

## Influence of coal properties and dust-control parameters on longwall respirable-dust levels

J.A. ORGANISCAK AND J.F. COLINET

J.A. Organiscak and J.F. Colinet, members SME, are mining engineer and industrial engineer, respectively, with the National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory, Pittsburgh, PA. Nonmeeting paper number 98-362. Original manuscript submitted for review October 1998 and accepted for publication April 1999. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME prior to Dec. 31, 1999.

### Abstract

*Longwall mining operations continue to increase extraction rates and the potential to generate higher amounts of airborne respirable dust (ARD). The National Institute for Occupational Safety and Health (NIOSH) has gathered data from underground longwall surveys and laboratory crushing tests to identify the important factors influencing the amount of ARD levels generated. Coal-seam characteristics, operational parameters (i.e., cut sequence, mining height, etc.), extraction rates and dust-control parameters (i.e., airflow, water flow, etc.) were examined to determine their influence on ARD levels measured at longwalls during actual mining operations. ARD generated by a laboratory crusher while crushing bituminous coal samples collected from underground longwalls was also examined to determine if there were correlations with coal-seam properties. Results from the longwall and laboratory data collected indicated that low-ash, high-volatile coals (low moist fuel ratio or MFR coals) generate higher amounts of ARD. It was found that face ventilation and water application to the coal product are essential elements to controlling longwall ARD levels.*

### Introduction

Longwall mining is one of the most efficient underground coal-extraction methods. It now accounts for about 50% of the coal mined underground in the United States (Fiscor, 1997). Since the mid-1980s, improvements in mine layout and equipment design have significantly improved the efficiency of longwall mining (US Department of Energy, 1995). The increase in panel size, equipment power and reliability have allowed the hourly efficiency of longwall mine workers to increase from 1.4 t/h (1.5 stph) in 1983 to 3 t/h (3.3 stph) in 1993 (US Department of Energy, 1995). During this period, the average length and face width of longwall panels have increased by 21% and 39%, respectively. The average panel size in 1994 was 230-m (750-ft) wide and 2,135-m (7,000-ft) long (US Department of Energy, 1995). Power to the average longwall mining operation has nearly doubled, and shearer availability for cutting is, on average, above 95% (i.e., 5% downtime) (Organiscak et al., 1996). These changes in mine layout and equipment design have provided higher coal-seam extraction ratios at higher extraction rates.

Higher longwall mining rates generate larger quantities of airborne respirable dust (ARD) without modification to the dust-control techniques being utilized (Webster et al., 1990). The Mine Safety and Health Administration (MSHA) determined from studying six longwall operations that higher production and lower air-quantity increases the ARD exposure of the shearer operator (Haney et al., 1993). Twenty-seven percent of mine operator-collected longwall shearer

occupation dust samples and 29% of MSHA-collected longwall shearer-operator samples have exceeded the 2.0-mg/m<sup>3</sup>-dust standard between 1988 and 1992 (National Institute for Occupational Safety and Health, 1995). More recent (1993 through 1997) mine-operator dust-sampling results have shown that 21% of the longwall designated-occupation (044 and 060)<sup>1</sup> samples continue to exceed the dust standard (Niewiadomski, 1998). Higher-capacity longwall-mining operations will likely continue to challenge the control of ARD at these operations.

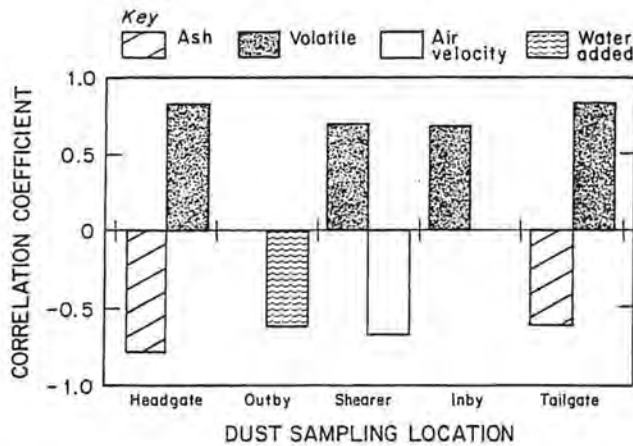
Prior research studies by the US Bureau of Mines (USBM) have shown that coal seam properties also can influence the amount of ARD generated. An underground survey of 20 longwalls operating in 16 different bituminous coal seams throughout the United States indicated that high-volatile, low-ash coal seams (lower-rank bituminous coals) tend to produce more ARD (Organiscak et al., 1992). Additional USBM laboratory work on crushing nine bituminous types of 4.8 to 5.7-mm (0.12 to 0.23 in.) feed coals through a small roll crusher (38.1-mm- or 1.5-in.-diam rolls spaced 3.2-mm or 0.13 in. apart) indicated that lower-rank coals, as described by their inherent moist fuel ratio:  $MFR = ((\text{fixed carbon}/\text{volatile matter})/\text{inherent moisture})$ , also produced more airborne dust (Page et al., 1993). Both of these individual studies indicate that coal seam properties influence the amount of ARD.

Recently, the National Institute

<sup>1</sup>These are coal mining occupation codes used by MSHA: 044 is Longwall Shearer Operator and 060 is Longwall Return Side Face Worker.

**FIGURE 1**

The most significant coal properties and dust-control parameters correlated with longwall dust levels.



for Occupational Safety and Health (NIOSH) completed a surveillance effort to quantify ARD levels, to identify the important dust-generation sources and to document the control technology being implemented (Colinet et al., 1997). During this surveillance effort, run-of-mine (ROM) coal product samples were also collected during mining to investigate the coal properties influence on ARD generated at these operations. Run-of-mine product coal samples were collected from 12 of the longwall operations surveyed. These ROM samples were air dried to determine the weight percent

water, and a proximate analysis was performed after laboratory crushing tests. Enough of the coal sample was available from nine of the operations to run laboratory dust-generation crushing tests under controlled laboratory conditions to determine the dustiness of the various coal types. This research report investigates and compares the influence of coal properties, operational factors and dust-control parameters on longwall ARD levels and the effect of coal properties on dust generated in the laboratory. Identification of the primary factors involved in longwall ARD levels could provide operators with important information for dust-control planning.

**Investigation methodology**

**Underground data collection.** To obtain data on operations from different mining regions of the United States, the underground ARD surveys were conducted at longwall mining operations in Alabama, Colorado, Illinois, Pennsylvania, Utah and West Virginia. More specific details concerning these longwall dust surveys can be found in Colinet et al., 1997. Both fixed-point and mobile ARD samples were collected with personal gravimetric samplers with a 10-mm-diam, Dorr Oliver nylon cyclone<sup>2</sup> operating at 2 L/min. The ARD concentrations measured by these personal dust samplers are not reported as mining research establishment (MRE) equivalents (Tomb et al., 1973). These samplers were operated on the longwall face for an extensive portion of the shift during coal extraction (up to six hours). Fixed sampling locations on the face were in the worker walkway at the headgate area of the face (approximately at

<sup>2</sup>Mention of any company name or product does not constitute endorsement by NIOSH.

**TABLE 1**

Longwall summary data by cut sequence (Colinet et al., 1997). Table gives average values with standard errors in parenthesis.

Operational variable	Bidirectional Cutting, 4 operations		Unidirectional head-to-tail cut, 3 operations		Unidirectional tail-to-head cut, 4 operations		Half-face <sup>1</sup> cutting, 1 operation	
	H-T	T-H	H-T	T-H	H-T	T-H	H-T	T-H
Face width, m	244 (21)		178 (14)		231 (14)		244	
Cutting height, m	2.0 (0.2)		2.4 (0.2)		2.7 (0.4)		2.7	
Cutting rate, m <sup>3</sup> /min	16.1 (2.7)		18.6 (2.4)		15.2 (4.2)		15.6	
Air quantity, m <sup>3</sup> /s	15.0 (2.3)		13.9 (4.7)		32.4 (6.2)		11.3	
Air velocity, m/s	2.4 (0.2)		1.7 (0.5)		3.8 (1.4)		1.5	
Water flow, L/min	365 (36)		439 (77)		360 (35)		303	
Spray pressure, kPa	1,034 (117)		574 (207)		1,302 (311)		827	
Water added to coal <sup>2</sup>	2.8 (0.6)		1.9 (0.5)		2.3 (0.7)		3.6	
Headgate ARD, mg/m <sup>3</sup>	1.0 (0.3)		1.3 (0.2)		1.1 (0.2)		1.1	
Tailgate, mg/m <sup>3</sup>	2.6 (0.4)		4.2 (0.8)		2.7 (0.6)		2.0	
Mobile ARD sampling Locations	H-T cut	T-H cut	H-T cut	T-H clean	H-T clean	T-H cut	H-T	T-H
Outby shearer, mg/m <sup>3</sup>	2.2 (0.3)	1.8 (0.5)	3.5 (1.0)	2.8 (0.8)	2.0 (0.5)	2.0 (0.7)	2.2	1.8
At shearer, mg/m <sup>3</sup>	2.6 (0.1)	3.1 (0.8)	5.4 (1.0)	5.8 (0.8)	2.4 (0.6)	2.9 (0.8)	2.4	3.2
Inby shearer, mg/m <sup>3</sup>	4.1 (0.5)	2.9 (0.6)	12.6 (7.1)	7.0 (1.7)	4.4 (1.5)	4.4 (1.2)	3.7	2.7

<sup>1</sup> Head-to-tail pass — cleanup shield 60, cut to tailgate; Tail-to-head pass — cleanup to shield 60, cut to headgate.

<sup>2</sup> Percent weight loss of moisture from air drying the ROM coal collected outby the shearer.

shield ten) and tailgate area of the face (approximately 10 shields from the end of the face). Mobile sampling locations were conducted in the worker walkway by NIOSH employees 7.6 m upstream (outby) of the shearer, at the shearer (near the tailgate side of the shearer body) and 15.2 m downstream (inby) of the shearer. A pair of personal samplers were operated during mobile sampling of each mining direction with respect to airflow, so the individual head-to-tail (H-T) and tail-to-head passes could be isolated for dust levels.

Operational and dust-control parameters were documented and measured during these dust surveys. All 12 longwalls used an external shearer clearer-type spray system on the shearing machine to control ARD levels around the shearing machine (Jayaraman et al., 1985). The operational parameters documented include longwall face width, seam height, web cutting depth, shearer haulage speed and cut sequence. Dust-control parameters measured included face airflow measurements, shearer water flow and cutting-drum water-spray pressure. Air velocity was measured every sampling shift at ten shield intervals along the face with a vane anemometer. A water flowmeter was installed in line to the shearing machine to determine total shearer water usage during mining, and a water pressure gauge was used to measure the drum pressure during an idle production period with all the shearer sprays operating.

ROM coal product samples from a cut pass were also collected from several conveyor locations outby the shearer. The longwall and panel belt conveyors were shut down for a few minutes during a cut pass and a cross section of coal was shoveled and collected from the panline outby the shearer, near the face conveyor transfer point (before the crusher) and the panel belt conveyor (outby the stage loader-crusher). The coal sampling strategy was to collect the coal product between water-spray application points to determine the amount of water applied by the spray systems (shearer sprays, transfer-point sprays and stage loader-crusher sprays). All the ROM samples collected were transported back to the laboratory from

the mine in airtight buckets.

**Laboratory tests.** The laboratory crushing test facility was comprised of a roll crusher located in the intake end of a 1.2-m- (4-ft-) high, 0.6-m (2-ft) wide, 6.1-m (20-ft-) long wood-framed, plastic-sheath-enclosed wind tunnel. A dust collector and exhaust fan were located at the discharge end of the tunnel. The crusher was a 1.1 kW compact double-roll crusher (79.4-mm-diam rolls) operating at approximately 70 rpm with twenty-four 12.7-mm- (0.5-in.) high staggered teeth on each roll. An inductive current transformer ( $\pm 0.1$  amp) was installed to monitor the crusher's current usage. The crusher's operating capacity was 227 to 1,361 kg/h (500 to 3,000 lb/hr) of up to 101.6 mm (4-in.) feed size lumps of coal or rock material.

The ROM coal samples were processed in the laboratory to determine the water weight added to the samples, the ARD generated from roll-crushing experiments, the size distribution of the roll-crushed product and the inherent coal constituents. Water weight added to the ROM product was determined by pre- and post-weighing the air-dried coal-product samples. The air-dried samples from each mine were combined and screened into four size ranges. The ROM product below 12.7 mm (0.5 in.) was not used for the crushing experiments, because the product size of the crusher was  $\leq 12.7$  mm (0.5 in.). Equal portions of the 12.7 x 19-mm (.05 x 0.75-in.), 19 x 25.4-mm (0.75 x 1-in.) and 25.4 x 50.8-mm (1 x 2 in.) ROM coal product sizes were mixed together for the crushing experiments. Preliminary crusher testing of various feed sizes of Pittsburgh coal obtained from PRL's experimental mine showed that the equivalent three-size mix provided good test repeatability for product size, crushing energy and ARD concentrations. Schuhmann product-size-function parameters (as defined in Table 4) for this Pittsburgh Research Laboratory (PRL) coal-tested crushing procedure averaged  $15.07 \pm 0.23$  mm ( $0.593 \pm 0.009$  in.) for the top size parameter (*a*) and  $0.87 \pm 0.02$  for the exponent parameter (*b*) at the

**TABLE 2**

**Longwall coal seam characteristics.**

Mine	Coal seam	Air dry loss moisture <sup>1</sup> % wt.	Inherent moisture <sup>2</sup> % wt.	Ash content <sup>2</sup> % wt.	Volatile matter <sup>2</sup> % wt.	Fixed carbon <sup>2</sup> % wt.
A	Blue creek	2.7	0.6	35.8	17.5	46.2
B	Sewickley	0.7	0.9	35.8	28.0	35.4
C	B seam	3.2	3.0	6.4	39.3	51.3
D	D seam	3.8	3.9	20.6	34.6	41.0
E	F seam	8.4	5.3	7.0	37.5	50.2
F	Herrin #6	5.2	3.2	15.6	31.7	49.5
G	Wadge	3.8	3.4	13.5	37.0	46.1
H	Pittsburgh	0.7	0.9	11.3	36.0	51.8
I	Lower Kittanning	1.5	0.9	60.2	18.7	20.2
J	Wattis	2.5	1.5	8.4	50.3	39.8
K	Sunnyside	1.2	0.7	39.0	27.9	32.4
L	Blind canyon	2.0	1.8	11.4	42.7	44.1

<sup>1</sup>Reported as a percent weight on an as-received basis.

<sup>2</sup>Reported as a percent on an as-determined basis (weight percentages determined without the air-dry loss).

**TABLE 3**

Correlation matrix of longwall operational variables and dust levels. Key:

**Bold number:** Correlation confidence level  $\geq 95\%$ ;  
**Nonbold number:**  $85\% \leq$  Correlation confidence level  $< 95\%$ ; and  
**Blank:** Correlation confidence level  $< 85\%$ .

Ash	Volatile	MFR	Seam height	Cut rate	Air velocity	Water flow	Water added	HG dust	Outby shearer	At shearer	Inby shearer	TG dust	
<b>1.00</b>	<b>-0.85</b>	0.48	<b>-0.63</b>					<b>-0.78</b>					Ash
	<b>1.00</b>	<b>-0.68</b>	0.50	<b>0.62</b>	-0.56	0.45		<b>0.82</b>		<b>0.68</b>	<b>0.67</b>	<b>0.84</b>	Volatile
		<b>1.00</b>	-0.47	-0.53	<b>0.83</b>			-0.44		-0.48		-0.57	MFR
			<b>1.00</b>	<b>0.62</b>									Seam height
				<b>1.00</b>	-0.51	<b>0.59</b>					0.47	0.52	Cutrate
					<b>1.00</b>				-0.50	<b>-0.69</b>	-0.48	-0.48	Air velocity
						<b>1.00</b>					0.56	0.48	Water flow
							<b>1.00</b>	-0.45	<b>-0.60</b>				Water added
								<b>1.00</b>		<b>0.63</b>	<b>0.63</b>	<b>0.75</b>	HG dust
									<b>1.00</b>	<b>0.57</b>			Outby shearer
										<b>1.00</b>	<b>0.82</b>	<b>0.73</b>	At shearer
											<b>1.00</b>	<b>0.80</b>	Inby shearer
												<b>1.0</b>	TG dust

95% confidence level. Additionally, the energy consumption and ARD levels for this procedure averaged  $77.09 \pm 6.08$  W·min and  $6.17 \pm 1.81$  mg/m<sup>3</sup>, respectively, at the 95% confidence level. Only nine of the 12 longwall coal samples had a sufficient amount of the +12.7-mm (+0.5-in.) material for laboratory-crusher testing. This was because the proximate analyses for inherent coal constituents (American Society for Testing and Materials, 1996) were conducted on a substantial portion of three ROM coal samples after air-drying. The equivalent mix of 12.7 x 19, 19 x 25.4 and 25.4 x 50.8-mm ROM coals from these longwalls were roll-crushed while monitoring for current usage and ARD.

Dust sampling was conducted at a location 3 m (10 ft) downstream of the crusher and approximately 2.4 m (8 ft) upstream of the tunnel transition to the dust collector and exhaust fan. Dust sampling was conducted with two Sierra 298 personal sampling impactors, each operated at 2 L/min and positioned at one-half the tunnel height from the floor and one-third the tunnel width from the wall. The impactor Stages 1 through 6 (20 to 1.55 μm cut-point sizes) were used with the <1.55 μm particles sizes collected on the final filter. An MIE RAM-1 real-time, light-scattering instrument continuously monitored the respirable fraction of dust from a 10-mm Dorr Oliver cyclone, located in the middle of the sampling location. All the sampler inlets were faced into the airflow with the impactors using the inlet cowl. Air velocities were determined from the time it took the dust to travel 3 m (10 ft) to the RAM-1 sampling location after crusher startup. Preliminary crushing tests indicated

that the lowest possible wind-tunnel air velocity to maximize dust concentrations and mass collection was 0.10 m/s (0.076 m<sup>3</sup>/s air quantity). Lower velocities permitted dust to escape from the tunnel inlet, so wind tunnel airflow was targeted for 0.10 m/s for all the experiments. Following these laboratory tests, the crusher product was screened for size analysis and riffled to obtain a sample for proximate analysis of the coal for its inherent constituents (American Society for Testing and Materials, 1996).

**Data analysis**

The 12 longwalls surveyed with ROM coal-characteristics data were included in this analysis. The longwall surveillance data is published in Colinet et al. (1997). This data was reexamined by mining sequence classifications, correlation analysis and scatter-plot examination. Operational, dust control and ARD data were summarized with respect to longwall mining sequence (cutting and/or cleanup direction) to examine for dominant longwall features associated with coal extraction methods. Correlation analysis and scatter-plot examination were also conducted on the mine data for identification of the important associations between operating parameters, dust-control parameters, seam characteristics and ARD levels. Significant correlations are defined in this analysis as those with confidence levels  $\geq 95\%$ , and less significant correlations are defined in this analysis as those with confidence levels  $< 95\%$  and  $\geq 85\%$ .

The laboratory data was used to determine the Schuhmann size function parameters, specific energy of

**TABLE 4****Laboratory crushing test results.**

Mine	Coal seam	Schuhmann top size <sup>1</sup> , Parameter <i>a</i>	Schuhmann exponent <sup>1</sup> , Parameter <i>b</i>	Specific energy, <i>W</i> *min/kg	Specific ARD, mg/kg	Normalized ARD, mg/kg/ <i>W</i> *min
A	Blue creek	NS	NS	NS	NS	NS
B	Sewickley <sup>2</sup>	18.0	0.93	15.6	14.8	0.08
C	B seam	16.2	1.13	2.8	10.2	0.23
D	D seam	15.5	1.01	2.7	9.3	0.23
E	F seam	NS	NS	NS	NS	NS
F	Herrin #6	15.5	0.93	2.8	10.6	0.45
G	Wadge	16.4	1.05	2.6	4.3	0.16
H	Pittsburgh <sup>2</sup>	19.3	0.94	13.9	6.7	0.03
I	Lower Kinnanning <sup>2</sup>	23.0	0.90	20.5	8.9	0.04
J	Wattis	NS	NS	NS	NS	NS
K	Sunnyside <sup>2</sup>	24.2	0.91	29.2	7.5	0.02
L	Blind canyon	16.6	0.88	3.8	14.3	0.32

<sup>1</sup>Schuhmann size function:  $Y = (X/a)^b$

where

*Y* is the cumulative percent of weight less than,

*X* is the size of the particles, mm,

*a* is the Schuhmann top size regression parameter and

*b* is the Schuhmann exponent regression parameter.

<sup>2</sup>Rock present in ROM coal samples collected.

NS means either no ROM coal sample or insufficient ROM coal sample available for laboratory roll crushing tests.

crushing, specific ARD and normalized ARD (for crushing energy). The Schuhmann size function parameters *a* and *b* of  $Y = (X/a)^b$  (Schuhmann, 1940) were determined by nonlinear least-squares regression of the cumulative size-distribution data. The specific energy was determined from crusher current, crusher voltage, crushing time and weight of the material crushed. Specific ARD was determined by applying the ACGIH definition of respirable dust to the mass collected on the Sierra 298 Impactors (Potts et al., 1990), the sampling rate, the sampling time, the tunnel air quantity and the weight of material crushed.

Because the specific energy was notably increased by the rock in some of the ROM coal, the specific ARD was normalized for the power consumption of crushing. Correlation analysis and scatter-plot examination were used on this laboratory information to identify coal properties related to ARD generation.

### Longwall survey results

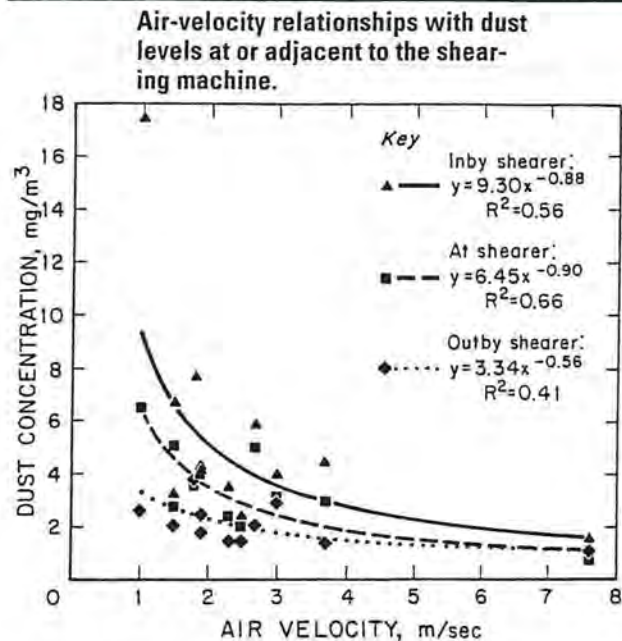
**Cut sequence.** Data from the longwall surveys were classified by cut sequence, and averages were calculated. These summary results are shown in Table 1. Initial examination of this table show that the longwalls using the H-T unidirectional cut sequence had the highest mobile ARD levels outby, at and inby the shearer during both the cut and cleanup segments of the mining cycle. To deduce if this particular cut sequence had a major effect on ARD levels, the cutting segment of this mining cycle was compared to a similar cutting segment of the bi-directional operations. Any noticeable differences in ARD levels for comparable cutting directions should be reflected by the differences in other operational and dust-control parameters.

Comparative examination of ARD levels for the same H-T cut direction of unidirectional and bi-directional operations showed higher ARD levels for the H-T pass of the unidirectional operations. Inspection of longwall operational and dust-control parameters showed that the H-T unidirectional cutting operations also had the least desirable measures with respect to controlling ARD levels. The factors that likely influenced higher ARD concentrations measured at these unidirectional H-T cut-sequence operations include higher extraction rate, lower face ventilation quantity/velocity, lower water pressure use at the cutting drums and less water added to the ROM coal. Correlation analysis between these parameters, coal characteristics and ARD levels are discussed below.

**Coal properties.** Correlation analysis and scatter-plot examination show that coal properties tend to have the highest correlations with longwall ARD, but operational variables also affect ARD levels and are highly interrelated to the coal seam properties. The mobile ARD levels measured for each cut sequence direction were time-weighted averaged to obtain an average concentration at these mobile locations for the correlation analysis. The ROM coal-product characteristics of these 12 longwalls surveyed are shown in Table 2. Variable associations and their significance levels are shown by the correlation matrix in Table 3, and the most significant correlations observed from the underground survey are shown in Fig. 1.

As can be seen in Fig. 1 and Table 3, the coal seam properties had significant correlations with most of the ARD sampling locations. Volatile content was positively and significantly correlated with almost all the sampling

**FIGURE 2**



locations. Ash had significant negative correlations at the fixed headgate and tailgate fixed sampling locations. Less significant correlations were observed for the inherent MFR, where  $MFR = (\text{fixed carbon/volatile matter}) / (\text{inherent moisture})$ , at the headgate, shearer and tailgate. These results reflect similar trends observed in previous studies (Organiscak et al., 1992; Page et al., 1993).

However, these seam properties were also significantly correlated to other operational variables (Table 3). Volatile matter had a significant positive correlation to coal extraction rate and ash had a significant negative correlation to seam height. Because volatiles and ash are both significantly and negatively correlated, the seam height also shows a significant correlation to the coal extraction rate. Longwalls in this study that operated in lower-ash, higher-volatile coals mined from thicker coal seams at higher extraction rates exhibited higher ARD levels. Coal characteristics are geologically related and uncontrollable by the mine operator.

**Dust-control parameters.** Dust-control parameters notably impacted ARD levels at several of the mobile sampling locations. Air velocity had a significant negative correlation to ARD levels at the shearer, while water added to the ROM product by the shearer had a significant negative correlation to outby shearer dust concentrations (Fig. 1 and Table 3). These correlations demonstrate that, at higher air velocities and when higher water percentages are added to the coal product, the ARD levels around the shearing machine are reduced. Both air velocity and water added to the coal showed similar, but less significant, correlations at other dust-sampling locations along the face, suggesting a beneficial effect of these dust-control parameters on ARD levels along the face.

Scatter-plot examination showed that the air velocity effect is a nonlinear relationship and that the water added effect is a linear relationship to ARD levels (Figs. 2 and 3). Nonlinear regression of an inverse power function ( $y = ax^{-b}$ ) to the air velocity and ARD levels show

that statistically significant relationships exist at all mobile sampling locations around the shearer (Fig. 2), explaining between 41% and 66% of the ARD variations. The most notable air-velocity impact on ARD levels are between 1 and 3 m/s. Shearer water added to the coal product shows a linear relationship with outby ARD levels with respect to the shearer (Fig. 3), explaining 38% of the ARD variation. A less significant linear correlation was also observed at the headgate sampling location. Other research has also shown that increasing air velocity and water usage at a particular longwall operation noticeably improved ARD levels (McClelland et al., 1987). Therefore, good air velocity along the face and water spray application to the coal product are the important dust-control parameters that influence longwall ARD levels and are controllable by the mine operator.

Other quantifying water and air-usage measurements did not seem to have as much impact on dust levels in this study. The shearer water flow showed no correlation with the water added to the ROM coal product outby the shearer, suggesting inconsistent proportioning of the available shearer water supply between the cutting drums and external sprays at these longwalls. Prior studies have shown that higher water flow through the cutting drum sprays reduces longwall dust concentrations (Jankowski and Organiscak, 1983; Kok et al., 1986). Others recommend a useful guide of water application to the mined coal of 2% to 4% by weight (Goddard et al., 1973). Correlations between air quantity and ARD levels were noticeably weaker than the air velocity correlations and were not included as part of the correlation matrix of Table 3. Finally, drum spray pressure had poor correlation to all of the operational, coal seam and ARD longwall variables and were also not included in the correlation matrix shown in Table 3.

### Laboratory crushing results

Similar longwall ARD and coal-characteristic trends were observed for the laboratory crushing tests when the laboratory ARD generated was normalized for the energy effect of rock present in some of the ROM coal samples. The laboratory crushing tests show higher specific-energy measurements and product top-size parameters for the ROM coal samples containing rock material. Table 4 shows the laboratory data for the nine ROM coal samples crushed, and Table 5 shows the correlation matrix for the laboratory test variables. The visible rock present in the ROM coal samples for mines B, H, I and K corresponded to notably higher specific-energy measurements than the other coal samples (Table 4). This association can also be seen in the high correlation coefficient between the ash content and the specific energy of crushing in Table 5. A similarly high correlation can also be observed in Table 5 between the Schuhmann top-size parameters, coal properties and specific energy of the laboratory crushed material. Therefore, the rock content in the ROM samples significantly affected the specific energy and crushed product variables in the laboratory.

The size distributions of the airborne dusts generated were similar for the various ROM coals crushed. The mean mass aerodynamic diameter and the geometric standard deviation for all the tests averaged  $14.3 \pm 0.9 \mu\text{m}$  and  $2.2 \pm 0.3$ , respectively, at the 95% confidence level. The specific ARD generated was determined from

**TABLE 5**

**Correlation matrix of seam constituents and laboratory crushing variables. Key:**

**Bold number: Correlation confidence level ≥ 95%;**  
**Nonbold number: 85% ≤ Correlation confidence level < 95%;**  
**Blank: Correlation confidence level < 85%.**

Ash	Volatile	MFR	Specific energy	Schuhmann top size	Schuhmann exponent	Specific ARD	Normalized ARD	
<b>1.00</b>	<b>-0.94</b>	-0.55	<b>0.76</b>	<b>0.77</b>			-0.58	Ash
	<b>1.00</b>	-0.54	<b>-0.71</b>	<b>-0.70</b>				Volatile
		<b>1.00</b>	<b>0.90</b>	<b>0.80</b>	-0.54		<b>-0.79</b>	MFR
			<b>1.00</b>	<b>0.96</b>		-	<b>0.80</b>	Specific energy
				<b>1.00</b>			<b>-0.80</b>	Schuhmann top size
					<b>1.00</b>			Schumann exponent
						<b>1.00</b>		Specific ARD
							<b>1.00</b>	Normalized ARD

these mass distributions, sampling time, air quantity and weight of material crushed. Specific ARD had low correlations to the coal seam properties, product size parameters and specific energy of the crushing tests, ranging between 0.01 and 0.36. Because specific energy was the most dominate crushing variable due to the presence of rock in some of the coal samples (Table 4), specific ARD was normalized for energy consumption to examine ARD generation on an equivalent energy basis. Correlation of ash, volatile and MFR (highest correlation) with the normalized ARD levels noticeably improved, ranging between 0.51 and 0.80. The volatile content had a correlation of 0.51 at the 84% confidence level (not shown in table). These seam property correlations were similar to the associations observed with the underground data in this and prior studies (Organiscak et al., 1992; Page et al., 1993).

**Conclusions**

A survey of 12 longwalls located geographically across the United States showed noticeable ARD level correlations with the inherent properties of the ROM coal product, air velocity and water added to the coal. The operations mining low-ash, high-volatile coals (generally low inherent MFR coals) had significantly higher ARD levels at many of the fixed and mobile sampling locations. These coal-seam properties were also highly correlated with other longwall operational and dust-control parameters that can influence ARD levels. In general, the longwalls in this study that mined low-ash, high-volatile coal types operated at faster mining rates, used lower air velocities and they applied less water to the coal product.

The dust-control parameters that showed significant influence on longwall ARD levels were air velocity and the amount of water added to the coal. Significant inverse relationships were observed for air velocity and ARD levels at all mobile sampling locations around the shearer. These air velocity and ARD relationships efficiently fit an inverse power model ( $y = ax^{-b}$ ) outby, at and inby the shearer location, explaining between 41% and

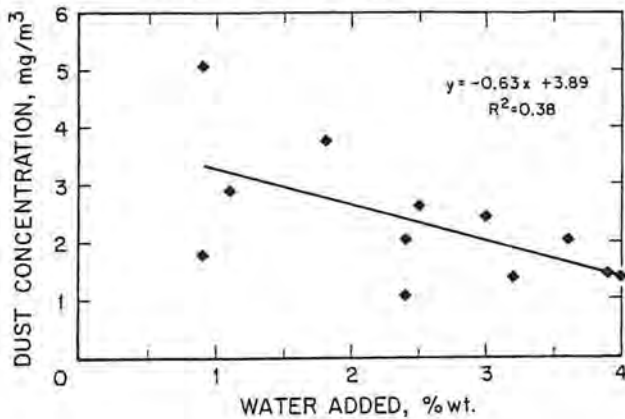
66% of the ARD variations. ARD relationships with air quantity were less significant than the air velocity relationships. The percent weight of water added to the ROM coal product by the shearer had a significant negative correlation with the ARD levels at the outby shearer sampling location. A negative linear model ( $y = ax + b$ ) explained 38% of the ARD variations. Proportioning more water flow through the shearer cutting drums is the most direct approach for increasing the amount of water added to the ROM coal. Both ventilation and water application to the coal product were the most controllable parameters in this study that significantly influenced ARD levels around the shearing machine.

Similar longwall ARD and coal-characteristic trends were observed for the laboratory crushing tests when the laboratory ARD generated was normalized for the energy effect of rock present in some of the ROM coal samples. Laboratory crusher testing of the ROM coal samples showed that the specific energy of crushing was the most dominant variable. Rock present in some of the coal samples that were crushed produced wide variations in the specific energy levels, which was significantly correlated to the coal seam properties and product size parameters. Specific ARD generated had low correlation to all of these crusher variables, but ARD correlations improved when specific ARD generated was normalized for crusher energy consumption.

Because the specific energy of crushing was an important factor measured in the laboratory crushing tests, the specific energy applied by the shearer to cut coal and/or rock could likely influence ARD levels through extraction rates. Although little specific-energy information exists from underground dust studies, the important variable affecting ARD levels underground is extraction rates. Increasing extraction rates without respective changes to ventilation and water application will increase ARD levels. ■

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**FIGURE 3****Relationship between the amount of water added to the coal and dust levels outby the shearer.**

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