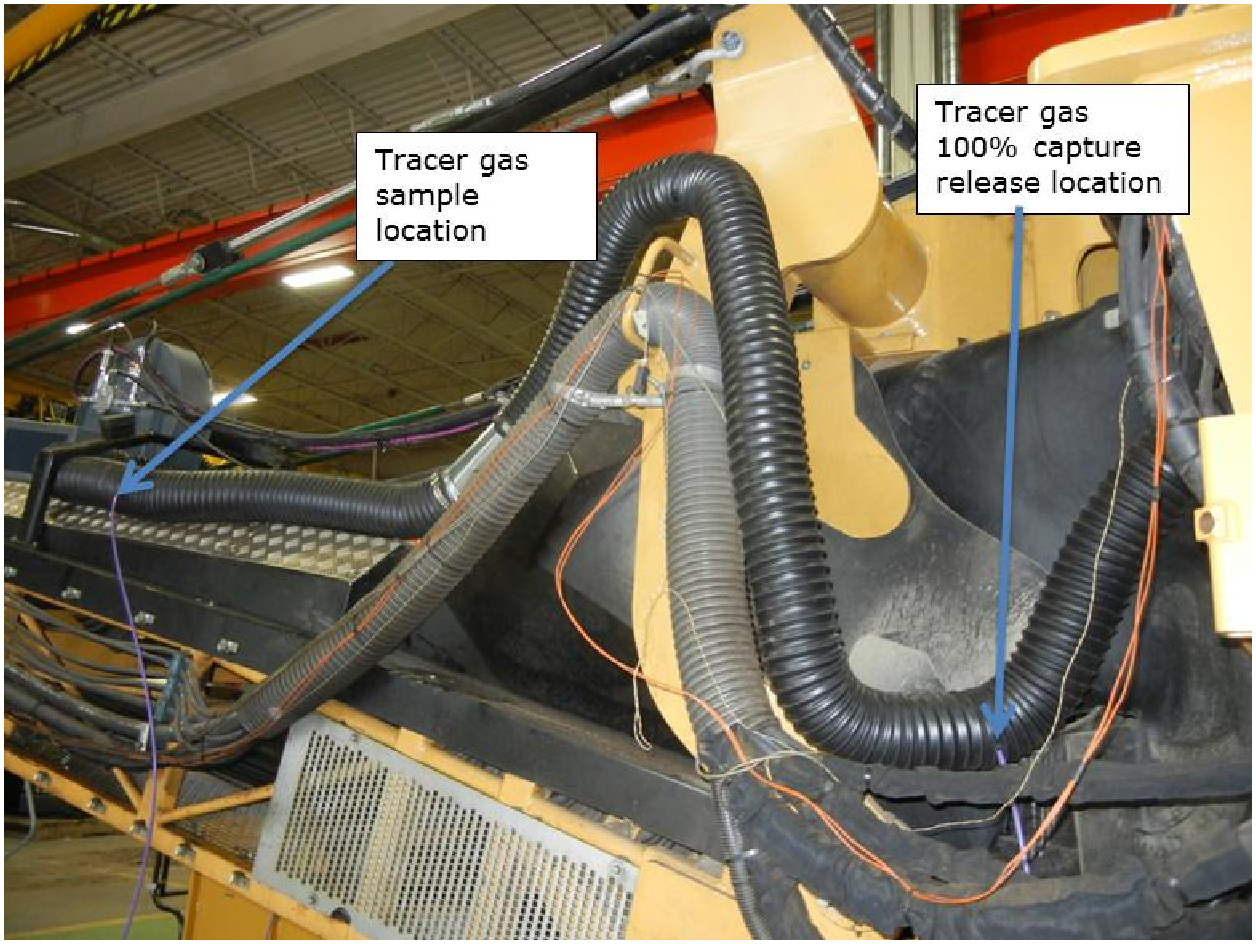

Figure 2: Tracer gas sampling and 100% release locations

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