SME Annual Meeting
Feb. 26-28, Denver, Colorado

Preprint 01-144

LABORATORY EVALUATION OF SHIELD DUST ENTRAINMENT IN HIGH VELOCITY AIRSTREAMS

J. M. Listak, G. J. Chekan, and J. F. Colinet
Natl Inst for Occuptnl Sfty and Health
Pittsburgh, PA, USA

ABSTRACT

In conjunction with steady increases in production levels, longwall operators have applied greater quantities of ventilating air and spray water in an effort to control respirable dust and/or methane. Air velocities greater than 7.6 m/s (1500 fpm) have been measured on longwall faces. Operators have expressed concern over the potential entrainment of respirable dust at these high velocities. The greatest likelihood for entraining dust into the high velocity airstream may occur as shields are advanced allowing relatively dry particles to fall from the shield canopy directly into the airstream. Laboratory tests to simulate dust liberation during shield movement were conducted at the Pittsburgh Research Laboratory of NIOSH at velocities ranging from 2.0 to 8.2 m/s (400 to1600 fpm). Airborne dust samples were obtained with personal impactors to quantify the size distribution and concentration of the dust entrained at the various air velocities. Statistically significant increases in both total and respirable dust concentrations were measured as test air velocities were increased.

INTRODUCTION

Longwall mining operations continue to be an increasing contribution of coal production, now accounting for approximately 50% of the underground coal produced in the U. S (Energy Information Administration, 2000). Although advances have been made at mitigating airborne respirable dust along longwall faces, many operations still have difficulty maintaining compliance with federal dust standards. Entrainment of dust along longwall faces contaminates the work place for face workers, thus increasing the risks of coal workers pneumoconiosis and silicosis.

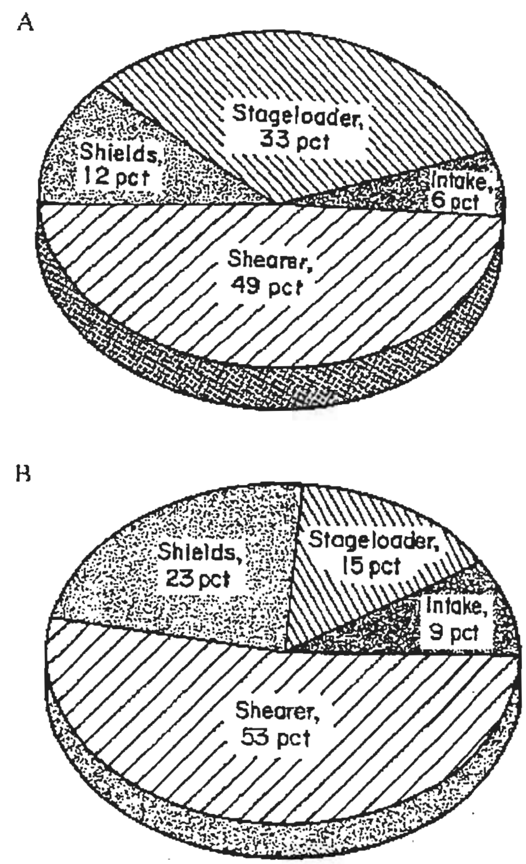

Figure 1. Comparisons of dust source contributions on longwalls from the: A) 1980s and B) 1990s.

Figure 1 compares the contribution of longwall dust from the major sources during the 1980's and 1990's (Colinet and Jankowski, 1997). During the early 1980's, face air velocities ranged from 0.6 to 3.3 m/s (125 to 650 fpm) (Jankowski and Organiscak, 1983), while average production was 810 tons/shift (890 st/shift) in 1981 (Niewiadomski, 2000). During the and 50.8 by 101.6 mm (2 x 4 in) wood framing. The dimensions of the tunnel were 0.6 x 1.2 m (2 x 4 ft) providing an area of 0.7 m^2 (8 ft^2). 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 waterproof painted 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. Two observation windows were built into the tunnel at the material dump point and at the sampling station to observe conditions during testing.

Variable speed axial vane fan: The fan provided a means to adjust air velocity in the tunnel. Air velocity was controlled with a 29.7 kw (40 hp) Joy axial vane fan capable of producing air velocities in the tunnel in excess of 10.2 m/s (2000 fpm). This was coupled with an Allen-Bradley variable speed controller to adjust fan rpm as needed. A 1.2 m (4 ft) long reducer duct between the tunnel and fan was used to transition the round fan opening to the rectangular tunnel and served to reduce shock loss and turbulence on the intake side of the fan. The exhaust side of the fan was connected by duct to a bag house (not shown) which filtered the dust from the air for environmental concerns.

Vibratory material feeder: The feeder provided a controlled means to introduce the material (dust and coarser coal) into the tunnel for each test. The unit was positioned on top of the tunnel as shown in figure 2. The feeder was a Eriez Model FBV-513 with a 0.1 m^3 (4 ft^3) hopper and dual controls to adjust vibration and feed rate. The feeder was retrofitted with a 56 cm (22 in) wide feeder pan that distributed the material across the entire width of the tunnel.

Dust sampling station: The sampling station provided a means to collect dust samples for each test. Dust samples were collected using gravimetric sampling pumps and personal impactors through three ports located in the sides of tunnel. Sampling probes were inserted into each port, which allowed the sampling pumps and impactors to be located on the outside of the tunnel. The distance between the material dump point and the location of the downstream sampling probes was 7.6 m (25 ft), as shown in figure 2.

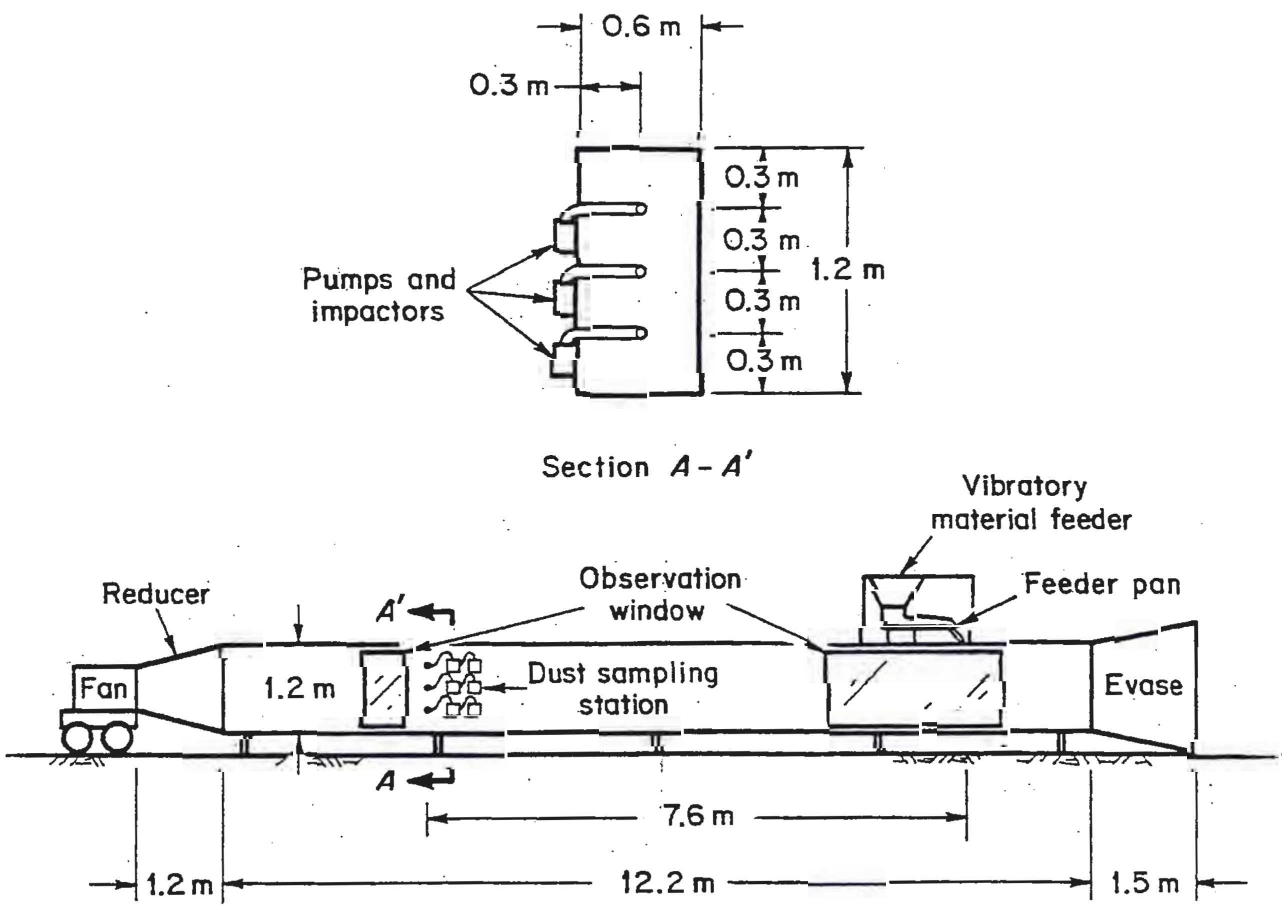

Figure 2. Dust entrainment tunnel schematic.

percent coal dust (less than 50 microns), 25 percent coal 4.75 to 1.18 mm (0.18 to 0.05 in), and 25 percent coal 9.5 to 4.75 mm (0.37 to 0.18 in). The feed rate was varied so test runs were between 20 to 60 minutes in length. A series of preliminary tests were run and it was determined that a material weight of 18.2 kg (40 lbs) introduced into the tunnel in 30 minutes time gave sufficient weight gains on the impactor mylar filters with no filter overloading problems at the different velocities. This material weight and time were standardized for each test. Six test were run at each air velocity for a total of 24 tests.

DATA ANALYSIS

As previously stated, a minimum face air velocity of 2.0 to 2.3 m/s (400 to 450 fpm) is required for improved dust control along a longwall face. Therefore, a velocity of 2.0 m/s (400 fpm) was used as a baseline velocity for data collection and to make comparisons with increased air velocities. The data collected from the dust entrainment tests are shown in Table I. The table shows the total and respirable dust concentrations for each of the six tests conducted at each air velocity. Respirable fractions of the collected dust samples were calculated using methods previously defined in earlier research (Potts et.al., 1990). The table also shows the average and standard deviation of the concentrations, and the 95% confidence interval using a t-distribution. Dust measurements collected by the impactors were also analyzed for size distribution characteristics relative to changes in air velocity.

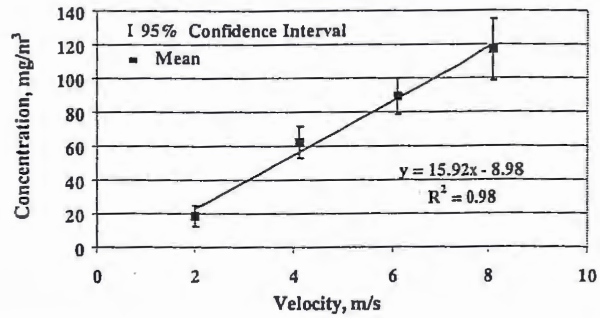

Figure 3. Relationship between total dust concentration and air velocity.

Dust concentrations

The data from Table I clearly show that, as velocity increases in the entrainment tunnel, average dust concentrations rise in both the total and respirable ranges. Figures 3 and 4 show the mean and the 95% confidence interval for total and respirable dust concentrations respectively, as a function of velocity. These figures show graphically how the dust concentrations rise with each air velocity increase. 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.

Table I. Total and respirable dust concentrations at each air velocity

Total dust										
Velocity m/s, (fpm)	Average Concentration, mg/m³ — Test						Mean	Standard Deviation	Ratio to Baseline Dust	95% Confidence Interval (+/-)
	T1	T2	T3	T4	T5	T6				
2.0, (400)	14.43	14.38	15.70	22.94	28.60	15.57	18.60	5.86	------	6.15
4.1, (800)	62.75	64.40	57.34	59.71	77.60	51.06	62.14	8.90	3.30	9.34
6.1, (1200)	80.77	103.03	92.60	93.40	92.16	75.06	89.50	10.00	4.80	10.49
8.1, (1600)	84.24	122.76	132.41	118.68	114.70	129.72	117.08	17.40	6.30	18.26
Respirable dust										
Velocity m/s, (fpm)	Average Concentration, mg/m³ — Test						Mean	Standard Deviation	Ratio to Baseline Dust	95% Confidence Interval (+/-)
	T1	T2	T3	T4	T5	T6				
2.0, (400)	1.03	1.42	1.35	1.51	2.30	1.18	1.47	0.44	------	0.47
4.1, (800)	5.14	6.03	5.52	4.78	7.39	5.04	5.65	0.96	3.80	1.00
6.1, (1200)	8.25	16.43	14.25	13.25	14.03	11.51	12.95	2.80	8.80	2.94
8.1, (1600)	15.39	19.67	24.89	20.73	16.54	21.84	19.84	3.49	13.50	3.67

Figure 6 shows the increase in dust concentration from one velocity to the next for both total and respirable dust. As evident from the graph, the largest increase in total and respirable dust concentrations occurs from the 2.0 to 4.1 m/s (400 to 800 fpm) and 4.1 to 6.1 m/s (800 to 1200 fpm), respectively. After 6.1 m/s (1200 fpm), the increase in dust concentrations level off. Previous studies(Foster-Miller Assc., 1982, Breuer, 1972) have shown that, increases in dust levels begin to occur at about the 2.0 to 2.3 m/s (400 to 450 fpm) velocity range for dust having moisture content of about 3%. Data collected during this study are consistent with the findings from these studies.

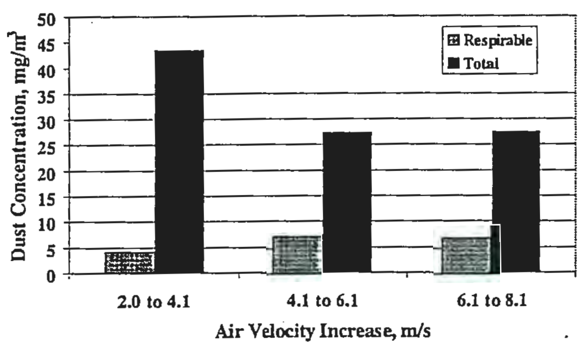

Figure 6. Rise in dust concentrations for each air velocity increase

Size Distribution

Particle size classification is important to examine how dust is transported and to determine its potential health effects on workers. To characterize the dust, multiple stage impactors were used to classify dust particle size in the entrainment tunnel. Table II shows the impactor stages and associated cut points, and the average particle weight for each stage at each velocity. Mass median diameters (MMD) of the dust sample at each velocity were determined and are also shown in Table 2. The MMD gives an overall measure of the size distribution of the particles and specifically 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.

Figure 7 shows the dust weights that were collected on each stage for the four different air velocities during the test. The x-axis shows the particle size of each of the stages ranging from 21 to 0.25 microns. The four curves represent the weight per stage for each of the four test velocities. As is evident in figure 7, an overall trend can be seen for each velocity and at each stage. In general, as the velocity increases from one speed to the next, the weights on each of the individual stages also increase. Therefore, as can be expected, as the velocity increases, less deposition is occurring and more of the dust is being transported further down the airstream. However, the stage weights at 2.0 m/s (400 fpm) remain consistently distributed over the entire range of stages relative to the other weights at the other velocities. The curves representing the three higher velocities show sharp increases in stage weights from 15 to 10 micron cut points and continues to increase into the respirable dust range (<10 microns). The differential in weight for all stages is the greatest at the 6 micron cut point. Comparing the 3.5 and 6 micron cut points to cut points 21 and 15 shows that dust collected at the non-respirable range was small compared to the respirable range.

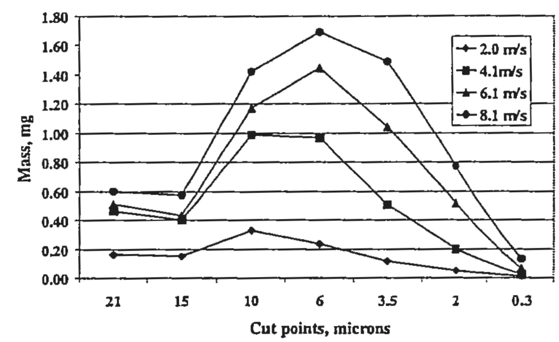

Figure 7. Average dust distribution by impactor cut points.

Table II. Mass on each impactor stage for test velocities

		Average Mass per Stage, mg			
Stage	Cut Points microns	2.0 m/s (400 fpm)	4.1 m/s (800 fpm)	6.1 m/s (1200 fpm)	8.1 m/s (1600 fpm)
1	21	0.159	0.461	0.512	0.599
2	15	0.153	0.400	0.433	0.570
3	10	0.330	0.990	1.172	1.421
4	6	0.232	0.969	1.449	1.691
5	3.5	0.113	0.505	1.041	1.488
6	2	0.048	0.195	0.514	0.770
Final	0.25	0.012	0.022	0.062	0.132

A graph of the mass median diameter at each air velocity is shown in figure 8, 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. This observation is in agreement with other studies (Shankar and Ramani, 1995) that showed similar findings from re-entrainment wind tunnel tests.

Hygiene Association Journal, Vol 60, No. 4, pp. 165-174.

Hall, D.A., 1956, "Factors Affecting Airborne Dust Concentrations with Special Reference to the Effects of Ventilation", Transactions of the Institution of Mining Engineers, Vol. 115, pp. 245-275.

Hartman, H.L., 1961. "Mine Ventilation and Air Conditioning," John Wiley and Sons, New York, p. 85.

Hodkinson, J.R. 1960, "The Relation Between Ventilation Airspeed and Respirable Airborne-dust Concentration in Coal Mines", Colliery Engineering, Vol. 37, No.6, pp. 236-239.

Jankowski, R.A., and Organiscak, J.A., 1983, "Dust Sources and Controls on the Six U.S. Longwalls Faces Having the Most Difficulty Complying With Dust Standards", Bureau of Mines Information Circular (IC 8957), 19 pp.

Niewadomski, G.E., 2000, Mine Safety and Health Administration, personal correspondence.

Organiscak, J.A, Listak, J.M., and Jankowski, R.A. 1985. "Factors Affecting Respirable Dust Generation from Longwall Roof Supports." Bureau of Mines IC 9019, 16 pp.

Potts, D.J., McCawley, M.A., and Jankowski, R.A. 1990, "Thoracic Dust Exposures on Longwall and Continuous Mining Sections", Appl. Occup. Environ. Hyg. Vol. 5, No. 7, pp. 440-447.

Quilliam, J.H. 1994 "Isokinetic Sampling", Journal of the Mine Ventilation Society of South Africa, Vol. 10, No. 7, pp. 153.

Shankar S., and Ramani, R.V., 1995, "Re-entrainment of Coal Dust particles: Wind Tunnel and In-Mine Studies. SME Preprint 95-93, SME Annual Meeting, Denver Colorado, March 6-9, 1995, 8 pp.

Tomb, T.F., Ondrey, R.S., Stoltz, R.T., Haney, R.A., Chiz Novakowski D.L., Atchison, D.L. and Gerbee, E.J., 1991 "Evaluation of Respirable Dust Control on Longwall Mining", SME Transactions, Vol. 288, pp. 1884-1878.