Preprint 20-066

EVALUATION OF ROOF BOLTER CANOPY AIR CURTAIN EFFECTS ON AIRFLOW AND DUST DISPERSION IN AN ENTRY USING EXHAUST CURTAIN VENTILATION

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ABSTRACT

Computational fluid dynamics (CFD) software has been used to aid in the design and improvement of the roof bolter canopy air curtain (CAC) system. A recent study conducted by the National Institute for Occupational Safety and Health (NIOSH) evaluated the roof bolter CAC system in a blowing face ventilation system demonstrating its effectiveness and illustrating the CAC protection zones. This study evaluates the roof bolter machine CAC while operating in an exhausting face ventilation system.

This study considers two scenarios: (1) a roof bolting machine in the center of the entry for installation of the fifth row of bolts from the face, and (2) a roof bolting machine positioned close to the face for the installation of the last row of bolts. In both scenarios, the bolting machine is placed in an environment that contains 6.0 mg/m^3 of respirable dust and is ventilated by an exhaust curtain with 9,000 cfm (4.25 m^3/s) of air. This environment is used to simulate the roof bolter machine operating downstream of a continuous mining machine. Two operation positions are simulated at the same bolting location: dual drill heads in the inward position for two inside bolts and dual drill heads in the outward position for two outside bolts. The influence of the CAC on airflows and dust dispersion is evaluated with the CAC operating at 250 cfm (0.12 m^3/s) with dust reductions ranging from 39.5 to 82.8%. When the roof bolter operated close to the face, increasing CAC airflow was required for adequate protection since the dust reductions can be as low as 39.5%. Additional CAC airflows of 350 cfm (0.17 m^3/s) and 450 cfm (0.21 m^3/s) were evaluated and demonstrated that dust reductions increased to 59.7% (350 cfm) and 72.0% (450 cfm) for the worst location where the roof bolter operators located.

INTRODUCTION

Roof bolting machines are used to drill bolt holes into the roof of an underground mine at specified patterns and to install roof bolts to secure the roof from falling. At times, the roof bolting machine is also used to install rib bolts; however, only the roof bolting operation was considered in this simulation.

Though the roof bolting operation drastically improved the safety of miners from roof falls, some roof bolter operators are experiencing health problems associated with respirable dust. Based on recent statistics [1], following a low point in the late 1990s where the prevalence of coal workers' pneumoconiosis (CWP) in miners with 25 years or more tenure was approximately 5%, CWP now exceeds 10% for the U.S. miners with 25 years or more of tenure. In central Appalachia (Kentucky, Virginia, West Virginia), 20.6% of long-tenured miners have CWP and 4.5% have progressive massive fibrosis, the most severe form of CWP.

CWP, also known as black lung, is an occupational respiratory disease that has no cure and can ultimately be fatal. The only way to prevent the incidence of black lung is to eliminate coal miners' exposure to respirable coal mine dust. Current U.S. regulations require that the overall respirable dust concentration be 1.5 mg/m^3 or less for a full-shift sampling if respirable quartz is not present; otherwise, the standard is 10 divided by the percent quartz (not to exceed the 1.5 mg/m^3 respirable dust standard) [2,3].

The dust sources for a roof bolting operation include: (1) insufficient maintenance of the roof bolter collection system, (2) improper cleaning of the dust collection system, and (3) working downwind of the continuous miner [4]. Recent field studies have revealed that vacuum dust collection systems are effective in capturing bolter-generated dust during bolting if operated and maintained properly [5,6]. However, when working downwind of an operating continuous miner, roof bolter operators can be exposed to air contaminated by respirable coal and quartz dusts [7].

To reduce the overexposure of respirable dust from upstream working activities, the use of canopy air curtain (CAC) systems as an engineering control method has become of interest to research institutes and mining equipment manufacturers [4,8-14]. The CAC uses a blower fan with a filtered intake to deliver clean air to mine workers. For roof bolter machines, the CAC is installed underside or combined with the bolting machine canopy, located above the roof bolter operator. The filtered air blows over the miner's breathing zone to reduce exposure to the dust-laden air.

CAC systems have been shown to be an effective respirable coal mine dust control for roof bolters in a laboratory setting with dust control efficiencies ranging from 14% up to 75%. Field studies revealed that the dust removal can be as high as 91% [11-13].

Previously, a CAC was modeled underneath the roof bolter canopy in a blowing curtain ventilation face downstream of a continuous miner. The ventilation condition is 3,000 cfm (1.42 m^3/s) with a consistent dust concentration of 6.0 mg/m^3.

In this study, an exhaust curtain ventilation face is investigated downstream of some mining activities that provide a consistent dust concentration of 6.0 mg/m^3. For the ventilation rate, however, the regulation [15] requires that the mean entry air velocity shall be at least 60 feet per minute reaching each working face where coal is being cut, mined, drilled for blasting, or loaded, and to any other working places as required in the approved ventilation plan. Therefore, the quantity of airflow is increased to 9,000 cfm (4.25 m^3/s) of face ventilation. The dust control reduction efficiency was evaluated for various locations in the planes below the CAC canopy.

STATEMENT OF THE PROBLEM AND GEOMETRIC SETUP

Figure 1 shows a working face with a roof bolting machine at two locations constructed in the ANSYS geometric modeling program. The size of the simulated entry is 20-ft (6.1-m) in width, 7-ft (2.1-m) in height, and 52.5-ft (16.0-m) in length. The width of the exhaust curtain is 4-ft (1.2-m). The size of the CAC fan inlet was measured as 8-in by 14-in (20.3-cm by 30.5-cm), and the CAC outlet was assumed as a 2-ft by 2-ft (61.0-cm by 61.0-cm) square plane with uniform fresh airflow from the outlet to the bolter operator underneath.

A dual-head roof bolting machine was represented in the geometric model. The two drill heads can install two outside or two inside roof bolts simultaneously for a four-bolt roof bolting pattern. The bolting machine is a walk-through model, which is a common machine used for conditions where unstable rib may present a hazard to roof bolter operators.

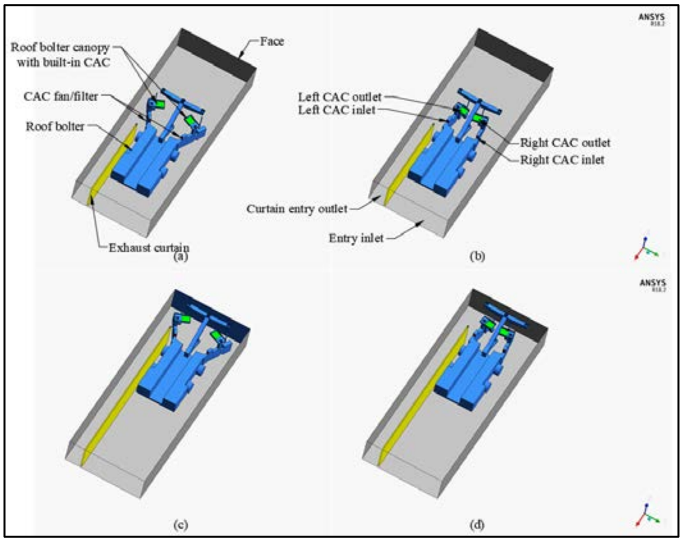

Figure 1. Roof bolter operation scenarios with built-in canopy air curtain in an exhaust curtain continuous miner face and boundary conditions used in the simulation: (a) start of the bolting operation for outside bolts; (b) start of the bolting operation for inside bolts; (c) end of the bolting operation for outside bolts; (d) end of the bolting operation for inside bolts.

Figure 1 (a) and (b) demonstrate a scenario in which the continuous miner (not shown) completed a 20-ft (6.1-m) cut and was moved to another upstream location to operate. In Figure 1 (a), the bolting machine begins to drill and bolt the outside two holes 4-ft (1.2-m) away from the left and right ribs at approximately 20-ft (6.1-m) from the face. In Figure 1 (b), the bolting machine works on the inside two holes 4-ft (1.2-m) apart and from the outside two holes at the same row of bolts. The curtain setback is 30-ft (9.1-m) from the face.

Figure 1 (c) and (d) is the scenario in which the bolting machine installs the last row of bolts closest to the face. The exhaust curtain is set up at 10-ft (3.0-m) outby the face. In Figure 1 (c), the roof bolter is working at the end of the bolting operation for the outside holes, and in Figure 1 (d) the bolter is drilling the two inside holes.

Figure 2 illustrates the four-bolt per row pattern of bolt placement. These four bolts per row can be defined as the two outside bolts and two inside bolts as shown in the figure. At the start of the bolting operation, the bolter operators drill either the inside or outside two holes along the 5th row from the face and will bolt the roof row by row advancing towards the first row, supporting the roof towards the face.

SIMULATION SETUP

Simulation cases

Computational fluid dynamics (CFD) simulations were conducted with ANSYS Fluent 18.2 in this study. Four simulation cases were considered in this paper with steady-state analysis. Table 1 includes all the cases in this research. The simulation domain was discretized into about 2.7 million hexahedral and tetrahedral control volumes (cells). The size of the mesh ranges from a minimum of 0.5-in. (1.3-cm) around the mining machine to a maximum of 3-in (7.6-cm) outby the face.

A species transport model without reactions was used to study the airflow and dust distribution in the mining face area. Dust was treated as a gas (CO_2), and a species transport model in Fluent was used. A previous study treated dust as a gas and provided agreeable results with laboratory data [16].

Boundary conditions and other input parameters

Figure 1 (b) illustrates the locations of the boundary conditions. Since the face region was downstream of another working area, airflow with 6.0 mg/m^3 of dust is simulated by an entry inlet providing 9,000 cfm (4.25 m^3/s) of air for face ventilation. The dust concentration of 6.0 mg/m^3 is often encountered by NIOSH researchers in the field when the bolting machine operates downwind of the continuous miner. The 9,000 cfm (4.25 m^3/s) of air quantity is the requirement from the current regulation for the exhaust ventilation working face [15]. Table 2 lists the velocity and mass fraction of the respirable dust (CO_2) to provide the 9,000 cfm (4.25 m^3/s) airflow with 6.0 mg/m^3 of dust to the face. Detailed calculations for determining this velocity and mass fraction can be found in Zheng et al. [16].

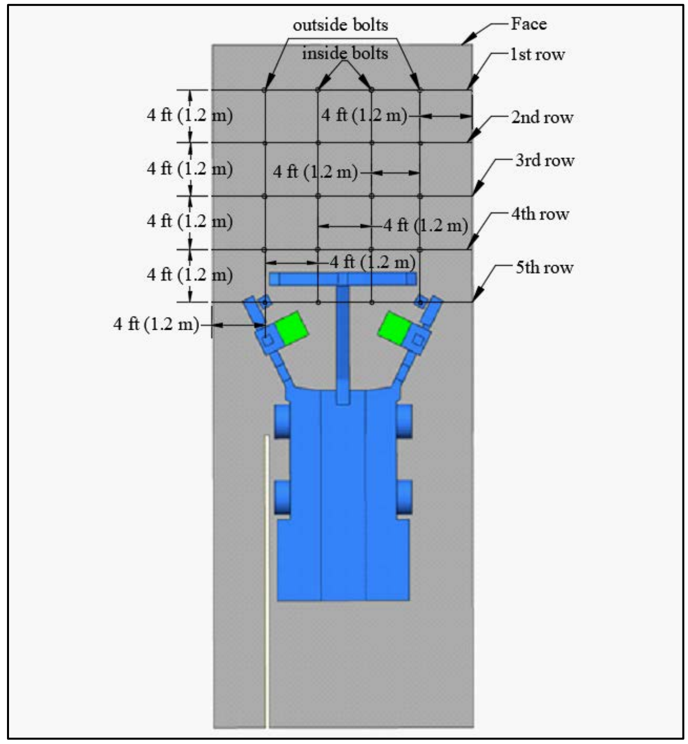

Figure 2. Bolting pattern with 4-ft (1.2-m) by 4-ft (1.2-m) spacing.

Table 1. Simulation cases for roof bolter canopy air curtain study with blowing curtain.

Cases	Description
1) Start-outside bolts	The bolting machine starts to bolt the outside two holes in the 5th row with the exhaust curtain 30-ft (9.1-m) from the face.
2) Start-inside bolts	The bolting machine starts to bolt the inside two holes in the 5th row with the exhaust curtain 30-ft (9.1-m) from the face.
3) End-outside bolts	The bolting machine is bolting the last outside two holes in the 1st row with the exhaust curtain 10-ft (3.0-m) from the face.
4) End-inside bolts	The bolting machine is bolting the last inside two holes in the 1st row with the exhaust curtain 10-ft (3.0-m) from the face.

The Fluent software allows an outlet to have zero gauge pressure applied. This allows modeling flow from an outlet where the details of the flow velocity and pressure are not known prior to solving the flow problem. Zero gauge pressure means there is no pressure jump at this outlet. The entry outlet in this model is the perpendicular plane behind the roof bolter, extending floor to ceiling from the left rib to the curtain. The left and right CAC blower inlets use exhaust fan boundary conditions to pull in the localized airflow. The capacity of the roof bolter CAC blower is 250 cfm (0.12 m^3/s) flowrate. Therefore, the pressure of the exhaust fan [~ 4 Pa (0.016 inch H_2O)] was adjusted through trial and error to obtain the desired volumetric flowrate. In this simulation, 100% filter efficiency was assumed providing clean air to the CAC plenums. As a result, on the left and right CAC outlets or plenums, a velocity condition is applied on each outlet plane to provide 250 cfm (0.12 m^3/s) of fresh airflow. In summary, Table 2 lists all the parameters of the CFD models. All simulations assume there is no leakage along the ventilating curtain.

Table 2. Input parameters for CFD models in this study.

Simulation setups	Parameter descriptions
Simulation model	Species transport model without reactions
Turbulence model	Standard k-ε, standard wall functions
Boundary conditions	Curtain entry inlet: velocity inlet (81.86 fpm [0.42 m/s], mass fraction of 5.10×10^{-6} of CO_2 to provide 9,000 cfm [4.25 m^3/s] of 6.0 mg/m^3 of dusty airflow to the face)
	Entry outlet: pressure outlet (0 Pa)
	Left/right CAC inlet: fan (~ 4 Pa to pull in 250 cfm [0.12 m^3/s] dusty flow)
	Left/right CAC outlet: velocity inlet (62.5 fpm [0.32 m/s] to provide 250 cfm [0.12 m^3/s] of fresh airflow)
	Others: wall or interior plane
Solution method	Pressure-velocity coupling scheme: SIMPLE
	Spatial discretization for gradient: Green-Gauss node based; for pressure: PRESTO; others: 2nd order upwind

RESULTS OF THE SIMULATION STUDY

Case 1：Start-outside bolts

In this case, the roof bolter starts to bolt the outside two holes after the continuous miner made the 20-ft (6.1-m) cut and finished loading the area. The bolting machine, in Figure 2, begins to bolt the outside two holes in the 5th row with the exhaust curtain 30-ft (9.1-m) away from the face. Figures 3 and 4 reveal the velocity vectors and dust concentration results.

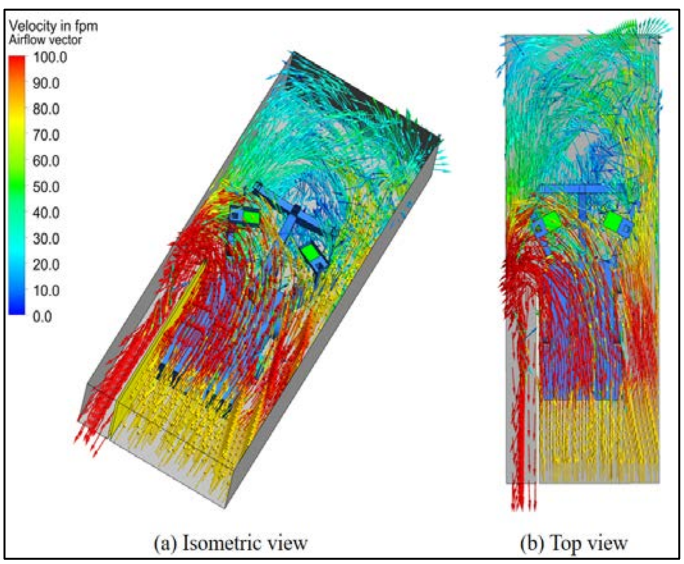

Figure 3. Velocity vectors for start of bolting scenario in drilling the outside bolts by velocity magnitude, 0–100 fpm (0–0.51 m/s): (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

In Figure 3, the airflow enters the entry at a speed of 81.86 fpm (0.42 m/s) to provide a flowrate of 9,000 cfm (4.25 m^3/s) to the face, then exits at 321.43 fpm (1.63 m/s) from the exhaust curtain. Most of the airflow goes directly toward the mouth of the curtain, while only part of the air flows to the face region. For the airflow that does go to the face, the CAC associated with the bolting boom and drill unit on the off-curtain side behaves like a curtain to guide the flow toward the face. The flow pattern inby the bolting machine resembles a "U" shape with air moving right to left across the face.

Due to the airflow pattern, the fresh airflow from the right CAC is directed toward the front of the roof bolter while the fresh airflow from the left CAC is drawn toward the curtain exit as shown in Figure 3. The comparison results can also be observed in the Discussion section below.

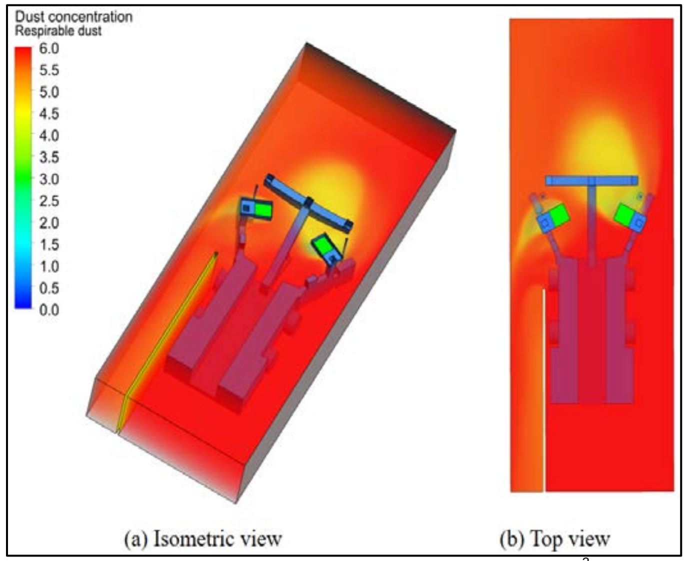

Figure 4. The respirable dust concentrations (1.5–6.0 mg/m^3) for start of bolting scenario for the outside bolts: (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

Case 2: Start-inside bolts

In this case, the roof bolter operators start to bolt the inside two holes in the 5th row in the newly developed face area. For both Cases 1 and 2, the exhaust curtain is 30-ft (9.1-m) from the face. Figures 5 and 6 reveal the simulation results of velocity vectors and dust concentrations for Case 2.

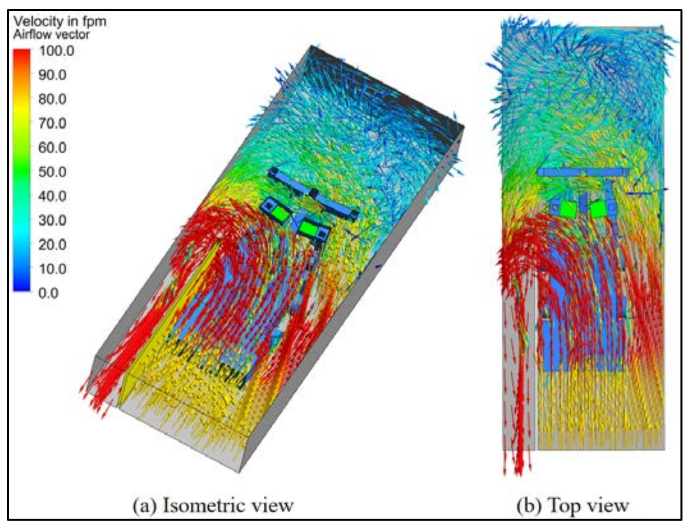

Figure 5. Velocity vectors for start of bolting scenario in drilling the inside bolts by velocity magnitude 0-100 fpm (0-0.51 m/s): (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

In Figure 5, the flow pattern shows again that most of the air goes directly to the return curtain, while in front of the bolting machine, the airflow is different from that in Case 1 above. The face ventilation resembles a "figure 8" with flow moving left to right across the face with lower velocity in the face compared to the U-shaped airflow pattern [17]. It was also described as an airflow separation phenomenon, where only a portion of the intake air can reach the face, while the other portion of ventilation flow goes directly back to the entry outlet. This phenomenon may affect the efficiency of methane dilution in the immediate face region [18].

In Figure 5, the intake airflow separation is taking place in front of the roof bolter. The flow at the location of the CAC goes from right to left, almost parallel to the face. Figure 6 illustrates the dust concentration in the face region with the fresh airflow from the CAC directed from right to left toward the return curtain. In the Discussion section of this paper, the averaged dust concentrations at different planes under the CAC are compared to evaluate the effect of the CAC for the bolter operators.

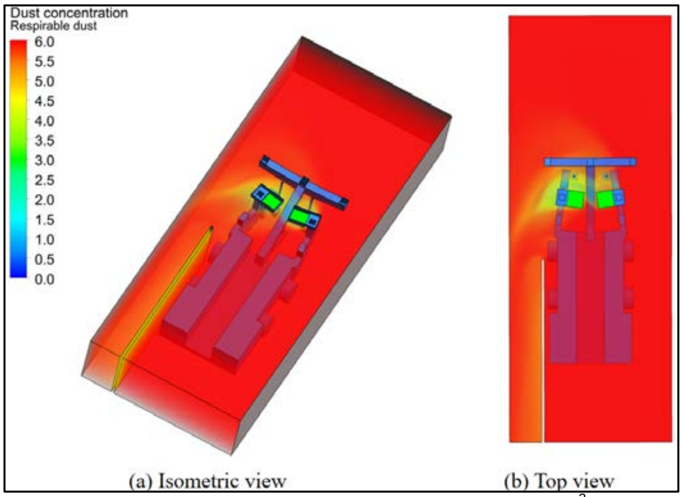

Figure 6. The respirable dust concentrations (1.5-6.0 mg/m^3) for start of bolting scenario for the inside bolts: (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

Case 3: End-outside bolts

In this case, the bolting machine is installing the outside two holes in the closest row to the face. As the machine advances, the exhaust ventilation curtain is extended to 10-ft (3.0-m) from the face. Figures 7 and 8 illustrate the results of the velocity and dust distribution in Case 3.

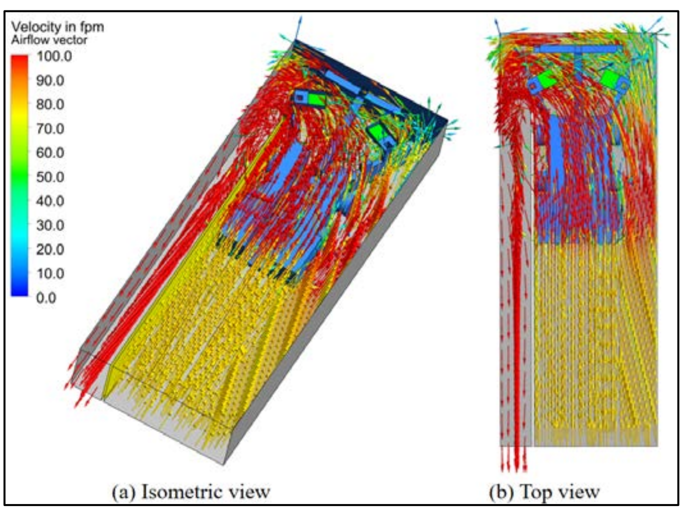

Figure 7. Velocity vectors for end of bolting scenario in drilling the outside bolts by velocity magnitude 0–100 fpm (0–0.51 m/s): (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

In Figure 7, due to the closeness of the end of the exhausting curtain, the air velocity across the face is higher than the previous two cases of the 30-ft (9.1-m) curtain setback. The off-curtain-side bolting boom and drill unit extend another 6-ft (1.8-m) toward the face beyond the end of the exhaust curtain. As a result, the front right corner of the face is swept with a U-shaped ventilation airflow with air moving right to left across the face.

Due to the higher velocity in the face region and the closeness of the CAC toward the face, the filtered airflow emanating from under the CAC can be impacted by the high-velocity, high-respirable dust concentration airflow from the upstream. Figure 8 shows that only the region close below the CAC has good reductions in respirable dust concentration. Beyond that, the fresh airflow is quickly blown toward the face and left corner of the right CAC and to the return airway for the left CAC.

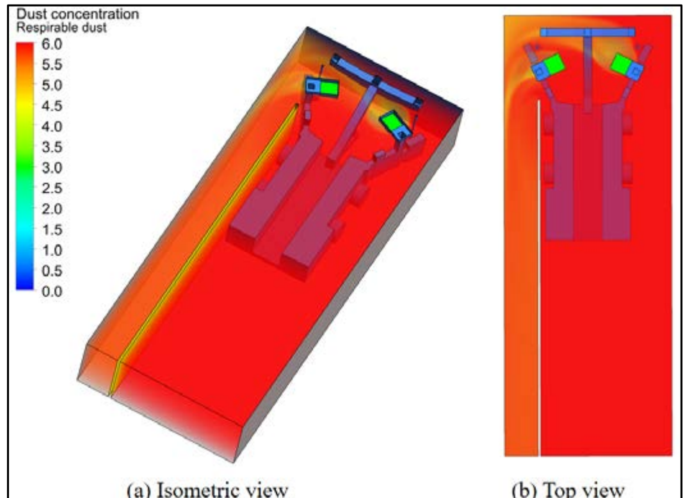

Figure 8. The respirable dust concentrations (1.5–6.0 mg/m^3) for end of bolting scenario for the outside bolts: (a) Isometric view, observed from the rear right toward the face; (b) Top view, seen from the roof toward the floor.

Case 4: End-inside bolts

In this case, the roof bolter operators are installing the inside two holes in the first row of the face area with the curtain extended to 10 ft (3.0 m) from the face. Figures 9 and 10 reveal the results of the velocity and dust distribution for Case 4.

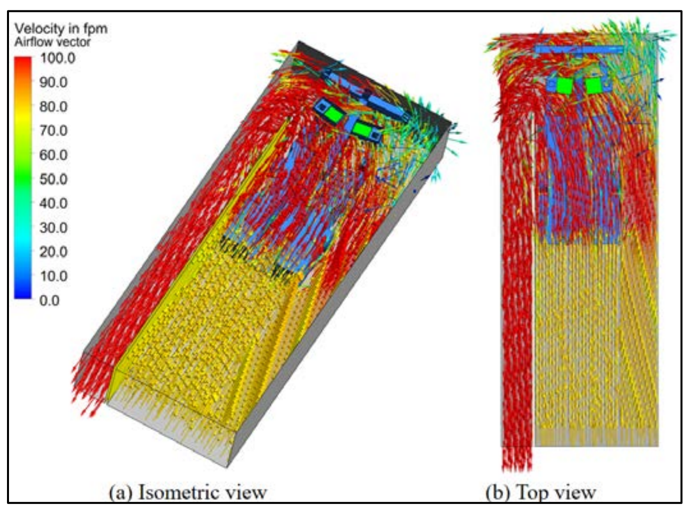

Figure 9. Velocity vectors for the end of bolting scenario in drilling the inside bolts by velocity magnitude 0–100 fpm (0–0.51 m/s): (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

Similar to Figure 7, the air velocity across the face is much higher than the previous two cases with 30-ft (9.1-m) curtain setback. The flow pattern in the 20-ft-wide entry, similar to Case 3, resembles a "U" shape with air moving right to left across the face. The space in front of the bolting machine is not enough to have the figure-8 flow pattern. The front right corner of the machine may not be penetrated by the exhausting curtain as compared with the same place in Case 3. But overall, the face region is ventilated well as indicated by the color of the velocity vectors.

Due to the higher velocity in the face region and the closeness of the CAC toward the face, the filtered airflow emanating from under the CAC may be affected by the high dust ventilation flow from the entry. Again, as in Case 3, Figure 10 shows that only the region close below the CAC has good respirable dust reduction efficiency.

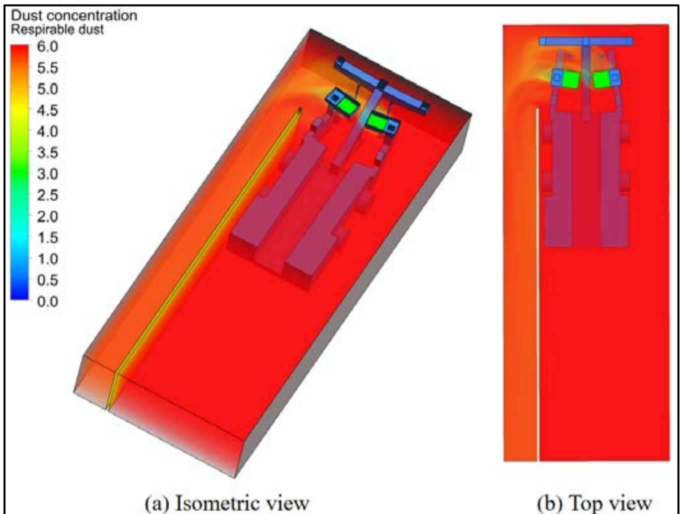

Figure 10. The respirable dust concentrations (1.5–6.0 mg/m^3) for the end of bolting scenario for the inside bolts: (a) Isometric view, observed from the rear right toward the face and (b) Top view, seen from the roof toward the floor.

DISCUSSION

To help evaluate the dust control efficiency of the CAC, four planes of 2-ft by 2-ft (61.0-cm by 61.0-cm), the same size as the CAC outlet, were defined vertically beneath the CAC outlet: 10-in (25.4-cm), 20-in (50.8-cm), 30-in (76.2-cm), and 40-in (101.6-cm). Table 3 (see APPENDIX) lists the average dust concentrations in these planes and the dust reduction rates. The percent reductions are calculated based upon the 6.0 mg/m^3 background atmospheric concentrations due to being downwind of the continuous miner.

It should be noted from previous field studies [11,13,14] that the amount of time the roof bolter operators working underneath the CAC ranged from 18% to 66% of the total operating time. The low time percentage under the CAC was due to the maintenance required on the roof bolting machine. During normal bolting operations, it is estimated that 2/3 of the operator's drilling time is spent under this canopy. The protection in Table 3 (see APPENDIX) shows the importance for the operator to remain directly underneath the CAC as much as possible in order to achieve the optimal protection it can offer.

Table 3 (see APPENDIX) reveals that the CAC has the ability to provide respirable dust protection for the roof bolter operators. This table shows that the optimum protection is provided when the roof bolter operators' breathing zone is located about 10-in (25.4-cm) below the CAC. The off-curtain-side operator seems to have better protection due to the fact that this location is less affected by the ventilation flow. The average velocity in the intake entry is 81.86 fpm (0.42 m/s), while the velocity increased to 321.26 fpm (1.63 m/s) when it goes to the return curtain. The high velocity and high respirable dust concentration flow can impact the fresh flow from the curtain side of the CAC more than the off-curtain side of the CAC. There is an exception for the bolting machine at the start location for installing the inside bolts case for which the curtain-side operator has a slightly better dust reduction rate than the curtain-side operator.

From the airflow shown in Figures 3, 5, 7, and 9, the low ventilation airflow velocities impacting the off-curtain side operator are lower than the ventilation airflow velocities impacting the curtain-side operator. The figures verify that the curtain-side operator is impacted by more of the high-velocity red streamlines than the off-curtain side operator. Past research has demonstrated that higher airflow velocities can penetrate the protection zone of the CAC [19-21], which can cause contaminated air to enter the CAC protection zone resulting in reduced dust control efficiencies. This phenomenon is shown for all four cases simulated by CFD.

Table 3 (see APPENDIX) also shows that as the distance increases from the roof bolter operators' breathing zone to the bottom of the CAC plenum, the protection provided by the CAC decreases. This is true for all cases evaluated. This decrease in protection when the space between plenum and breathing zone increases has been proven in prior testing conducted in laboratory studies [4,12]. These CFD results demonstrate the importance of maintaining a small distance from the CAC plenum to the roof bolters' breathing zone in order for the roof bolter machine's CAC to be optimally effective.

In addition, Table 3 (see APPENDIX) shows that once the bolting machine comes closer to the face, the environmental conditions are becoming worse due to the higher ventilation airflow speed around the operators as shown in Figures 7 and 9 compared to Figures 3 and 5. It seems that the 250-cfm (0.12-m^3/s) CAC capacity with a 62.5-fpm (0.32-m/s) fresh airflow speed at the outlets cannot provide desirable dust reduction at 10-in below the CAC. To help evaluate the possible requirements of CAC capacity for future field tests, the airflows from the CAC outlets are increased to 350 cfm (0.17 m^3/s with 87.5 fpm [0.44 m/s]) and 450 cfm (0.21 m^3/s with 112.5 fpm [0.57 m/s]) for the two bolting-machine-closer-to-face cases (cases 3 and 4).

Table 4 (see APPENDIX) shows that with a 350-cfm (0.17-m^3/s) CAC the off-curtain side operator can be much improved in the 10-in plane below the CAC, while the curtain-side operator may still have some undesirable respirable dust exposures. Once the CAC capacity increased to 450 cfm (0.21 m^3/s), the dust levels for the curtain-side operator were acceptable. If a further increase in the CAC capacity is not practical, other solutions may need to be considered, like the double-slot outlet design [12], etc.

CONCLUSIONS AND FUTURE PLANS

In this study, the dust control effect of CACs for roof bolter operators was evaluated in an exhaust curtain continuous mining face. A dual-head roof bolter was placed at two locations after a continuous miner made a 20-ft (6.1-m) cut into the face. With a four-bolt-per-row and 4-ft (1.2-m) spacing pattern, the bolting machine operator starts bolting the fifth row and ends at the last row toward the face. At each location, the bolting machine has two positions: bolting the outside two holes or bolting the inside two holes. The dust source comes from upstream mining activities with a constant dust concentration of 6.0 mg/m^3 entering the exhausting face. It is difficult to evaluate the airflow and dust patterns in the working site or even in the lab; therefore, the CFD simulation was employed to make this evaluation.

The results show how the operation of the roof bolting machine equipped with CACs can affect the airflow pattern in the face area. At the start of the bolt installation with the setback of the exhaust curtain 30-ft (9.1-m) away from the face, the following occurs: when the machine is installing the outside two bolts of the fifth row, the bolting boom and drill unit on the off-curtain side can help the face ventilation to penetrate to the immediate face zone; when the machine is installing the inside two bolts on the same row, flow separation can occur in front of the bolting machine (Case 2). The flow separation causes a figure-8 airflow pattern with only a portion of the ventilation reaching the face. At this distance away from the face, it has been noted that this separation will occur no matter how the ventilation velocity is changed [18].

Once the machine is installing the last row of bolts, the exhaust curtain is 10-ft (3.0-m) from the face. The airflow sweeps the face from right to left at high velocities. There is no flow separation in either roof bolter machine positions, inside or outside. It should be noted that in all cases, the downward roof bolter CAC flow does not hinder the ventilation flow to sweep the face.

It is clearly revealed in the simulation that the closer the breathing zone of the roof bolter operator is toward the CAC plenum, the fresh airflow outlet, the better the dust control for the roof bolter operator. In this study, with 250 cfm (0.12 m^3/s) of fresh air uniformly distributed from the CAC outlet and within 10 in (25.4 cm) underneath the CAC, the roof bolter operators are provided the optimal protection from respirable coal mine dust. There can be a difference in protection between the off-curtain-side roof bolter operator and the curtain-side roof bolter operator. The curtain-side operator's protection is lower due to being subjected to the higher-velocity, high respirable dust concentration ventilation airflow going toward the nearby curtain. However, protection is still provided as long as the operator remains, as much as possible, directly underneath the CAC plenum within the CAC's protection zone. The results from this CFD study emphasize the importance of remaining underneath the plenum while operating the roof bolter machine.

In addition, as the bolting machine moves closer to the face, the dust levels for both roof bolters increases. To improve the working environment, especially for the curtain-side operator, the CAC capacity increased to 350 cfm (0.17 m^3/s) and 450 cfm (0.21 m^3/s). The higher the CAC capacity, the better dust reduction. If increasing the CAC capacity does not lower respirable dust concentrations for the curtain-side operator, other solutions like different CAC outlet design [12] or using blowing curtain ventilation when downstream of other mining activities [21] can be considered.

Overall, this study confirms the ability of the roof bolter machine's CAC to protect roof bolter operators, especially during high dust concentration environments of ≈ 6.0 mg/m^3, which generally occur when the bolting machine operates downwind of the continuous miner.

ACKNOWLEDGEMENT

The authors of this paper sincerely acknowledge J. Drew Potts, Jay F. Colinet, Liming Yuan, Peter Zhang, and Lihong Zhou for their technical support.

DISCLAIMER

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, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by NIOSH.

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APPENDIX

Table 3. Comparison of dust concentration and reduction on the planes under the CAC for different scenarios for 9,000-cfm exhaust curtain ventilation and 250-cfm CAC capacity.

Inside bolts cases with planes	**10-ft Curtain dust concentration (mg/m^3)**		**30-ft Curtain dust concentration (mg/m^3)**	
	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right
10-in below CAC	3.26 (45.7)	2.18 (63.7)	1.56 (74.0)	1.72 (71.3)
20-in below CAC	5.78 (3.7)	4.75 (20.8)	3.81 (36.5)	3.55 (40.8)
30-in below CAC	6.00 (0.0)	5.84 (2.7)	4.70 (21.7)	5.16 (14.0)
40-in below CAC	6.00 (0.0)	5.98 (0.3)	4.23 (29.5)	5.71 (4.8)
Outside bolts cases with planes	**10-ft Curtain dust concentration (mg/m^3)**		**30-ft Curtain dust concentration (mg/m^3)**	
	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right
10-in below CAC	3.63 (39.5)	1.94 (67.7)	1.99 (66.8)	1.03 (82.8)
20-in below CAC	5.98 (0.3)	4.26 (29.0)	4.48 (25.3)	2.88 (52.0)
30-in below CAC	6.00 (0.0)	5.62 (6.3)	5.45 (9.2)	4.86 (19.0)
40-in below CAC	5.99 (0.2)	5.84 (2.7)	5.25 (12.5)	5.44 (9.3)

Table 4. Dust concentration and reduction in cases 3 and 4 on the planes under the CAC for 9,000-cfm exhaust curtain ventilation and 350-cfm and 450-cfm CAC capacity.

Inside bolts cases with planes	**10-ft Curtain dust concentration (mg/m^3) 350-cfm CAC capacity**		**10-ft Curtain dust concentration (mg/m^3) 450-cfm CAC capacity**	
	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right
10-in below CAC	2.04 (66.0)	1.35 (77.5)	1.34 (77.7)	0.74 (87.7)
20-in below CAC	5.12 (14.7)	3.52 (41.3)	4.20 (30.0)	2.34 (61.0)
30-in below CAC	5.98 (0.3)	5.40 (10.0)	5.97 (0.5)	4.47 (10.0)
40-in below CAC	6.00 (0.0)	5.91 (1.5)	6.00 (0.0)	5.59 (6.8)
Outside bolts cases with planes	**10-ft Curtain dust concentration (mg/m^3) 350 cfm CAC capacity**		**10-ft Curtain dust concentration (mg/m^3) 450 cfm CAC capacity**	
	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right	Curtain side (reduction %) Left	Off-curtain side (reduction %) Right
10-in below CAC	2.42 (59.7)	1.02 (83.0)	1.68 (72.0)	0.76 (87.3)
20-in below CAC	5.56 (7.3)	3.12 (48.0)	4.45 (25.8)	2.17 (63.8)
30-in below CAC	6.00 (0.0)	5.35 (10.8)	6.00 (0.0)	4.49 (25.2)
40-in below CAC	5.99 (0.2)	5.73 (4.5)	5.98 (0.3)	5.42 (9.7)