Benchmarking longwall
dust control technology and practices

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Abstract ■ Significant advances in longwall mining technology and equipment have occurred over the last decade. By the late 1990s, longwall mine output accounted for 40% of all underground output in the U.S. and today longwall mines account for approximately 50% of coal produced underground in the United States. A 51% increase in average shift production rates has occurred over the last 15 years. This increased longwall productivity has meant that far more dust is being produced and controlling respirable coal dust presents an ongoing challenge for coal mine operators. The National Institute for Occupational Safety and Health (NIOSH) conducted a series of benchmark surveys at longwall operations across the country to identify current operating practices and the types of controls being used. Gravimetric and instantaneous dust sampling was completed to quantify the dust levels generated by major sources on the longwall section and to identify different control technologies in use today. Substantial reductions in dust levels were realized at sampling locations on the face when compared with ongwall surveys conducted in the 1990s. Results from the underground dust surveys and current longwall dust control technology and operating practices will be discussed.

Introduction

The longwall mining industry has seen remarkable and significant improvements in longwall mining equipment and mining practices since the mid-1990s. Average shift production has increased from 3,266 t (3,600 st) per shift in 1994 to approximately 4,990 t (5,500 st) per shift in 2008. A dramatic decrease in working faces from 80 to 46 has occurred over the same time period. Today, the average face width has increased to 318 m (1,043 ft), with one longwall operation reporting a face width of 549 m (1,800 ft) compared to an average of 229 m (750 ft) in 1994 (Fiscor, 2009). Panel lengths in 2008 averaged 3,276 m (10,749 ft) compared to 2,134 m (7,000 ft) in 1994. Also, the average cutting height was 2.7 m (8.5 ft) with a range between 2.1 and 3.4 m (7 and 10 ft). The power made available to the shearer has increased dramatically. Today, the average power installed on the shearer is 1,185 kW (1,589 hp) compared to 940 kW (1,260 hp) just five years ago. Overall production from U.S. longwall mines peaked in 2004 and decreased by approximately 10 percent in 2007 with over 160 Mt (176 million st) mined (Energy Information Administration, 2008). These production rates continue to challenge dust control efforts of the industry.

Longwall personnel can be exposed to harmful respirable dust from multiple dust generation sources including: intake entry, belt entry, stageloader/crusher, shearer and shield advance. For a five-year period ending in 2008, valid compliance sampling for longwall designated occupations or high-risk occupations, taken by mine operators and U.S. Mine Safety and Health Administration (MSHA) inspectors, indicated that 11% of the samples exceeded 2.1 mg/m^3 (Niewiadomski, 2009). In addition, MSHA inspector sampling results for the same five-year period showed that longwall face workers were exposed to elevated levels of respirable silica dust. For MSHA occupation codes 044 (tail-side shearer operator) and 041 (jack-setter), which are subject to reduced dust standards due to silica levels, 31% and 21% of the samples, respectively, exceeded the reduced standard (MSHA, 2009).

NIOSH initiated a surveillance program to quantify the levels of dust being generated by major sources found on today's longwalls, identify the types of controls in use and quantify the levels of application for these control technologies. Survey results were compared to results from a U.S. Bureau of Mines (USBM) study conducted in the 1990s (Colinet et al., 1997).

Sampling methodology

Gravimetric dust samplers, identical to those used in compliance sampling, were operated at 2 L/min (0.071 cu ft/min) in conjunction with 10-mm (0.04-in.) Dorr-Oliver nylon cyclones. Samplers were utilized at stationary and mobile sampling locations to quantify the levels of respirable dust generated at prominent sources along the longwall face. Gravimetric sampling was conducted for four to six hours and calculated concentrations were not converted to mining research establishment (MRE) equivalent dust levels and should not be compared to compliance sampling concentrations.

Personal DataRAMS (pDRs) were used adjacent to the gravimetric samplers at select sampling locations to obtain a time-related profile of dust levels generated during each sampling period. The pDR is an MSHA-approved, instantaneous dust measuring device in which dust-laden air passes through a sampling chamber and a light source. The amount of light deflection in the chamber is measured and provides a relative measure of the dust concentration. Instantaneous dust levels were stored at 10-second intervals in an internal data logger and then downloaded onto a computer for analysis. Dust levels measured with the pDR can be calculated for any time period of interest (e.g., head-to-tail or tail-to-head passes).

Mobile dust sampling to determine the amount of dust generated by the shearer and by movement of advancing shields was conducted by a three- or four-member NIOSH sampling team. Ideally, the upwind sampling location was approximately 4.6-7.6 m (15-25 ft) upwind of the headgate cutting drum and measured intake dust levels reaching the shearer. The shearer sampling location was located between mid-shearer and upwind of the tailgate drum. This sampling crew member tried to position himself within a shield or two of the tailgate shearer operator. Sampling data from this location provided an indication of the amount of dust generated by the headgate drum that migrated into the walkway. If permitted, the downwind sampling location was approximately 4.6-7.6 m (15-25 ft) downwind of the tailgate drum. Each team member maintained their relative position with the shearer as it moved across the face. Differences in dust levels between the upwind and downwind sampling locations can be attributed to dust generated by the shearer. Also, whenever possible, sampling was conducted upwind and downwind of shield movement on head-to-tail passes to determine dust liberated during shield advance.

At each mobile sampling location, sampling crew members wore a specially designed sampling vest that contained two permissible sampling pumps and four cyclone sampling units with appropriate filter cassettes, along with tygon tubing used to connect the sampling units to the pumps. The respirable dust fraction was deposited onto preweighed 37-mm (0.15-in.) PVC filters. All filters were pre- and post-weighed in an environmentally controlled NIOSH laboratory in Pittsburgh and respirable dust concentrations were calculated. The sampling units were fastened to the upper chest area near the shoulders, two units on the left side of the chest area and two units on the right side. One sampling unit on the right and left side of the chest area were connected to the permissible pumps and used to sample dust levels during head-to-tail passes. When the shearer reached the tailgate area, the tubing from these sampling units was disconnected from the pumps and tubing from the other two sampling units was connected to the pumps and used to monitor dust levels for tail-to-head passes. If the shearer was stopped for an extended period (approximately greater than 3 minutes), the gravimetric pumps were paused, so that mobile sampling along the face was representative of dust levels during active mining. Along with the gravimetric sampling package, members of the sampling crew carried a pDR sampler. Gravimetric concentrations were compared to the associated pDR data and correction factors were calculated by dividing the concentrations from the gravimetric samplers by the pDR average concentration. The correction factors were then applied to the instantaneous readings from the pDRs, as recommended by the pDR manufacturer.

Mobile sampling was augmented with stationary sampling packages. At each stationary sampling location, two gravimetric samplers were located adjacent to one another and operated over the same sampling period. Stationary sampling locations included the intake, belt entry, shield 10, and approximately 10 shields from the tailgate. Intake samplers were typically located in the last open crosscut and used to isolate the dust contamination from sources outby the longwall face. If the mine was using the belt entry for additional intake air, gravimetric samplers were located in the belt entry at least 15.2 m (50 ft) outby the stageloader-crusher unit. Shield 10 samplers were hung in the walkway close to the shield legs and used to monitor the respirable dust moving onto the face. The difference between dust levels measured at shield 10 and outby sources (intake and belt) represent an estimate of dust liberated by the stageloader/crusher dust source. The tailgate sampling package provided an indication of the total dust generated along the face. The sampling units were typically started after arrival upon the longwall face and operated continuously until sampling was completed.

In addition to dust measurements, sampling personnel monitored airflow quantities on the longwall section. During each shift of sampling, spot air velocity readings were taken with handheld anemometers at 10-shield intervals down the face. These measurements were one-minute readings taken approximately 0.3 m (1 ft) above the spill plate of the face conveyor. Also, an estimate of the area at each velocity sampling location was calculated to estimate the air quantity present. If possible, water flow meters were installed in the water line supplying the shearer and the line supplying the stageloader/crusher sprays. Periodic readings were taken from each of these meters to monitor the quantity of water being used to suppress dust.

Longwall conditions and controls

Approximately 25% of the active longwall faces in the U.S. were surveyed to quantify dust generation from major sources and determine the relative effectiveness of the different control technologies. Respirable dust surveys were completed at longwall mining operations located in Alabama, Colorado, New Mexico, Pennsylvania and West Virginia to collect data representative of mining conditions found in the mining regions across the country. Five longwalls were located in the eastern United States and five longwalls were surveyed in western states. Seven of the mines utilized a bi-directional cutting sequence and three were taking unidirectional cuts. Mining heights ranged between 2.3-3.7 m(7.5-12 ft), while face widths varied between 229 and 305 m(750 and 1,000 ft).

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Velocity readings were recorded approximately every 10 shields along the longwall face. Face velocities are seldom uniform and may not be representative of average face velocities but, with a ventilation profile, the mine operator may discover problem areas and more accurately assess the ventilation parameters on the face. Average face velocities increased by 28% (0.71 m/sec or 140 ft/min) when compared to air velocities reported in the mid 1990s longwall study (Colinet et al., 1997). The average velocity of the surveyed longwalls was 3.4 m/sec (637 ft/min). Eight of the longwalls had average air velocities greater than 3.0 m/sec (600 ft/min) and two mines averaged over 4.1 m/sec (800 ft/min). Average air quantities increased approximately 51% when compared to the mid-1990 longwall study. The average volume along the face was approximately 30.7 m^3/sec (65,100 cu ft/min), with a range between 24.3 to 39.1 m^3/sec (51,600 to 83,000 cu ft/min). Air quantity observed for seven of the longwalls was greater than 30.2 m^3/sec (64,000 cu ft/min).

Along with an escalation of air down the face, the use of water to the shearer has also increased in an effort to control dust liberated from the face. An average of 492 L/min (17.3 cu ft/min) of water volume was observed at the shearer. The number of shearer drum sprays ranged between 35 and 62, and the average drum spray pressure was approximately 1,034 kPa (150 psi). Half of the mines surveyed utilized crescent sprays on the ranging arms, with the number of sprays ranging between 7 and 10.

Headgate splitter arm directional spray systems were observed on 90% of the surveyed longwalls. The exact type, number and location of these sprays varied significantly between mines, but all were operating on the principle of splitting the ventilating air as it reaches the headgate side of the shearer and holding the dust-laden air near the face. The length of the splitter arms varied between 2.7 m (9 ft), and 4.6 m (14 ft), while the number of sprays ranged between 6 and 19. Thirty percent of the surveyed longwalls utilized venturi sprays, which were mounted on top of the splitter arm and operated with spray pressures in excess of 1,551 kPa (225 psi). Average spray pressures were approximately 690 kPa (100 psi) when hollow cone sprays were used. Sprays were directed downwind and oriented in the direction of the roof, toward the face or face conveyor. Extension arms attached to the end of splitter arms were observed on three longwall faces. The lengths of the extension arms ranged between 45.7 to 61.0 cm (18 to 24 in.) and were angled between 30 and 45 degrees toward the face.

Water spray manifolds positioned between the drums or sprays located on deflector plates spanning the length of the shearer were observed on all longwall surveys. Various types of spray manifolds were observed at the eastern longwall sites. Three or four manifolds consisting of four or five sprays were evenly spaced across the length of the shearer. The manifolds were either located on the face side of the shearer or on the top of the shearer close to the face. At one longwall operation, spray manifolds were located toward the middle of the shearer and elevated 15.2 to 30.5 cm (6 to 12 in.) above the shearer body. Sprays were oriented downwind toward the face, roof or floor. Deflector or sloughing plates were observed at 80% of the western longwalls. The primary function of the shearer deflector plates is to protect shearer operators from debris flying off the face.

However, in a raised position, the deflector plates seem to enhance the directional spray system effectiveness by providing a physical barrier that helps to confine contaminated air close to the face. Deflector plates were either a single plate that covered the length of the shearer or were split into three independent sections that spanned the length of the shearer. All deflector plates were equipped with sprays located near the center or top of the plate and evenly spaced across the length of the plate. The type of sprays were mine-specific and were either venturi or hollow cone sprays.

Manifolds located above the lump breaker or on the shearer body to control dust in the tailgate drum area were observed on all but two longwalls. A minimum of four and maximum of 16 sprays were directed toward the cutting drum or down onto the conveyor. The use of the tailgate-side splitter arm has declined when compared to the 1990s longwall surveys (Colinet et al., 1997). Tailgate-side splitter arms were observed on 20% of the surveyed longwalls. An alternative to the tailgate-side splitter arm is a spray manifold on the tailgate end of the shearer that was seen on two surveys. These sprays were oriented parallel to the tailgate ranging arm or angled slightly toward the tailgate drum and act as a water curtain confining the dust cloud near the face. These sprays carried water a distance of 4.6 to 7.6 m (15 to 25 ft) downwind of the shearer and seemed to enhance the air split created by the shearer's directional spray system.

Shield sprays were mounted on the underside of the shields on one-fifth of the longwalls. These sprays were automatically activated by the shearer with the intent to create a moving water curtain to contain the dust cloud near the headgate and tailgate drum areas. Each shield was equipped with one or two rows of two sprays located near the tip of the shield. The sequencing of when the sprays were activated and deactivated was mine-specific. Proper sequencing of shield sprays is critical for these sprays or a negative impact on controlling dust level may occur as observed during the surveys. Shield sprays interacted with the upwind splitter arm sprays, creating turbulence that resulted in a dust and mist cloud rolling into the walkway.

Longwall dust concentrations

Table 1 summarizes gravimetric dust concentrations from both the stationary and mobile sampling locations. The minimum, average and maximum dust levels for mobile and stationary sampling locations along with shield dust are shown in Fig. 1. Intake dust levels averaged 0.20 mg/m^3, with 70% of the longwalls below 0.25 mg/m^3. Six of the longwall faces utilized belt air to supplement the intake air on the longwall face. Dust levels ranged between 0.30 mg/m^3 and 0.72 mg/m^3. The average dust concentrations from these two outby sources researching the stageloader area was 0.23 mg/m^3 and ranged between 0.03 mg/m^3 and 0.44 mg/m^3. The dust level monitored at shield 10 is a good indication of the dust entering the face from the stageloader/crusher along with outby sources from the intake and belt. Average dust concentration found at shield 10 was 0.70 mg/m^3. The difference between shield 10 dust levels and the outby dust sources is primarily dust generated by the stageloader-crusher unit. On average, the amount of dust that can be attributed to the stageloader/crusher was 0.47 mg/m^3.

A good indication of the amount of total dust generated

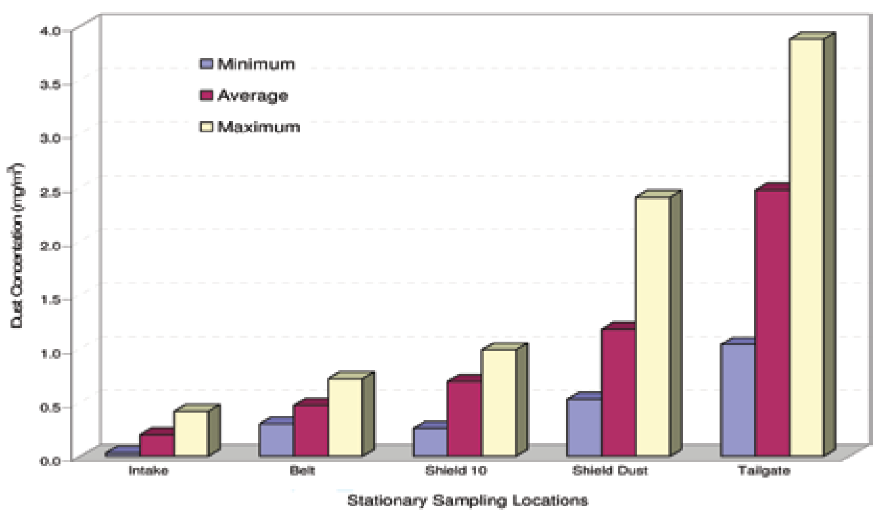
Table 1

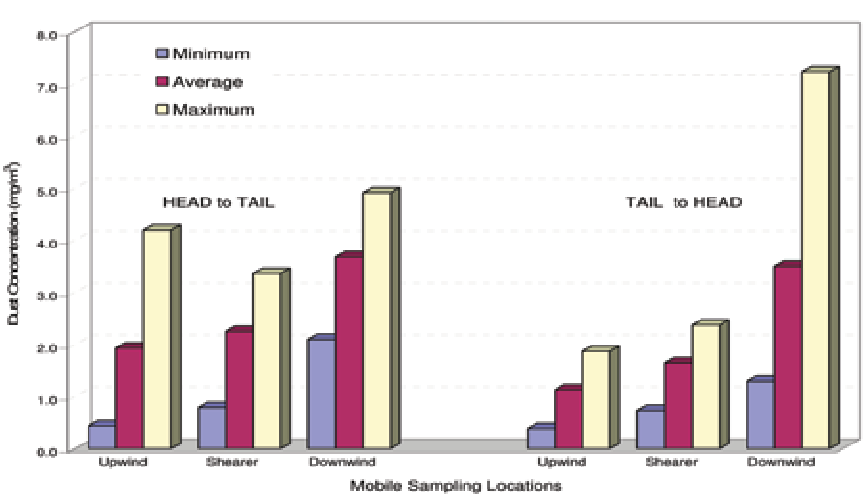
Summary of average gravimetric dust concentration for stationary and mobile sampling locations (mg/m³).

Mine	Intake	Belt	Shield 10	Upwind		Shearer		Downwind		Tailgate
				H to T	T to H	H to T	T to H	H to T	T to H	
A	0.18	NA	0.80	2.68	1.50	2.23	1.68	4.03	4.35	2.36
B	0.22	0.35	0.78	4.19	1.53	3.36	1.42	4.91	1.57	3.88
C	0.34	0.55	0.99	1.33	1.53	1.94	2.37	4.30	7.23	3.80
D	0.16	0.42	0.91	1.96	1.87	2.15	2.29	3.56	2.91	2.21
E	0.03	NA	0.26	0.43	0.43	2.27	1.59	4.26	6.24	3.16
F	0.17	NA	0.48	2.96	0.81	2.12	1.08	2.46	2.98	1.04
G	0.04	NA	0.26	0.84	0.38	0.79	0.73	NA	NA	2.33
H	0.26	0.30	0.86	1.05	1.30	3.09	2.29	3.92	2.45	1.72
I	0.42	0.50	0.89	2.42	1.15	3.17	1.44	3.56	1.29	1.91
J	0.20	0.72	0.72	1.42	0.80	1.35	1.60	2.10	2.51	2.34

Figure 1

Range of dust levels measured for stationary and mobile sampling locations.





along the face was monitored at the tailgate sampling location. Dust levels ranged between 1.04 mg/m³ to 3.88 mg/m³ and averaged 2.48 mg/m³. Overall dust levels were below 2.5 mg/m³ for 7 of the 10 longwalls. Shield dust could only be isolated on half of the longwall faces, due to either shield movement occurring downwind of the shearer or adverse roof conditions, where shield advances were random and unpredictable. Average dust generation attributed to shield movement was 1.18 mg/m³.

Comparing dust levels at shield 10 with the upwind samples from the tail-to-head passes showed an increase of 0.43 mg/m³ near the shearer. Dust liberated by face spalls, from the face conveyor and dust migrating from the gob may be causing the increase in dust levels. As air velocities increase, it is important to ensure that sufficient wetting of the coal is provided to minimize the potential of increased entrainment with the higher air velocities.

An assessment of the dust levels when shields were advanced outby the shearer com-

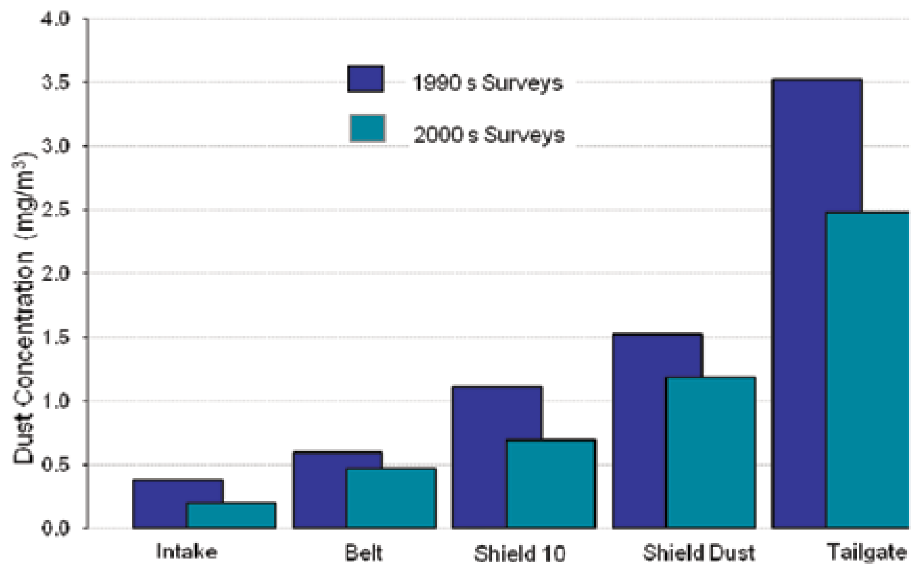
Table 2

Comparison of dust levels when shields were advanced upwind of the shearer vs. downwind.

	Shield movement outby shearer (mg/m³)					
	Head-to-tail			Tail-to-head		
	Upwind	Shearer	Downwind	Upwind	Shearer	Downwind
Minimum	0.43	0.79	2.46	0.38	0.73	1.29
Average	2.17	2.40	3.81	1.12	1.57	3.11
Maximum	4.19	3.36	4.91	1.87	2.29	6.24
	Shield movement inby shearer (mg/m³)					
	Head-to-tail			**Tail-to-head**		
	Upwind	**Shearer**	**Downwind**	**Upwind**	**Shearer**	**Downwind**
Minimum	1.33	1.35	2.10	0.80	1.60	2.51
Average	1.38	1.65	3.20	1.17	1.99	4.87
Maximum	1.42	1.94	4.30	1.53	2.37	7.23

Figure 2

Comparison of average dust concentration for stationary sampling locations and shield dust from the 1990s and 2000s surveys.

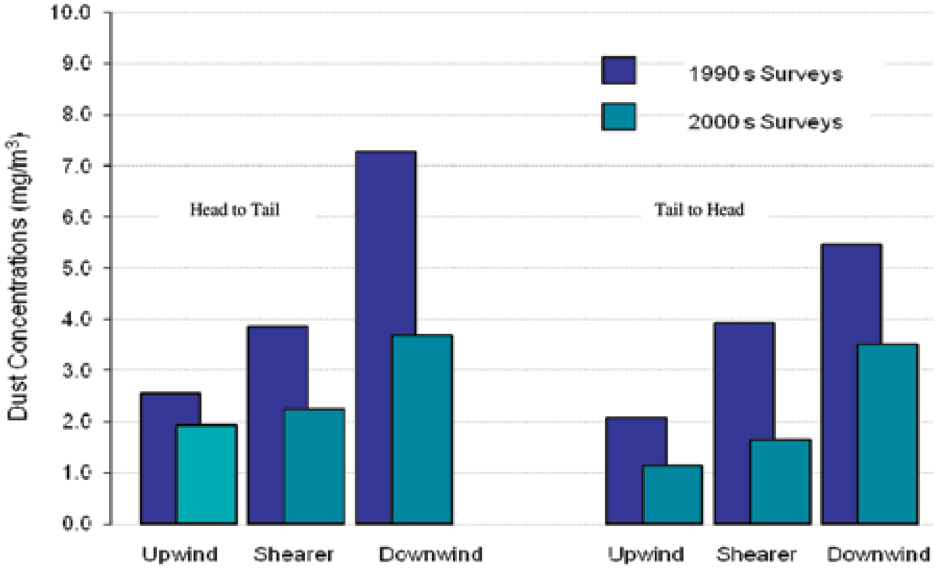


pared to shields movement inby the shearer is shown in Table 2. A prominent increase in dust levels occurred at the upwind and shearer sampling locations on head-to-tail cuts when shields were advanced outby the shearer. This result supports the hypothesis that much of the dust liberated during head-to-tail passes is generated by advancing shields. On the recently completed surveys, shields were shearer activated and advanced between two and five shields outby the headgate drum. These advancing shields are the only major dust generation source between the stageloader-crusher unit and the shearer on head-to-tail cuts. A good indication of the amount of dust attributed to shield movement is to compare head-to-tail upwind samples when shields were activated upwind of the shearer with tail-to-head upwind samples. The tail-to-head samples include dust generated by face spalling and conveyor dust and are a good indicator of dust levels outby the advancing shields. Evaluating these upwind sampling locations showed a substantial increase of 1.05 mg/m³ that may be directly attributed to fugitive dust generated by advancing shields. Also, a comparison of head-to-tail upwind samples from shield movement outby and inby the shearer showed an increase of 0.79 mg/m³.

The difference in average dust levels between the upwind and shearer sampling position isolates the dust generated by

Figure 3

Comparison of average dust concentration for mobile sampling locations from the 1990s and 2000s surveys.



the headgate drum. Increases of 0.32 mg/m^3 and 0.52 mg/m^3 occurred for head-to-tail and tail-to-head cuts, respectively. During tail-to-head cuts, the headgate drum is the primary cutting drum, which resulted in a 0.20 mg/m^3 increase in dust levels compared to the dust levels from the headgate drum on cleaning passes. On tail-to-head passes, the cutting drum is exposed directly to the airflow, which may result in increased turbulence and the potential to elevate dust levels. Calculating dust levels generated by the shearer is accomplished by subtracting the upwind sampling concentrations from the downwind concentrations. Average shearer-generated dust was found to be 1.75 mg/m^3 when mining headgate to tailgate. Identifying shearer dust for tail-to-head passes could not be performed because of the close proximity of the shield movement to tailgate drum. Dust samples locations varied between inby and outby advancing shields; consequently, shield dust could not be separated out of some of the downwind samples. As expected, downwind dust levels were approximately 1.1 mg/m^3 higher than the dust measured at the tailgate sampling location. Downwind dust levels represent dust generated during mining, while the tailgate samples include dust levels for the entire sampling period, including downtime.

Discussion

Figure 2 compares average dust levels at the stationary sampling locations and shield dust with the survey data from the 1990s study (Colinet et al., 1997). Reductions in dust levels ranged between 20% and 47%. A significant reduction, 47%, in intake dust levels and reduced dust levels on the face may be attributed to a 22% increase in air velocity on the face observed in the recently conducted surveys compared to 1990s surveys. Past research efforts (Jankowski and Colinet, 2000) have shown that higher velocities provide greater quantities of air to the face for better dilution of intake dust, as well as dust generated during support movements. A 37% reduction in dust levels at the shield 10 sampling location is a good indication that the enclosed stageloader-crusher units with installed water sprays systems and scrubbers have had a positive impact at reducing face workers' dust exposure levels.

An evaluation of the average dust levels at mobile sampling locations for the surveys conducted in the 1990s and the recently completed surveys is shown in Fig. 3. Substantial reductions have occurred at all three sampling locations for both cutting directions. A greater-than 22% increase in air velocity and air volume on longwall faces in the current survey results, along with much improved directional spray systems, had a positive effect at reducing face dust levels. Upwind dust levels were reduced between 24% and 45%. Although a reduction was seen at head-to-tail upwind and shearer sampling locations, these dust levels may be influenced by the number of operations performing bidirectional cuts, the close proximity to the shearer shield movement is occurring and the increase in the number of shields activated per shift. Past research (Tomb et al., 1992) has shown that higher air velocities provide better dilution of fugitive dust. If roof conditions allow, advancing shields as far outby the shearer as possible when mining toward the tailgate may allow for better dilution of the shield-generated dust and may lower dust levels for the shearer operators. A 58% reduction in dust levels can be seen at the shearer sampling location for tail-to-head cuts when comparing surveys from 1990 and the current surveys. Reductions of 45% and 39% were realized at the downwind sampling position, once again confirming that an increase in air and much improved directional spray systems had a positive effect on lowering longwall face dust levels.

Identifying the contribution level of respirable dust sources was accomplished by calculating the difference between dust levels immediately upwind and downwind of the known source. As in previous surveys, dust contributions from the shearer, shield movement, intake and stageloader-crusher were used to calculate the percentage of dust attributed to each source. Pass times calculated from time study data collected at each mine were used to weight the contribution of each source. For example, if 55% of the total time to complete a pass across the face can be attributed to the

Figure 4

Average dust contributions from major dust sources from the 2000s surveys.

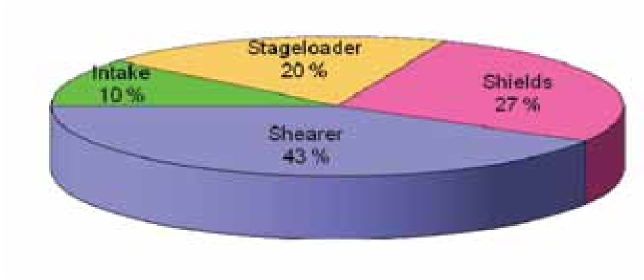
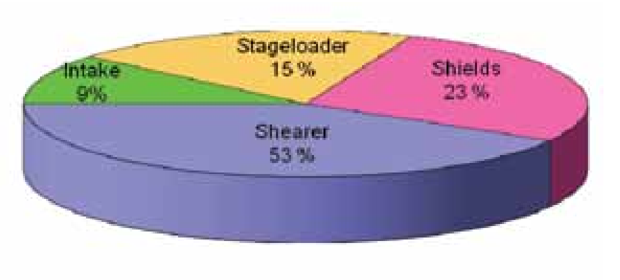


Figure 5

Average dust contributions from major dust sources from the 1990s surveys.



tail-to-head pass, then tail-to-head shearer dust levels would receive a weighting of 55%, while head-to-tail shearer dust along with shield dust would receive a 45% weighting. Contribution levels from the surveys where shield and shearer data was collected are displayed in Fig. 4. The percentage of dust contributed by the shearer was 43% and remained the largest source of dust on the face but decreased by 10% when compared to the source contribution data (Fig. 5) from the 1990s study. Improved directional spray systems coupled with higher face velocities have resulted in keeping fugitive dust close to the face and out of the walkway.

Higher production levels, along with a 39% increase in the width of longwall panels, have resulted in a dramatic increase in the number of shields advanced and the amount of coal passing through the stageloader crusher, as seen by the increased potential for dust exposure from shield and stageloader sources.

Significant increases in coal extraction rates have occurred over the last 10 years and, consequently, the potential to liberate respirable dust is much greater. Mine operators have made substantial strides in the application of dust control technology. Although average shift production rates rose approximately 53%, dramatic reductions in average dust levels, between 20% and 58%, were realized at each face sampling location when dust levels were compared to the 1990s study. Significant increases in both face air velocity and quantity, along with a vastly improved directional spray system, help create an envelope of clean air in the walkway around the shearer, resulting in lower dust levels. ■

Disclosure

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

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