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DEVELOPMENT OF A ROOF BOLTER CANOPY AIR CURTAIN FOR RESPIRABLE DUST CONTROL

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ABSTRACT

Testing of the NIOSH-designed roof bolter canopy air curtain (CAC) has gone through many iterations demonstrating successful dust control performance under controlled conditions. J.H. Fletcher & Co. (Fletcher), an original equipment manufacturer of mining equipment, has further developed the CAC concept by incorporating it into the design of its roof bolting machines. A new CAC design has been developed incorporating the results of testing of the NIOSH design and the recent Fletcher design. Observations from smoke testing conducted on this new CAC design in a laboratory setting show promise for improved performance.

INTRODUCTION

Exposure to respirable coal mine dust can cause coal workers' pneumoconiosis (CWP) otherwise known as black lung. If silica is present in the dust, the miner may develop silicosis in addition to CWP. CWP and silicosis are occupational respiratory diseases that are ultimately fatal and have no cure. The only method of prevention is through elimination of exposure to respirable coal mine dust and crystalline silica (quartz). The current occupational exposure limit (on an MRE basis) for respirable coal mine dust is 2.0 mg/m^3 during each shift that a miner is exposed in the active workings of the mine or in mine facilities [30 CFR 70.100 2015]. Recently enacted legislation changes this standard beginning in August 2016 to 1.5 mg/m^3 for a full working shift [Federal Register, 2014]. If the respirable coal mine dust contains more than 5% silica, the applicable respirable dust standard is reduced; calculated as 10 divided by the percent quartz present [30 CFR 70.101] so that the effective exposure limit for respirable quartz is 0.1 mg/m^3 for a full working shift.

Sources of exposure to respirable coal mine dust for the roof bolting occupations include infrequent maintenance and cleaning of the vacuum dust collection system and operating the bolter downwind (in the return air) of the continuous miner [Goodman and Organiscak, 2003]. Recent studies have demonstrated that vacuum dust collection systems are effective in capturing bolter-generated dust, if maintained and operated correctly and if proper face ventilation techniques are used. However, most exposure to respirable coal mine dust for the roof bolter occurs when the roof bolter machine is operated downwind of the continuous miner [Potts et al., 2011; Colinet et al., 2013]. Because of this higher exposure downwind of the continuous miner, the roof bolter is generally limited to working downwind of the miner only once during a production shift.

In order to prevent over-exposures to the roof bolter operators, research and development is underway to design engineering controls—specifically the canopy air curtain. The canopy air curtain (CAC) is an engineering control intended to protect workers from airborne dust exposure. The CAC uses a blower fan with a filtered intake to move clean air to a canopy which is located on the underside of the bolting machine canopy above the miner. The filtered air blows over the miner's breathing zone to reduce exposure to the dust-laden air (Figure 1). Application of a CAC for the mining industry was originally developed under a U.S. Bureau of Mines (USBM) contract, by Donaldson Co., for use on continuous miners when cabs were incorporated into the rear of the continuous miner body [Krisko, 1975].

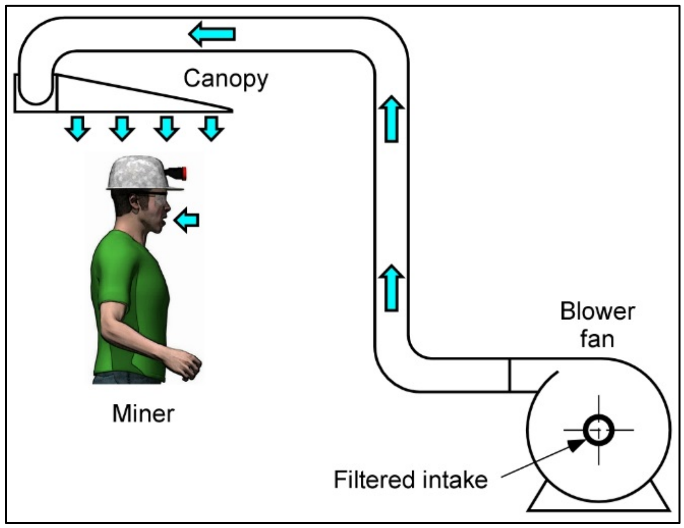

Figure 1. Schematic of canopy air curtain components with blue arrows showing airflow directions.

Limited successful field testing of the CAC was completed on continuous miners and demonstrated that the performance of the CAC for dust control was successful but variable. Table 1 shows the results of field testing at several different mine sites. Excluding the initial testing at Mine B where reductions were very low (0–9%) due to problems with sampling, canopy operation, and operator positioning outside the CAC influence during testing, the respirable coal mine dust reductions of the CAC were variable, ranging from 23 to 69%. Additionally, the first test at Mine A was noted as an anomaly, but no explanation was provided for the low reduction. It was noted that the portion of total time the operator spent underneath the CAC was very important in determining the effectiveness of the CAC [Krisko, 1975].

In the United Kingdom, the National Coal Board Mining Research and Development Establishment's Dust Branch (a U.K. government entity) field tested the initial USBM design in both blowing and exhausting face ventilation configurations on an underground cutting machine. Personal dust sampling was conducted with a sampler affixed to the miner's hard hat. The concentrations outside of the canopy were measured using a sampler mounted just outside the canopy. In the blowing ventilation, the use of the CAC during cutting reduced dust concentrations from 18.6 mg/m^3 to 9.2 mg/m^3 (48% reduction). In the exhausting ventilation, the use of the CAC during cutting reduced dust concentrations from 7.3 mg/m^3 to 2.7 mg/m^3 (66% reduction) [ECC, 1981]. As stated previously, the time the operator spent directly under the canopy greatly impacted its effectiveness.

Remote control technology has since eliminated the need for the cab on the continuous miner thereby eliminating the need for a CAC on the continuous mining machine. Although obsolete for the continuous miner, the CAC concept can be applied to the roof bolter to prevent respirable coal mine dust over-exposures.

Table 1. Results from field testing initial USBM canopy air curtain in a continuous miner.

Mine	Sampling time (hours)	Operator Time under CAC (hours)	Average Outside Conc. (mg/m³)	Operator Conc. (mg/m³)	Underneath CAC Conc. (mg/m³)	Operator % Reduction	Test Machine
A	6.25	NA	2.20	2.80	NA	0%	Joy 12 CM
A	6.33	NA	1.97	1.30	NA	34%	
A	6.42	NA	4.23	1.70	NA	60%	
A	3.25	NA	3.60	2.10	NA	42%	
B	6.00	1.80	9.27	8.40	NA	9%	Goodman
B	5.75	1.30	8.90	8.20	4.40	8%	
B	3.33	1.10	2.75	2.70	1.50	2%	
B	4.25	0.77	1.10	1.10	0.90	0%	
C	6.67	2.17	1.15	0.56	0.32	51%	Jeffery 120 H
C	4.20	2.12	1.59	1.06	1.16	33%	
C	6.35	2.77	3.63	1.37	2.27	62%	
C	6.53	3.80	2.33	0.71	0.94	69%	
B	7.00	3.37	4.21	1.40	4.88	67%	Joy 12 CM
B	7.00	5.30	4.52	1.78	0.78	61%	
B	2.00	0.93	3.75	2.08	1.67	44%	
B	6.00	3.20	16.46	12.64	9.86	23%	
B	5.00	4.22	11.17	4.67	3.83	58%	
B	6.50	4.20	6.62	3.46	3.72	48%	

NA –Not available
Krisko, 1975

NIOSH-DESIGNED CAC

To implement the CAC for the roof bolter, NIOSH designed a new prototype CAC for retrofit installation onto a roof bolter [Listak and Beck, 2012]. Other designs were investigated previously and the results of those investigations can be reviewed in the literature [ECC, 1983; Engel et al, 1987; Goodman and Organiscak, 2001; Goodman and Organiscak 2003]. The small size and square shape of the USBM design was found to provide insufficient cover for the roof bolter operator due to the range of movements the operator typically makes. Therefore a larger CAC that could provide increased area coverage based upon a typical existing roof bolter canopy size and could be easily retrofitted to an existing roof bolter canopy was developed.

The resulting prototype (NIOSH CAC) maintained all important design considerations from the original CAC design. Design specifications of this prototype included using a perforated plate with 33% open area for the horizontal outlet, changing the air inlet and geometry to include internal baffles and vanes, incorporating an internal adjustable angle plate, and using 80 mesh stainless steel screen as a flow straightener. Air filtration was accomplished using a filter (Donaldson P123990) with an efficiency rating of 99.9%.

To demonstrate its effectiveness for respirable coal mine dust reductions, the NIOSH CAC was set up in a test facility [Listak and Beck, 2012]. Gravimetric samplers using Dorr-Oliver cyclones were placed underneath the CAC (Figure 2) and 152 cm (5 ft) upwind of the CAC. Interference airflows of 0.05 m/s (10 fpm), 0.30 m/s (60 fpm), and 0.61 m/s (120 fpm) to represent a range of bolting place ventilation were tested. The target environment for respirable coal mine dust was approximately 6.0 mg/m^3. Approximately 0.165 m^3/s (350 cfm) of filtered air was supplied to the canopy during testing. The results of testing are shown in Table 2 [Listak and Beck, 2012]. Reductions under the NIOSH CAC ranged from 67 to 75%.

Field testing of the NIOSH CAC was planned for two mine sites. However, field testing was limited due to difficulties with the installation of the NIOSH CAC, specifically integrating the CAC blower system into the roof bolter's existing hydraulic system, and the inability to control the roof bolter's hydraulic supply to the CAC system. Table 3 presents the available data from the field testing. During this limited testing, the roof bolter operator was underneath the CAC approximately 66% of the time when operating the roof bolter.

Although, an evaluation of the NIOSH CAC lab results showed that the prototype can be successful, implementing the NIOSH CAC in the field proved to be difficult. Problems were encountered due to inability to control the roof bolter's hydraulic capacity to the CAC system on the roof bolter, thus causing fan seal damage. Therefore, the NIOSH CAC did not progress from the laboratory to the field implementation at that time.

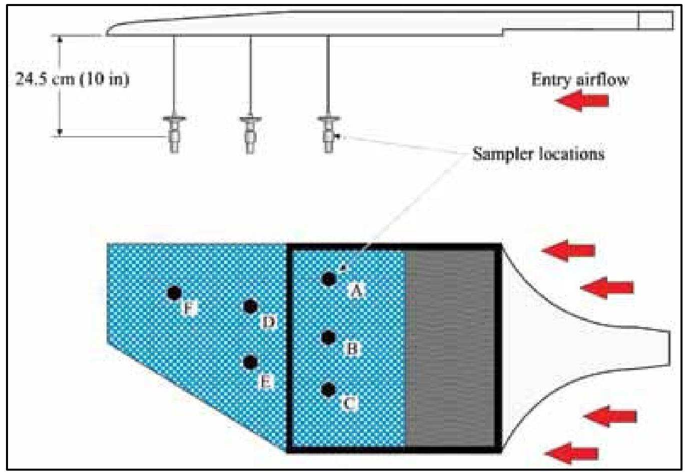

Figure 2. Gravimetric sample locations underneath the NIOSH CAC.

Table 2. Results of testing for NIOSH CAC showing respirable dust concentrations (mg/m^3) and percent reductions.

Velocity m/s (fpm)	Under plenum	Entry (outside plenum)	Reduction, %
0.05 (10)	1.95	6.90	72
0.03 (60)	1.68	5.01	67
0.61 (120)	1.50	6.07	75

Table 3. Results from field testing of NIOSH CAC showing respirable dust concentrations (mg/m^3) and percent reductions.

Dust concentration of operator under CAC(mg/m³)	Dust concentration of operator under unmodified canopy (mg/m³)	Reduction (%)	Face ventilation velocity at bolter
1.81	3.88	53	Negligible
4.73	7.30	35	Negligible

FLETCHER CAC

J.H. Fletcher & Co. (Fletcher) has begun implementing the CAC on its roof bolters, as a dust control device in response to increased interest in the mining industry to further reduce miners' exposure to respirable dust. In order to implement the CAC effectively there have been some notable design changes. The primary change is that the CAC is incorporated into the roof bolter canopy at the design stage instead of being an "add-on" device. The bolting machine hydraulic system is used to operate the filtered-air blower fan which provides the clean air to the CAC, and a new horizontal outlet design was built using slotted openings instead of a perforated plate with screen mesh backing. The slotted design resulted in a perimeter airflow pattern, which had not previously been tested. These design changes revised the NIOSH prototype substantially. Advantages to this revised prototype (Fletcher CAC) are that it has a much thinner profile and is incorporated into the existing machine design, making it much simpler to operate.

Fletcher provided a redesigned prototype CAC to NIOSH for testing in the laboratory setting (Figure 3). The Fletcher CAC was tested for respirable dust control effectiveness. The Fletcher design consisted of a removable plate with slots cut around the perimeter of the plate. Figure 4 shows a close-up of the opening pattern of the removable plate. Specifications of the plate openings are listed in Table 4.

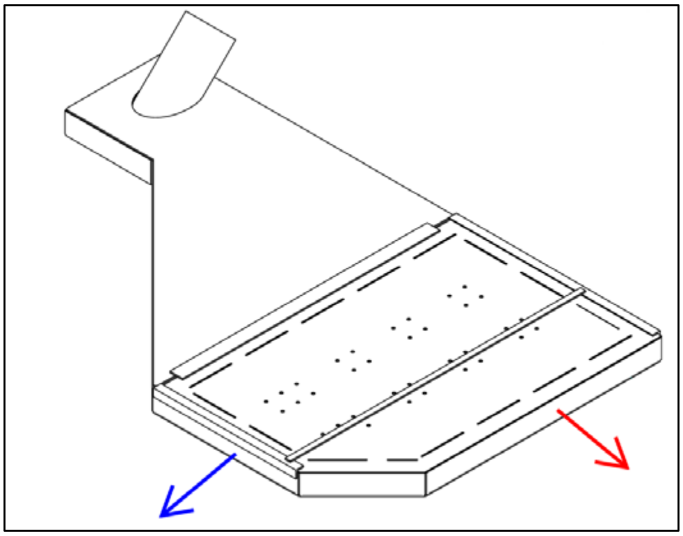

Figure 3. An underside view of the canopy air curtain (Fletcher CAC) with the Fletcher plate installed. The red arrow points towards the drill head; the blue arrow points towards the rib.

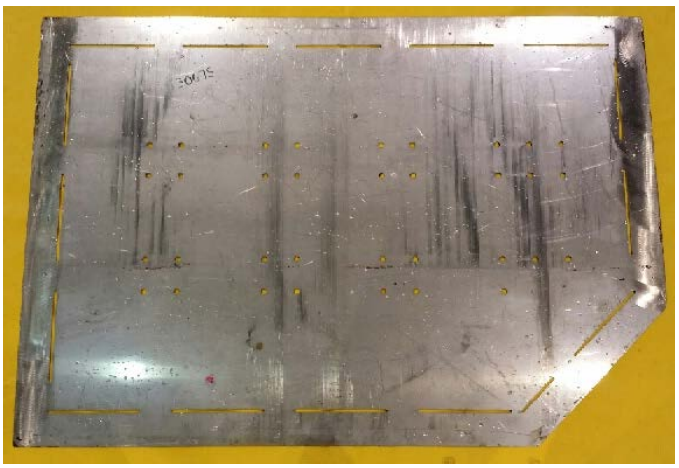

Figure 4. The removable plate tested in Fletcher's canopy air curtain.

Table 4. Specifications of the plate openings used in the Fletcher canopy air curtain.

Fletcher Design	
Opening Type	Slots & Holes
Opening location	Slots -Perimeter Holes - Linear/central
Opening Dimensions	Slots - 106 x 3 mm (4.1875" x 0.125") Holes 6.35mm Dia. (0.25")
Open Area	1.55%
Total Plate Area	3406 cm^2 (528 in^2)

TEST PROCEDURE

Testing of the Fletcher CAC was conducted in two phases. The first phase measured the velocity profile of the air distribution from the plenum. The second phase tested the effectiveness of the Fletcher CAC for respirable dust control. During these two phases, approximately 0.142 m^3/s (300 cfm) airflow was supplied to the canopy plenum. This airflow was filtered using a filter (Donaldson P123990) with an efficiency rating of 99.9%. These test procedures followed protocols developed for CAC testing by Listak and Beck [2012] and Goodman and Organiscak [2003].

Air velocity measurement

This phase determined the air velocity profile of the Fletcher CAC. A test stand was built to support the CAC. A 10.2-cm by 10.2-cm (4-in by 4-in) grid was placed 25.4 cm (10 in) below and in the same plane as the plenum face. The measurement grid extended approximately 30.5 cm (12 in) beyond the perimeter of the Fletcher CAC. The velocity distribution test was repeated with the measurement grid 76.2 cm (30 in) below the Fletcher CAC.

Table 5 presents airflow velocity information for the Fletcher design. Air velocity profiles are presented in Figure 5 and Figure 6. Higher CAC air velocities were observed near the front of the Fletcher CAC. The airflow supply is directed toward the front of the Fletcher CAC (by design), and an internal angle plate directs the airflow downward, forcing greater downward airflow at the front. This phenomenon results in the higher velocities being located towards the front of the CAC. Overall, the downward airflow velocity from the Fletcher designed plenum was greater than the airflow from the NIOSH design: 3.82 m/s (751 fpm) maximum velocity for the Fletcher design compared with 2.29 m/s (450 fpm) maximum velocity for the NIOSH design.

Table 5. Airflow statistics for the Fletcher CAC.

Plate	Height Underneath Canopy (cm)	Max Airflow Velocity (m/s)	Airflow Quantity Supplied (m^3/min)
Fletcher	25.4 (10-in)	3.82 (751 fpm)	0.142 (300 cfm)
Fletcher	76.2 (30-in)	2.18 (429 fpm)	0.144 (306 cfm)

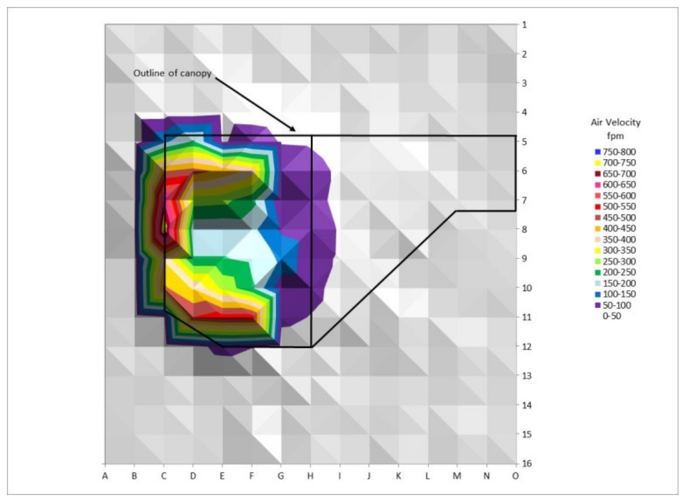

Figure 5. Airflow velocities at 25.4-cm (10-inch) height underneath the Fletcher CAC.

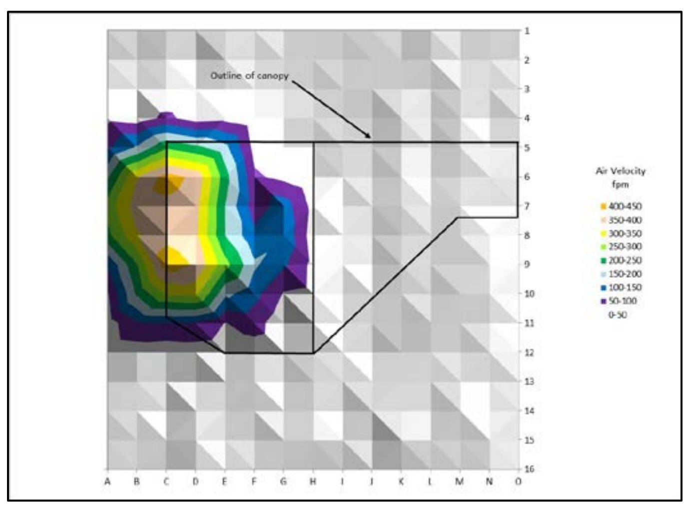

Figure 6. Airflow velocities at 76.2-cm (30-inch) height underneath the Fletcher CAC.

Respirable dust control effectiveness

Testing for respirable dust control was performed in the NIOSH model longwall gallery return section. The return section is 2.29-m (90-in) high by 1.98-m (78-in) wide. The Fletcher CAC was centered in the return with the slotted distribution plate surface 1.83 m (72 in) above the floor. The Fletcher CAC was placed approximately 24.4 m (80 ft) downwind of the dust feeder. The dust used for testing was a fine-sized coal dust (80% passing 20 microns)—Keystone Black (325BA Mineral Black Filler).

Both gravimetric and instantaneous samplers were used for testing the Fletcher CAC. The gravimetric samplers consisted of 10-mm Dorr-Oliver cyclones and 37-mm 5-µm PVC filters with a vacuum pump providing a sampling airflow of 2.0 l/min regulated by individual critical orifices. The instantaneous samplers were Thermo Scientific personal Data Ram 1000 (pDR-1000) nephelometers. A sampling package comprising two gravimetric and one instantaneous sampler was used to sample respirable dust at a location 1.52 m (5 ft) upstream of the CAC test stand in the center of the entry at the same vertical position as the air distribution plate. This sampling package was used to monitor the respirable upstream dust concentration throughout the test. A similar sampling package was also placed downstream 1.52 m (5 ft) from the CAC test stand, also in the center of the entry. To test the Fletcher CAC for dust control effectiveness, six gravimetric samplers were placed 25.4 cm (10 in) and 76.2 cm (30 in) underneath below the Fletcher CAC (see Figure 7 for sampler locations).

Nominal ventilation air velocities of 0.05 m/s (10 fpm), 0.3 m/s (60 fpm), and 0.6 m/s (120 fpm) were established in the return section where the CAC test stand was located. The orientation of the Fletcher CAC to the ventilation airflow is shown in Figure 7. The velocities in the entry were verified prior to and after testing using a vane anemometer. A dust feeder was used to introduce dust into a pressurized airflow stream through a conduit system with a 2.5-cm (1-in) diameter outlet in the longwall gallery to obtain an upwind respirable dust concentration targeting approximately 6.0 mg/m^3. This target concentration was selected because previous NIOSH studies have shown that this level of dust is encountered in the return of continuous miners using scrubbers [Listak and Beck, 2012; Colinet et al., 2013; Potts et al. 2011]. The instantaneous samplers (pDR-1000) were used to monitor dust concentrations during testing.

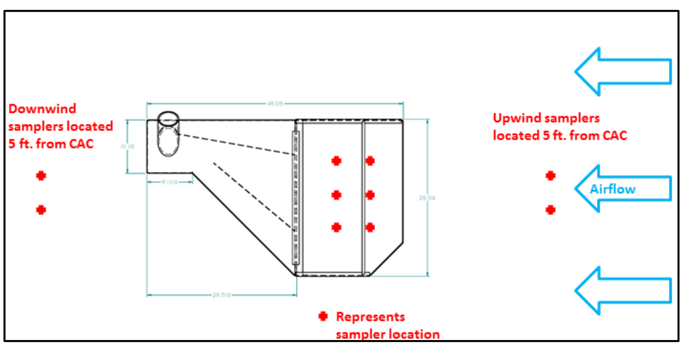

Figure 7. The Fletcher CAC showing gravimetric filter locations and ventilation airflow direction.

Following development of the test dust concentration, the evaluation proceeded, testing the Fletcher CAC with the air supply blower off (baseline condition) and then testing with the air supply blower turned on (test condition). Dust concentrations were measured for 30 minutes in each condition.

Because the upwind dust concentration varied between tests, the ratio of the average of the six under-canopy gravimetric samplers to the average of the two upwind gravimetric samplers was used to assess the effect of the Fletcher CAC. The upwind gravimetric samplers were designated 1 and 2; the under-canopy gravimetric samplers were designated A through F. The ratio determined for each test condition (canopy blower on) and each baseline condition (canopy blower off) was:

$$ratio = \frac{canopy}{upwind}$$

where

canopy = the average of the six respirable dust concentrations (A–F) underneath the canopy.
upwind = the average of the two upwind respirable dust concentrations (1 and 2).

The dust control efficiency was calculated by comparing the ratios from the canopy on and canopy off trials using the following equation:

$$Efficiency = \left(1 - \left(\frac{ratio\ on}{ratio\ off}\right)\right) \times 100$$

where

ratio on = the ratio from the canopy "on trial."
ratio off = the ratio from the canopy "off trial."

Test data results are presented in Table 6 and Table 7. Dust control efficiencies were calculated from the ratios and the data sets were evaluated to determine if the averages from the canopy off and canopy on were statistically different. The t-test using a 95% significance level was applied in this evaluation [Natrella, 1963]. In all cases, the results demonstrated that there was a statistically significant difference between the two data sets—canopy off ratio and canopy on ratio.

Table 6. Summary of dust reduction for Fletcher CAC at 10 inches below the canopy.

Velocity	Average Canopy off ratio (canopy/upwind)	Average Canopy on ratio (canopy/upwind)	Dust Reduction (%)	Statistically Significant (t-test Equal Variance, 95%)	Count
120 fpm	1.100	0.911	17.2	Yes	5
60 fpm	1.048	0.836	20.2	Yes	5
10 fpm	1.005	0.759	24.5	Yes	5

Table 7. Summary of dust control efficiency for Fletcher CAC at 30-inch height below the canopy.

Velocity	Average Canopy off ratio (canopy/upwind)	Average Canopy on ratio (canopy/upwind)	Dust Reduction (%)	Statistically Significant (t-test Equal Variance, 95%)	Count
120 fpm	1.103	0.941	14.7	Yes	5
60 fpm	1.088	0.934	14.2	Yes	5
10 fpm	1.026	0.830	19.2	Yes	5

The results from this testing did not compare well with the results from testing the NIOSH CAC. The testing parameters were essentially the same but with a few variations. The face ventilation airflow for this testing was directed toward the front of the Fletcher CAC instead of the rear as with the NIOSH CAC. The ventilation airflow was measured at the Fletcher CAC instead of at the regulator as for the NIOSH CAC. The dust feed for this testing did not require dispersion. This testing evaluated results from both on and off conditions of the Fletcher CAC and at distances of 25.4 cm (10 in) and 76.2 cm (30 in) below the CAC. Finally, the analysis used ratios for evaluation, whereas the NIOSH CAC was evaluated using direct dust concentrations. However, these differences were not expected to be the cause of the major difference between the NIOSH CAC and the Fletcher CAC results.

The results show at the 25.4-cm (10-in) location underneath the Fletcher CAC that the range of reductions of coal mine respirable dust are 17.2–24.5% (Table 6) instead of 67–75% (Table 2) as with the NIOSH CAC. To discover the reason for the lower performance of the Fletcher-designed CAC, NIOSH conducted computational fluid dynamics (CFD) analysis on the Fletcher CAC horizontal outlet slotted openings (Figure 8) using ANSYS Fluent Version 15.0. Single slots were modeled to determine the possible cause for the inadequate results. Subsequent modeling of double slots was completed to discover if two rows of staggered slots could be a solution to improve reductions of coal mine respirable dust concentrations.

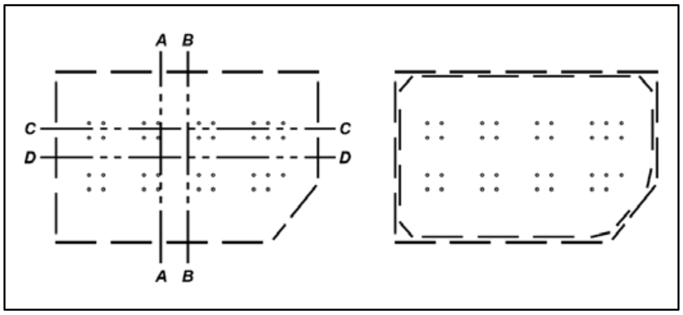

Figure 8. The canopy air curtain geometric model used in CFD analysis. The original single slot is shown on the left with the modified double slot on the right. Locations of cross-section planes are represented on the single-slot CAC (left).

An entry (1.8-m (6-ft) high x 2.0-m (6.5-ft) wide x 3.0-m (10.5-ft) length) with the CAC at the roof was modeled to display airflow vectors from the CAC and its influence on dust concentrations in the entry (Figure 9). Cross-sectional planes are shown to display the effect of airflow vectors on dust concentrations. Input airflow to the CAC slots was set at 300 cfm. Interference or ventilation airflow velocity was 60 fpm and had a background dust concentration of 6.0 mg/m^3. Air leakage from the CAC was not considered, i.e., all airflow flowed vertically downward from the slots.

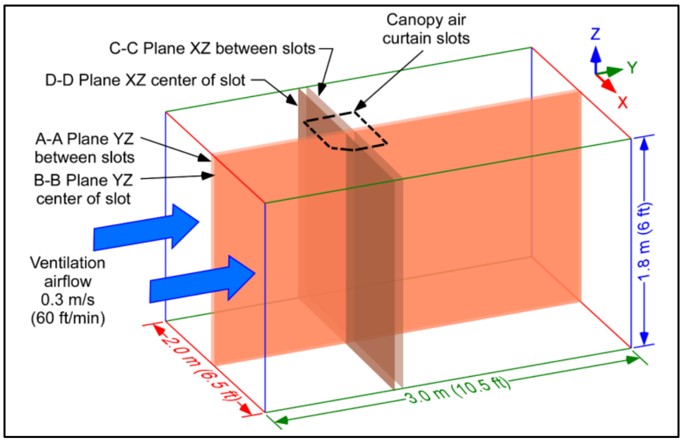

Figure 9. Geometric volume modeled in CFD software that shows location of CAC slots. Cross-sectional planes are shown to display results from subsequent analysis.

A plan view of the dust concentration contour results from the CFD simulation in Figure 10 shows a limited view of the surrounding area of the CAC domain. Figure 10 shows that the gap between the single row of slots (displayed in plan view) allows the outside airflow to enter the CAC domain (the area inside the slotted perimeter) as can be seen by the higher dust concentrations (5.0–5.5 mg/m^3) entering through the gap area (Figure 10A). The addition of the second staggered row of slots seems to be effective for preventing outside airflow entering inside the CAC domain (Figure 10C). The average respirable dust concentration directly underneath the plenum for the single-slotted CAC domain is calculated as 2.72 mg/m^3, and the average respirable dust concentration for the double-slotted CAC domain is 1.84 mg/m^3. At 25.4 cm (10 in) below the CAC, the CAC with the double staggered row of slots (Figure 10D) provides better protection from coal mine respirable dust with the average respirable dust concentrations in the CAC domain calculated as 3.43 mg/m^3, which is lower than the single-row-slotted CAC (Figure 10B) with average respirable dust concentrations in the CAC domain calculated as 4.18 mg/m^3.

Reviewing the figures for the YZ cross-sectional planes (A-A and B-B), the single-row-slotted CAC has a larger area of protection, especially at heights further away from the slot outlets (Figure 11A left and Figure 12A left). This is due to the higher clean airflow velocity from the CAC since both the single- and double-slot CAC are supplied with the same 300 cfm airflow amount. But the double staggered row CAC has lower dust concentrations within its area of protection (Figure 11B left and Figure 12B left). The total area of protection from the CAC downward airflow (lower dust concentrations) angles downstream due to the influence of the ventilation airflow. This phenomena occurs for both the YZ plane between the slots (A-A) and the YZ plane on the center of the slot (B-B). The airflow velocity vectors corroborate the phenomena showing how the ventilation airflow impacts the downward airflow. For area of protection directly underneath the CAC, the single-row-slotted CAC seems to allow the ventilation airflow to enter the CAC domain, especially between slots (Figure 11A right). The double staggered row CAC has an area of recirculation at the rear of the CAC (Figure 11B right and Figure 11B right). This recirculation area still provides protection to the CAC domain due to the downward airflow from both rows of slots, but it tends to allow ventilation airflow into the CAC domain at the rear of the CAC albeit at heights further away from the slot outlets.

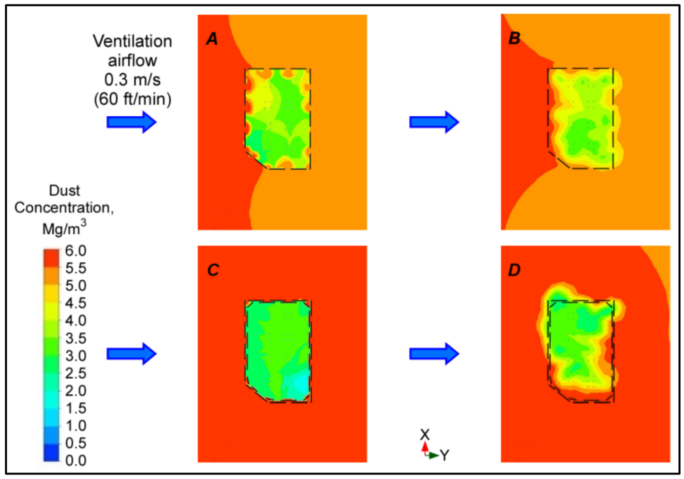

Figure 10. A plan view of dust concentrations displayed underneath the canopy air curtain in the XY plane (only a limited area of CAC domain is displayed). A) Single slots directly underneath CAC, B) Single slots 25.4 cm (10 in) below CAC, C) Double slots directly underneath CAC, and D) Double slots 25.4 cm (10 in) below CAC.

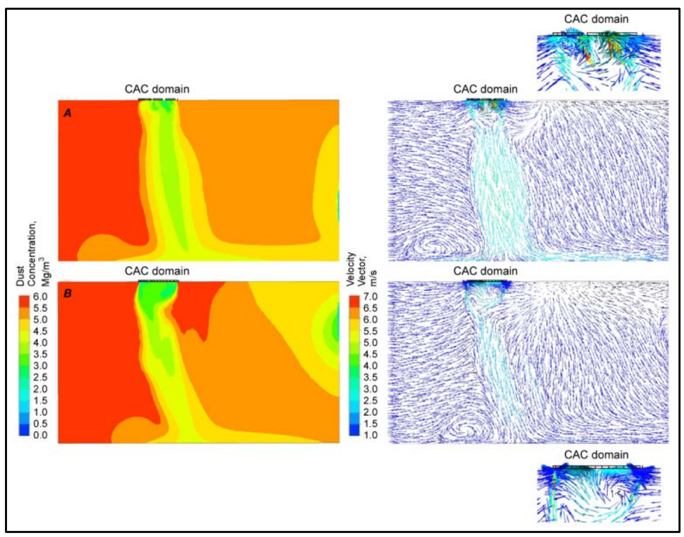

Figure 11. Cross-section of dust concentrations and airflow vectors in YZ plane between slots (A-A). A) Display of single-slot CAC dust concentrations (left) and airflow vectors (right). Right top inset picture shows zoomed view of canopy area velocity vectors (A Right). B) Display of double-slotted CAC dust concentrations (left) and airflow vectors (right). Right bottom inset picture shows zoomed view of canopy area velocity vectors (B Right).

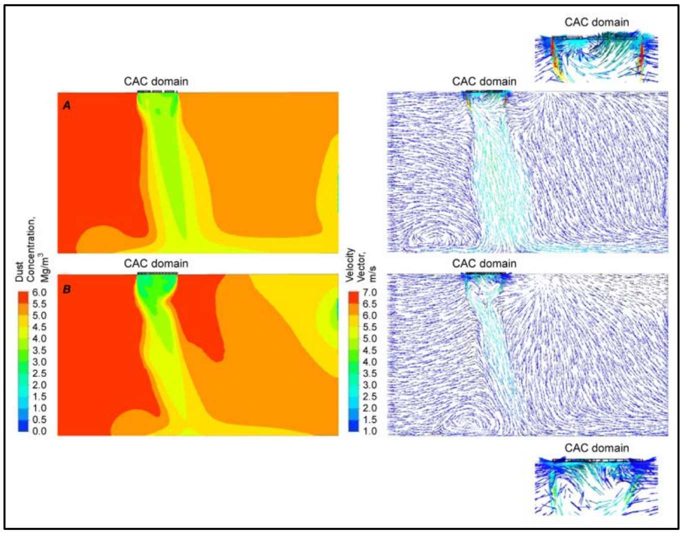

Figure 12. Cross-section of dust concentrations and airflow vectors in YZ plane on the center of slot (B-B). A) Display of single-slot CAC dust concentrations (left) and airflow vectors (right). Right top inset picture shows zoomed view of canopy area velocity vectors (A Right). B) Display of double-slotted CAC dust concentrations (left) and airflow vectors (right). Right bottom inset picture shows zoomed view of canopy area velocity vectors (B Right).

Reviewing the figures for the XZ cross-sectional planes (C-C and D-D), the single-row-slotted CAC has a better defined area of protection directly underneath the CAC, especially at heights further away from the slot outlets (Figure 13A left and Figure 14A left). Again, that is due to the higher airflow velocity at the single slot. The double staggered row CAC area of protection tends to expand, especially at lower heights away from the CAC slots. Additionally, the double slots have lower dust concentrations within the CAC area of protection (Figure 13B left and Figure 14B left). This phenomena occurs for both the XZ plane between the slots (C-C) and the XZ plane on the center of the slot (D-D). Reviewing the airflow velocity vectors for the single-row-slotted CAC, it seems that some ventilation airflow enters the CAC domain, especially between slots (Figure 13A right). The double staggered row CAC provides protection to the CAC domain due to the downward airflow from both rows of slots (Figure 13B right and Figure 14B right), but it tends to allow ventilation airflow into the CAC domain at heights further away from the slot outlets.

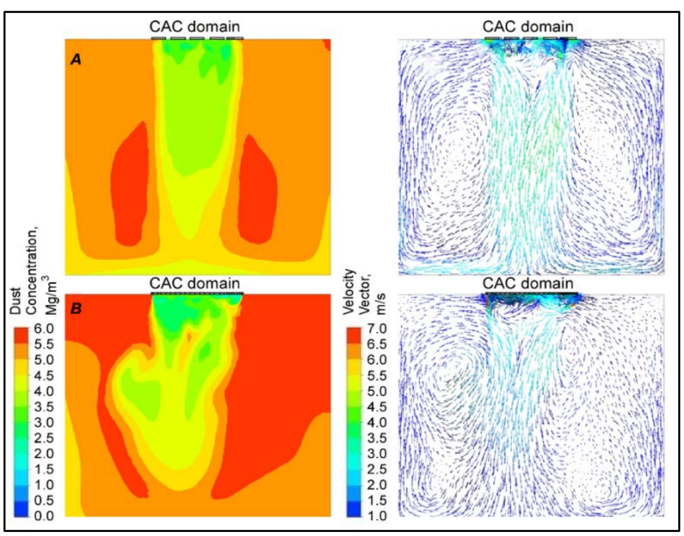

Figure 13. Cross-section of dust concentrations and airflow vectors in XZ plane between slots (C-C). A) Display of single-slot CAC dust concentrations (left) and airflow vectors (right). B) Display of double-slotted CAC dust concentrations (left) and airflow vectors (right).

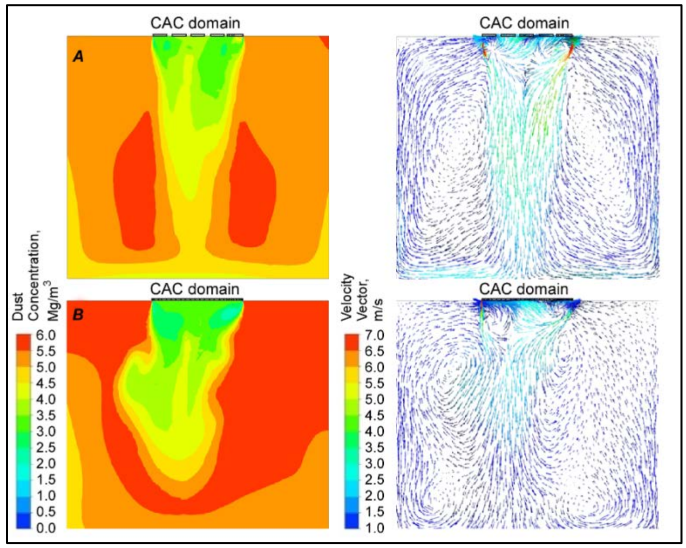

Figure 14. Cross-section of dust concentrations and airflow vectors in XZ plane on the center of slot (D-D). A) Display of single-slot CAC dust concentrations (left) and airflow vectors (right). B) Display of double-slotted CAC dust concentrations (left) and airflow vectors (right).

Further examination of the XZ plane airflow velocity vectors shows the airflow from the CAC blowing down to the floor and then returning up along the laboratory walls and returning towards CAC slot outlets. It is expected that this airflow pattern would translate to what occurs on the rib side of the CAC in an underground entry. However, the opposite side of the CAC would be further away from the rib and the airflow pattern would only be affected by the roof bolter machine itself. Therefore the airflow pattern on this "off rib" side may be different from that depicted in Figure 13 and Figure 14.

From a review of these figures, adding an additional staggered row or rows of slots behind the original row does help to prevent the contaminated ventilation airflow from entering the CAC domain, improving the dust control performance. The addition of 80 mesh stainless steel screen on the interior of the horizontal outlet plate may also help to improve dust control performance by ensuring downward airflow through the slots.

SUMMARY AND CONCLUSIONS:

The CAC has been proven to be effective as a dust control against respirable coal mine dust in laboratory testing. Limited testing of the CAC in mining applications has been conducted, demonstrating effective dust control ranging from 23 to 69% reductions in respirable coal mine dust. However, there is still variability in effectiveness of the CAC for respirable coal mine dust control.

NIOSH partnered with Fletcher in an important step to improve the performance of the CAC for respirable dust control on underground coal mine roof bolting machines. The company has the expertise to incorporate the CAC successfully on its roof bolters. Fletcher reviewed the results from lab testing the NIOSH CAC design (67–75% dust reductions) and the results from the recent Fletcher CAC lab testing (17–24% dust reductions), and is redesigning the CAC for better implementation on the roof bolter for dust control. Improvements include better component placement, including hose routing and guarding, upgraded filtration, replacing a MERV 11 filter with a MERV 13, and improved canopy design to better protect the operator against respirable coal mine dust.

NIOSH also completed CFD analysis of the current Fletcher CAC design to determine the cause for the under-performance of respirable coal mine dust control. The analysis showed that the single-slot design allows for contaminated ventilation air to enter the CAC domain, thus causing the inadequate performance for respirable dust control. To improve the CAC design, NIOSH conducted CFD analysis on a design that contained double staggered rows of slots (Figure 8 right). This design was demonstrated to be an improvement in relation to the ability of the CAC to provide protection from respirable coal mine dust. The CFD analysis demonstrated that the key to improvement is preventing ventilation airflow from entering the CAC domain.

To improve the CAC performance for respirable dust control, Fletcher has redesigned the CAC and contracted with Marshall University to conduct CFD analysis for improved outlet designs. Using the new design, CFD simulations were run on various configurations, with the most promising tested using handheld smoke tubes and a theatrical smoke generator. Fletcher has prototyped a design that is able to maintain a clear air volume underneath the canopy during smoke tests (Figure 15). This new design uses the mesh screen and perforated plate concept from the NIOSH canopy. Additionally, a double row of nozzles (staggered) in a separate conduit surrounding the perimeter of the perforated plate has been added. This double row of nozzles should improve dust control performance by preventing ventilation air from entering the CAC domain as demonstrated by NIOSH CFD analysis for the double staggered row of slots. This new design provides two separate airflows to the canopy—the perimeter nozzles provide a barrier to prevent ambient air from entering the canopy area, while the perforated plate provides clean air to the operator. This new concept, while tested only with smoke, shows promise. Additional lab and field testing of the new design is planned to evaluate its performance as a respirable dust control technology.

Figure 15. The improved canopy air curtain design.

DISCLAIMER

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

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