Evaluating longwall dust sources and controls

As longwall operators in the US have been experiencing record production levels, in turn the potential to generate higher levels of respirable dust has increased. J. P. Rider, J. F. Colinet, J. M. Listak and G. J. Chekan, National Institute for Occupational Safety and Health, US, describe recent research that has been undertaken to find ways of minimising dust levels.

Health surveillance efforts indicate that the development of lung disease and overexposure to respirable dust in underground coal mines continues to afflict mine workers. Results from the most recent round (1992 - 1996) of the Coal Worker's X-ray Surveillance Program[1] indicate that approximately 8% of the examined miners who had at least 25 years of mining experience were diagnosed with Coal Worker Pneumoconiosis (CWP) (category 1/0+). During the period between 1995 - 1999, mine operators and MSHA inspectors collected 9968 and 1365 dust samples respectively, from longwall designated occupation (DO) personnel. Analysis of these samples showed that 1970 (20%) of the mine operator samples and 258 (19%) of the MSHA samples[5] exceeded the 2 mg/m^3 dust standard. The continued development of CWP in coal mine workers and the magnitude of respirable dust over-exposures in longwall mining occupations illustrate the need for improved dust control technology on longwalls. Figure 1 illustrates the major longwall dust sources as determined in the early 1990's.[4] This article describes the ongoing research to find ways to minimise shearer dust levels as a function of changes in dust control parameters, and research to determine the impact of high air velocities on shield dust entrainment.

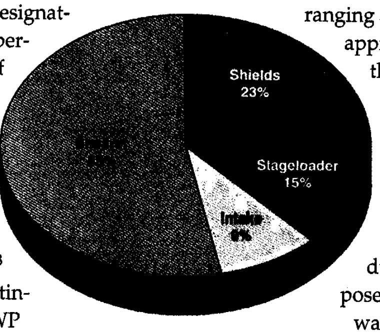

Figure 1. Dust sources on Longwalls.

Longwall gallery testing

Test facility

Tests to evaluate the interactions between different longwall dust control parameters and the impact that altering the parameters has on dust levels on the longwall face are being conducted at a full scale longwall test facility (Figure 2), at the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory (PRL). A wooden mock-up of a double ranging arm shearer was located approximately one half of the distance from the headgate to the tailgate. Each cutting drum was equipped with 33 water sprays, which produced full cone spray patterns for dust suppression purposes. Respirable coal dust was introduced with compressed air through hoses into the gallery at the head and tail drum locations. A commercially available minus 50 micron coal dust was used for all tests.

Sampling procedures

Sampling packages consisting of two gravimetric samplers and one real-time aerosol monitor (RAM), an instantaneous light-scattering instrument, were used to collect dust samples at headgate operator, tailgate operator and jacksetter positions. The samplers were suspended from the shield supports at the approximate breathing zone of the shearer operators. At each of these sampling locations, the sampling package was moved across a five shield sampling area in an effort to simulate the relative work area for each occupation on the face (headgate operator: shields 8 - 12, tailgate operator: shields 13 - 17, jacksetter: shields 19 - 23).

Tests were conducted to evaluate the effect of changing face air velocity, drum water spray pressure, external water spray pressure, and water quantity on the dust levels at typical operators' positions along the face. A total of 132 tests with nine different test conditions were conducted at the 2.29 m seam height with air velocities ranging between 1.27 - 2.29 m/s, drum water spray pressure ranging between 413.7 - 965.3 kPa, external water spray pressure between 689.5 - 1241.1 kPa, and the quantity of water delivered to the shearer ranging between 302.8 - 454.3 l/min. Two external spray configurations were evaluated, a directional spray system (shearer clearer) and a basic spray system with sprays oriented perpendicular to the face. Tests were carried out simulating head-to-tail cutting followed by tail-to-head cutting at the low, midrange and high levels for each control parameter.

Data analysis

Dust levels from the two gravimetric samplers at each of the three sampling locations along the face were normalised for fluctuations in dust feed. Average dust concentrations for each face worker location and test condition were calculated and are provided in Table 1.

The relative effectiveness of each control parameter was examined by comparing dust levels at the centre-point test condition, B (1.78 m/s, 378.5 L/min, 689.5 kPa drum spay pressure and 965.3 kPa external spray pressure) to dust levels at the high and low test limits for each of the four control parameters. The following describes the impact that varying the control parameters had on dust levels along the face.

- Concentrations at the face sampling locations dramatically increased when airflow was reduced, while increases in air velocity reduced dust levels between 12 - 26% for shearer clearer and basic spray system.
- When shearer water quantity was increased (test condition E) face sampling dust levels rose 13% with the external sprays oriented perpendicular to the face and decreased 7% while utilising the shearer clearer spray system.
- A substantial increase in dust levels (16%) was observed when the drum spray water pressure was increased to 965.3 kPa (test condition G) and the basic spray system was tested. Minimal fluctuations in dust levels were observed for the other test conditions associated with the drum spray pressure parameter.
- When the external spray pressure was lowered to 689.5 kPa (test condition H) dust levels were reduced by 10% for tests conducted with the shearer clearer system and 18% when the basic spray system was used.

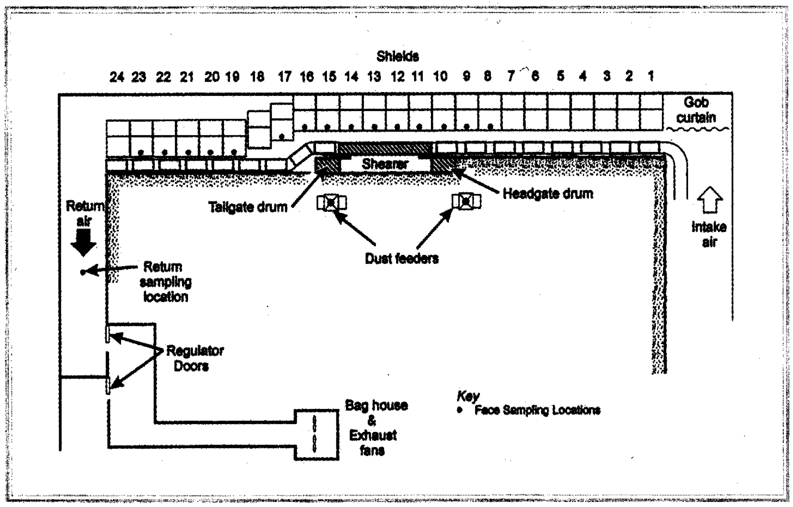

Figure 2. Diagram of longwall testing facility at the Pittsburgh research laboratory.

Profiles of the dust levels measured by RAM data loggers at the 15 sampling locations along the face showed air velocity had a significant impact on dust levels, as shown in Figure 3, especially when the external sprays were oriented perpendicular to the face. Increases in air velocity held the dust

Table 1. Summary test results for the 2.29 m seam height

[illegible]

	Average dust levels (mg/m^3)									
Test condition					Headgate		Tailgate		Jacksetter	
	Air velocity (m/s)	Water quantity (l/min)	Drum pressure(kPa)	External pressure (kPa)	H to T	T to H	H to T	T to H	H to T	T to H
A	1.27	378.5	689.5	965.3	0.07	0.25	8.42	4.16	7.83	6.26
B	1.78	378.5	689.5	965.3	0.03	0.17	6.38	3.01	5.22	3.87
C	2.29	378.5	689.5	965.3	0.07	0.10	5.17	2.57	4.95	3.57
D	1.78	302.8	689.5	965.3	0.13	0.13	6.84	2.81	5.63	3.77
E	1.78	454.3	689.5	965.3	0.12	0.24	6.20	2.88	5.55	2.82
F	1.78	378.5	413.7	965.3	0.08	0.18	7.01	2.07	5.57	5.01
G	1.78	378.5	965.3	965.3	0.06	0.24	6.69	2.62	5.69	3.32
H	1.78	378.5	689.5	689.5	0.07	0.15	5.51	2.86	4.47	3.56
I	1.78	378.5	689.5	1241	0.12	0.15	7.37	1.59	6.06	4.92

[illegible]

	Average dust levels (mg/m^3)									
Test condition					Headgate		Tailgate		Jacksetter	
	Air velocity (m/s)	Water quantity (l/min)	Drum pressure (kPa)	External pressure (kPa)	H to T	T to H	H to T	T to H	H to T	T to H
A	1.27	378.5	689.5	965.3	0.05	0.11	5.90	7.46	6.99	4.5
B	1.78	378.5	689.5	965.3	0.03	0.02	4.28	4.88	4.24	2.80
C	2.29	378.5	689.5	965.3	0.05	0.36	2.64	3.60	2.43	2.85
D	1.78	302.8	689.5	965.3	0.13	0.08	4.18	4.62	4.31	3.35
E	1.78	454.3	689.5	965.3	0.06	0.50	3.82	6.13	4.35	3.7
F	1.78	378.5	413.7	965.3	0.05	0.25	4.21	4.84	3.96	3.42
G	1.78	378.5	965.3	965.3	0.04	0.20	4.96	5.27	5.42	3.14
H	1.78	378.5	689.5	689.5	0.07	0.00	2.66	4.03	3.70	2.69
I	1.78	378.5	689.5	1241	0.04	0.17	4.79	3.36	4.63	3.00

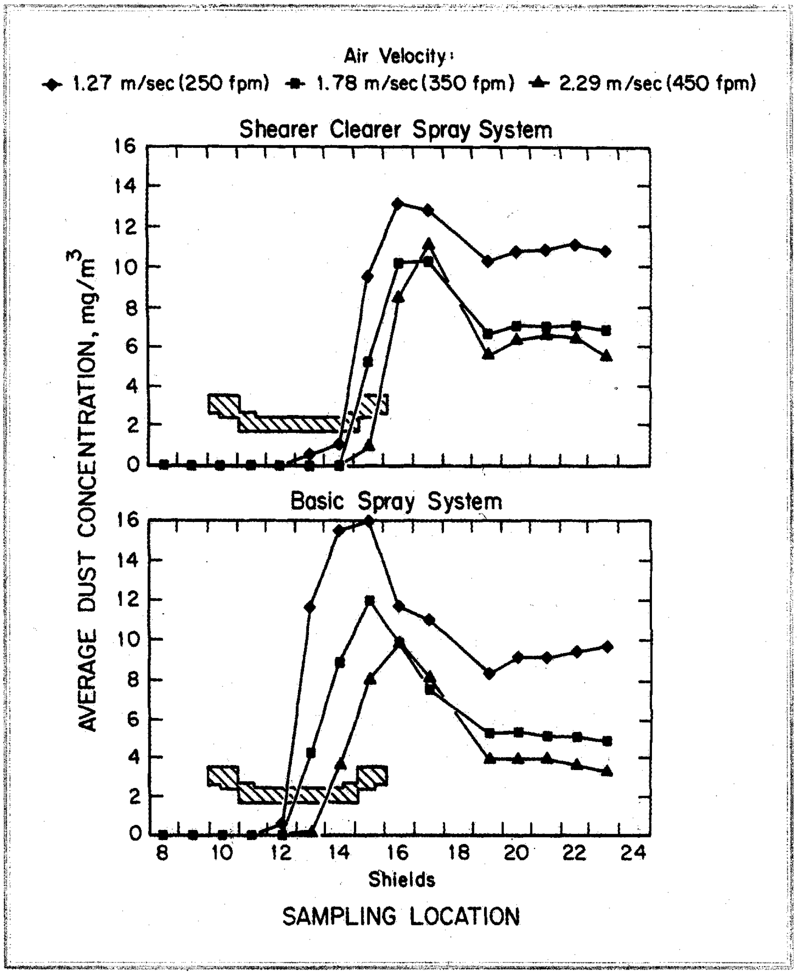

Figure 3. Dust profiles for air velocity tests with the shearer cutting in the tail-to-head direction.

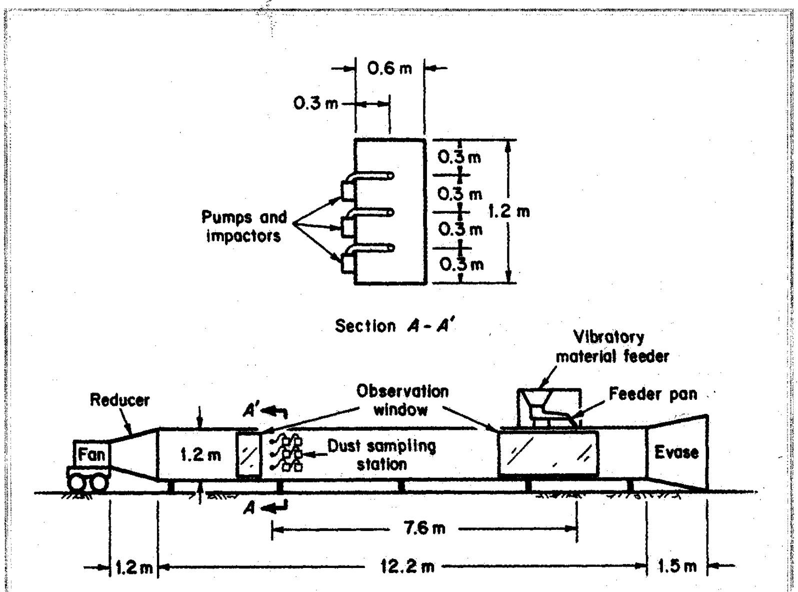

Figure 4. Dust entrainment tunnel schematic.

cloud against the face at a greater distance and lowered peak concentrations. Significant reductions in dust levels were observed at the sampling locations downwind of the shearer at higher air velocities. Examining the tests conducted with the shearer clearer spray system shows the dust cloud was contained against the face until it was influenced by the tailgate drum (shield 14/15). Turbulence created by the tailgate drum cutting action appeared to force the dust cloud out away from the face. Dust levels dramatically increased and peaked at 1.5 - 3.0 m downwind of the tailgate drum. Once the cloud detaches from the face it becomes diluted and mixed with ventilating air, resulting in constant but elevated levels throughout the entire cross-sectional area of the longwall face, downwind of the shearer.

Results from the tail-to-head tests, utilising basic sprays, showed the dust cloud detached from the face at the shearer midpoint, 4.6 m upwind of the tailgate drum. This spray system would expose the tailgate shearer operator to higher levels of dust than those found with the shearer-clearer sprays. Concentrations were elevated over a 9.2 m area (shield 12 - 18) and peaked at 1.5 m upwind of the tailgate drum. Downwind of the shearer, dust levels stabilised slightly lower but close to levels observed with the shearer clearer spray system. The dust cloud was contained against the face for a greater distance and dust concentrations were lower at the tailgate operator when comparing the shearer clearer external spray system to the basic system.

Shield dust entrainment testing and sampling protocol

Test facility and sampling method

A test facility was constructed to simulate dust dropping from shield canopies as shields are advanced. A vibratory feeder was used to trickle dust into the wind tunnel air stream as shown in Figure 4. Marple cascade impactors, operated at 2 l/min, were used to quantify the entrainment characteristics of both total dust (<50 microns) and respirable dust (<10 microns) and to study the change in size distribution of the airborne dust. Isokinetic sampling, a sampling method by which dust laden air is drawn into a sampling nozzle at a velocity equal to that of the air in the tunnel,[3,6] was employed. Tests were conducted at four velocities, 2.0, 4.1, 6.1 and 8.1 m/s. Three impactors sampled on 0.3 m spacings in relation to each other and the sides of the tunnel and measured dust levels were averaged to minimise the variation in dust levels that may occur due to dust gradients within the tunnel. A 18.2 kg coal sample, consisting of a mix of 50% coal dust (<50 microns), 25% coal 4.75 - 1.18 mm, and 25% coal, 9.5 - 4.75 mm, was fed into the tunnel over a 30 minute test period. The purpose of the larger sized coal was to simulate the coarser debris that falls into the air stream as face supports are advanced and may enhance/hinder entrainment of the respirable portion of the coal dust. Air-dry loss analysis on the total material mixture was <1%. Six tests were run at each air velocity for a total of 24 tests.

Table 2. Entrainment test results for each air velocity

[illegible]									
	Average concentration, mg/m³								
Velocity (m/s)	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Mean	Standard deviation	95% confidence interval (+/-)
2.0	14.4	14.4	15.7	22.9	28.6	15.6	18.6	5.86	6.15
4.1	62.8	64.4	57.3	59.7	77.6	51.1	62.1	8.90	9.34
6.1	80.8	103.0	92.6	93.4	92.2	75.1	89.5	10.00	10.49
8.1	84.2	122.8	132.4	118.7	114.7	129.7	117.1	17.40	18.26
[illegible]									
	Average concentration, mg/m³								
Velocity (m/s)	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Mean	Standard deviation	95% confidence interval (+/-)
2.0	1.0	1.4	1.4	1.5	2.3	1.2	1.5	0.44	0.47
4.1	5.1	6.0	5.5	4.8	7.4	5.0	5.7	0.96	1.00
6.1	8.3	16.4	14.3	13.3	14.0	11.5	13.0	2.80	2.94
8.1	15.4	19.7	24.9	20.7	16.5	21.8	19.8	3.49	3.67

Entrainment results

Table 2 provides the total and respirable dust concentrations measured for the six individual tests at each air velocity, as well as summary test statistics for each velocity. Figures 5 and 6 show the mean and the 95% confidence interval for total and respirable dust concentrations, respectively. At a 95% confidence level, statistically significant differences in mean dust levels at each air velocity were observed except for the total dust levels between 6.1 and 8.1. Adding a regression line to each of the data sets show a positive correlation between the two variables, and high (>98%) coefficients of determination (R^2), indicating that a strong relationship exists between the total and respirable dust concentrations and air velocity.

As anticipated, sampling results suggest that there is substantially less particle deposition at the higher velocities, allowing significantly more of the total dust to reach the sampling station. Higher air velocities have the energy necessary to entrain larger particles and transport these particles greater distances before deposition occurs. Figure 5 shows that respirable dust levels rise at each velocity increase and overcome the impact of increased dilution. These dust level increases are contrary to a study by Tomb[7] which found that as face air velocities increase above 5.1 m/s, respirable dust exposure levels decrease. However, in the study by Tomb, water spray systems were being utilised at primary dust sources (shearer and stageloader), which indicated that there was moisture added into the material to promote particle agglomeration. In addition, at these sources dust is not introduced directly into the air stream.

Respirable sampling results suggest that some agglomeration was occurring within the feed coal but moisture levels were not high enough to keep all of this material agglomerated as the higher air velocities were encountered. Elevated levels of moisture

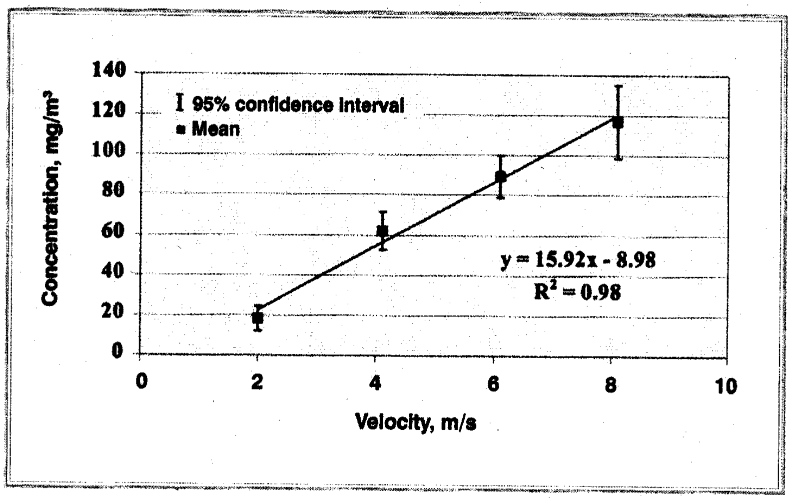

Figure 5. Relationship between total dust concentration and air velocity.

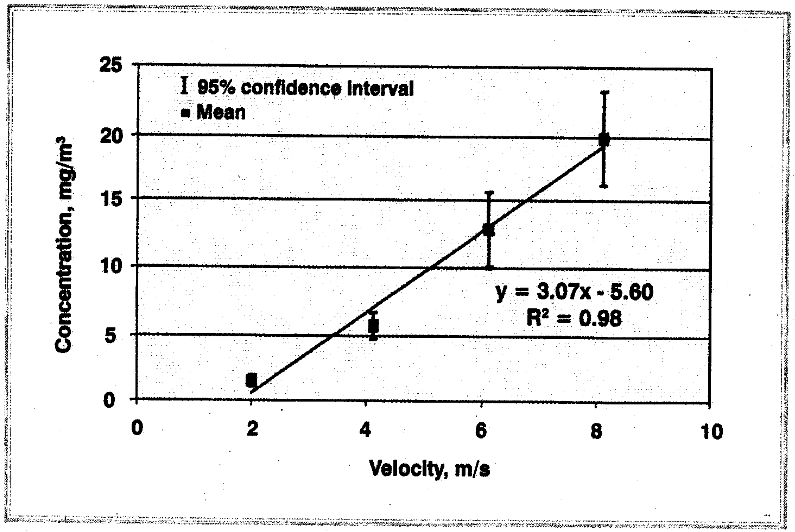

Figure 6. Relationship between respirable dust concentration and air velocity.

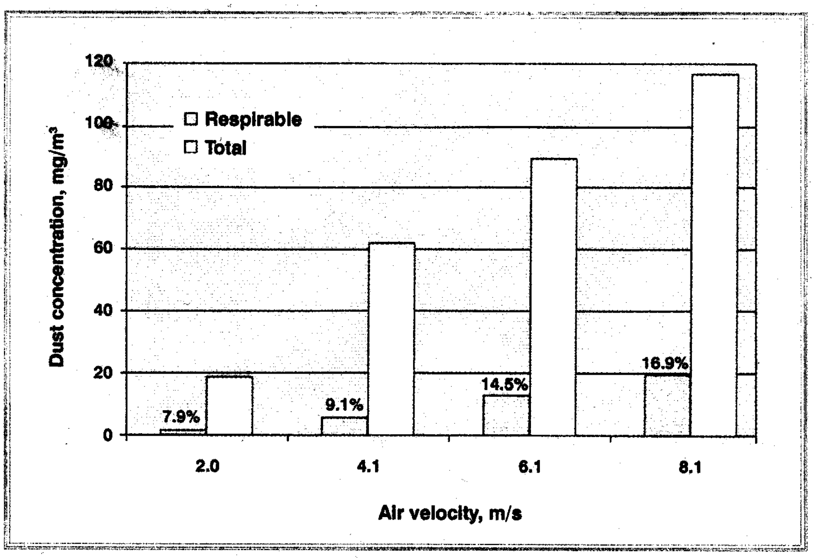

Figure 7. Percent of respirable dust in impactor samples at each air velocity.

increase the bond between particles and increase the energy needed to separate agglomerated particles.[2] Therefore, at the lowest test velocity the respirable particles remained agglomerated and were deposited in the tunnel before they reached the sampling station or were deposited on the upper stages of the impactors. At higher velocities, the adhesion forces became less dominant, allowing more of the particles to be entrained into the air stream as respirable-sized dust particles. Figure 7 supports this hypothesis by showing how the percentage of respirable dust in the collected samples increased as the air velocity increased.

To further characterise the airborne dust, the mass median diameter (MMD) at each air velocity was calculated. The MMD gives an overall measure of the size distribution of the particles and specifically the particle size at which 50% of the particles are greater than the MMD and 50% of the particles are smaller than the MMD. Mass median diameters for air velocities of 2.0, 4.1, 6.1 and 8.1 m/s were 10.8, 9.8, 8.2 and 7.7 microns respectively. There is a noticeable decrease in particle size as velocities increase. The fact that finer dust is being collected at the higher velocities further suggests that the increased energy of the higher velocity air promotes separation of loosely agglomerated particles.

Conclusion

NIOSH is conducting full-scale laboratory studies to evaluate dust liberation and control for dust generated by shearer cutting. Varying face air velocities had the greatest impact on dust levels at the sampling locations along the face. Gravimetric sampling results showed dust levels were reduced for all test conditions when the air velocity was increased to 2.29 m/s across the face. Dust levels were reduced by 55% when compared to tests conducted with the air velocity at 1.3 m/s. Results also show increases in drum spray pressure had minimal but adverse effects on dust levels when the shearer was cutting in the head-to-tail direction, for both the shearer clearer and basic external spray systems. Lower drum spray pressure impacted respirable dust levels when the shearer clearer spray system was tested and the cutting sequence was in the tail-to-head direction. Dust levels at the tailgate position were reduced while levels downwind of the shearer increased when compared to higher drum spray pressures. Gravimetric sampling results at the tailgate and jacksetter operator positions increased substantially when the external spray pressure was increased, while the shearer was cutting head to tail and the shearer clearer spray system was operational.

Dust profiles along the longwall face for tests conducted with the shearer cutting in the tail-to-head direction showed the dust cloud was contained against the face a distance of 3.1 - 4.6 m further downwind when the shearer clearer external sprays were used. Also, the dilution of the dust cloud occurred faster and peak dust concentrations in the walkway were not as severe with the shearer clearer external sprays. The type of external spray configuration had minimal impact on dust levels downwind of shearer. When the dust cloud mixed with the ventilating air it seemed to stabilise and remained reasonably constant. Once again, variations in air velocities had a significant impact on the dust levels along the face.

To better understand the effects of shield dust entrainment at air velocities being observed on today's longwall faces, research was conducted in a wind tunnel at test velocities of 2.0, 4.1, 6.1 and 8.1 m/s. Higher air velocities result in higher air quantities, which can serve to dilute dust and should therefore lower concentrations in the wind tunnel. However, both total and respirable dust concentrations rose at each successive higher air velocity indicating that particle entrainment was greater than dilution effects for these tests. Statistical analysis of the concentrations measured at each velocity resulted in significant differences at a 95% confidence interval.

Size distribution of the sampled dust shows that as velocities increased, a higher percentage of the dust particles in the air stream were finer (<10 microns) than those collected at the lowest test velocity (2.0 m/s). The mass median diameter was found to be 10.8 microns at 2.0 m/s and decreased to 7.7 microns at 8.1 m/s. Higher concentrations and finer particle size distributions suggest that at a moisture content of approximately 1%, a portion of the dust particles were loosely agglomerated and remained agglomerated at the 2.0 m/s velocity. As the velocity increased, the adhesion forces were overcome by the increased energy supplied to the system resulting in higher concentrations and smaller particle sizes in the air stream. ■

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