Impact of air velocity and support advance on shield-generated dust

G.J. CHEKAN, J.P. RIDER, J.M. LISTAK,
J.F. COLINET AND J.D. POTTS

G.J. Chekan, J.P. Rider, member SME, **J.M. Listak, J.F. Colinet,** member SME, and **J.D. Potts** are lead research engineer, acting team leader, lead research engineer, acting branch chief and research engineer, with the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh, PA.

Abstract

Steady increases in longwall production have required operators to apply greater quantities of ventilating air in an effort to control and dilute respirable dust. Significant increases in shearer speeds necessitate that longwall supports also be advanced at a faster rate. Both of these factors may contribute to overall respirable dust levels on the longwall face because as supports are lowered and advanced, broken material falling from the top of the canopy is entrained directly into the air stream. To address this issue, the Pittsburgh Research Laboratory collected respirable dust samples from four longwall faces to characterize shield-generated dust. This paper investigates the influence of air velocity and shield advance rates on respirable dust levels. Also discussed are engineering controls currently used to reduce shield dust and alternative controls being investigated by the National Institute for Occupational Safety and Health (NIOSH).

Introduction

Reducing respirable dust levels on longwalls through the development of engineering controls remains a primary health concern for the National Institute for Occupational Safety and Heatlh (NIOSH), industry, regulators and university researchers. NIOSH researchers from the Pittsburgh Research Laboratory conducted longwall dust surveys in an effort to better understand the influence of both air velocity and support advance on shield-generated respirable dust. Ultimately, this research will lead to lowering worker exposure to respirable coal and silica dust.

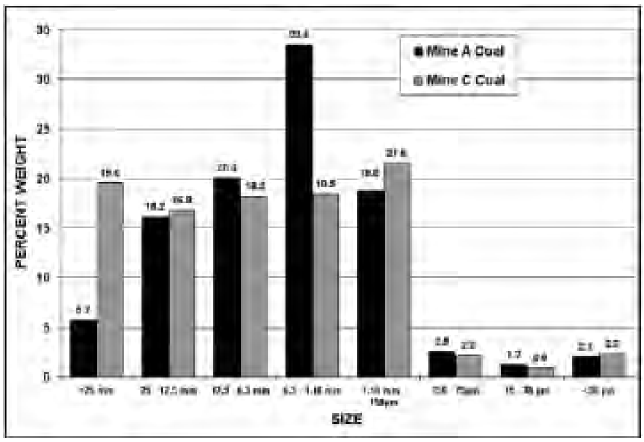
Increased production has put a greater demand on longwall dust control systems as operators have had difficulty maintaining consistent compliance with federal dust standards. During the five-year period 2000-2004, analysis of mine operator and U.S. Mine Safety and Health Administration (MSHA) inspector samples shows that the percentage of these samples exceeding 2.1 mg/m^3 (the level at which a citation is issued) was 14% and 15%, respectively (Niewiadomski, 2004).

Dust control technology employs both air and water as a means to limit, direct and eliminate respirable dust. Historically, longwall dust control research focused on reducing dust generated by the two largest sources: the shearer and stageloader. Increasing air velocity on the face is a fundamental control used to dilute dust generated by these sources. A minimum longwall face air velocity of 2 to 2.3 m/s (6.5 to 7.5 ft/sec) is recommended for proper dilution of dust along the face (Foster-Miller Assc., 1982; Breuer, 1972). A research study conducted during the1980s found that face air velocities ranged from 0.6 to 3.3 m/s (2 to 11 ft/sec), while average production was 735 t/shift (810 st/shift) (Jankowski and Organiscak, 1983). The shearer and stageloader combined accounted for 82% of the total respirable dust generated. A second study during the 1990s showed that the range of air velocities increased to 1 to 7.6 m/s (3.3 to 25 ft/sec), while the average production increased nearly four-fold to 2,885 t/shift (3,180 st/shift) (Niewiadomski, 2004). Despite increased production, the total dust contribution of the shearer and stageloader decreased to 68% as a result of improved dust control measures. Increased ventilation, improved water spray application at the shearer and enclosing the stageloader and adding water sprays were the primary modifications that led to this reduction (Colinet and Jankowski, 1997).

Despite the above advances in dust control, due to faster shearer speeds or the presence of methane gas, higher air velocities are often required for dilution. Past studies (Hall, 1956; Hodkinson, 1960) have shown that, for low moisture coals, velocities in excess of about 2.3 m/s (7.5 ft/sec) can increase dust levels. More recent studies (Tomb et al., 1991; Breuer, 1972) have shown that with adequate moisture on the coal, such as that provided by sprays, airflow may be increased beyond 5.1 m/s (16.7 ft/sec), without significantly increasing the dust levels on the face. In these studies, the shearer and stageloader were being shielded from the face airflow by physical barriers, and/or water spray systems were being used to increase moisture and promote particle agglomeration. Dust sampling on these longwalls clearly indicates that if moisture content is adequate, increasing air velocity does

FIGURE 1

Percent weight distribution by size for coal samples collected from shield canopy at mines A and C.



not promote dust generation from controlled sources, such as the shearer or stageloader.

Studies conducted by the U.S. Bureau of Mines in the 1980s investigated support-generated dust as it related to geology, support design and cutting sequence (Organiscak et al., 1985). The studies found a correlation between support-generated dust and the geology of the immediate roof strata. Studies conducted during the early 1990s showed that shield dust was a significant contributor to the total dust generated from all sources (Colinet et al., 1997, Colinet and Jankowski, 1997). Dust attributed to shield movement almost doubled from 12% in the 1980s to 23% in the 1990s. NIOSH studies show that the primary factors responsible for this increase are most likely a combination of higher production and lack of effective control technology for shield dust (Rider and Colinet, 2006). Higher production rates have led to increased shearer speeds, which requires that shields be moved faster and in greater numbers. As shield supports are lowered and advanced, broken coal and/or rock falls from the top of the shield canopy and is being introduced directly into the air stream ventilating the longwall face. Also, the amount of air required to ventilate longwall faces continues to trend upward (Rider and Colinet, 2006). This has the potential to entrain greater quantities of respirable dust during shield advance under certain conditions. Further complicating the issue, most longwall operations utilize a bi-directional cutting sequence. When mining from headgate to tailgate, shield movement upwind of the shearer also contributes to dust exposure of the shearer operators. In mines where roof rock is the main component on the shield canopy, the entrainment of respirable silica dust becomes more of an issue, since the quartz component of rock is the primary contributor to silica dust generation (Ramani et al., 1987).

In laboratory studies, NIOSH conducted tests using a wind tunnel to study the basic behavior of dust dropped into an airstream under varying air velocities (Listak et al. 2001; Chekan et al., 2001; Chekan et al., 2004). The studies were designed to determine dust concentration as it relates to increasing both the air velocity and the shield rate of advance. Results from these laboratory tests showed two fundamental relationships for low moisture coals (<1%): 1) increasing the air velocity increases airborne dust concentrations and 2) increasing the rate at which respirable dust is introduced into the airstream (faster shield advance rate) also increases airborne dust concentrations.

Tests in the wind tunnel were conducted at air velocities of 2 m/s, 4.1 m/s, 6.1 m/s and 8.1 m/s (0.6 ft/s, 1.2 ft/s, 1.8 ft/s and 2.5 ft/s). Respirable dust concentrations increased as air velocity increased in a linear relationship, indicating that particle entrainment was greater than dilution effects. Respirable dust concentrations increased from 1.47 mg/m^3 at 2.0 m/s (0.6 ft/s) to 19.84 mg/m^3 at 8.1 m/s (2.5 ft/s). Statistical analysis of the concentrations measured at each velocity resulted in significant differences at a 95% confidence interval. Analysis of the size distribution of the sampled dust showed an inverse relationship between velocity and mass median diameter of the dust. As velocity increased, the mass median diameter of the entrained dust particles decreased in a near linear manner. The mass median diameter was found to be 10.8 microns at 2.0 m/s (400 fpm) and decreased to 7.7 microns at 8.1 m/s (1,600 fpm). Higher concentrations and finer particle size distributions suggest that at a moisture content of approximately 1, a portion of the dust particles were adhering to each other at the 2.0 m/s (400 fpm) velocity. As the velocity increases, the adhering forces are overcome by the increased energy supplied to the system, resulting in higher concentrations and smaller particle sizes in the airstream. Although the particle size decreased with increased velocity, dilution was not observed in any of the tests. In summary, the tests showed that adhesion of respirable dust to larger material and to other respirable particles plays an important role in determining the fraction of airborne dust that is measured as respirable.

To further investigate the relationships from these laboratory studies, a research effort was conducted in the field to characterize shield generated dust at four longwall mines. The longwall surveys would help ascertain if shield dust generation may be influenced by face air velocity and/or the rate of shield advance.

Shield-dust size characterization from bulk samples

Shield-generated dust differs from mining-gener-

FIGURE 2

Percent weight distribution by size for rock samples collected from shield canopy at mines A and C.

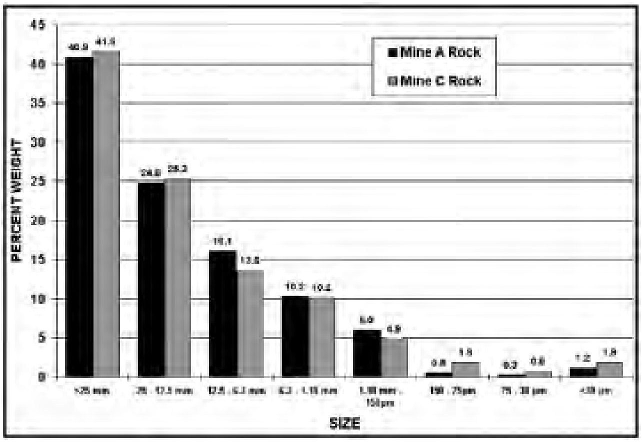


Table 1

Site specific information for each mine.

Mine	Location	Shearer	Survey No. of head to tail passes	No. of shields on face in minutes	Survey avg. shearer pass advanced/min.	Avg. No. of shields time	Survey avg. air velocity m/s
A	Eastern	Bi-directional	6	185	27.5	6.7	1.7
B	Western	Uni-directional	5	129	14.0	9.2	2.3
C	Eastern	Bi-directional	4	156	30.0	5.2	3.4
D	Eastern	Bi-directional	8	160	31.5	5.1	4.2

ated dust in that the fracture mechanism can be best described as a repeated crushing of the material on the canopy as the shields are continually lowered and reset. To better characterize the coarse and fine material on top of the canopy, bulk samples were collected at two of the four survey mines, mines A and C. Four coal samples and four rock samples, ranging in weight from 13.6 to 18.2 kg (30 to 20 lb), were collected separately from the top of the shield supports at each mine.

Sieve analysis was used to size the coarse material in eight different size fractions ranging from >25 mm to <38 µm. Figures 1 and 2 show the results as a percent weight of the total sample for both the coal and rock, respectively. The results show that for coal, more than half the sample by weight fractured primarily in the medium sizes, ranging from 12.5 mm to 150 µm. Mine A had 72.2% and Mine C had 58.2% of the coal sample in this range. Conversely, for rock, more than half the sample fractured in the two largest sizes, ranging from >25 mm to 12.5 mm at 65.7% and 67% for Mines A and C, respectively. As expected, coal, being the softer material, tended to fracture into a smaller size range from repeated shield crushing as compared to the rock.

Light-scattering analysis was used to determine the respirable fraction (<10 µm) of the remaining product <38 µm in size. As shown in Figs. 1 and 2, this component averaged 2.2% for the coal samples and 1.5% for the rock samples. Analysis of this material shows that for both coal and rock, respirable dust was a small percentage of the total sample weight. Respirable dust averaged 41% of the remaining product <38 µm and as a result, made up less than 1% of the total material on the canopy by weight.

Although shield dust is generated by a crushing mechanism, these results are similar to results from other studies that measured the amount of respirable dust in run-of-mine coal. Studies in continuous mining operations show that for typical run-of-mine product, approximately 0.5 to 1.0% of the sample by weight consists of respirable dust (Ramani et al., 1987; Cheng and Zukovich, 1973). These studies also showed that the amount of respirable dust that became airborne was related to moisture content. A significant portion (99.6%) of the respirable dust was agglomerating and adhering to the over-sized coal in the run-of-mine (ROM), primarily due to a high moisture content resulting from the large volumes of water used to suppress mining-generated dust. For shield dust, this may not be the case if canopy spray systems do not function properly. The lower moisture content may result in a higher percentage of the respirable dust becoming entrained into the airstream.

Sampling strategy

To sample shield-generated dust, surveys were conducted at longwall mines using mobile sampling. Mobile sampling involved the wearing of dust sampling instruments by several NIOSH personnel moving along the longwall face to isolate dust generation from shield advance or shearer cutting. To isolate shield-generated dust, NIOSH personnel would position themselves upwind and downwind of all shield movement during the head-to-tail pass only, so that dust generated by the shearer was downwind of both mobile sampling locations. However, on some longwall faces using shearer-activated shield advance, the shields typically were advanced within two shields of the headgate drum. When these conditions were present, shield dust samples could not be collected because shield dust could not be separated from shearer-generated dust.

Shield dust samples were obtained at four mines where sufficient distance was available to isolate shield advance. One person was located directly upwind of shield advance. The second person was located directly downwind of shield advance to collect shield dust samples before air dilution influenced the concentration. Shield dust is calculated as the difference in dust concentrations between position one (upwind of shield movement) and position two (downwind of shield movement).

Two types of instruments were used to collect dust samples. Marple cascade impactors were used to collect dust samples to determine the size distribution of dust particles (less than 50 µm) that become airborne during shield advance. These samples were collected from two of the four mines. The cascade impactor is a seven-

FIGURE 3

Percent weight distribution of airborne dust on impactor stages versus cut points in microns.

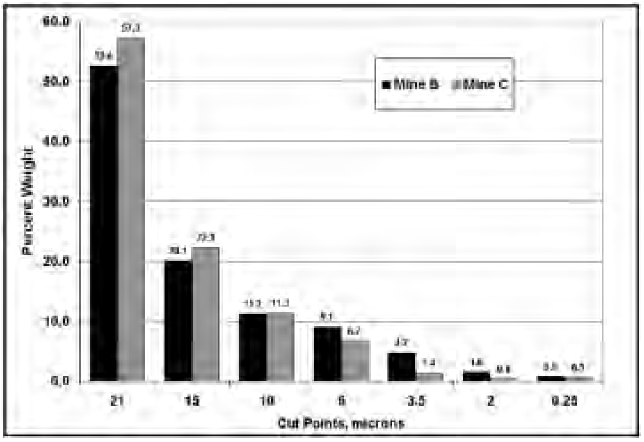
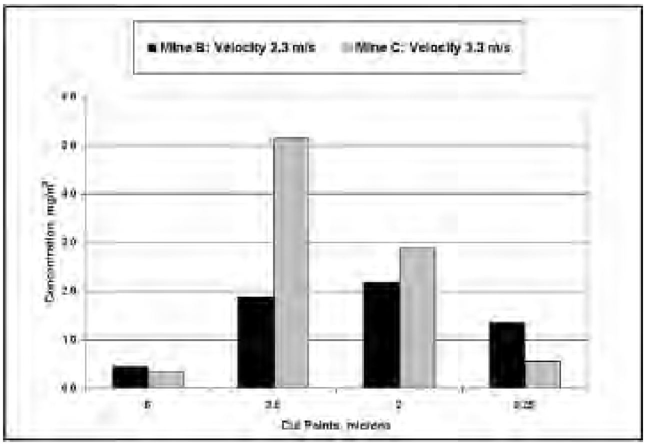


FIGURE 4

Impactor respirable dust concentrations calculated from final four stages.

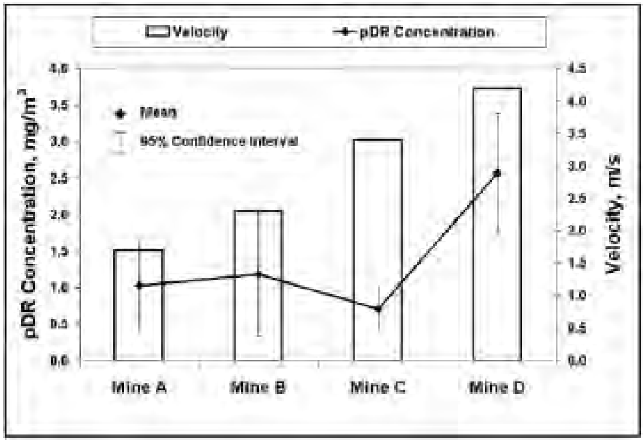


stage instrument that measures the size distribution of airborne particles and separates dust into aerodynamic sizes or cut points ranging from 21 to 0.025 µm. As dust-laden air is drawn into the instrument using a pump operated at 2 L/min (0.53 gpm), the aerosol stream moves with relatively low velocity over the upper stages and increases in velocity at each subsequent stage. The dust collection process is made possible through the use of mylar substrates on each of the instrument's stages. Those particles with higher inertia (larger particles) will "impact" the mylar substrate and be collected on the upper stages, whereas smaller particles will pass through the stage openings and be collected on the subsequent lower stages. The mylar substrates were coated with silicone grease to minimize particle bounce from one stage to the next.

The substrates are pre- and post-weighed to determine the mass distribution on each stage of the impactor. The amount of dust collected on each stage is based on the mass median diameter (MMD) of the particle. MMD gives an overall measure of the size distribution of the particles. Specifically, MMD is the particle size at which 50% of the particles are greater than the cut point and 50% of the particles are smaller than the cut point.

FIGURE 5

Average pDR concentration versus average air velocity at each mine.



The main sampling instrument used in all four longwall surveys was the Thermo-Fisher personal DataRAM (pDR). The pDR measures and records the concentration of respirable airborne particulate from 0.1 to 10 microns using a light-scattering technique. Light-scattering instruments offer only a relative measure of dust concentrations. However, the logged data was adjusted to a the gravimetric sampler concentration to correct each logged concentration value (Listak et al., 2007; Chekan et al., 2006). The pDR provides continuous record of particulate levels so that dust concentrations can be evaluated over any time interval during the sampling period. Using spreadsheet software, concentration data logged by the unit can be analyzed during the exact time of each head-to-tail pass. For all surveys, the pDRs were set to log concentrations at 10-second intervals.

During each sampling shift, 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 one foot above the spill plate of the face conveyor. Face velocity for each sampling day was calculated by averaging the 10-shield interval velocity readings. Table 1 summarizes site-specific information for each mine.

Results from cascade impactors

Impactor samples were collected at mines B and C. Figure 3 graphs the percent weight on the seven stages versus the cut points in microns. The graph shows that the size distribution of airborne particles is similar in trend for both mines. Averaging data from both mines, 87.4% of the dust by weight was 10 µm or greater. The respirable dust (<10 µm) constituted 12.6% of the sample. This size distribution is similar to results from other studies that have characterized airborne dust using cascade impactors from various sources in both longwall and continuous mining sections (Potts et al., 1990, Seixas et al., 1995). The MMD for Mine B and Mine C were 27.5 µm and 32.7 µm, respectively, which is in agreement with the findings by Potts et al. that the MMD of support-generated dust was usually greater than 21 µm.

Figure 4 graphs the respirable dust concentrations calculated for the final four stages. Concentrations are calculated using the sampling time, pump rate and the mass weight on that specific stage. The graph shows a trend in that the highest concentrations occur at the 3.5 and 2.0 micron range and concentration increases relative to velocity.

Results from personal DataRAM

Table 2 shows the pDR concentration, air velocity and number of shields moved per minute for each head-to-tail pass at each mine. Also shown are the mean, standard deviation and the 95% confidence interval using t-distribution for the pDR concentration. Average pDR concentrations ranged between 0.71 mg/m^3 to 2.57 mg/m^3 indicating that advancing shields are generating and entraining a significant amount of respirable dust in the walkway.

Figure 5 graphs the mean concentration from Table 2, versus the average air velocity for each mine from Table 1. Figure 5 shows that, except for mine C, higher air velocity tends to increase dust concentration. How-

Table 2

pDR concentration, air velocity and shield advance for each head-to-tail pass at each mine.

Mine	Head to tail pass	Shift	pDR concentration mg/m³	Velocity per shift m/s	No. of shields advanced/min.	pDR concentration mean	pDR concentration standard deviation	pDR concentration 95% confidence interval (+, -)
A	1	1	0.50	1.61	6.9	1.03	0.59	0.62
	2		0.39		6.6			
	3	2	1.44	1.94	7.7			
	4		0.88		7.4			
	5	3	1.02	1.60	6.2			
	6		1.94		6.0			
B	1	1	1.83	2.15	12.9	1.18	0.68	0.85
	2		1.35		9.9			
	3		0.45		9.9			
	4	2	1.81	2.46	9.9			
	5		0.48		6.1			
C	1	1	0.58	3.58	5.6	0.71	0.19	0.31
	2		0.51		6.0			
	3	2	0.87	3.18	5.1			
	4		0.88		4.9			
D	1	1	1.35	4.29	5.0	2.57	0.98	0.82
	2		1.11		5.0			
	3		2.90		5.0			
	4	2	3.57	3.91	5.5			
	5		3.96		5.7			
	6		2.75		5.5			
	7	3	2.48	4.52	5.0			
	8		2.42		4.2			

ever, Fig. 6 plots the average pDR concentration per shift versus the air velocity and illustrates that there is not a consistent trend in concentration as air velocity increases. Large variations in pDR concentrations were evident for the head-to-tail passes on each shift. A possible explanation for this variation could be that caving behind the shields in the gob may be causing spikes in the respirable dust concentrations.

Figure 7 graphs the mean concentration from Table 2, versus the average number of shields advanced for each mine, from Table 1. Based on the average shield movement for the particular mine, Fig. 7 shows that three of the four mines show a trend, as the number of shields advanced per minute increases, so does the concentration. The exception is mine D, which has the lowest rate of shield advance and the highest pDR concentration. However, Fig. 8 plots shield advance rates on a shift basis for each mine versus the pDR concentrations. Similar to velocity, the data reveals that there is not a consistent trend in concentration as shield advance rates increase. Once again, the variances in pDR concentrations could not be explained, but may be attributed to the geology of the roof strata.

Discussion of shield dust control

The majority of the dust liberated by shield movement was observed dropping off the canopy between the shields as they were lowered and advanced. Spring-actuated side plates were used to close the gap between shields and prevent material from the canopy from falling into the walkway. These are generally effective when the support is set; however a gap is created as the shield is lowered for advance. Most of the shield dust becomes entrained whenever the gap is created, as the material falls between the supports and directly into the airstream.

Shield spray systems have been used to wet the unconsolidated coal/rock on the tops of shields before it becomes exposed to ventilating air during shield advance. The primary dust control method, available on most shield supports, is a spray system that consists of

FIGURE 6

Average pDR dust concentrations versus increasing air velocity on a per shift basis.

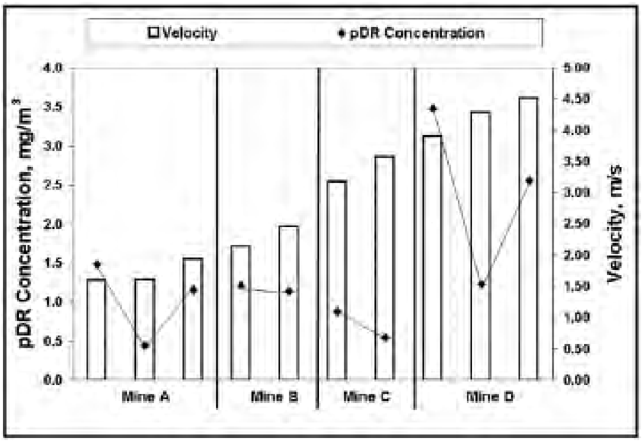
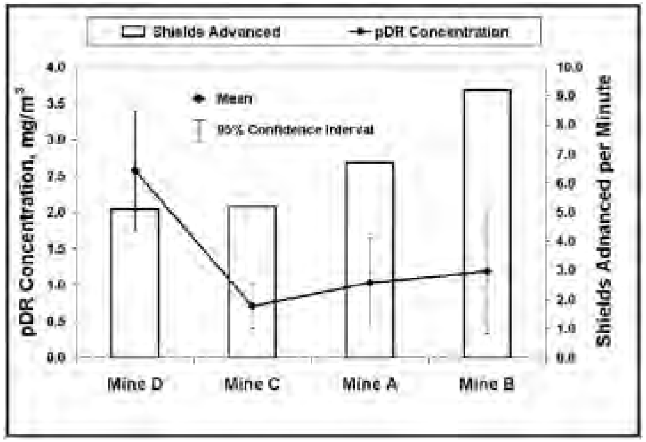


FIGURE 7

Average pDR concentration versus average number of shields moved per minute at each mine.

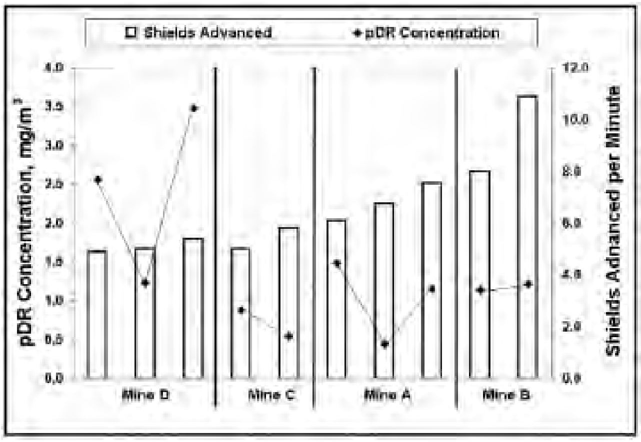


six to 10 sprays mounted on top of the canopy to add moisture to the material. The sprays are typically activated when the shield is lowered and advanced, with an operating pressure range from 350 to 2800 kPa and a flow rate of 9 to 28 L/min. Adding moisture can be an effective means of controlling dust, however, the effectiveness of these spray systems has not been documented. Factors that determine the effectiveness of these systems are the spray location, number, and spacing; how uniformly the sprays wet the material across the canopy; and how long these sprays operate as designed. As with all water spray systems, regular maintenance is imperative for proper performance, and some operators have expressed difficulty in maintaining the shield sprays through the life of a longwall panel because of their location. NIOSH is currently investigating a directional spray system in the laboratory that, if successful, will direct shield dust toward the face, away from the walkway airstream, and be located on the underside of the shield for easier maintenance.

A control technology investigated by the Bureau of Mines in the early 1990s involved a foam spray that would adhere to the roof in front of the support as it was lowered, advanced and reset. The foam would penetrate the broken material on top of the canopy, increasing its moisture content, thereby lowering support-generated dust. Initial studies were inconclusive due to slow shield advance in the mines where trials were conducted. With faster shield movement on longwalls today, this control may show more promise. A primary administrative control is dust avoidance. Operational changes such as unidirectional cutting may allow for greater flexibility to place workers upstream of the dust sources than bi-directional cutting. Depending on roof conditions, this may allow the operators to modify the cut sequence so that shields are only advanced downwind of the shearer. Activating the shields as close to the tailgate drum as possible and keeping the jacksetter upwind of the advancing shields may keep the worker in a clean air envelope created by the shearer's directional spray system and thus protect the worker from elevated dust levels.

FIGURE 8

Average pDR concentration versus increasing shield advance rate on a per shift basis.



Summary

Substantial gains in production have led to increasing levels of air and water usage to control dust generation from all longwall sources. Research and application of control technologies have focused on the shearer and stageloader/crusher, which were the two highest sources of respirable dust as characterized by a U.S. Bureau of Mines study in the 1980s. A similar study by the Bureau in the 1990s indicated that dust liberation during shield movement was beginning to emerge as a significant contributor to dust generation on longwalls. As shields are advanced, material drops off of the shield canopy directly into the airstream. Increases in shearer speed, have resulted in a greater numbers of shields being advanced at a faster rate and in closer proximity to the headgate shearer operator. The faster advance rate minimizes the time available to dilute dust prior to reaching the shearer operator on head-to-tail passes. This may elevate dust exposure associated with support-generated dust.

The intent of these field surveys was to record real-time dust levels using pDRs, directly downwind of shield movement, before shield dust concentrations were influenced by shearer-generated dust and/or the impact of dilution. Analysis of resulting data shows that both air velocity and frequency of shield movement have an effect on dust concentrations. However, data analysis suggests that the combined influence of both variables can raise or lower dust concentrations and neither variable appears to have a stronger effect than the other on dust levels. Laboratory research by NIOSH in a wind tunnel to study the fundamental relationship between air velocity and dust levels clearly indicates that increased air velocities have the potential to raise the level of airborne respirable dust (Listak et al. 2001, Chekan et al., 2001; Chekan et. al., 2004). The tests showed that regardless of the percentage of respirable dust in the test samples, increases in air velocity still resulted in higher levels of respirable dust. It is important to note that these results were obtained with dry dust (<1% moisture) dropped directly into the airstream without any method of dust control in use. Dilution or decreasing levels of airborne respirable dust with increasing air volume were not observed. This was attributed to greater air velocity, creating particle separation in the respirable range and entraining more dust, thus overcoming the effects of dilution.

Field studies through the 1980s and 1990s, and more recently completed longwall surveys show that shield dust is a growing source of respirable dust on longwall faces. Studies show a strong relationship between the rock and quartz in the sample (Ramani et al., 1987). In mines where roof rock is the main component on the canopy, the entrainment of respirable quartz dust becomes more of an issue, as elevated quartz in the dust samples results in a reduced permissible exposure limit. To lower dust exposure to workers, mine operators, shield manufacturers and government researchers will need to work closely together in the future to mitigate this emerging dust source.

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