Field evaluation of air-blocking shelf for dust control on blasthole drills

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In previous studies, an air-blocking shelf has been shown to be successful in reducing respirable dust leakage from the drill shroud in a laboratory setting. Dust reductions of up to 81% were achieved with the shelf under operating conditions consisting of a 1.9:1 collector-to-bailing airflow ratio and a 5.1-cm gap between the shroud and ground. Recent research focused on evaluating the shelf on two actual operating blasthole drills, in much more severe environments. In the field, the shelf reduced dust levels in the areas surrounding one operating blasthole drill by 70%. Dust reductions measured in the immediate vicinity of the shroud were reduced by 66% at one mine and 81% at the other mine. These field tests confirm that the air-blocking shelf is useful for reducing respirable dust generation from blasthole drills.

1. Introduction

Surface blasthole drilling can generate large amounts of respirable crystalline silica dust. A properly designed surface drill shroud enclosure and dust collector is essential to assure that drilling dust does not enter into the work environment. It is important to reduce worker's overexposure to respirable crystalline silica dust because it can cause silicosis, a serious and debilitating respiratory disease that has no cure and often results in death. To prevent silicosis, the US Mine Safety and Health Administration (MSHA), which regulates the exposure of miners to hazardous substances, has set the permissible shift exposure limit for coal mine respirable dust at 2.0 mg/m^3 when the crystalline silica level does not exceed 5% [1]. If the respirable dust sample exceeds 5% crystalline silica, the standard is reduced to a limit equal to the quotient of 10 divided by the percentage of crystalline silica in the sample. For example, if the crystalline silica content is 10%, the reduced standard would be 1.0 mg/m^3.

A review of MSHA's respirable dust sample database for surface coal crystalline silica samples shows that drill operators have recorded some of the highest frequencies for non-compliance with the crystalline silica dust standard. During the time period from 2005 to 2009, the percentage of samples exceeding the permissible

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exposure limit for crystalline silica dust varied from 16 to 27% [2]. Compliance problems are caused by the high levels of respirable dust generated by the drilling machines and the fact that drilling often occurs in overburden that contains silica-bearing materials such as sandstone and shale. A primary source of the operator's respirable dust exposure is dust escaping from the drill shroud enclosure.

Previous studies have established the airflow patterns within the shroud enclosure [3,4]. The airflow patterns consist of the bailing air exiting the drill hole. This air travels through the middle of the shrouded area, maintaining its course along the drill steel to the underneath side of the drill table, where it exhibits a Coanda effect as it fans out across the bottom of the drill table and continues down the sides of the shroud. All of this occurs at a high velocity. Dust emissions at the ground surface occur when the air strikes the ground and fans out from underneath the enclosure (Figure 1, left).

Observation of the dust emission process led to the development of the air-blocking shelf. The 15.2-cm wide shelf is placed along the inside perimeter of the shroud where it disrupts the airflow and redirects it toward the centre of the enclosure to prevent the air from striking the ground (Figure 1, right). This redirection of air reduces dust leakage from underneath the shroud. Testing of this shelf has been conducted in a full-scale drill table simulator in Pittsburgh, PA. The simulator has been described in detail previously [5] and can produce operating parameters similar to a medium-sized rock drill. During laboratory testing, each of the independent variables, including the collector airflow to bailing airflow ratio (airflow ratio), shroud gap height and the use of the air-blocking shelf, were found to significantly impact dust levels with similar orders of magnitude [3].

Figure 2 shows results of the laboratory testing. Use of the shelf decreased dust levels outside the shroud by 81% at an airflow ratio of 1.9:1 and a shroud gap height of 5.1 cm. With an airflow ratio of 1.9:1 and a 20.3-cm gap, the reduction rate achieved with the shelf was 70%. With a ratio of 1.2:1 and a 5.1-cm gap, the reduction rate was 77%. A reduction of 38% was achieved while using the shelf under poor operating conditions [6] consisting of an airflow ratio of 1.2:1 and a

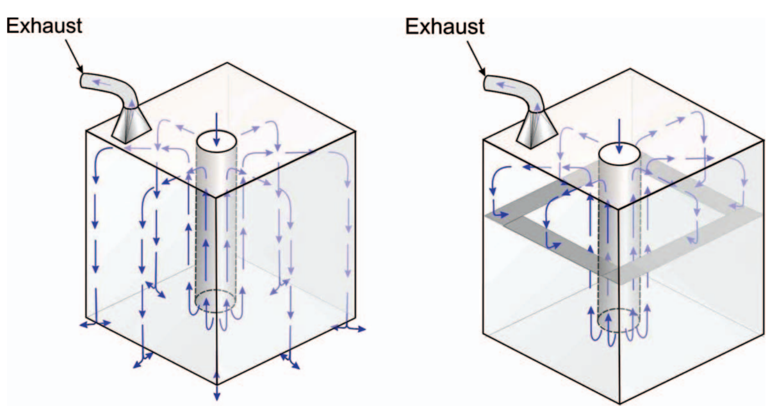

Figure 1. Qualitative model showing airflow patterns underneath a drill shroud model. Airflow patterns without the air-blocking shelf (left) and with the air-blocking shelf (right) are displayed.

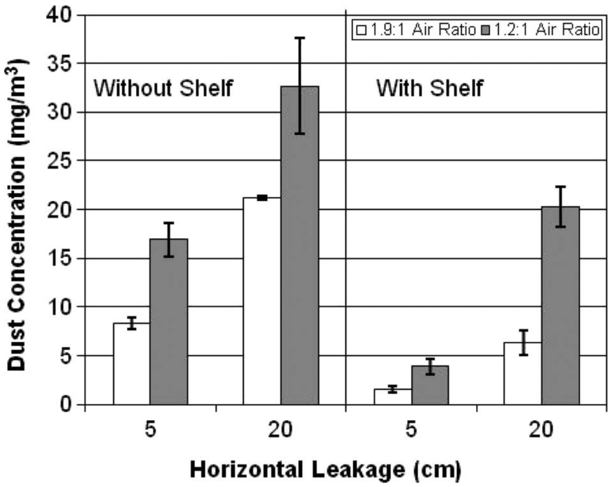

Figure 2. Laboratory results showing dust concentrations outside of the shroud both with and without the air-blocking shelf. Standard deviation bars also shown.

20.3-cm shroud gap height. Since the blasthole drill environment is much more severe than laboratory conditions, field testing was conducted at two surface mine sites to validate the laboratory results. The succeeding sections of this report describe the sampling protocol and findings of the field studies.

2. Dust sampling protocol

The sampling strategy employed during this study was designed to determine a representative respirable dust concentration in the area surrounding the drilling machine. Conditions were tested with and without the air-blocking shelf. Six sampling locations, labelled A–F, were used on the drilling machine (Figure 3). Instantaneous and gravimetric respirable dust levels were measured at each location.

Instantaneous respirable dust levels were measured using model 1000 personal data rams (PDRs) manufactured by Thermo Electron Corporation (Franklin, MA). PDRs use light-scattering technology to measure dust particles with aerodynamic diameters in the range of 0.1 to 10 micrometres. For this study, the PDRs were operated in data-logging mode using a 5-s sampling interval, and sampling times ranged from 4 to 7 hours. Despite being very precise instruments, PDRs must be calibrated gravimetrically for a particular aerosol (e.g. dust, smoke and mist) to yield accurate data. The gravimetric samplers used for this purpose consisted of 37-mm filter cassettes and Dorr-Oliver cyclones operated at a flow rate of 2.0 l/min using Escort ELF pumps. Two gravimetric samplers were used to calibrate each PDR. The instruments were turned on and off simultaneously, and the PDR correction factor was calculated by dividing the daily average gravimetric concentration by the daily average PDR concentration. A unique correction factor was determined at each sampling location (A through F) for each day of the dust survey. These correction factors were then multiplied by the measured PDR values to obtain accurate PDR values. The corrected PDR data, along with a detailed time study conducted by NIOSH personnel, allowed for the isolation of respirable dust levels during the drilling of each hole.

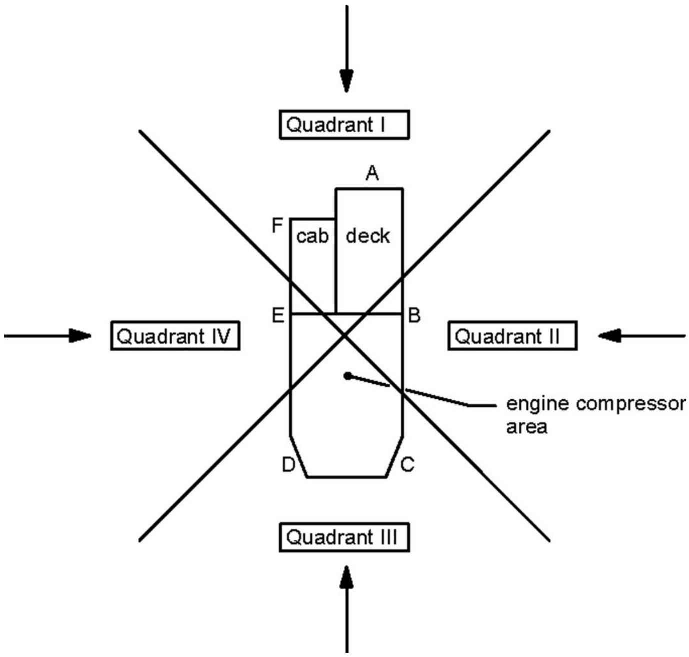

Figure 3. Plan view of blasthole drill with sampling locations and four wind quadrants displayed.

The mean values reported in this study are the geometric mean of the gravimetrically calibrated PDR data. Use of log-transformed data and the geometric mean is typical when analyzing environmental airborne dust samples that exhibit a large range in values, as was the case for this particular study [7]. Calculation of the geometric mean for the six sampling locations (A through F) was interpreted to be indicative of the dust level in the area surrounding the blasthole drill. A separate analysis was also conducted for data collected at Location A because its close proximity to the drilling process should provide a reasonable measure of dust leakage from the shroud.

Wind direction has a considerable effect on dust sampling at surface mining operations because dust samplers that are downwind of the dust source will record higher dust concentrations than dust samplers that are upwind of the source [8,9]. Therefore, data were categorized into wind quadrants to ensure comparable results for this study.

A Young (Traverse City, MI) wind direction and speed instrument and Telog (Victor, NY) data loggers recorded wind conditions for each drilled hole. In addition, the orientation of the drill with respect to true north was determined for each hole using a Garmin (Olathe, KS) GPS device. This information facilitated the categorization of data into four distinct wind quadrants (Figure 3). Quadrant I data included holes drilled when the wind was blowing from the front of the drill toward the back, Quadrant II was right-to-left, Quadrant III was back-to-front and Quadrant IV was left-to-right. Wind speed information is omitted from this report because a regression analysis found no correlation between the wind speeds of 0 to 4.5 m/s encountered during the field studies and respirable dust concentrations.

3. Field testing of air-blocking shelf

3.1. Mine A

Mine A was a surface coal mine in southwestern West Virginia, which used an Atlas-Copco (Commerce City, CO) DM45E blasthole drill. Blastholes were drilled using rotary drilling with a 20-cm tricone roller bit and a 12.7-cm drill pipe. The blastholes required an average time of 7 min to complete and depths varied from 7.6 m to 10.7 m. The drill's compressor was rated at 425 l/s at 827 kPa. The dust collector was rated at 1700 l/s. The drilling machine at Mine A was operated on the same bench for the first 3 days of the study. During the fourth day, it was moved to a different location. However, the overburden geology was the same at the new location, so all data collected during the study were assumed to be comparable.

The drill shroud at Mine A was constructed of a single piece of reinforced rubber material with a hydraulic access door on the frontside of the machine. Figure 4 shows installation of the air-blocking shelf at the mine with the mast in the lowered position. The shelf was constructed of 15.2-cm wide conveyor belting material (63.5-mm thick), which was bolted to 5.1-cm light gauge angle iron. The angle iron was then bolted to the inside perimeter of the shroud. A section of shelf (not pictured) was added to the door flap of the shroud to assure complete coverage of the parametric cross-section. Two people were able to install the shelf in less than an hour.

Table 1 shows the geometric mean dust levels in the area surrounding the drill (comprised of data collected at all sampling locations) as well as dust levels collected at the shroud (Location A). Values are presented for both the shelf-off and shelf-on conditions and are segmented by wind quadrant. The table also shows the number of drill holes comprising each mean, the geometric standard deviations and the 95% confidence intervals (CIs). When the 95% CIs for the shelf-on and shelf-off conditions did not overlap, the difference was assumed to be significant. Significant

Figure 4. Installation of the air-blocking shelf at Mine A. The shelf is constructed of light gauge angle iron (silver) and thin, 63.5 mm, conveyor belting material (red).

Table 1. In-field testing results showing the geometric means of dust levels (mg/m^3) in the area surrounding the drill with confidence intervals, as well as dust reductions achieved with the shelf.

Mine	Quadrant	Sample location	Condition	n	Geometric mean (μ_g)	Geometric standard deviation (σ_g)	95% CI for μ_g	Percent reduction
A	I	All	Shelf-off	11	1.59	1.66	1.13 to 2.24	
A	I	All	Shelf-on	14	0.49	2.02	0.33 to 0.73	69
A	I	A	Shelf-off	11	0.65	2.95	0.32 to 1.35	Not
A	I	A	Shelf-on	14	0.14	12.55	0.03 to 0.61	Significant
A	IV	All	Shelf-off	8	1.12	1.89	0.66 to 1.91	
A	IV	All	Shelf-on	29	0.34	2.13	0.26 to 0.45	70
A	IV	A	Shelf-off	8	1.82	2.33	0.90 to 3.69	[a]Not
A	IV	A	Shelf-on	29	0.61	3.96	0.36 to 1.03	Significant
B	IV	All	Shelf-off	23	0.19	2.30	0.13 to 0.28	Not
B	IV	All	Shelf-on	9	0.34	2.28	0.18 to 0.64	Significant
B	IV	A	Shelf-off	23	4.16	2.35	2.88 to 6.02	
B	IV	A	Shelf-on	9	0.77	3.25	0.31 to 1.91	81

Data units are mg/m^3.
n, number of drill holes; CI, confidence interval.
[a]66% reduction significant at 90% CI.

percent reductions achieved with the air-blocking shelf are reported in the last column of Table 1. At Mine A, there were too few data points for the shelf-on condition in Quadrants II (three data points) and III (two data points) to develop meaningful CIs; so, these data are omitted from the report. The lack of data in certain quadrants occurred because the wind direction and the orientation of the drilling machine on the bench remained relatively consistent on a daily basis. However, there were sufficient data for Quadrants I and IV. Dust levels measured in the areas surrounding the drill during Quadrant I wind conditions were 69% lower when using the air-blocking shelf (0.49 mg/m^3) vs. not using the shelf (1.59 mg/m^3). Dust levels measured in the areas surrounding the drill during Quadrant IV wind conditions were 70% lower when using the shelf (0.34 mg/m^3) vs. not using the shelf (1.12 mg/m^3). The dust levels at the shroud position (Location A) were not significantly different using 95% CIs; however, shroud dust levels under Quadrant IV wind conditions were significantly lower (66%) for the shelf-on condition when using 90% CIs. The level of reduction measured at the shroud was consistent with reductions measured in the areas surrounding the drill.

Although the air-blocking shelf was successful in reducing dust levels at Mine A, two minor issues were identified. First, because the shelf diverted material away from the sides of the shroud, the drill operator found it more difficult to judge when the drill penetrated the coal seam. At this particular mine, the operator visually confirmed when the drill penetrated the coal seam by observing when the material escaping the shroud changed colour from light grey or tan (mineral) to black (coal). The operator told researchers that this was a minor operational issue since it only impacted the last few feet of drilling.

A second issue was related to the buildup of material on top of the shelf. The weight of this material, as well as the weight of the shelf itself, caused the shelf to slump at a 45-degree angle because of the weakness of the shroud material. This was addressed during the second field study by attaching chains from the outer edge of the shelf to a point higher on the shroud to add support.

3.2. *Mine B*

Mine B was a surface limestone mine in southwestern Pennsylvania, which used a Reich (Philipsburg, PA) C-650-C blasthole drill. Blastholes were drilled using a down-the-hole hammer drill with a 16.5-cm hammer bit and a 12.7-cm drill pipe. The blastholes required an average of 7.5 min to complete and depths varied from 6.1 m to 13.7 m. The drill's compressor was rated at 472 l/s at 2410 kPa. The dust collector was rated at 1180 l/s. All of the holes that were drilled throughout the study occurred on the same bench and were considered comparable. The drill shroud at Mine B was constructed similar to the one at mine A.

The sampling strategy and equipment used at Mine B was similar to Mine A with one exception. At Mine B, a smaller Atlas Copco ROC-L8 drill was operated on the bench simultaneously with the Reich drill. To account for the smaller drill's potential dust contribution to the larger drill, a tripod containing a PDR and two gravimetric samplers were positioned between the large and small drill. The orientation of the small drill with respect to the large drill was calculated using the Garmin GPS device. This orientation data, combined with the wind direction data, allowed researchers to determine when the small drill was operating upwind of the larger drill, thereby potentially contributing to dust measured at the six sampling locations. For example, assuming a line drawn from the large drill to the small drill was 90 degrees from true north, then wind directions from 0 to 180 degrees were considered to position the smaller drill upwind of the sampled drill. A comparison of dust levels measured on the large drill when the small drill was operated upwind of the large drill to dust levels when the small drill was downwind, under the same wind quadrant and shelf conditions, yielded no statistically significant difference. Therefore, the tripod data were not used in the analyses for Mine B.

Table 1 summarizes the data collected at Mine B. No comparisons were possible for Quadrants I, II and III because there were no data for the shelf-off condition in Quadrants I and II and no data for the shelf-on condition in Quadrants II and III. Dust levels in the area surrounding the drill were quite low for both the shelf-off (0.19 mg/m^3) and shelf-on (0.34 mg/m^3) conditions and were not significantly different. An analysis of dust levels at Location A, which may be a better indicator of control technology effectiveness due to its close proximity to the shroud, indicated a reduction of 81% when using the shelf. However, it appears that when dust levels in the areas surrounding the drill are already quite low, that incremental reductions achieved with the shelf may have no significant bearing on the dust exposures of personnel working in the vicinity of the drill unless they are in an area in close proximity to the shroud.

Two design issues were identified at Mine B when using the air-blocking shelf. When the boom was lowered, the material that collected on the shelf became dislodged, resulting in a dust plume from under the shroud. Based on this occurrence, researchers recommend installing the shelf at a 45-degree angle to minimize the build-up of material on the shelf. This can be accomplished by bending the angle iron before installation. Installing the shelf at a similar angle in the laboratory only slightly (76 reduction vs. 81%) diminished its performance [3].

The second design issue was related to the length of the shelf sections used at Mine B. The shelves were cut to the same dimensions as the drill table. A follow-up visit to the mine approximately 4 months after installation found that the shelf, while still functional, had been damaged. The angle iron became bent because of interactions between the shroud and rock piles on the bench. Therefore, it may be beneficial to install the shelf using smaller and staggered sections to allow greater shroud flexibility.

4. Conclusions

The air-blocking shelf installed around the inside perimeter of the blasthole drill shroud improves dust control. This simple and inexpensive modification reduced dust concentrations in areas surrounding an operating blasthole drill by 70% in the field. Dust reductions measured in the immediate vicinity of the shroud were reduced by 66 to 81%. Without the use of this shelf, the strong Coanda-effect airflow pattern, inside the shroud, results in dust leakage to the environment at the shroud-to-ground interface. The shelf prevents this dust leakage by redirecting the downward airflow adjacent to the shroud toward the centre of the enclosure, where it can be captured by the dust collection system.

Some drill shrouds are constructed of four separate pieces of conveyor belting that are joined at the corners of the drill deck, which can result in vertical gaps. The air-blocking shelf is also capable of overcoming the adverse impact of vertical leakage from shroud seams if the source of leakage is confined to an area below the horizontal plane defined by the shelf location [3]. Vertical leakage does not occur for shrouds constructed of a single piece of conveyor belting material that surrounds the perimeter of the drill deck.

The shelf sections, constructed of angle iron and 15.2-cm wide conveyor belting material, are not required to be installed on the same horizontal plane, but coverage of the cross-sectional perimeter is essential [3]. In fact, installing the shelf using smaller and staggered shelf sections may help prevent damage resulting from interactions between the shelf and rock piles on the bench or uneven bench levels. From a dust control and operational perspective, higher shelf locations work better than lower ones [3]. During field testing, the shelf was located at a height approximately equal to half the distance measured from the bottom of the shroud to the bottom of the drill deck.

A disadvantage to the shelf occurs when lowering the drill mast. If the shelf is installed at a 90-degree angle to the shroud, cuttings accumulate on the top surface of the shelf, and when the mast is lowered, this fine material falls off causing a dust plume. This may not be a problem if the mast is only lowered occasionally; however, it may be significant if the mast is lowered after every drill hole. To prevent this problem, the shelf can be installed at a 45-degree angle toward the ground, allowing the material to roll off of the shelf during drilling, thus minimizing the dust plume created during lowering. The 45-degree angle of the shelf can be accomplished by bending the angle iron before installation. Installing the shelf at this angle has been found to only slightly diminish its performance in laboratory testing [3]. If the shelf is installed at a 45-degree angle, the shelf width should be increased to 21.6 cm to achieve the same horizontal blockage area. Finally, it is necessary to attach chains to the outside edges of the shelves and to anchor the chains to points higher on the shroud to prevent the shelf from sagging. This procedure preserves the desired angle of installation.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

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