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Correlations Between Measurements with RAM-1 and Gravimetric Samplers on Longwall Shearer Faces

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Simultaneous RAM-1 and gravimetric personal sampler respirable dust measurements were made by the Bureau of Mines at two locations adjacent to a moving shearer on longwall faces. These locations were (1) 4.6 to 6.1 m (15 to 20 ft) on the ventilation intake side of the shearer headgate drum and (2) at the shearer midpoint, between the two operators. Despite the fact that the RAM-1 monitors were laboratory-calibrated to give equivalent readings, underground readings were often lower, particularly at the intake side of the shearer. The RAM-gravimetric ratio of all readings was 0.53 at the intake position and 0.75 at the midpoint position for all data. When only head-to-tail cut passes were analyzed, the RAM-gravimetric ratios were 0.53 at the intake position and 1.00 at the midpoint position. The difference between RAM and gravimetric dust readings is attributed to a combination of factors such as ambient air velocity and cyclone orientation.

Introduction

The Bureau of Mines has recently developed an improved method to evaluate the effectiveness of longwall dust control techniques. This improved method involves the use of a RAM-1 (real-time aerosol monitor), a dust monitor developed by GCA Corp.* under a Bureau contract. The RAM-1 measures dust by the light-scattering principle. It is generally accepted that the response of such devices is quite dependent upon factors such as dust size distribution.

*Reference to trade names, manufacturers, or specific equipment does not imply endorsement by the Bureau of Mines.

It is important to know how well RAM-1 and gravimetric measurements correlate because the RAM-1 is frequently used for dust source and dust control evaluations and differing responses may lead to wrong conclusions.

The data collected in this study involved simultaneous gravimetric and RAM-1 measurements made in proximity to the moving shearer. Analysis of these data yielded an estimate of the difference between the RAM-1 and gravimetric measurements at two positions on a longwall shearer face. This report tells how the difference was determined and analyzes the data for the probable reasons causing this difference.

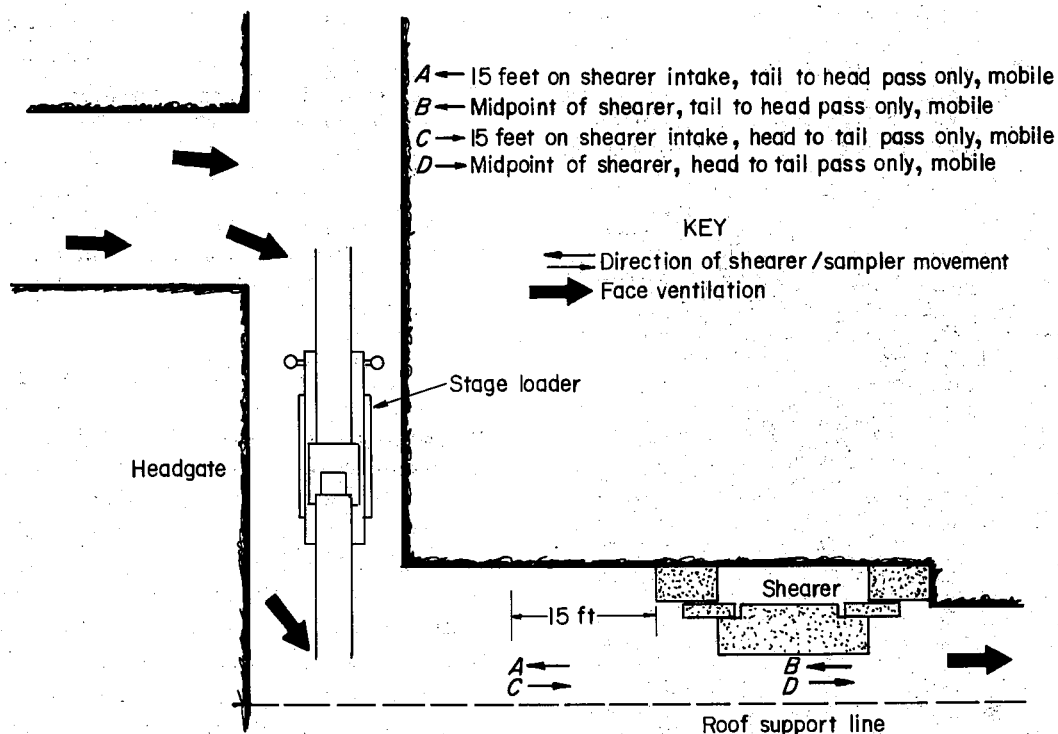


Figure 1 — Plan view of mining/sampling operations.

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Dust Measurement Procedures

The dust measurements used for this study were obtained during a Bureau research program to reduce dust at longwall mining operations. Personal gravimetric measurements and instantaneous measurements using a RAM-1 were made simultaneously at each of two locations: (1) 4.6 to 6.1 m (15 to 20 ft) on the ventilation intake side of the headgate drum (ventilation was from headgate to tailgate) and (2) at the shearer midpoint, between the operators (Figure 1). Eleven double-drum shearer longwall faces with seam heights ranging from 1.8 to 2.4 m (6 to 8 ft) were sampled.

The gravimetric samples were obtained with DuPont model P2500 flow-regulating pumps and sampling heads consisting of the standard 10-mm Dorr-Oliver cyclone and MSA filter cassettes. In general, the samplers were worn by Bureau personnel, a Bureau contractor, MSHA personnel, and the miners where the work was done so that the test crew varied for each mine. Each individual wore a fishing vest (Figure 2), which was equipped with either two or four samplers distributed across the chest from shoulder to shoulder. When only two samplers were worn, they were located one on each shoulder. If four samplers were worn, they were worn high on the chest, as shown in Figure 2. Since the sampling pumps were self-regulating, no flowrate checks or adjustments were made during sampling.

Short-term gravimetric sampling (18 to 87 minutes total time per sample) was performed whereby the test crew fol-



Figure 2 — Sampler vest.

lowed the shearer along the face while maintaining their respective positions (shearer intake and midpoint) in the walkway. These short-term samples represent, for each sample, a total of one to four headgate-to-tailgate (H-T) or tailgate-to-headgate (T-H) shearer passes, and the samplers were operated only during the period that the shearer was cutting coal. In addition, the samplers were not operated during cutouts at the headgate or tailgate.

For most of the gravimetric measurements, each member of the test crew made simultaneous RAM-1 dust measurements. Readings were taken at every third roof support shield. RAM-1 measurements were made with the instrument approximately chest high, in the vicinity of the gravimetric samplers. Individual RAM-1 measurements made during each gravimetric sampling period were averaged to provide a single value corresponding with the gravimetric dust concentration.

Prior to each underground study the RAM-1 monitors were laboratory-calibrated in a static (zero net velocity) chamber so that the concentration readings were equal to those measured with gravimetric samplers. That is, the RAM was calibrated to make the RAM-gravimetric ratio equal to 1.0. The test dust was coal with a mass median size of 8.5 μm .

Data Treatment

Table I gives the RAM-gravimetric dust concentration ratio for all pairs of data. There are 26 pairs for the shearer intake position and 38 pairs for the shearer midpoint.

For both sets of data, a linear regression was made. A statistical t-test was then performed to see if there was any significant difference between the regression slopes and y-intercepts at the two sampling positions. If a significant difference was found, 95% confidence limits for the true population difference were calculated.

A second statistical test was made to see if there was any difference in results when only one cut pass direction was selected. Most of the data pairs (21) for one direction were the H-T cut pass at the shearer midpoint.

Results

The results of the linear regression analyses are shown in Table II. For all data, the y-intercepts for the intake and midpoint positions are 0.16 and 0.33, respectively. The slopes (RAM-gravimetric ratio) for the intake and midpoint positions are 0.53 and 0.75, respectively. The analysis for only H-T cut passes at the shearer midpoint shows that the y-intercept and slope at the midpoint have changed to -0.32 and 1.00, respectively. The same intake data set was used for comparison with the two sets of midpoint data. In Figure 3 all of the intake data and the H-T midpoint data are plotted.

Table III shows that in either case there is no difference in y-intercepts at the 5% significance level, since at the 5% level t_{sample} would have to exceed 2.00. However, there is significant difference in slopes. When all data were analyzed, a $t_{\text{sample}} = 2.39$ was obtained for the difference in midpoint and

TABLE I
RAM-I and Gravimetric Dust Data

Mine	Cut sequence	Intake concentration mg/m ³			Midpoint concentration mg/m ³		
		RAM-I	Grav.	Ratio	RAM-I	Grav.	Ratio
1	H-T cut	ND	1.79	----	1.84	1.99	0.92
	H-T cut	ND	1.87	----	2.33	2.47	.94
	H-T cut	0.76	2.24	0.34	1.94	2.12	.92
	H-T cut	.92	1.64	.56	1.97	2.26	.87
	H-T cut	.65	.68	.96	1.50	1.74	.86
	H-T cut	.77	1.79	.43	2.09	2.38	.88
	H-T cut	1.00	2.04	.49	1.90	2.85	.67
	H-T cut	ND	1.30	----	2.24	1.88	1.19
	H-T cut	ND	1.78	----	1.95	2.74	.71
	H-T cut	1.04	1.46	.71	3.01	2.74	1.10
	H-T cut	1.28	1.93	.66	3.38	3.15	1.07
	H-T cut	1.50	1.60	.94	5.09	4.35	1.17
	H-T cut	1.39	1.84	.76	3.11	2.70	1.15
	2	H-T cleanup	ND	2.09	----	4.13	2.53
T-H cut		ND	.97	----	3.01	2.86	1.05
H-T cleanup		1.20	1.55	.77	3.21	5.33	.60
T-H cut		ND	1.43	----	3.11	6.60	.47
3	H-T cut	.77	1.18	.65	.88	1.41	.62
	T-H cut	1.54	1.53	1.01	3.10	3.47	.89
4	H-T cut	ND	3.15	----	10.51	10.73	.98
	H-T cut	1.78	2.78	.64	8.65	8.21	1.05
	T-H cleanup	.76	1.41	.54	2.64	1.64	1.61
	T-H cleanup	1.35	2.25	.60	3.23	3.52	.92
5	H-T cleanup	ND	1.37	----	6.67	9.78	.68
	H-T cleanup	ND	1.84	----	5.96	7.18	.83
	T-H cut	ND	1.58	----	2.00	2.22	.90
	T-H cut	ND	.54	----	2.96	2.31	1.28
6	H-T cut	3.87	6.58	.59	4.82	6.38	.76
	T-H cleanup	1.53	3.60	.43	2.63	4.47	.59
7	H-T cut	1.42	3.23	.44	1.64	3.10	.53
	T-H cut	1.59	2.57	.62	2.92	5.52	.53
8	H-T cut	1.40	2.40	.58	2.20	3.80	.58
	H-T cut	1.50	1.88	.80	2.80	2.79	1.00
9	H-T cut	2.30	2.36	.97	3.40	3.33	1.02
	H-T cleanup	.70	1.14	.61	1.50	3.70	.41
10	T-H cut	.50	1.08	.46	1.80	2.32	.78
	H-T cut	.40	1.07	.37	2.20	3.23	.68
11	H-T cut	.40	1.03	.39	3.80	5.46	.70

ND = Not determined.
---- = Not calculated.

intake regression slopes. When only H-T cut passes were analyzed, a $t_{\text{sample}} = 5.10$ was obtained, showing a much higher level of significance and definitely indicating that the RAM-gravimetric ratio at the shearer midpoint is not the same as that measured at the shearer intake.

Analysis Results

In seeking a cause for the above differences in RAM-gravimetric ratio, a number of factors were examined, including differences in dust size distribution and/or mineral content between shearer and intake, cyclone orientation, water mist, and stray electromagnetic fields at the shearer midpoint.

The most likely causes are cyclone orientation and differences in dust type, although the difference in size distribution was small, as indicated in the Appendix. The Appendix

also discusses the effect of water mist and stray electromagnetic fields and concludes these are not important.

Cyclone Orientation Effects

The most viable explanation for the changing RAM-I response arose from recent tests by the Bureau of Mines which indicate that cyclone orientation and ambient air velocity effects are the main causes. It will be shown that cyclone orientation and air velocity affect the particle size distribution within the RAM-I instrument, which in turn affects its response.

Figure 4 shows a plan view of cyclone inlet orientations at one location in the longwall face walkway. The small solid arrows represent the air direction into the cyclone inlet. Figure 4 also illustrates gravimetric personal samplers and RAM-I dust monitors located at both the shearer intake and

TABLE II
RAM-1 vs Gravimetric Linear Regression Parameters

	All data		H-T cut
	Intake	Midpoint	Midpoint
N, data points	26	38	21
a ₀ , y-intercept	0.16	0.33	-0.32
a ₁ , slope	0.53	0.75	1.00
r ² , coefficient of determination	0.76	0.74	0.92
S _{y·x} , standard error of estimate	0.35	1.01	0.69
S _{a₀} , standard error of a ₀	0.14	0.33	0.28
S _{a₁} , standard error of a ₁	0.06	0.07	0.07

midpoint positions. Data for the RAM-1 and gravimetric samples at both positions are made up of head-to-tail (H-T) and tail-to-head (T-H) passes.

During sampling on the H-T pass the individual walks down the face with his back to the airflow for three shields, turns perpendicular to the airflow, and makes a RAM-1 measurement (see A in Figure 4). During sampling on the T-H pass, the individual walks up the face facing into the airflow for three shields, turns perpendicular to the airflow, and makes a RAM-1 measurement (see B in Figure 4).

Consider next the gravimetric personal samplers on the H-T pass. For this pass, the cyclone inlets are located 180° to the airflow and are shielded by the wearer most of the time (see C in Figure 4), except when RAM-1 measurements are made. On the T-H pass the cyclone inlets are oriented directly into (0°) the airflow and unshielded by the wearer (see D in Figure 4), except when RAM-1 measurements are made.

For the RAM-1 cyclones, the cyclone orientation remains the same for both passes at both shearer midpoint and intake

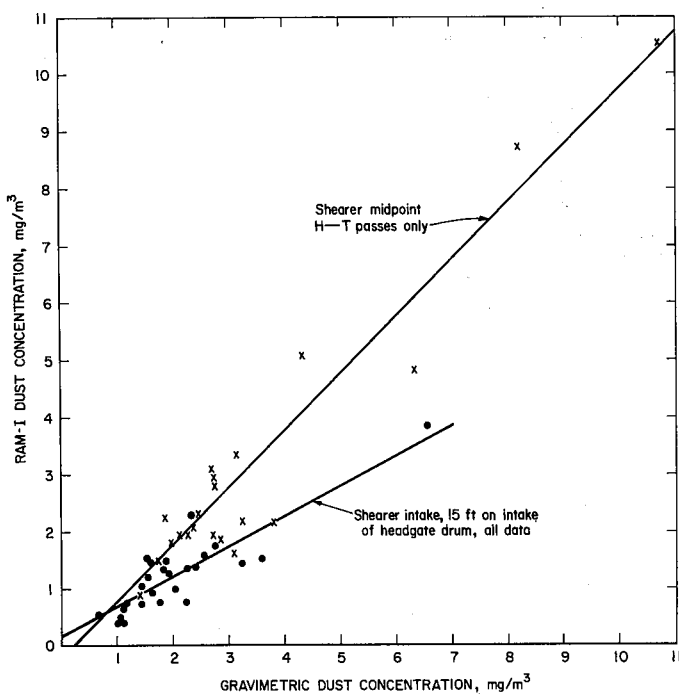


Figure 3 — RAM-1 vs. gravimetric linear regression.

TABLE III
Linear Regression Parameter Test Statistics

Test statistic	t _{.050}	t _{sample}	μ _s = μ _i	95% confidence limits
(μ _{os} - μ _{oi}) ^A	2.00	0.47	Accept	-----
(μ _{is} - μ _{ii}) ^A	2.00	2.39	Reject	0.04 < (μ _{is} - μ _{ii}) < 0.47
(μ _{os} - μ _{oi}) ^B	2.00	1.53	Accept	-----
(μ _{is} - μ _{ii}) ^B	2.00	5.10	Reject	0.29 < (μ _{is} - μ _{ii}) < 0.65

^AAll data.

^BH-T cut passes only.

(μ) denotes true regression parameter with subscripts o, l, s, i, referring to y-intercept, slope, shearer midpoint, and shearer intake, respectively.

positions. They are always oriented 90° to the airflow and unshielded when measurements are made on both H-T and T-H passes (A and B in Figure 4). However, the air velocities at the intake and midpoint positions are different. For the longwall faces studied, the average face airflow velocities were 2.03 m/sec (400 ft/min) and 3.60 m/sec (710 ft/min) at the shearer intake and midpoint positions, respectively.

Preliminary RAM-1 laboratory tests comparing shielded and unshielded cyclones at various ambient airflow velocities and orientations have been made by Cecala *et al.*,⁽²⁾ and a portion of their results pertinent to this study is presented in Table IV. The under- or oversampling results presented are in reference to a cyclone oriented 0° into a low-velocity airflow. From Table IV it is seen that there is significant undersampling, as well as a significant velocity effect, at the 90° orientation. Additional support for an orientation effect was obtained by the Bureau during a recent underground study. The data (Table V) were obtained downwind of a shearer on a longwall face using two RAM-1 instruments *side by side* at various orientations with respect to wind velocity. Once again, the large variations were seen to occur for a cyclone oriented 90° to the airflow. The cyclone at 90° undersampled the 0° cyclone by 24% and 30% in two test series.

It appears then that the RAM-1 samplers are reading lower than the gravimetric samplers in part due to their different orientation with respect to the face airflow. The velocity effect is not so apparent, however. In the laboratory higher velocities produced a greater degree of 90° undersampling. Underground, the undersampling primarily took place at the intake position, which had a lower air velocity. This was possibly due to the fact that the researcher who held the RAM-1 at the midpoint position was actually shielded by the shearer operator, who was standing a few feet upwind of him.

Dust-Type Effect

The shearer midpoint samples are, by nature, a composite of shearer-generated dust as well as intake dust. If the previously discussed results of intake regression slope = 0.53 and midpoint (H-T pass) regression slope = 1.00 are valid, we should expect to see a plot of the midpoint RAM-gravimetric ratio vs shearer dust fraction increase from approximately 0.53 when the midpoint dust is all intake dust to 1.00 when

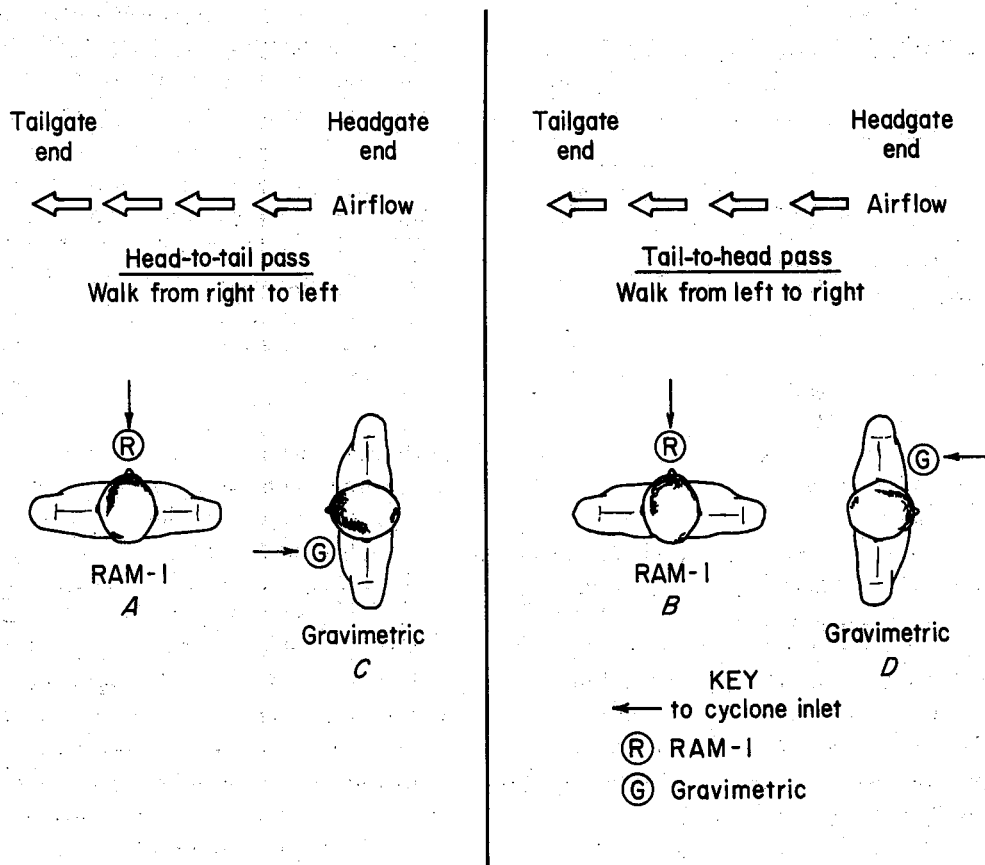


Figure 4 — Cyclone inlet orientations.

TABLE IV
Cyclone Velocity-Orientation Data

Sampler	Cyclone orientation	Condition	Airflow velocity, m/sec	Difference, ^A ± %
RAM-I w/cyclone	90°	Unshielded	2.03	-18
RAM-I w/cyclone	90°	Unshielded	3.60	-32
RAM-I w/cyclone	180°	Shielded	2.03	+9
RAM-I w/cyclone	180°	Shielded	3.60	+4
RAM-I w/cyclone	0°	Unshielded	2.03	+2
RAM-I w/cyclone	0°	Unshielded	3.60	-1

^A+(-) = oversampling (undersampling) referenced to a 0° oriented cyclone in low-velocity airflow where 0° orientation means the cyclone inlet points into or against the airflow.

TABLE V
Underground Cyclone Orientation Data

RAM A, mg/m ³	Cyclone orientation	RAM B, mg/m ³	Cyclone orientation	RAM A - RAM B difference, %
3.7	90°	3.9	180°	-5
3.8	90°	5.0	0°	-24
3.7	90°	5.3	0°	-30
3.4	90°	3.3	90°	+3

Airflow velocity = 3.30 m/sec (650 ft/min).

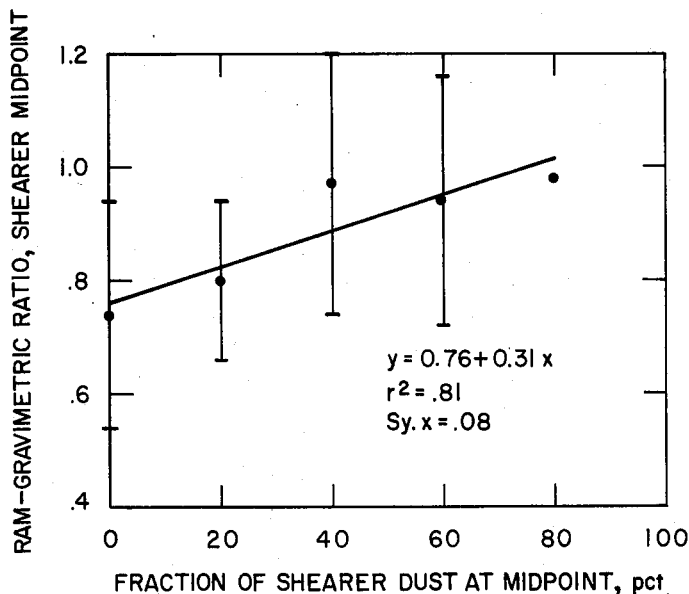


Figure 5 — RAM/Gravimetric ratio vs. shearer dust linear regression.

the midpoint dust is primarily shearer-generated dust. This fraction of shearer-generated dust may be represented by the equation:

$$\text{Shearer dust, \%} = \frac{\text{midpoint concentration (grav.)} - \text{intake concentration (grav.)}}{\text{midpoint concentration (grav.)}} \times 100,$$

and inspection of Table I shows that the percentage of shearer dust at the midpoint (H-T pass) ranges from -6% to +71% (negative value due to either sampling error or dilution effects). There are 21 data points available from Table I, and they were grouped in shearer dust intervals of -10% to 10%, 10% to 30%, 30% to 50%, 50% to 70%, and 70% to 90%. Within each percentage range, all RAM-gravimetric ratios were averaged to obtain a single value representative of that range. The results are shown in Figure 5, which plots the midpoint RAM-gravimetric ratio vs the fraction of shearer dust at the midpoint. The error bars for each interval mid-

point represent the standard deviations obtained from averaging the RAM-gravimetric ratios within each interval. There was only one data point for the interval 70% to 90%. The linear regression shows that the RAM-gravimetric ratio is 0.76 for 0% shearer dust, and 1.01 for 80% shearer dust.

This indicates that differences in dust type, whether differences in size distribution or not, cannot be completely ruled out, even though the Appendix indicates that no statistically significant difference in size distribution could be proven.

Conclusions

The conclusions based on analysis of the data are:

1. There is a significant statistical difference between the RAM-1 and gravimetric ratios at the shearer intake and midpoint positions of longwall faces.
2. It appears that the change in RAM-1 response between the shearer intake and midpoint sampling positions may be due to the dust size distribution at the two positions, although analysis of the gravimetric samples for size distribution and mineral content showed no difference between the two positions.
3. Airflow velocity and cyclone orientation to the airflow direction may have a significant impact on the RAM-1 response because of changes in the size distribution as seen by the RAM-1 caused by inlet bias.
4. The RAM-1 sampling error has minimal impact on shearer intake dust measurements that are small compared with shearer midpoint dust measurements.

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Appendix

Dust Size Distributions

It was initially thought that any significant difference in regression parameters between the shearer intake and midpoint might very well be caused by size distribution effects. This was a logical assumption since the responses of light-scattering devices are sensitive to the size distribution of a dust cloud.

Only 35 gravimetric samples (0° and 180° cyclone orientations only) from 5 mines were available, and 16 of these were analyzed by Coulter counter for size distribution. The results

of the Coulter analysis for each sample were then analyzed by linear regression since dust size distributions are generally lognormally distributed and plots of cumulative probability vs log x are straight lines. The coefficient of determination ranged from .93 to .99.

The range of geometric means (X_g) was from 2.19 to 5.30 μm , and the range of geometric standard deviations (σ_g) was from 1.64 to 3.73 μm . The average X_g was 3.31 μm for all intake positions and 3.09 μm for all midpoint positions. There did not appear to be any substantial difference

between the Xgs, nor did there appear to be a systematic relationship between the intake and midpoint Xgs; *i.e.*, one was not consistently higher or lower than the other, even on a mine-to-mine basis. Statistically, there was no difference between the Xgs at these two positions. It is quite possible that solution preparation for Coulter analysis may have separated agglomerated particles.

Mineral Content

Of the 35 gravimetric samples from 5 mines, 19 were submitted for mineral content analysis. The 19 samples were taken simultaneously with the samples submitted for Coulter analysis since either 2 or 4 gravimetric samplers were worn by an individual. The samples were low-temperature-ashed, redeposited, and analyzed by infrared transmission for mineral content.

The samples had, in most cases, no mineral content other than coal. The only substantial change in mineral content was for two intake positions at one mine where the dolomite content was 17.4% and 24.6%. The only observation made from the data is that these values, being significant percentages, gave two of the lowest RAM-gravimetric ratios (0.37 and 0.39) in Table I. As a result of the analyses, it appears that mineral content is not an explanation for the different RAM-1 responses at the shearer intake and midpoint positions.

Water Droplets in Air

One possible explanation for the different RAM-1 responses is water droplets in the air. Double-drum shearers frequently use external water spray systems on the drums to either suppress the dust⁽³⁾ or keep it confined against the face.⁽⁴⁾ However, what most often occurs is that the water sprays, mixing with the turbulent ventilation air, are blown out into the walkway and create a significant amount of water at the operator's positions. However, tests performed by the Bureau of Mines have shown that the 10-mm cyclone on the RAM-1 inlet is very effective in removing water droplets, due to their size, from the airstream before it enters the RAM-1, and therefore water droplets have very little effect on the RAM-1 response.

Electromagnetic Fields

Another possible effect that was suspected of influencing the RAM-1 response was electromagnetic fields generated by the shearer. A double-drum shearer test facility at the Pittsburgh Research Center was used in a post-test evaluation. Two RAM-1 instruments were located at positions relative to the shearer as previously described. The shearer and panline were energized and trammed with drums rotating. No response of the instruments was observed, thereby eliminating the possibility of electromagnetic effects.

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