The effects of water spray placement for controlling respirable dust and face methane concentrations

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Abstract

A series of laboratory evaluations examined the impact of water spray pressure, curtain setback distance, and external and underboom spray use for controlling respirable dust levels and sulfur hexafluoride tracer gas concentrations around a continuous mining machine. This mining machine was equipped with a flooded-bed dust scrubber and was positioned in the box or slab cut. Exhaust line brattice was used for all tests.

Dust levels were measured in the return airway and at locations representing the operators of the continuous mining machine and the standard and off-standard shuttle cars. Increasing water pressure or using the underboom sprays produced no significant impacts on dust levels, although their interactions did produce some significant impacts. Increasing curtain setback distance often elevated dust levels, likely by reducing the amount of airflow reaching the face. Use of the external sprays created additional airflow around the mining machine that pushed the dust cloud past the scrubber inlets. This significantly increased dust levels at all sampling locations.

Tracer gas levels were measured on the off-curtain and curtain sides of the cutter head and in the return airway. Increasing water pressure generally led to significantly increased gas levels on the curtain side, although a slight decrease was observed on the off-curtain side with the machine in the box cut. Increasing setback distance elevated gas levels on both sides of the cutter head and in the return by limiting the quantity of ventilation airflow reaching the face. Use of the external sprays provided additional airflow along the off-curtain side of the machine, significantly reducing gas levels in this region. These sprays adversely impacted the dilution and removal of gas on the curtain side of the cutter head. Use of the underboom sprays adversely impacted gas levels on both sides of the cutter head.

Use of the external sprays provided the best control of respirable dust and face gas concentrations. The smaller increases in miner operator dust levels produced by these sprays were offset by larger reductions in face gas levels on the off-curtain side of the cutter head. Although the underboom sprays minimally impacted respirable dust levels, use of these sprays was not recommended because they increased face gas levels.

1. Introduction

Federal coal mine regulations in the United States limit exposures to respirable coal dust to 2.0 mg/m^3 for a working shift (Mineral Resources, 1999). This level is measured gravimetrically using a nylon classifying cyclone and a sampling rate of 2.0 L/min. If the quartz content of the dust exceeds 5% by weight, a new exposure limit is calculated using the formula 10/(% quartz). Compliance with the 2.0 mg/m3 standard or a reduced standard maintains quartz dust levels at or below 100 µg/m^3. Federal regulations also limit concentrations of methane gas at the face area to 1%. Methane readings are typically taken with a machine-mounted methanometer or a hand-held detector and usually taken as close to the face as practical, although they cannot be taken closer than 0.3 m from the roof, floor, face, or ribs (Mineral Resources, 1999).

Many factors affect the ability of a dust scrubber to control respirable dust exposures and methane gas concentrations during coal mining. These include face ventilation airflow quantity, water spray pressure, and ventilation curtain setback distance, among others. Past work showed that increased curtain airflow reduced both respirable dust and face gas concentrations (Colinet, McClelland & Jankowski, 1991). Increased water pressure created turbulence that could improve the dilution of face gas (Foster-Miller Inc., 1985). However, excessive turbulence created dust rollback that pushed the dust cloud toward the machine operator (Jankowski, Jayaraman & Babbit, 1987). Shorter setback distances directed more airflow to the face, which could improve control of dust and gas.

Control and confinement of the dust cloud is necessary to improve suppression and capture of these dust particles. To control face gas levels, however, turbulence is needed to promote dilution of the gas cloud. This suggests that ventilation airflows, spray pressures, and setback distances needed for optimal control of respirable dust concentrations may not be as effective for control of methane gas at the face.

A series of laboratory tests evaluated the impacts of face ventilation flow rate, water spray pressure, curtain setback distance, and the uses of external and underboom sprays on respirable dust levels measured at the miner operator, shuttle car operators, and in the return airway. Corresponding tracer gas concentrations were measured on the curtain and off-curtain sides of the cutter head and in the return airway. Recommendations were made regarding the best use of the external and underboom sprays for controlling respirable dust and face gas levels.

2. Experimental design

This laboratory work was conducted at a full-scale surface test gallery simulating a cut 12.2 meters deep, 5.5 m wide, and roughly 2.0 m high. A full-scale mockup of a continuous mining machine used for this testing featured a 0.9-m diameter cutting drum rotating at 50 rpm. The machine was positioned at the end of the box cut or slab cut for testing. While in the box cut, a coal slab measuring 2.4 m by 6.1 m remained to the right of the machine (Figure 1). Exhaust curtain ventilation was created in the laboratory by drawing air via a main gallery fan through a curtain positioned on the left side of the test gallery. Airflow was measured at the mouth of the curtain using a conventional vane anemometer.

The mining machine was equipped with a flooded bed dust scrubber rated at 3.3 m^3/s. The scrubber included a 30-layer stainless steel filter screen. The machine used a standard water spray system as offered by the manufacturer of 24 BD3-3 hollow cone sprays (Spraying Systems, Wheaton, IL, USA) positioned above, below, and along the sides of the cutting head.

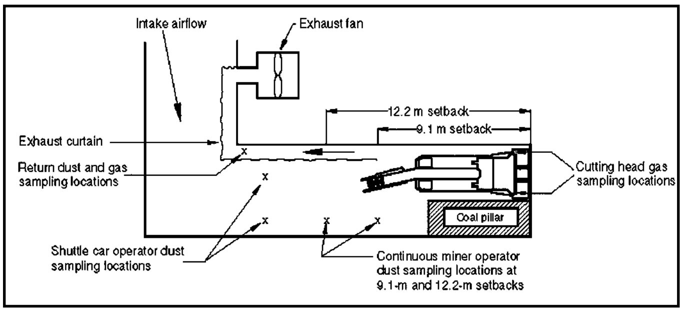


Figure 1. Plan view of full-scale test gallery

Past work showed that high methane gas levels could occur at the face when using exhaust curtain ventilation, evidence that fresh airflow was not reaching the face, but, instead, was flowing directly behind the curtain (Luxner, 1969). This testing showed that the corner of the face on the off-curtain side of the entry often showed the highest gas levels.

Preliminary testing of the dust scrubber with the standard water spray system showed relatively high gas levels in this corner. To clear this area of gas, external spray manifolds were placed on the right side of the machine frame 2.4 m outby the hinge point of the cutting boom and on top of the cutting head at the hinge point. Each manifold consisted of two BD 20-2 hollow cone sprays oriented to “flush out” this corner of the face. These external manifolds were plumbed separately from the standard spray system to evaluate the effect of these added sprays on controlling respirable dust and face gas (Figure 2).

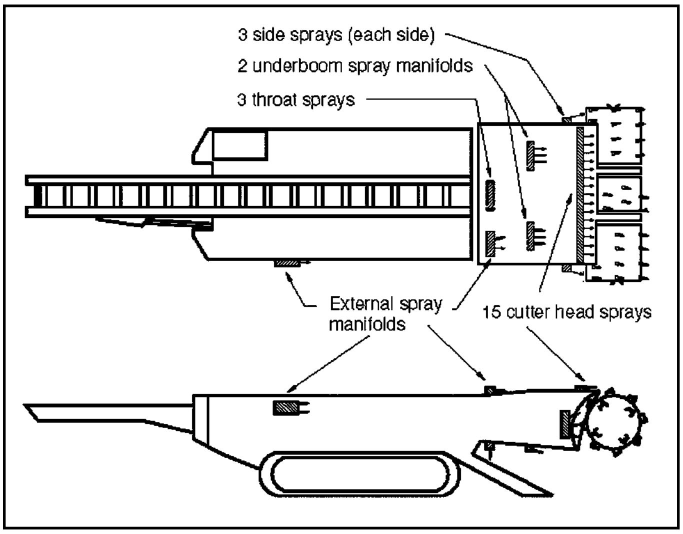


Figure 2. Water spray designs used with dust scrubber (Top-plan view, Bottom-side view)

Two additional spray manifolds were placed under the cutting boom, each manifold consisting of three BD3-3 hollow cone sprays oriented toward the cutting drum. These underboom manifolds also were plumbed separately to assess their effects on dust and gas levels.

A 10% mixture of quartz dust in coal dust was introduced into the gallery at the miner cutting head via a compressed air/eductor system. Two LH-½ brass eductors (Penberthy, Prophetstown, IL, USA) were connected to a 34.5 kPa compressed air source. These eductors mixed the dust mixture with the compressed air to deliver the dust to the cutting head at a rate of 25 grams/minute. One eductor discharged along the left front side of the cutting drum while the other discharged along the right front of the drum. The rotating cutting drum ensured mixing of the dust with the ventilation airflow.

For dust sampling, constant airflow pumps pulled dust-laden air through 10-mm nylon cyclone separators at a rate of 2 L/min as specified by 30 CFR 70.205 (Mineral Resources, 1999). The respirable mass was deposited onto pre-weighed 37-mm filters that were subsequently post weighed and dust levels calculated. Selected filters with a minimum weight gain of 0.30 mg were sent to an independent laboratory for x-ray diffraction analysis of respirable quartz using NIOSH Method Number 7500 (NIOSH, 1994).

A pair of gravimetric samplers placed on the off-curtain (right) side of the entry, outby the mouth of the exhaust curtain, represented the location of the remote mining machine operator, which moved with curtain setback distance. Two pairs of samplers placed 7.6 m outby the rear of the mining machine on the left and right sides represented locations of the standard and off-standard shuttle car operators, respectively. Finally, gravimetric samplers placed in the return airway monitored dust levels in that location (Figure 1).

This testing also evaluated the impact of face ventilation flow rate, water spray pressure, and setback distance on the removal and dilution of hazardous gas concentrations. Due to safety concerns, however, methane gas could not be used in this testing. Instead, sulfur hexafluoride (SF_6) was used as a surrogate or tracer gas. This gas is tasteless, odourless, not found naturally in the atmosphere, and is nontoxic in the amounts used in this testing. It is also detectable in the parts per million (ppm) concentration level. This substance was introduced at the cutting drum where its rotation mixed the gas with the face airflow.

A model 1303 multipoint gas doser (California Analytical Instruments, Orange, CA, USA) metered the gas into the gallery at a rate of 6 milliliters/sec for four 20-minute periods. Each period consisted of an initial 3-minute period of sampling with no dosing, a 14-minute period of dosing and sampling, and a final 3-minute period of sampling with no dosing. Real-time measurement of the sulfur hexafluoride gas levels was made with a California Analytical Instruments model 1312 photoacoustic gas monitor. Gas sampling was conducted at locations representing typical methanometer locations on a continuous mining machine: on the left and right sides of the cutting boom approximately 0.6 m outby the cutting drum. Gas levels also were measured in the return airway (Figure 1). Tracer gas dosing and sampling ran concurrently with dust sampling. Disposable filters, placed at the ends of the gas sampling tubes, prevented dust from entering the gas monitoring equipment.

Only a single curtain flow rate of 3.8 m^3/s was used to minimize the size of the test matrix. Curtain setback distance was either 9.1 m or 12.2 m and water pressure was either 620 kPa or 1172 kPa. This testing also evaluated the impacts of the external spray manifolds and the underboom spray manifolds. Measured water flow rates for the various spray combination ranged from 76.6 to 145.9 liters per minute (Table 1.). Each test ran 90 minutes.

Table 1. Water flow rates (L/min) measured for different spray system designs.

Spray system design	Spray pressure	
	620kPa	1172 kPa
Standard sprays	76.6	98.5
Standard + externals	89.4	120.9
Standard + underbooms	94.4	127.7
Standard + externals + underbooms	145.9	106.5

For this analysis, only the effects of the four independent variables and six two-way interactions were considered; three-way and four-way interactions were not evaluated. Two replicates of each test were made to obtain a measure of the error associated with each combination. We also randomized the order in which tests were run.

The dust concentration at each sampling location was calculated using the average of the concentrations for each group of samplers. The tracer gas concentration at each location was the average of the concentrations recorded for the four pulses. Respirable dust and tracer gas concentrations for each series of test conditions were calculated using the average concentration for each test comprising that set of conditions.

3 Effects on respirable dust exposures

Analyses of variance (ANOVA) were used to define the impact of the independent variables (water pressure, curtain setback distance, external spray usage, underboom spray usage) on respirable dust exposures measured at the miner operator, standard and off-standard shuttle car operators, and in the return airway. A significance level of 0.05 was set for all analyses.

The data collected did not typically exhibit normal distributions. To improve normality of the data and equality of the variances, square root transformations were used on the respirable dust concentrations. Although some transformed data showed departures from normality, the F-tests used in these analyses are robust and little affected by such departures. Also, the balanced design of this analysis minimizes the impact of unequal variances (Neter, Wasserman, Kutner, 1985). The untransformed data in Table 2 show the mean and standard deviation for each operator and return sampling location with the machine in the box and slab cut position. Results in the following sections are based upon square root transformed data.

3.1 Continuous Miner in Box Cut

Curtain setback distance and external spray use significantly impacted dust levels for the miner operator (Table 3). Increasing curtain setback distance significantly increased dust levels for the mining machine operator likely by reducing the amount of fresh air reaching the cutting face. Use of the external sprays also significantly increased these dust levels, likely by increasing air velocity along the machine that pushed the dust cloud past the scrubber inlets. Similar effects of increased air velocity have been reported by others (Hole & Von Glehn, 1998; Schultz & Fields, 1999). The interaction of water pressure and underboom spray use significantly impacted miner operator dust levels. Increasing water pressure led to higher dust levels with use of the underboom sprays and lower levels without these sprays. An interaction of curtain setback distance and external spray use was noted.

The use of the external sprays increased dust levels for the standard shuttle car operator by pushing the dust cloud past the scrubber inlets where it could flow to outby locations. Changing curtain setback distance produced significant changes in dust levels for the off-standard shuttle car operator by placing the mouth of the curtain near this location. Dust entering the curtain mouth likely contaminated these samples. Use of external sprays significantly increased dust levels at this location with the greatest impact occurring at high pressure.

Water pressure interacted with underboom spray use to significantly impact off-standard car dust levels. Increasing water pressure reduced dust levels when using underboom sprays and increased dust levels without these sprays. The interaction of water pressure and the external sprays produced the opposite effect. Increasing water pressure led to higher dust levels with use of the external sprays and lower dust levels without these sprays. Use of the external sprays led to greater increases in dust levels with the underboom sprays off than with these sprays on.

Use of the external sprays led to significant increases in dust levels measured in the return airway. A mechanism similar to that described for the off-standard shuttle car operator likely applied in this case. Interactions between

Table 2. Untransformed gravimetric dust levels measured in box and slab cuts (mg/m^3)

Water spray pressure	Curtain setback distance	External	Underboom sprays	Dust levels in box cut, mg/m^3 (standard deviation) Dust levels in slab cut, mg/m^3 (standard deviation)			
(kPa)	(m)	(on/off)	(on/off)	Mining machine operator operator	Standard shuttle car operator	Off-standard shuttle car	Return
620	9.1	off	off	0.03 (0.00)	0.05 (0.02)	0.07 (0.02)	0.63 (0.04)
			0.11 (0.09)	0.09 (0.02)	0.11 (0.00)	1.24 (0.20)	
1172	9.1	off	off	0.04 (0.02)	0.06 (0.04)	0.07 (0.02)	0.46 (0.07)
			0.04 (0.02)	0.06 (0.03)	0.12 (0.01)	0.94 (0.26)	
620	12.2	off	off	0.15 (0.01)	0.06 (0.02)	0.16 (0.08)	0.72 (0.03)
			0.09 (0.02)	0.04 (0.02)	0.10 (0.07)	1.11 (0.05)	
1172	12.2	off	off	0.11 (0.01)	0.04 (0.03)	0.11 (0.06)	0.52 (0.12)
			0.20 (0.04)	0.09 (0.01)	0.09 (0.01)	0.96 (0.13)	
620	9.1	off	on	0.04 (0.03)	0.03 (0.03)	0.14 (0.02)	1.08 (0.13)
			0.05 (0.03)	0.08 (0.05)	0.13 (0.10)	1.29 (0.91)	
1172	9.1	off	on	0.02 (0.02)	0.03 (0.02)	0.11 (0.03)	0.98 (0.08)
				0.06 (0.06)	0.04 (0.05)	0.16 (0.03)	1.39 (0.08)
620	12.2	off	on	0.17 (0.03)	0.07 (0.03)	0.22 (0.08)	0.88 (0.13)
				0.30 (0.20)	0.11 (0.07)	0.16 (0.03)	1.89 (0.70)
1172	12.2	off	on	0.14 (0.03)	0.06 (0.05)	0.20 (0.06)	0.82 (0.11)
				0.24 (0.20)	0.09 (0.08)	0.08 (0.03)	1.57 (0.79)
620	9.1	on	off	0.04 (0.04)	0.06 (0.04)	0.15 (0.07)	1.30 (0.16)
				0.07 (0.02)	0.10 (0.06)	0.18 (0.05)	1.72 (0.60)
1172	9.1	on	off	0.10 (0.05)	0.08 (0.04)	0.26 (0.06)	2.39 (0.16)
				0.05 (0.03)	0.07 (0.03)	0.16 (0.06)	1.34 (0.15)
620	12.2	on	off	0.28 (0.06)	0.09 (0.04)	0.27 (0.05)	1.33 (0.33)
				0.44 (0.12)	0.15 (0.03)	0.23 (0.09)	2.44 (0.25)
1172	12.2	on	off	0.32 (0.03)	0.08 (0.02)	0.45 (0.07)	1.87 (0.22)
				0.35 (0.16)	0.14 (0.06)	0.24 (0.12)	2.38 (0.33)
620	9.1	on	on	0.06 (0.05)	0.07 (0.06)	0.19 (0.09)	1.65 (0.22)
				0.03 (0.03)	0.05 (0.04)	0.13 (0.03)	1.10 (0.21)
1172	9.1	on	on	0.05 (0.01)	0.05 (0.03)	0.15 (0.02)	1.22 (0.08)
				0.02 (0.01)	0.05 (0.03)	0.11 (0.02)	0.91 (0.13)
620	12.2	on	on	0.30 (0.01)	0.12 (0.09)	0.32 (0.06)	1.43 (0.17)
				0.50 (0.20)	0.17 (0.04)	0.31 (0.11)	2.03 (0.43)
1172	12.2	on	on	0.21 (0.07)	0.05 (0.05)	0.30 (0.01)	1.24 (0.09)
				0.31 (0.14)	0.13 (0.04)	0.16 (0.10)	1.73 (0.57)

water pressure and use of either the underboom or external sprays and an interaction between the uses of the underboom and external sprays produced variations similar to those seen for the off-standard shuttle car operator.

3.2 Continuous Miner in Slab Cut

As with the box cut data, changing curtain setback distance and use of the external sprays produced significant changes in dust levels for the miner operator. The interaction of curtain setback distance and external spray use produced significant increases in dust concentrations.

At the two shuttle car sampling locations and in the return airway, dust levels were significantly affected by use of the external sprays and by the interaction of these sprays with curtain setback distance. This interaction increased dust levels at the off-standard car location with use of the external sprays and reduced dust levels without these sprays. At the standard shuttle car location and in the return airway, increasing setback distance elevated dust levels. Use of external sprays produced higher dust levels at the larger curtain setback distance for all sampling locations. Use of the external sprays significantly increased dust levels with the underboom sprays off and slightly reduced these levels with the underboom sprays on.

Low dust concentrations were measured at the miner operator and shuttle car operator sampling locations. The required filter weight gain of 0.30 mg could not be obtained for quartz analysis, even when combining filters from multiple tests. However, dust concentrations were higher in the return, allowing us to obtain sufficient weight by combining filters according to box or slab position and use of either the external or underboom sprays. Respirable quartz contents on the filters varied from less than 1.1% by weight to nearly 4.6% with an average of 2.9%. ANOVA analyses showed no impact on quartz percentages with changes in machine position (box cut versus slab cut) or with use of either the external or underboom sprays.

4. Effects of SF_6 tracer gas levels

Gas concentration data collected at the off-curtain side, curtain side, and return sampling locations also were square root transformed to improve normality of the data and equality of the variances. The original untransformed data is given in Table 4, while the following analyses are based upon transformed data.

Table 3. F-ratios from ANOVA analyses of square root transformed gravimetric data, box and slab cuts (n=3)

Source of variation (box-cut)	Mining machine operator	Standard shuttle car operator	Off-standard shuttle car operator	Return
A: water pressure	0.33	1.76	0.23	0.03
B: curtain setback distance	231.43*	1.99	44.40*	2.02
C: external spray use	40.99*	5.34*	55.59*	150.52*
D: underboom spray use	0.52	1.28	1.87	1.76
Interaction: AB	3.30	1.94	0.00	0.11
Interaction: AC	2.05	0.05	6.08*	8.16*
Interaction: AD	6.71*	0.94	4.68*	8.86*
Interaction: BC	6.43*	0.07	1.81	0.39
Interaction: BD	0.05	1.89	0.00	0.61
Interaction: CD	1.44	0.00	11.01*	29.74*
Source of variation (box-cut)	**Mining machine operator**	**Standard shuttle car operator**	**Off-standard shuttle car operator**	**Return**
A: water pressure	1.59	1.35	1.68	2.57
B: curtain setback distance	89.62*	10.85*	1.54	16.30*
C: external spray use	4.93*	5.64*	13.23*	10.37*
D: underboom spray use	0.05	0.55	0.02	0.05
Interaction: AB	0.09	1.31	2.94	0.02
Interaction: AC	1.17	0.11	0.51	0.06
Interaction: AD	0.16	1.17	1.70	0.11
Interaction: BC	12.20*	4.76*	8.10*	7.35*
Interaction: BD	3.49	4.08	0.56	1.11
Interaction: CD	1.48	0.54	1.88	15.10*

Critical F-value = F0.95,1,37 = 4.11

* = significant at 0.95 level of confidence

4.1 Continuous Miner in Box Cut

Gas concentrations on the off-curtain (right) side of the cutter head significantly decreased with higher water pressure and use of the external sprays, indicating improved ventilation and dilution at this site (Table 5). The external sprays were more effective in reducing gas levels at the higher water pressure. Increasing curtain setback distance led to elevated gas levels. The underboom sprays increased gas levels, likely by trapping the gas on the off-curtain side of the face or restricting the flow of dilution airflow to this area.

Higher gas levels on the curtain (left) side arose from increasing water pressure, possibly a result of the higher pressure forcing the gas to this side. These levels also increased with use of either external or underboom sprays. The increase in water pressure led to higher gas levels at the smaller setback distance.

Increasing curtain setback distance led to a statistically significant increase in return airway gas level, although the increase was minimal. No interactions were noted among the independent variables.

4.2 Continuous Miner in Slab Cut

Tracer gas levels on the off-curtain (right) side increased significantly with curtain setback indicating less dilution airflow in this area (Table 5). Levels increased with use of underboom sprays, suggesting that these sprays were impeding the flow of air to this area. Use of external sprays significantly reduced gas levels on the off-curtain side, a result of increasing air velocity around the cutter head.

Gas levels on the curtain (left) side increased with water pressure. Use of external or underboom sprays also increased gas levels, likely by creating airflow patterns that hindered removal and dilution of the gas cloud. Increases in setback distance reduced airflow reaching the curtain side of the cutting head. Use of the external sprays produced greater increases in face gas levels with the underboom sprays off than with use of these sprays. Return gas levels were not significantly impacted by changes in any independent variable or interaction of these variables.

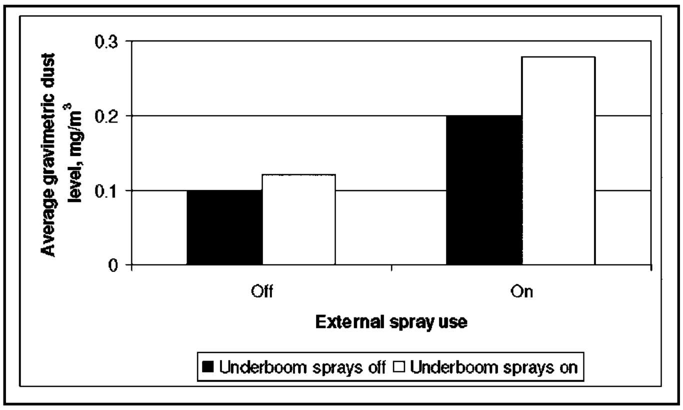
5. Controlling full-cut dust and gas concentrations

The best use of either the external or underboom sprays should ideally result in the lowest dust and gas concentrations. This study showed that use of these sprays often produced opposite effects on respirable dust and tracer gas levels. The practical use of these sprays, therefore, should lead to minimal negative impact on dust or gas concentrations. We made a final analysis by assuming that the continuous miner spends 60% of the cut time in the box cut and 40% mining the slab cut. We computed equivalent full-cut concentrations for respirable dust and tracer gas by using these weightings (Table 6).

For these tests, full-cut dust concentrations measured at the miner operator locations varied from 0.04 to 0.38 mg/m^3. Variations in full-cut dust levels were similar at the two shuttle car operator locations and in the return. Full-cut tracer gas levels ranged from 0.65 to 6.49 ppm on the off-curtain (right) side of the cutter head from 0.97 to 3.18 ppm on the curtain (left) side. Little variation was seen in return gas levels. Tracer gas levels around the machine were impacted more than respirable dust levels by changes in water pressure, setback distance, and spray manifold use. The best application of these sprays should provide control of full-cut tracer gas levels.

Based upon the data collected, use of the external sprays reduced gas concentrations on the off-curtain side of the cutter head by a factor of ten (Table 6). These sprays, however, increased gas levels on the curtain side of the cutter head by a factor of slightly more than three. This increase was minimised by turning off the underboom sprays, which did not effectively control face gas levels anyway.

Use of the external sprays (without the underboom sprays) increased full-cut miner operator dust levels approximately 0.10 mg/m^3 (Figure 3). Similar effects were noted at the standard and off-standard shuttle car operators sampling locations. While the external sprays produced only a small increase in miner operator dust exposure, they created larger reductions in full-cut gas levels on the off-curtain side of the cutter head. A smaller increase in gas levels occurred on the curtain side of the cutter head, especially at the lower pressure of 620 kPa. The external sprays should be used while the underboom sprays need not be used (Figure 4).



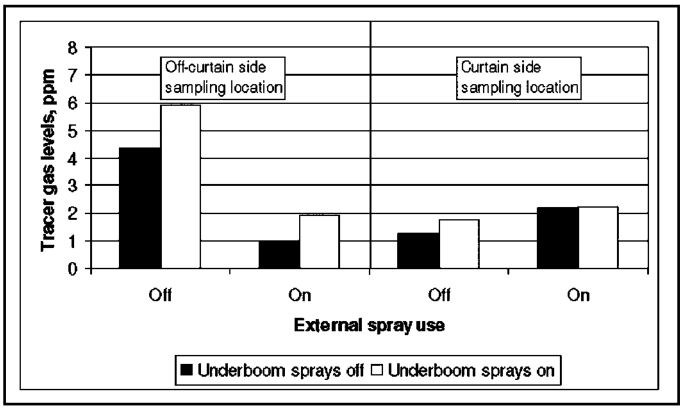


Figure 3. Impact of external and underboom sprays on untransformed miner operator dust levels.

Table 4. Untransformed tracer gas levels measured in box and slab cuts (ppm)

Water spray pressure	**Curtain setback distance**	**External sprays**	**Underboom sprays**	**Tracer gas levels in box cut, ppm (standard deviation) Tracer gas levels in slab cut, ppm (standard deviation)**		
(kPa)	**(m)**	**(on/off)**	**(on/off)**	**Off-curtain side**	**Curtain side**	**Return**
620	9.1	off	off	4.34 (0.37) 3.48 (0.21)	0.58 (0.03) 2.05 (0.37)	1.48 (0.04) 1.52 (0.07)
1172	9.1	off	off	4.35 (0.19) 3.95 (0.31)	1.17 (0.03) 2.06 (0.53)	1.49 (0.10) 1.49 (0.07)
620	12.2	off	off	4.72 (0.20) 4.84 (0.40)	0.92 (0.02) 1.06 (0.11)	1.61 (0.06) 1.47 (0.01)
1172	12.2	off	off	4.59 (0.24) 4.38 (0.31)	1.32 (0.17) 1.57 (0.24)	1.48 (0.02) 1.51 (0.16)
620	9.1	off	on	5.72 (0.66) 5.59 (3.23)	0.77 (0.20) 2.96 (0.92)	1.52 (0.06) 1.51 (0.05)
1172	9.1	off	on	5.43 (0.65)	1.39 (0.38) 4.49 (0.42)	1.42 (0.05) 3.17 (0.27)1.55 (0.09)
620	12.2	off	on	6.74 (0.59)	1.13 (0.16) 6.12 (0.70)	1.51 (0.05) 1.63 (0.15)1.51 (0.05)
1172	12.2	off	on	6.71 (0.27)	1.70 (0.20) 6.13 (0.57)	1.58 (0.05) 2.14 (0.21)1.48 (0.03)
620	9.1	on	off	0.84 (0.10)	0.66 (0.14) 1.01 (0.06)	1.42 (0.05) 3.32 (0.24)1.48 (0.02)
1172	9.1	on	off	0.48 (0.06)	2.59 (0.26) 0.91 (0.08)	1.54 (0.12) 4.05 (0.31)1.50 (0.08)
620	12.2	on	off	1.57 (0.14)	1.33 (0.09) 1.16 (0.20)	1.59 (0.16) 2.08 (0.29)1.52 (0.04)
1172	12.2	on	off	0.94 (0.06)	1.73 (0.21) 1.02 (0.12)	1.50 (0.04) 2.67 (0.28)1.50 (0.07)
620	9.1	on	on	1.74 (0.03)	1.64 (0.17) 2.31 (0.46)	1.50 (0.07) 3.28 (0.43)1.46 (0.03)
1172	9.1	on	on	1.17 (0.03)	2.28 (0.54) 1.90 (0.17)	1.46 (0.13) 3.46 (0.04)1.49 (0.07)
620	12.2	on	on	2.35 (0.12)	1.46 (0.04) 2.81 (0.13)	1.54 (0.05) 2.28 (0.10)1.55 (0.06)
1172	12.2	on	on	1.68 (0.14)	1.93 (0.14) 1.91 (0.29)	1.55 (0.10) 2.29 (0.04)1.57 (0.08)

Table 5. F-ratios from ANOVA analyses of square root transformed SF6 data, box and slab cuts (n=3)

Source of variation (box cut)	Off-curtain side	Curtain side	Return
A: water pressure	35.79*	82.96*	0.61
B: curtain setback distance	86.00*	2.84	7.32*
C: external spray use	2716.20*	51.51*	0.00
D: underboom spray use	248.86*	12.79*	0.02
Interaction: AB	0.05	10.85*	0.00
Interaction: AC	24.33*	1.36	0.56
Interaction: AD	0.00	3.95	0.02
Interaction: BC	5.82*	0.42	0.00
Interaction: BD	0.56	7.38*	0.02
Interaction: CD	0.02	0.02	0.02
Source of variation (slab cut)	**Off-curtain side**	**Curtain side**	**Return**
A: water pressure	2.36	12.19*	0.20
B: curtain setback distance	7.94*	108.18*	0.46
C: external spray use	275.14*	73.37*	0.13
D: underboom spray use	47.34*	11.14*	0.55
Interaction: AB	0.25	1.22	0.13
Interaction: AC	0.78	0.03	0.07
Interaction: AD	1.20	1.18	0.16
Interaction: BC	2.35	0.11	3.81
Interaction: BD	0.09	0.04	0.28
Interaction: CD	2.42	24.83*	0.00
Critical F-value = $F_{0.95,1,37}$ = 4.11			
* = significant at 0.95 level of confidence			

6 Conclusions

Miner operator dust exposures increased with increasing curtain setback distance and use of the external sprays with the machine in the box or slab cut. The interaction of these variables also significantly impacted operator dust levels. In the box cut, the interaction of water pressure and underboom spray use negatively affected dust levels.

The external sprays increased dust levels for the standard and off-standard shuttle car operators and in the return by blowing the dust cloud past the scrubber inlets. These effects were similar with the mining machine in either the box or slab cut. Curtain setback distance impacted the off-standard operator in the box cut and return airway dust levels with the miner in the slab cut. With the machine in the box cut, interactions between water pressure and use of the underboom or external sprays and interactions between the underboom and external sprays significantly impacted dust levels at the off-standard shuttle car location and in the return airway. In the slab cut, an interaction between curtain setback and external spray use significantly affected dust levels at the two shuttle car locations and in the return airway. A final interaction between uses of the external and underboom sprays impacted dust levels in the return.

The external sprays increased air velocity around the cutter head, decreasing gas levels on the off-curtain side and elevating levels on the curtain side. The underboom sprays increased gas levels on both sides. In general, increasing water pressure reduced off-curtain side gas levels while increasing curtain side gas levels. Increasing setback distance elevated gas levels on the off-curtain side of the cutter head for all positions of the continuous miner and

Table 6. Untransformed full-cut dust and gas levels

				Full-cut dust levels, mg/m^3				Full-cut tracer gas levels, ppm		
Water spray pressure (kPa)	**Curtain setback distance (m)**	**External sprays (on/off)**	**Underboom sprays (on/off)**	**Mining machine operator**	**Standard shuttle car operator**	**Off standard shuttle car operator**	**Return**	**Off curtain side**	**Curtain side**	**Return**
620	9.1	off	off	0.06	0.07	0.09	0.88	3.99	1.17	1.50
1172	9.1	off	off	0.04	0.06	0.09	0.65	4.19	1.53	1.49
620	12.2	off	off	0.13	0.05	0.14	0.87	4.77	0.97	1.55
1172	12.2	off	off	0.15	0.06	0.10	0.70	4.50	1.42	1.49
620	9.1	off	on	0.04	0.05	0.14	1.16	5.67	1.64	1.52
1172	9.1	off	on	0.04	0.03	0.13	1.14	5.05	2.10	1.47
620	12.2	off	on	0.22	0.08	0.20	1.28	6.49	1.33	1.51
1172	12.2	off	on	0.18	0.07	0.15	1.12	6.48	1.88	1.54
620	9.1	on	off	0.05	0.08	0.16	1.47	0.91	1.72	1.44
1172	9.1	on	off	0.08	0.08	0.22	1.97	0.65	3.18	1.52
620	12.2	on	off	0.34	0.12	0.25	1.77	1.41	1.63	1.56
1172	12.2	on	off	0.33	0.10	0.37	2.08	0.97	2.11	1.50
620	9.1	on	on	0.05	0.06	0.16	1.43	1.97	2.29	1.48
1172	9.1	on	on	0.04	0.05	0.13	1.10	1.46	2.75	1.47
620	12.2	on	on	0.38	0.14	0.32	1.67	2.54	1.79	1.54
1172	12.2	on	on	0.25	0.08	0.24	1.44	1.77	2.07	1.56

increased gas levels on the curtain side with the machine in the slab cut. In the box cut, interactions between water pressure and external spray use and setback distance and underboom spray use impacted off-curtain side gas levels. Interactions between setback distance and water pressure or underboom spray use significantly affected gas levels on the curtain side of the cutter head. n the slab cut, external spray use interacted significantly with underboom spray use to increase gas levels on the curtain side of the cutter head.

Use of the external sprays reduced full-cut gas levels measured on the off-curtain side of the cutter head and increased these levels on the curtain side, although the increase was minimal at the lower spray pressure. These sprays had minimal impact on full-cut dust levels at all sampling locations. The underboom sprays, which adversely affected full-cut gas levels and provided little benefit on full-cut dust levels, are not recommended.

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