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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 percent of all underground output in the U.S., and today longwall mines account for approximately 50 percent of coal produced underground in the United States. A 53 percent increase in average shift production rates has occurred over the last fifteen years. This increased longwall productivity has meant that far more dust is being produced and controlling respirable coal dust provides an ongoing challenge for coal mine operators. The National Institute for Occupational Safety and Health (NIOSH) has completed 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 dust generation from major sources on the longwall section and to determine the relative effectiveness of the different control technologies in use today. Substantial reductions in dust levels were realized at sampling locations on the face when compared longwall surveys conduct in the 1990's. This paper summarizes the results from the underground dust surveys and discusses current longwall dust control technology and operating practices.

Introduction

The longwall mining industry has seen remarkable and significant improvements in longwall mining equipment and mining practices over the last several years. Average shift production has increased from 3,600 tons per shift in 1994 to approximately 5,500 tons 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 (1043 ft) with one longwall operation reporting a face width of 549 m (1800 ft) compared to an average of 229 m (750 ft) in 1994 (Fiscor, 2009). Panel lengths in 2008 averaged 3276 m (10,749 ft) compared to 2134 m (7000 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 horsepower installed on the shearer is 1589 hp compared to 1260 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 176 million tons mined (Energy Information Administration 2008). These production rates continue to challenge dust control efforts of the industry.

Medical studies have shown that prolonged exposure to excessive levels of airborne respirable coal dust can lead to coal workers' pneumoconiosis (CWP), progressive massive fibrosis (PMF), and chronic obstructive pulmonary disease (COPD). These diseases are irreversible and can be debilitating, progressive, and potentially fatal. Coal workers' pneumoconiosis contributed to the deaths of 69,377 miners during the period of 1970 through 2004 (NIOSH 2008). Over 39 billion dollars in CWP benefits have been paid to miners and their families covering a 25-year period ending in 2005. Today, pneumoconiosis continues to be a very serious health threat to underground coal mine workers. Recent x-ray surveillance data has uncovered cases of rapidly progressing CWP and also revealed an upturn in the prevalence rate (CDC 2006).

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 5-year period ending in 2008, valid compliance sampling for longwall designated occupations or high-risk occupations, taken by mine operators and MSHA inspectors, indicated that 11percent of the samples exceeded 2.1 mg/m3 (Niewiadomski 2009). In addition, MSHA inspector sampling results for the same 5-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) that were subject to reduced dust standards due to silica levels, 31 percent and 21 percent of the samples, respectively, exceeded the reduced standard (MSHA 2009).

The continued occurrence of CWP in underground coal mine workers and the magnitude of respirable dust overexposures in longwall mining occupations illustrate the need for NIOSH and the mining industry to improve existing dust control technology on longwalls. NIOSH researchers recently completed a research effort to quantify and document dust levels being generated by various sources on longwall faces and to identify and document the effectiveness of control technology in use.

Sampling Methodology

Gravimetric dust samplers, identical to those used in compliance sampling, were operated at 2 liters/minute in conjunction with 10-mm 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 4 to 6 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 where 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 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, 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 pre-weighed 37-mm 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 on 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 utilized to monitor dust levels for tail-to-head passes. If the shearer was stopped for an extended period (approximately 3 minutes or longer), 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 utilizing 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 hand-held anemometers at 10-shield intervals down the face. These measurements were one-minute readings taken approximately .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 percent of the active longwall faces 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 5 longwalls were surveyed in western states. Seven of the mines utilized a bi-directional cutting sequence and 3 were taking uni-directional 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 1000 ft).

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 22 percent (0.71 m/sec (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 then 3.0 m/sec (600 ft/min), and two mines averaged over 4.1 m/sec (800 ft/min). Average air quantities increased approximately 37 percent when compared to the mid-1990 longwall study. The average volume of along the face was approximately 30.7 m^3/sec (65,100 ft^3/min), with a range between 24.3 to 39.1 m^3/sec (51,600 to 83,000 ft^3/min). Air quantity observed for seven of the longwalls was greater than 30.2 m^3/sec (64,000 ft^3/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 492.0 liters/minute (130 gpm) 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 1034.2 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 arms with directional water sprays were observed on 90 percent 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 sprays. Thirty percent the surveyed longwalls utilized venturi sprays which were mounted on top of the splitter arm and operated with spray pressures in excess of 1551.3 kPa (225 psi). Average spray pressures were approximately 689.5 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 length of the extension arms ranged between 45.7 to 61.0 cm (18 to 24 inches) 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 inches) above the shearer body. Sprays were oriented downwind toward the face, roof, or floor. Deflector or sloughing plates were observed at 80 percent 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 4 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 1990's longwall surveys (Colinet et al. 1997). Tailgate-side splitter arms were observed on 20 percent 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 Figure 1. Intake dust levels averaged 0.20 mg/m^3 with 70 percent 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 reaching 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 along the face was monitored at the tailgate sampling location. Dust levels ranged between 1.04 mg/m^3 to 3.88 mg/m^3 and averaged 2.48 mg/m^3. Overall dust levels were below 2.50 mg/m^3 for 7 of the 10 longwalls. Shield dust could only be isolated on half of the longwall faces because of 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/m^3.

Comparing dust levels at shield 10 with the upwind samples from the tail-to-head passes showed an increase of 0.43 mg/m^3 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 compared 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 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 2 and 5 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/m^3 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/m^3.

Table 1. Summary of average gravimetric dust concentrations for stationary and mobile sampling locations (mg/m^3).

Mine Identifier	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

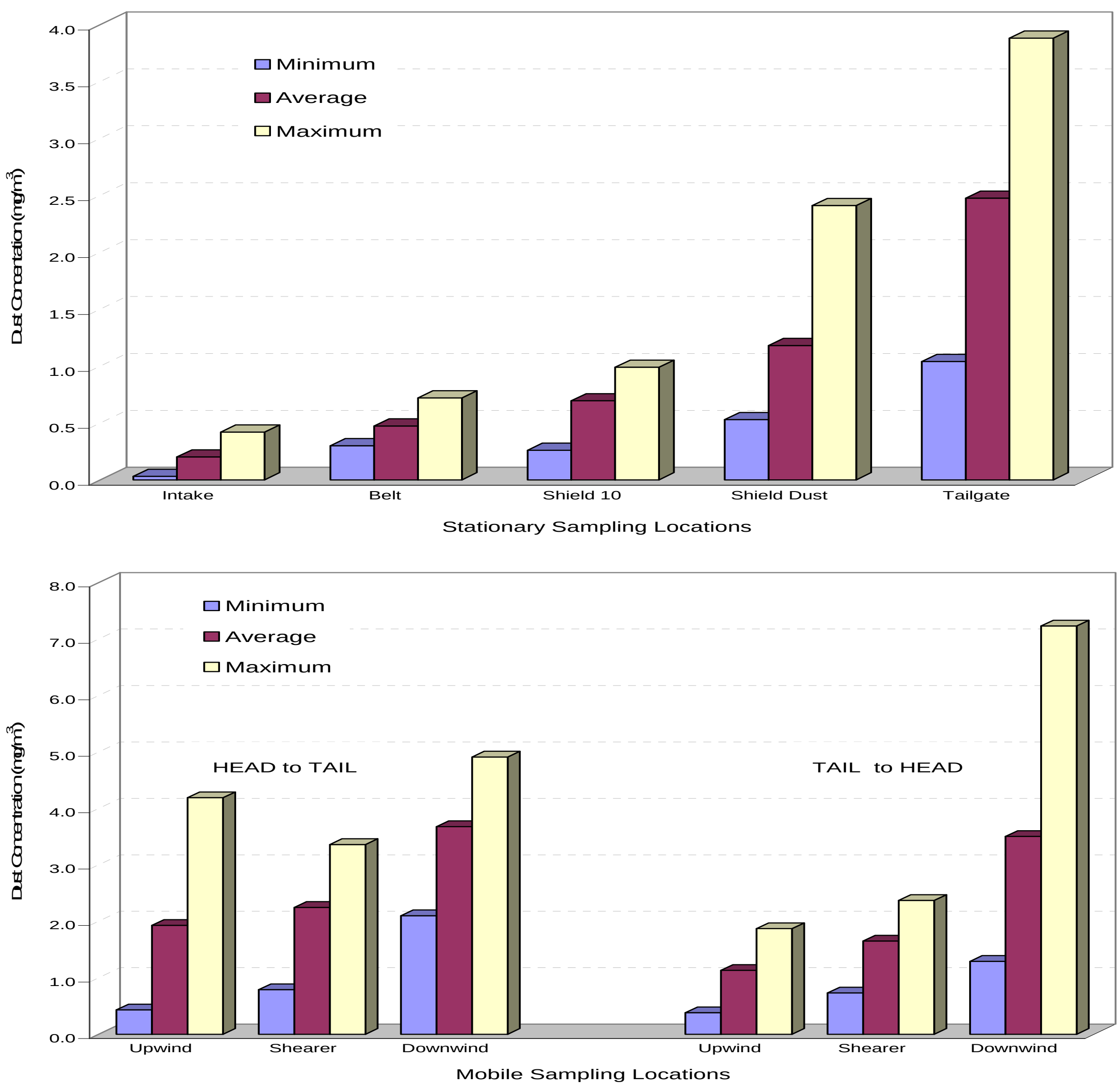

Figure 1. Range of dust levels measured for stationary and mobile sampling locations.

Table 2. Comparison of dust levels when shields were advanced upwind of the shearer vs downwind.

Shield movement outby shearer (mg/m^3)

	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/m^3)

	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

The difference in average dust levels between the upwind and shearer sampling position isolates the dust generated by 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 1990's study (Colinet et al. 1997). Reductions in dust levels ranged between 20 and 47 percent. A significant reduction of 47 percent in intake dust levels and reduced dust levels on the face may be aided by a 22 percent increase in air velocity on the face observed in the recently surveys compared to 1990's 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 percent 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 worker's dust exposures levels.

A comparison of average dust levels at mobile sampling locations for the surveys conducted in the 1990's and the recently completed surveys is shown in Figure 3. Substantial reductions have occurred at all three sampling locations for both cutting directions. Greater than a 22 percent increase in air velocity and air volume on longwall faces in the 2000 surveys along with much improved directional sprays systems had a positive effect at reducing face dust levels. Upwind dust levels were reduced between 24 and 45 percent. 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 bi-directional cuts, the close proximity to the shearer that shield movement is occurring, and the increase in the number of shields advanced 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

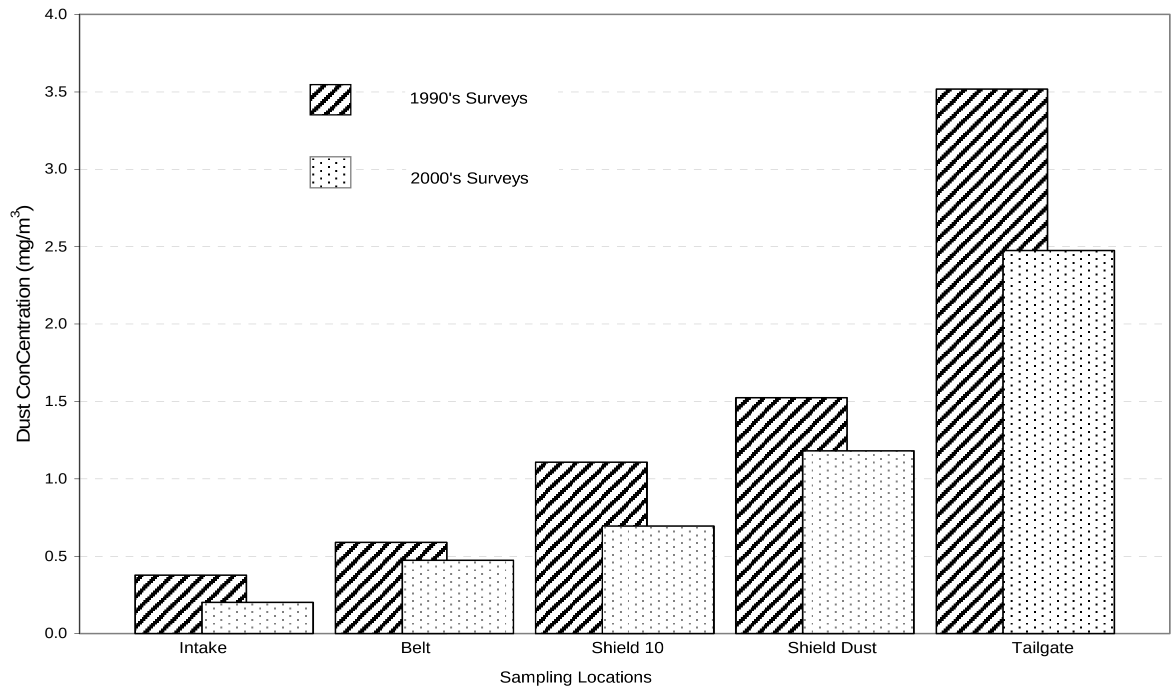

Figure 2. Comparison of average dust concentration for stationary sampling locations and shield dust from the 1990's and 2000's surveys.

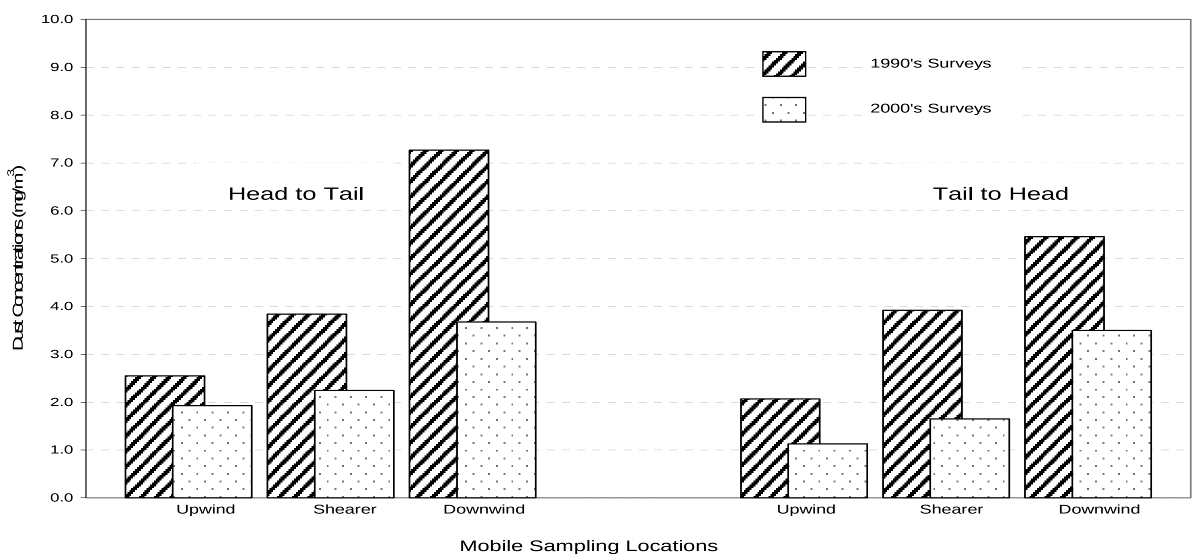

Figure 3. Comparison of average dust concentration for mobile sampling locations from the 1990's and 2000's surveys.

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 occurred at the shearer sampling location for tail-to-head cuts when comparing survey data from 1990 and 2000. Reductions of 45 and 39 percent were realized at the downwind sampling position, once again confirming that 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 percent of the total time to complete a pass across the face can be attributed to the tail-to-head pass then tail-to-head shearer dust levels would receive a weighting of 55 percent while head-to-tail shearer dust along with shield dust would receive a 45 percent weighting. Contributions levels from the surveys where shield and shearer data was collected are displayed in Figure 4. The percentage of dust contributed by the shearer was 43 percent and remained the largest source of dust on the face but decreased by 10 percent when compared to the source contribution data (Figure 5) from 1990's study. Improved directional sprays systems coupled with higher face velocities have resulted in keeping fugitive close to the face and out of the walkway.

Higher production levels along with a 39 percent increase in the width of longwall panels have resulted in a dramatic increase the number of shields advanced and the amount of coal passing through the stageloader crusher as seen with increased the potential of 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 more 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 percent, dramatic reductions in average dust levels between 20 and 58 percent were realized at each face sampling location when dust levels were compared to the 1990's study. Substantial increases in both face air velocity and quantity along with improved directional spray systems help create an envelope of clean air in the walkway around the shearer resulting in lower dust levels.

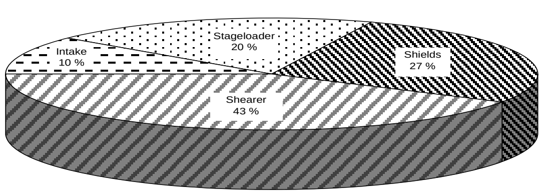

Figure 4. Average dust contributions from major dust sources from the 2000's surveys.

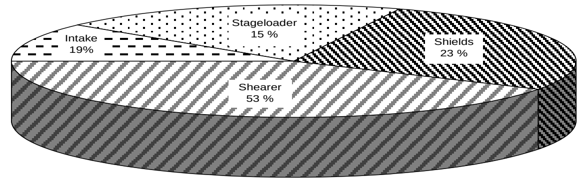

Figure 5. Average dust contributions from major dust sources from the 1990's surveys

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