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# **Longwall Operational Parameters and Dust Levels Measured in Poland's Coal Mines**

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A joint Polish and US research project was conducted on respirable coal dust generation under the Maria Skłodowska-Curie Joint Fund II. This project investigated coal seam parameters and its effect on respirable dust generation, so dust control recommendations could be formulated for Poland's longwall mining operations. During this project 8 longwalls were surveyed in Poland's coalfields. Operational parameters coal compressive strengths, production rates, dust control parameters, and dust levels were measured during these longwall surveys. This paper will examine the results from these underground surveys and discuss their relevance as compared to longwall mining practices in the United States.

### **John A. Organiscak**

John A. Organiscak has BS in Mining Engineering from the Pennsylvania State University and MBA for Duquesne University. John has worked for 15 years in research and development of respirable dust control technologies for the former U.S. Bureau of Mines. John is working in the Dust and Toxic Control Branch for the Office of Mine Safety and Health at the National Institute for Occupational Safety and Health's Pittsburgh Research Laboratory. John is also involved in the development of engineering control technologies for the prevention of mineworker silicosis.

### **Jay F. Colinet**

Jay F. Colinet has BS in Mining Engineering from West Virginia University and an MS in Industrial Engineering for the University of Pittsburgh. In 1968, Jay entered government service at the Pittsburgh Research Center as a Mining Engineer for the Dust Control and Ventilation Group of the U. S. Bureau of Mines. The research functions at the Pittsburgh laboratories have been transferred into the National Institute for Occupational Safety and Health NIOSH, where Jay is serving as Supervisor Team Leader in the Dust and toxic Substances Control Branch. Jay is responsible for overseeing dust control research being conducted in an effort to reduce mine worker exposure to respirable coal and siliceous dust.

### **Anotni Koziel**

Antoni Koziel had a Ph.D. in Engineering and has worked as Senior Research Specialists in the Longwall Systems department at the KOMAG Mining Mechanization Centre in Gliwice, Poland. He recently was promoted to Division Manager of the Underground Mechanization systems Department of KOMAG. Antoni's interests are in the engineering advancement of underground coal mining equipment technologies for worldwide applications.

## LONGWALL OPERATIONAL PARAMETERS AND DUST LEVELS MEASURED IN POLAND'S COAL MINES

by John A. Organiscak<sup>1</sup>, Jay F. Colinet<sup>2</sup> and Antoni Koziel<sup>3</sup>

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### ABSTRACT

A joint Polish and U.S. research project was conducted on respirable coal dust generation under the Maria Skłodowska-Curie Joint Fund II. The project goal was to investigate the effect coal seam properties on respirable dust generation in an effort to formulate dust control recommendations for Poland's longwall mining operations. During this project, 8 longwalls were surveyed in Poland's coal fields. Operational parameters, coal seam parameters, dust control parameters, and dust levels were measured during these longwall surveys. This report examines the results from these underground surveys and compares longwall mining operations in Poland to longwall mining practices in the United States.

### INTRODUCTION

Implementation of higher-productivity mining methods are increasing in Polish coal mines [Koziel and Soltysik 1996]. The expanded application of highly productive integrated mining systems in Poland raises concerns about increased dust generation on longwall faces, with the potential for more severe health effects on coal miners. Coal Workers' Pneumoconiosis CWP is responsible for 77 % of deaths among retired Polish coal miners [Koziel, et al. 1999]. From 1995 to 1996, CWP increased by 28 %, accounting for above 18 % of all occupational diseases in Poland [Koziel et al. 1999]. Increases in compensation payments and medical treatment is expected to rise rapidly with the evolution of a free-market economy in Poland and with the changes in legal regulations regarding workers' health protection. The only realistic means to reduce Poland's long-term CWP costs, both human and financial is to mitigate workers' dust exposure. Thus, a cooperative research study was undertaken between Polish and U. S. scientists under the U.S.-Poland Maria Skłodowska-Curie Joint Fund II to examine the primary factors of coal dust generation and to identify methods for reducing dust levels in Polish coal mines. The Maria Skłodowska-Curie Joint Fund II are financial grants to Polish institutions and their U.S. counterparts to support a wide range of scientific research activities and technical cooperation between these countries.

This joint research included both laboratory tests on 3 Polish coal seam types (coal hardness-easy, moderate, and hard-to-cut coals) and field measurements of 8 Polish longwall operations. The laboratory and field study results of the influence of the compositional and mechanical properties of 3 Polish coal seam types on respirable dust generation were previously published [Koziel et al. 1999] and will be briefly discussed in this paper. The main focus of this paper is to examine the operational parameters, coal seam parameters, dust control parameters, and dust levels measured at the 8 Polish longwall operations and discuss their them in relation to longwall mining practices in the United States.

### RESEARCH PROJECT

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A research project, entitled "The Influence of Coal Rock Variables on Respirable Dust Generated and Recommended Control Techniques," was carried out under the U.S.-Poland Maria Skłodowska-Curie Joint Fund II. This project involved both laboratory testing of coals and field surveys of longwalls. The Polish scientist Antoni Koziel managed the project and collected all the data in Poland. The U. S. scientist John A. Organiscak was responsible for input into the underground dust sampling strategy and running laboratory tests on 3 types of coal (easy, moderate, and hard to cut coals).

The project's objective was to examine the factors of coal dust generation and identify potential areas for dust reduction in Poland's coal mines. Since longwalls are the primary method of coal production in Poland, this study examined longwall dust generation and control in Poland's coal mines. The underground longwall surveys collected data on the operational parameters (face width, production rate, shearer energy consumption, etc.), coal seam properties (seam height, compressive strength), dust control parameters (ventilation, spray systems, water flow, etc.) and dust levels at various locations along the face. The respirable dust levels were measured using MiniRAM<sup>4</sup> instruments operated in the passive mode [Organiscak et al. 1986]. Dust levels were measured at fixed locations at the headgate and tailgate locations of the face, and at mobile locations on the shearer and among support movers. The shearer's power consumption, haulage speed, and dust measurements were electronically logged into an electrical parameters' measuring transformer for data analysis [Koziel and Soltysik 1996]. A time study of mining was conducted to correlate the shearer operating parameters to the mining cycle. The compressive strength of the coal seams was measured by a ultrasonic material tester [Koziel and Soltysik 1996].

Laboratory roll crushing tests were conducted on 3 Polish coal seam types (easy, moderate, and hard to cut coals) at the National Institute for Occupational Safety and Health's Pittsburgh Research Laboratory. About 30 kg of coal (easy, moderate, and hard-to-cut coal) were collected from 3 different Polish coal seams and sent from Poland to the Pittsburgh Research Laboratory. The laboratory test procedures and facility used were identical to those used in a prior study of the influence of coal seam properties (U. S. coals) on respirable dust generation [Organiscak and Page 1998]. Each coal type was segregated by size and split (riffled) into 2 representative laboratory test samples containing an equivalent weight mix of 50.0 by 25.0 mm, 25.0 by 19.0 mm, and 19.0 by 12.5 mm coal lumps. Laboratory roll crushing tests were conducted on these coal test samples in a wind tunnel in order to measure the amount of airborne dust generated. Laboratory measurements included coal composition (proximate analysis), coal Hardgrove Grindability Index (HGI), crusher specific energy, coal product size characteristics, coal dust cloud electrostatic field, and airborne respirable coal dust generated. More detailed information on the experimental facility, instrumentation, and laboratory procedures can be found in Organiscak and Page 1998.

The laboratory test data were compared with the longwall field data collected for the 3 coal seam types to identify which of the coal seam characteristics best described the amount of airborne dust generated. The underground Polish longwall data were also examined with respect to similar U.S. longwall dust study data in order to identify potential control practices that may help reduce dust levels in Poland's coal mines.

## PROJECT RESULTS

### Coal Seam Properties and Dust Generation

Table 1 summarizes the comparison of laboratory and underground data collected for the three coal types (coal hardness-easy, moderate, and hard-to-cut) mined in Poland [Koziel et al. 1999]. The coal compositional data show that the three coals tested were high volatile bituminous coals with noticeable differences in air dry loss moisture and ash content. Both the laboratory and underground data reflect

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<sup>4</sup>Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

good agreement between the relative dust levels generated from these Polish coals. The laboratory tests showed that the crusher specific energy and respirable dust generated were also positively associated. However, discrepancies exist between the amount of specific energy measured for the crusher (laboratory) and the amount of specific energy measured for the shearer (underground). These differences may be a result of the coal being cut under confining pressures underground and coal being crushed without confining pressures in the laboratory. Also, the differences may be due to the diversity in shearer design parameters, which affect the efficiency of the cutting and loading processes.

Discrepancies were also observed between the coal product size and the amount of airborne dust generated in the laboratory. As table 1 shows, the size of the crusher product decreases (median product size) with more product fines (weight percent of product less than 250  $\mu\text{m}$ ) for coal seams A, B, and C, respectively, while the amount of airborne respirable dust generated increases for seams B, C, and A, respectively. This discrepancy between the amount of product fines and the amount of airborne dust generation indicates that the three coal seams liberate different percentages of the dust fines from the product.

Identical laboratory crusher tests on a wider rank of U.S. bituminous coals showed a similar discrepancy between the amount of product fines produced and the amount of airborne respirable dust generated. The prior laboratory dust generation research on U.S. coal seams indicated that the percentage of respirable coal dust liberated from the product fines is related to the air dry loss moisture in the coal and/or the electrostatic charge field of the dust cloud [Organiscak and Page 1998]. As air dry loss content increases in the coal, the electrostatic charge decreases, increasing the percentage of coal dust that becomes airborne from the product. Organiscak and Page [1998] proposed a serpentine type mathematical model relating the dust cloud electrostatic field to the quantity of coal dust particles created (a mechanical coal strength factor) and the electrostatic charge properties of these particles (a coal composition factor).

The air dry loss and ash content differences observed in the Polish coals tested are suggested as likely influences on the electrostatic charge field and the airborne respirable dust generated. Currently, work continues on incorporating both the Polish and U.S. coal compositional properties into formulating and verifying a quantitative model for the amount of airborne dust generated.

#### Underground Longwall Surveys

Table 2 shows the data collected for the 8 longwalls surveyed in Poland. Bi-directional cutting was universally used at all these longwalls under a varying range of operating parameters (face width, production rate, shearer energy consumption, etc.), coal seam parameters (seam height, compressive strength, etc.), dust control parameters (ventilation, spray systems, water flow, etc.), and dust levels. Several mining practices that were not universally employed at the Polish longwalls were the use of drum cowls and the use of water sprays on the cutting drums. Only 3 out of 8 longwalls used drum cowls and only 1 out of 8 longwalls used internally plumbed drum sprays. Also, the external water sprays used on the shearer were not wind- directional nor shearer-clearer type water spray systems [Jayaraman et al. 1985; Ruggieri et al. 1983].

Coal seam height seemed to be a key parameter that was notably interrelated to several other longwall parameters (coal compressive strength, shearer specific energy, and production). Figure 1 shows these parameter relationships measured at the 8 Polish longwalls. An unexpected relationship observed from the longwall data was a negative correlation between coal compressive strength and shearer specific energy (see Figure 1a). A harder coal is expected to require more specific energy to be cut by the shearer, but the opposite relationship was observed. Coal seam height seemed to be the key parameter related to production rate, coal strength, and shearer specific energy (see figures 1b, 1c, and 1d). Positive coal seam height correlations were observed with both production rate and compressive strength, while a negative coal seam height correlation was observed with shearer specific energy. The negative specific energy relationships with seam height and compressive strength were likely caused in

part by inherent design limitations on shearers operating in lower coal seams. Both the diameter of the cutting drums and the shearer's drive motors were smaller in lower coal seams than in higher coal seams, limiting the shearer's production capacity in the lower coal seams. Also, the lower seam height could limit workers' mobility along the face, reducing longwall production rates and cutting efficiency of the shearer.

The MiniRAM dust levels measured during coal extraction at these longwalls showed very little correlation to most of the operational and dust control parameters. The lack of an expected ventilation and production relationship with dust levels may have been a result of their limited operating ranges measured during the field surveys or a more domineering parameter overshadowed their effect. Water pressure and drum rotational speed were the only dust control and operational parameters notably correlated with shearer dust levels (see figure 2). The water pressure was positively correlated to shearer dust levels for the tail-to-head pass, with a less significant relationship observed during the head-to tail pass (see figure 2a). This relationship was likely caused by the misdirected orientation of external water sprays (no shearer-clearer type spray system) on the shearing machine, which pushes the shearer generated dust into the adjacent worker walkway at higher water pressures, especially when cutting against the airflow [Ruggieri et al. 1983]. The drum rotational speed was positively correlated to the shearer dust levels for the head-to-tail pass, with a less significant relationship observed during the tail-to-head pass (see figure 2b). Faster drum speeds tend to reduce cutting efficiency (reduce bit penetration) and increase the amount of dust generated as mentioned previously [Ludlow and Jankowski 1984].

The strongest dust level relationships were observed between the various sampling locations on the face for both cutting directions. Figure 3 shows the dust levels measured at several of the sampling locations along the face. The shearer and support mover locations were strongly related to the tailgate dust levels for both cutting directions (see figures 3a and 3b). Notably higher dust levels were observed for the shearer and support mover locations during the tail-to-head cut pass, contributing to a larger portion of the tailgate dust levels measured. During this pass, the shearer cuts directly into the face ventilation airflow with support movement downstream of the shearer, exposing support movers to higher dust levels generated by the shearer. Figure 3c shows that the dust levels for the shearer and support movers were on average more than 1.5 and 4.5 times higher (regression slopes), respectively, during the tail-to-head pass as compared to the head-to-tail pass. Since the shearer appears to be the greatest dust source and affects other worker locations on the face, the primary focus in relation to dust control should be on reducing the amount of dust generated by the shearer.

#### COMPARISON OF POLISH AND U.S. LONGWALLS

Dust and operational data were previously collected from 13 U.S. longwall operations and have been presented in Colinet et al., 1997. Since the U.S. longwall study was very similar to the longwall study in Poland, a comparative examination of this longwall data was conducted. Table 3 shows the average and the range of longwall parameters measured in both countries. This comparison reveals that although both countries operated longwalls in similar coal seam thicknesses at similar longwall face widths, many of the longwall parameters were noticeably different.

Most of the U. S. longwall operational parameters, dust control parameters, and production levels notably exceeded those measured in Poland. Shearer water flow rates, longwall face ventilation quantities, and production rates measured in the U. S. were more than double the levels measured in Poland. Shearer drum crows, internally plumbed drum spray systems, and externally mounted wind directional spray systems (shearer-clearer) are commonplace in the U.S. but are rarely used in Poland. Also, uni-directional cutting practices are more widely used in the U. S. than in Poland. These longwall parameter differences most likely influenced the lower dust levels measured at U.S. operations as compared to those in Poland.

Dust levels were noticeably lower for the U. S. longwalls as compared to Poland's longwalls, especially at the shearing machine. These lower U.S. dust levels are believed to be achieved at higher production levels than in Poland because of improved water usage at the shearer and elevated ventilation

parameters. Past studies have shown that water flow through the cutting drums is a key factor in reducing dust generated by the shearer [Jankowski and Organiscak 1983; Kok et al., 1986]. Others recommend water application to the mined coal of 2% to 4% by weight [Goddard et al, 1973]. The shearer-clearer spray system commonly used in the U.S. is also another key use of water at the shearing machine. This system confines the shearer-generated dust cloud over the shearer body, reducing the amount of dust in the adjacent worker walkway [Jayaraman et al. 1985; Ruggieri et al. 1983]. Finally, higher longwall face ventilation also notably reduces dust levels at the shearer [Haney et al. 1993] and optimization of both ventilation and water sprays can significantly reduce shearer dust levels [McClelland et al. 1987].

The uni-directional cutting sequence and improved shearer cutting parameters are other key practices used at U.S. longwalls that can reduce worker dust levels. A uni-directional cutting sequence can reduce worker dust exposure by locating workers away from the most significant dust sources for a portion of the mining cycle [Jankowski and Organiscak 1983]. Also, increasing drum web width [Organiscak et al. 1988] and increasing bit penetration depth have been shown to reduce the amount of dust generated by the shearer [Ludlow and Jankowski 1984]. The drum web width was 20% greater and the shearer haulage speed was more than double for longwalls in the U. S. as compared to Poland. Both of these cutting parameters increase the cutting efficiency of the shearer drums and should thus reduce the amount of dust generated per ton of coal mined.

### CONCLUSIONS

Data collected from the joint Polish and U. S. Maria Sklodowska-Curie Joint Fund II research project have indicated that dust levels generated at Poland's longwall mining operations are influenced by coal seam properties, operational parameters and dust control parameters, similar to U.S. longwall operations. Laboratory roll crusher testing validated that the longwall dust levels measured in Poland's underground coal mines were partly influenced by the inherent coal seam properties. Analysis of the longwall parameters measured in Poland and the U. S. indicates that notable differences in longwall operating and dust control parameters between the two countries appear to influence the difference in dust levels observed.

Some of the basic longwall practices common place in the U. S. that may yield positive results in combating coal mine dust levels in Poland include:

- Implementation of water spray use through the cutting drums for improved suppression and product wetting. The use of directional external spray systems (shearer-clearer) for localized dust control for workers should also be introduced. Good water quality is required, so additional attention must be given to filtering the longwall water supply.
- Better design of face ventilation systems for Polish longwall conditions. An increase in air quantity where practical (where spontaneous combustion is not a problem).
- The use of alternative cut sequences and administrative control measures to reduce the amount of time workers spend on the return side of the shearer.
- Machine design efforts focused on improving the cutting and loading efficiency of shearer drums, such as reducing drum rotational speeds, increased drum web depth and using cowls.
- Increased awareness of dust exposure health effects and control measures among workers and supervisory personnel.

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Table 1 - Summary of laboratory and longwall parameters measured on three coal types in Poland  
(*Polish counterpart measurements in italics*)

LABORATORY OR LONGWALL PARAMETER	COAL SEAM A (Longwall No. 5)	COAL SEAM B (Longwall No. 6)	COAL SEAM C (Longwall No. 7)
*Air Dry Loss, %	5.4	6.0	1.4
*Inherent Moisture, %	2.8	3.1	1.2
*Ash Content, %	12.7	5.0	16.3
*Volatile Matter, %	34.6	36.5	33.7
*Fixed Carbon, %	49.9	55.6	48.7
Hardgrove Grindability Index (HGI)	38	46	49
Median Crusher Product Size, mm	7.92	7.38	5.86
Percent of Crusher Product < 250 µm	1.6	2.2	2.9
Crusher Specific Energy, W·min/kg	8.12	3.59	3.98
<i>Shearer Specific Energy, kW·hr/mt</i>	<i>0.50</i>	<i>0.56</i>	<i>0.43</i>
<i>Coal Compressive Strength, MPa</i>	<i>27.0</i>	<i>30.6</i>	<i>15.5</i>
Crusher Dust Electrostatic Field, V/cm	-23.4	13.2	-0.6
<sup>1</sup> Crusher Respirable Dust, mg/m <sup>3</sup>	21.4	2.7	8.6
<sup>2</sup> <i>Shearer Respirable Dust, mg/m<sup>3</sup></i>	<i>10.8</i>	<i>3.3</i>	<i>5.2</i>

\*Reported as percent weight on an as received basis.

\*Reported as percent weight on an as determined basis (weight percentages determined without the Air Dry Loss).

<sup>1</sup>Seria 298 Impactor Measurements.

<sup>2</sup>MiniRAM Measurements.

Table 2 - Longwall parameters measured in Poland

LONGWALL PARAMETERS MEASURED	LONGWALLS SURVEYED IN POLAND (all the longwalls cut bi-directional and had only hydraulic support control systems)							
	1	2	3	4	5	6	7	8
Face Width, m	247	230	155	240	150	250	250	156
Seam Height, m	1.8	2.2	3.0	1.5	3.0	3.0	1.5	3.0
Seam Depth, m	800	402	500	600	500	650	600	500
Coal Strength, MPa	22.6	11.5	28.5	15.5	27.0	30.6	16.5	28.5
Production, mt/hr	330	500	600	350	600	600	270	605
Shearer Power, kW	245	450	530	345	454	750	345	530
Drum Diameter, m	1.25	1.60	2.00	1.25	2.00	2.00	1.25	2.00
Web Width, m	0.63	0.80	0.63	0.67	0.75	0.70	0.60	0.63
Drum Cows	No	No	No	No	Yes	Yes	Yes	No
Drum Speed, rev/min	53	32	38	38	24	25	38	38
Shearer Haulage Speed, m/min	3.5	6.0	4.5	4.0	4.5	4.5	3.5	2.5
Shearer Energy, kWhr/min	0.63	0.70	0.48	0.58	0.54	0.50	0.68	0.56
Air Velocity, m/s	1.7	0.7	1.3	1.3	1.7	1.5	0.6	1.3
Air Quantity, m <sup>3</sup> /min	655	320	610	610	810	600	150	610
External/Internal Sprays	Yes/No	Yes/Yes	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Water Quantity, t/min	100	184	200	70	250	110	160	200
Water Pressure, MPa	2.0	2.5	1.6	1.2	1.3	1.5	1.2	1.6
*Headgate Dust Level	2.0	5.5	0.5	1.5	1.2	1.2	0.5	0.7
*Support H-T Dust Level	12.0	11.0	5.0	4.8	1.5	2.3	5.2	4.6
*Shearer H-T Dust Level	25.0	15.0	3.5	5.5	5.7	2.8	9.5	7.5
*Shearer T-H Dust Level	45.0	37.0	27.0	6.5	12.5	3.2	7.5	17.0
*Support T-H Dust Level	60.0	38.0	9.0	5.5	11.8	2.8	10.6	10.0
*Tailgate Dust Level	75.0	35.0	31.0	5.2	11.2	3.1	8.5	11.2

\*Average instantaneous dust level measured with the MiniRAM instrument during the mining cycle. MiniRAM instruments were manufacturer calibrated to standard Arizona road dust and measure airborne respirable dust by the forward light scattering method to estimate dust concentrations in mg/m<sup>3</sup>.

Table 3 - Comparison of longwall parameters measured in Poland and U. S. coal mines

OPERATIONAL PARAMETERS	POLISH LONGWALLS (8 surveyed) Mean [Minimum, Maximum] or % Utilization	U. S. LONGWALLS (13 surveyed) Mean [Minimum, Maximum] or % Utilization
Face Width, m	210 [150, 250]	219 [152, 259]
Seam Height, m	2.4 [1.5, 3.0]	2.3 [1.7, 3.4]
<sup>1</sup> Production Rate, mt/hr	482 [270, 605]	1308 [678, 2124]
Cutting Sequence	100 % Bi-directional Cutting 0 % Uni-directional Cutting	38 % Bi-directional Cutting 62 % Uni-direction Cutting
Shearer Haulage Speed, m/min	4.1 [2.5, 6.0] (Cutting) No Clean-up Passes	9.0 [4.3, 21.5] (Cutting) 14.1 [7.6, 18.9] (Clean-up)
Web Width, m	0.68 [0.60, 0.80]	0.82 [0.38, 1.02]
Drum Cows	38 % have Drum Cows	100 % have Drum Cows
Air Velocity, m/s	1.3 [0.6, 1.7]	2.5 [1.0, 7.6]
Air Quantity, m <sup>3</sup> /min	546 [150, 810]	1152 [228, 3000]
<sup>2</sup> Water Spray Usage	100 % External 12 % Internal	100 % External 100 % Internal
<sup>1</sup> Shearer-Clearer Spray System	0 % have System	92 % have System
Shearer Water Quantity, l/min	159 [70, 250]	377 [265, 568]
Shearer Water Pressure, Mpa	1.6 [1.2, 2.5]	1.0 [0.2, 2.1]
<sup>3</sup> Headgate Dust Level, mg/m <sup>3</sup>	1.6 [0.5, 5.5]	1.1 [0.4, 1.8]
<sup>3</sup> Shearer H – T Dust Level, mg/m <sup>3</sup>	9.3 [2.8, 25.0]	3.8 [0.7, 11.0]
<sup>3</sup> Shearer T – H Dust Level, mg/m <sup>3</sup>	19.5 [3.2, 45.0]	3.9 [0.7, 7.2]
<sup>3</sup> Tailgate Dust Level, mg/m <sup>3</sup>	22.5 [3.1, 75.0]	3.5 [1.0, 10.0]

<sup>1</sup>Production rates are reported for cutting passes and are reported in metric tons per min (mt/min).

<sup>2</sup>External sprays are defined as sprays mounted on the shearer body. Internal sprays are defined as drum sprays operated by internal water channels within the drums.

<sup>3</sup>All wind directional external spray systems similar to the shearer-clearer design are included

<sup>3</sup>Dust levels were measured with the MiniRAM instruments at Polish Longwalls and with personal dust samplers at U. S. Longwalls during production segments of the shift.

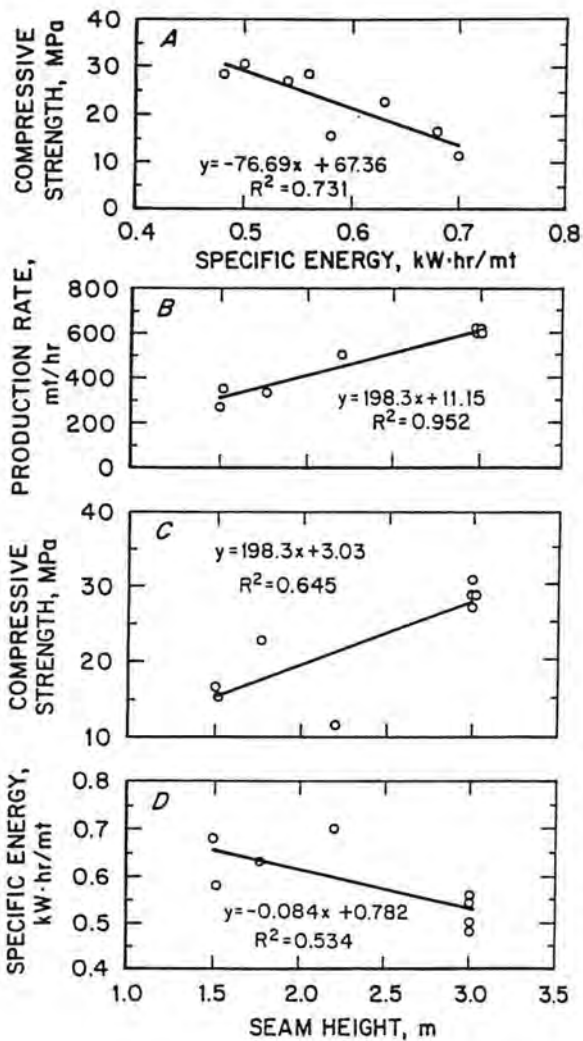


Figure 1 - Interrelationship between seam height and other parameters

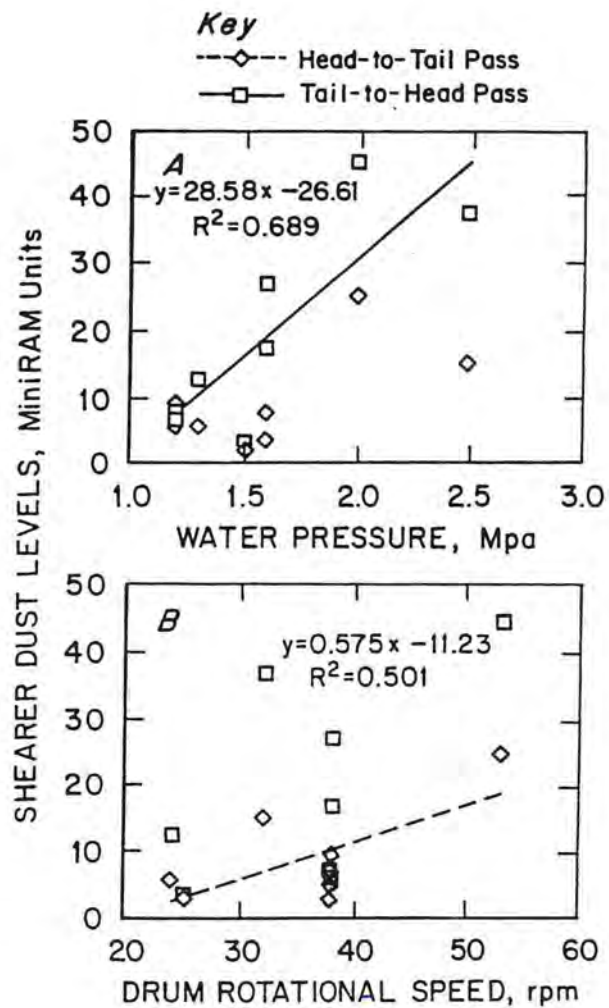


Figure 2 -Operational Parameters Related to Shearer Dust Levels

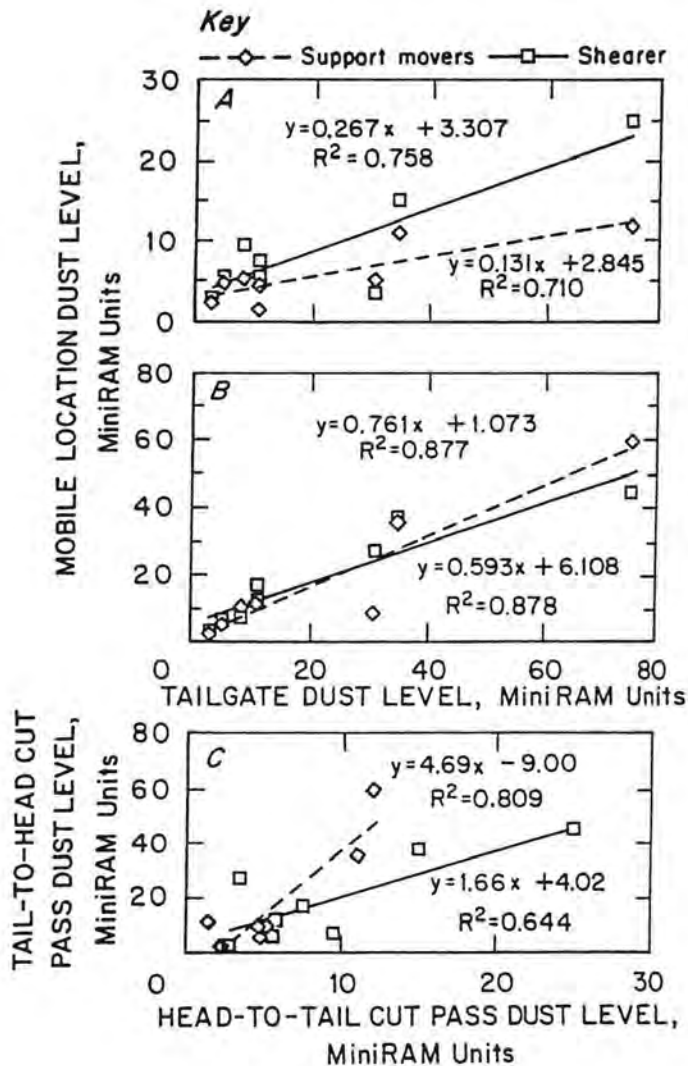


Figure 3 - Dust levels measured a several longwall face locations