LABORATORY AND FIELD EVALUATION OF DUST COLLECTOR BAGS FOR REDUCING DUST EXPOSURE OF ROOF BOLTER OPERATORS

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) conducratory and field tests to evaluate the effectiveness of dust collector bags for reducing dust liberation and operator exposure from a roof bolter's dust collection system. The laboratory tests evaluated the bag's effectiveness to contain dust and the effect on canister filter loading in both a bag and bagless condition. The dust emissions from the collector's exhaust were also measured in each condition during laboratory testing and show that nearly 100% of the test dust fed into the collector was captured by the dust bags. Loading and pressure drop on the dust collector's canister filter is greatly decreased when using the bags, enabling longer periods of drilling without filter removal/cleaning. The field results showed that, even though dust standards were met, respirable dust in exhausted emissions was reduced around the bolter. Laboratory and field results show that benefits from use of the bags are realized in all areas of operator exposure.

Introduction

Respirable dust samples, taken by the Mine Safety and Health Administration, show that roof bolter operators are still at high risk for overexposure. During the years 2000 to 2004, Mine Safety and Health Administration (MSHA, 2004) inspectors collected nearly 5,000 respirable dust samples at roof bolting occupations. Of these samples, 20% exceed a respirable silica dust concentration of 100μg/m^3, a level that MSHA considers excessive. Previous studies have shown that the contents of the roof bolter dust box can contain high amounts of respirable silica dust (Colinet et al, 1985; Kok et al, 1985). A study by Ondrey et. al. showed that mining downwind of the continuous miner was the major source of dust on roof bolting operations (Ondrey, et. al.). However, improper ventilation and poor dust-box cleaning procedures can add to the over exposure of bolter operators.

Most roof bolting machines use an MSHA accepted (30CFR, Part 33) vacuum dust collection system to capture dust as holes are drilled. The drill steel, bit, dust box, filter and hoses together form a single unit approved by MSHA for use in underground coal mines. It is not possible to modify or change any part of this dust control system without violating approval from MSHA.

The system uses a vacuum pump on the machine to create negative pressure at the drill bit and draw the drill cuttings through the bit and drill steel. Many of these dust collection systems are equipped with a pre-cleaner that collects the larger drill cuttings before they enter the dust box. These cuttings are deposited onto the mine floor while the remaining, finer, dust proceeds to the collector box. The dust box itself has several compartments and functions as a rough size classifier allowing the coarser dust sizes to settle out of the dust stream in the main chamber (about 95% of all the dust entering the box). A field sample showed that 36% of the dust in the main chamber is <10 μm. The dust that passes through the main chamber is routed through cyclones and then into the filter chamber for deposition on a paper canister filter. The filtered air flows through the vacuum pump, a noise reducing muffler, and then into the mine environment. Figure 1 shows a schematic of the dust collector system. Normally, the dust box is emptied at the end of every cut. As the filter accumulates fine particles of dust, resistance increases and flow through the system decreases requiring removal and cleaning of the filter, usually after several cuts.

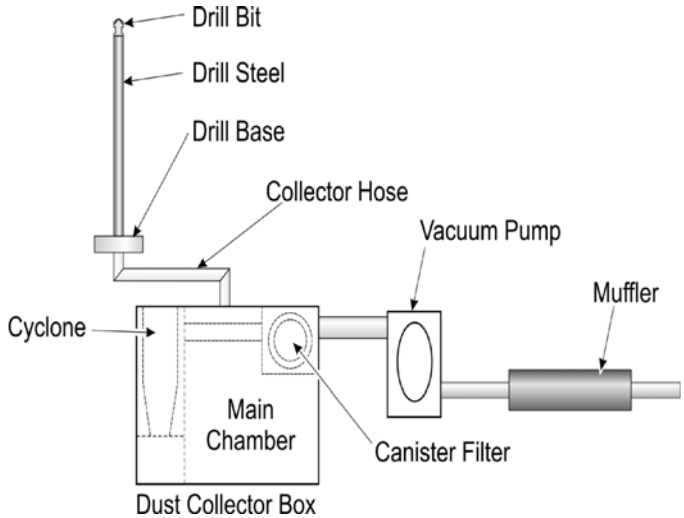

Figure 1. Schematic of a roof bolter dry dust collector system.

The dust that is collected in the main chamber of the collector box is removed by opening the door and pulling a 'rake' toward the opening to drag the dust out, allowing it to dump onto the mine floor. If cleaned improperly or in poorly ventilated workings, exposure can occur as the operator drags the dust from the box, entraining it into the air as it falls to the floor. A study by Goodman and Organiscak (2002) showed that using open containers constructed of either steel or line brattice, helped contain dust in the main chamber for disposal against the rib, thus reducing operator exposure during cleaning. The four-sided, reusable containers are fitted into the bottom of the main chamber and contained the dust as it settled. The containers were then removed, carefully dumped near the rib, and replaced. Another source of operator exposure comes from the canister filter. Dust that is too fine to be captured in the main and subsequent dust box chambers passes through to the filter. When the filter is removed for cleaning, it is shaken or tapped against the rubber tire of the bolter or a hard surface to dislodge the dust. This method of cleaning often creates a respirable dust cloud that contaminates the breathing area of the operator if he is not upwind of the dust. The operator must take care not to damage the filter or filter seal while cleaning, as dust not captured by the filter or that bypasses the filter seal is exhausted into the mine air. Care must be taken to stay upwind of the dust box during cleaning. At times, roof bolting machines operate in areas with minimal fresh airflow. Any dust liberated through cleaning of the dust box or filter will remain around the bolting machine, increasing silica exposures for the machine operators (Colinet et al, 1985).

A collector bag (Wildwood Industries, Bloomington, IL) was developed to capture and contain the collector dust and prevent it from contaminating the air around the roof bolter during cleaning. The dust collector bags are placed in the main chamber of the dust collector box to contain the dust that enters the boxes' main chamber. The bags are installed on a bracket and hose retrofit kit (J.H. Fletcher Co., Huntington, WV) in the main chamber of the collector box. Figure 2 shows a collector bag, and the collector box with and without a collector bag installed.

Figure 2. Left: Dust collector bag. Right: Dust box without bag and with bag installed.

This study evaluated the performance of the collector box and the effectiveness of the collector bags to reduce respirable dust exposure of bolter operators during the bolting process. These bags are installed in the main chamber of the dust box to contain the majority of dust and allow operators to empty the box without being exposed to entrained dust. Both laboratory and field investigations were conducted to determine dust capture, filter loading, and dust concentrations around the bolter while operating in both bag and bagless conditions.

Experimental Design

The laboratory test apparatus consisted of a dust collector system representative of the type and size found on many roof bolting machines used in underground coal mines (figure 3). The test protocol consisted of comparing two operational conditions of the collector, testing with a collector bag and testing without. A total of 60 tests were conducted, 30 with the bag installed and 30 without. To avoid potential health risks of working with quartz dust, ground limestone dust was used as feed material (=2.58 g/cc). Each test used 22.7 kg (50 lbs) of the limestone material as feed dust. This amount was determined by assuming that five 2.4 m (8 ft) holes are drilled in material with a density of 2403 kg/m^3 (150 lbs/ft^3). The duration of the each test was 90 seconds. The particle size distribution of the limestone dust was compared to the distribution of dust obtained from a bolter dust box during an underground study. The results show that ground limestone dust has a bulk size distribution very similar to that of the dust from the roof bolter.

Under typical operating conditions (without a dust bag), the dust enters the collector at the top of the box and the heavier particles fall to the bottom of the main chamber. Due to the high velocities within the box, the smaller, lighter dust particles are carried to two cyclones that further classify the aerosol with the oversized fraction falling out to a compartment below. The finest size fraction then flows to the filter chamber where it collects on a single final canister filter (Model 123990, Donaldson, Inc., Minneapolis, MN). The filtered air then flows from the dust box as exhaust.

Airflow through the box is provided by a Roots DVJ Whispair vacuum pump (Airtek Inc., Irwin, PA) rated at 0.03 m^3/s (60 cfm), at a pressure of 50.8 cm (20 in) mercury column. To simulate the drilling process, dust is fed into the collector box using an “Accu-rate” bulk dust feeder with a 5.7 cm (2.25 in) screw (Schenck, Inc., Whitewater, WI). The dust feed rate for each test was 22.7 kg/min (50 lbs/min). An additional 30 seconds were added to assure that all the dust had cleared the hopper and feed tube.

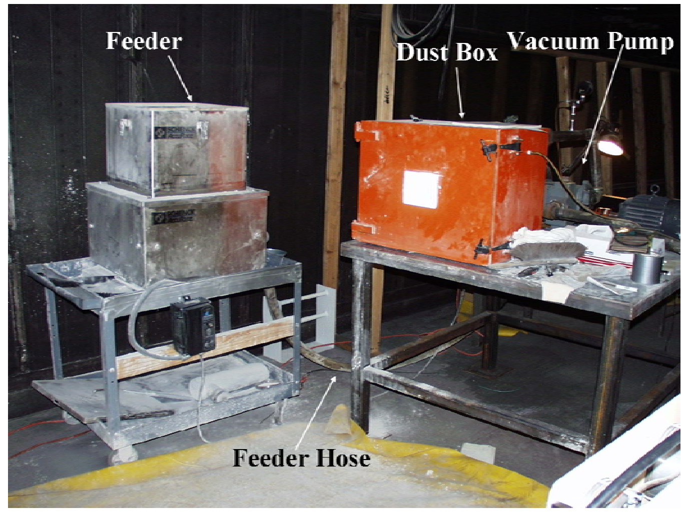

Figure 3. Laboratory dust box simulator.

When testing in the bag condition, the collector bags were weighed after each test to determine the amount of dust that is contained by the bags compared to the amount of dust fed into the system. Likewise, the feed dust bags were weighed before loading the feeder and then the empty bags were weighed to determine the net amount of dust fed. The canister filter was weighed after each test to determine filter loading and to make comparisons between the bag and bagless test conditions. The exhaust air was sampled to determine the dust concentration and the amount of particles that escape the collector and is subsequently reintroduced into the air. Since the exhaust air exits at a velocity that is too high to sample, the air is routed through a short length of 5.1-cm (2-in) diameter hose and then into a 3.1-m (10-ft) length of 15.2-cm (6-in) diameter PVC pipe. Particle sizes were measured in the 15.2-cm (6-in) diameter pipe, 2.4 m (8 ft) away from the entry of the 5.1-cm (2-in) hose into the PVC pipe. Aerodynamic particle sizes were measured using a TSI Aerodynamic Particle Sizer (APS) (Model 3310, TSI, Inc., Minneapolis, MN) with a TSI diluter (Model 3302) (100:1 diluter nozzle). A laptop computer was interfaced with the APS and data acquired using the available TSI software. The theory and operation of the APS and diluter are available in other publications (Chen et al, 1985; Baron, 1986; Cheng et al, 1993). Aerosol was drawn isokinetically into the diluter at 5 l/m through a 1.2-m (4-ft) length of 7.9-mm (0.31-in) ID conductive tubing. Calibration of the 3310 analyzer was checked periodically using PSL spheres with mean diameters of 1.020±0.022 µm, 5.010±0.035 µm, and 10.03±0.05 µm (Duke Scientific, Palo Alto, CA). A sample of each was placed in small Petri dishes and allowed to dry overnight. The dried particles were brushed into the diluter inlet with a small artist brush (Maynard and Kenny, 1995). Dust concentrations were recorded continuously in the 15.2-cm (6-in) diameter pipe using a RAM-1 (Realtime Aerosol Monitor) instantaneous dust monitor (Thermo Andersen Inc., Smyrna, GA). Vacuum pressures within the box and across the filter were also recorded continuously during each test. Figure 4 shows a schematic of the laboratory setup.

Laboratory Results

The collected data were analyzed to determine the effectiveness of the collector bags to: collect and contain the dust within the box, reduce dust accumulation on the canister filter, and reduce emissions in the collectors’ exhaust. In addition, the pressure drop within the system was monitored to determine the resistance of filter loading over the course of testing in both bag and bagless conditions.

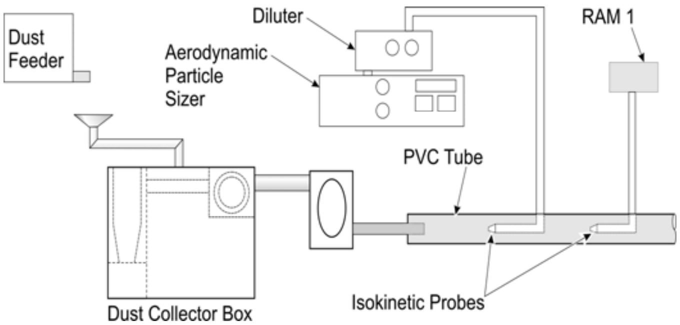

Figure 4. Schematic of laboratory test apparatus.

To determine the amount of dust the bag collected and contained, the net weight of the feed dust and collector bag dust was measured before and after each test. An average feed dust of 22.9±0.34 kg (50.54 ± 0.75 lbs) was fed into the box over the entire testing period. The average dust in the collector bags after all tests were conducted was 22.8±0.39 kg (50.38 ± 0.85 lbs). The results show that over 99% of the feed dust entering the dust collector was contained by the dust bags.

Before each testing condition, a new canister filter was installed in the collector box. The filter was carefully removed, weighed, and reinstalled after each test. To determine the cumulative dust accumulation on the paper media over the course of testing, the filter was not cleaned between tests. As dust accumulates on the filter, resistance within the system increases. Therefore, the pressure drop in the collector was also monitored to determine the effect the collector bag had on the systems' ability to maintain vacuum pressure. Figure 5 shows the nearly linear progression of weight gain on the filter and the associated pressure drop in the collector box during testing in both conditions. The data show that the filter weight gain is over 5 times higher when the bag is not used and that the pressure drop across the filter for all tests ranged from 76.2 to 83.8 mm (3.0 to 3.3 in) WG when the bag was used compared to 101.6 to 213.4 mm (4.0 to 8.4 in) WG without the bag. Figure 6 shows the total weight gain of the filter after testing was completed for both conditions.

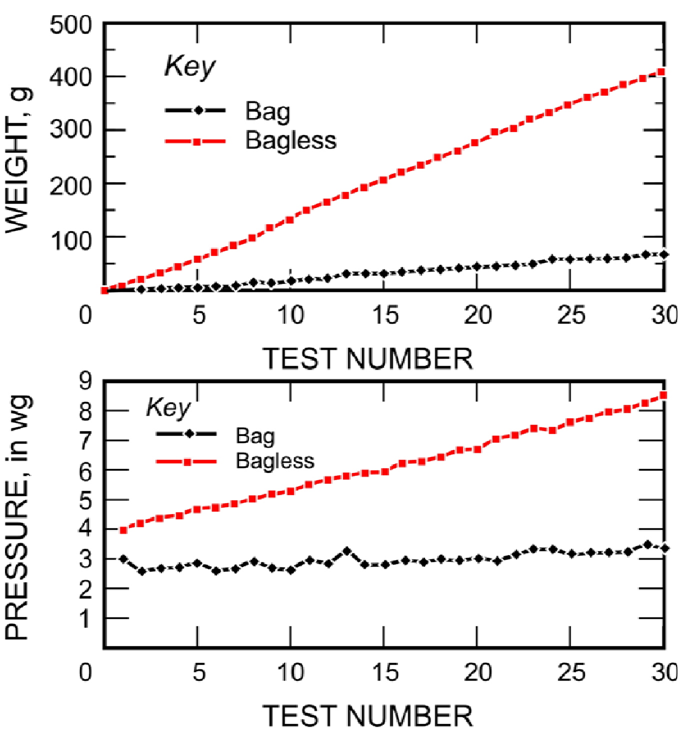

Figure 5. Top: Canister filter weight gain. Bottom: Pressure across filter.

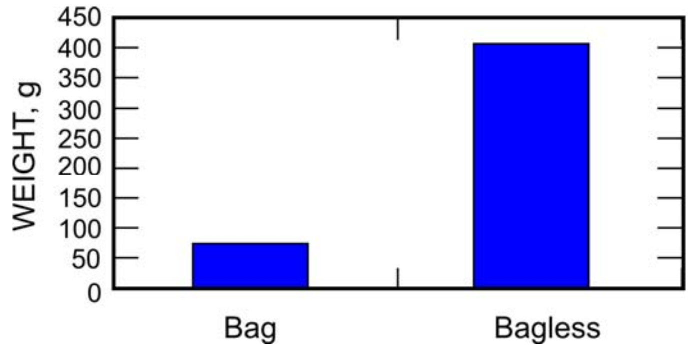

Figure 6. Total weight gain on canister filter for each test condition.

Dust emissions from the collector box exhaust were monitored for dust concentration levels during testing by the RAM-1 and APS. The RAM-1 is not a dust compliance instrument; therefore, RAM-1 concentration measurements are only used for direct comparison purposes and will be referred to as RAM-1 Units. Figure 7 shows the dust concentration levels from the RAM-1 in the collector box emissions over the course of testing. A high concentration reading was measured during the first test for both bag and bagless tests. This initial high reading was caused by the installation of a new filter for the testing condition. The newly installed filter allows a momentary passage of fine particles before the dust can load and clog openings in the paper media. This event is recorded as a high dust concentration for a relatively brief period of time. After the first test, the dust measurements became more consistent and show that dust levels are higher when testing in the bagless condition. The APS measured particles in the collector exhaust from 30 to < 0.487µm. However, over 80% of all particles measured were less that 2 µm. Therefore, the range from 2 to <0.887 µm was examined for this analysis. Figure 8 shows the particle counts/cc over the duration of each test. The graph shows similar results to what was seen by the RAM-1.

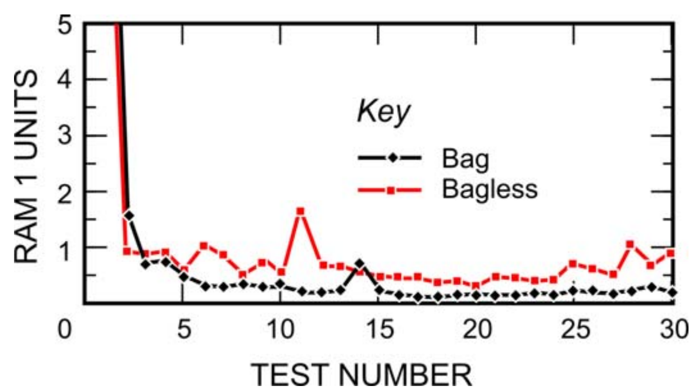

Figure 7. Dust levels recorded by RAM-1 in bolter exhaust.

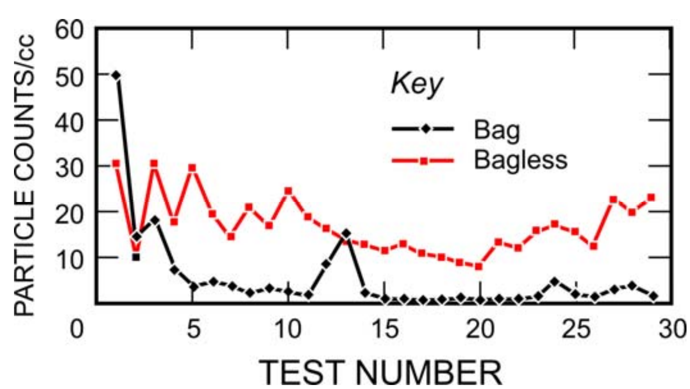

Figure 8. Particle counts in bolter exhaust.

Field Study

Dust sampling took place on a Fletcher dual boom bolter Model DDR-13. The bolter was equipped with dust collector boxes with vacuum bags on either side of the machine. The original sampling strategy called for sampling the exhaust of the collectors for one shift using bags in both collectors and for one shift without bags in the collectors. However, due to operational constraints and at the request of mine officials, sampling without bags in both collectors was not conducted. Exhaust emissions were sampled for one shift from both collectors while using a bag in the right collector and without a bag in the left collector. Then sampling was conducted for one shift using a bag in both collectors. As a result, the study involved sampling a shift without the bag in one of the collectors for a shift (this will be considered the bagless condition) and then with the bag in both collectors for a shift (the bag condition) to determine the difference in dust concentration under the two conditions. Therefore, any dust levels seen while in the "bagless condition" will be assumed to be greater than the measured levels. The bolter's exhaust ports for the collectors were situated side by side on the left rear side (from the rear of the machine) of the bolter.

Exhausting ventilation was used on the sections which provided intake air over the bolter from rear to front. Air velocity in the entries ranged from 0.34 to 0.96 m/s (66 to 188 ft/m). Sampling took place only when the bolter was upwind of the continuous miner.

Before sampling began, the left collector box was cleaned, the bag was removed, and the filter replaced. The right collector box was cleaned and a new bag was installed. Sampling began at approximately 11:00 am and continued until about 2:10 pm on the first day of sampling. Two places were bolted during that time period. On the second day of sampling, bags were used in both collector boxes. Three places were bolted over a time period of 4 hours and 40 minutes (9:20 am to 2:00 pm).

Three sampling packages were used to measure dust levels around the bolter. Area samples were taken each day of testing with 3 different instruments in each sampling package. Two gravimetric samplers and 1 Personal Data Ram (pDR) (ThermoFisher Scientific) were used in each package. One of these packages was hung in the intake air and the other was hung in the return air to isolate the bolter section from other dust sources. The other package was placed on a tri-pod 1.5 m (5 ft) behind the bolter in the collector box exhaust to sample the air passing through the dust collection system. Personal Dust Monitors (PDMs) were worn by NIOSH researchers to collect personal samples on either side of the bolter. Figure 9 shows the instrument arrangement, locations, and sampled areas.

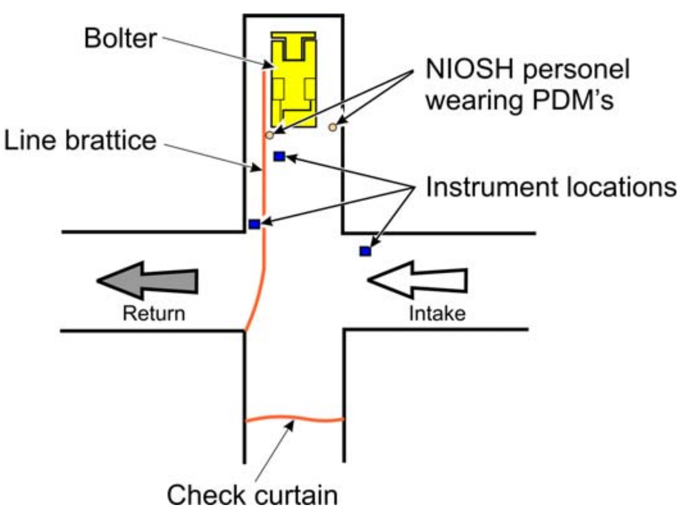

Figure 9. Instrument and sampling locations.

Like the RAM-1, the pDRs are instantaneous samplers that provide a profile of dust levels over the entire sampling period. Unlike gravimetric samplers that provide a single mass sample over the entire sampling period, pDR samplers use light scattering technology to measure and record ambient air. Although not a compliance sampling instrument, the pDR is very good for direct comparison measurements. The measurements are recorded in10-second intervals so that changes in dust levels can be compared to mining activities to determine sources of dust. The collected data is then downloaded to a computer for graphical representation and analysis. In addition to the gravimetric and pDRs, Personal Dust Monitors were worn by two NIOSH personnel to gather exposure data from either side of the bolter during the bolting and collector box cleaning cycles. Like gravimetric samplers, the PDMs provide the personal dust exposure over the course of the shift of the person wearing it. Although NIOSH personnel could not be in the same position as the bolter operators, positions that approximate their positions on either side of the bolter were assumed. NIOSH personnel also cleaned the collector boxes when needed to measure the exposure from that activity.

Data Analysis and Results

The intake and return samplers are used as a control to ensure that the dust sampled at the bolter is not confounded by other sources. Gravimetric samplers were used to sample the areas in the intake, return, and bolter exhaust. The pDR graphs will show the changes in dust levels in the exhaust during bolting with and without the bag in place. The PDM data will show a personal sample of the total concentration of dust exposure for each person for bag versus bagless operation. It should be noted that on the first day of sampling, while in Place 2, rock dusting took place outby which elevated dust concentrations over a 10-minute period. This period of elevated dust concentration is taken into account, as will be shown in the data analysis. The time taken to clean the dust from the box and the canister filter when required was also recorded.

Gravimetric Samples

These data includes the two places bolted without the bag in place on the left collector box and the three places bolted with both bags in place on the second day of sampling. To determine the dust coming into the bolter entry, the two intake gravimetric samples were averaged. The two gravimetric samples collected in the proximity of the bolter were also averaged. To determine the dust concentration from the bolter exhaust, the intake concentration average was then subtracted from the bolter concentration average to arrive at the concentrations. Average dust concentrations of the two gravimetric samplers taken at each position are shown in Table 1. The higher concentration in the intake air during the bagless test is attributed to the rock dusting outby during testing. The net average concentration of the bolter exhaust when operating without the bag was 0.96 mg/m^3 as opposed to 0.14 mg/m^3 when sampling with the bag installed. Figure 10 shows a graph of the gravimetric sampler data taken at the collector exhaust position over the sampling period for each collector box condition. The gravimetric results show an improvement in dust concentration of nearly 7 times when the bag is used. This difference would be greater if neither collector had the benefit of a collector bag during the test.

Table 1. Average dust concentrations for each test condition.

	Gravimetric Averages, mg/m^3	
	Bagless Test	Bag Test
Intake	0.23	0.17
Bolter exhaust (adjusted for intake)	0.96	0.14
Return	0.33	0.23

Personal Dust Monitors (PDMs)

Typically, the downwind bolter operator will experience the highest exposures on a dual boom bolter. The PDMs were worn by NIOSH personnel to measure personal dust concentrations on the left and right rear (exhaust versus non exhaust side) of the bolter to differentiate between test conditions. Figure 11 illustrates the dust concentrations recorded by the PDMs from the two test conditions. The graph shows that during the bagless condition, dust concentration was over 2 times higher on the left side (exhaust side) of the bolter than on the right. PDM data for the bag condition shows little difference in dust concentration from the left to the right side of the bolter. The time period during which the collector box was emptied in a bagless condition was isolated in the PDM data file and showed no increase in dust levels.

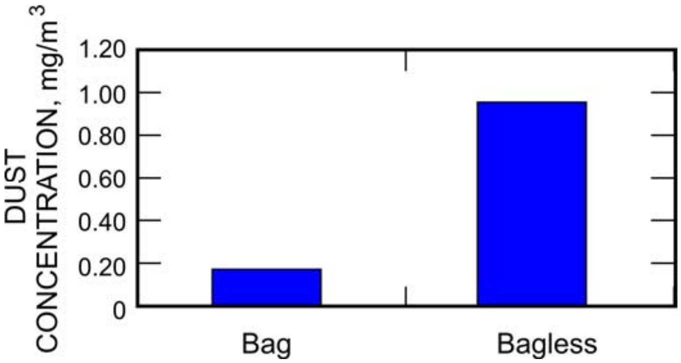

Figure 10. Gravimetric sampler data from dust collector exhaust.

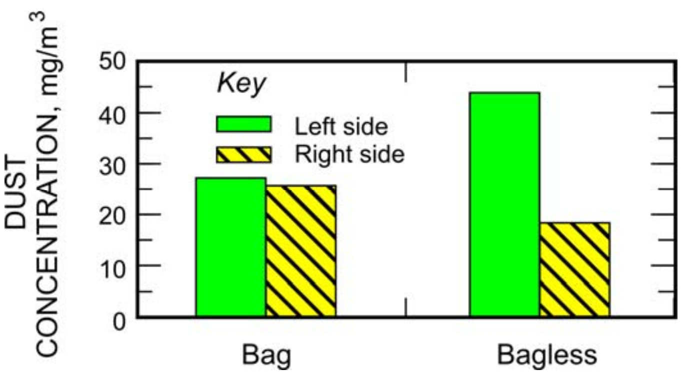

Figure 11. PDM sample data worn by NIOSH personnel on the left (exhaust) and right sides of the bolter.

Personal DataRams (pDRs)

The pDRs show variation in dust levels during the shift at 10-second intervals and show how the dust levels fluctuate over the course of the sampling period. Figures 12 and 13 show the dust profiles of a place bolted each day without and with the collector bag respectively. These two bolted places were in entries 5 and 6 and had similar entry velocities of 0.96 m/s (188 fpm) and 0.90 m/s (177 fpm) respectively. Entry 5 had 7 rows of 2.7 m (9 ft) bolts installed and 1.2 m (4 ft) rib bolts installed each row for a total of 42 holes. Entry 6 had 6 rows of 2.7 m (9 ft) bolts installed and 1.2 m (4 ft) rib bolts installed every other row for a total of 33 holes. Figure 12 shows the bagless test. Although these dust levels are higher than the bag test, the levels are consistently low for most of the 63-minute time interval. However, the graph shows brief elevated levels of dust at irregular intervals occurring throughout the bolting cycle. Figure 13, the bag test, shows low consistent dust levels with elevated levels occurring similar to those in figure 12. The elevated levels in entry 6 are fewer in frequency than those in entry 5, possibly due to the number of holes drilled in each place. The elevated levels in both bag and bagless tests show that dust is bypassing the canister filter and escaping the collector system during the bolting cycle. Based on the limited testing performed, the reason for this occurrence cannot be determined.

Table 2 shows a summary of average bolter exhaust dust levels recorded by the pDRs for the places that were sampled during bolting. The averages were calculated by extracting the data interval recorded by the pDR while the bolter was bolting each place to arrive at an average dust level while bolting. On the bagless day of operation, rock dusting took place outby for a 10-minute period while sampling in Place 2. The rock dust raised the dust levels during the bolting of this place. The table shows two values for Place 2 for the bagless test condition. The value with the asterisk shows the dust level in Place 2 with the 10-minute rock dusting interval removed. The double asterisk shows the average of Place 1 and Place 2 without the rock dusting interval. With the rock dusting time period removed, the collector operating without the bag during bolting of two places is over 2 times the dust level recorded with the bag during bolting of three places.

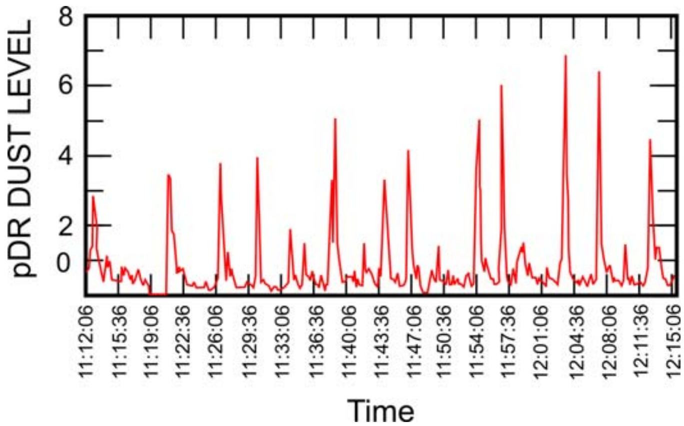

Figure 12. Bagless test dust levels measured in the bolter exhaust in entry 5 with a pDR.

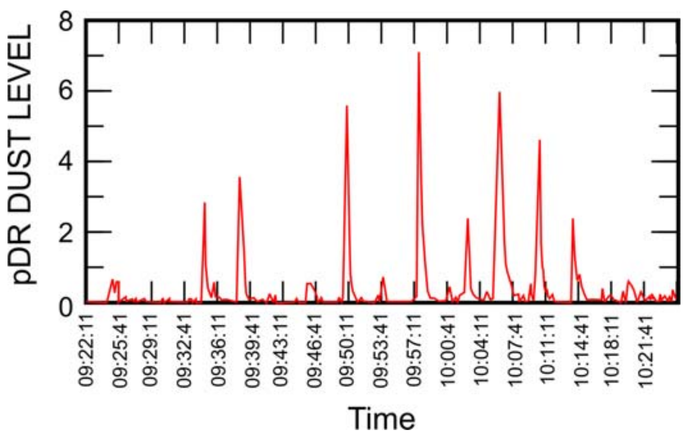

Figure 13. Bag test dust levels measured in the bolter exhaust in entry 6 with a pDR.

Table 2. Dust level averages from pDRs at the bolter exhaust during bolting of each place.

	Average pDR dust levels at the bolter, pDR units	
	Bagless	Bag
Place 1	0.77	0.32
Place 2	2.78 *1.13	0.19
Place 3		0.75
Average	1.78 **0.95	0.42

*Dust level with 10-minute rock dusting period removed.
**Average dust level with 10-minute rock dusting period removed.

The time required to clean the bagless collector side and filter was 4 minutes as opposed to 30 seconds to remove and replace the bag from the other collector.

Summary

Lab tests

The laboratory dust collector tests show that nearly 100% (99.6%) of the test dust fed into the collector was captured by the dust bags. Figure 14 shows the condition of the main chamber before and after testing for each test condition. Total weight gain on the canister filter was over five times higher without use of the bag. The RAM-1 unit shows respirable dust levels in the collector exhaust to be over 2 times higher when tests were conducted without the bags in place. The APS showed that the number of total dust particles emitted from the exhaust was 2 times greater when the tests were conducted without the bags.

Since nearly all the dust is contained in the bag, operator exposure is improved when emptying the collector box's main chamber. Filter loading is greatly decreased when using the bags enabling longer periods of drilling without filter removal/cleaning. Pressure drop across the filter for all tests ranged from 76.2 to 83.8 mm (3.0 to 3.3 in) WG when the bag was used and 101.6 to 213.4 mm (4.0 to 8.4 in) WG without the bag. Filtered air emitted from the collector has less respirable dust and fewer total dust particles when the bags are used.

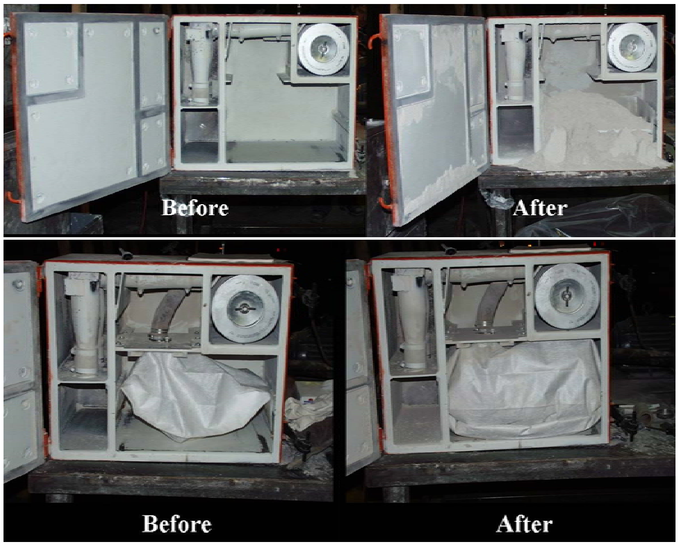

Figure 14. Top: collector box conditions without use of a bag. Bottom: collector box conditions with use of bag

Field Tests

Although limited data were collected, all sampling results show a similar trend. Dust reductions around the bolter were shown in both area and personal samplers when the bag was used in the dust collector system. The following observations were made:

- Gravimetric samplers at the bolter show a dust improvement from 0.96 mg/m^3 to 0.14 mg/m^3 when the bag is in use.
- Personal samples from the PDMs show that the left side (exhaust side) of the bolter experienced 2 times the amount of respirable dust than the right side. NIOSH personnel cleaned the dust boxes when required so that the samplers would measure dust from cleaning process. Depending on the amount of ventilation air, dust box cleaning and dust piles on the mine floor may add to operator exposure. However, PDM data showed no increase from one side to the other. The time required to clean the bagless collector side and filter was 4 minutes as opposed to 30 seconds to remove and replace the bag from the other collector. Use of the bag limited exposure time while cleaning the dust box and prevented dust from accumulating on the mine floor avoiding possible re-entrainment.
- Overall dust level averages for the bolter as recorded by the pDRs were lower for each place when the bags are used. However, the recorded data also show unexplained elevated dust levels in short time periods over the course of both sampling conditions.

Both laboratory and field results show that benefits from use of the bags are realized in all areas of operator exposure. In order to utilize these bags in underground coal mines, the dust bags must be accepted by MSHA as an optional item for the specific dust collection system and machine model (CFR30, part 33). In addition, the collector must be equipped with a pre-cleaner option and a retrofit kit installed inside the collector to connect to the bag. Without the pre-cleaner option, the bags would fill too quickly and need replaced too often.

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