Applied Occupational and Environmental Hygiene
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/uaoh20

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Available online: 30 Nov 2010

To cite this article: Alan Echt, Karl Sieber, Erica Jones, Donald Schill, Daniel Lefkowitz, Joseph Sugar & Ken Hoffner (2003): Control of Respirable Dust and Crystalline Silica from Breaking Concrete with a Jackhammer, Applied Occupational and Environmental Hygiene, 18:7, 491-495

To link to this article: http://dx.doi.org/10.1080/10473220301453

Applied Occupational and Environmental Hygiene, 18: 491–495, 2003
ISSN: 1047-322X print / 1521-0898 online
DOI: 10.1080/10473220390192827

Case Studies

Control of Respirable Dust and Crystalline Silica from Breaking Concrete with a Jackhammer

Dawn Tharr, Column Editor

Reported by Alan Echt, Karl Sieber, Erica Jones, Donald Schill, Daniel Lefkowitz, Joseph Sugar, and Ken Hoffner

The Engineering and Physical Hazards Branch (EPHB) of the National Institute for Occupational Safety and Health (NIOSH) has been given the lead within NIOSH to study and develop engineering controls and assess their impact on reducing occupational illness. The objective of each of these studies has been to evaluate and document control techniques and to determine their effectiveness in reducing potential health hazards in a specific industry or for a specific process. The goal of the project reported in this article was to quantify the exposure reduction that could be achieved through the use of a water-spray attachment and two different tool-mounted local exhaust ventilation shrouds during concrete pavement breaking with jackhammers. In this case, the water-spray attachment consisted of a spray nozzle (of the type used with oil-burning furnaces) and associated hoses and fittings. Water was supplied by a pressurized tank mounted on the air-compressor trailer. The local exhaust ventilation (LEV) included an off-the-shelf shroud typically used with hand-held rock drills and a custom-made shroud. The same dust collector (one sold for use with the rock-drill hood) was used for both LEV attachments.

Background

This study evaluated the effectiveness of LEV and water-spray controls. Two different LEV controls were tested. The first (see Figure 1) was an off-the-shelf rock-drill dust control shroud (Suction Hood PN 3214 2203 00, Atlas Copco Construction Mining Technique USA, Inc., Commerce City, CO). This shroud is intended to lie flat on the work surface, while the bit of the pneumatic tool is inserted through the shroud into the work surface below. The shroud is split to allow for easy insertion and removal of the bit. Air is exhausted through a take-off in the side of the shroud, parallel to the plane of the work surface. To prevent the shroud from climbing the jackhammer bit during use, a length of 4-inch-diameter corrugated black plastic drainage pipe was placed between the shroud and the jackhammer and secured with duct tape.

FIGURE 1
The rock-drill shroud.

The second shroud (see Figure 2) was designed and custom made for this project (Eurovac, Concord, Ontario, Canada). It consisted of a steel collar welded to a steel "U," which was in turn welded to two steel tangs that were attached to the jackhammer with the latch bolt. A 7-inch length of 3-inch-diameter, wire-wound, clear flexible tubing was

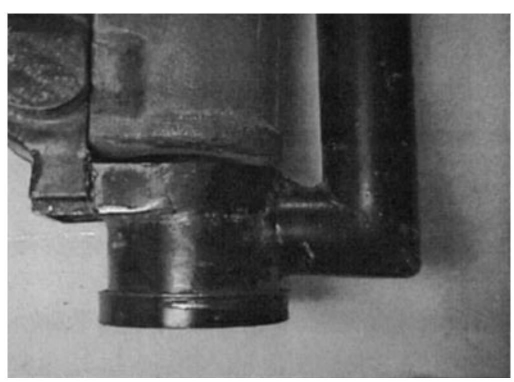

FIGURE 2
The custom-made shroud (flexible tubing removed for clarity).

attached to the bottom of the collar with a hose clamp. This tubing served as the inlet for the shroud. The shroud was exhausted through a length of 1.5-inch-diameter steel tubing that was attached to the collar at a 90-degree angle, which was welded to another length of 1.5-inch steel tubing at a near 90-degree angle, with the opening (the vacuum hose attachment point) pointing up the barrel of the jackhammer toward the handle. A NIOSH technician welded a piece of flat steel plate across the top of the steel "U" to prevent air from entering the exhaust stream through that opening. The manufacturer recommends an exhaust flow rate of 100 cubic feet per minute (cfm) at 70 to 80 inches of water to effectively capture the dust.[1]

The water-spray attachment was fabricated by one of the contractors who participated in this study (Mt. Hope Rock Products, Inc., Wharton, NJ, a division of Tilcon New York, Inc., West Nyack, NY). The water nozzle used was a solid-cone nozzle of the type used for oil burners (Type B, 11.00 GPH, 80°, Delavan Inc. Fuel Metering Products, Bamberg, SC). It was mounted in a bracket welded on the end of the jackhammer and connected via flexible, 16–pounds–per–square–inch (psi), $^3/_8$-inch-diameter hydraulic line to a quarter-turn valve mounted near the handle of the jackhammer. A length of $^3/_8$-inch-diameter air hose led from the valve to a 60-gallon water tank (pressurized to 22 psi) mounted on the air compressor trailer (see Figure 3). The pressure in the tank was controlled by a regulator. The contractor estimated that the cost for parts and machining was approximately $200.00.[2]

Experimental Design

For the trials with the ventilation controls, 60-pound (lb) jackhammers (also known as pavement breakers) were used that were similar to the types typically used by the contractors with whom we worked on this project. Due to a lack of communication among the partners, a 90-lb jackhammer was used for the trials with the water-spray control. The ventilation control/jackhammer pairs were connected via flexible hose to a rock-drill dust collector (DCT-10, Atlas Copco Construction Mining Technique USA, Inc., Commerce City, CO). The manufacturer reports that this unit has a maximum flow capacity of approximately 100 cfm at an operating pressure of 8 bar (116 psi). At that flow rate, the maximum static pressure is reported to be approximately 450 millimeters of water (17.7 inches of water).[4] The jackhammers were used with 3-inch chisel bits for all trials except for the first use of the water-spray control, where a standard moil-point chisel was used. For the trials where no control was used, the construction workers used the 60-lb jackhammer normally supplied by their employer.

The aim of this study was to estimate the reduction in dust produced by the units with controls compared to that produced by those without controls. Percent reduction was estimated by:

$$\text{Estimated \% Reduction} = 100 \times [1 - (\text{control mean})/(\text{no-control mean})] \quad [1]$$

In order to measure this reduction, trials of the controls were conducted in four rounds consisting of four trials each. The order of the trials was randomized within each round. Each trial lasted approximately 10 minutes. Real-time and filter samples were collected during each trial. (Note: A weld on the custom-made shroud broke after the third trial.)

Each trial consisted of using a jackhammer to break up a slab of reinforced concrete pavement or a concrete sound barrier (laid on its side) in the materials storage yard of the participating construction company. Two construction workers participated in the study. Both workers wore hard hats, safety glasses, ear plugs, work gloves, work boots, and half-facepiece dual cartridge air-purifying respirators with P100 filters. In addition, each wore a metal toe guard on one foot while operating the jackhammers.

Methods

The effectiveness of the dust controls examined in this study was evaluated by measuring the reduction in the respirable dust exposure in the breathing zone of the construction worker when a dust control device was used compared to the exposure when no dust control device was used. Respirable dust exposure was measured in real time using a portable laser photometer (DUSTTRAK™ Aerosol Monitor, TSI Inc., St. Paul, MN) connected via flexible tubing to a respirable dust pre-selector (a nylon cyclone) placed in the employee's breathing zone.

In addition, personal breathing zone samples were collected at a flow rate of 4.2 liters per minute using a battery-operated sampling pump at the employee's waist, connected via Tygon® tubing to a pre-weighed, 37-mm-diameter,

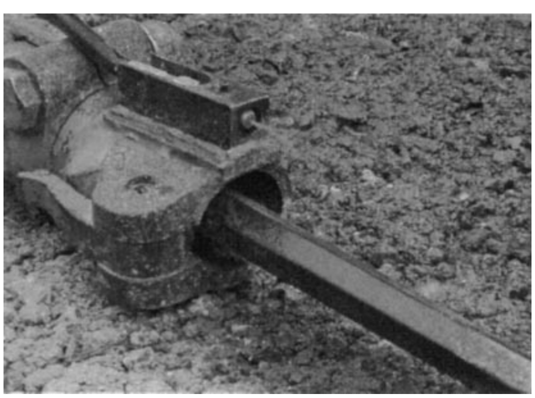

FIGURE 3
The water-spray attachment, showing method used to attach the nozzle to the tool.

5-micron (μm) pore-size polyvinyl chloride filter supported by a backup pad in a three-piece filter cassette sealed with a cellulose shrink band in accordance with NIOSH Methods 0600 and 7500, and a cyclone (GK 2.69 Respirable/Thoracic Cyclone, BGI, Inc., Waltham, MA) placed in the employee's breathing zone.[5]

In addition to the personal samples, bulk samples of settled dust were collected in accordance with NIOSH Method 7500. Bulk samples were collected from two sound barriers and two reinforced concrete pavement slabs. A bulk sample was collected from the bag at the outlet of the dust collector as well, representing a composite of the material that was chipped and collected.

Gravimetric analysis for respirable particulate was carried out with the following modifications to NIOSH Method 0600: (1) the filters and backup pads were stored in an environmentally controlled room (20 ± 1°C and 50 ± 5% relative humidity) and were subjected to the room conditions for at least two hours for stabilization prior to tare and gross weighing; (2) two weighings of the tare weight and gross weight were performed.[5] The difference between the average gross weight and the average tare weight was the result of the analysis. The limit of detection for this method was 0.02 milligrams (mg).

Crystalline silica analysis of filter and bulk samples was performed using X-ray diffraction. NIOSH Method 7500 was used with the following modifications: (1) filters were dissolved in tetrahydrofuran rather than being ashed in a furnace; (2) standards and samples were run concurrently, and an external calibration curve was prepared from the integrated intensities rather than using the suggested normalization procedure.[5] These samples were analyzed for quartz and cristobalite. The limits of detection for quartz and cristobalite on filters were 0.01 mg and 0.02 mg, respectively. The limit of quantitation is 0.03 mg for both quartz and cristobalite. The limits of detection in bulk samples were 0.8 percent for quartz and 1 percent for cristobalite. The limit of quantitation is 2 percent for both forms of crystalline silica in bulk samples.

Wind direction and velocity were measured using an ultrasonic wind sensor (WindObserver II, Gill Instruments Ltd., Lymington, England) placed on a low wooden stand near (but not blocked by) the air compressor trailer. The compressor's battery provided power to the system through a voltage inverter. Temperature and relative humidity were recorded twice during the course of the day using a multi-parameter ventilation meter (VELOCICALC® Plus Model 8386, TSI, Inc., St. Paul, MN).

Water flow through the spray nozzle was measured using a stopwatch and a measuring cup. The stopwatch and water flow were started simultaneously, and the amount of water dispensed in one minute was recorded. Three measurements were performed in order to obtain an average flow rate.

All data were first tested for lognormality, and data were found to be lognormal. Statistically significant differences in mean concentrations with various types of controls were determined using a one–way analysis of variance of the log-transformed data. Bonferroni adjustments were done for comparisons between mean control levels.

Results and Discussion

Mean respirable dust concentrations when using water as a control were consistently statistically lower at the $p < 0.05$ level than the means of all other types of controls, for both the personal breathing zone samples collected on filters and the real-time results. Reductions using exhaust ventilation controls were not statistically significantly different from each other or from no control at the $p < 0.05$ level due to the variability of the measurements made when exhaust ventilation controls were used. Air sampling results from the filter samples are presented in Table I. Real-time air sampling results are provided in Table II.

Use of water also resulted in the greatest reduction in respirable dust concentration when compared with no control (72% for air samples and 90% for

TABLE I
Results of personal breathing zone samples for respirable dust collected on filters

Round	Trial	Description	Concentration (mg/m^3)	Geometric mean (mg/m^3)	Geometric standard deviation
1	1	No control	1.45	2.06	1.53
2	5	No control	1.43		
3	10	No control	3.33		
4	14	No control	2.62		
1	2	Water spray	0.23	0.55	1.87
2	7	Water spray	0.90		
3	9	Water spray	0.52		
4	15	Water spray	0.83		
1	3	Rock-drill shroud	0.76	0.87	1.42
2	6	Rock-drill shroud	0.60		
3	12	Rock-drill shroud	0.93		
4	13	Rock-drill shroud	1.36		
1	4	Custom-made shroud	1.26	1.12	1.33
2	8	Custom-made shroud	1.38		
3	11	Custom-made shroud	0.81		

Note: A weld broke on the custom-made shroud after the third trial. A fourth trial was not conducted with that control.

TABLE II
Direct-reading respirable dust results

Round	Trial	Description	N	Geometric mean concentration (mg/m^3)	Geometric standard deviation	Minimum (mg/m^3)	Median (mg/m^3)	Maximum (mg/m^3)
1	1	No control	758	0.38	6.52	0.01	0.39	27.16
2	5	No control	613	0.70	4.76	0.01	0.81	23.72
3	10	No control	611	1.35	4.39	0.02	1.69	36.91
4	14	No control	659	0.52	6.65	0.01	0.50	63.97
1	2	Water spray	651	0.04	3.59	0.01	0.03	4.57
2	7	Water spray	675	0.05	4.66	0.01	0.04	7.28
3	9	Water spray	617	0.07	4.76	0.01	0.05	8.23
4	15	Water spray	619	0.16	3.54	0.01	0.15	3.44
1	3	Rock-drill shroud	595	0.45	3.02	0.01	0.49	5.32
2	6	Rock-drill shroud	642	0.59	3.30	0.02	0.66	20.48
3	12	Rock-drill shroud	607	0.52	3.40	0.02	0.51	27.77
4	13	Rock-drill shroud	629	0.60	2.83	0.03	0.64	16.01
1	4	Custom-made shroud	623	0.44	4.66	0.01	0.52	12.50
2	8	Custom-made shroud	631	0.15	7.54	0.00	0.11	40.14
3	11	Custom-made shroud	621	0.22	4.66	0.01	0.19	17.00

Note: A weld broke on the custom-made shroud after the third trial. A fourth trial was not conducted with that control.

real-time samples). Both shroud and vacuum controls showed reductions in the 50- to 60-percent range. Percent reduction for each type of control is presented in Table III.

Analysis of the sound barrier bulk samples indicated that they contained 19 percent quartz (by weight). The two samples of reinforced concrete pavement contained 23 percent and 28 percent quartz. The sample from the dust collector contained 19 percent quartz.

Three of the personal breathing zone samples were not analyzed for silica because the mass of respirable dust collected on the filter did not exceed the limit of quantitation for silica (0.03 mg for both quartz and cristobalite on filter samples). These samples were collected during the use of the water spray in Rounds 1 and 3, and during the use of the rock-drill shroud in Round 2. Cristobalite was not detected on any of the filters (the limit of detection was 0.02 mg). Trace amounts of quartz, between the limit of detection and limit of quantitation, were found on three filters. These were collected when no control was used in the third and fourth rounds, and when the custom-made hood was used in Round 3. Quartz was not detected in the remaining personal breathing zone samples. These results were due in part to the fact that the mass of respirable dust collected on all of the samples was low ($<$0.02 mg to 0.14 mg of respirable dust). Even if the dust in those samples contained 22 percent quartz, the average amount in the bulk samples (resulting in 0.004 mg to 0.03 mg of quartz on the filters), the mass of quartz on the filters would not have exceeded the limit of quantitation. This illustrates one of the drawbacks of using short sampling times when evaluating controls.

TABLE III
Reduction in exposure for each control versus no control

Type of sampling	Control	% Reduction
Respirable dust on filters	Water spray	71.7
	Rock-drill shroud	58.7
	Custom-made shroud	47.9
Real-time	Water spray	90.1
	Rock-drill shroud	57.3
	Custom-made shroud	58.7

The average wind speed was 4 miles per hour (mph), with a maximum of 13 mph. The prevailing wind was to the west (average bearing 90°). The workers' positions in relation to the wind direction changed throughout the day, so no attempt was made to correlate wind speed with exposure. However, based on observations of the airborne dust, the wind did not appear to hinder the effectiveness of the controls. The temperature ranged from 71 to 73°F, and the relative humidity ranged from 41 to 43 percent.

The water-spray attachment delivered approximately 350 milliliters (ml) of water per minute at the jackhammer. This flow rate reduced dust by an average of 72 to 90 percent when compared to no control. Water supplied at this flow rate did not add a substantial amount of water to the work surface. In fact, the surface dried to the touch after the pavement–breaking trial stopped. Additionally, use of the water-spray control device did not wet the workers' clothing or shoes.

Conclusions and Recommendations

This study demonstrates that a water-spray control using a readily available nozzle at a low flow rate is capable of achieving a 70- to 90-percent reduction in respirable dust exposures. Two ventilation shrouds were capable of achieving reductions in the range of 50 to 60 percent. Although these reductions were not significantly different from no control, they indicate that ventilation shrouds merit further investigation. In addition, the dust collector selected for this evaluation did not operate within the parameters recommended by the maker of the custom-made shroud. Thus, the custom-made shroud should be re-evaluated using a dust collector that is capable of producing a negative pressure in the range specified by the shroud manufacturer. The fact that the shroud broke indicates that a more rugged design may be required (perhaps a cast piece rather than a welded shroud would suffice).

Another limitation of this study is that a 90-lb jackhammer was used with the water-spray control, while 60-lb jackhammers from three different manufacturers were used for the two LEV controls and the no-control condition. The effect of the heavier hammer on the sampling results when compared to the lighter hammers is unknown. Although the three 60-lb jackhammers were nearly identical in their appearance, the effect of using jackhammers from different manufacturers is not known. The fact that the jackhammer used with the custom-made shroud was new at the time of the survey, while the other jackhammers were not, may have also introduced error.

The water-spray device was very effective in reducing respirable dust concentrations. The current configuration consisted of one nozzle aimed at the front of the jackhammer chisel. Additional designs should be constructed and tested to determine if a different nozzle arrangement, flow rate, or nozzle type would result in better control.

Full-shift sampling should be conducted using the water-spray control to confirm its effectiveness during actual pavement–breaking tasks. This would also allow investigators to determine if point-of-operation visibility is hampered by this control. Future versions of the water-spray device may utilize pressurized water lines rather than a pressurized water tank.

The benefits of the experimental design used in this study were reduced exposure to the worker, and relatively quick assessment of controls, which were made possible through the use of a real-time aerosol instrument and the higher-flow cyclone. The design also allowed the investigators to select the water-spray control for further evaluation in the field.

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EDITORIAL NOTE: Alan Echt and Erica Jones are with the Engineering and Physical Hazards Branch, and Karl Sieber is with the Surveillance Branch, NIOSH. Donald Schill and Daniel Lefkowitz are with the New Jersey Department of Health and Senior Services (NJDHSS). Joseph Sugar is with Mt. Hope Rock Products, Inc. Ken Hoffner is with the New Jersey Laborers' Health and Safety Fund. For more information, contact Alan Echt, Engineering and Physical Hazards Branch, NIOSH, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: (513) 841-4111.

The authors gratefully acknowledge the assistance of Michael Coyne, NJDHSS; George Rosazza, Bishop Sanzari Companies; Mike Cackowski, Laborers' International Union of North America, Local 472; Kris Hoffman, Occupational Safety and Health Administration (OSHA); and the New Jersey Silica Partnership.