

## Ventilation impacts on respirable dust control

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**ABSTRACT:** The Health Branch of the Pittsburgh Research Laboratory conducts research to reduce the dust exposure of mine workers through development of improved control technologies. In underground mining operations, ventilation continues to be utilized as a primary control by diluting dust levels and carrying airborne dust away from mine workers. However, as mining conditions and mining practices change, the application of ventilating air must also be evaluated to achieve optimum results. For longwall mining, laboratory tests were conducted to evaluate the impact of increased air velocity on dust entrainment during shield advance and to evaluate the impact of air velocity changes in controlling dust generated by the shearer. In underground limestone mines, research is being conducted to evaluate the use of an auxiliary fan to control dust generated by an underground crusher and evaluate the impact of adding stoppings to better control air movement and isolate dust generating sources. Research procedures are discussed and test results summarized.

### 1 INTRODUCTION

Mine worker exposure to excessive levels of respirable dust can lead to the development of Coal Workers' Pneumoconiosis or silicosis. Both of these lung diseases can become disabling or fatal, depending upon the levels and duration of exposures. Mine operators have employed numerous dust control technologies in an effort to minimize airborne dust concentrations and worker exposures. Ventilating air is used as a primary control to dilute the dust and remove the dust from the breathing zones of mine workers.

In underground coal mines, ventilating air is used to control both methane and dust liberation during mining. As such, Federal regulations require minimum airflow quantities in coal mining operations. However, production levels can have a direct impact on dust and methane liberation. Average production from longwall mining units has increased five-fold over the past 20 years. In response, substantially higher quantities of airflow are being applied on longwall faces. A review of data collected by the Mine Safety and Health Administration (MSHA 1999) indicates that the average face velocity observed on US longwalls in 1999 was 3.2 m/sec (633 fpm), with a number of longwalls supplying air velocities between 5.1 and 8.1 m/sec (1,000 and 1600 fpm). Concern has been expressed regarding the potential for these ever-increasing air velocities to entrain greater quantities of dust. The most likely

source of increased dust entrainment may occur when shield supports are advanced. During advance, relatively dry coal and/or rock particles drops from the sides of the shields directly into the airstream ventilating the longwall face. Laboratory tests are being conducted at the Pittsburgh Research Laboratory (PRL) to evaluate the impact of increased air velocity on dust entrained during the advancement of shield supports.

In addition, airflow can have a major impact on dust levels generated by the shearer machine on a longwall. Full-scale laboratory tests are being conducted to evaluate the impact of changing control parameters on dust generated by longwall shearers. Changes in air flow, water spray flows and pressures, spray system designs, mining direction, and cutting height are being evaluated to assess their impact on dust levels in the area around the shearer and downwind of the shearer.

The number of underground limestone mines in the US has continued to grow over the past decade. In underground limestone mines, ventilation systems have not been as structured as in coal mining but greater emphasis is now being placed on both localized and mine-wide ventilation systems. PRL dust research has been conducted to evaluate the impact using an auxiliary fan to establish localized ventilation near an underground crusher. Research has also been initiated to evaluate the impact of adding stoppings throughout the mine to better direct ventilating air in defined patterns.

## 2 LONGWALL DUST ENTRAINMENT RESEARCH

As indicated, production from longwall faces has shown dramatic increases, with the potential to generate higher levels of dust. In response, longwall operators have increased face airflow to levels previously unseen on longwalls. A specially designed test facility was constructed at PRL to evaluate the impact of high velocity airstreams on dust entrainment. The four air velocities that were evaluated include: 2.0, 4.1, 6.1 and 8.1 m/s (400, 800, 1200, and 1600 fpm).

### 2.1 Entrainment Test Facility

A dust entrainment tunnel, Figure 1, was constructed to provide a controlled area to simulate shield dust falling into a high velocity airstream. The dimensions of the tunnel were 0.6 x 1.2 m (2 x 4 ft) providing an area of 0.7 m<sup>2</sup> (8 ft<sup>2</sup>). The length of the wind tunnel was 12.2 m (40 ft) with a 1.5 m (5 ft) long evase at the open end to reduce head loss and turbulence as air entered the tunnel. The interior of the tunnel was coated with waterproof paint and all seams sealed with caulking. A clean-out was provided in the tunnel to wash accumulated dust from the interior surface with water after each test. Air velocity was supplied with a 29.7 kw (40 hp) axial vane fan coupled to a variable speed controller, which was used to adjust fan speed as needed. A vibratory feeder was used to provide a controlled means to introduce the test material (dust and coarser coal) into the tunnel. The feeder was positioned on top of the tunnel and was retrofitted with a 56 cm (22 in) wide feeder pan that distributed the material across the entire width of the tunnel. A dust sampling station provided a means to collect dust samples for each test by inserting sampling probes into ports in the sidewall of the tunnel. The distance between the material dump point and the location of the downstream sampling probes was 7.6 m (25 ft).

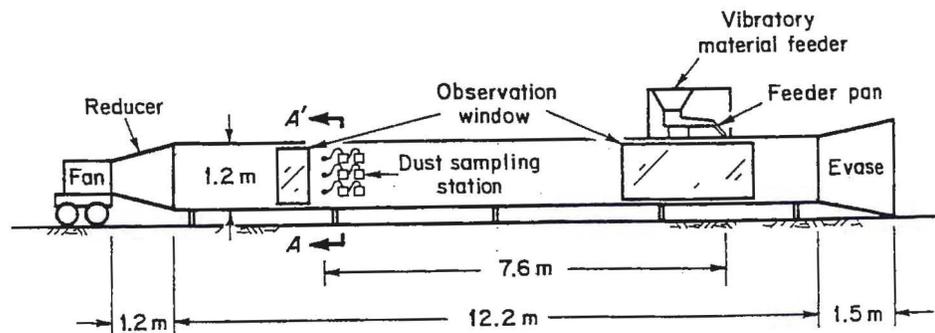


Figure 1. Entrainment test facility.

### 2.2 Sampling methodology

Dust samples were collected using personal impactors in conjunction with gravimetric sampling pumps. The personal impactor classifies dust by airborne particle diameter. Impactor sampling results were used to study the entrainment characteristics of total dust (< 50 microns), respirable dust (< 10 microns), and changes in size distribution of the airborne dust cloud.

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 (Brockman 1993, Quilliam 1994) was employed. Three sampling probes with isokinetic tips were placed on 0.3 m (1 ft) spacing in relation to each other and the sides of the tunnel. The use of three-point sampling grid to calculate an average concentration over the area of the tunnel minimized the variation in dust levels that may occur due to dust gradients within the tunnel.

Fan settings at the four selected air velocities were established using a pitot tube to conduct a cross-sectional traverse within the tunnel, which consisted of averaging the velocity over sixteen quadrants. These air velocity profile measurements were conducted at the sampling station to determine fan settings for each test velocity.

A previous shield dust study (Organiscak et. al. 1985) showed that mines that left coal as the immediate roof had higher amounts of support generated respirable dust than those with non-coal roofs. Therefore, initial studies were conducted using coal as the feed. The feed material consisted of finely ground bituminous coal and larger crushed coal. The coal dust is a commercially available product with consistent physical properties. The dust has a maximum particle size of 50 microns, 65% of which is less than 10 microns. The purpose of adding the larger sized coal was to simulate the coarser debris that falls into the airstream as face supports are advanced and may enhance/hinder entrainment of the respirable portion of the coal dust.

Feed material consisted of a mix of three different sizes of coal: 50% of coal dust at 50 microns and smaller, 25% of coal at 4.75 to 1.18 mm (0.18 to 0.05 in), and 25% of coal at 9.5 to 4.75 mm (0.37 to 0.18 in). A material weight of 18.2 kg (40 lbs), the stated size mix, and a test time of 30 minutes were used for each test. Six tests were run at each air velocity for a total of 24 tests.

### 2.3 Entrainment test results

Table 1 provides the total and respirable dust summary test statistics for each velocity. 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 (1200 and 1600 fpm). 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.

Figure 2 shows the mean and the 95% confidence interval for total dust concentration as a function of velocity. Dust concentration is a measure of dust mass within a given air quantity. Increasing air velocity in the tunnel would increase the air quantity supplied per test and for the same quantity of introduced-dust, should provide greater dilution of the introduced dust. However, 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, thus overcoming dilution effects. It is hypothesized that the higher air velocities had the energy necessary to

entrain larger particles and transport these particles greater distances before deposition occurs. In addition, moisture can affect the agglomeration of particles and impact the entrainment and transport potential of dust particles. Elevated levels of moisture increase the bond between particles and increase the energy needed to separate agglomerated particles (Breuer 1972). Representative samples of the feed material were air-dried and found to have an average moisture loss of less than 1%. Consequently, the increased energy available at the high air velocity and relatively low moisture content of the feed material combine to allow total dust levels to rise significantly as air velocities increase. Unfortunately, rock and coal crushed above the shield canopies of longwall face supports can often have low moisture content and as previously indicated, air velocities on longwalls are increasing. The test results show that when these factors are combined the potential for greater entrainment of total dust from shields along longwall faces also increases.

The respirable concentration of the dust collected by the impactors is determined by calculating the respirable fraction deposited on each stage of the impactor (Potts et al. 1990). The average respirable dust concentration at 2.0 m/s (400 fpm) was relatively low at 1.5 mg/m<sup>3</sup>. Figure 3 illustrates how the respirable dust levels rise at each velocity increase, with respirable dust levels at 8.1 m/s (1600 fpm) found to be 13.5 times greater than baseline levels. These dust level increases are contrary to a study by Tomb (Tomb et al. 1990) which found that as face air velocities increase above 5.1 m/s (1000 fpm), respirable dust exposure levels decrease. However, in the study by Tomb, water spray systems were being utilized at primary dust sources (shearer and stageloader), which indicates that there was moisture added into the material to promote particle agglomeration. In addition, the dust generated at these sources was being shielded from the face airflow by physical barriers and/or water sprays in an effort to minimize entrainment.

Table 1. Summary of entrainment dust sampling results.

Test velocity m/sec (fpm)	Mean dust concentration mg/m <sup>3</sup>		MMD microns
	Total	Respirable	
2.0 (400)	18.6	1.5	10.8
4.1 (800)	62.1	5.7	9.8
6.1 (1200)	89.5	13.0	8.2
8.1 (1600)	117.1	19.8	7.7

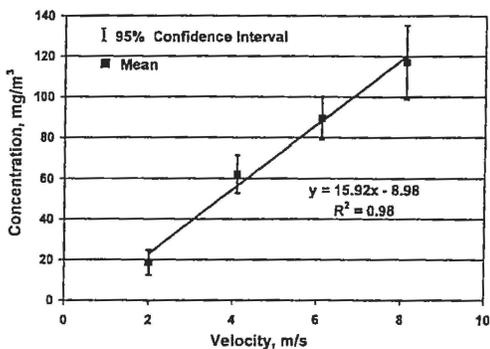


Figure 2. Impact of velocity on total dust concentrations.

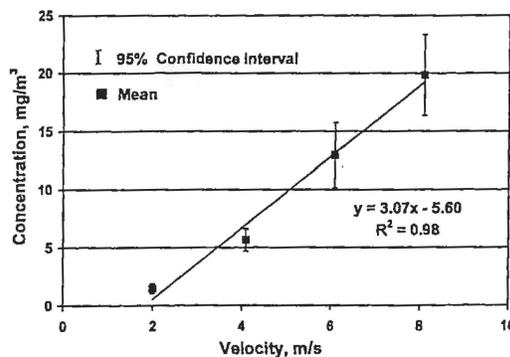


Figure 3. Impact of velocity on respirable dust concentrations.

After completing the original test series, a few additional tests were conducted with high volume (4.2 l/min) samplers and metal cyclones to obtain a respirable fraction using a cyclone separator. Four tests were completed at 2.0 m/s and an average dust concentration of 2.9 mg/m<sup>3</sup> was measured. Three tests were conducted at 8.1 m/s and had an average concentration of 22.8 mg/m<sup>3</sup>. These dust concentrations were slightly higher than the respirable concentrations calculated from the impactors but illustrated a very similar trend.

Respirable sampling results from the laboratory tests 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. Therefore, at the low end of the test velocity, 2.0 m/s (400 fpm), these 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 and auto-adhesion forces become less dominant allowing more of the particles to be entrained into the airstream as respirable-sized dust particles. Figure 4 supports this conclusion by showing the respirable and total dust concentrations and the percent of respirable dust observed at each velocity. As shown, the percent of respirable dust in the collected dust sample increases as the velocity increases.

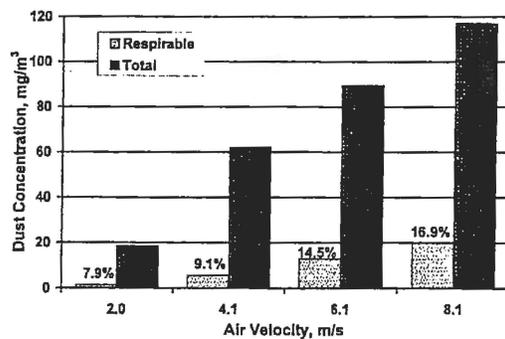


Figure 4. Percentage of respirable dust in impactor samples at each air velocity.

To further characterize the airborne dust at each air velocity, dust weights from the multiple stage impactors were used to calculate the mass median diameter (MMD). The MMD is the particle size at which 50% of the particles are greater than the MMD and 50% of the particles are smaller than the MMD. The mass median diameter at each air velocity is provided in Table 1, and identifies the 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.

### 3 LONGWALL SHEARER DUST CONTROL

Ventilating air on longwall faces helps to dilute dust generated by the shearer and also carries dust away from the breathing zones of the shearer operators. Tests were conducted in a full-scale long-wall gallery to evaluate the impact of changing air and water flow conditions on dust levels at and downwind of the shearer. Table 2 lists the test parameters and the levels at which they were tested.

Table 2. Control parameters evaluated in longwall gallery tests.

Test Condition	Air Velocity m/sec	Water Quantity L/min	Drum Pressure KPa	External Pressure kPa
A	1.27	378.5	689.5	965.3
B	1.78	378.5	689.5	965.3
C	2.29	378.5	689.5	965.3
D	1.78	302.8	689.5	965.3
E	1.78	454.3	689.5	965.3
F	1.78	378.5	413.7	965.3
G	1.78	378.5	965.3	965.3
H	1.78	378.5	689.5	689.5
I	1.78	378.5	689.5	1241.1

#### 3.1 Longwall dust gallery

As shown in Figure 5, twenty-four simulated shield supports [1.52-m (5-ft) wide] span the length of the test facility. A full-scale wooden mock-up of a double ranging arm shearer was located approximately one half of the distance from the headgate to the tailgate. For this series of tests, the height from floor to roof was set to 2.29-m [7.5-ft]. Each cutting drum was equipped with 33 water sprays, which produced full cone spray patterns for dust suppression purposes. Ventilation for the longwall gallery was provided by two exhaust fans capable of supplying approximately 19.17 m<sup>3</sup>/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 supplied to these locations through hoses connected to mini-eductors that use compressed air to transport the dust. A commercially available minus 50-micron coal dust was fed to the mini-eductors with a screw feeder.

Two external spray configurations were evaluated during the test program. The first system tested was the "shearer clearer" spray system developed by the U.S. Bureau of Mines (Jayaraman 1985). The spray system consisted of 10 hollow cone sprays that were installed on the shearer based upon the guidelines provided in the Bureau publication. This spray system utilizes the air-moving capacity of water sprays in an effort to confine shearer-generated dust near the face and delay dust migration into the walkway. Also, a "basic" spray system where the external sprays are oriented perpendicular to the face was in-

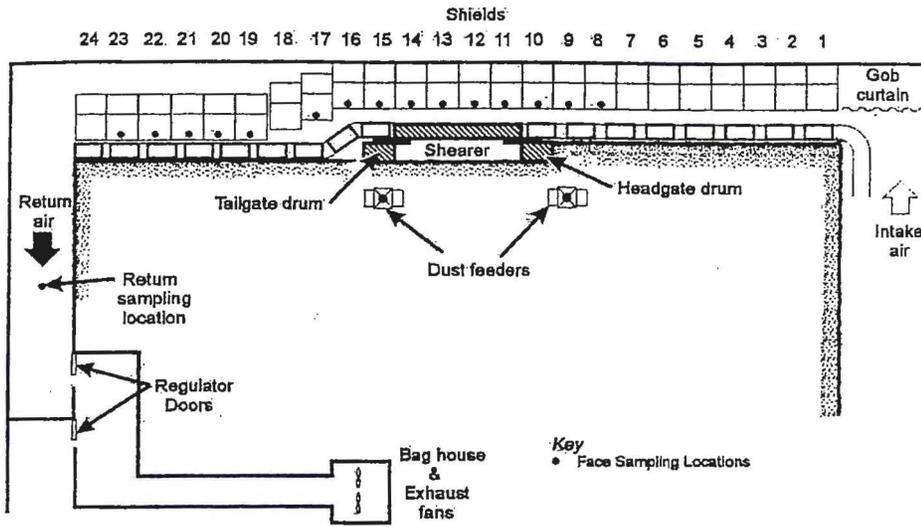


Figure 5. Schematic of longwall dust gallery at the Pittsburgh Research Laboratory.

stalled and tested. 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 headgate, tailgate and jacksetter operator's position and in the return.

### 3.2 Sampling procedures

Gravimetric samplers and Real-time Aerosol Monitors (RAM) were utilized to measure dust levels during testing. Constant flow gravimetric sampling pumps, operating at 2 L/min, pulled dust-laden air through 10-mm nylon cyclone pre-separators. The respirable portion of the dust-laden air was separated out and deposited on 37-mm filters for weighing. 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 through a light source. The amount of light deflection was representative of a relative dust concentration. The instantaneous dust concentrations were downloaded to a multi-channel 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.

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 changes in dust concentrations resulting from test-to-test fluctuations in the dust feed, which would be used to normalize the data from each test. 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).

### 3.3 Data analysis

Dust levels from the head-to-tail and tail-to-head tests [Rider et al. 2001] were averaged to obtain a full-cycle concentration. The difference in dust concentration resulting from a change in a test parameter was calculated by subtracting the dust concentration from the test with the parameter at its highest level from the concentration measured at the lowest

level of the test parameter. The other control parameters were held constant for both test conditions. For example, the impact of increasing airflow was determined by subtracting dust levels measured for test condition C from dust levels measured for test condition A. Table 3 provides a summary of the changes resulting from making these comparisons for each test parameter, for three sampling locations and for both external spray systems.

Table 3. Summary of dust changes found when increasing parameter from lowest to highest level.

Parameter Changed	Tg Operator		Jacksetter		Return	
	mg/m <sup>3</sup>	%	mg/m <sup>3</sup>	%	Mg/m <sup>3</sup>	%
Shearer Clearer Spray System						
Airflow	2.42	38	2.79	40	3.28	38
Water quantity	0.29	7	0.51	11	0.48	7
Drum pressure	+0.12	+3	0.78	15	1.65	21
External press.	+0.29	+7	+1.47	+37	+0.50	+8
Basic Spray System						
Airflow	3.56	53	3.11	54	3.45	41
Water quantity	+0.58	+13	+0.20	+ 5	0.16	2
Drum pressure	+0.59	+13	+0.59	+16	0.92	13
External press.	+0.73	+22	+0.62	+19	0.16	3

+ represents a dust level increase when parameter was changed

As shown in Table 3, airflow had the largest and most positive impact on dust levels at all three sampling locations. Increasing airflow on the face by 1.02 m/sec (200 fpm) resulted in an average decrease in dust concentration of 2.83 mg/m<sup>3</sup> (39% reduction) with the shearer clearer spray system and 3.37 mg/m<sup>3</sup> (49% reduction) with the basic spray system. Obviously, the increase in airflow made the most significant impact on dust levels at the shearer and downwind of the shearer.

It should be noted that airflow was the only test parameter that consistently exhibited a decrease in dust levels when changing from the low level of the test parameter to the high level for that parameter. Increasing water flow or water pressure was observed to increase dust levels for some test conditions. All water sprays, to some degree, will induce airflow movement with the water droplets. At higher pressures and flows, greater airflow inducements could be expected, which can create greater turbulence and potentially hinder dust control efforts.

RAM instantaneous sampling results were utilized to develop a dust profile around the shearer for the sampling points along the face. Figure 6 shows the relative dust levels that were measured for the shearer clearer and basic spray systems. As shown, higher air velocities on the face helped confine the dust near the face for a greater distance down the face. Also, dust levels downwind of the shearer were lower when the higher air velocities were supplied.

The test results from the longwall gallery (higher airflows reduce dust levels) appear to contradict the findings of the entrainment work. However, several key differences between these tests are thought to

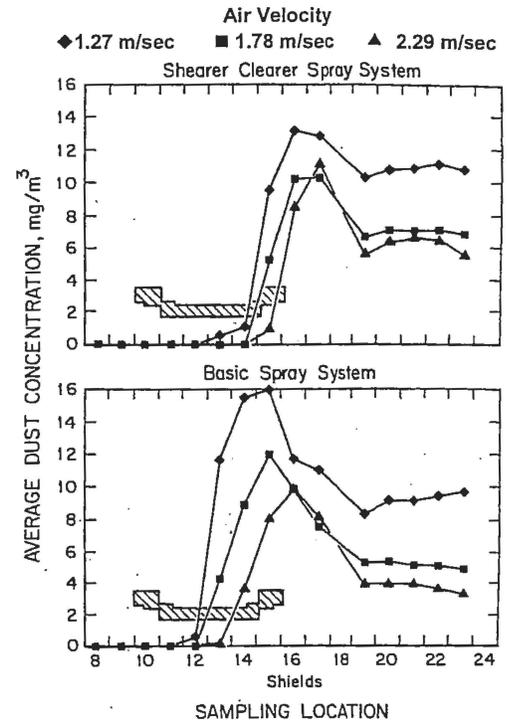


Figure 6. Impact of air velocity on shearer dust levels.

explain the apparent conflict in findings. For the entrainment tests, no water was being applied in an effort to control dust levels and the dust was dropped directly into the airstream. In the longwall gallery, large quantities of water were being applied through two different spray locations and the dust injection points were shielded from direct contact with the air moving down the face. In addition, the magnitude of the air velocity in the entrainment tests was much greater than the gallery testing. As indicated before, previous research has suggested that increasing airflow on longwall faces to higher levels can benefit dust control when control technologies are properly applied (Tomb 1990).

#### 4 LIMESTONE MINE SURVEYS

Mine-wide and localized ventilation systems in underground limestone mines have not been as regulated or structured as those found in coal mining operations. The physical dimensions associated with stoppings for openings that can be 12.2 m (40 ft) wide and 12.2 m (40 ft) high can be challenging and expensive, particularly when these stoppings must withstand the pressures generated by blasting. Consequently, defined airflow patterns are often hard to identify and quantify in underground limestone mines.

#### 4.1 Underground crusher survey

Company officials at an underground limestone mine were concerned that dust liberated at an underground crusher had the potential to rollback toward the fresh air entry. In an effort to prevent this rollback and to move the crusher dust toward the main return, an auxiliary fan was placed near the crusher with fan airflow directed from the intake air toward the main return. Stoppings were also constructed along the belt entry to isolate the belt and direct airflow toward the main return.

Dust sampling was conducted for three shifts with gravimetric samplers operated at 1.7 L/min. Samplers were placed at several locations around the crusher, as shown in Figure 7. Average dust concentrations are provided in Table 4.

Table 4. Sampling Results Around Crusher.

Sampling Station	Average Dust Concentration mg/m <sup>3</sup>
1	0.42
2	3.06
3	9.43
4	4.55
5	0.97
6	2.74

Sampling results from stations 1 and 5 were relatively low and indicated that the fan did prevent rollback toward the fresh air entry. However, dust levels from station 3 indicate that the fan was not effectively moving dust from the area around the crusher. Visual observation of the dust cloud indicated that the liberated dust was suspended in a slow moving airstream. Samples from station 6 also indicated that dust leakage was occurring through the stopping line on the right side of the belt entry.

Based upon these findings, the mine is planning to install additional fan capacity near the crusher in an effort to improve the transport of the dust during dumping and crushing. Additional fan capacity will also improve the air velocity in the belt entry to more quickly move dust toward the return. These sampling results also indicate that the stoppings along the belt entry need tightened to reduce leakage into the parallel entries. After these modifications have been completed, a follow-up survey will be conducted to document the impact on dust levels liberated at the crusher.

#### 4.2 Mine-wide ventilation research

In addition to expressing an interest in improving localized ventilation, this limestone operation is interested in improving mine-wide ventilation. The mine would prepare to conduct face shots at the end of the day shift. After all personnel had evacuated the mine, the face shots would be detonated and no personnel would enter the mine for several hours after

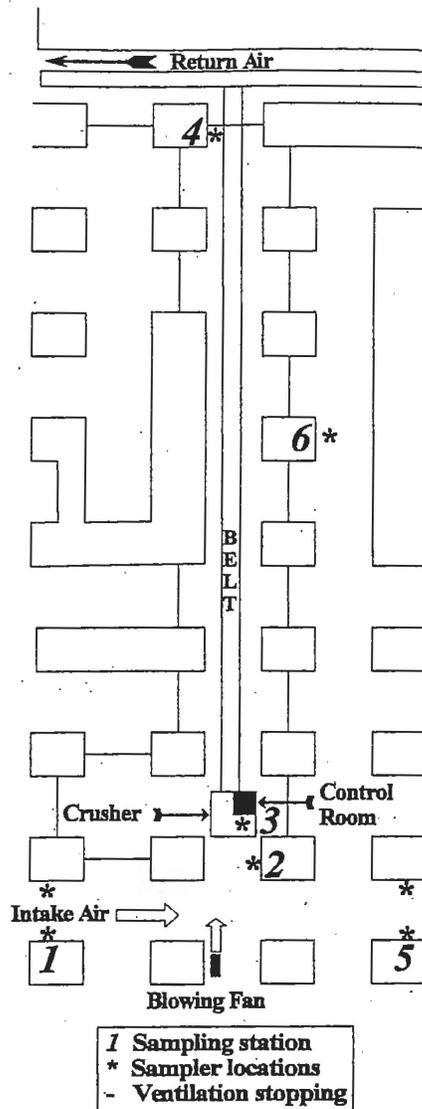


Figure 7. Sampling locations around crusher.

the shots. However, mine personnel did not have information on migration of the dust resulting from the blast or how much time was needed to clear the blast dust from the mine. Preliminary dust sampling has been completed in an effort to document baseline dust levels resulting from blasts at the face. The mine has initiated a mining sequence that will result in a new airflow pattern in a portion of the mine and is also adding additional stoppings to better control airflow patterns. After these modifications have been completed, a second survey will be conducted to document changes in ventilation and its impact on mine dust levels after blasting has occurred.

A similar study has also been initiated at a second underground limestone mine. This mine planned to install additional mine fans and additional mine stoppings in an effort to improve the quantity of airflow and improve control of airflow patterns through the mine. A baseline survey has been completed to document dust levels under existing conditions. After the new mine fans and stoppings have been installed, a follow-up survey is planned to document the impact on airflow and dust migration throughout the mine.

## 5 SUMMARY

In underground mining, ventilating air is a primary control used for diluting liberated respirable dust and moving dust away from mine workers. In underground coal mines, increases in longwall production levels have resulted in the potential to generate larger quantities of respirable dust. In response, mine operators have supplied higher quantities of air in an effort to control dust levels. Results of recent research by NIOSH at the Pittsburgh Research Laboratory have shown that increased airflow can improve dust control at and downwind of the shearer. However, additional testing to simulate dust liberated during shield movement has shown that increased air velocities can entrain higher quantities of respirable dust. These results suggest that with the application of spray water and the shielding of dust sources from high velocity airstreams, higher air quantities can be beneficial.

In underground limestone mines, the difficulty associated with the installation and maintenance of stoppings has hindered the degree to which directed mine-wide ventilation systems have been successfully implemented. Several limestone mine operators are now pursuing the establishment of improved ventilation systems at their mine. NIOSH personnel

are providing technical assistance and sampling analysis to document the impact of improved ventilation in these operations. Similarly, NIOSH is participating with a mine operator to evaluate improved localized ventilation at an underground crusher facility. Baseline dust survey results suggest that the proposed changes in both the mine-wide and localized ventilation systems have the potential to make a significant impact on airborne dust levels.

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