



Field investigation to measure airflow velocities of a ram dump car using circular routing at a Midwestern underground coal mine: a case study

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Abstract Due to the successful application of roof bolter canopy air curtains (CACs) to protect roof bolter operators from high levels of coal mine respirable dust, a shuttle car CAC is currently being developed. Since a shuttle car consistently trams from the continuous miner to the feeder and back at a speed up to 9.66 kph (6 mph) or 2.68 m/s (528 fpm), it is thought that the shuttle car may encounter very high air velocities (mine ventilation air velocity + max shuttle speed (2.68 m/s (528 fpm))). Past research and preliminary lab testing showed that CAC protection in high interference air velocities is difficult to achieve. Therefore, testing was conducted at a Midwestern US coal mine to determine the air velocities their shuttle car actually encounters. This mine used ram dump cars as their shuttle cars. Results showed that coal mine dust exposure is generally very low at the feeder and when tramping. Elevated concentrations are encountered at the ram dump car operator position when the car is being loaded by the continuous miner. Recorded air velocities while tramping did not reach the max air velocity of mine ventilation air velocity + 2.68 m/s (528 fpm) calculated as 3.32 m/s (653 fpm). High velocities, while encountered, were of low

frequency and associated with low respirable coal mine dust concentrations. Therefore, using this new information, designing the shuttle car CAC for maximum interference air velocity may not be as important as previously thought.

Keywords Shuttle car · Air velocity · Canopy air curtain

Introduction

Roof bolter canopy air curtains (CACs) are being used to protect roof bolter operators from exposure to coal mine respirable dust. Both laboratory and field studies testing the roof bolter CAC show promising results (Goodman and Organiscak 2002, Listak and Beck 2012, Reed et al. 2019). Since this dust control technology has shown to be successful with the roof bolter, it could also be applicable to a shuttle car to protect shuttle car operators from coal mine respirable dust.

To develop the canopy air curtain (CAC) concept for shuttle cars, NIOSH has issued a contract (contract no.: 200-2015-63485) with Marshall University and J.H. Fletcher to develop a canopy air curtain (CAC) specifically for coal mine shuttle cars. The design provides filtered air, ventilated over the operator, through a plenum built into the shuttle car canopy.

A shuttle car is different from a roof bolter in that it can travel at speeds approaching 9.66 kph (6 mph) or 2.68 m/s (528 fpm) (Joy Global 2016). Designing a CAC to withstand environmental air velocities is thought to be critical for the effectiveness of such a

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system in order for the clean air to reach the operator. Past calculations used the measured mine ventilation air velocity from two different mine locations added to the maximum shuttle car velocity of 2.68 m/s (528 fpm), i.e., mine ventilation air velocity + 2.68 m/s (528 fpm). The resulting calculated environmental air velocities call for the CAC to withstand a range from 3.30 to 4.32 m/s (650 to 850 fpm) at the two different mine locations. Additionally, in blowing face ventilation systems, the shuttle car operator operates directly downwind of the continuous miner where respirable coal mine dust exposures to shuttle car operators can be elevated (NIOSH 2011, 2013).

Past research (Engel et al. 1987) and a laboratory study recently completed by NIOSH on the shuttle car CAC showed that CAC protection in high-ventilation air velocities of 4.32 m/s (850 fpm) can be difficult to achieve (Reed et al. 2019). Due to this difficulty, it was questioned if the CAC actually encounters air velocities of this magnitude. In order to properly design the shuttle car CAC and determine the required velocities of the air exiting the plenum to protect the operator, the air velocities experienced during a shuttle car traverse need to be determined. A field investigation was completed to determine these air velocities as well as operator dust exposure during shuttle car operation.

Test procedure

A study was conducted at a Midwestern room and pillar coal mine in the Herrin no. 6 seam that uses blowing face ventilation to ventilate the working faces. This mine used ram dump cars as its shuttle cars to haul coal to the feeder from the continuous miner (CM). The designed entry dimensions of the continuous miner cut were typically 6.1 m (20 ft) wide, 2.4 m (8 ft) high, and 12.2 m (40 ft) deep. The route used by the ram dump cars was a one-way circular route from the CM to the feeder and back. This is a route that is commonly used with diesel or electric-powered ram dump cars (Stefanko 1983). Figure 1 shows the route used by the ram car to travel from the CM to the feeder for entry no. 4 left. For entry 2, the route would expand to accommodate access to the entry (route not shown in figure). During testing, up to four ram dump cars were used to haul coal from the CM to the feeder.

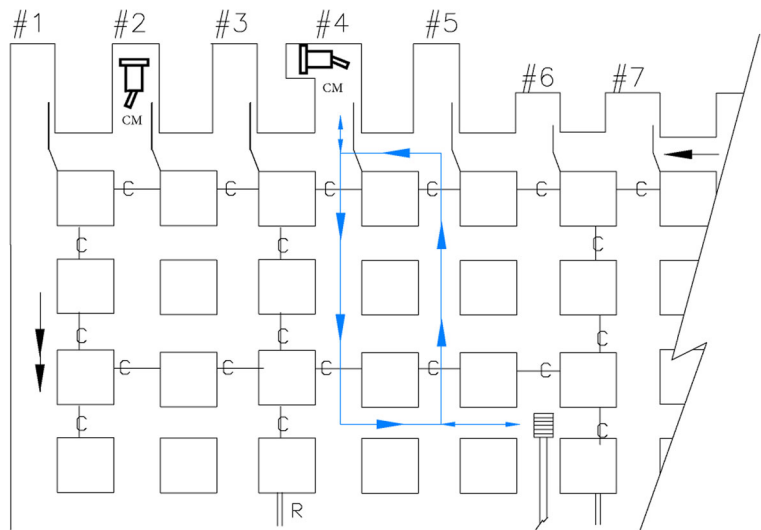
One ram dump car cab was evaluated during this testing: a Joy BH-20AC ram car. During the evaluation,

the ram dump car operator was advised to perform the normal routine of coal haulage in order to obtain a representative sample of standard conditions. A Kestrel model 4500 weather station was mounted in the ram dump car cabin. This weather station has the capability to measure and record air velocities at specific time intervals. However, these Kestrel monitors are not US Mine Safety and Health Administration (MSHA)-approved for underground coal use as they are not intrinsically safe for use in potentially explosive environments. In order to use the Kestrel monitors, permission from the mine and MSHA was obtained to allow their use in the mine with the stipulation that these monitors could not be used in by the last open cross-cut. Therefore, the weather stations were removed from the ram dump car before going in by the last open cross-cut and re-installed after going out by the last open cross-cut.

For this test, the Kestrel's recording time was set to 5-s intervals. Air velocity measurements at the coal face and at the feeder were measured using a vane anemometer. NIOSH personnel were stationed nearby the CM, the feeder, and along the ram dump car route. Each researcher wore a Personal Dust Monitor 3700 (PDM) in conjunction with a personal Data Ram 1000 (pDR-1000) as well as the appropriate personal protective equipment, including half mask NIOSH P100 respirators. Dust sampling units were installed on the ram dump car. The sampling units consisted of PDM along with the pDR-1000 and two gravimetric samplers. A gravimetric sampler consisted of an ELF pump, Dorr-Oliver Cyclones, and 37-mm filters. These sampling units were placed inside the ram dump car cabin. The pDR-1000 was programmed to record at 5-s intervals, while the PDM only has the ability to record 1-min intervals. The gravimetric sampler can only provide a time-weighted average (TWA) dust concentration.

During the study, a NIOSH researcher near the CM recorded the ram dump car arrival and departure times at the CM. Another researcher was stationed just out by the last open cross-cut and was responsible for removing and installing the Kestrel monitor as the ram dump car moved toward (in by) and departed (out by) the CM. The Kestrel monitor "off" and "on" times when the monitor was removed and installed were recorded. These times are different from the CM loading times because they include a small portion of tramping to and from the CM and any wait times for loading. A third researcher, located at the feeder, recorded the feeder arrival and departure times.

Fig. 1 Typical one-way circular route used for ram dump cars. CM denotes continuous miner location in entry no. 2 and entry no. 4 left. Each entry was developed independently. Route is shown for entry 4 left in blue with blue arrows showing direction of travel. Black arrows denote ventilation airflow, single arrow represents intake air, and double arrow represents return air



The ventilation airflows at the CM were documented. Sampling was conducted for 2 h which included 10 complete ram dump car passes and represents 2 complete cuts by the CM. Each pass was defined as unloading of the ram dump car at the feeder, trampling to the miner, loading at the miner, and trampling back to the feeder.

Results

The ventilation air velocity measurements were taken at the continuous miner. For this study, the miner completed 2 complete cuts. Due to high ram dump car traffic volume, entry ventilation air velocity measurements along the travel routes where the ram dump car trammed were not able to be obtained. The ventilation results are shown in Table 1.

The data acquired from the pDR-1000, PDM, and Kestrel 4500 were analyzed for the dust concentrations and air velocities measured. The PDM data are presented only to substantiate the results from the instantaneous measurements. Table 2 shows the overall TWA dust concentration from the PDMs located on the researchers. It can be seen that during the study, the concentrations at both the feeder (feeder researcher) and prior to the last open cross-cut (last CC researcher A) were very low. The dust concentrations at the last CC researcher A locations were very low because this position was in an isolated cross-cut which received minimal airflow and was isolated from the ventilation provided to the CM. The ram dump car concentration was higher

than that at the feeder, because, besides operating at the feeder location, it also operated downwind of the miner during cutting operations. The feeder never receives ventilation air from CM entries, but movement from the ram car by means of traveling or unloading operations was a source of dust generation. The PDM at the miner location displayed an error message thus preventing any dust measurement at the CM.

Instantaneous data acquired by the pDR-1000 requires calibration with the gravimetric samples collected in the ram dump car. The following equation was used to correct the instantaneous data collected by the pDR-1000 (Williams and Timko 1984):

$$\text{Ratio} = \frac{\text{Grav}}{\text{Instant}}$$

where

- Ratio the calibration ratio
- Grav the gravimetric TWA concentration
- Instant the instantaneous optical TWA concentration from the pDR-1000

Table 1 Ventilation measurements at continuous miner entries

Location	Entry dimensions (m)	Air velocity (m/s)	Air quantity (m ³ /s)
Entry no. 2	2.45 × 5.79	0.64	9.08
Entry no. 4 left	2.59 × 5.49	0.61	8.66

Table 2 PDM data collected on researchers positioned along ram dump car traverse

Location	Time-weighted average dust concentration (mg/m ³)
Feeder researcher	0.227
Ram dump car	0.416
Last CC researcher A	0.131
Cont. miner researcher	Error

CC = cross-cut

The instantaneous pDR-1000 data was then multiplied by the ratio to calibrate it to the mine dust. Then the pDR-1000 dust concentration data along with the Kestral 4500 air velocity data were segmented to show dust concentrations for feeder unloading, trammig, inby the last open cross-cut, and CM loading. The average dust concentration and average air velocity measured on the ram dump car sampling package can be found in Table 3.

The highest average dust concentrations observed during the ram dump car operation occurred when the ram dump car was being loaded at the CM (1.344 mg/m³), which had an average air velocity of 0.62 m/s (121.98 fpm). The second highest was when the ram dump car was located inby the last open cross-cut (0.633 mg/m³). At this location, the Kestral 4500 weather station was not allowed to be used. Minimum air velocity is assumed to be the CM entry air velocity measured during testing. Ram dump car staging (wait time) occurred at this location as well as trammig prior to and after loading by the CM. However, high traffic in the area precluded researchers from safely observing the operations inby the last open cross-cut. Trammig of the ram dump car experienced an average dust concentration of 0.131 mg/m³ with an average air velocity of 1.53 m/s (300.38 fpm). The dust concentration observed at the feeder was the lowest and measured 0.123 mg/m³ with an average air velocity of 0.82 m/s (161.20 fpm). The overall dust concentration of the ram dump car was 0.314 mg/m³, which is the TWA concentration of the ram dump car.

A graph depicting the instantaneous air velocities recorded and the instantaneous dust concentrations encountered during the ram dump car traversing the mine is shown in Fig. 2. In reviewing the ram dump car traverse, the time from 10:24:20 to 10:46:30 am represents the time the ram dump car trammed from the

feeder to the CM. It can be seen in this section that the air velocity was 0 fpm from 10:24:40 to 10:26:00 am and from 10:27:10 to 10:41:20 am. These two blocks of time represent the time the ram dump car was staging/waiting outby the last open cross-cut until the other ram dump car departed from the CM. These locations show 0.0 m/s because they are in neutral entries where airflow is minimal, i.e., no sufficient airflow to turn the vanes on the Kestral 4500. However, in actuality, there is some minimal air velocity, it is just not measurable at these locations. At 10:43:00 am, the ram dump car passed inby the last open cross-cut. At this point, until the ram dump car exited the last open cross-cut (10:47:40 am), the entry velocity 0.64 m/s (125 fpm) was used as the velocity encountered by the ram dump car when working in entry no. 2 and 0.61 m/s (120 fpm) entry velocity was used when working in entry no. 4 left. The light blue section represents the time the ram dump car was being loaded at the continuous miner (10:46:35 am to 10:47:10 am). The time from approximately 10:47:10 am to 10:48:55 am represents the time the ram dump car trammed from the CM to the feeder. The maximum air velocities encountered by the ram dump occurred during the ram dump car trammig cycle.

Results from the other traverses observed are shown in graphs in the Appendix. All the other traverse graphs depict the typical movement of the ram dump car as previously described. There are variations due to differing loading and unloading times. Also, there are variations of trammig times due to differences in staging and trammig routes. But overall, the graphs depict fairly similar results for each segment.

A histogram of all of the measured air velocities of the ram dump car experienced during operation can be found in Fig. 3. From the data, it can be observed that the ram dump car spent a large portion of time encountering air velocities of 0.76 m/s (150 fpm) or 0.0 m/s. The 0.76 m/s air velocity is apparently a common velocity that is encountered at this mine site. The ram dump car also spent a significant time idle. The idle time was during staging outby the CM where ventilation air velocity was motionless which translates to the 0.0 m/s airflow. Higher air velocities commonly encountered with frequencies approximately > 30, ranged from 1.02 to 2.03 m/s (200 to 400 fpm). The highest air velocity measured occurred during the trammig of the ram dump car to and from the feeder: 2.75 m/s (540 fpm).

Table 3 Ram dump car dust concentration and air velocity statistics at various locations

Ram dump car segment	Average dust concentration (mg/m ³)	Dust concentration standard deviation	Maximum dust concentration (mg/m ³)	Minimum dust concentration (mg/m ³)	Count	Average air velocity (m/s)	Air velocity standard deviation	Maximum air velocity (m/s)	Minimum air velocity (m/s)
Feeder unloading	0.123	0.058	0.361	0.049	55	0.82	0.46	1.75	0.00
Tramming	0.131	0.160	1.340	0.004	453	1.53	0.59	2.75	0.30
Inby last open x-cut	0.633	0.439	1.634	0.030	337	0.62	0.01	0.64	0.61
CM loading	1.344	0.405	2.458	0.485	96	0.62	0.01	0.64	0.61
Overall	0.314	.444	2.458	0.000	941	0.47	0.62	2.75	0.00

A box and whisker plot of the instantaneous data for measured air velocities and dust concentrations encountered during tramming is presented in Fig. 4. Figure 5 shows the dust concentrations encountered at different air velocities at the feeder with Fig. 6 at the CM. Figure 7 shows the dust concentrations encountered inby the last open cross-cut. Box and whisker plots present the range of dust concentrations encountered at a specific air velocity, with the bottom whisker representing the 10th percentile, the bottom box representing the 25th percentile, the line across the box representing the median, the top of the box representing the 75th percentile, and the top whisker representing the 90th percentile. The numerical value associated with the “x” represents the mean.

In analyzing the instantaneous air velocities encountered, the velocities were grouped in a range that spanned 0.60 m/s, which was used because 0.60 m/s was close to the ventilation air velocities encountered in the CM entries and when inby the last open cross-cut. Using the 0.60 m/s span allowed for direct comparison with the CM and inby the last open cross-cut data. The first box and whisker icon in Fig. 4 shows the dust concentrations encountered at 0.0 m/s. The second, all air velocities up to 0.60 m/s, the third shows the dust concentrations encountered at all air velocities from 0.60 to 1.20 m/s, the fourth shows the dust concentrations encountered at all air velocities from 1.20 to 1.80 m/s, and the fifth shows the dust concentrations encountered at all air velocities from

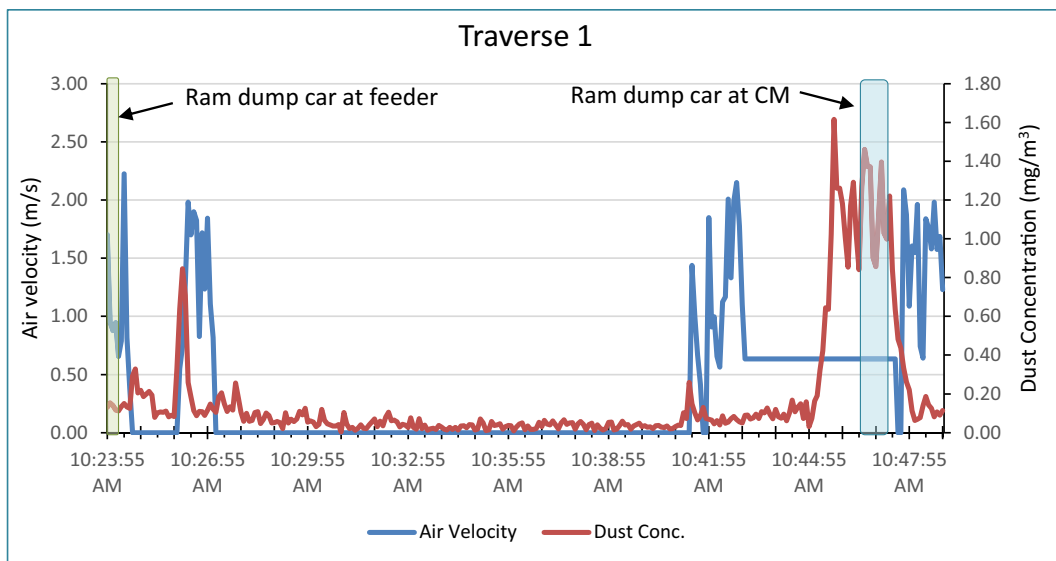


Fig. 2 Traverse of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

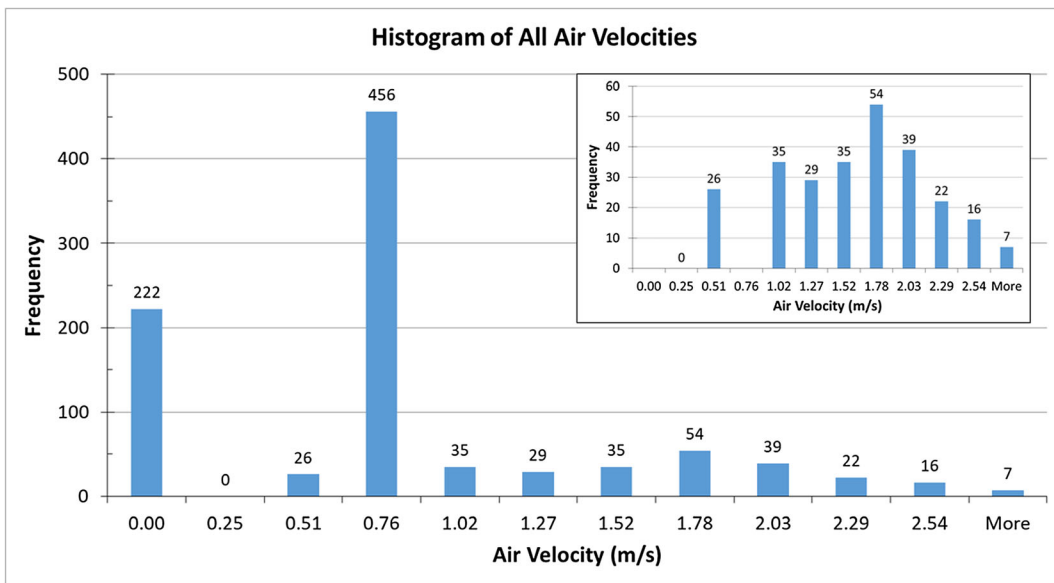


Fig. 3 Histogram presenting the frequency of all instantaneous air velocities (5-s intervals) measured on the ram dump car during operation. Inset shows the histogram with the two highest frequencies removed (222 and 456)

1.80 to 2.70 m/s. The graph of the dust concentrations encountered at air velocities for the feeder (Fig.

5) follows the same methodology, but only through 1.70 m/s air velocity.

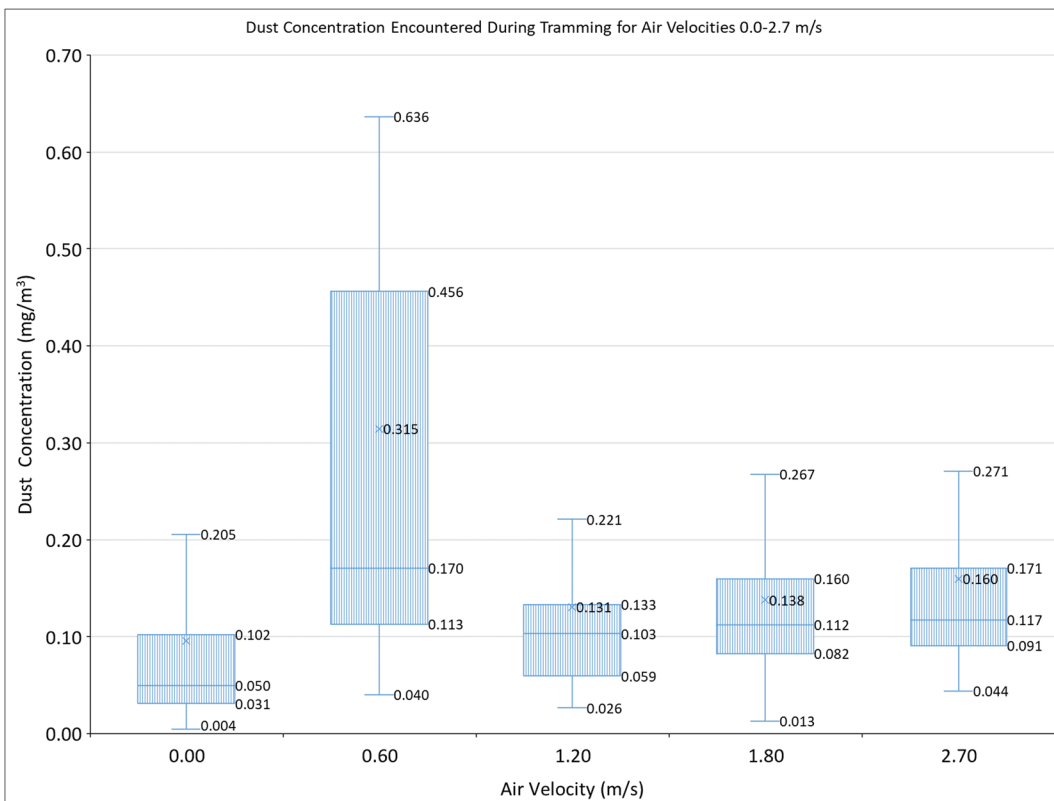


Fig. 4 The range of dust concentrations encountered at different air velocities during shuttle car trimming

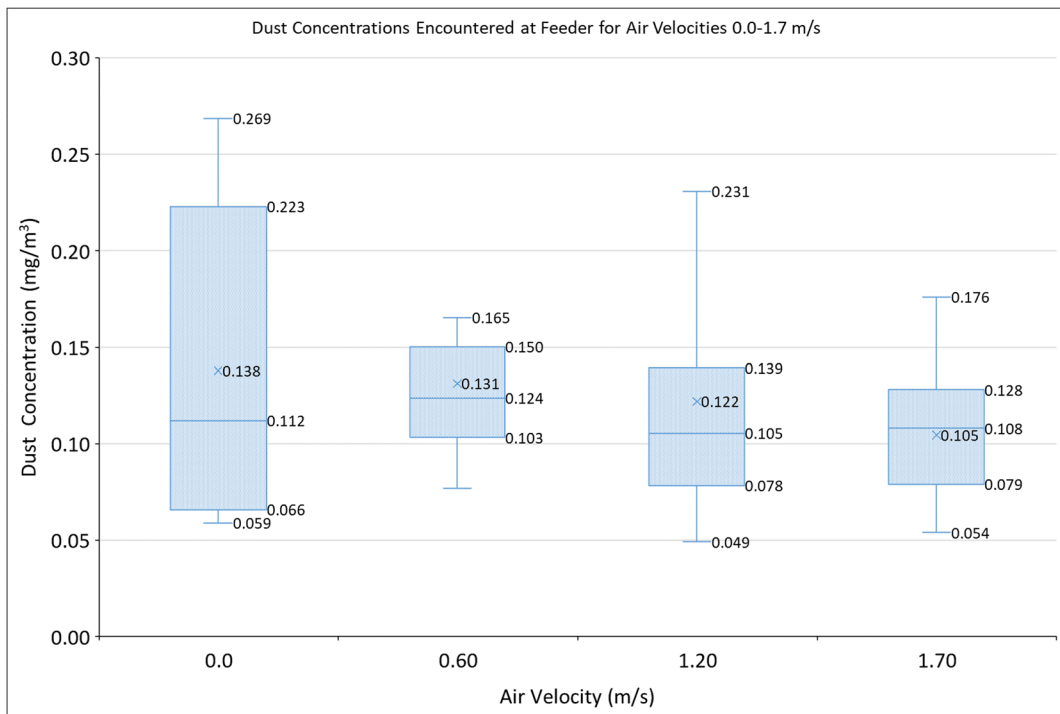


Fig. 5 The range of dust concentrations encountered at different air velocities during shuttle car operation at the feeder

Tramming was expected to represent the worst-case scenario for CAC design due to the high air velocities anticipated to be encountered during the movement of the ram dump car. It was observed, however, that the

operator’s exposure to dust while tramming was relatively low, averaging 0.131 mg/m³ during this study. Reviewing Fig. 4 shows that the dust concentrations encountered, while increasing with increasing velocity

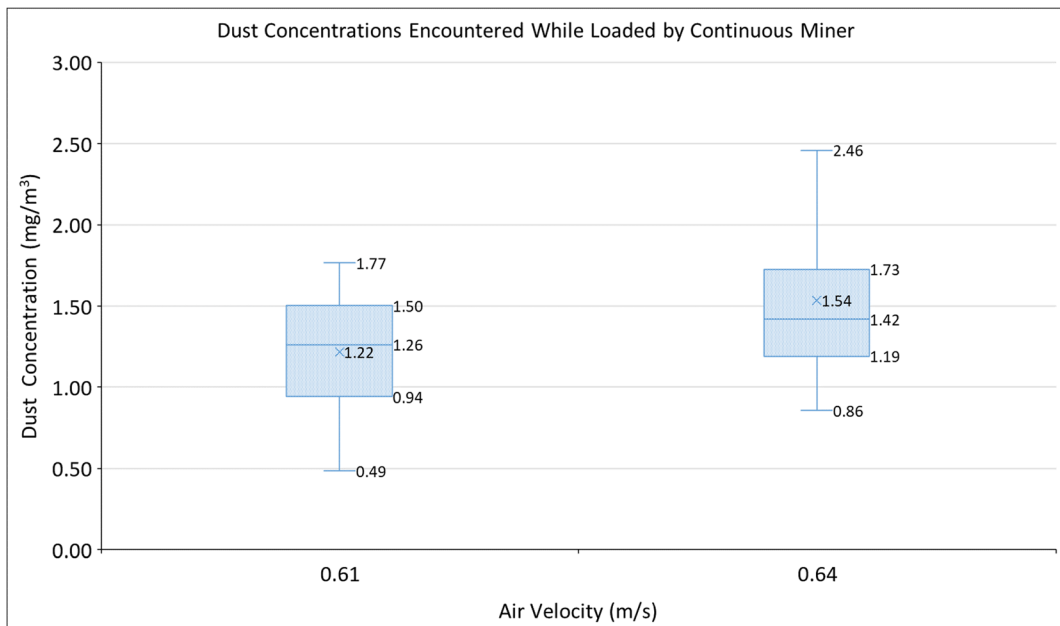


Fig. 6 The range of dust concentrations encountered at air velocities 0.61 m/s and 0.64 m/s during shuttle car operation while being loaded by the CM

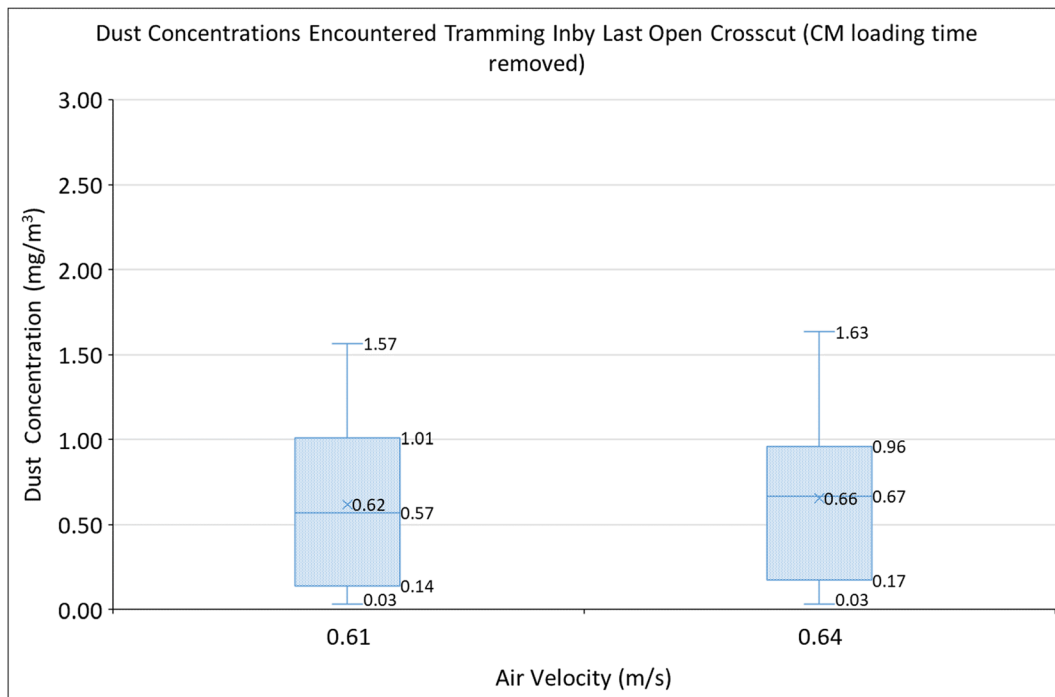


Fig. 7 The range of dust concentrations encountered at different air velocities 0.61 m/s and 0.64 m/s during shuttle car operation while trimming inby the last open cross-cut (excludes loading time at the CM)

spans, were relatively low through all air velocities. Median dust concentrations ranged from 0.055 to 0.117 mg/m³ with the 25th percentile ranging from 0.033 to 0.091 mg/m³ and the 75th percentile ranging from 0.113 to 0.171 mg/m³. Surprisingly, at the highest air velocities ranging from 1.80 to 2.70 m/s, the dust concentrations encountered were low with the median at 0.117 mg/m³ with the 25th percentile being 0.091 mg/m³ and the 75th percentile being 0.171 mg/m³. The highest dust concentrations encountered occurred at air velocities up to 0.60 m/s with the median at 0.170 mg/m³ with the 25th percentile being 0.113 mg/m³ and the 75th percentile being 0.456 mg/m³.

The dust concentrations encountered at the feeder location were also relatively low, averaging 0.123 mg/m³ during this study. Reviewing Fig. 5 shows that the dust concentrations encountered were relatively stable through all air velocities. Median dust concentrations ranged from 0.105 to 0.124 mg/m³ with the 25th percentile ranging from 0.079 to 0.091 mg/m³ and the 75th percentile ranging from 0.139 to 0.153 mg/m³. Again, the highest air velocities ranging from 1.20 to 1.70 m/s, the dust concentrations encountered were low with the median at 0.108 mg/m³ with the 25th percentile at 0.079 mg/m³ and the 75th percentile at 0.128 mg/m³.

From the data in Fig. 6, it can be observed that the highest respirable dust concentrations (the ram dump car operator was exposed to) occurred when located being loaded by the CM. The air velocities during loading were the 0.61 m/s and 0.64 m/s ventilation air velocities measured in the CM entry. The median exposure was 1.261 mg/m³ (0.941 mg/m³ 25th percentile, 1.503 mg/m³ 75th percentile) and 1.419 mg/m³ (1.190 mg/m³ 25th percentile, 1.728 mg/m³ 75th percentile), in entry no. 4 left and entry no. 2, respectively.

Inby the last open cross-cut, the Kestrel 4500 was removed. Therefore, actual air velocities encountered cannot be determined. Using the ventilation air velocity measured at the continuous miner entries is the best estimate available for air velocities. Figure 10 shows that dust concentrations are elevated with medians of 0.571 mg/m³ and 0.667 mg/m³ while trimming inby the last open cross-cut to and from the CM entries, entry no. 4 left and entry no. 2, respectively. These elevated dust concentrations are most likely due to tramming in areas downwind of the CM. Table 4 summarizes the dust concentrations encountered at each location by the air velocity ranges depicted in Figs. 4, 5, 6, and 7.

It should also be noted that although the ram dump car encountered instances of maximum air velocities

between 2.29 and 2.75 m/s (450 and 540 fpm), from the histogram in Fig. 3, these instances were relatively short in duration. There were 45 instances of high air velocity 2.29 to 2.75 m/s (450 to 540 fpm), and since each instance represents a 5-s interval, this represents 225 s of total time encountering high air velocity out of approximately 20 min or 1185 s of total tramming time of the ram dump car (0.0-m/s velocities were not included), showing that the high air velocity represents approximately 19% of the air velocities the ram dump car encounters during tramming. When reviewing air velocities > 1.80 m/s (354 fpm) from Fig. 4, there are 75 instances of high air which represent approximately 32% of the air velocities encountered during tramming. During these velocities, 1.80 to 2.75 m/s (354 to 540 fpm), dust concentrations ranged from 0.044 to 0.696 mg/m³.

The canopy air curtain has the ability to protect workers within its protection zone in interference airflows as high as 1.02 m/s (200 fpm) (Engel et al. 1987). At interference velocities of 2.03 m/s (400 fpm), protection is still provided, but the canopy protection may only be approximately 50% of the protection provided in air velocities up to 1.02 m/s (200 fpm) (Reed et al. 2018).

The instances when the ram dump car encountered high air velocity seemed to occur as it entered and left the last open cross-cut. Because air velocities were unable to be recorded from the last open cross-cut to the CM and from the CM to the last open cross-cut, there may be a possibility that higher and more frequent air velocities occurred during these times.

High dust concentrations were encountered during loading by the CM. These concentrations ranged from a low of 0.485 to 2.458 mg/m³. The air velocities associated with these concentrations are 0.61 and 0.64 m/s (120 and 125 fpm) and the canopy air curtain is able to provide protection at these velocities.

Conclusions

The Kestrel model 4500 weather station proved to be a viable tool to measure and record the air velocity that a ram dump car operator would be subjected to during a continuous mining operation. The data collected from this survey provided important information on dust concentration versus ram dump car air velocity. This information will also be useful in designing a CAC system for the ram dump car.

During this particular field investigation, the majority of the ram dump car operator's exposure to high dust concentrations occurred while loading coal from the CM and while inby the last open cross-cut. At the CM, instantaneous dust concentrations ranged from 0.485 to 2.458 mg/m³ with an average concentration of 1.344 mg/m³ during air velocities of 0.61 and 0.64 m/s (120 and 125 fpm). During this study, the ram car spent 10% (480 s out of 4705 s) of its time receiving coal from the CM. The CAC should be able to provide protection to the shuttle car operator while being loaded by the CM due to the low air velocities encountered.

The other incidence of high dust concentrations encountered occurred while inby the last open cross-cut. The instantaneous dust concentrations ranged from 0.031 to 1.634 mg/m³ with an average concentration of 0.633 mg/m³. During this time, the air velocities were assumed to be 0.61 and 0.64 m/s (120 and 125 fpm). But actual air velocities are unknown because the use of the Kestrel model 4500 was prohibited at this location. Actual air velocities could be higher. The ram car spent approximately 36% (1685 s out of 4705 s) of its time during this study at this location. As long as air velocities encountered remain at 1.02 m/s (200 fpm) or lower, the CAC protection is feasible. At air velocities up to 2.03 m/s (400 fpm), the CAC protection diminishes and minor redesign of the CAC may be needed, requiring a spoiler and relocation of the CAC some specified distance into the headwinds of the ram car (Reed et al. 2018).

Tramming and unloading at the feeder are ram car actions during the remaining 54% (2540 s out of 4705 s) of its time during this study. During this time, higher air velocities were encountered, up to 2.75 m/s (540 fpm). Instantaneous dust concentrations ranged from 0.004 to 1.340 mg/m³ with an average of 0.123 mg/m³ during feeder unloading and 0.131 mg/m³ during tramming. While the air velocities encountered are higher, the number of high air velocity measurements > 1.20 m/s (236 fpm) occur only 19% (880 s out of 4705 s) of the time during the study. Additionally, the average dust concentrations encountered during tramming and feeder unloading are much lower than at the average concentrations for the CM loading and inby the last open cross-cut locations. It is expected that the CAC would be able to provide sufficient protection against respirable coal mine dust.

Since the majority of the air velocities encountered by the ram dump car were ≤ 1.80 m/s (354 fpm) with an overall average dust concentration of 0.314 mg/m³, it

Table 4 Summary of dust concentrations encountered at the various velocity ranges at the different operating locations of the shuttle car

Location description	Velocity (m/s)	Average dust concentration (mg/m ³)	Confidence interval (95%)	Count	Standard deviation	Maximum dust concentration (mg/m ³)	Minimum dust concentration (mg/m ³)	Median concentration (mg/m ³)	25th percentile (mg/m ³)	75th percentile (mg/m ³)
Feeder unloading	0.00	0.138 ±	0.088	6	0.083	0.269	0.059	0.112	0.066	0.223
Feeder unloading	up to 0.60	0.131 ±	0.025	15	0.046	0.267	0.077	0.124	0.103	0.150
Feeder unloading	0.60 to 1.20	0.122 ±	0.029	23	0.067	0.361	0.049	0.105	0.079	0.139
Feeder unloading	1.20 to 1.70	0.104 ±	0.024	11	0.036	0.176	0.054	0.108	0.079	0.128
Tramming	0.00	0.095 ±	0.021	216	0.156	1.340	0.004	0.050	0.031	0.102
Tramming	up to 0.60	0.314 ±	0.114	26	0.186	1.055	0.040	0.170	0.113	0.456
Tramming	0.60 to 1.20	0.131 ±	0.047	46	0.157	0.846	0.026	0.103	0.059	0.133
Tramming	1.20 to 1.80	0.138 ±	0.022	90	0.105	0.710	0.013	0.112	0.082	0.160
Tramming	1.80 to 2.70	0.160 ±	0.028	75	0.122	0.696	0.044	0.117	0.091	0.171
Inby last open x-cut	0.61	0.618 ±	0.062	204	0.451	1.566	0.287	0.571	0.138	1.011
Inby last open x-cut	0.64	0.657 ±	0.072	133	0.421	1.634	0.031	0.667	0.173	0.961
CM loading	0.61	1.219 ±	0.086	58	0.326	1.767	0.485	1.261	0.941	1.503
CM loading	0.64	1.536 ±	0.145	38	0.440	2.458	0.857	1.419	1.190	1.728

may not be necessary to design a ram dump car CAC for maximum ventilation air velocity. A CAC system that is designed to reduce the respirable coal mine dust exposure during ram dump car loading may be sufficient to reduce a ram dump car operator’s overall shift exposure.

Limitations of this study are the short time period the study was conducted. While it is expected that these results would be typical of a longer study at a mine site using blowing face ventilation, changes in ram car routes during mining of the entire section could result in findings that could differ. These results may not be typical of other mine locations. The other limitation is the inability to use the Kestrel model 4500 to measure and record air velocities inby the last open cross-cut. The assumptions of the air velocity inby the last open cross-cut could be incorrect.

Compliance with ethical standards

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

Appendix

Ram dump car traverses showing dust concentration and air velocity encountered during cycle. Blue-shaded areas = time behind CM, green-shaded areas = time at feeder.

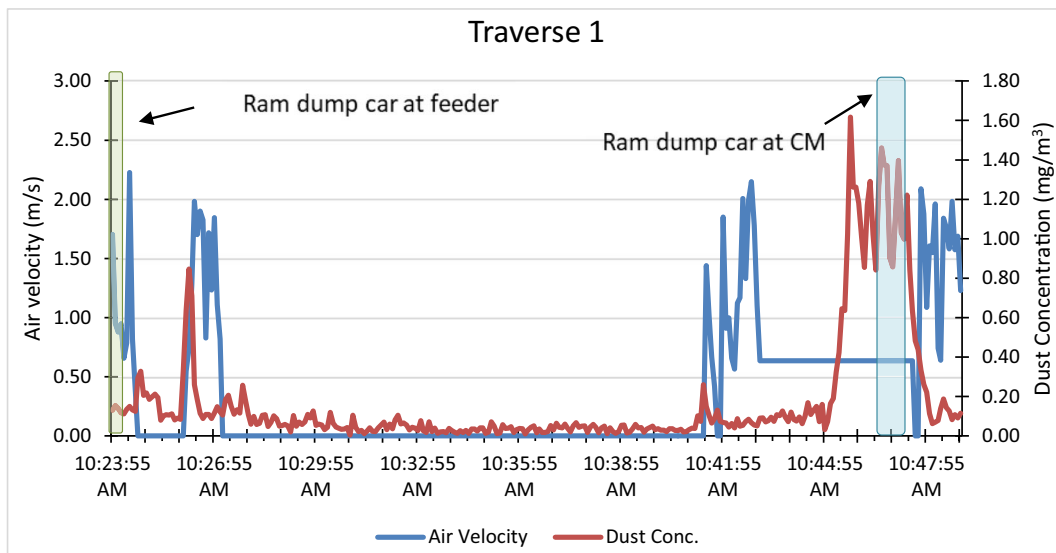


Fig. 8 Traverse no. 1 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

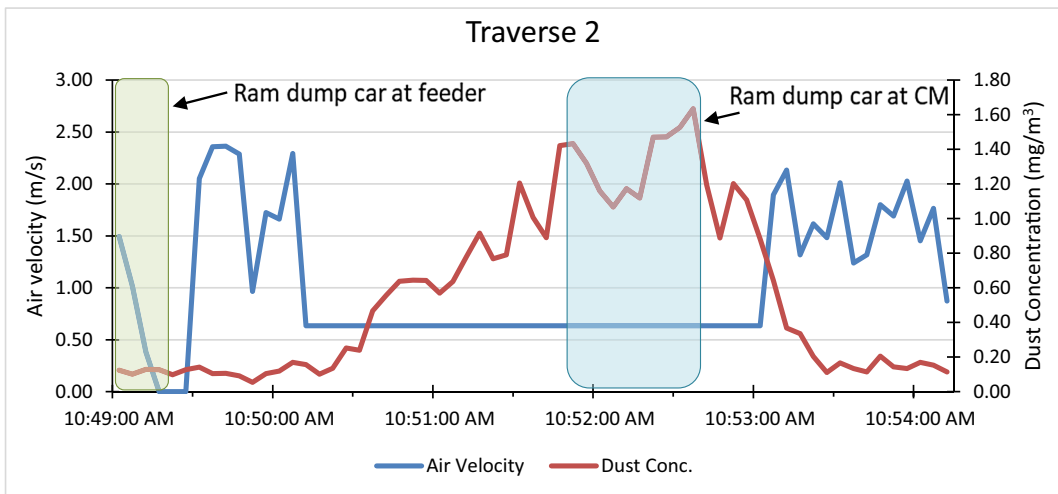


Fig. 9 Traverse no. 2 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

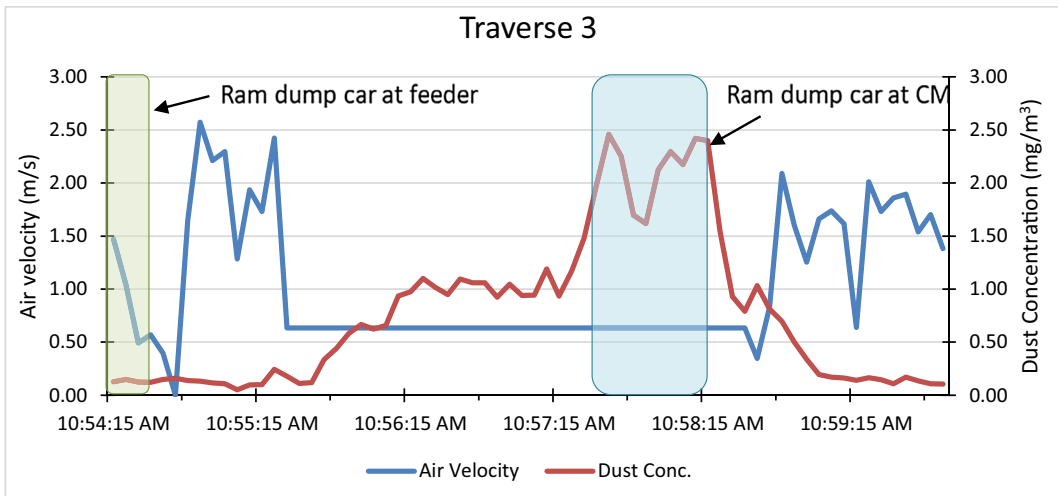


Fig. 10 Traverse no. 3 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

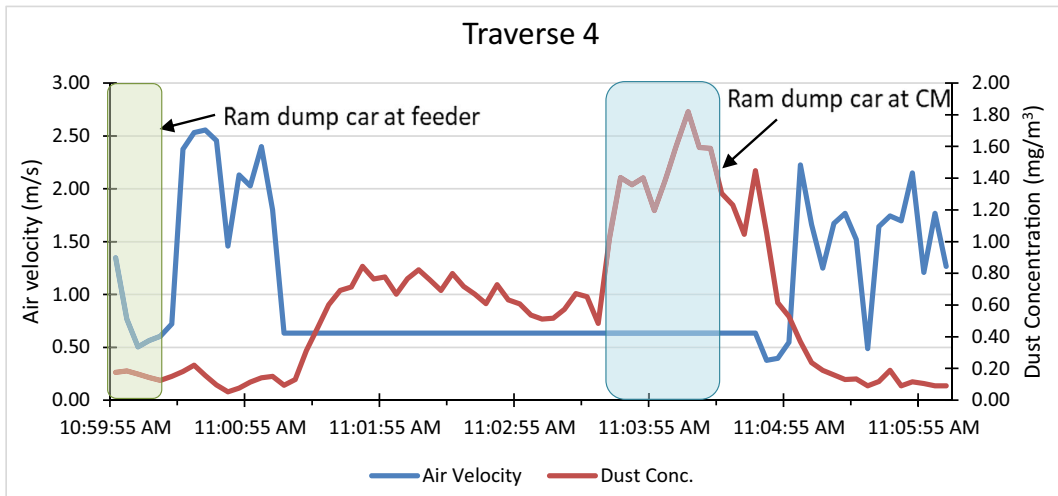


Fig. 11 Traverse no. 4 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

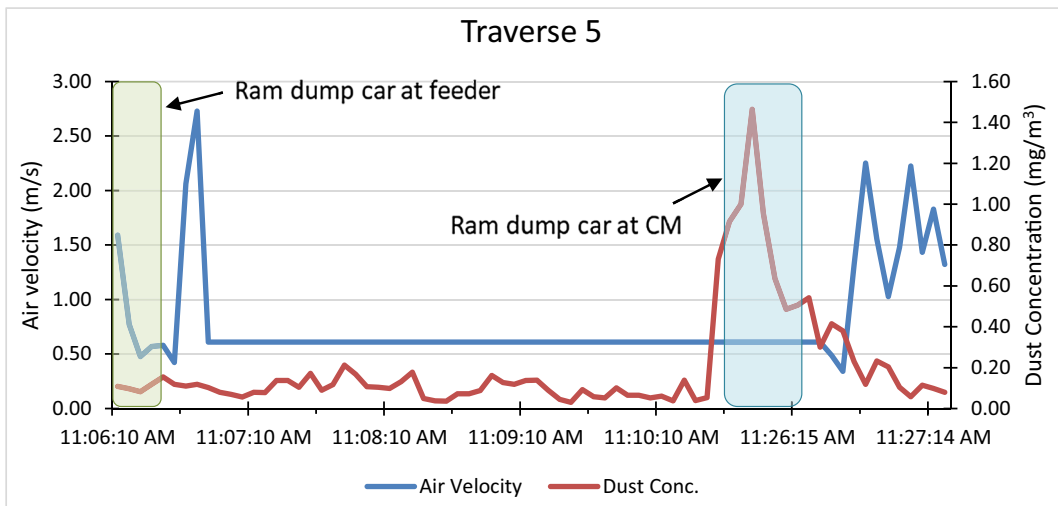


Fig. 12 Traverse no. 5 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

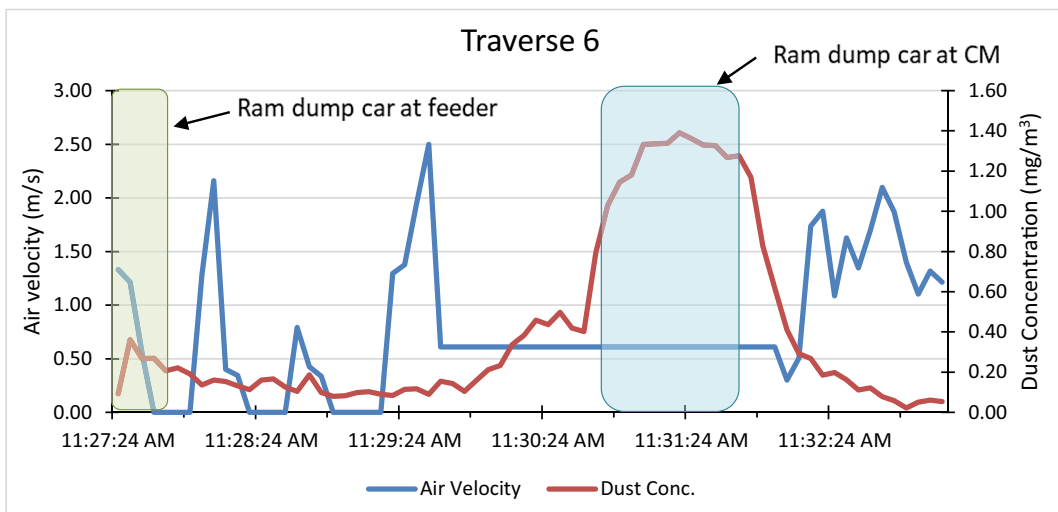


Fig. 13 Traverse no. 6 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

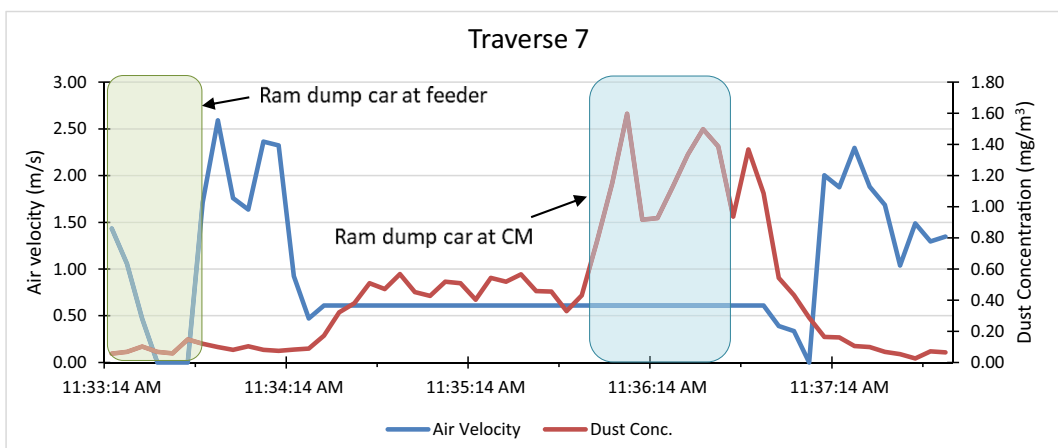


Fig. 14 Traverse no. 7 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

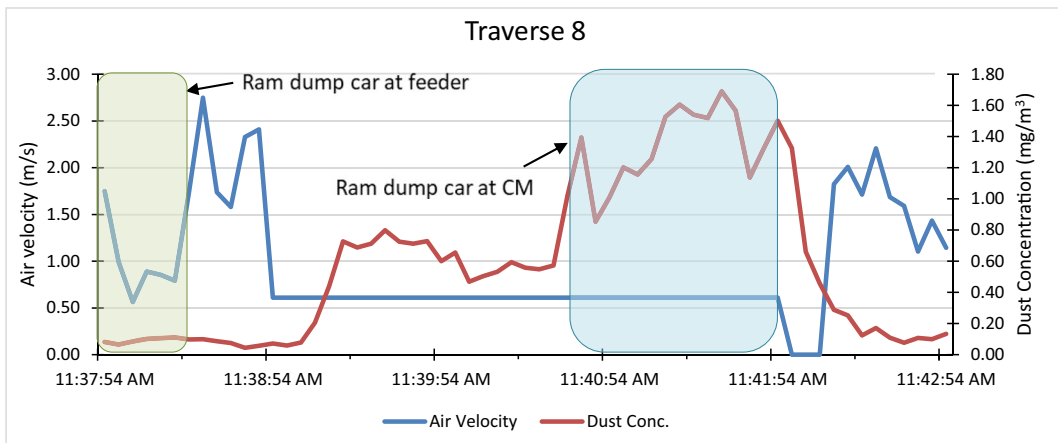


Fig. 15 Traverse no. 8 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

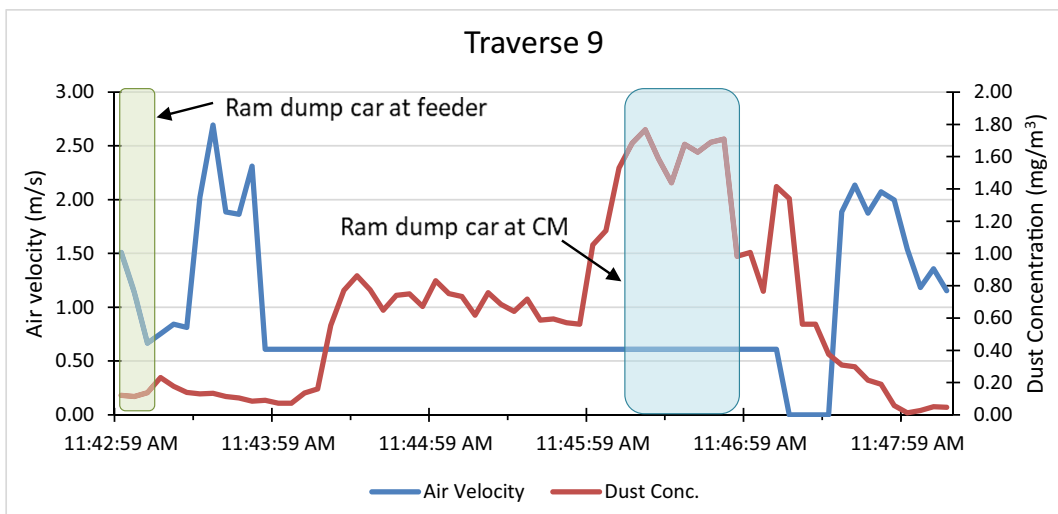


Fig. 16 Traverse no. 9 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

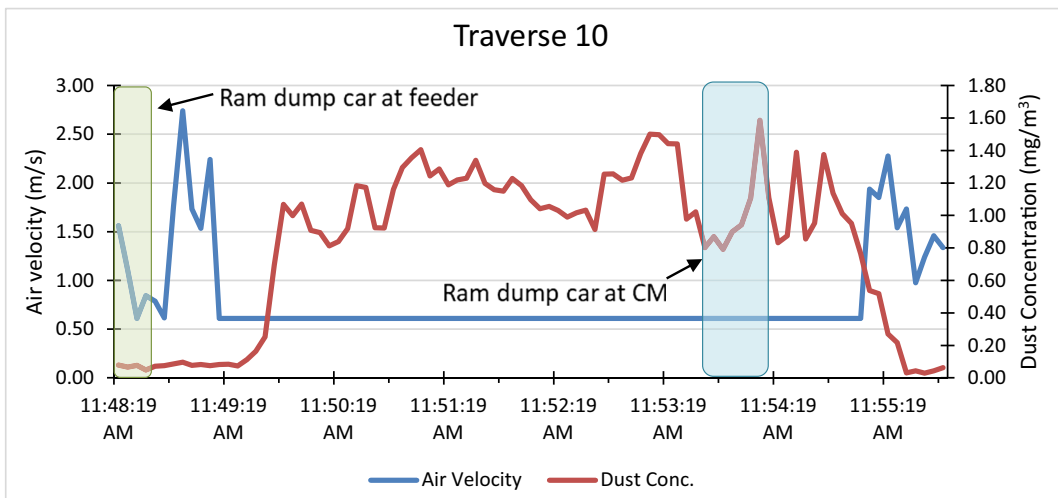


Fig. 17 Traverse no. 10 of ram dump car (blue-shaded area = ram dump car at CM) (green-shaded area = ram dump car at feeder)

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