Chapter 41

REDUCING WORKER EXPOSURE TO DUST GENERATED DURING LONGWALL MINING

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ABSTRACT

Average production from longwall mining operations in the United States has risen from approximately 800 tons per shift in 1980 to over 4,600 metric tons per shift in 1999. Such a large increase in production has the potential to generate significantly more dust. Previous NIOSH research has shown that, on average, respirable dust levels generated by the shearer accounts for 50% of the airborne dust generated during longwall mining. Ventilating air and water are primary controls being used in an effort to reduce longwall dust levels. Longwall operators are applying more air and water than ever before and have expressed concern over reaching maximum practical limits for these controls. Full-scale laboratory tests are being conducted to evaluate the impact on shearer-generated dust levels for changes in face air velocity, water quantity at the shearer, water spray pressure, spray system design, mining height and cutting direction. Results of this research should identify the most appropriate control levels for various operating conditions. In addition, general recommended dust control practices for longwall mining will be discussed.

KEYWORDS

Longwall, coal dust

INTRODUCTION

Longwall mining equipment has improved dramatically over the last 15 years. In 1999, approximately 75% of longwall mines operated with shearer horsepower at 746 kw (1000 hp) or greater. Since1994, the average width and length of longwall panels have increased by 17% and 21%, respectively. Today, one-third of the longwall faces have face widths greater than 305-m (1000-ft) and longwall panels that measure 3050-m (10,000-ft) or longer (Anon., 2000). Although significant gains in longwall dust control have been made, they have been challenged by significant increases in coal extraction rates resulting in more dust being generated. Consequently, longwall operations continue to have difficulty in maintaining compliance with the federal dust standard of 2 mg/m^3.

During the period of 1995 through 1999, mine operators and MSHA inspectors collected 9,968 and 1,365 dust samples respectively, from longwall designated occupation [D.O.] personnel. The analysis of dust samples showed that 1,970 (20%) of the mine operator samples and 258 (19%) of the MSHA samples (Niewiadomski, 1999) exceeded the 2 mg/m^3 dust standard. Pneumoconiosis continues to be a very serious health threat to underground coal mine workers. According to the most recent results of the (1992-1996) Coal Workers X-ray Surveillance Program (Anon., 1999), findings indicated approximately 8% of the miners that were examined with at least 25 years of mining experience were diagnosed with Coal Worker Pneumoconiosis (CWP) (category 1/0+). Furthermore, the majority of the workers examined in the study have been employed since the passage of the Federal Coal Mine Health and Safety Act of 1969. 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 in underground coal mines.

The typical longwall in the United States ventilates the face with air flowing from the headgate to the tailgate. Also, the majority of the longwalls utilize a bi-directional cutting sequence. As with all mining methods, ventilating air and water sprays are the primary means used to control dust and methane in longwall operations. To meet ever-increasing production levels, mine operators have increased face air velocities and water quantities in an attempt to protect mine workers from excessive dust exposures. Unfortunately, increasing air and water quantities does not guarantee lower dust level and may adversely escalate worker exposure to higher levels of dust. This paper describes general recommended dust control practices for longwall mining operations along with an on-going research effort to identify relative differences in dust levels as a function of changes in the control parameters and/or operating conditions.

VENTILATION PROCEDURES TO MINIMIZE DUST LEVELS

To accurately assess face airflow, ventilation measurements should be taken at every 10th support. The resulting profile could be used to determine the "average" face airflow, along with the effective utilization of the primary intake air, and the loss of air into the gob. With a ventilation profile, the mine operator can discover problem areas and more accurately determine the specific ventilation parameters on a given longwall face. Minimum average face air velocity of 2 to 2.3 m/sec (400 to 450 fpm) appear to control respirable dust in three ways. The higher air velocities over the shearer help to confine the dust to the face area and lower contamination in the walkways. Higher velocities provide greater air quantities for better dilution on intake dust as well as dust generated on the face. Also, higher air velocities improve diffusion of dust from stagnant areas in the headgate and along the support line where respirable dust is rapidly removed from the breathing zones of the face workers.

Often, loss of air into the gob in the headgate area prevents the maximum utilization of the air available to ventilate the longwall face. A large opening is created between the first support and the entry rib when the area immediately behind the first few supports remains open. A substantial portion of the ventilation air from the headgate entry may leak back into the gob, thus reducing the airflow along the face. Furthermore, fresh air in the gob area may become inundated with dust during gob falls and may reenter the face area compounding the dust problem. A gob curtain (Figure 1) installed between the first support and the rib in the headgate entry can force the ventilation airstream to make a 90 degree turn down the longwall entry rather than leaking into the gob. Previous research (Jankowski, 1983) collected extensive face air-velocity data with and without the gob curtain in use. The average face air velocity with the curtain installed was approximately 35% greater than without the curtain. The biggest improvement due to the curtain was seen at the first 25 to 30 supports, where increased air volume lowered dust concentrations through dilution. In addition, a number of U.S. longwall operations have extended the brattice curtain along the first five to ten shields to further reduce leakage into the gob area and increase airflow down the face. Previous research by the U.S. Bureau of Mines indicated that approximately 75% of U.S. longwalls were utilizing gob curtains (Colinet, 1997).

Longwall shearer operators are exposed to high levels of dust when the headgate drum cuts into the headgate entry. As the cutting drum advances into the entry, it is exposed to the primary ventilation airstream. The high velocity air passes through and over the cutting drum, resulting in large quantities of dust being carried in the walkway and over the shearer operators. To overcome this problem, a "cutout" curtain (Figure 2) can be used in the headgate to shield the lead drum from the ventilation airstream as it cuts out into the headgate. The curtain redirects the primary air so that it flows out and around the drum.

It is usually located 1.2 to 1.8 m (4 to 6 ft) back from the corner of the face to provide maximum shielding from the dust and not to interfere with the cutting cycle. Tests (Jankowski, 1986) were conducted to monitor dust levels at the operator positions with and without a curtain as the headgate drum cut into the entry. Results indicated that the curtain reduced the exposure of the tailgate shearer drum operator by 50% to 60% during this phase of the mining cycle. To achieve these improvements, the curtain must be installed tightly against the roof and it must extend sufficiently into the headgate entry.

WATER SPRAY SYSTEMS

In the United States, all shearer cutting drums in operation since the late 1970's have been equipped with drum-mounted water sprays. The intent is to apply water directly at the point of coal fracture for dust suppression and to add moisture to the product to minimize dust liberation during the transport of the coal along the conveyor off the longwall face. Once respirable dust becomes airborne and is entrained by the primary airstream, it is then carried throughout the entire cross-sectional volume of the longwall face.

Water sprays are very effective air-moving devices and when mounted on the shearer body can act very much like small fans that move air and entrain dust in the direction of the airflow. Poorly designed shearer-mounted spray systems with the water sprays oriented upwind into the primary ventilation can cause high levels of dust to be transported away from the face area and into the primary airstream. If applied properly, water sprays can be used to augment the primary airflow and reduce the amount of shearer-generated dust. A shearer-clearer spray system (Jayaraman *et al*., 1985) takes advantage of the air-moving capabilities of water sprays. This system (Figure 3) consists of several shearer mounted water sprays oriented downwind and one or more passive barriers that split the airflow around the shearer into clean and contaminated air splits.

The air split is initiated by a splitter-arm, extending from the gob-side corner of the shearer body. Spray manifolds mounted on the splitter-arm confine the dust cloud generated by the cutting drum. The dust laden air is drawn over the shearer body and held against the face by two spray manifolds positioned between the drums. The air is directed around the downwind drum by a set of sprays located on a downwind splitter-arm. Past research has shown that the shearer clearer can reduce operator dust exposures by approximately forty percent. Over 90% of U.S. longwall shearers are equipped with shearer clearer spray systems.

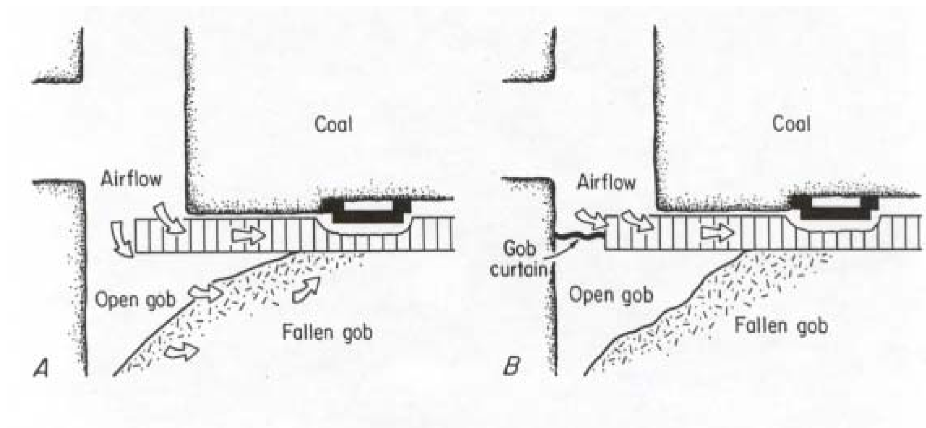

Figure 1. Installation of a gob curtain at longwall headgate

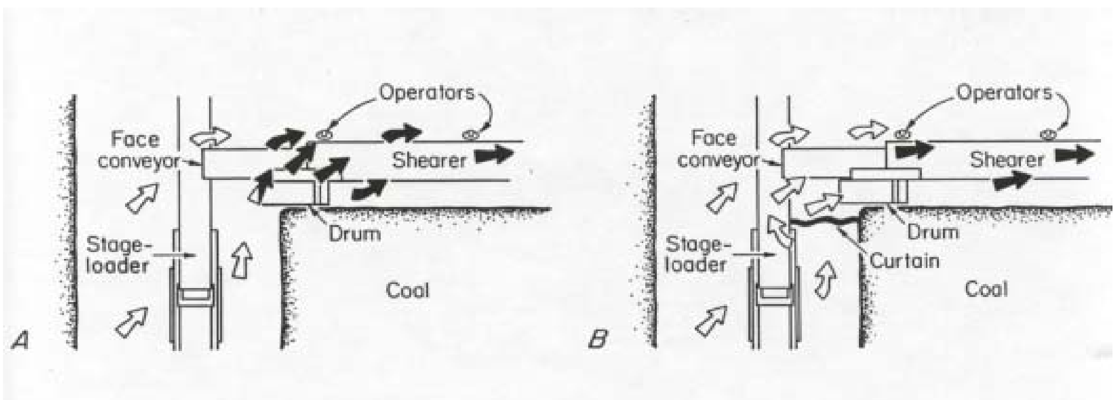

Figure 2. Location of cutout curtain at longwall headgate

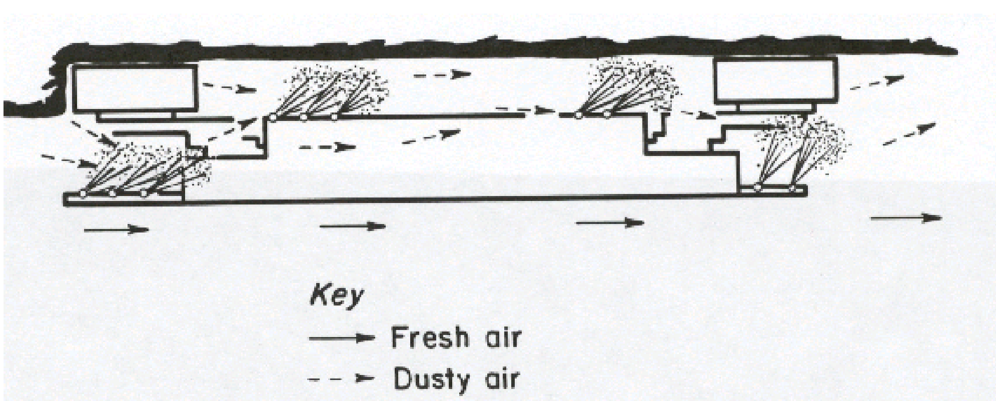

Figure 3. Shearer Clearer Spray System

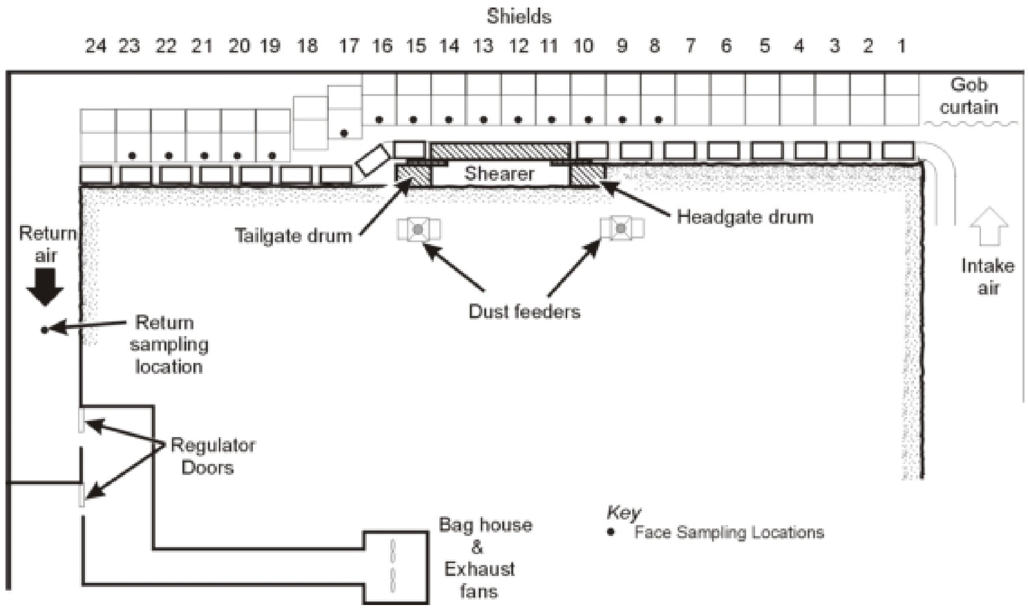

Figure 4. Diagram of the Longwall Test Facility at the Pittsburgh Research Laboratory

SIMULATED LONGWALL GALLERY

Tests to evaluate the interactions of different longwall dust control parameters and the impact that altering the parameters have on dust levels on the longwall face are being conducted at a full scale longwall test facility at the National Institute for Occupational Safety and Health Pittsburgh Research Laboratory (NIOSH-PRL). The simulated face is 38.13-m [125-ft] long and the height from floor to roof is 2.29-m [7.5-ft] as shown in Figure 4. Twenty-four simulated shield supports [1.52-m (5-ft) wide] cover the length of the test facility. A full scale wooden mock-up of a Joy 4LS 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 drum mounted water sprays which produced a uniform and consistent full cone spray pattern for dust suppression purposes. Ventilation for the longwall gallery was provided by two exhaust fans capable of supplying approximately 19.17 m^3 /sec (40,500 cfm) of air along the face.

Respirable coal dust was introduced into the gallery at the head and tail drum locations. Dust was generated by using a screw type feeder system which funneled coal dust into mini-eductors. Utilizing compressed air, these mini-eductors carried dust through hoses and into the gallery. A commercially available minus 50-micron coal dust was used for all tests. Gravimetric samplers along with real-time aerosol monitors (RAM) for instantaneous dust measurements were utilized to collect the dust samples during testing. Constant flow gravimetric sampling pumps, operating at 2 L/min, pulled dust-laden air through 10-mm nylon cyclone pre-separator. The respirable portion of the dust-laden air was separated out and deposited on pre-weighted 37-mm filters. After each test, the net weight for each filter was calculated and used in subsequent analysis. The RAM instrument was used to supplement the gravimetric samplers. Again, dust laden air was pulled through a 10-mm cyclone at 2L/min and the respirable dust was separated out and passed though a light source. The amount of light deflection in the chamber was considered to be representative of a relative dust concentration. The instantaneous dust concentrations were download to a multichannel data acquisition system for monitoring throughout the test and for later analysis.

Sampling packages consisting of a RAM monitor adjacent to two gravimetric samplers were used to collect dust samples at typical headgate and tailgate operator positions along the face. The samplers were suspended from the shield supports at the approximate breathing zone of the shearer operators. Also, a sampling package was used to collect dust samples approximately 9.1-m (30-ft) downwind of the shearer in an area simulating the approximate breathing zone of the jacksetter operator. 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. In addition to the sampling packages along the face, three sampling packages were located in the return at three distinct heights between the floor and the roof.

Two external spray configurations were evaluated during the test program. The first system to be tested is the standard "shearer clearer" spray system developed by the U.S. Bureau of Mines (Jayaraman, 1985). The spray system consisted of 11 eleven hollow cone sprays that were installed on the shearer based upon the guidelines provided in the Bureau publication. Also, a "basic" spray system where the external sprays are oriented perpendicular to the face was installed and will be tested. Tests were conducted to evaluate the effect of changing air face velocity, drum water spray pressure, external water spray pressure, and water quantity on the dust levels at typical headgate, tailgate and jacksetter operator's position and in the return.

A total of 132 tests with 9 different test conditions were examined at the 2.14-m (7.5-ft) seam height with air velocities ranging between 1.27 and 2.29 m/s (250 and 450 fpm), drum water spray pressure ranging between 413.7 and 965.3 kPa (60 and 140 psi), external water spray pressure between 689.5 and 1241.1 kPa (100 and 180 psi), and the quantity of water delivered to the shearer ranged between 302.8 and 454.3 L/min (80 and 120 gpm) as shown in Table 1. Test were carried out simulating a head-to-tail cutting sequence followed by the tail-to-head cutting sequence at the low, midrange and high levels for each control parameter.

Table 1. Test Combinations at 7 ft seam height

Test Conditi	Air Velocity m/sec (fpm)	Water Quantity L/min (gpm)	Drum Pressure kPa (psi)	External Pressure kPa (psi)
A	1.27 (250)	378.5 (100)	689.5 (100)	965.3 (140)
B	1.78 (350)	378.5 (100)	689.5 (100)	965.3 (140)
C	2.29 (450)	378.5 (100)	689.5 (100)	965.3 (140)
D	1.78 (350)	302.8 (80)	689.5 (100)	965.3 (140)
E	1.78 (350)	454.3 (120)	689.5 (100)	965.3 (140)
F	1.78 (350)	378.5 (100)	413.7 (60)	965.3 (140)
G	1.78 (350)	378.5 (100)	965.3 (140)	965.3 (140)
H	1.78 (350)	378.5 (100)	689.5 (100)	689.5 (100)
I	1.78 (350)	378.5 (100)	689.5 (100)	1241 (180)

Prior to the start of the baseline period, the test parameters were set, face ventilation was established, shearer drums started rotating, the dust injection system was energized, and the dust cloud was allowed to stabilize. A 10 minute baseline test cycle began without the water sprays operating. The RAM samplers in the return entry were turned on to record dust concentrations, as a means of monitoring fluctuations in the dust feed. The completion of the baseline period triggered the activation of the drum and external water sprays systems. RAM samplers along the face and all the gravimetric samplers were activated, and the 1.5 hour test cycle started. The dust sampling packages along the face were operated for 18 minutes or 20 % of the total test time at each of the five shield locations in the designated sampling areas (headgate operator - shields 8-12, tailgate operator - shields 13-17, jacksetter operator - shields 19-23).

DATA ANALYSIS

Utilizing a data acquisition / software package, dust levels recorded by the RAM samplers at the locations along the face and in the return were captured and downloaded every two seconds for the duration of the test. Dust levels from the two gravimetric samplers at each of the three sampling locations along the face were combined resulting in an average dust concentration for each face worker. The individual dust concentrations for the six return samples were combined to calculate an average return concentration for each test. The average gravimetric dust concentrations at the four sampling locations (headgate, tailgate, jacksetter, and return) were then normalized for fluctuations in the dust feed. Dust concentrations that were recorded during the 10 minute baseline test period from the three RAM return samplers were averaged together to obtain a single baseline return concentration. A normalizing ratio was calculated by dividing the average baseline return dust level at the same airflow by the RAM return dust level from the test being normalized. Average gravimetric concentrations from each sampling location and specific airflow were multiplied by the normalizing ratio. A summary of the average normalized gravimetric concentrations for the four sampling locations and test conditions is provided in Table 2. All subsequent data analysis utilized normalized dust concentrations.

Gravimetric dust concentrations measured for each cutting direction were averaged to formulate a dust concentration representing a complete pass at the headgate, tailgate, and jacksetter sampling locations. Test results show the lowest dust levels were observed at test condition C [2.29 m/sec (450 fpm)] followed by test condition H [689.5 kPa (100 psi) external pressure] for both the shearer clearer and basic spray systems.Higher face air velocities provide greater air quantities for better dilution of ventilating air across the face and help confine shearer dust to the face and lower contamination in the walkway (Jankowski, 2000).

The relative effectiveness of each control parameter was examined by comparing dust levels at the center-point test condition B [1.78 m/sec (350 fpm), 378.5 L/min (100 gpm), 689.5 kPa (100 psi) drum spay pressure and 965.3 kPa (140 psi) 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.

Table 2. Summary Test Results at the 2.13 m (7 ft) seam height

SHEARER CLEARER SPRAY SYSTEM

	Average Dust Levels [mg/m³]							
Test	Headgate		Tailgate		Jacksetter		Return	
Condition	H to T	T to H	H to T	T to H	H to T	T to H	H to T	T to H
A	0.07	0.25	8.42	4.16	7.83	6.26	9.46	7.98
B	0.03	0.17	6.38	3.01	5.22	3.87	7.15	5.73
C	0.07	0.10	5.17	2.57	4.95	3.57	5.53	5.35
D	0.13	0.13	6.84	2.81	5.63	3.77	7.79	6.60
E	0.12	0.24	6.20	2.88	5.55	2.82	7.38	6.06
F	0.08	0.18	7.01	2.07	5.57	5.01	7.68	8.01
G	0.06	0.24	6.69	2.62	5.69	3.32	6.90	5.50
H	0.07	0.15	5.51	2.86	4.47	3.56	6.83	5.72
I	0.12	0.15	7.37	1.59	6.06	4.92	7.63	5.92

BASIC SPRAY SYSTEM

	Average Dust Levels [mg/m³]							
Test	Headgate		Tailgate		Jacksetter		Return	
Condition	H to T	T to H	H to T	T to H	H to T	T to H	H to T	T to H
A	0.05	0.11	5.90	7.46	6.99	4.51	9.94	6.95
B	0.03	0.02	4.28	4.88	4.24	2.80	7.24	5.01
C	0.05	0.36	2.64	3.60	2.43	2.85	5.02	4.98
D	0.13	0.08	4.18	4.62	4.31	3.35	7.43	5.88
E	0.06	0.50	3.82	6.13	4.35	3.71	7.64	5.36
F	0.05	0.25	4.21	4.84	3.96	3.42	7.52	6.74
G	0.04	0.20	4.96	5.27	5.42	3.14	7.14	5.28
H	0.07	0.00	2.66	4.03	3.70	2.69	7.32	5.32
I	0.04	0.17	4.79	3.36	4.63	3.00	7.11	5.20

- Concentrations at the face sampling locations dramatically increased when airflow was reduced, while increases in air velocity reduced dust levels between 12 and 26% for shearer clearer and basic spray system.
- Decreasing the amount of water directed to the shearer had little effect on dust levels across the face. However, it should be noted that the testing conducted in the gallery could not simulate the potential benefit of increasing moisture content in the coal product.
- When shearer water quantity (test condition E) was increased; face sampling dust levels were elevated 13% with the external sprays oriented perpendicular to the face and decreased 7% while utilizing 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 (140 psi) [test condition G] and the basic spray system was tested. Minimal fluctuations in dust levels were observed for the other test conditions associated the drum spray pressure parameter.
- When the external spray pressure was lowered to 689.5 kPa (100 psi) [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.

Profiles of the dust levels measured by RAM data loggers at the 15 sampling locations (Figure 4) along the face showed air velocity had a significant impact on dust levels especially when the external sprays were oriented perpendicular to the face as shown in Figure 5. Increases in air velocity held the dust cloud against the face a greater distance and lowered peak concentrations.

Significant reduction in dust levels were observed at the sampling locations downwind of the shearer at the 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 seems to overwhelm the spray system and forces the dust cloud out away from the face. Dust levels dramatically increase and peak 5 to 10 ft downwind of the tailgate drum. Once the cloud detaches from the face it become diluted and mixed with ventilating air resulting in constant but elevated levels through out the entire cross-sectional volume of the longwall face downwind of the shearer. Results from the tests utilizing external sprays that were oriented perpendicular to the face showed the dust cloud detached from the face at the shearer mid-point 4.57 m (15 ft) upwind of the tailgate drum (shield 12).

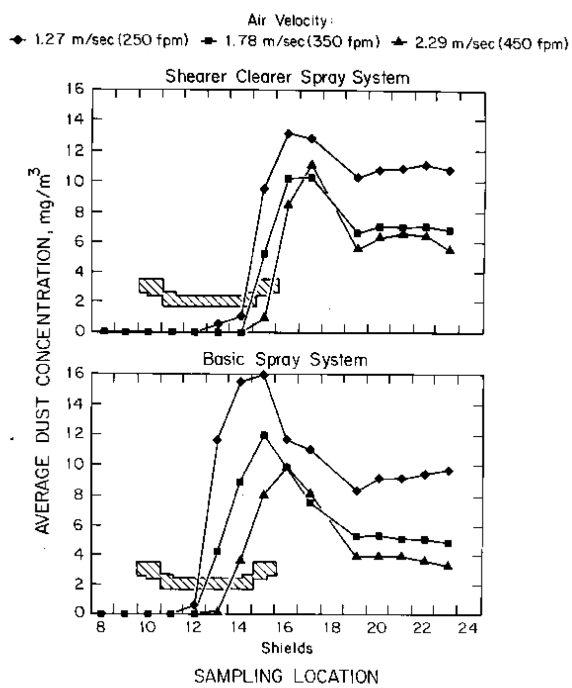

Figure 5. Dust profiles for air velocity tests with the shearing cutting in the tail-to-head direction

Concentrations were elevated over a 9.15 m (30 ft) area (shield 12 - 18) and peaked 1.52 m (5 ft) 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. Downwind of the shearer the dust levels stabilize close to levels observed with the shearer clearer external spray system. The dust cloud was contained against the face for a greater distance and dust concentrations were lower when comparing the shearer clearer external spray system to the basic system.

SUMMARY

During the past decade researchers at NIOSH's Pittsburgh Research Laboratory in cooperation with the longwall mining industry have identified and documented the effectiveness of certain improved face-ventilation techniques for longwall operations. Research activities to provide longwall operators valuable information concerning the interactions between longwall dust control parameters and respirable dust concentrations along the face are continuing at PRL.

Research has shown a gob curtain installed between the first support and the rib in the headgate entry reduces the amount fresh air being lost into gob area. The curtain turns the ventilating airstream 90 degrees and directs fresh air down the longwall entry rather the into the gob area. Underground experiments showed that the air velocity along the face was approximately 35% higher with a gob curtain installed in the headgate entry compared to tests conducted without a curtain. Face air velocities of at least 2 to 2.3 m/sec (400 to 450 fpm) appear to be the minimum appropriate for dust control. The higher air velocities over the shearer help to confine the dust to the face area and lower contamination in the walkways.

As the headgate drum "cuts out" advances into the headgate entry, large quantities of dust are carried into the walkway and over the shearer operators. A "cutout" curtain located in the headgate entry shields the lead drum from the ventilation airstream as it cuts into the headgate and substantially reduces operator exposure to respirable dust. Underground experiments have shown that the headgate "cutout" curtain reduced tailgate shearer drum operator exposure by approxiamtely 50% to 60 % during this phase of mining.

The intent of drum-mounted water sprays is to apply water directly at the point of coal fracture for dust suppression and to add moisture to the product to minimize dust liberation during the transport of the coal along the conveyor. Water sprays are very effective air-moving devices and when mounted on the shearer body can act very much like small fans that move air and entrained dust in the direction of the airflow. If applied properly, water sprays can be used to augment the primary airflow and reduce the amount of shearer-generated dust. A typical shearer-clearer spray system consists of several shearer mounted water sprays oriented downwind and one or more passive barriers that split the airflow around the shearer into clean and contaminated air splits.

A face-centered-cube experimental design test program is being utilized to study the impact of air velocity, drum spray pressure, external spray pressure, water quantity, and seam height have on dust levels at typical headgate, tailgate, and jacksetter operator positions along the face. A full scale model of a Joy 4LS double ranging arm shearer located in a simulated longwall test facility was used for testing. A shearer clearer external spray system and basic spray system were evaluated during testing. Gravimetric samplers along with RAM monitors were employed to collect dust samples for all test. The samplers were suspended from shield supports at the approximate breathing zone of the shearer operators.

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/sec (450 fpm) across the face. Dust levels were reduced by 55% when compared to tests conducted with the air velocity at 1.3 m/sec (250 fpm). Results from the gravimetric sampling showed that changes in the flow of water to the shearer had minimal effect on shearer generated airborne dust levels. The potential benefits from increasing the moisture content of the coal as it traveled along conveyor belt or through the stageloader / crusher could not be simulated. Increases in drum spray pressure had minimal but adverse effect 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 test conducted with the shearer cutting in the tail to head direction showed the dust cloud was contained against the face a distance of 3.05 to 4.57 m (10 to 15 ft) further downwind when the shearer clearer external sprays were used. Also, the dilution of the dust cloud occurred faster and peak dust concentrations 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 stabilize and remained reasonably constant. Once again variations in air velocities had significant impact on the dust levels along the face. While reducing face air velocity had the greatest impact on dust levels, increasing the air velocity from 1.78 to 2.29 m/sec (350 to 450 fpm) had minimal impact on dust levels when shearer clearer external spray were tested.

Research to determine if changes in control parameters and/or operating conditions significantly alter respirable dust levels along the face is continuing at the Pittsburgh Research Laboratory. The dust control parameter data identified in this paper could be used to assist the mine operator in the selecting the appropriate dust control approach for the unique conditions that exist at their longwall mining operation.

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