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# Effects of vertical air-blocking ring of drill shroud on dust control for surface mine drilling operation using CFD

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ABSTRACT: Dust control by a horizontal air-blocking shelf inside a drill shroud was effective in a previous study by researchers at the National Institute for Occupational Safety and Health (NIOSH). However, when a medium-sized drilling machine lowers its mast, material deposited on the shelf can produce a significant dust cloud. To minimize this dust exposure hazard, researchers applied a 208-L (55-gallon) drum-sized ring, installing it concentrically with the drill stem under the deck table to act as a vertical air-blocking ring to control the drill dust leakage. Simultaneously, gravity force was utilized to minimize material buildup. Computer simulation was used in the evaluation. Three groups of ring heights were studied: short [5.1-cm (2-in), 7.6-cm (3-in), and 10.2-cm (4-in)], medium [15.2-cm (6-in), 30.5-cm (12-in), and 45.7-cm (18-in)], and long [61.0-cm (24-in) and 76.2-cm (30-in)]. The dust leakage was simulated using computational fluid dynamics (CFD) under the commonly encountered field conditions of a 2:1 dust-collector-to-bailing airflow ratio and a 5.1-cm (2-in) shroud-to-ground gap. Based on this simulation study, the vertical air-blocking ring with medium heights has the potential to effectively confine the dust inside the drill shroud. Other shorter or longer height rings may not be as effective in preventing dust leakage from the shroud. The results of this study can be used to guide future laboratory tests.

## 1 INTRODUCTION

Drilling operations are common sources of respirable dust generation and liberation at surface mines. These dust emissions can cause high dust exposures for the drill operator and nearby mineworkers downwind of the drill if windy conditions are present. When drilling through silica-bearing materials, such as sandstone and shale, mineworkers can be exposed to high concentrations of respirable silica dust. Silica dust overexposures can lead to silicosis, an occupational lung disease that has no cure and is often fatal [Lara, 2020].

To reduce or eliminate the likelihood of developing silicosis, many rotary drilling operations use a dry collection system [Organiscak and Page, 2005]. Figure 1 shows a typical dry dust collection system schematic for medium and large drills. Compressed bailing air is forced through the inside of the hollow drill stem and released at the end of the drill bit to flush the drill cuttings to the surface. On the surface, the bailing air with cuttings are contained by the drill deck and deck shroud. The larger cuttings are deposited inside the shroud area while fine particles are pulled into a dust collection system, where they are trapped in filters prior to the air being exhausted back into the environment through the fan. To prolong filter life, the filters are back-flushed regularly with compressed air to remove excess particulates, typically known as the dust filter cake. This dust falls out into the collector chamber and then ultimately drops out of the bottom of the collector onto the mining bench. More detailed descriptions of this operation can be found in studies conducted by the U.S. Bureau of Mines and the NIOSH [Maksimovic and Page, 1985; Organiscak and Page, 1995; Reed et al., 2008].

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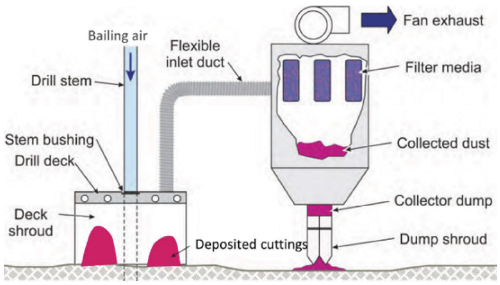


Figure 1. A basic dry dust collection system on a drill.

Previous laboratory tests and CFD studies have demonstrated that under a 5.1-cm (2-in) deck shroud-to-ground gap condition, if the dust collector-to-bailing airflow ratios are 3:1, the dust leakage from the drill shroud will be greatly reduced. If the ratios can be increased to 4:1, the respirable dust can be well-confined within the drill shroud. However, this higher ratio is difficult to attain at mining sites. The ratio encountered during past NIOSH studies of operating drills averaged about 2:1 [Zheng et al., 2016].

To better confine the dust cloud inside the drill shroud, the airflow pattern was further investigated. The Coanda effect was observed [Potts and Reed, 2008]. Two common phenomena of the Coanda effect are: first, the tendency of an air jet approaching a curved surface to remain attached to the surface even after the surface curves away from the initial jet direction; and second, the tendency of an air jet to adhere to a nearby surface [Trancossi, 2011]. Within a drill shroud, the airflow tends to follow the inner surfaces of the drill shroud and leaks out at any shroud-to-ground gap. An air-blocking shelf was configured to reduce the Coanda effect and was shown to be effective in both laboratory and field test scenarios [Potts and Reed, 2008; 2011]. CFD simulations also evaluated the air-blocking shelf and estimated that a dust-collector-to-bailing airflow ratio as low as 1.75:1 when using the air-blocking shelf may effectively confine dust inside the drill shroud [Zheng et al., 2018].

During field studies, a considerable amount of debris was deposited on the air-blocking shelf during the drilling process (Figure 2), and these deposits did not appear to affect the dust control effects of the air-blocking shelf. However, when the drill mast was lowered to move from one location to another, the buildup of materials on the air-blocking shelf liberated a dust cloud when the material fell off the shelf, as shown in Figure 3.

To eliminate debris on top of the air-blocking shelf, NIOSH researchers proposed two types of inner-shaped drill shrouds, U-shaped and V-shaped, along with a drill shroud with air-blocking shelves installed at a 45° angle from the horizontal direction. Those three designs provide a sloped shelf surface with an angle greater than the dust's angle of repose. This allows gravity to overcome the material's internal friction to prevent material accumulations. The research results revealed that the U-shaped drill shroud and the 45° air-blocking shelves can potentially confine the dust inside the drill shroud [Zheng et al., 2021].

This study uses a vertical air-blocking ring to eliminate debris accumulation. To simplify the application, commercially available 208-L (55-gallon) drums (Figure 4) can be utilized accordingly and cut into different heights. The resulting drum section can then be installed concentrically with the drill stem under the drill deck to act as a vertical air-blocking ring. A total of eight cases were studied using CFD analysis with different heights of rings cut from the commercially available 208-L (55-gallon) drum [0.58-m (23-in) in diameter and 0.86-m (34-in) in total height]: 5.1-cm (2-in), 7.6-cm (3-in), 10.2-cm (4-in), 15.2-cm (6-in), 30.5-cm (12-in), 45.7-cm (18-in), 61.0-cm (24-in), and 76.2-cm (30-in). The dust leakage was evaluated under commonly encountered field conditions of a 2:1 dust-collector-to-bailing airflow ratio and a 5.1-cm (2-in) shroud-to-ground gap. This current study, along with previously validated CFD studies, was adopted to evaluate whether the dust-laden airflow can still be effectively confined inside the drill shroud with minimal leakage when using the vertical air-blocking ring.

Figure 2. The buildup of drill cuttings on the air-blocking shelves.


Figure 3. Dust generated during the lowering of the drill mast.


Figure 4. 208-L (55-gallon) drums manufactured with different materials with 0.58-m (23-in) in diameter and 0.86-m (34-in) in total height [EBK, 2022].

## 2 CFD MODELING

The ANSYS Fluent Version 18.2 program (ANSYS, Canonsburg, PA) was used to perform the analysis of dust distribution within the drill shroud and surrounding space. The schematic of the airflow domain inside the drill table simulator was built according to the geometry measured from NIOSH's full-sized test facility. Figure 5 (a) shows the size of the dust chamber: 3.66-m wide by 3.05-m deep by 2.44-m high (12-ft by 10-ft by 8-ft). The shroud, located in the center of the dust chamber, measures 1.52-m wide by 1.22-m deep by 1.22-m high (5-ft by 4-ft by 4-ft). More detailed setup of the full-scale facility can be found in previous literature [Organiscak and Page, 2005; Potts and Reed, 2008, 2011].

A schematic of the computational domain is shown in Figure 5. Only two cases out of the eight geometric models are shown here. In Figure 5 (a), the segment of the drum is a 5.1-cm (2-in) height ring under the bottom of the drill deck with a common drum diameter of 58.4-cm (23-in). In Figure 5 (b), the height of the ring shown is 45.7-cm (18-in).

The locations of the boundary conditions for CFD are illustrated in Figure 5 (b). The boundary conditions applied in the simulation include roof inlet, bailing air inlet, and dust collector outlet. Intake airflow is pulled into the simulation domain through the three openings on the roof, shown as "Roof inlet" in Figure 5 (b). At the same time, the bailing air with dust is injected into the simulation domain from a circular face inside the drill pipe, as indicated by the bailing air inlet. The dust collector pulls air from inside the drill shroud and discharges it at the dust collector outlet.

Previously validated CFD models were used in this study to evaluate the effect of these vertical air-blocking rings of the drill shroud on dust control [Zheng et al., 2016; 2018]. Dust was treated as a gas ($CO_2$), and a species transport model in ANSYS Fluent was used. The boundary conditions used to determine the dust distribution inside the domain can be referred to in Zheng [2016]. The airflow patterns and dust control capabilities were simulated for the eight

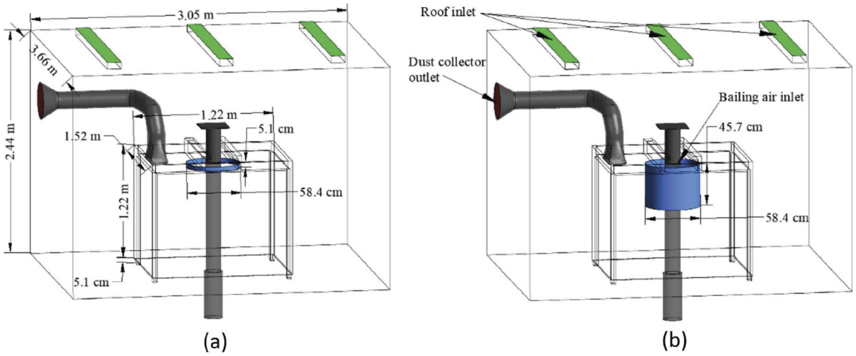


Figure 5. Overview of the CFD model with boundary conditions for (a) 5.1-cm (2-in) vertical air-blocking ring; (b) 45.7-cm (18-in) vertical air-blocking ring.

configurations and evaluated under the same ventilation conditions: 0.24 $m^3$/s (500 cfm) of bailing airflow, 0.24 $m^3$/s (500 cfm) of intake roof airflow, and 0.48 $m^3$/s (1,000 cfm) of dust air mixture collected by the dust collector outlet, which equates to a 2:1 collector-to-bailing airflow ratio.

## 3 AIRFLOW AND DUST DISTRIBUTION RESULTS FROM CFD MODELS

The vertical air-blocking ring has a 90° slope angle in all eight cases, which is much larger than the angles of repose of minerals commonly encountered during drilling, which range from 0° to 50° [Dougherty and Schissler, 2020]. Under the vertical slope angle, the materials on the ring's inner walls cannot stay in place and will fall to the ground during the drilling process. The inner surface of the ring should be smooth enough to not provide any rough surfaces that allows any deposition of small dust particles. In addition, the material of the drum should not offer any electrostatic force to attach small particles. Based on the simulation results of the eight cases, the phenomena and dust control effects can be separated into three groups and are described in the following sections:

### 3.1 *Effect of the short vertical air-blocking ring from 5.1-cm (2-in) to 10.2-cm (4-in)*

Similar airflow patterns are observed for the vertical air-blocking ring with 5.1-cm (2-in), 7.6-cm (3-in), and 10.2-cm (4-in) height cases. Overall, the ring can divert airflow toward the ground, but cannot confine the dusty air inside the drill shroud.

Figure 6 shows that after the dust-laden air is released into the bailing air inlet, the air travels down inside the hollow drill stem, then reverses direction up the gap between the drill steel and drill hole. As the air flows up, it attaches to the outside surface of the drill steel and encounters the underside of the drill deck, where it fans out in all directions and flows to where the vertical air-blocking ring is located.

After the flow encounters the vertical air-blocking ring, the CFD simulation shows that the flow is blocked by the ring and is diverted downward, as shown in Figure 6 (b). Then, on the left rear corner of the drill shroud where the inlet of the dust collector is located, the dusty bailing air is exhausted into the dust collector pipe after the ring. On the right side of the drill shroud, the bailing air encounters additional air that is drawn into the drill shroud through the 5.1-cm (2-in) shroud-to-ground gap. The combined air is then recirculated counterclockwise toward the upper region of the drill shroud and flows toward the dust collector inlet.

Some bailing airflow at the front right corner of the drill shroud, after being deflected from the vertical ring, flows outward and is attached to the vertical deck shroud. It then flows down to the shroud-to-ground gap. Part of this airflow can leak out of the drill shroud after striking the ground.

The airflow before encountering the vertical air-blocking ring shows a Coanda effect. For the three cases with 5.1-cm (2-in), 7.6-cm (3-in), and 10.2-cm (4-in) ring heights, the diverted downward flow can still flow outward and attach to the vertical deck shroud wall. This is also a Coanda effect and can cause dust leakage. It can be observed in Figure 6 that airflow path lines are shown outside of the shroud and in Figure 7 that dust can leak out of the shroud and potentially expose any workers around the drill to respirable dust. The amount of dust leakage can result in potential relative dust concentrations ranging from 1.5 to 15.5 mg/m$^3$. In addition, the dust leakage occurs on the opposite side of the collector inlet, where the influence of the dust collector is relatively weak. This side is generally where the drill operator's cab is situated.

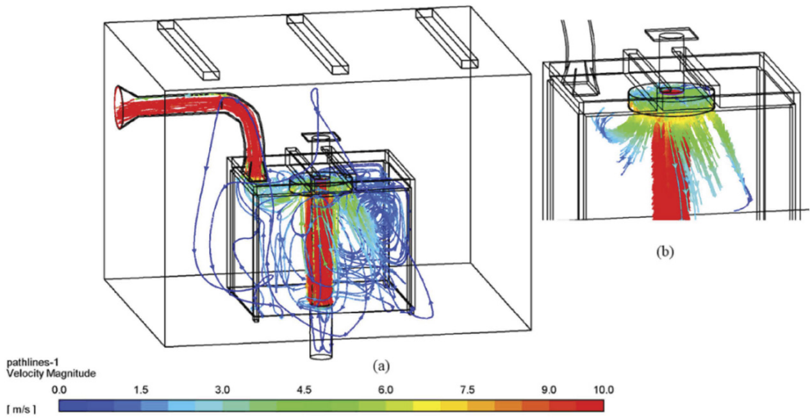


Figure 6. The pathlines of bailing airflow colored by velocity magnitude (0.0–10.0 m/s), 10.2-cm (4-in) height vertical air-blocking ring: (a) fully developed pathlines; (b) bailing air as it passes by the ring.

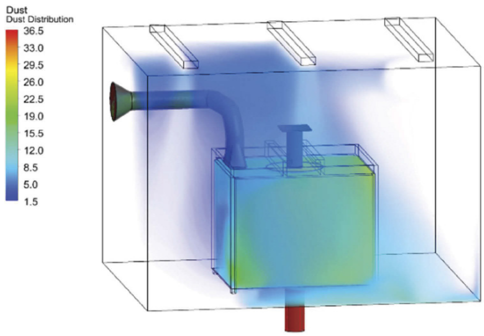


Figure 7. Respirable dust concentration distributions under 10.2-cm (4-in) height vertical air-blocking ring; legend shows the dust levels (1.5–36.5 mg/m$^3$).

### 3.2 *Effect of the medium vertical air-blocking ring from 15.2-cm (6-in) to 45.7-cm (18-in)*

For the cases with 15.2-cm (6-in), 30.5-cm (12-in), and 45.7-cm (18-in) height rings, the increased ring height can confine dusty bailing air more effectively at the center region inside the drill shroud as shown in Figure 8. The dust-laden air travels down the inside of the hollow drill stem, then goes up along the outside surface of the drill steel and fans out in all directions on the underside of the drill deck before the vertical air-blocking ring, similarly to the airflows depicted in Figure 6 (b).

As the airflow comes out below the ring, there are roughly three groups of flow: 1) the flow that goes directly toward the dust collector inlet on the left rear corner of the drill shroud; 2) the flow on the right side of the drill shroud, where the bailing air flows counterclockwise toward the upper region of the drill shroud and then flows toward the dust collector inlet through the upper front and upper rear regions outside of the ring; and 3) the flow that comes down at the front and right corner of the drill shroud which generally does not reach the ground, then flows toward the dust collector inlet. Compared to the flow in Figure 6, the difference is the third group of bailing airflow which is diverted by the vertical ring closer to the center of the drill shroud without attachment to the vertical drill shroud wall and therefore has a smaller chance to leak out of the shroud. This can also be observed in Figure 9 which demonstrates no respirable dust outside of the shroud.

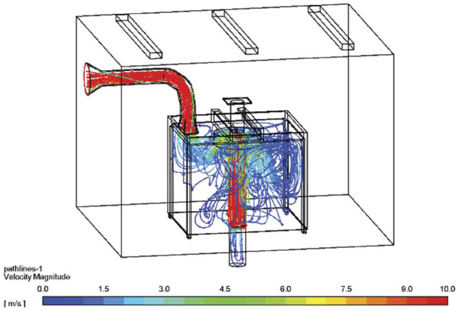


Figure 8. The pathlines of bailing airflow colored by velocity magnitude (0.0–10.0 m/s), 15.2-cm (6-in) height vertical air-blocking ring.

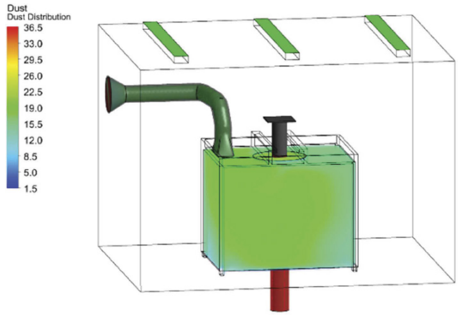


Figure 9. Respirable dust concentration distributions under 30.5-cm (12-in) height vertical air-blocking ring; the legend shows the dust levels (1.5–36.5 mg/m$^3$).

### 3.3 *Effect of the long vertical air-blocking ring from 61.0-cm (24-in) to 76.2-cm (30-in)*

As the vertical air-blocking ring increases to 61.0-cm (24-in) and 76.2-cm (30-in), the airflow pattern changes. There is a Coanda effect that shows up on the ground, which can be a problem, as revealed by this study.

The results from the CFD simulation in Figure 10 show that the pathlines of bailing airflow have the same flow patterns before they leave the bottom edge of the ring. At this point, the airflow remains directed downward, and the airflow velocity can be in the range of 4.0–5.0 m/s (787.4–984.3 fpm). Because the distance from the ground to the bottom of the ring is 52.8-cm (20.8-in) for the 61.0-cm (24-in) height ring and 42.7-cm (16.8-in) for the 76.2-cm (30-in) height ring, the high-velocity downward flow can reach the ground.

Once the airflow reaches the ground, it fans out horizontally in all directions (Coanda effect) toward the shroud-to-ground gap where it encounters the inflow from outside of the drill shroud. Although there is incoming flow in the opposite direction, dusty bailing air can still leak

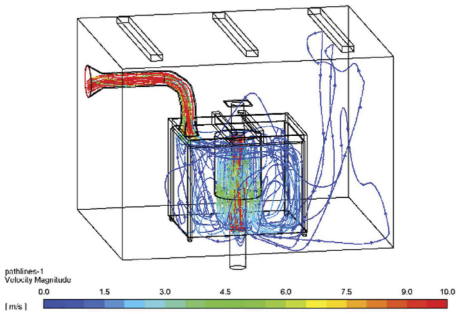


Figure 10. The pathlines of bailing airflow colored by velocity magnitude (0.0–10.0 m/s), 76.2-cm (30-in) height vertical air-blocking ring.

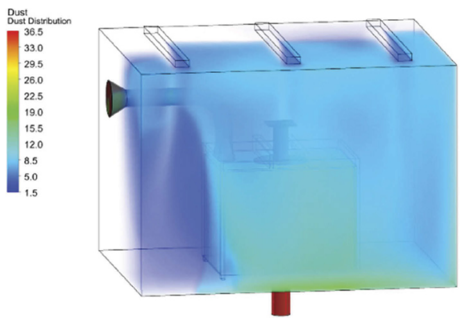


Figure 11. Respirable dust concentration distributions under 76.2-cm (30-in) height vertical air-blocking ring; legend shows the dust levels (1.5–36.5 mg/m$^3$).

out of the drill shroud in regions where the inflow is weak. As shown in Figure 11, these regions are located at the front right corner of the drill shroud, opposite of the dust collector inlet.

## 4 DISCUSSIONS

It was observed from the eight CFD simulations in this study that when the vertical air-blocking ring is short (not higher than 10.2-cm or 4-in), it can divert the airflow away from the bottom of the drill deck. However, it cannot alter the airflow direction completely from horizontal to vertical. The angled downward bailing airflow can still reattach to the vertical deck shroud walls and flow to the shroud-to-ground gap. Leaking can occur at the front and right corner where the influence of the dust collector is weak. This location is where the drill operator's cab is situated. Therefore, it is important for the drill operator's cab to have a properly designed and maintained enclosed cab filtration and pressurization system to prevent the drill operator from respirable dust exposure during drilling [Organiscak et al., 2018].

When the height of the vertical air-blocking ring increases to the medium range, from 15.2-cm (6-in) to 45.7-cm (18-in), most of the bailing airflow is confined in the central region of the drill shroud. Very little airflow reattaches to the vertical deck shroud walls contrary to the short vertical air-blocking ring cases (as shown in Section 3.1). There may be some airflow that reaches the ground as in longer vertical air-blocking ring cases (as shown in Section 3.3). However, most of the airflow remains in the center region of the drill shroud and can be confined effectively by the inflow of air from outside the drill shroud.

In the long range, once the heights of the vertical air-blocking ring are increased to 61.0-cm (24-in) and above, the bailing airflow is redirected vertically down to the ground and fans out in all directions due to the Coanda effect. As a result of the relatively high speed of the flow from the vertical ring, the outflow fanning at the ground surface can break through the shroud-to-ground gap, overwhelm incoming airflow from the opposite direction and increase the dust exposure to the surrounding environment.

For medium and large drill equipment with similar drill shroud size, this CFD simulation provides a range of vertical air-blocking ring heights that may be effective for dust control. However, it should be noted that as the drill cuttings accumulate on the ground inside the drill shroud (as shown in Figures 1 and 2), the distance between the growing cuttings and the bottom of the ring can dramatically decrease. The application of the vertical air-blocking ring may need to be adjusted accordingly based on the field conditions. For example, if the cuttings gradually accumulated to 25.4-cm (10-in) above the ground, the ring heights from 15.2-cm (6-in) to 45.7-cm (18-in) that were shown to be effective in this simulation may be required to be changed to between 15.2-cm (6-in) and 20.3-cm (8-in).

## 5 CONCLUSIONS

It has been previously demonstrated by NIOSH researchers that horizontally installed air-blocking shelves can effectively control the respirable dust inside the drill shroud during the drilling process. These shelf designs have no impact on drill operations or present any additional maintenance requirements. Once installed, the device is invisible, and drilling can continue as before with no change in productivity. However, the deposits on these shelves can create dust plumes when the machine changes drilling locations. In this study, various heights of vertical air-blocking rings were investigated to utilize gravity force to remove the deposit during drilling operations, preventing the buildup of material.

To simplify the application and minimize cost, the dimension of a commercially available 208-L (55-gallon) drum was built in the simulation and cut into a specific height of ring. The ring was then put concentrically with the drill stem under the deck table to act as a vertical air-blocking ring. The dust control capacities of eight rings' heights were evaluated using a previously validated CFD model.

Based on this study, the vertical air-blocking ring, categorized as medium, with a height between 15.2-cm (6-in) and 45.7-cm (18-in), has the potential to effectively confine the dust inside the drill shroud. The cases with shorter heights between 5.1-cm (2-in) and 10.2-cm (4-in) and longer heights above 61.0-cm (24-in) may have dust-leaking problems at regions where the dust collector's influence is weak.

The results of this study can be used to guide future laboratory tests. The vertical air-blocking ring combined with a different inner-shaped drill shroud design [Zheng et al., 2021] can provide a solution to dust problems while drilling and when the surface drill location is changed.

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