

FIELD TEST OF A CANOPY AIR CURTAIN ON A RAMCAR FOR DUST CONTROL IN AN UNDERGROUND COAL MINE

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ABSTRACT

The canopy air curtain (CAC) has been proven to provide protection to roof bolter operators in underground coal mining. This technology is being adapted for use with shuttle/ramcars. The plenum is mounted on the shuttle car canopy over the operator's position. The blower providing clean air to the operator is plumbed into the shuttle car's existing hydraulic system. Once the system was installed and tested, field testing of the CAC ability to provide respirable dust control was conducted. Results showed that overall respirable dust reductions during the total time the operator was underneath the canopy ranged from 11% to 34%, demonstrating adequate performance. However, further analysis demonstrated that the CAC performance was exceptional when the ramcar was being loaded by the continuous miner in blowing face ventilation. At this location, a position where the shuttle car operator has their highest potential for respirable dust exposure, the CAC provided dust reductions ranging from 57% to 65%. These results, especially during ramcar loading at the CM, demonstrate that the CAC can be an important dust control device to protect ramcar operators from overexposure to respirable coal mine dust.

**KEYWORDS:** Respirable dust, Shuttle car, Canopy air curtain, Coal.

INTRODUCTION

The canopy air curtain (CAC) was initially developed to protect continuous miner (CM) operators from respirable coal mine dust exposures [Krisko 1975] when the operator was located in a cab on the CM. CAC development has been successfully adapted to protect roof bolters in underground coal mines against overexposure to both respirable silica and coal dust [Goodman and Organiscak 2001, Reed et al. 2017, Reed et al. 2020]. These overexposures generally do not occur from the roof bolting operation if the bolter dust collection system is operating properly. Overexposure to respirable dust transpires from other sources operating in the area, especially when the roof bolter operates downwind of the CM. When the roof bolter machine operates downwind of the CM, studies conducted by the National Institute for Occupational Safety and Health (NIOSH) have documented that roof bolter operators can encounter respirable dust concentrations ranging up to approximately 12 mg/m<sup>3</sup> [Potts et al. 2011, Colinet et al. 2013].

To prevent overexposures to respirable dust when downwind of the CM, the roof bolter CAC has been integrated into the roof bolter canopy that the bolter operator works beneath when bolting a 6-m to 12-m (20-ft to 40-ft) coal face cut. The idea is to provide filtered air, blown over the operator, through a plenum built into the roof bolter canopy. This filtered air serves as a curtain which is designed to protect the operator from respirable dust overexposure from contaminated ventilating airflow by providing a fresh-air source to the bolter operator. Field studies have documented dust reductions ranging up to 60% for roof bolter operators when using the CAC [Reed et al. 2020]. Maximum protection up to 90% is possible if the operating conditions are correct [Reed et al. 2019].

The CAC is now being expanded to include shuttle and ramcar operators to provide respiratory protection from respirable coal mine dust. The design provides filtered air, blown over the operator, through a plenum attached to the ramcar canopy. This new version of the CAC is being developed under a NIOSH contract with Marshall University and J.H. Fletcher. Laboratory testing of the shuttle car CAC demonstrated promising results, providing shuttle/ramcar operators with potential dust reductions up to 83% [Reed et al. 2018]. Field testing was necessary to determine the protection from respirable coal mine dust that the ramcar CAC will provide ramcar operators at an operating mine. Two tests were scheduled to assess the performance of the ramcar CAC; one in March 2019 and the other in September 2019. During the March study, problems were encountered with powering the blower of the ramcar CAC, which made the data from the March study unusable. Discussions of the problem encountered with the installation and operation of the CAC and how it was overcome are presented in this paper along with the results from the September 2019 study.

INSTALLATION OF THE CAC

The CAC was installed onto a ramcar at an underground coal mine just prior to the September 2019 study. The testing was conducted at one of the mine's super sections on the right side of the section, with no sampling conducted on the left side. The right-side section consisted of a CM, three ramcars, and a roof bolter machine.

A unique characteristic of the right-side super section was that the discharge of the CM flooded-bed scrubber was located on the right side of the CM. This discharge location was directly in line with the ramcar cabs which were located on the right side of the ramcar. This side of the super section was selected for testing as the mine indicated the ramcar operators on the right side of the super section typically had higher dust exposures.

The CAC, with all necessary components for generating airflow, was installed on ramcar #1 prior to testing during a nonproducing shift. Components included a blower, filter housing, canopy plenum, and associated hosing for connection. The 45.5 cm x 45.5 cm (18" x 18") plenum was welded to the underside of the canopy of the ramcar and located above the ramcar operator's seat (Figure 1). Welding, drilling and or cutting on the canopy would require certification for its structural integrity. The blower and intake filter housing were located on a flat area of the ramcar adjacent to the cab (Figure 2).

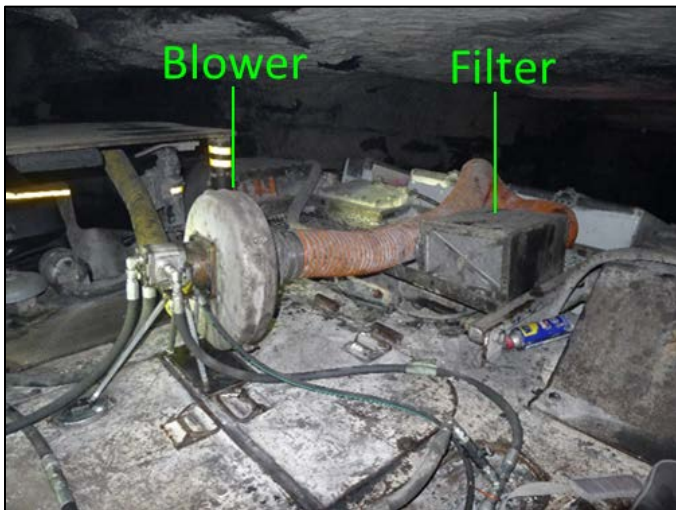
Representatives from J.H. Fletcher coordinated with the mine site on CAC installation to the selected ramcar. The blower was operated using a hydraulic motor that was plumbed into the existing ramcar hydraulic system (shown on left side of the blower in Figure 2). The blower was set to operate continuously throughout testing.

During the March 2019 study, the CAC operating components were plumbed into the existing hydraulic system. While the test was underway, it was observed that the CAC was not operating properly.

The blower did not consistently operate during ramcar operation. It was found that the ramcar hydraulic system did not have the capacity to operate the CAC system in addition to normal ramcar operation. For example, when the CAC was operated during loading and unloading of the ramcar, the blower motor would either slow down or completely stop, depending upon the hydraulic requirements of the ramcar. This situation was also noticed during steering of the ramcar. When the ramcar turned while tramping, the blower motor would, again, either slow down or completely stop, depending upon the hydraulic requirements of the ramcar steering system. Therefore, the results of the March 2019 study were not representative of a properly operating CAC system on the ramcar and were omitted from this paper.



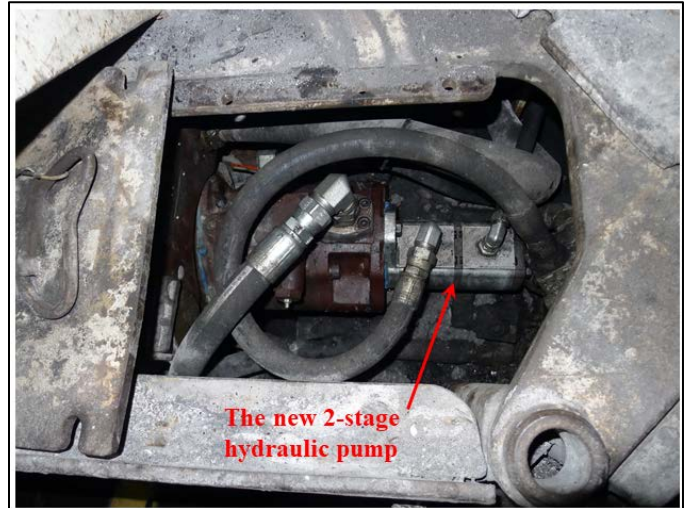
**Figure 1.** Air curtain plenum welded to underside of ramcar canopy located above the operator's seat.



**Figure 2.** Location of blower and intake filter housing on the ramcar.

Prior to the September 2019 study, it was determined that the addition of a 2-stage hydraulic pump "piggybacked" onto the existing ramcar hydraulic pump and plumbed into the hydraulic system should solve the problem with the canopy blower motor slowing down or stopping during ramcar operation (Figure 3). A 2-stage hydraulic pump was obtained and installed. The hydraulics of the new 2-stage pump were plumbed into the existing hydraulic system to allow operation of the blower. The new CAC system was tested the day before the September 2019 study began. The CAC system operated correctly allowing continuous operation of the blower. Therefore, the results presented for the September 2019 study are reliable results of a properly operating CAC system on the ramcar. A listing of components, supplied as a kit by J.H Fletcher, for CAC installation is provided in Appendix A. It should be noted that the electrical system

may require approval from MSHA's Approval and Certification Center if the load on the electrical system is affected.



**Figure 3.** The new 2-stage hydraulic pump installed "piggyback" on the existing ramcar hydraulic pump.

During testing of the ramcar CAC, the criteria for face ventilation used the parameters stated in the mine's ventilation plan. Testing was conducted in blowing face ventilation, as blowing face ventilation has been found to be more detrimental to shuttle/ramcar operators' respirable dust exposure than exhausting face ventilation [Potts et al. 2011].

#### DUST SAMPLING METHOD

A combination of Continuous Personal Dust Monitor 3700s (CPDM) (Figure 4), Personal Data Ram 1000s (pDR-1000), and gravimetric samplers were used for testing the CAC for respirable dust control. The gravimetric sampler consisted of an Escort ELF pump, Dorr-Oliver Cyclone, and 37-mm PVC filter in a coal cassette. Two gravimetric samplers were used in conjunction with a pDR-1000 (Thermo Scientific) to create a gravimetric sampling package (Figure 5). The pDR-1000 was set to record instantaneous respirable dust concentrations at 2-second intervals. Gravimetric sampling packages were placed at the front of the ramcar cab outside the zone of influence of the CAC, at the CM intake, CM return, and at various locations around the feeder. The CPDM sampling inlet was worn by the ramcar operator, and a pDR-1000 was located alongside the CPDM inlet to record the dust levels underneath the CAC. All ramcars were outfitted with the gravimetric sampling packages, the CPDM, and the pDR-1000 samplers.



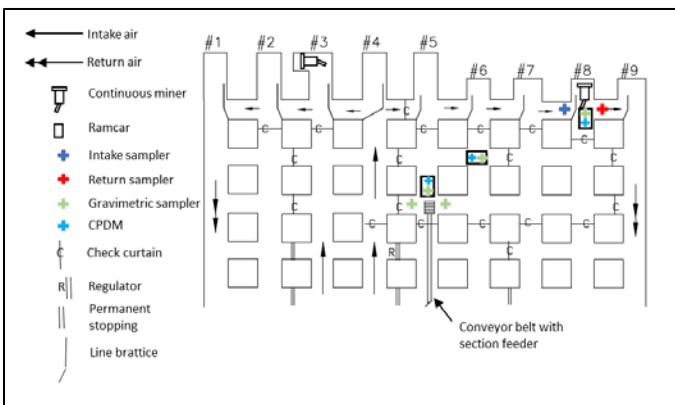
**Figure 4.** A PDM 3700 respirable dust sampler.



**Figure 5.** A typical gravimetric sampling package consisting of a pDR-1000 and two gravimetric samplers. This package is typically hung from a roof bolt or mounted on mining equipment.

### TESTING

Figure 6 shows the layout of the 9-entry super section where the testing was conducted. Intake air is brought into the section through entries # 3 and # 4. The intake air splits at entry #4 with the return air leaving the section in entries #1, #2, and #7 - #9 with "neutral air" in #5 and #6. The feeder was located in entry #5.



**Figure 6.** The super section for testing ramcar CAC. Entry #8 has the right-side CM, and entry #4 left has the left-side CM (not sampled). Ramcars are shown in various locations and are not necessarily representative of their actual location during operation.

The CPDMs used on the ramcars in this study are shown in Figure 6 as light blue markers. The CM was also sampled for coal mine respirable dust during this study. The CM intake (dark blue marker) and return (red marker) samplers were placed in their respective locations shown in Figure 6 using the gravimetric sampling package. Additionally, the gravimetric samplers used on the ramcars and placed at the feeder in different entries are shown as green markers in Figure 6. The gravimetric samplers were all started at the beginning of the shift at the section and shut off prior to leaving the section.

During testing, a time study of the ramcars was conducted. Since the ramcars traveled from the CM to the feeder and vice versa, times were recorded during ramcar loading at the CM and the unloading at the feeder. The ramcars always entered the entry where the CM was located and were loaded behind the CM. All the ramcars of the study generally entered the feeder through entry #5. Sometimes entry #6 left was used, but this rarely occurred due to the wet conditions in that entry. The left-side ramcars (which were not part of the study) entered the feeder from entry #4 right. Tram times were calculated from the recorded loading and unloading times. The face ventilation was recorded at the CM location. The ventilation at the feeder was not able to be measured due to the constant maneuvering of the ramcars into and out of the feeder entries. Table 1 shows the face ventilation quantities encountered at the CM entries during the September 2019 study.

**Table 1.** Face ventilation quantities at the CM entries for the September 2019 study.

Date	Entry	Entry or Curtain Width (cm)	Entry Height (cm)	Velocity (m/s)	Quantity (m <sup>3</sup> /s)
10-Sep	#9	548	196	1.4	15.0
10-Sep	#6 left	569	218	0.9	11.1
10-Sep	#6	556	216	0.8	10.1
11-Sep	#6 left	531	198	0.7	7.6
11-Sep	#6	564	208	0.6	6.6
11-Sep	#8	546	203	1.4	15.2
11-Sep	#9	548	239	1.0	12.7
11-Sep	#7 right	NA	NA	NA	NA
12-Sep	#7 left	152	224	1.0	3.5
12-Sep	#8	NA	NA	NA	NA
12-Sep	#9	533	244	1.0	13.3
12-Sep	#6	518	203	0.6	6.2
12-Sep	#7 right	518	203	0.6	6.2

NA = Not Available

### RESULTS

It should be noted that all data results of respirable dust sampling from this study cannot be used for compliance purposes. The gravimetric time-weighted-average (TWA) data are area samples, not personal samples. The samples are also not full-shift samples. All samples were not collected by MSHA-certified persons.

To compare the CPDM and gravimetric TWA data, the sampling timeframes must be equivalent. Both samplers are mass based. The gravimetric sampling occurs as long as the pumps are operating. The CPDM was programmed to sample for a time period longer than the anticipated shift. Therefore, the CPDM sampled for much longer than the gravimetric samplers. Since the CPDM records the cumulative mass of respirable dust collected in 1-minute intervals [Volkwein et al. 2006], the respirable dust concentration comparable to the gravimetric sampler was calculated using the gravimetric samplers' time interval. The CPDM data was downloaded to calculate the dust concentrations of the specific time interval of the gravimetric samplers, which are the start and stop times of the gravimetric samplers used in conjunction with the CPDM. The following equation is used to calculate the respirable dust concentration that is comparable to the gravimetric sampling concentration:

$$Conc. = \frac{(Mass_2 - Mass_1) \times 1000}{(2.2 \times Time_{Int})} \quad (1)$$

where

- Conc. = the CPDM concentration (mg/m<sup>3</sup>);
- Mass<sub>2</sub> = the cumulative mass recorded at end time of time interval (mg);
- Mass<sub>1</sub> = the cumulative mass recorded at begin time of time interval (mg);
- 2.2 = flowrate of the CPDM (lpm);
- Time<sub>Int</sub> = the total gravimetric sampling time from beginning to ending (minutes);

In order to compare the gravimetric results with the CPDM results, all samples must be converted to MRE (Mine Research Establishment)<sup>1</sup> equivalent results. For the gravimetric samples, the MRE equivalent is 1.38 times the sample concentration result (Tomb et al., 1973). For the CPDM samples, the MRE equivalent is 1.05 times the sample concentration result (Page et al., 2008). All results comparing gravimetric and CPDM data are shown as MRE equivalent.

The instantaneous data from the pDR-1000 are used to quantify the dust control efficiency of the CAC for different segments of the ramcar travel route when the operators were under the canopy. These average concentrations were calculated using the instantaneous pDR-1000 data. In order to compare the data among the different pDR-1000s used in the study, the pDR-1000 data must be corrected because they are measured using a light scattering instrument (Williams and Timko, 1984). Correction is accomplished using the average MRE equivalent concentration from the two gravimetric samplers or single CPDM operated adjacent to a specific pDR-1000. The data from the two types of samplers are used to calculate a calibration ratio with the following equation:

$$Ratio = \frac{Grav}{Instant} \quad (2)$$

where

- Ratio* = the calibration ratio;
- Grav* = the gravimetric TWA concentration or CPDM TWA concentration; both concentrations are MRE equivalent;
- Instant* = the instantaneous optical TWA concentration from the pDR-1000.

Next, the ratio is multiplied by each instantaneous optical concentration recorded every two seconds by the pDR-1000 in order to obtain calibrated instantaneous concentrations. All subsequent calculations were completed using the corrected pDR-1000 data.

**CM intake, CM return, and feeder samples**

The CM intake and return gravimetric TWA concentrations are shown in Table 2. While the sampling times are long, they are not full shift samples. The sampling times are the duration of sampling during the daily survey. These results show that the return air downstream of the CM contains more respirable dust than the intake air provided to the CM. It should be noted that the flooded-bed scrubber on the CM was consistently operated during each cut.

**Table 2.** CM intake and CM return concentrations during September 2019 testing.

Date	Location	Time (minutes)	MRE Concentration (mg/m <sup>3</sup> )
10-Sep-19	CM Intake	323	0.168
10-Sep-19	CM Intake	323	0.176
10-Sep-19	CM Return	328	1.384
10-Sep-19	CM Return	328	1.625
11-Sep-19	CM Intake	296	0.322
11-Sep-19	CM Intake	295	0.348
11-Sep-19	CM Return	294	3.356
11-Sep-19	CM Return	295	3.810
12-Sep-19	CM Intake	326	0.866
12-Sep-19	CM Intake	326	0.884
12-Sep-19	CM Return	328	4.031
12-Sep-19	CM Return	329	4.649

The feeder gravimetric TWA concentrations are presented in Table 3. These results show that the respirable dust concentrations at the feeder were relatively consistent. These concentrations (Tables 1 and 2) are presented to provide awareness of the conditions during

mining during this field study. These results would be typical of normal operations and show that no unusual conditions exist.

**Table 3.** Feeder concentrations during September 2019 testing.

Date	Location	Time (minutes)	MRE Concentration (mg/m <sup>3</sup> )
10-Sep-19	Feeder 1	310	0.318
10-Sep-19	Feeder 1	310	0.324
10-Sep-19	Feeder 2	311	0.253
10-Sep-19	Feeder 2	310	0.245
11-Sep-19	Feeder 1	320	0.255
11-Sep-19	Feeder 1	321	0.206
11-Sep-19	Feeder 2	321	0.193
11-Sep-19	Feeder 2	320	0.178
12-Sep-19	Feeder 1	340	0.516
12-Sep-19	Feeder 1	340	0.521
12-Sep-19	Feeder 2	340	0.430
12-Sep-19	Feeder2	339	0.429

**Ramcar results**

Table 4 shows the air velocity from the plenum of the CAC installed on the ramcar. During early testing in March, the air velocity was lower and indicative of problems with the CAC operation during the March study described earlier in this section. The air velocity during the September testing was higher, with the last day being lower due to the night shift adjusting the canopy airflow and not setting it properly for the last day of testing.

**Table 4.** Air velocities measured from the ramcar CAC plenum.

Date	Canopy airflow (m/s)
12-Mar	0.9
13-Mar	1.0
14-Mar	0.6
10-Sep	1.8
11-Sep	1.6
12-Sep	0.9

Table 5 shows the respirable dust concentrations from sampling the ramcars during the study. Ramcar #1 had the CAC installed. To calculate the percent reduction of respirable dust when using the CAC installed on ramcar #1 for each corresponding date, the following equation was used.

$$\% \text{ reduction} = \left[ 1 - \left( \frac{MRE \text{ CPDM underneath canopy}}{\text{average}(MRE \text{ TWA outside canopy})} \right) \right] \times 100 \quad (3)$$

Where

- % reduction = the percent reduction of respirable dust (%)
- MRE PDM underneath canopy = the concentration of the MRE PDM underneath concentration (mg/m<sup>3</sup>)
- MRE TWA outside canopy = the concentrations of the MRE TWA outside concentrations (mg/m<sup>3</sup>)

In addition to the respirable dust concentrations measured, the % reduction due to the CAC is shown for ramcar #1. These % reductions are based upon the samples which were collected the entire time the samplers were operating during the day. Therefore, these samples may include a substantial amount of idle time, i.e. time when the ramcar was not operating. Ramcars #2 and #3 have no % reductions as they did not have the canopy installed. Therefore, their % reduction is demarcated as NA or not applicable.

Comparing operator respirable dust exposures of ramcar #2 and #3 to ramcar #1, the car with the CAC installed, is possible with the data available. However, it would be difficult to glean any important information from the comparison because, while all ramcars operate in the same section, the operators are in different environments at any single point in time. It would be impossible to discern any impact from the CAC on ramcar #1 to the operators of ramcars #2 and #3.

<sup>1</sup> MRE is the United Kingdom Mining Research Establishment which used a sampler designed specifically to match the United Kingdom British Medical Research Council (BMRC) criterion (Page et al., 2008).

**Table 5.** Results of respirable dust sampling of ramcars for September 2019 study.

Ramcar #	Date	Time (minutes)	MRE TWA outside concentration (mg/m <sup>3</sup> )	MRE PDM underneath concentration (mg/m <sup>3</sup> )	% reduction outside /underneath comparison of MRE
1	10-Sep-19	379	1.118	0.873	14.8
1	10-Sep-19	379	0.930		
1	11-Sep-19	340	0.864	0.693	23.2
1	11-Sep-19	340	0.941		
1	12-Sep-19	345	1.124	1.074	8.0
1	12-Sep-19	345	1.213		
2	10-Sep-19	311	0.664*	0.730	NA
2	10-Sep-19	357	2.293		
2	11-Sep-19	329	0.823	2.379	NA
2	11-Sep-19	330	0.850		
2	12-Sep-19	337	1.564	1.807	NA
2	12-Sep-19	338	1.636		
3	10-Sep-19	342	0.717	0.697	NA
3	10-Sep-19	342	0.691		
3	11-Sep-19	192	0.714	0.756	NA
3	11-Sep-19	192	0.747		
3	12-Sep-19	358	1.527	1.533	NA
3	12-Sep-19	358	1.585		

\*Sample discarded; cassette broken during transport.

NA – not applicable

Again, these samples cannot be used for compliance purposes for the reasons stated previously. These samples are not full-shift samples and the samplers used to obtain these samples remained in the shuttle cars, whether the operators were in the cab or not. The CPDM and gravimetric samplers did not move with the shuttle car operators.

#### Analysis of ramcar #1 results

Additional analysis of ramcar #1 was conducted to show the impact of the CAC system on respirable dust concentrations at the different ramcar locations. This impact was analyzed using the data from the gravimetric and CPDM sampling and the instantaneous sampling using the pDR-1000.

Table 6 shows the time the ramcar spent at each location during the September study: at the CM being loaded, at the feeder unloading car, tramping from feeder to CM, and tramping from CM to feeder. Tramping from feeder to CM had the largest amount of time, and it may represent tramping time including staging time for the CM (i.e., time waiting to be loaded by the CM). During these activities the operator should be underneath the CAC. The amount of time underneath the canopy is shown to range from 41% to 66% of the time during the shift. Although, during staging time, it is unknown what the operator was doing—whether the operator stayed under the canopy or left the ramcar to perform other duties.

**Table 6.** Time (minutes) underneath the CAC for September 2019 study.

	9/10/2019	9/11/2019	9/12/2019
Time at CM	33	31	20
Time at Feeder	22	24	15
Time tramping Feeder to CM	55	106	87
Time tramping CM to Feeder	47	65	46
<b>Time underneath</b>	157	226	168
<b>Total Time</b>	379	340	345
<b>% of time under</b>	41.4%	66.5%	48.7%

Table 7 (see APPENDIX A) shows the average of the instantaneous concentrations of the respirable dust encountered by ramcar #1 along with the 95% confidence interval and the percent reduction due to the canopy. These data are from instantaneous respirable dust concentrations measured outside the canopy and the respirable dust concentrations measured underneath the canopy using the pDR-1000 and are dependent upon the location of the ramcar. The average concentrations are the average of all the concentrations for the time intervals when the ramcar was at their corresponding locations—at the CM, at the feeder, tramping from CM to feeder, and tramping from feeder to CM. These specific time interval

concentrations are calculated by averaging the instantaneous 2-second interval data points recorded by the pDR-1000.

The CM location is where the majority of the respirable dust exposure occurs. Tramping can be the second highest source of respirable dust exposure and may be due to any tramping occurring downwind of the continuous miner. However, in this study, the tramping was not able to be closely observed. Therefore, segregating the tram into smaller segments, i.e., tramping downwind of the CM, tramping upwind of the CM, etc., was not possible. This eliminated the ability to isolate these smaller segments to determine how much of an impact the canopy would have for reducing respirable dust exposures at those segments (tramping downwind of the CM). This study is only able to document the reductions for the entire tram from CM to feeder. The feeder location tends to be the location where the lowest amount of respirable dust exposure occurs, which makes sense as this area is generally isolated from other ventilated areas.

Table 7 also provides results of the CAC impact on respirable dust exposures for the ramcar operator. Analysis of the impact on respirable dust exposures was conducted using the calibrated pDR-1000 instantaneous data. The average instantaneous concentration for each documented time interval at each ramcar segment (CM loading, feeder unloading, tram CM to feeder, and tram feeder to CM) was calculated for both the underneath canopy concentration and outside canopy concentration. This was completed for each time interval recorded throughout the day. These average concentrations for each time interval underneath the canopy during the day were averaged to determine a single daily average underneath the canopy. Similarly, the average concentration for outside the canopy was calculated. A comparison was made using Equation (4):

$$\% \text{ reduction} = \left[ 1 - \left( \frac{\text{MRE pDR underneath canopy}}{\text{MRE pDR outside canopy}} \right) \right] \times 100 \quad (4)$$

Where

- % reduction = the percent reduction of respirable dust (%)
- MRE pDR underneath canopy = the concentration of the MRE pDR underneath concentration (mg/m<sup>3</sup>)
- MRE pDR outside canopy = the concentration of the MRE pDR outside concentration (mg/m<sup>3</sup>)

Results show that the CAC performs very well. At the CM loading location, the location with the highest concentration of respirable dust, the percent reductions in respirable dust ranged from 57% to 65%. When unloading at the feeder, the percent reductions in respirable dust ranged from 35% to 45%. While tramping, the percent reductions in respirable dust ranged from 15% to 27% when the CAC airflow was above 1.5 m/s (300 fpm) but dropped on the last shift when the CAC airflow was below 1.0 m/s (200 fpm). Statistical analysis was conducted using the t-test: two samples assuming unequal variances function in MS Excel on the individual average concentrations for each daily time interval comparing underneath concentrations with outside concentrations for each ramcar segment. All reductions were statistically significant at the significance levels shown in Table 7. Most significance levels are 95%. But two significance levels are 85%. Significance levels of 95% are commonly used in statistical analysis. However, in underground mining situations the environment can be difficult to control. Fluctuations during changing operating parameters, such as line curtain setback distances, moving equipment, differing ventilation airflows, limited sampling times, etc., can add variability to the dust concentration data, and collecting the amount of data to attain 95% significance can be difficult to obtain. Therefore, 85% significance levels are acceptable [Potts et al., 2011]. Other reductions, including -10% (increase), 4%, and 15%, were not statistically significant, meaning that the CAC could not be isolated as the sole effect on the data used to calculate the percent reductions.

The ramcar CAC has shown to be successful for reducing respirable dust exposure for the ramcar operator when being loaded by the CM. At this location, the ramcar is stationary and the CAC has

been proven to work in typical ventilation velocities shown in Table 1. Generally, the CAC was able to reduce dust to a level below the coal mine respirable dust limit of 1.5 mg/m<sup>3</sup>. The last day of the study (Sept. 12<sup>th</sup>) was an exception. While the CAC did not reduce the dust level to below 1.5 mg/m<sup>3</sup>, it was able to provide substantial protection—reducing dust concentrations by 57%. The confidence limits are large, but this is to be expected due to the variability in dust concentrations due to the cut, load, and advance cycles of the CM.

During tramming, the reductions in respirable dust are lower due to several factors. One factor is that tramming can introduce additional air velocity to the normal ventilation air velocity. Higher interference velocities have been shown to reduce the protection provided by the CAC, although modifications can be made to the CAC to improve its performance [Reed et al. 2018]. No modifications to the CAC were made in this study.

A second factor is that the concentrations encountered during tramming are low, especially on Sept. 10<sup>th</sup> and Sept. 11<sup>th</sup> in this study. It has been found in previous studies that there are diminishing returns to attempting to reduce low respirable dust concentrations. In some instances, attempting to develop a control to reduce low respirable dust concentrations can result in re-entrainment of more dust in protected areas, resulting in reduced performance of the dust control device, in this case the CAC [Reed et al. 2019].

A third factor is the unknown. Due to the inability to observe the ramcars during tramming, it is unknown if the ramcars traveled mostly in return or intake air. Return air would expose the operator to more respirable dust, while operating in intake air would result in less exposure to respirable dust. Also, it is unknown what the impact of traveling through check curtains would be on respirable dust exposure to the operator. Check curtains can potentially be contaminated with rock and coal dust, thus becoming a source of re-entrained dust when disturbed [Reed et al. 2019]. It is unknown what protection the CAC provides when traveling through check curtains.

The reductions in respirable dust provided by the CAC when unloading at the feeder are higher than when tramming but lower than when being loaded by the CM. The air velocity at the feeder is lower since the feeder is generally isolated from the section ventilation. However, the low respirable dust concentrations encountered in this area can make it difficult to control due to diminishing returns as stated previously.

The TWA of the total protection provided or the percent reduction for respirable dust while the operator is underneath the CAC can be calculated from the data in Tables 6 and 7. The resultant percent reductions are 34% for Sept. 10<sup>th</sup> and 31% for Sept. 11<sup>th</sup> when the CAC airflow was properly adjusted. These results demonstrate that the CAC would be an adequate device for respirable dust control. However, when reviewing the percent reductions in respirable dust when the ramcar is loaded by the CM, the percent reductions are 65% for Sept. 10<sup>th</sup>, 64% for Sept. 11<sup>th</sup>, and 57% for Sept. 12<sup>th</sup>. These reductions are substantial, considering this is the location where the ramcar operators would realize their highest respirable dust exposures during the shift. These results support that the CAC on the ramcar is an important dust control device.

### CONCLUSIONS

The CAC can provide improved protection from respirable dust for the ramcar operator when operating in a blowing face ventilation scenario. With the CAC operating at the desired airflow, the reductions of respirable dust were 57% to 65% when being loaded by the CM, 35% to 45% while unloading at the feeder, 20% to 27% when tramming from the feeder to the CM, and 21% when tramming from the CM to the feeder.

Conducting a total time-weighted average using the data from Tables 6 and 7, the overall reductions in respirable dust the entire time the operator is underneath the CAC were 34% on Sept 10<sup>th</sup> and 31% on Sept 11<sup>th</sup>. Comparing these overall reductions to the air velocity from the plenum, 361 fpm was measured on Sept 10<sup>th</sup> and 315 fpm on Sept 11<sup>th</sup>. On Sept 12<sup>th</sup>, the air velocity from the plenum was only 185

fpm, and dust reductions under the CAC were lower or slightly increased when tramming to the feeder. These results show there was a relationship of higher plenum air velocities providing higher protection. These results, and results from other NIOSH lab and field testing of CACs, show that higher air velocities from the plenum can provide better protection from respirable dust. Overall, the ramcar CAC, with percent reductions of respirable dust during CM loading of 57% to 65%, can provide exceptional protection to these ramcar operators in blowing face ventilation situations as this is the location where ramcar operators receive their highest exposure to respirable coal mine dust.

### DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company name or product does not constitute endorsement by NIOSH.

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**APPENDIX A**

**Table 7.** Average dust concentration of instantaneous data measured by pDR-1000 at each location of ramcar #1.

Location	Date	Outside CAC Average Concentration (mg/m <sup>3</sup> )	Confidence Interval @ 95%	Underneath CAC Average Concentration (mg/m <sup>3</sup> )	Confidence Interval @ 95%	Percent reduction (%)	T-test	Significance
@ CM	10-Sep	2.821	± 0.872	0.996	± 0.433	65%	t(37)=(3.86, p=0.0004)	Yes @ 95%
@ Feeder	10-Sep	0.433	± 0.084	0.277	± 0.078	36%	t(62)=(2.70, p=0.009)	Yes @ 95%
Tramming Feeder to CM	10-Sep	0.581	± 0.081	0.425	± 0.071	27%	t(53)=(2.96, p=0.005)	Yes @ 95%
Tramming from CM to Feeder	10-Sep	0.658	± 0.135	0.523	± 0.105	21%	t(55)=(1.63, p=0.110)	Yes @ 85%
@ CM	11-Sep	2.829	± 0.725	1.009	± 0.400	64%	t(61)=(4.45, p=3.75E-05)	Yes @ 95%
@ Feeder	11-Sep	0.223	± 0.033	0.144	± 0.015	35%	t(55)=(4.41, p=4.88E-05)	Yes @ 95%
Tramming Feeder to CM	11-Sep	0.630	± 0.085	0.503	± 0.080	20%	t(66)=(2.22, p=0.030)	Yes @ 95%
Tramming from CM to Feeder	11-Sep	0.975	± 0.166	0.824	± 0.163	15%	t(62)=(1.32, p=0.191)	No
@ CM	12-Sep	4.524	± 2.089	1.952	± 1.208	57%	t(22)=(2.29, p=0.032)	Yes @ 95%
@ Feeder	12-Sep	0.601	± 0.343	0.329	± 0.094	45%	t(28)=(1.58, p=0.126)	Yes @ 85%
Tramming Feeder to CM	12-Sep	1.540	± 0.797	1.483	± 0.715	4%	t(42)=(0.11, p=0.912)	No
Tramming from CM to Feeder	12-Sep	1.799	± 0.612	1.981	± 0.779	-10%	t(44)=(0.38, p=0.706)	No

Equipment required for installation of the SC CAC on the battery powered haulage equipment used during underground testing is listed in the following table. The kit can be ordered from J.H. Fletcher & Co. as JHF # 641292.

Parts kit for SC CAC used in underground test.

JHF #	DESCRIPTION	QTY
569711	HYDRAULIC MOTOR, SAE10 SIDE PORTS	1
516542	FAN, PRESSURE, HYD. DRIVEN, 390 CFM	1
569755	OVERHUNG LOAD ADAPTER	1
549391	FILTER BOX ASS'Y	1
549249	FILTER BOX ELEMENT	1
626994	TANDEM GEAR PUMP	1
587515	SC CAC NIOSH	1
300529	HUMP REDUCER	1
554279	FRESH AIR HOSE	10 FEET
516542	BLOWER	1
154622	HUMP REDUCER	1
514864	FLEXTRA ROCK DUST HOSE	10 FEET
145746	T-CLAMP 5-1/2"	3
525416	T-CLAMP 6-1/2"	1
145751	T-CLAMP 4-1/2"	2
556740	TUBING, 4"	1
566359	TUBING CUT TO LENGTH, 5"	1
566477	BLOWER MOUNT W/HARDWARE	1