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Field investigation to measure airflow velocities of a shuttle car using independent routes at a central Appalachian underground coal mine

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Abstract

Canopy air curtains on roof bolting machines have been proven to protect miners from respirable dust, preventing their overexposure to dust. Another desired application for canopy air curtains is in the compartments of shuttle cars. The challenges faced in developing the design of canopy air curtains for shuttle cars include mine ventilation rates in tandem with the shuttle car tram speeds. The resulting cab airspeeds may exceed 182 m/min (600 fpm), as found in the present study conducted in a central Appalachian underground coal mine by U.S. National Institute for Occupational Safety and Health (NIOSH) researchers. Prior research and laboratory testing had indicated that successfully protecting a miner in high air velocities is difficult, because the clean air from the canopy air curtain is unable to penetrate through the high-velocity mine air. In this study, the dust concentrations to which a shuttle car operator was exposed were measured, and air velocities experienced by the operator were measured as well using a recording vane anemometer. The results indicate that the highest exposure to respirable dust, 2.22 mg/m^3, occurred when the shuttle car was loading at the continuous miner, where the average airspeed was 48 m/min (157 fpm). While tramming, the operator was exposed to 0.77 mg/m^3 of respirable dust with an average airspeed of 62 m/min (203 fpm). This study indicates that a canopy air curtain system can be designed to greatly reduce an operator's exposure to respirable dust by providing clean air to the operator, as the majority of the operator's dust exposure occurs in air velocities slower than 61 m/min (200 fpm).

Disclaimer

Mention of any company or product does not constitute endorsement by the NIOSH. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH.

Introduction

The U.S. National Institute for Occupational Safety and Health (NIOSH) issued contract #200-2015-63485 to develop a canopy air curtain for coal mine shuttle cars with Marshall University and J.H. Fletcher & Co. (Salem, Begley and Ross, 2016). The proposed design maintains a design similar to that of a roof bolter canopy air curtain by providing filtered air through a blower over the operator. The plenum, which will provide uniform airflow over the operator, is anticipated to be built into the shuttle car canopy. One of the main interferences with a canopy air curtain is ventilation airflow perpendicular to the plenum airflow (Engel, Johnson and Raether, 1987). This ventilation airflow can shear the downward flow from the plenum, and this shear can reduce the effectiveness of the canopy air curtain by either disrupting the downward flow or allowing contaminated mine air into the canopy air curtain zone of protection.

In order to have an effective design of a shuttle car canopy air curtain, the contract required the canopy air curtain to be successful in high ventilation airflows. In the case of a shuttle car, high ventilation airflow is defined as mine ventilation velocity in an intake airway plus the maximum speed of a shuttle car. According to Joy Global (2016), the maximum speed of a shuttle car is approximately 9.7 km/h (6 mph, or 528 fpm). The mine ventilation velocity to overcome at the testing site, a central Appalachian underground coal mine, was 86 m/min (283 fpm), measured during a previous visit to the mine site. The maximum shuttle car speed plus the mine ventilation velocity result in a top airflow of approximately 247 m/min (811 fpm). A threshold of 259 m/min (850 fpm) was therefore selected.

During recent laboratory testing by NIOSH researchers, it was shown that the successful shuttle car canopy air curtain performance for dust reduction was difficult to achieve. Modifications to the canopy air curtain design improved the performance to approximately 50 percent respirable dust reduction without affecting performance at lower ventilation interference airflows (Reed et al., 2017). A 50 percent dust reduction is substantial, and the selected airflow threshold of 259 m/min (850 fpm) was questioned as to whether it is actually encountered during shuttle car operation. In order to determine the required velocities of the air exiting the plenum, the air velocities actually encountered during a shuttle car traverse needed to be obtained.

Field investigation

The present study was conducted in a room-and-pillar central Appalachian coal mine in the Pocahontas #3 seam. The mine produces approximately 1 Mt (1.1 million st) of coal per year. Cable-reel shuttle cars are used to haul coal to the feeder from the continuous miner. The routes used by these shuttle cars are independent, which each car must follow to prevent the crossover/overlapping of their electric cables (Stefanko, 1983). A schematic of a general shuttle car route is shown in Fig. 1. One of the two shuttle cars was evaluated during this testing: a Narco 10SC32-64AB end-drive shuttle car. During the evaluation, the shuttle car operator was advised to perform the normal routine of coal haulage in order to obtain a representative sample of standard operating conditions. A Kestrel 4500 weather station (Kestrel Instruments, Boothwyn, PA) was mounted in the shuttle car compartment and had the capability to measure and record airflows at specific time intervals. Kestrel monitors are not U.S. Mine Safety and Health Administration (MSHA)-approved for underground coal use, so the weather stations had to be removed from the shuttle car before going inby the last open crosscut and reinstalled after going outby the last open crosscut. For this test, the Kestrel monitor was set to record at five-second intervals. The mine was using blowing ventilation. Airflow measurements at the coal face and the feeder were taken using a vane anemometer. The continuous miner scrubber air flowrate during the survey was 218 m^3/min (7,700 cfm).

During the field investigation, NIOSH researchers were stationed near the continuous miner, by the feeder and along the shuttle car route. Each researcher wore a Thermo Scientific 3700 continuous personal dust monitor (CPDM) in conjunction with a personal DataRAM 1000 (pDR 1000) (Thermo Fisher Scientific, Waltham, MA), as well as the appropriate personal protective equipment, including half-mask NIOSH P100 respirators. Dust sampling units were installed on the shuttle car. Each sampling unit consisted of a CPDM along with a pDR and two gravimetric samplers, each made up of two Elf pumps (Zefon International, Ocala, FL), two Dorr-Oliver cyclones and two 37-mm filters. These sampling units were placed inside the shuttle car cab with the pDR programmed to record at five-second intervals.

Test procedure

The NIOSH researcher near the continuous miner recorded the shuttle car arrival and departure times. This researcher was stationed just outby the last open crosscut and was responsible for removing and installing the Kestrel monitor as the shuttle car moved toward (inby) and departed (outby) the miner. A second researcher recorded the Kestrel monitor “off” and “on” times when the monitor was removed and installed, respectively. These times differ from the loading times of the continuous miner because they include a small portion of time traversing to and from the continuous miner. A third researcher, located at the feeder, recorded the feeder arrival and departure times, allowing for documentation of a complete shuttle car traverse.

During the field investigation, the ventilation airflows at the continuous miner and at the feeder were documented. The airflows were collected using a vane anemometer with measurements taken at each shuttle car pass. Sampling was conducted for two hours, which included 10 complete shuttle car passes. This data represented two complete cuts by the continuous miner. Each pass was defined as (1) unloading of the shuttle car at the feeder, (2) tramming to the continuous miner, (3) loading at the continuous miner and (4) tramming back to the feeder.

The sampling unit placed on the shuttle car provided real-time airflow and dust concentration measurements. The data were used to determine when and if the shuttle car operator was exposed to respirable dust as well as to determine the air velocity experienced during this exposure.

Results

The data acquired during the survey were analyzed. The gravimetric samples collected in the shuttle car were used to correct the instantaneous data collected by the pDR-1000 using the equation *Ratio* = *Grav* / *Instant*, where *Ratio* is the calibration ratio, *Grav* is the gravimetric time-weighted-average concentration, and *Instant* is the instantaneous optical time-weighted-average concentration from the pDR-1000.

The instantaneous pDR data were then multiplied by the ratio thus obtained. The average dust concentration and average airspeed measured on the shuttle car sampling package are shown in Table 1.

The highest average dust concentration observed during the shuttle car operation, 2.22 mg/m^3, occurred when the shuttle car was being loaded at the continuous miner, which had an average airspeed of 48 m/min (157 fpm). While tramming the shuttle car, the operator experienced an average dust concentration of 0.77 mg/m^3 with an average airspeed of 62 m/min (204 fpm). The dust concentration observed at the feeder was the lowest, 0.39 mg/m^3, with an average airspeed of 27 m/min (89 fpm). The overall time-weighted-average dust concentration of the shuttle car was 0.86 mg/m^3.

Table 2 shows the overall time-weighted-average dust concentrations from the CPDMs located on the researchers. During the study, the concentrations at both the feeder and the last open crosscut were very low. The concentrations at the last open crosscuts were higher than at the feeder because the researchers at those crosscuts were downwind of the continuous miner during cutting operations.

The results from eight traverses of the shuttle car are shown in Figs. 2a-j.

In reviewing the shuttle car traverse in Fig. 2a, the time from 11:29:00 am to 11:31:00 am was the time the shuttle car trammed from the feeder to the continuous miner. In this time segment, the airspeed was 0 from 11:30:40 am to 11:31:00 am, which was when the shuttle car was staging/waiting outby the last open crosscut until the other shuttle car departed from the miner. The light blue section is the time the shuttle car was being loaded at the continuous miner (11:31:00 am to 11:33:20 am). The time from approximately 11:33:45 am to 11:35:00 am was when the shuttle car trammed from the continuous miner to the feeder. The maximum airspeed encountered by the shuttle car occurred in this section of the cycle.

All of the other traverse graphs depict the typical movement of the shuttle car as previously described. There are variations due to differing loading and unloading times. Variations in tramming times due to differences in staging and tramming routes exist as well. Overall, the graphs depict fairly similar results for each segment: that is, unloading at the feeder, tramming, loading at the continuous miner. It should be noted that traverse 6 contained a long downtime of approximately 15 min. During this downtime, the continuous miner moved from entry 9 to entry 8 left.

A histogram of all of the observed airspeeds the shuttle car experienced during the study is shown in Fig. 3. It can be observed that the shuttle car spent a large portion of time idle.

These areas were staging areas outby the continuous miner where ventilation airflow was motionless. The shuttle car spent most of its tramming time at airspeeds below 76 m/min (250 fpm). The highest airspeeds measured occurred during the tramming of the shuttle car to and from the feeder. A histogram of the measured airspeeds during tramming is shown in Fig. 4.

This histogram does not include data for when the shuttle car was stationary (0 m/min), as these data were excluded for this graph. There were several instances where the shuttle car was stopped for extended periods of time, such as while waiting on the continuous miner and for completion of an MSHA inspection on the continuous miner. Table 3a shows the general statistics of the shuttle car tramming airspeeds. This table does not include data for when the shuttle car was stationary.

Tramming would represent the worst-case scenario for canopy air curtain design due to the high air velocities in conjunction with the movement of the shuttle car. It was observed, however, that the operator's exposure to dust while tramming was relatively low, averaging 0.77 mg/m^3 during this study. Table 3b shows the statistics of the dust concentrations from the pDR observed during the entire study. Table 4 presents the statistics of the dust concentration data for each segment of the shuttle car traverse. It should be noted that these segmented results do not include the times when the shuttle car was stationary.

The dust exposure of the shuttle car operator was correlated to observed airspeed. The data was analyzed for instantaneous exposures occurring from 0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0 and greater than 2.0 mg/m^3. This analysis was conducted to profile the dust exposures of the shuttle car operator and determine the environmental conditions present when the operator is susceptible to the classified dust exposures. Histograms of the observed airspeeds were developed for each dust classification and are shown in Figs. 5-9.

From Fig. 9, it can be observed that the highest respirable dust concentrations, great than 2.0 mg/m^3, to which the shuttle car operator was exposed occurred when located in air streams from 0 to 61 m/min (0 to 200 fpm). This is likely the case because it was observed that the majority of the shuttle car operator's exposure was attained when loading coal from the continuous miner, which had an average air velocity of 47.8 m/min (156.75 fpm) found in Table 1.

It should also be noted that although the shuttle car en-countered instances of top airflows from 152 to 198 m/min (500 to 650 fpm), these were relatively short in duration. There were only 12 cases of these top airflows, and because each instance represents a five-second interval, this represents only 60 s of total time encountering high-speed airflows. This is out of approximately 109 min or 6,560 s of total tramming time of the shuttle car, which demonstrates that the high speed airflow encounters represent a very small portion of the airflow the shuttle car encounters during tramming. Instances during which the shuttle car encountered high airflow speeds seemed to occur as the shuttle car left the last open crosscut. No airflows were able to be recorded from the last open crosscut to the continuous miner, and from the continuous miner to the last open crosscut. There could possibly be more instances of higher airflows encountered during these times. Air velocities, however, were measured using a vane anemometer at the blowing curtain inlet behind the continuous miner without the shuttle car present. This velocity would represent the maximum airflow that could have been experienced by the shuttle car while located in the loading positon.

Conclusions and recommendations

The overall time-weighted-average concentrations as measured by the CPDMs at the site were fairly low, ranging from 0.577 to 0.969 mg/m^3, as illustrated in Table 2. The CPDMs located near the continuous miner had the highest time-weighted-average concentrations as these CPDMs were generally downwind of the continuous miner during cutting and loading operations.

The purpose of this study was to determine the airflows that the shuttle car would encounter during its operation, with the goal to develop a shuttle car canopy air curtain system that coal operators could incorporate into their equipment to reduce overexposures to respirable coal dust. During this study, the total shuttle car operation times were categorized into tramming, unloading and loading segments. Dust sampling units were used to record coal mine respirable dust exposure at five-second intervals. A Kestrel 4500 weather station was used to record shuttle car airflows at five-second intervals along with the corresponding time study. This allowed an analysis of the airflows and dust concentrations that were encountered to be conducted.

In reviewing the dust concentrations encountered during the individual unloading, tramming and loading segments, loading at the continuous miner had the highest dust exposure, 2.2 mg/m^3. Tramming exposure was 0.77 mg/m^3, and feeder unloading exposure was 0.39 mg/m^3. The overall shuttle car respirable coal mine dust exposure was 0.89 mg/m^3.

The Kestrel 4500 weather station proved to be a viable tool to measure and record the airspeeds that a shuttle car operator would be subjected to during a continuous mining operation. The data collected from this survey will be used to establish the design parameters to provide a filtered air protection layer to the shuttle car operator in the form of a canopy air curtain system. During this field investigation, the majority of the shuttle car operator’s dust exposure occurred while loading coal from the continuous miner. A canopy air curtain system that was designed to drastically reduce the exposure during shuttle car loading would greatly reduce a shuttle car operator’s overall shift exposure.

From the histograms segregating the dust concentrations (Figs. 5-9), dust exposures occurred during all airspeeds. The majority of the airflow speeds encountered by the shuttle car were 137 m/min (450 fpm) or less. When evaluating the dust concentrations greater than 1.5 mg/m^3, the majority of the airflow speeds encountered were less than or equal to 91 m/min (300 fpm). Encountering high airflow speeds was minimal during this testing, representing only 60 s out of a total of 6,560 s total tram time, and designing for these speeds may have minimal impact on canopy air curtain dust control effectiveness. The airflows encountered from the last open crosscut to the continuous miner, and from the continuous miner to the last open crosscut, are unknown and may be where the highest airflows are found. This time was observed to be minimal, however, with the shuttle quickly reaching the last open crosscut and being fitted with the instrumentation.

It is recommended that subsequent testing be conducted at other mining facilities to gain further insight into the spectrum of air velocities and dust concentrations that a shuttle car operator experiences to strengthen the design criterion for the canopy air curtain. NIOSH plans to continue laboratory testing of the J.H. Fletcher-designed canopy air curtain and provide technical insight about its performance and review.

Acknowledgments

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References

Engel M, Johnson D, and Raether T, 1987, “Improved Canopy Air Curtain Systems,” USBM Open File Report 25-88, U.S. Bureau of Mines, Washington, DC.

Global Joy, 2016, “Haulage Systems Product Overview,” Komatsu America Corp., Rolling Meadows, IL.

Reed WR, Zheng Y, Ross G, Salem A, andYekich M, 2017, ”Preliminary Laboratory Testing of a Shuttle Car Canopy Air Curtain,” 2018 SME Annual Conference & Expo, Society for Mining, Metallurgy & Exploration Inc., Englewood, CO.

Salem A, Begley R, and Ross G, 2016, “Progress Report #2,” NIOSH Contract #:200-2015-63485, Marshall University Research Corp., Huntington, WV.

Stefanko R, 1983, Coal Mining Technology, Theory and Practice, Society of Mining Engineers, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York.

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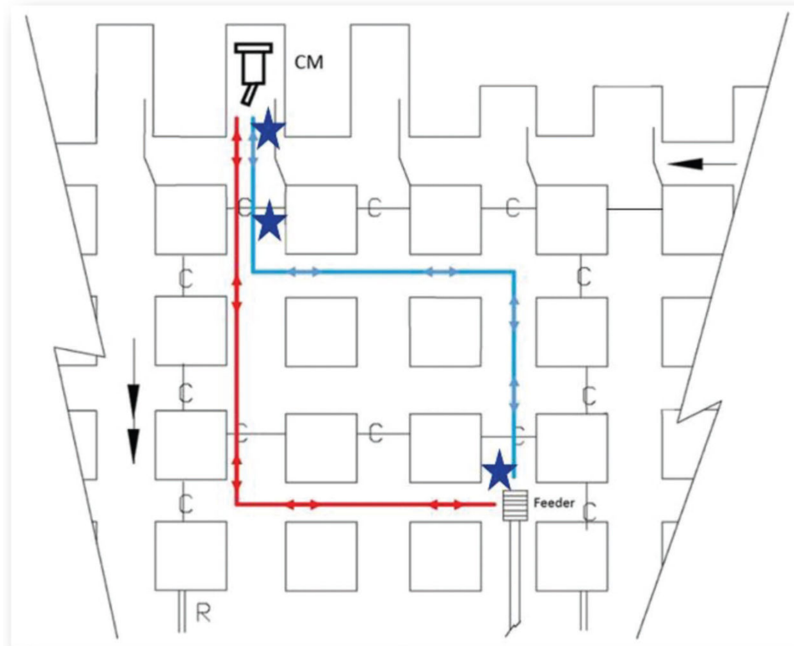

Figure 1.
Two typical routes of shuttle cars during testing: Blue (fitted with instrumentation) and red. (CM = continuous miner)

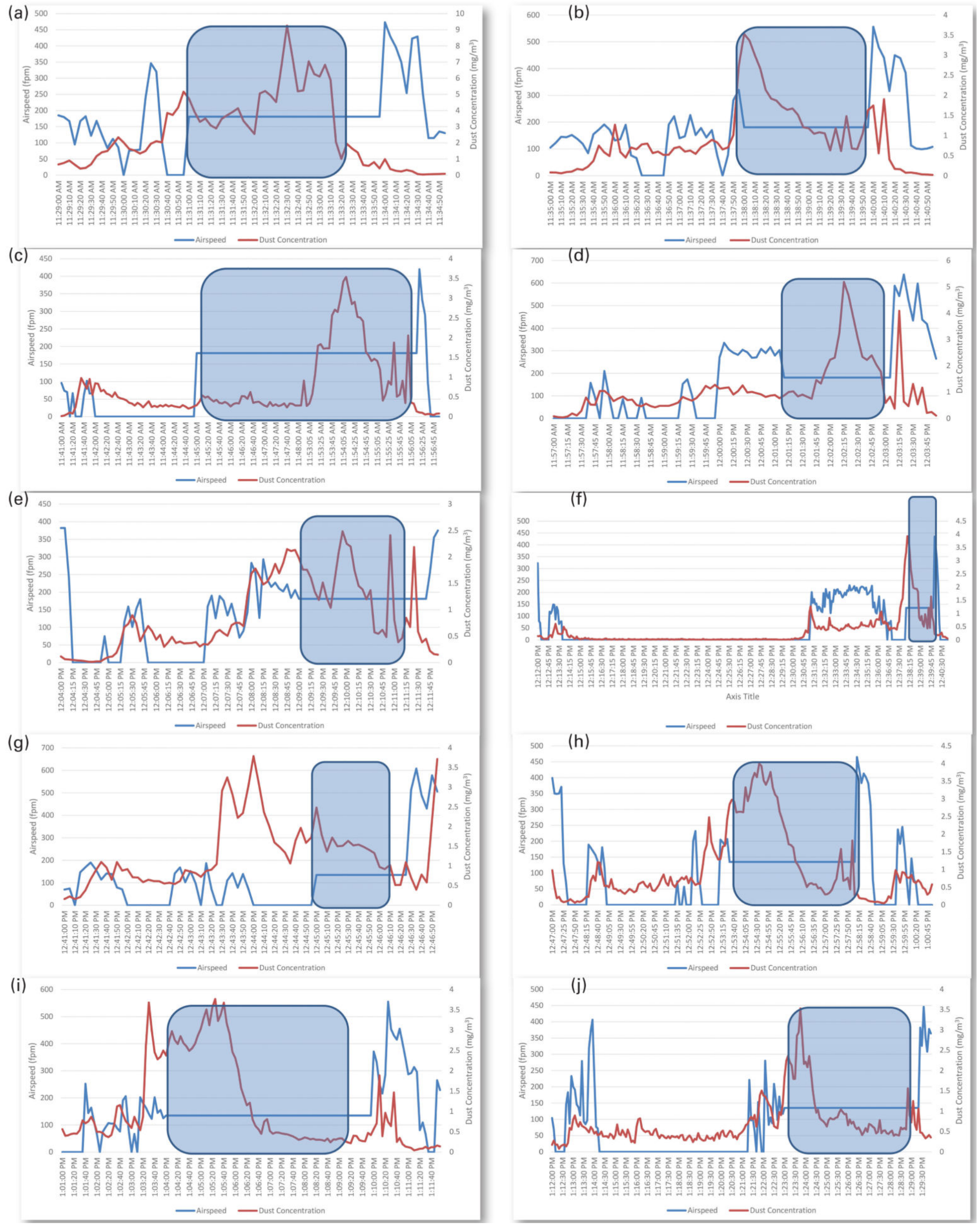

Figure 2.

Traverses (a) 1, (b) 2, (c) 3, (d) 4, (e) 5, (f) 6, (g) 7, (h) 8, (i) 9 and (j) 10 of the shuttle car (blue shaded area = the time the shuttle car was loading at the continuous miner during each traverse).

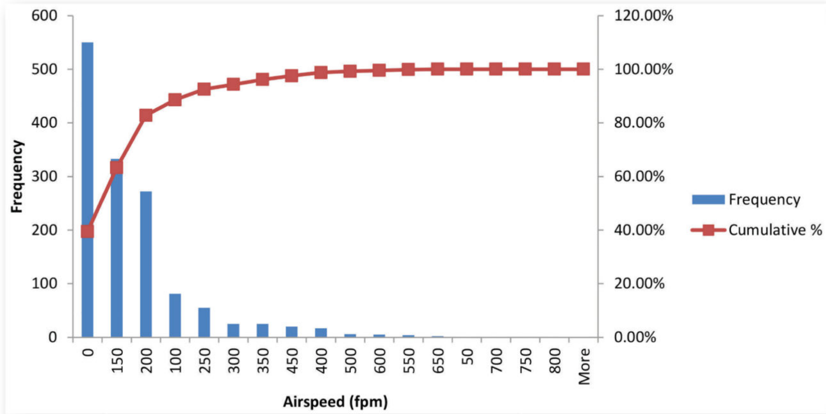

Figure 3.
Histogram of all airspeeds observed on the shuttle car during the study.

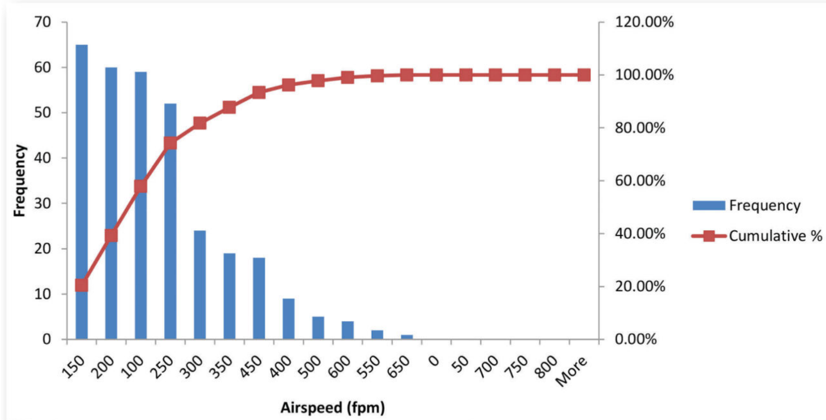

Figure 4.
Histogram of shuttle car tramming airspeeds.

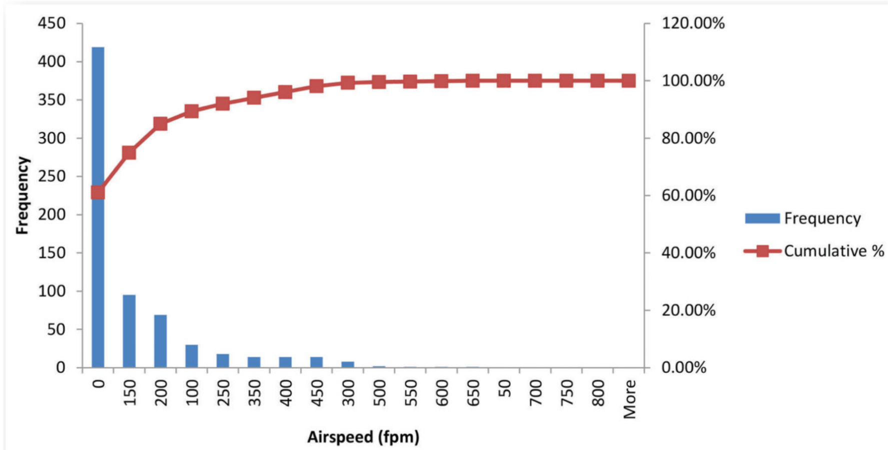

Figure 5.

Shuttle car operator dust exposures of 0 to 0.5 mg/m^3 at various airspeeds.

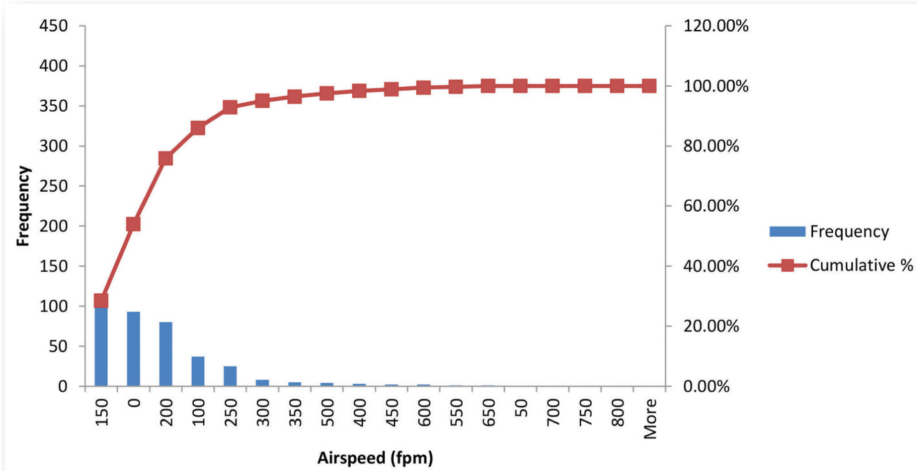

Figure 6.
Shuttle car operator dust exposures of 0.5 to 1.0 mg/m^3 at various airspeeds.

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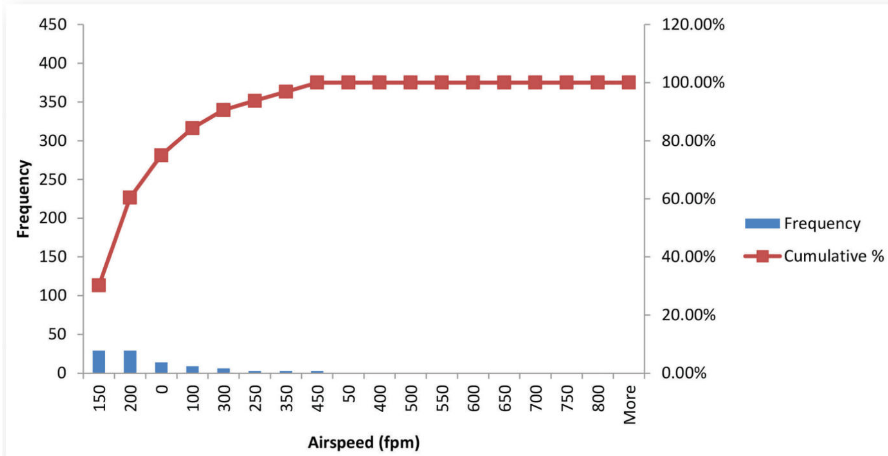

Figure 7.
Shuttle car operator dust exposures of 1.0 to 1.5 mg/m^3 at various airspeeds.

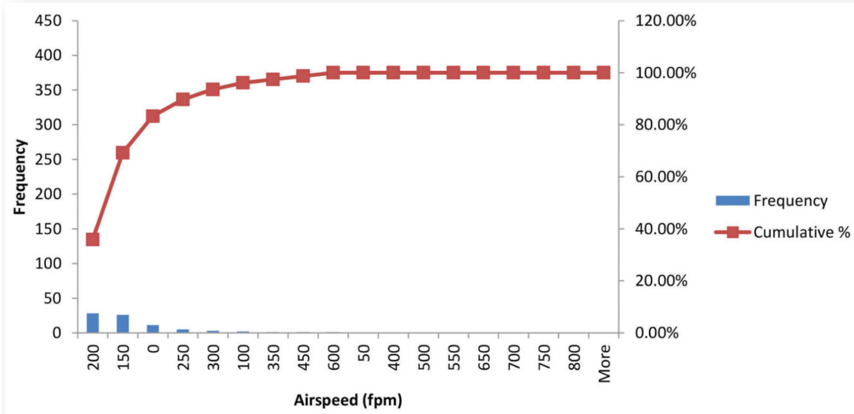

Figure 8.
Shuttle car operator dust exposures of 1.5 to 2.0 mg/m^3 at various airspeeds.

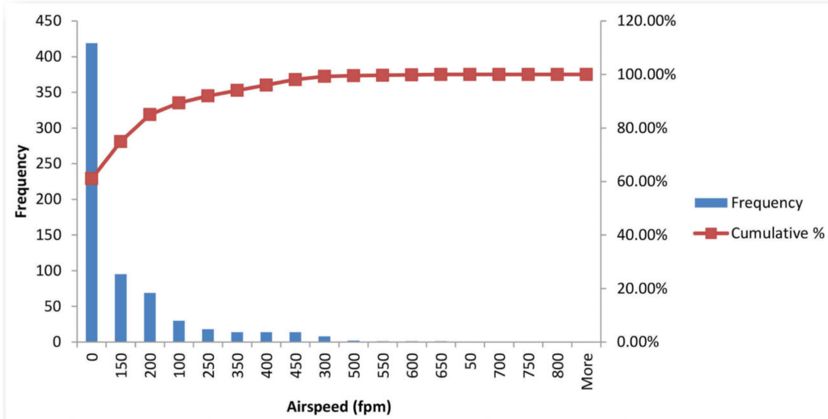

Figure 9.
Shuttle car operator dust exposures of greater than 2.0 mg/m^3 at various airspeeds.

Table 1

Shuttle car sampling results with dust concentrations calculated from pDR-1000 data.

Shuttle car segment	Average dust concentration (mg/m^3)	Average airspeed (fpm)	Maximum airspeed (fpm)	Minimum airspeed (fpm)	Airspeed standard deviation (fpm)
Feeder unloading	0.39	89	399	0	101
Tramming	0.77	204	638	57	116
CM loading	2.22	157	181	135	23
Overall	0.86	108	638	0	110

Table 2

CPDM data collected on researchers positioned along shuttle car traverse.

Location	Time-weighted-average dust concentration (mg/m^3)
Feeder researcher	0.577
Last open crosscut researcher A	0.694
Last open crosscut researcher B	0.969

Table 3

Statistics of (a) shuttle car tramming airspeeds (fpm) and (b) overall shuttle car operator dust concentrations (mg/m^3) during field investigation.

Statistic	(a)	(b)
Mean	203.93	0.857
Standard error	6.52	0.028
Median	182	0.508
Mode	76	0.013
Standard deviation	116.35	1.048
Sample variance	–	1.097
Kurtosis	–	8.925
Skewness	–	2.531
Range	581	9.247
Minimum	57	0.004
Maximum	638	9.250
Sum	64,851	1,195.413
Count	318	1,395.000
Confidence level (95%)	12.84	0.055

Table 4

Statistics of various shuttle car activities performed during the field investigation.

Statistic	Dust concentrations (mg/m^3) while		
	unloading	tramming	loading
Mean	0.389	0.771	2.225
Standard error	0.037	0.036	0.107
Median	0.184	0.612	1.921
Mode	0.059	0.708	3.553
Standard deviation	0.413	0.637	1.521
Sample variance	0.17	0.406	2.314
Kurtosis	4.333	5.057	2.801
Skewness	1.79	1.989	1.427
Range	2.329	4.069	8.814
Minimum	0.013	0.02	0.436
Maximum	2.342	4.089	9.25
Sum	48.281	245.136	451.637
Count	124	318	203
Largest	2.342	4.089	9.25
Smallest	0.013	0.02	0.436
Confidence level (95%)	0.073	0.07	0.211