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LABORATORY TESTING OF A WATER CURTAIN DESIGNED TO REDUCE FLOAT DUST ACCUMULATIONS IN LONGWALL RETURNS

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ABSTRACT

Float coal dust (FCD) is an explosion hazard affecting all underground coal mine workers. This hazard is currently mitigated by the application of inert rock dust. The National Institute for Occupational Safety and Health has conducted research aimed at developing a water curtain to reduce accumulation of FCD in longwall returns reducing the likelihood of a dust fueled explosion. The curtain was tested by varying spray spacing and curtain spans for single and dual spray bar configurations. The knockdown efficiency of the control on FCD ranged from 16% to 56% based on the spray configuration. A single bar with sprays placed in areas of high dust concentration yielded the maximum knockdown per liter of water consumed.

INTRODUCTION

Accumulation of float coal dust (FCD), diameter ≤74 μm, poses an explosion hazard to all underground coal miners (Cashdollar, 1996; Hertzberg & Cashdollar, 1987). Mining operations generate FCD, which is transported by ventilating air designed to purge methane and other respirable aerosols from the mine airways, eventually settling on the floor, ribs, and roof of mine entries. In the event of a methane explosion, this dust may become re-entrained and, if sufficient concentrations exist, fuel a secondary dust explosion that may propagate throughout the mine (Abbasi & Abbasi, 2007; Nagy, 1981). Dust-fueled explosions are considered a low-occurrence, high-risk event, with the last three occurrences (2001, 2006, and 2010) representing 31%, 36%, and 60% of the underground coal mining fatalities for their respective years (MSHA, 2016.). Current federal regulation requires that mines apply rock dust to mine entries in order to maintain a total incombustible content of 80%, which inhibits explosion propagation (Maintenance of incombustible content of rock dust, 2011). In the case of longwall mines, it may be possible to reduce the amount of FCD that settles in the mine airways by developing strategies to limit the amount of dust that is able to leave the active mining face.

The National Institute for Occupational Safety and Health (NIOSH) has a long history of developing controls to reduce worker exposures to respirable coal mine dust, which is linked to coal workers' pneumoconiosis (CWP) and other chronic and acute health problems (NIOSH, 2011). Respirable dust controls are designed with the sole purpose of keeping mine workers in clean air, and a targeted control can achieve this by moving dust-laden air away from miners, typically by face ventilation and open-air water sprays. There have been extensive studies focused on understanding the effects of specific factors, such as operating pressure, orientation, ventilating airflow, droplet size, and spray nozzle type, on the knockdown performance of sprays in the presence of respirable dust (Chander et al., 1991; Cheng, 1973; Organiscak et al., 2018; Ruggieri et al., 1983; USBM, 1982; USBM, 1979). However, in order for FCD controls to be effective, they must remove dust from the airstream. NIOSH conducted an investigation to evaluate water sprays commonly used to control respirable dust and evaluated their ability to reduce dust concentrations in the general airstream, known as knockdown efficiency (KE). This study had two significant results. First, the guidelines for spray operation established for respirable dust held true when operating a spray with the goal of removing FCD, and secondly, there is a relationship between coal particle size and spray effectiveness, with spray knockdown efficiency increasing with increasing diameter of FCD (Beck et al., 2018, Seaman et al., 2018). The current study makes use of these findings to develop a FCD control by using spray bars to form water curtains that can knockdown airborne dust to reduce FCD accumulations in longwall returns. Near real-time samplers were used to evaluate the KE of curtains when varying spacing between operational sprays, cross-directional span of the sprays, and the number of spray bars that are used. The water curtain was evaluated for both total KE and for KE per liter of water consumed.

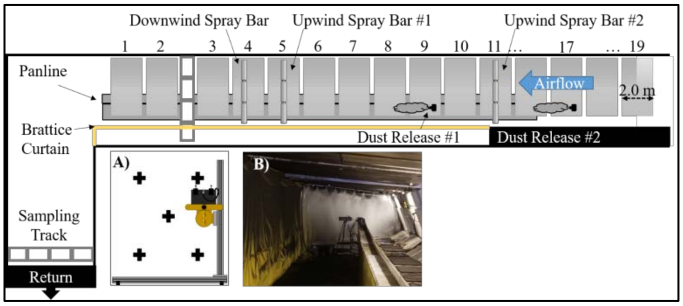

Figure 1. A schematic of the NIOSH longwall gallery. A) a cross-sectional view of the sampling area in the return with the plus marks indicating the locations where readings were taken during the test and B) a photo of the water curtain operating the gallery.

METHODS

Tests to determine the KE of the water curtain were conducted at a full-scale longwall test facility at the National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Mining Research Division (Figure 1). The simulated face is 38.1 m (125 ft) long and 2.29 m (7.5 ft) high from floor to roof. Nineteen mock 2.0-m (6.5-ft) longwall shields cover the length of the longwall face, with a panline spanning from shield 16 to the return. Brattice curtain was hung from the shields, spanning from shield 11 to the return, creating a tunnel 1.6 m (5.4 ft) high by 3.0 m (10 ft) wide. The ventilation of the tunnel was set to 3.5 m/s (700 fpm).

A series of three tests were conducted, and the details of the longwall gallery configurations for each test series are shown in Table 1. The first set of tests evaluated water curtain KE after varying the spacing and span of the active water sprays. The second series of tests evaluated the water curtain KE for a series of spray bars placed one shield width apart. The third series of tests evaluated the water curtain KE for a series of two spray bars spaced 50 ft apart.

Table 1. Table of spray bar and dust release configurations for the three test series.

Test Series	Number of Spray Bars	Location of Spray Bars	Location of Dust Release
Single Bar	1	Shield 4	Shield 9
Dual Curtain 2 m	2	Shield 4 and 5	Shield 9
Dual Curtain 13 m	2	Shield 4 and 11	Shield 17

The release point was directed such that dust was ejected halfway between the face and the panline, 0.51 m (20 in) from the underside of the shields. Dust was generated by using a screw-type feeder system with coal dust funneled into an eductor that used compressed air to carry the dust through hoses to the release point in the gallery. The dust supplied to the feeder (mean: 23.02 µm, standard deviation: 18.22 µm) was custom-milled to contain float-dust-sized particles. The screw feeder was adjusted until dust was provided to the gallery at an approximate rate of 50 g ± 2 g per min. The dust concentration and distribution (Figure 2) for this study were similar to the levels observed in the field (Kissell et al., 1986; Rao, 1993; Shahan et al., 2017).

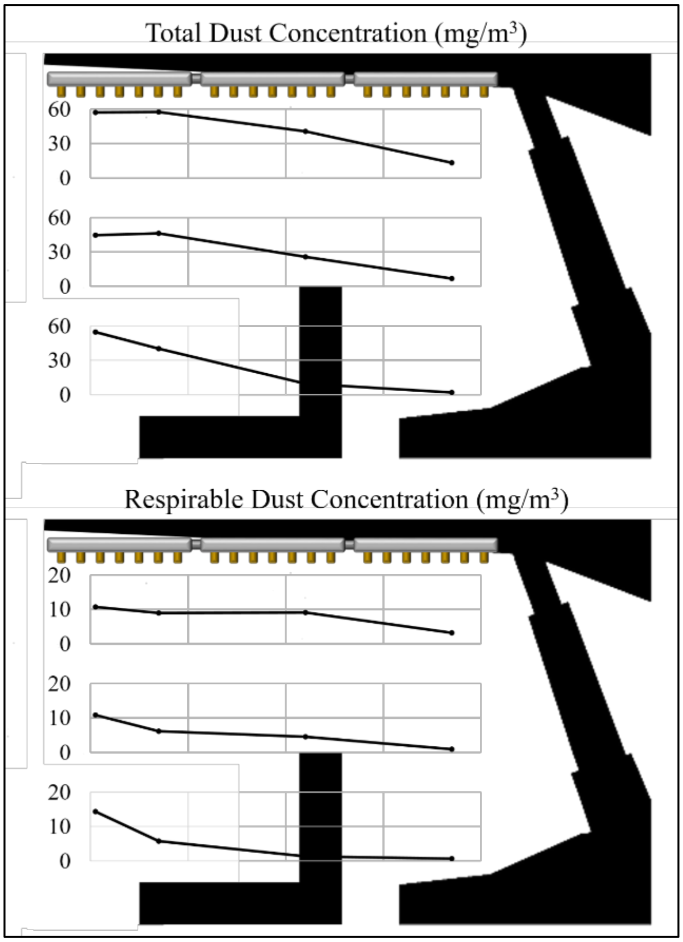

Figure 2. Graphs of the total (top) and respirable (bottom) dust concentrations across the gallery face between shields 2 and 3 at three different heights for dust dispersed from shield 9.

The spray bar tested in this study was constructed from three manifolds (Repair King, Shinnston, WV), each capable of holding a maximum of seven sprays spaced 0.15 m (0.5 ft) apart. Full cone sprays (SpiralJet Nozzle No. GG3, Spraying Systems Co., Wheaton, IL) were selected for use in this study because they provided maximum knockdown during single spray tests and also have no preferential orientation (Beck et al., 2018; Seaman et al., 2018). The operating pressure of each active spray bar was maintained at 160 psi. The first series evaluated KE for varying spray intervals and varying cross-directional span of a water curtain consisting of a single spray bar (Table 2, see APPENDIX). Using the results from the first series of tests, the second and third series tested a selection of active spray configurations on two spray bars placed in series for two different distances between the spray bars (Table 3, see APPENDIX). One curtain was formed by the spray bars located 2 m (6.5 ft) apart. For the second curtain, the spray bars were located 13.7 m (45 ft) apart. In each configuration, the location of the downwind spray bar in the series was held constant at shield 4.

Located in the return, 7.9 m (26 ft) downwind of the tailgate was the XY Planar Motion System. The system consists of two 2-m (80-in) linear actuators (Tolomatic, Inc., Hamel, MN), each with a 1.3-m (55-in) stroke with one actuator positioned horizontally with a sled carrying the second actuator mounted vertically to a length of 80-20 slotted aluminum framing. The instrumentation in this study was mounted to a sled on the vertical actuator. Both sleds were driven by NEMA 34 high-torque stepper motors (Applied Motion Products, Watsonville, CA) capable of achieving a 20,000 micro-step resolution and controlled using STAC6 stepper drives (Applied Motion Products, Watsonville, CA) using serial commands. A 10:1 ratio gear box was installed between each drive motor and actuator. A custom LabVIEW virtual instrument was created to automate the motion, allowing precise and repeatable positioning of the monitoring instruments (LabVIEW software, National Instruments).

Two types of instruments were used in this study. Respirable dust measurements were collected using the Personal Dust Monitor PDM3700 (PDM; Thermo-Fisher Scientific, Waltham, MA). Float dust measurements were taken using the continuous float dust monitor (CFDM). The CFDM allows a regular PDM3600 or PDM3700 to measure total dust by bypassing the cyclone responsible for separating out the respirable fraction of dust. It consists of a housing with an isokinetic nozzle for the tapered element oscillating microbalance (TEOM) module of a regular PDM and an insert into the TEOM chamber on the PDM for connecting the electronic and airflow controls. Return concentrations were measured using one PDM3700 and two CFDMs placed on the sampling track. Each sampling phase lasted 25 minutes, and each test condition was repeated three times. The KE of the control was calculated by comparing the return dust concentrations before and after the control was activated. Statistics were calculated using SAS 9.4 (SAS Institute, Cary, NC), using a p-value of 0.05 as a threshold for significance.

RESULTS

Single Curtain Results

The first set of tests evaluated the water curtain for varying distances between operational sprays. These results are shown in Figure 3. The maximum KE for float dust (48.8%) and respirable dust (33.0%) occurred for the bar with all 21 sprays operating. Both total and respirable dust KE decreased in a linear fashion as distance between operational sprays increased. When taking water consumption into consideration, the KE for total dust increased with increased spacing between the operational sprays until reaching a peak performance when operational sprays were located 30.5 cm apart. The water curtain performance for respirable dust remained relatively constant, averaging a KE of 1.8% ± 0.09% for spray spacing ranging from 15.2 cm to 30.5 cm between sprays. The KE then decreased to an average KE of 0.82% ± 0.05% as the spacing between sprays increased beyond 30.5 cm.

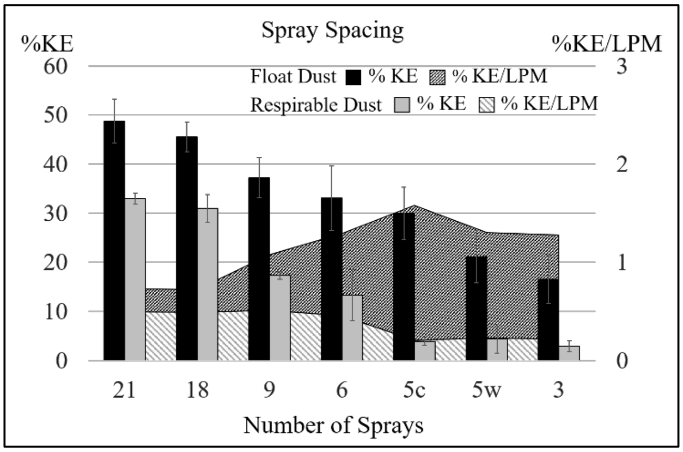

Figure 3. Average water curtain performance for float dust and respirable dust for varying spray intervals.

The second set of tests in this series evaluated the water curtain for varying cross-directional spans. These results are shown in Figure 4. Peak performance of the curtain occurred for the full width 21-spray curtain configuration for both the total (48.8%) and respirable (33.0%) measurements. For respirable dust, none of the cases were significantly different ($p < 0.05$), while the only significant difference for total dust occurred between the narrowest (3-spray) and widest (21-spray) curtain. When accounting for water consumption, the narrowest curtain had the highest performance for both total (13.7%) and respirable (5.9%) dust. The narrowest curtain KE/LPM was significantly different from all other curtain widths for float dust, while none of the KE/LPM results were significantly different for respirable dust.

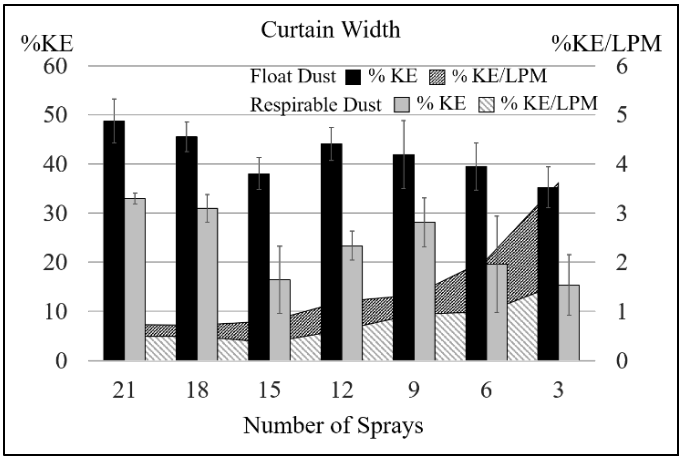

Figure 4. Average water curtain performance for float dust and respirable dust for varying curtain widths.

Dual Bar Curtain 2 Meter Results

The results for a water curtain consisting of two spray bars located 2 meters apart are shown in Figure 5. The peak performance for a water curtain constructed of two spray bars in series occurred during the full operation of both bars (21/21) and had a KE of 56.1% for float dust and 42.7% for respirable dust. The minimum curtain KE occurred for the 3/3 configuration with a float dust reduction of 39.7% and a respirable dust reduction of 23.6%. The peak performance when accounting for consumption occurred during the 3/3' configuration, with the float dust reduction measuring 2.0% and the respirable dust reduction measuring 1.3%.

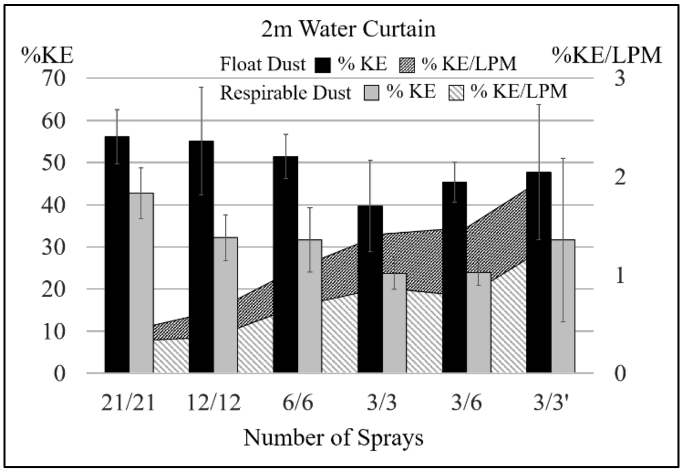

Figure 5. Average water curtain performance for float dust and respirable dust for two spray bars placed 2 m apart.

Comparisons between float dust KE for the single bar water curtain tests and the 2-m dual spray bar water curtain tests are shown in Figure 6. Conditions 21/21, 12/12, and 3/3 can be directly compared to their counterparts from the curtain width tests. The dual bar water curtain KE was 15.0%, 16.6%, and 12.7% higher than the single bar tests for the 21, 12, and 3-spray configurations respectively. None of the performances were significantly different from each other. The 6/6 configuration consisted of two bars each with 6 sprays spread 30.5 cm apart. When taken together, the staggering of the sprays between the two bars covered the same space as the 12-spray configuration of the single bar curtain width test. The 6/6 configuration did not perform significantly differently, yielding only a 16.6% higher KE for float dust, from its 12-spray single bar counterpart. The 3/3' dual bar curtain used two bars with 3 consecutive operational sprays staggered to create a curtain similar to the 6-spray curtain from the curtain width tests. Similarly to the other dual to single bar comparisons, the dual bar outperformed the single bar by 20.7%, but the difference was not significant.

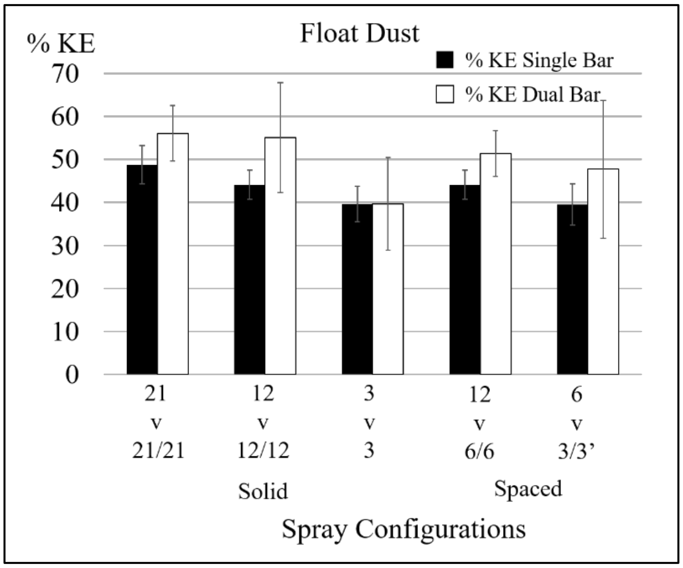

Figure 6. Comparison of the water curtain performance constructed from a single bar versus two bars in series 2 m apart.

Dual Curtain 13 Meter Results

The results of two water curtains placed in series 13 m apart are shown in Figure 7. The peak performance for a water curtain constructed of two spray bars in series occurred during the full operation of both bars (21/21) and had a KE of 44.3% for float dust and 26.8% for respirable dust. The minimum curtain KE for total dust occurred for the 12/12 configuration, with a float dust reduction of 24.9% and a respirable dust reduction of 21.9%. The minimum curtain KE for respirable dust occurred for the 6/6 configuration, with a respirable dust KE of 11.7% and a total dust reduction of 30.4%. The 21/21 and 12/12 spray bar configurations were significantly different from each other for total dust.

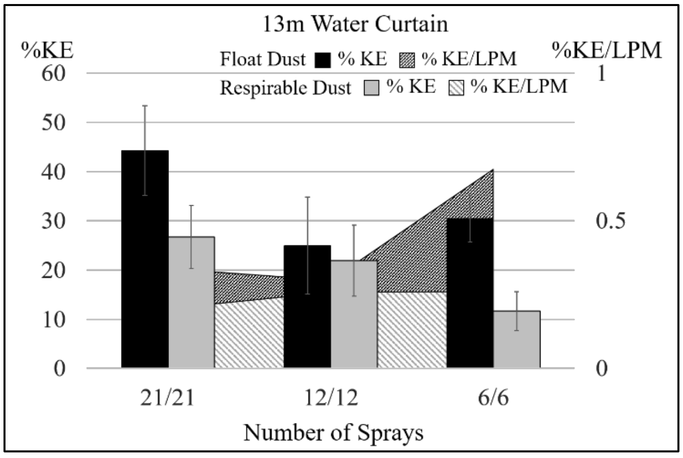

Figure 7. Average water curtain performance for float dust and respirable dust for two spray bars placed 13 m apart.

DISCUSSION

The set of single bar tests determined the effect of spray spacing and curtain span on the performance of a water curtain to reduce longwall return float dust accumulations. It was found that increasing spray spacing led to a linear reduction of the KE of the water curtain for both float and respirable dust fractions. Taking water consumption into account showed that KE/LPM increased with increasing spray spacing until the spacing exceeded 2 ft, at which point the performance began to decrease. Curtain width also had a slight negative effect on curtain KE for decreasing cross-directional span of the active sprays. However, this effect only yielded significant differences between the widest and narrowest curtains. Curtain width was tested due to a specific concern because previous research has shown that sprays are effective air movers, but the air movement may not always be a benefit to dust control (Jayaraman et al., 1986). However, this study found that the sprays did not cause significant dust migration and, therefore, if water consumption by the curtain is a concern, placing sprays only in areas with high dust concentration will not significantly reduce the overall curtain effectiveness.

The dual bar tests examined two types of bar uses. The first series of dual bar tests evaluated whether two bars placed in series with respect to airflow would improve dust knockdown by increasing local turbulence. Previous NIOSH studies have found turbulence caused by water sprays to be undesirable when controlling for respirable dust as it may cause the dust cloud to roll back into areas where miners are located (Jayaraman et al., 1984; Ruggieri et al., 1985). However, dust knockdown relies on particle collisions, which may be increased by turbulence (Courtney & Cheng, 1977; Hinds, 1999; Maxey, 1987; McPherson, 1993). In the tests conducted for this study, there was an overall increase in KE between the dual bar water curtain and the corresponding single bar water curtain, but this difference was not significant.

This study demonstrated that a water curtain may be effective at reducing airborne float dust concentrations and that the curtain can be designed to minimize water consumption by targeting areas of high dust concentrations. Dust will be most concentrated immediately downwind of the shearer, and so a series of curtains along the face may provide the greatest airborne FCD reductions, but field testing is needed to determine the optimal distances between the shearer and a downwind water curtain. The second series of dual bar tests spaced the bars far apart to determine the effectiveness of operating multiple bars spaced along the longwall face. When the 21/21 and 12/12 dual bar conditions were compared to their single bar counterparts, the differences were not significant for either total or respirable dust size fractions. These results indicate that, while more than one bar may be necessary to maximize dust reduction, there may be limited utility in simultaneously operating more than one water curtain along a longwall face.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of company names or products does not constitute endorsement by NIOSH.

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REFERENCES

1. Abbasi, T., & Abbasi, S. A. (2007). Dust explosions–Cases, causes, consequences, and control. *Journal of Hazardous Materials*, *140*, 7–44. https://doi.org/10.1016/j.jhazmat.2006.11.007
2. Beck, T. ., Seaman, C. E., Shahan, M. R., & Mischler, S. E. (2018). Open-air sprays for capturing and controlling airborne float coal dust on longwall faces. *Mining Engineering*, *70*(1), 42–48.
3. Cashdollar, K. L. (1996). Coal dust explosibility. *Journal of Loss Prevention in the Process Industries*, *9*(1), 65–76. https://doi.org/http://dx.doi.org/10.1016/0950-4230(95)00050-X
4. Chander, S., Alaboyun, A. R., Aplan, F. F., & Section, M. P. (1991). On The Mechanism of Capture of Coal Dust Particles By Sprays. In R. Frantz & R. Ramani (Eds.), *Proceedings of the 3rd symposium on respirable dust in the mineral industries* (pp. 193–202). Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc.
5. Cheng, L. (1973). Collection of airborne dust by water sprays. *Industrial & Engineering Chemistry Process Design*, *12*(3), 221–225. Retrieved from http://pubs.acs.org/doi/abs/10.1021/i260047a002
6. Courtney, W., & Cheng, L. (1977). Control of Respirable Dust by Improved Water Sprays. *Respirable Dust Control-Proceedings of Technology Transfer Seminars*, 92–108.
7. Hertzberg, M., & Cashdollar, K. L. (1987). Introduction to dust explosions. In *Industrial Dust Explosions*. ASTM International.
8. Hinds, W. C. (1999). *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles* (2nd ed.). New York, NY: John Wiley & Sons.
9. Jayaraman, N., Kissell, F. N., & Schroeder, W. E. (1984). Modify spray heads to reduce the dust roll-back on miners. *Coal Age*, *89*(6), 56–57. Retrieved from https://www.cdc.gov/niosh/nioshtic-2/10003988.html
10. Jayaraman, N., Schroeder, W., & Kissel, F. (1986). Studies of dust knockdown by water sprays using a full-scale model mine entry. *Transcations of Society of Mining Engineers*, *278*, 1875–1882.
11. Kissell, F. N., Ruggieri, S. K., & Jankowski, R. A. (1986). How to Improve the Accuracy of Coal Mine Dust Sampling. *American Industrial Hygiene Association Journal*, *47*(10), 602–606. https://doi.org/10.1080/15298668691390313
12. Maintenance of incombustible content of rock dust, Pub. L. No. Part 75.403, 561 (2011).
13. Maxey, M. R. (1987). The gravitational settling of aerosol particles in homogeneous turbulence and random flow fields. *Journal of Fluid Mechanics*, *174*(1), 441. https://doi.org/10.1017/S0022112087000193
14. McPherson, M. J. (1993). *Subsurface Ventilation and Environmental Engineering*. Chapman & Hall.
15. MSHA, Mine Safety and Health Administration. (2016). Coal Fatalities for 1900 Through 2017. Retrieved January 30, 2017, from http://arlweb.msha.gov/stats/centurystats/coalstats.asp.
16. Nagy, J. (1981). *The explosion hazard in mining* (IR 1119). Pittsburgh, PA: US Department of Labor Mine Safety amd Health Administration.
17. NIOSH. (2011). *Coal Mine Dust Exposures and Associated Health Outcomes: A Review of Information Published Since 1995*. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Current Intelligence Bulletin 64, DHHS (NIOSH) Publication No. 2011–172.
18. Organiscak, J. A., Klima, S. S., & Pollock, D. E. (2018). Empirical engineering models for airborne respirable dust capture from water sprays and wet scrubbers. *Mining Engineering*, *70*(10), 50–57.
19. Rao, B. S. (1993). *Design and development of a multi-scrubber dust control system for longwall faces : experimental and modelling studies*. University of Wollongong.

20. Ruggieri, S.K., Muldoon, T. L., Schroeder, W., Babbitt, C., & Rajan, S. (1983). Optimizing water sprays for dust control on longwall shearer faces.
21. Ruggieri, Steven K., Muldoon, T. L., Babbit, C. A., & Lee, E. (1985). *Improved Diffuser and Sprayfan Systems for Ventilation of Coal Mine Working Faces.* Pittsburgh, PA. Retrieved from https://www.cdc.gov/niosh/nioshtic-2/10005019.html
22. Seaman, C. E., Shahan, M. R., Beck, T. W., & Mischler, S. E. (2018a). Comparison of the CAS-POL and IOM samplers for determining the knockdown efficiencies of water sprays on float coal dust. *Journal of Occupational and Environmental Hygiene*, *15*(3), 214–225. https://doi.org/10.1080/15459624.2017.1411597
23. Shahan, M. R., Seaman, C. E., Beck, T. W., Colinet, J. F., & Mischler, S. E. (2017). Characterization of airborne : Float coal dust emitted during continuous mining, longwall mining and belt transport. *Mining Engineering*, *69*(9). https://doi.org/10.19150/me.7746
24. USBM. (1982). *Dust Knockdown Performance of Water*. *Technology News*. U.S. Department of the Interior, U.S. Bureau of Mines.
25. USBM. (1979). *Water Spray Systems for Control of Respirable Dust on a Longwall Plow Underground Investigation and Dust Tunnel Evaluation*. Monroeville, PA: Bituminous Coal Research, Inc. U.S. Department of the Interior, U.S. Bureau of Mines.

APPENDIX

Table 2. Table listing the spray configurations tested for the single bar test series.

Test	Number of Sprays	Average Water Consumption (L/min)	Spray Configuration (Shaded = On)																				
			Face																				Gob
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Varied spray interval	21	66.8	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	18	63.2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
	9	34.4	■		■		■		■		■		■		■		■		■				
	6	22.9			■			■			■			■			■			■			
	5c*	19.0			■			■			■			■			■						
	5w*	18.9			■				■				■				■				■		
	3	13.3				■							■							■			
Varied cross-directional span	21	66.8	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	18	63.2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
	15	43.6	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
	12	37.1	■	■	■	■	■	■	■	■	■	■	■	■									
	9	32.5	■	■	■	■	■	■	■	■	■												
	6	19.6	■	■	■	■	■	■															
	3	10.2	■	■	■																		

*The “c” designation represents 5 sprays spaced closely (two off sprays between operating sprays) compared to a wider spacing for a “w” designation (three off sprays between each operating spray).

Table 3. Table of dual bar water curtain test series showing active spray configurations.

Test Series	Number of Sprays*	Average Water Consumption (L/min)	Spray Configuration (Shaded = On)																				
			Face																				Gob
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Dual Curtain 2 m	21/21	131.8	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	12/12	88.9	■	■	■	■	■	■	■	■	■	■	■	■									
			■	■	■	■	■	■	■	■	■	■	■	■									
	6/6	48.7		■		■		■		■		■		■									
			■		■		■		■		■		■										
	3/3	28.6	■	■	■																		
			■	■	■																		
	3/6	30.8	■	■	■																		
			■		■		■		■		■		■										
	3/3’	23.4	■	■	■																		
						■	■	■															
Dual Curtain 13 m	21/21	131.8	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	12/12	84.0	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■				
	6/6	45.6	■		■		■		■		■		■		■								
			■		■		■		■		■		■		■								

* The first number denotes the number of sprays on the upwind bar, and the second number denotes the number of sprays on the downwind bar.