

# Horizontal air-blocking shelf reduces dust leakage from surface drill shroud

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## Abstract

*Installation of a horizontal air-blocking shelf around the inside perimeter of the surface mining drill deck shroud is proposed to improve dust capture. Without the use of this shelf, a strong Coandă effect airflow pattern results in dust leakage to the environment, especially at the shroud-to-ground interface. Bailing air exits the drill hole and travels along the drill steel to the underside of the table, where it fans out across the bottom of the drill table and continues down the sides of the shroud. This dust-laden bailing air then strikes the ground and fans out under gaps between the shroud and the ground. The proposed shelf prevents dust-laden air from striking the ground by redirecting it toward the center of the enclosure, where it can be captured. Laboratory tests demonstrated that the shelf reduced dust levels outside of the shroud by 81% under operating conditions consisting of a 1.9:1 collector-to-bailing-airflow ratio and a 51-mm (2-in.) gap between the shroud and ground. The shelf was 152-mm (6-in.) wide and was located at a height equal to 2/3 the distance measured from the bottom of the shroud to the bottom of the drill table. The air-blocking shelf was also capable of overcoming the adverse impact of vertical leakage along the shroud seams as long as this leakage was confined to an area below the horizontal plane defined by the shelf location.*

## Introduction

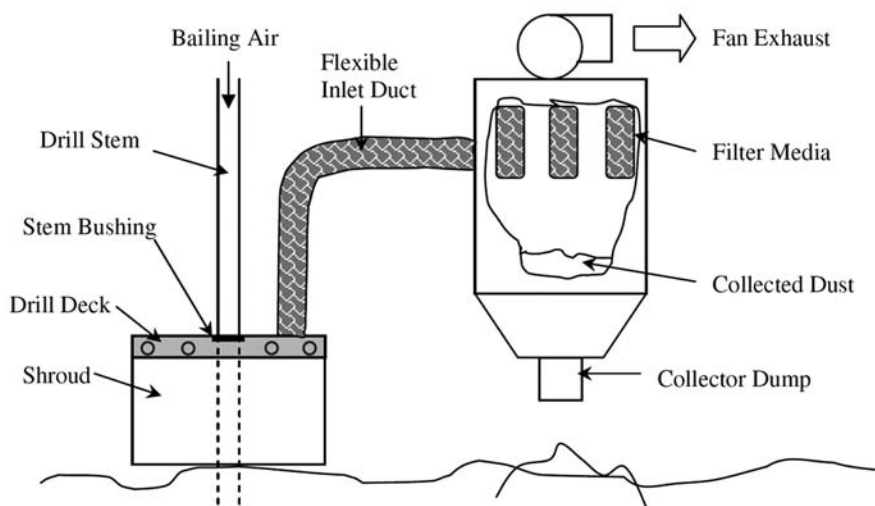
Overexposure to respirable crystalline silica dust can result in the development of silicosis, a serious and often fatal respiratory disease. The U.S. Mine Safety and Health Administration (MSHA) regulates the exposure of coal miners to hazardous substances and has set the permissible shift exposure limit for respirable dust at  $2.0 \text{ mg/m}^3$  when the crystalline silica level does not exceed 5%. If silica in the sample exceeds 5%, the respirable dust standard is reduced to a level equal to the quotient of ten divided by the percentage of quartz in the sample, resulting in an effective silica exposure limit of  $0.1 \text{ mg/m}^3$ .

Surface-coal drill operators have had some of the highest frequency for noncompliance, with the respirable dust standard exceeding the limit 15% to 19% of the time during the period from 2001 through 2006 (Joy, 2007). Compliance problems are exacerbated by both the level of respirable dust generated by the drilling machines and the fact that they are often being used to cut silica-bearing materials such as sandstone and shale. One study found that time-weighted average respirable dust levels in areas surrounding the drill shroud could exceed  $95 \text{ mg/m}^3$  (Organisak and Page, 1995). Depending on wind direction and worker location, rotary drills can potentially expose all surface workers to elevated silica levels. A recent voluntary study of Pennsylvania surface miners showed that nearly 7%

had radiological evidence of silicosis (Tyson et al., 1997). As demonstrated by the data above, additional technology is needed to reduce the exposure of surface miners to silica. A recent research project initiated by the National Institute for Occupational Safety and Health (NIOSH) identified improvement of the drill shroud design as one of its main objectives for reducing the exposure of surface miners to respirable dust. Priority was assigned to designs that would minimize operational resources and maintenance. A method utilizing a horizontal shelf attached to the inside perimeter of the shroud to disrupt the Coandă airflow pattern under the shroud shows promise for reducing dust leakage to the environment.

## Background

Many surface mining operations use dry drilling techniques to eliminate problems associated with wet drilling, including maintaining a constant water supply, short bit lives and freezing-related issues in colder climates. Dry drilling requires a dust collection circuit to remove dust from the bailing air. Components common to all dry dust collection systems are shown in Fig. 1, including a shroud to enclose the area under the drill deck, an inlet and flexible duct to route the dusty air to a filtration device and an exhaust fan to power the system. Dust emissions from this circuit can result from several sources, including the collector



**Figure 1** — Dry dust collection circuit.

exhaust, drill stem bushing leakage, shroud leakage and the dust collector dump discharge (Organiscak and Page, 2005). From a control standpoint, poor collector exhaust quality and drill stem leakage are largely a function of improper maintenance, which can be easily remedied. In addition, an effective dust-control technique, which makes use of a simply constructed shroud, has already been identified for minimizing collector discharge dust generation (Reed et al., 2004). Therefore, NIOSH research efforts have focused on minimizing leakage from the shroud with field evaluations demonstrating that openings or gaps in the shroud can significantly diminish dust capture (Zimmer and Lueck, 1986; Zimmer et al., 1987). Oftentimes these gaps are unavoidable due to uneven and sloping ground surfaces and outward forces created by the accumulation of drill cuttings at the base of the shroud.

Drill shrouds commonly found in the field can be categorized into two main types: those constructed of a single piece of material wrapped around the drill table and those constructed of sectional pieces. A typical sectional arrangement is constructed of four separate pieces of conveyor material hung from each of the four sides of the drill table. Another common arrangement is a single piece of material around the table with a hinged access door on the front side of the shroud. The access door allows the operator to move the drill to the next hole without forcing the cuttings into the hole. Shrouds constructed of a single piece of material are subject mainly to horizontal leakage under the shroud, whereas sectional configurations are additionally subject to vertical leakage along the seams.

Airflow patterns within the shroud enclosure were investigated in a full-scale drill table simulator (described in the next section) to determine if dust-capture could be improved through simple modifications. A qualitative airflow model was developed using smoke tubes and a tuft grid technique (SAE, 1986), which uses a mesh and streamers to visualize the flow directions. One side of the simulator's shroud was constructed of transparent acrylic plastic to allow observation of the area enclosed by the shroud. The tuft grid was created by attaching lightweight vinyl streamers to fencing material, which was cut to the same dimensions as the horizontal parametric cross-section of the shroud enclosure. Airflow patterns were observed at various heights under the shroud during operation of the drill simulator to develop the qualitative model

shown in Fig. 2. As a result of a strong Coandă airflow effect, the bailing air exits the drill hole and travels up the middle of the shrouded area, maintaining its course along the drill steel to the underneath side of the drill table, where it fans out across the bottom of the drill table and continues down the sides of the shroud. A dead air zone was found between the drill steel and sides of the shroud. Dust emissions from horizontal leakage occurred when the air traveling downward along the sides of the shroud struck the ground and fanned out underneath the enclosure. This leakage was observed when smoke tubes were aspirated at the base of the shroud.

A concept to reduce dust emissions caused by the above process was to disrupt this airflow and to redirect it toward the center of the enclosure to prevent air from striking the ground. This was accomplished, as shown in Fig. 3, by installing a 152-mm- (6-in.-) wide horizontal shelf

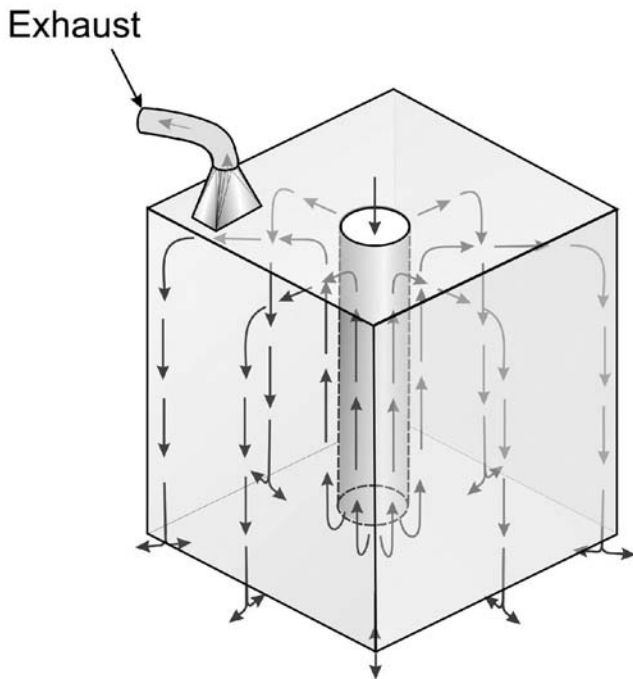
along the inside perimeter of the shroud. This paper describes the laboratory development of the concept and provides important design criteria for its successful application.

## Testing facility

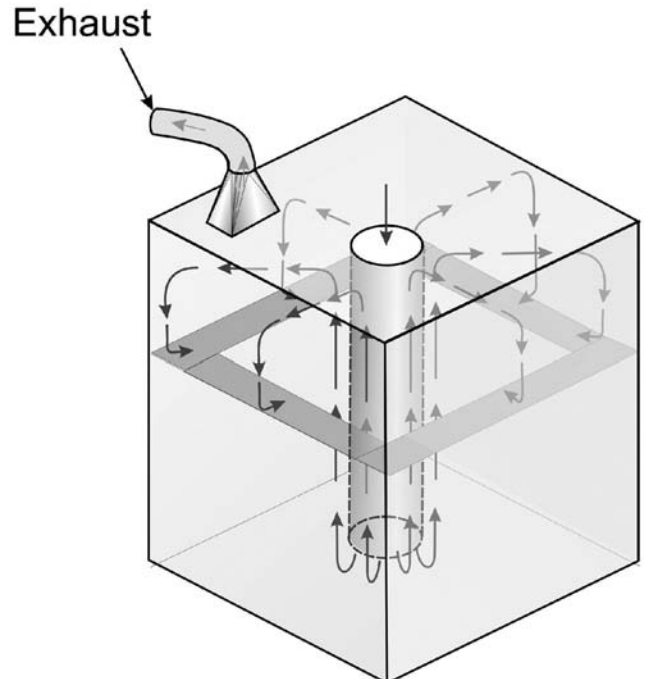
All preliminary and designed experimentation was conducted in NIOSH's full-scale drill table simulator located at the Pittsburgh Research Laboratory. The simulator is shown in Fig. 4 and described in detail in previous publications (Organiscak and Page, 2005). Operating parameters similar to a medium-sized rock drill can be produced in the lab. The dimensions of the shroud, which is located in the center of the dust chamber, are 1.52 m wide by 1.22 m deep by 1.22 m high (5 x 4 x 4 ft). The dust chamber dimensions are 3.66 m wide by 3.05 m deep by 2.44 m high (12 x 10 x 8 ft). The base of the shroud is fitted with hinged sections of plywood, allowing simulation of horizontal leakage at the ground surface with shroud gap heights of 51, 203 and 356-mm (2, 8 and 14-in.). To generate bailing airflow velocities typical of those found in the field, a compressor capable of generating 0.326 m<sup>3</sup>/s (690 cfm) at 758 kPa (110 psi) is used to force air down the inside of a 152-mm (6-in.) schedule 40 pipe, which simulates the drill steel. The 152-mm (6-in.) pipe is concentrically located and suspended within a capped 203-mm (8-in.) schedule 80 pipe, which simulates the drill hole. In this way, air is forced through the end of the 152-mm (6-in.) pipe and then upward between the outside diameter of the 152-mm (6-in.) pipe and inside diameter of the 203-mm (8-in.) pipe at velocities exceeding 30.5 m/s (6,000 fpm).

To simulate dust generation, a Vibra-Screw feeder is used to meter a constant flow of limestone dust (100% < 200 mesh) into the bailing airflow using a compressed air eductor. The dust collector utilized in the simulator is capable of providing a maximum airflow of 0.944 m<sup>3</sup>/s (2,000 cfm). The collector inlet is rectangular, measuring 457 by 191 mm (18 x 7.5 in.) and is located in the corner of the drill table, which is typical of field conditions.

During operation of the simulator, the dust concentration within the test chamber reaches a state of equilibrium because make-up airflow equals collector airflow and dust feed is constant. Adjustable louvers on top of the chamber ensure that make-up air velocities are significantly high to prevent dust



**Figure 2** — Coandă air effect under drill shroud.



**Figure 3** — Air-blocking shelf concept.

leakage from the chamber. This chamber configuration allows a direct comparison of the efficacies of various simulated drilling parameters and control technologies on shroud leakage.

### Preliminary testing

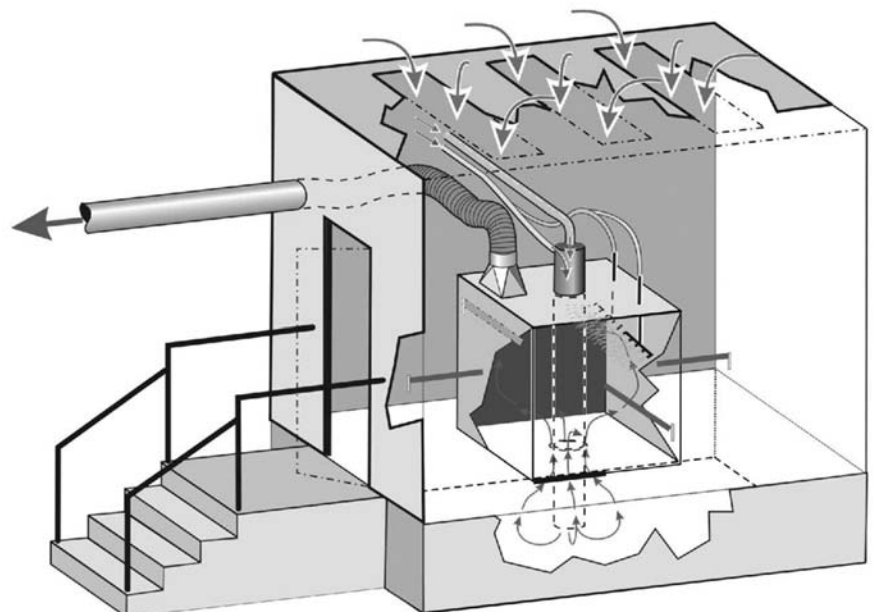
Preliminary testing was conducted to determine if the horizontal shelf warranted additional experimentation. It was also used to determine whether basic design criteria, such as shelf width and location, as well as material loading on top of the shelf, played any role in the effectiveness of the shelf for reducing dust concentrations.

Preliminary testing was conducted with two GCA real-time aerosol (RAM) instruments located outside the shroud at the front side (on inlet) and rear side (off inlet) of the drill table. Tests were conducted using an A-B format over a 30-minute sampling period, where the horizontal shelf was utilized during the first 15 minutes of the test and then removed for the last 15 minutes. All preliminary testing was conducted using a collector to bailing airflow ratio (airflow ratio) of 2:1, and shroud gap height at 51-mm (2-in.).

The first series of tests were conducted to determine if blocking width affected dust capture. Horizontal shelves were constructed of plywood at widths of 152, 89 and 38 mm (6, 3.5, and 1.5 in.). Each shelf was tested at a height of 813 mm (32 in.) above the bottom of the shroud, which equated to 2/3 of the total shroud height. All of the boards significantly improved capture, decreasing average dust levels outside of the box by 92%, 86% and 81%, respectively. Because decreasing the board width appeared to slightly diminish the ef-

fectiveness of the horizontal shelves, a 152-mm (6-in.) board width was used for a subsequent two-level factorial designed experiment.

A second series of tests were conducted to determine if board location would influence capture efficiency. For the first test, all of the 89-mm (3.5-in.) boards were placed at a lower location about 64-mm (2.5-in.) above the ground. During this test, dust levels were reduced about 72%, indicating that this is a less desirable location because the 89 mm (3.5 in.) boards lowered dust 86% at the higher location. Also, the higher location is less likely to interfere with the cuttings pile generated during drilling; therefore, no further testing was



**Figure 4** — NIOSH's full-scale drill table simulator.



**Table 1** — Two-level factorial experiment matrix and average gravimetric results.

Airflow ratio	Horizontal leakage	Blocking shelf	Test No.	Gravimetric average, mg/m <sup>3</sup>
1	1	0	14	8.48
1	1	0	15	8.87
1	1	0	19	7.7
1	0	0	2	21.04
1	0	0	8	21.29
1	0	0	17	21.43
0	1	0	1	18.83
0	1	0	5	15.39
0	1	0	10	16.61
0	0	0	7	27.04
0	0	0	21	34.67
0	0	0	24	36.28
1	1	1	9	1.67
1	1	1	12	1.25
1	1	1	20	1.85
1	0	1	3	5.57
1	0	1	18	5.65
1	0	1	23	7.77
0	1	1	13	4.7
0	1	1	16	3.15
0	1	1	22	3.9
0	0	1	4	18.72
0	0	1	6	19.54
0	0	1	11	22.57

1 = 1.9:1 airflow ratio, 51 mm (2 in.) shroud gap, with blocking shelf  
0 = 1.2:1 airflow ratio, 203 mm (8 in.) shroud gap, without blocking shelf

conducted at the lower position. For the second test, the positions of the 152-mm (6-in.) boards were offset to determine if gaps in placement would diminish performance. The front sideboard was lowered 102 mm (4 in.), while the rear sideboard was raised 102 mm (4 in.). During this test, dust levels outside of the shroud were reduced by 86%, indicating that locating the boards on the same horizontal plane was not an important design criterion. This may be a beneficial attribute for installation because operators will not have to be concerned with placing all of the blocking shelves on the same horizontal plane as long as they cover the parametric cross-section of the shroud. However, for final testing, the 152-mm (6-in.) boards were kept on the same horizontal plane.

The last preliminary test was conducted to determine if the buildup of material on the shelf would negate the dust-reduction effects of the horizontal shelf by altering the path of airflow within the shroud. For this test, sections of 208-mm- (8.2-in.-) wide cardboard were secured between the sides of the shroud and the outer edges of the 152-mm (6-in.) boards to simulate material collected on top of the shelf at a 43° angle of repose. During this test, dust levels were reduced 76%, indicating a somewhat diminished but still dramatic reduction in dust under the loaded condition. The unloaded condition was used for the designed experiment because any material buildup would fall off when the drill mast is lowered.

## Two-level factorial experiment

As a comparison to the successful testing detailed above, a two-level factorial experiment was designed to determine the dust

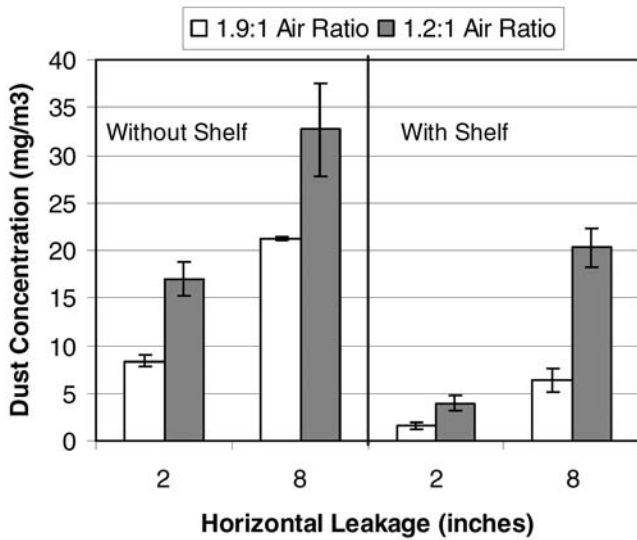
reduction potential of the horizontal shelf under more severe operating conditions. Collector-to-bailing airflow ratios of 2:1 and 1.25:1 were tested, as well as shroud gap heights of 51 and 203-mm (2 and 8-in.). Using these parameters and conducting experiments both with and without the use of the horizontal blocking shelf resulted in a matrix of eight (2 x 2 x 2) different tests. Each test was run three times for a total of 24 tests. All 24 tests were conducted in random order (Table 1).

Airflow ratios of 2:1 and 1.25:1 were attempted by targeting collector volumes of 0.472 and 0.295 m<sup>3</sup>/s (1,000 and 625 cfm), while keeping the bailing airflow volumes constant at 0.236 m<sup>3</sup>/s (500 cfm). After adjusting for temperature and pressure changes, actual bailing airflow volumes averaged 0.242 m<sup>3</sup>/s (513 cfm) and ranged from 0.236 to 0.245 m<sup>3</sup>/s (500 to 519 cfm). For tests targeting a collector volume of 0.472 m<sup>3</sup>/s (1,000 cfm), the actual levels varied between 0.437 and 0.464 m<sup>3</sup>/s (925 and 984 cfm) and averaged 0.450 m<sup>3</sup>/s (953 cfm), resulting in an average airflow ratio of 1.9:1. Tests targeting a collector volume of 0.295 m<sup>3</sup>/s (625 cfm) varied between 0.278 and 0.300 m<sup>3</sup>/s (589 and 636 cfm) and averaged 0.288 m<sup>3</sup>/s (610 cfm), resulting in an average airflow ratio of 1.2:1. Experimental airflow ratios were slightly lower than targeted ratios due to a slight drop in collector airflow observed during the course of each test, which occurred due to material loading on the baghouse filters.

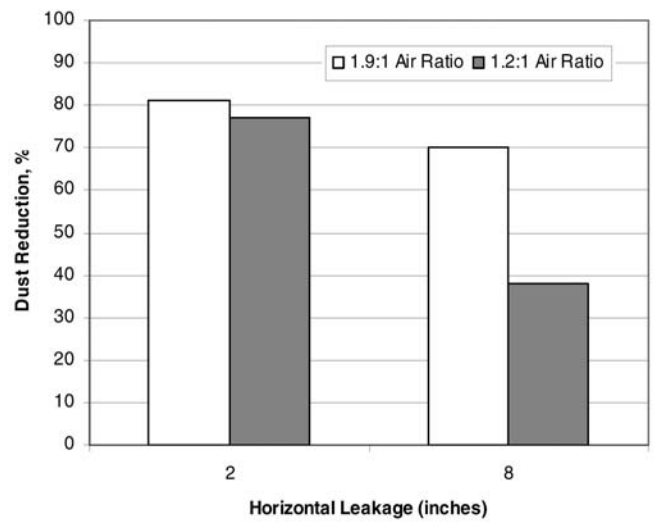
Respirable dust levels outside of the shroud were measured using samplers consisting of 37-mm filter cassettes and 10-mm Dorr-Oliver cyclones operated at a flow rate of 2 L/min. Two samplers were placed on each side of the box, approximately 406 mm (16 in.) from the box and 610 mm (24 in.) above the ground. The RAM samplers described in the preliminary testing section were also used to determine when dust levels in the chamber had stabilized. At this point, the gravimetric samplers were energized for a period of 30 minutes for each test. The limestone dust feed rate averaged 23.8 g/min during the factorial experiments, ranging from 21.4 to 25.0 g/min. This level allowed sufficient gravimetric filter loading during low dust concentration tests. The final chamber dust concentration was determined from the average of the eight gravimetric samples.

## Analysis of two-level factorial experiment

Use of a two-level factorial design experiment facilitated an analysis of variance (ANOVA) to determine the relative importance of the independent variables, including airflow ratio, shroud gap height, and the use of the blocking shelf on the dependent variable of dust concentration outside the shroud. Table 1 shows the experiment matrix and average gravimetric results. Table 2 shows the ANOVA for the experiment. Each independent variable was found to be highly significant (95% confidence interval did not include zero) and had a similar impact, in terms of magnitude, on dust levels outside of the shroud. Results from the experiment suggest that the use of a horizontal blocking shelf can overcome the detrimental effects on dust concentrations resulting from increasing the horizontal gap between the bottom of the shroud and the ground from 51 to 203 mm (2 to 8 in.) or resulting from decreasing the airflow ratio from 1.9:1 to 1.2:1. Figure 5 shows dust levels under various operating conditions both with and without the use of the air-blocking shelf. Figure 6 shows relative percentage dust reductions measured when using the shelf. At an airflow ratio of 1.9:1 and a 51 mm (2 in.) shroud gap height, the use of the shelf decreased dust levels outside of the shroud by 81%. The reduction achieved with the shelf was 70% at a ratio of 1.9:1 and a 203-mm (8-in.) gap and was 77% at a ratio of 1.2:1 and a 51-mm (2-in.) gap. A reduction of 38% was achieved through



**Figure 5** — Dust concentrations outside the shroud with and without the air-blocking shelf, standard deviation bars shown.



**Figure 6** — Measured dust reductions using the air-blocking shelf.

the use of the shelf under poor operating conditions consisting of an airflow ratio of 1.2:1 and a 203-mm (8-in.) shroud gap height. The independent variables examined for this experiment accounted for approximately 90% (adjusted  $R^2$ ) of the difference in measured dust levels outside of the shroud.

### Analysis of the blocking shelf when vertical leakage occurs

Two separate experiments were conducted to test the effectiveness of the air-blocking shelf for reducing dust when vertical leakage was present in the shroud design. As discussed above, vertical leakage scenarios can arise when sectional conveyor belt pieces are incorporated into the shroud design. The first experiment examined full-seam vertical leakage, where the vertical leakage extended from the base of the shroud to the bottom of the drill table. This condition was simulated by attaching hinges to the top side of the plywood on the off-inlet side of the shroud and propping the shroud open a distance of 152 mm (6 in.) at the base. The second experiment examined partial vertical seam leakage, where the vertical leakage extended from the base of the shroud to a point just below where the blocking shelves were installed. Figure 7 shows the shroud configurations for both the full and partial vertical leakage scenarios. During these experiments, both the airflow ratio and shroud gap height were kept constant at 2:1 and 51 mm (2 in.), respectively. A total of six tests were conducted for each experiment, alternating between using and not using the air-blocking shelf.

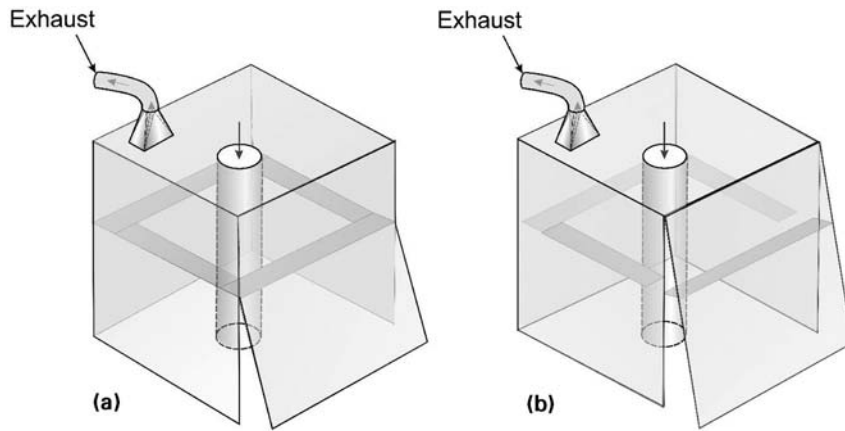
For the full vertical leakage experiment, dust concentrations outside of the shroud averaged 10.69  $\text{mg}/\text{m}^3$  (0.50 standard deviation) when using the shelf, and 10.61  $\text{mg}/\text{m}^3$  (0.44 standard deviation) when not using the shelf. Calculation of the 95% confidence interval ( $0.08 \pm 1.04$ ) for

comparing the difference between two means with equal variance could not exclude zero, indicating that no true difference between the means existed. Therefore, the air-blocking shelf was not effective for controlling dust under the condition of full vertical leakage. Researchers hypothesized that air traveling down the sides of the shroud struck the shelf and was forced out through the gap created to simulate vertical leakage during the experiments.

For the partial vertical leakage experiment, dust concentrations outside of the shroud averaged 2.06  $\text{mg}/\text{m}^3$  (0.26 standard deviation) when using the shelf, and 9.60  $\text{mg}/\text{m}^3$  (0.65 standard deviation) when not using the shelf. Calculation of the 95% confidence interval ( $-7.54 \pm 1.11$ ) for the difference between these two means excluded zero, indicating that a true difference did exist. The air-blocking shelf reduced dust levels outside

**Table 2** — ANOVA for two-level factorial experiment.

Regression statistics				
Multiple R				0.958
R square				0.918
Adjusted R square				0.905
Standard error				3.17798
Observations				24
ANOVA				
	Degrees of freedom	Sum of squares	Mean square	Significance F
Regression	3	2252.438	750.813	74.341
Residual	20	201.991	10.100	
Total	23	2454.430		
	Coefficients	Standard Error	t-value	Significance t
Intercept	30.553	1.297	23.549	0.000
Airflow ratio	-9.069	1.297	-6.99	0.000
Shroud gap	-12.431	1.297	-9.581	0.000
Air blocking shelf	-11.774	1.297	-9.075	0.000



**Figure 7** — Shroud configurations for both (a) partial and (b) full vertical leakage configurations.

the shroud by 79% when the vertical leakage was contained below the shelf plane.

The results from the vertical leakage experiments underscore the importance of maintaining a tight shroud seam seals at least to the horizontal plane created by the lowest air-blocking shelf. Angle iron installed at the seam corners may be suitable for creating these seals.

## Conclusions

One objective of a recently initiated NIOSH project was to develop an improved shroud design for lowering dust liberation from surface mine drilling machines. Emphasis was placed on a design that would minimize resources and maintenance. During the course of the project, researchers discovered a Coandă effect airflow pattern under the shroud enclosure created by the bailing air, which traveled upward along the drill steel, fanning out across the bottom of the drill table and flowing down the sides of the shroud. This dust-laden bailing air struck the ground and fanned out under gaps between the shroud and the ground, resulting in respirable dust leakage to the environment.

Laboratory tests showed that installation of a horizontal air-blocking shelf around the inside perimeter of the shroud disrupted this Coandă pattern and improved dust capture under the shroud. The blocking shelf was 152-mm (6-in.) wide and located at a height equal to 2/3 the distance measured from the bottom of the shroud to the bottom of the drill table. Under operating conditions consisting of a 1.9:1 collector to bailing airflow ratio, and a 51-mm (2-in.) shroud gap height, the air-blocking shelf reduced dust levels outside the shroud by approximately 81%. The air-blocking shelf was also shown to be capable of overcoming the adverse impact of vertical leakage along the shroud seams, as long as this leakage was confined to an area below the horizontal plane defined by the shelf location. Performance of the shelf was diminished to a 38% reduction in dust levels when the operating conditions

were poor, including a 1.2:1 airflow ratio and a 203-mm (8-in.) shroud gap height.

Laboratory testing also identified several important design criteria for a horizontal air-blocking shelf. First, a 102- to 152-mm (4- to 6-in.) shelf width appeared to be sufficient. Second, lowering the shelf did not improve performance. Third, the shelves, which were located on each side of the shroud, did not have to be placed on the same horizontal plane in order to be effective. Rather, coverage of the parametric cross-section of the shroud seemed to be the important design criteria. Finally, testing also demonstrated that material loading on top of the shelf only slightly diminished performance. Future research efforts will focus on evaluating the air-blocking concept for dust control on actual surface drilling machines.

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