Effects of different shapes of drill shroud on dust control for surface mine drilling operation

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ABSTRACT: Dust control using drill shroud air-blocking shelves was confirmed effective. However, when the drilling machine moves to different locations, deposits on these shelves can produce a large dust cloud. To minimize this dust exposure hazard, this study modified the drill shroud air-blocking shelves by utilizing the concept of angle of friction to eliminate the deposits and, at the same time, still be able to confine the dust inside the drill shroud. Two types of inner shape were evaluated using CFD models: U-shaped and V-shaped drill shrouds. In addition, a drill shroud with 45° blocking shelves was also built to examine its dust control capacity. Based on the study, the angle of friction used to minimize the dust problems during mast lowering was shown to be effective in reducing the dust problems during drilling. However, care must be taken to use a properly designed shroud as the V-shaped drill shroud can potentially exacerbate the dust leakage.

1 INTRODUCTION

Surface blasthole drilling can generate considerable amounts of respirable dust. These high dust concentrations can be exacerbated by the high silica content as drilling cuts through silica-bearing materials such as sandstone and shale, causing overexposures for miners to respirable silica dust. These 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 blasthole drilling operations use a dry collection system [Cecala et al., 2012]. 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, where they 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 collector system, where they are trapped in the filters as the airflow exhausts through the fan. To prolong the life of the filters, the filters are back-flushed regularly by compressed air to clean the filters of excess particulate. The dust on the filters falls out into the collector chamber, then drops out of the bottom of the collector to the collector dump. More detailed descriptions of this operation can be found in studies conducted by researchers from the National Institute for Occupational Safety and Health (NIOSH) [Maksimovic and Page, 1985; Organiscak and Page, 1995; Organiscak and Page, 2005; Reed et al., 2008].

Previous lab tests and computational fluid dynamics (CFD) studies have demonstrated that under a 5.1 cm (2 in.) shroud-to-ground gap, if the dust collector-to-bailing airflow ratios are 3:1, the dust leakage from the drill shroud (drill deck and deck shroud shown in Figure 1) 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, at actual mining operations, this ratio is difficult to
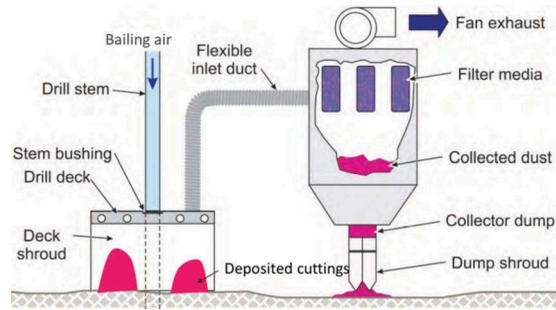
Figure 1.   A basic dry dust collection system on a drill.

attain. The ratio commonly encountered on operating drills normally averages about 2:1 [Page and Organiscak, 2004; Page et al., 2008; Zheng et al., 2016].

To better confine the dust cloud inside the drill shroud, the airflow pattern was further investigated and the Coanda effect [Potts and Reed, 2008; Trancossi, 2011] was observed, in which the airflow tends to follow the inner surfaces of the drill shroud and leaks out at the shroud-to-ground gap area. An air-blocking shelf was configured to reduce the Coanda effect and showed to be effective in both the 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 of 1.75:1 can still effectively confine dust inside the drill shroud [Zheng et al., 2018].

During the field studies, it was noticed that there was a considerable amount of debris deposited on the air-blocking shelf during the drilling process (Figure 2). These deposits do not affect the dust control effects of the air-blocking shelf at the same drilling site. However, once the drill moves from one location to another, especially when lowering the drill mast, the build-up of materials on the air-blocking shelf can generate a dust cloud, as shown in Figure 3.

To eliminate the debris on the top of the air-blocking shelf, the NIOSH researchers propose the use of the vertical drill shroud walls to provide a slope with an angle greater than the angle of friction. Under the greater slope angle, the materials on the sloped drill shroud walls cannot stay stable on the slope and will fall from the shroud down to the bench floor from its own gravity force during the drilling process. The mineral friction angle can be in the range of

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

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

226

0° to 50° with normal loose and dry minerals in the range of 17° to 44° [Geotechdata.info, 2013]. It is desirable to design the inner slope of the drill shroud greater than 45°.

To reduce the dust generation and liberation process when moving to different drilling sites, this study uses CFD to evaluate the dust control capacities of three configurations that are illustrated in Figure 4: a 45° inclined air-blocking shelf, U-shaped shrink drill shroud, and V-shaped shrink drill shroud. Among them, the 45° inclined air-blocking shelf has been field and lab tested to be effective in minimizing the dust deposits, and at the same time, reducing the dusty air leakage [Potts and Reed, 2008; 2011]. These three configurations were designed to minimize the deposits on the inner surface of the shroud. Previously validated CFD studies are adopted to evaluate whether the dust-laden airflow can still be confined inside the drill shroud without apparent leaking out. This study can provide critical information on future test setup in the lab and helpful suggestions for the engineers and miners to modify their working facilities.

2   CFD MODELING

The ANSYS Fluent Version 18.2 program [ANSYS, 2017] was used to perform the analysis of dust distribution within the drill shroud. The schematic of the airflow domain inside the drill table simulator was built according to the geometry measured from the full-sized facility. Figure 4 (a) shows the size of the dust chamber: 3.66 m wide by 3.05 m deep by 2.44 m high (12 × 10 × 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 × 4 × 4 ft.). In all the cases of this study, there is 5.1 cm (2 in.) of the shroud-to-ground gap. More detailed setup of the full-scale facility can be found in previous literature [Page and Organiscak, 2004; Organiscak and Page, 2005; Page et al., 2008; Potts and Reed, 2008, 2011].

A schematic of the computational domain for three different inner shape drill shrouds is shown in Figure 4. The geometric models considered in this study were: 1) 45° angled air-blocking shelf, Figure 4 (a); 2) U-shaped shrink shroud, Figure 4 (b); 3) V-shaped shrink shroud, Figure 4 (c).

In Figure 4 (a), the shelf was set at a 45° angle downward from the horizontal and located at two levels: 0.74 m (29 in.) and 0.52 m (20 in.) above the bottom of the drill shroud, which is 5.1 cm (2 in.) above the ground. Since the shelf was angled downward, the air-blocking shelf was 0.22 m (8.5 in.) wide to maintain a 0.15 m (6 in.) horizontal width. In Figure 4 (b), the drill shroud shrinks the same 0.15 m (6 in.) horizontal width toward the drill stem at 0.56 m (22 in.) below drill deck, then goes vertically 0.56 m (22 in.) until 5.1 cm (2 in.) above the ground and is denoted as the U-shaped shrink drill shroud. The locations of the boundary conditions for CFD are also illustrated in Figure 4 (b). In Figure 4 (c), the drill shroud shrinks 0.15 m (6 in.) horizontally toward the drill stem at 0.56 m (22 in.) below drill deck, then gradually expands to its original top size at 5.1 cm (2 in.) above the ground and is denoted as the V-shaped shrink drill shroud.

In all the cases, the same horizontal block width of 0.15 m (6 in.) is maintained to ensure the settings are comparable. As a result, the slope of the upper U-shaped and V-shaped shrink drill shroud is approximately 75° as shown in Figure 4 (b) and (c).

The boundary conditions applied in the simulation are illustrated in Figure 4 (b). Intake airflow is pulled into the simulation domain through the three openings on the roof, shown as roof inlet in Figure 4 (b). At the same time, the bailing air with dust is injected into the simulation domain from a circular face inside the hollow drill pipe, as indicated by the bailing air inlet in Figure 4 (b). The dust collector pulls air into the drill shroud and discharges at the dust collector outlet.

Previously validated CFD models were used in this study to evaluate the effect of these inner shapes 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 NIOSH full-scale drill shroud laboratory can be referred in Table 1 of previous study [Zheng et al., 2018].
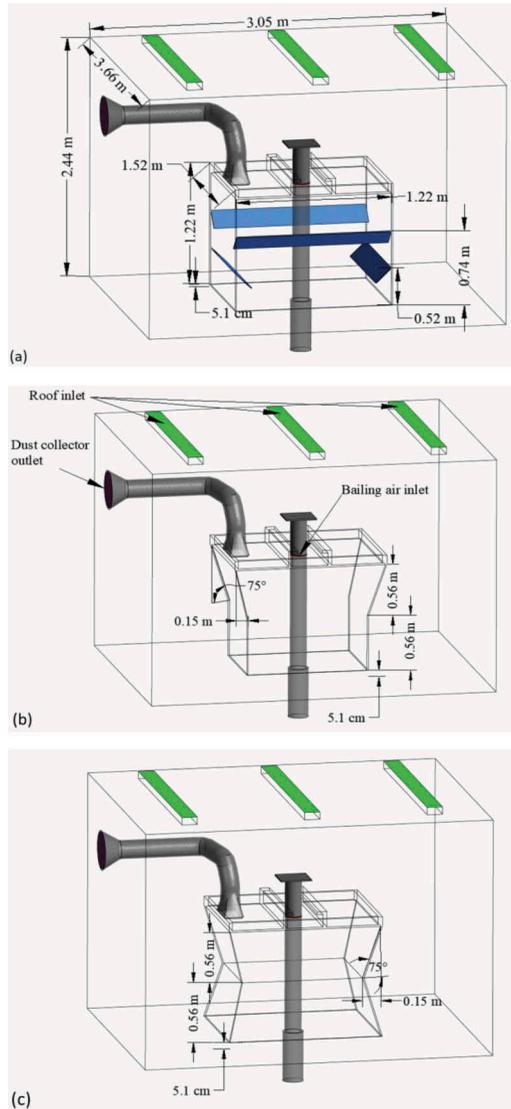
Figure 4. Overview of the CFD model with boundary conditions for (a) 45° inclined air-blocking shelf; (b) U-shaped shrink drill shroud; (c) V-shaped shrink drill shroud.

3 CHARACTERISTICS OF AIRFLOW AND DUST UNDERNEATH THE DRILL SHROUD

Since the slope of all three cases are greater than the friction angle of the overburden soil and ore minerals encountered during mining, it is assumed in this study that there should not be any deposit on the slope during and after the drilling process. The surface of the slope should be made smooth enough to provide a consistent slope. Otherwise, a tiny rough surface may offer different localized slope angles as a deposit area for small dust particles. In addition, the material of the slope should not offer any electrostatic force to attach small particles.

The airflow patterns and dust control capabilities were simulated for the three inner shape configurations. They were evaluated under the same ventilation conditions: 0.24 m³/s (500

cfm) of bailing airflow, 0.24 m³/s (500 cfm) of intake roof airflow, and 0.48 m³/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. All the drill shrouds have a 5.1 cm (2 in.) shroud-to-ground gap.

3.1 *Effect of 45° angled air-blocking shelves*

It can be seen from Figure 5 (a) that, after the dust-laden air is released from the bailing air inlet, it travels down inside the hollow drill stem, then makes a 180° turn up the gap between the drill steel and drill hole. As the air flows up, it follows the outside surface of the drill steel and encounters the underside of the drill deck, where it fans out in all directions and continues to follow the inner shape of the shroud down to where the air-blocking shelf is located.

After the flow encounters the 45° air-blocking shelves, the CFD simulation shows that most of the flow is guided toward the drill steel and then follows the upward bailing air and repeats the pattern while it continues to be drawn in by the dust collector. At the same time, some of the dust-laden air travels below the air-blocking shelves, where it mixes with incoming airflow that is drawn into the drill shroud through the 5.1 cm (2 in.) shroud-to-ground gap. The dust-laden bailing airflow below the level of the air-blocking shelves shows a complicated 3D flow pattern due to the combined forces from the dust collector and incoming intake airflow but cannot escape under the current conditions outside of the drill shroud.

The airflow above the air-blocking shelves shows a strong Coanda effect, where the airflow tends to attach to nearby surfaces [Potts and Reed, 2008; Trancossi, 2011], while the airflow below the air-blocking shelves does not show any apparent Coanda effect. Therefore, no respirable dust leaks out the drill shroud. It can be observed in Figure 5 (b) that higher dust level airstream (above 15.5 mg/m³) is located mostly above the sloped air-blocking shelves. Small amount of dust does migrate in the lower central region close to the ground, but nothing is emigrating out of the shroud.

3.2 *Effect of U-shaped shrink shroud*

It can be observed from Figure 6 (a) that the dust-laden air travels down inside 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. The airflow, so far, is similar to the 45° air-blocking shelves case above.

As the airflow follows the inner slope of the drill shroud, it shows a complicated 3D pattern. Some of the dust-laden air flows toward the drill steel, while other parts of the dusty air may attach to the adjacent side of lower part or corner of the drill shroud and flow to the shroud-to-ground gap. However, the flow that does come close to the 5.1 cm (2 in.) gap will not have
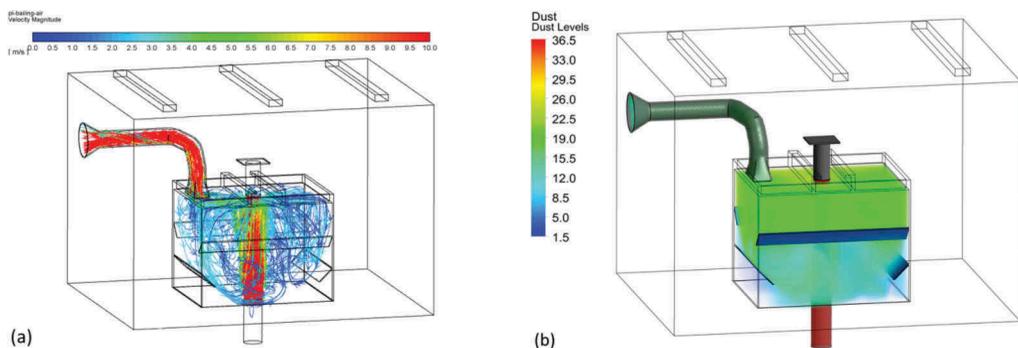

Figure 5.   Dust control by 45° angled air-blocking shelves: (a) the pathline of bailing airflow colored by a velocity magnitude (0.0–10.0 m/s); (b) the respirable dust concentration distribution; legend shows the dust levels (1.5–36.5 mg/m³).
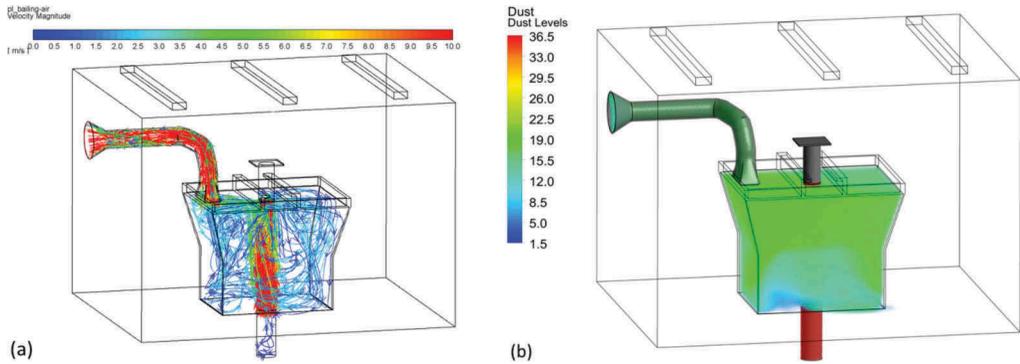
Figure 6. Dust control by U-shaped drill shroud: (a) the pathline of bailing airflow colored by a velocity magnitude (0.0–10.0 m/s); (b) the respirable dust concentration distribution; legend shows the dust levels (1.5–36.5 mg/m^3).

enough energy to strike the ground and leak out as shown by the pathline in Figure 6 (a). Figure 6 (b) shows that the respirable dust is mixed more uniformly inside the whole space compared to the sloped air-blocking shelves above. It is also possible that a tiny amount of dust leaks out of the drill shroud at the corner farthest from the dust collector pipe at a level of 1.5 to 5.0 mg/m^3. But it should not be a serious leak as the surrounding intake air is continuously bringing it back to the drill shroud. Overall, the U-shaped drill shroud can still effectively keep the respirable dust-laden air under control.

3.3 *Effect of V-shaped shrink shroud*

The results from the CFD simulation in Figure 7 (a) show that the pathlines of bailing airflow have similar flow patterns as the U-shaped shroud at the shrinking slope. As the airflow traveling down to the lower expansion part of the shroud space, it can be observed that some dust-laden flow can re-attach to the lower parts of the shroud walls. Since this part of the shroud wall expands away from the drill steel, it can guide the dust-laden airflow out of the shroud space at some spots along the shroud-to-ground gap where the inflow cannot hold them inside.
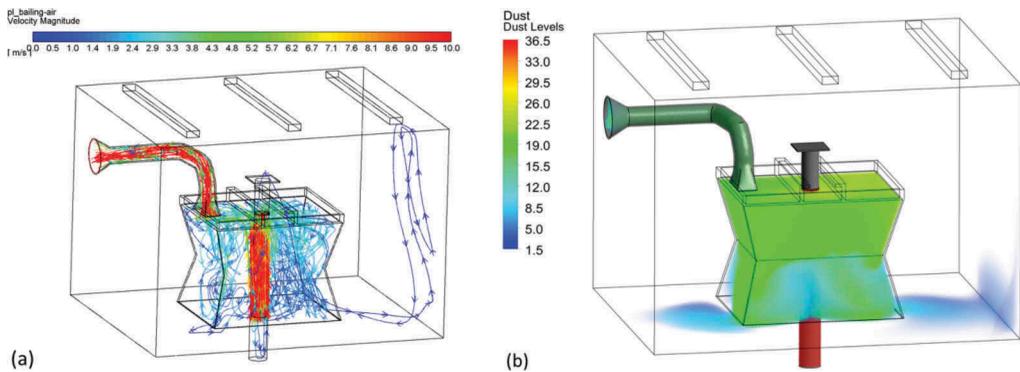

Figure 7. Dust control by V-shaped drill shroud: (a) the pathline of bailing airflow colored by a velocity magnitude (0.0–10.0 m/s); (b) the respirable dust concentration distribution; legend shows the dust levels (1.5–36.5 mg/m^3).

This arrangement of shrinking then expanding inner shroud cannot effectively confine the respirable dust under the 2:1 collector-to-bailing airflow ratio and the 5.1 cm (2 in.) shroud-to-ground gap condition. As shown in Figures 7 (b), dust can leak out of the shroud to affect the surroundings at localized areas. The amount of dust leakage can result in potential dust concentrations ranging from 1.5 to 15 mg/m^3. Note that more of the dust leakage occurs on the opposite side of the collector inlet, where the influence of the dust collector is relatively weak. At the same time, this side is generally the side where the drill operator's cab is situated. This location of the dust leakage is similar to that found in a previous CFD study on medium-sized blasthole drill shroud [Zheng et al., 2016]. The similar trend showing a similar location of this leakage indicates that it is important for the drill operator's cab to be well sealed and properly maintained to prevent the drill operator from respirable dust exposure during drilling.

4   DISCUSSION

It can be observed from Figure 5 (a) that the airflow pattern was guided by the 45° air-blocking shelves toward the drill steel. There was no airflow that re-attached to the vertical shroud walls below the air-blocking shelves. Therefore, the dust-laden airflow was away from the shroud-to-ground gap and can be well confined inside the drill shroud.

For the U-shaped drill shroud, however, some of the airflow coming down from the slope of one upper plate can stick to the adjacent lower vertical shroud wall, as shown in Figure 6 (a). As these airflows went down, they were not vertically striking the ground. Therefore, it is not easy for them to leak dust outside the shroud as intake air was sucked into the drill shroud by the dust collector. For the V-shaped drill shroud, there was also airflow re-attachment to the adjacent upper shroud walls. However, the expansion of the lower shroud walls can guide the dust-laden air to go directly toward the outside of the drill shroud as shown in Figure 7 (a). Therefore, the V-shaped drill shroud does not work as effectively as the 45° air-blocking shelf, because any surfaces inside the inner drill shroud, especially the lower shroud walls, can guide the airflow toward the outside space or close to the shroud-to-ground gap and may result in dust leakage. Naturally, as the drill cuttings accumulate inside the drill shroud (as shown in Figures 1 & 2), the slope of the growing cuttings can guide the dust-laden bailing airflow escape out of the drill shroud. Therefore, it is possible with the V-shaped drill shroud that more dust may be leaking out at the end of the drill process even though the dust collector is working properly all the time, although this is not the focus of this study.

In this study, for all three configurations of the inner shaped drill shroud designs, the dust control effects of the 45° air-blocking shelves and U-shaped drill shroud are better than the V-shaped drill shroud. If applicable, the 45° air-blocking shelves and U-shaped drill shroud are recommended to use in the mining sites.

5   CONCLUSIONS

To minimize the dust created by material deposited on the inner surface of drill shrouds which can be released during drilling and drill moves, this study evaluated three drill shroud designs. The slopes of the inner surfaces are all configured higher than the angle of friction of the minerals encountered in mining to make sure they cannot stay on the inner surface. The dust control capacities of the above three inner shaped drill shrouds during drilling were evaluated using a previously validated CFD model.

The dust leakage was investigated under the conditions of a 2:1 dust-collector-to-bailing air-flow ratio and a 5.1 cm (2 in.) shroud-to-ground gap. The setup of the simulation was based on the geometric condition of the full-scale drill table simulator at the NIOSH Pittsburgh Research Laboratory.

It was determined that a drill shroud with 45° blocking shelves can effectively confine the respirable dust inside the drill shroud with no dust leakage. The dust-laden air can also be

quite effectively controlled inside a U-shaped drill shroud, in which the shroud shrinks toward the drill steel and then goes vertically. By comparison, a V-shaped drill shroud can have dust leakage as the dust-laden air can re-attach to the expanded lower shroud walls and be guided out of the shroud-to-ground gap. The leakage is normally located at the opposite side of the dust collector inlet and can affect the close-by operator's cab. Similar dusty air leakage was also found in previous drill shroud studies.

This study can provide guidelines for drill shroud design by presenting the airflow stream-lines inside the shroud. Understanding the airflow inside the shroud area can aid in minimizing dust emissions from the drill shroud of the surface blasthole drill. This study also provides two possible solutions by using the angle of friction to minimize the dust cloud caused by dust deposited on the inner surface of the drill shroud—the 45° air-blocking shelf and the U-shaped drill shroud.

DISCLAIMERS

The findings and conclusions in this manuscript are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH). Mention of company names or products does not constitute endorsement by NIOSH.

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