

Continuous miner spray considerations for optimizing scrubber performance in exhaust ventilation systems

by J. Organiscak and T. Beck

Abstract ■ A majority of continuous mining machines employ a water spray system and a machine-mounted flooded-bed scrubber to suppress and capture dust during coal mining. These machine-mounted dust control systems must be designed to function within the localized face ventilation system at the mining section to control both dust and methane. Spray systems can impede or improve the scrubber effectiveness in controlling dust or methane at the mining face. Laboratory experiments were conducted to examine the effect of spray type, spray pressure, machine body blocking sprays and scrubber airflow on dust and gas levels, while using a 12.2-m (40-ft) exhaust ventilation curtain setback from the face. These experiments were conducted with the mining machine positioned at the end of a simulated 6.1-m (20-ft) sump and slab cut. Results indicate that the hollow cone nozzles with blocking sprays best complement the flooded-bed scrubber performance in an exhaust ventilation system. This external spray system notably reduced dust and gas levels on the off-curtain side of the mining machine for both the sump and slab cut compared to the flat spray nozzles. Higher scrubber airflows reduced dust and gas levels on the curtain side and in the return of the continuous mining machine. The remote operator position, located on the off-curtain side and parallel to the inlet end of the exhaust curtain, sustained the most stable and lowest dust levels around the mining machine.

Introduction

Coal miner overexposure to respirable coal and crystalline silica (or quartz) dust can cause pneumoconiosis and silicosis, respectively, which are debilitating and potentially fatal respiratory lung diseases. Although significant progress has been made in the United States (U.S.) with the reduction of coal workers' pneumoconiosis, severe cases continue to occur among coal miners,

especially within several geographic clusters of the Appalachian coal region (Antao et al., 2005). Mining also has some of the highest incidences of worker-related silicosis, with mining machine operators being the occupation that is most commonly associated with the disease (NIOSH, 2008).

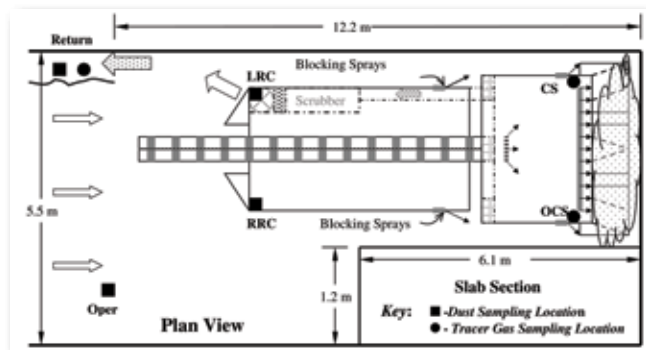
The U. S. Mine Safety and Health Administration (MSHA) enacts and enforces mine worker safety and health standards to mitigate mine worker injuries and occupational diseases. MSHA's permissible coal mine dust exposure limit is 2.0 mg/m³ during an eight-hr shift for coal mine workers, as defined by the Mining Research Establishment (MRE) Criteria (30 CFR 70-72, 74 2009). If more than 5% quartz mass is determined to be in the coal mine worker dust sample using MSHA's P7 infrared method (Parobeck and Tomb, 2000), the applicable respirable dust standard is reduced to the quotient of 10 divided by the percentage of quartz in the dust sample. This reduced dust

standard, based on the percentage of quartz content, is intended to limit worker respirable crystalline silica (quartz) exposure to 0.1 mg/m³ or less for the shift.

Coal mine worker overexposure to coal and quartz dust continues to be a problem at underground coal mining operations in the U.S. Over 90% of mechanized mining units operating in U.S. underground coal mines are continuous mining machines (MSHA, 2009). The percentage of valid MSHA inspector dust samples for continuous mining machine operators from 2004 to 2008 that exceeded the respirable coal dust standard or the reduced dust standard was 7.2% and 19.5%, respectively (U.S. Department of Labor, 2009). Therefore, many continuous mining machine operators continue to be overexposed to coal and quartz dust.

The primary dust controls used on most continuous mining machines are water sprays and flooded-bed scrubbers. Initially, flooded-bed scrubbers

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Figure 1**Plan view of continuous miner gallery test setup.**

were used with blowing face ventilation systems in gassy coal seams to help remove dust being blown over workers at the mine face, while providing satisfactory face methane removal for curtain setback distances up to 15.2 m (50 ft) (Volkwein et al., 1985; Jayaraman et al., 1990). With the development of remote control technology for continuous mining machines, flooded-bed scrubbers were also adopted on exhaust face ventilation systems for use in extended-cut mining applications (beyond 6.1 m or 20 ft of entry advance). Research has shown that positioning the operator away from the mining machine during extended-cut mining was a significant factor in lowering operator dust exposures on both blowing and exhaust ventilation systems (Fields et al., 1990). The best continuous miner operator position for blowing ventilation is in front of the discharge end of the intake curtain (Jayaraman et al., 1987; Goodman and Listak, 1999). The best operator position for exhaust ventilation is parallel to or outby the inlet end of the return curtain on the opposite side of the entry (Colinet and Jankowski, 1996; Goodman and Listak, 1999).

Since continuous miner operators cannot or do not always stay at these optimum positions during mining, their dust exposure can notably increase at other positions around the rear of the mining machine (Goodman and Listak, 1999). Previous research on machine-mounted scrubbers in blowing face ventilation systems have shown that the lowest dust levels at the rear corners and return of the mining machine are achieved when the face ventilation-to-scrubber airflow ratio is at or slightly above 1 (Jayaraman et al., 1992). Another scrubber study with blowing ventilation showed that dust rollback at the rear of the mining machine was reduced when the face ventilation curtain setback distance was increased from 6.1 m (20 ft) to 12.2 m (40 ft) and/or when blocking sprays are used on both sides of the mining machine outby the scrubber inlets (Goodman, 2000). Machine-mounted scrubber research with exhausting face ventilation systems showed dust levels increased at the remote operator position outby the mining machine when using a larger curtain setback distance, 12.2 m (40 ft) versus 9.1 m (30 ft), external directional sprays and/or under boom sprays (Goodman et al., 2006). Although the external directional sprays redirected dust past the scrubber inlets and increased operator dust levels, these sprays noticeably reduced gas levels on the off-curtain side of the face. On the other hand, the under boom sprays showed increases to both operator dust levels and gas levels at the face.

In order to improve dust and gas control around a continuous mining machine using a scrubber and external sprays with exhaust ventilation, the National Institute for Occupa-

tional Safety and Health (NIOSH) conducted additional experiments in its full-scale continuous miner gallery at the Pittsburgh Research Laboratory (PRL). The objective of these experiments was to examine external water spray configurations that are complementary to scrubber performance for exhaust ventilation systems. The experimental factors studied were spray nozzle type (hollow cone vs. flat), water spray pressure (550 kPa vs. 1,100 kPa or 80 psig vs. 160 psig), blocking sprays (off vs. on) and scrubber airflow (reduced vs. maximum). This paper describes the experiments conducted and the dust and gas level results measured around the mining machine.

Experimental design

Laboratory experiments were conducted within a full-scale continuous miner gallery as shown in Fig. 1. The gallery entry dimensions were 5.5 m (18 ft) wide by 2.0 m (6.5 ft) high, with a full-scale plywood mockup of a Joy CM14 continuous mining machine positioned at a simulated mining face. This mining machine was equipped with a flooded-bed scrubber, several banks of external spray nozzles and a 0.91-m (36-in) diameter cutting drum that rotates at 50 rpm. The flooded-bed scrubber utilized a 30-layer pleated stainless steel filter wetted by three spraying system full-cone QPH-6.5 nozzles (Spraying Systems, Wheaton, IL) and was powered by a variable frequency ac drive speed-controlled fan. Scrubber inlets were located under each side and center of the cutter boom near the hinge point. External sprays consisted of 15 top-mounted boom sprays directed at the top of the rotating drum, three under boom throat sprays directed at the loading pan and three sprays on each side of the cutter boom directed at the drum's end rings. Two blocking sprays were vertically mounted 7.6 cm (3 in.) apart on each side of the mining machine body, located two feet outby the scrubber inlets and two feet above ground level. These blocking sprays were oriented at a 15° angle away from the machine body toward the rib and were operated at the same pressure as the other external sprays.

Coal dust and sulfur hexafluoride (SF_6) gas were introduced in front of and along the length of the rotating cutting drum. Pulverized coal dust (Keystone mineral black 325BA, Keystone Filler & Manufacturing Co., Muncy, PA) was fed into the gallery at 25 g/min (0.9 oz/min) with a screw feeder (Vibra Screw, Inc., Totowa, NJ) and two LH-1/2 brass educutors (Penberthy, Prophetstown, IL) operated with 30 kPa (4 psig) of compressed air. One educutor discharged dust through a hose along the left front side of the drum and the other educutor discharged dust through a hose along the right front side of the drum. SF_6 gas was also released from tubing at each end of the dust discharge hoses to mix in the gas with the dust. A model 1303 multipoint gas doser (California Analytical Instruments, Orange, CA) released the SF_6 gas at a flow rate of 6 mL/sec (177 fl oz/sec). The rotating drum ensured their mixing and simulated dust and gas emissions from the face during mining.

Respirable dust and SF_6 gas concentrations were measured at several locations around the mining machine, as shown in Fig. 1. Respirable dust concentrations were measured with coal mine dust personal sampling units (CMDP-SU), comprised of an ESCORT-Elf constant flow air sampling pump pulling dust-laden air through a 10-mm nylon cyclone

Table 1

Experimental parameters.

Experimental Test factors	Sump cut, 9.1 m (20 ft) deep		Slab cut, 9.1 m (20 ft) deep	
	Low level (-1)	High level (+1)	Low level (-1)	High level (+1)
Nozzle type	Hollow cone	Flat	Hollow cone	Flat
Spray pressure	550 kPa	1,100 kPa	550 kPa	1,100 kPa
Blocking sprays	Off	On	Off	On
Scrubber airflow	Reduced ~ 20%	Maximum	Reduced ~ 20%	Maximum

(respirable dust classifier) and depositing the respirable fraction onto a preweighed 37-mm filter cassette (MSA, Pittsburgh, PA). A pair of samplers (CMDPSU) were placed and operated at the remote operator (Oper) position, the right rear corner (RRC) of the mining machine, the left rear corner (LRC) of the mining machine and the return (Return) air course. Each pair of dust concentration measurements was averaged to determine the dust concentration at each sampling location. SF₆ gas measurements were made using a California Analytical Instruments model 1312 photoacoustic gas monitor, which sequentially drew gas samples through tubing from the off-curtain side (OCS) of the cutting boom, the curtain side (CS) of the cutting boom and the Return air course. This data was collected with a computer-based data acquisition system and the gas concentrations at each location were averaged for the test.

Other operating parameters measured and recorded were water spray pressure, machine water flow, face return airflow and scrubber airflow. Water pressure and flow were measured with electronic instruments and recorded with a computer data acquisition system. Face return airflow was measured at the inlet end of the ventilation curtain with a handheld vane anemometer (moving transversely), with the scrubber off at the beginning and end of each test. Scrubber airflow was also measured with a handheld vane anemometer at the discharge end of the scrubber (moving transversely) at the beginning and end of each test. A moving traverse airflow measurement at the scrubber exhaust was found to be very comparable to a fixed-point traverse measurement within the scrubber duct.

For these scrubber/spray experiments, the continuous miner gallery was configured for exhaust curtain ventilation with a 12.2-m (40-ft) setback from the face as shown in Fig. 1. A 2-level, 4-factor experimental design was conducted and is shown in Table 1. Return airflow for these experiments was set to approximately 1.25 times the maximum scrubber airflow rate. The maximum scrubber airflow averaged 2.27 m³/s (4,810 ft³/min) and the return airflow averaged 2.90 m³/s (6,150 ft³/min) for these experiments. The water sprays tested were Spraying Systems 3/8-BD-3 hollow cone nozzles (77° spray angle @ 550 kPa or 80 psig) and Spraying Systems 3/8-TT-5006 flat nozzles (56° spray angle @ 550 kPa or 80 psig). These nozzles were chosen because their specifications showed comparable water flow rates at the same water pressures. All the external sprays, including the blocking sprays, used the same nozzle type during experimental comparisons. The flat spray pattern orientation was parallel to the roof for the top boom sprays and parallel to the ribs for the side boom and blocking sprays. The low and high operational water spray pressures averaged 560 kPa (81 psig) and 1,110

kPa (161 psig), respectively. An approximately 20% reduction in scrubber airflow was also used to simulate a realistic decrease from material buildup on the filter screen during the shift. The reduced scrubber airflow was controlled by decreasing the fan speed with the variable frequency drive, yielding a 1.78 m³/s (3,780 ft³/min) average for these experiments. These experimental factors were examined for both a simulated 9.1-m (20-ft) sump and slab cut. All testing is limited to examining airborne dust captured around a continuous mining machine and do not represent dust suppression from coal wetting.

Each experimental factor combination in Table 1 was replicated for at least three tests. Experimental tests were blocked or separately conducted for the sump and slab cuts for experimental practicality. Experimental tests were also blocked by nozzle type. A test of random combinations of spray pressure, blocking sprays and scrubber airflow combinations was conducted for each nozzle type before it was changed. The nozzle types were alternated to complete the three test replicates. All experimentally controlled test factors were precisely maintained and had relative standard deviations (RSD = (standard deviation /average) x 100%) less than 3% of their measured average.

Experimental results

Test replicate averages and standard errors were determined for respirable dust and SF₆ gas concentrations at the multiple locations around the mining machine during these experiments. The averages and standard errors for the sump cut are illustrated in Figs. 2-4 and for the slab cut in Figs. 5-7. The tests without blocking sprays are presented on the left side of these figures and the blocking spray tests are presented on the right side of these figures. Their x-axes are labeled by water pressure in descending order and scrubber airflow in ascending order.

Stepwise regression analysis was also conducted on the experimental data to examine the significant test factor relationships (at a 95% confidence level) with dust and gas concentrations. The low and high experimental test factor levels were represented as -1 and +1, respectively, in the regression model. Regression analyses were separately conducted at each dust and gas sampling location during the sump and slab cut. Since the dust concentrations measured at the RRC and LRC locations exhibited an extensive data range, non-normality and unequal variances, natural logarithms of these concentrations were used to stabilize their regression model variance (Myers and Montgomery, 1995). The most significant experimental test factors are shown in Table 2, with a "+" symbol illustrating a direct relationship and a "-" symbol illustrating a negative relationship in the regression models.

Table 2

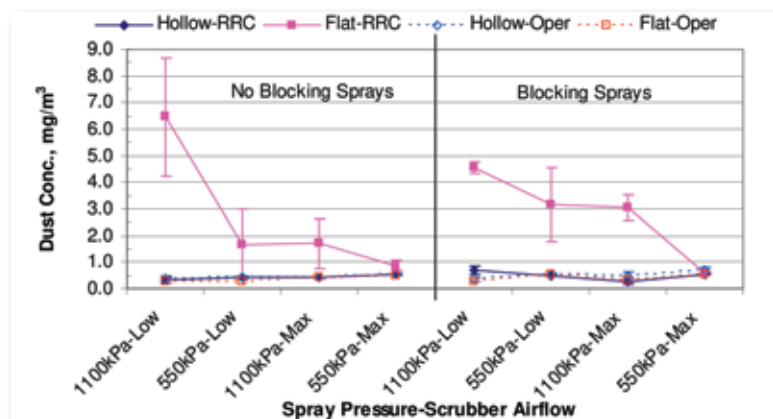
Significant dust and gas concentration relationships.

Sample location	Sump cut				Slab cut			
	Nozzle type	Spray pressure	Blocking sprays	Scrubber airflow	Nozzle type	Spray pressure	Blocking sprays	Scrubber airflow
Dust-RRC	+				+	+	–	–
Dust-LRC				–		+		–
Dust-Return		–		–				–
Gas-OCS	+		–		+		–	
Gas-CS	–		+				+	–
Gas-Return	+			–	+			–

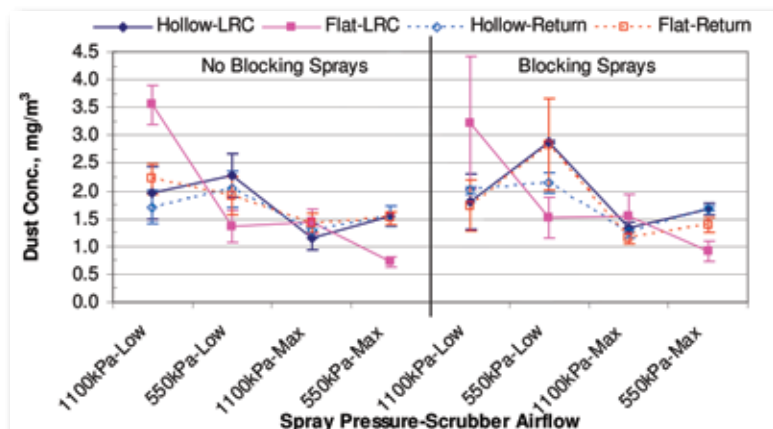
Key: + and – symbols refer to direct and indirect relationships, respectively, at the 95% confidence level.

Figure 2

Sump cut dust concentrations on the off-curtain side of the entry.

**Figure 3**

Sump cut dust concentrations on the curtain side of the entry.



Since the operator position had minimal concentration changes in these experiments and there were very few regression factor interactions at the other sampling locations, these regression results were not shown in Table 2 for simplicity.

Sump cut

Figures 2 and 3 show the dust concentrations measured for the sump cut on the off-curtain side and curtain side of the entry, respectively. The SF₆ gas concentrations measured for the sump cut are shown in Fig. 4. Table 2 shows the significant dust and gas relationships in these figures.

The most significant factors affecting dust concentrations in the sump cut were the nozzle type and scrubber airflow. The hollow-cone nozzle appeared to exhibit very little dust rollback to the RRC of the machine, whereas the flat nozzle created significant dust rollback to the RRC. Blocking sprays didn't seem to have a significant effect on controlling dust in the sump cut with either of the spray nozzle types. The dust concentrations on the curtain side of the entry were most affected by scrubber airflow. Dust levels at the LRC and in the Return were significantly reduced with higher scrubber airflows. The remote operator position had the lowest and most stable dust concentrations observed for these sump cut tests.

The most significant factors affecting SF₆ gas concentrations in the sump cut were nozzle type and blocking sprays. Figure 4 shows that the highest gas concentrations are at the OCS of the continuous miner boom with no blocking sprays operating. Hollow cone sprays achieved lower gas concentrations on both sides of the miner boom with no blocking sprays, compared to the flat sprays. The blocking sprays significantly reduced the OCS gas concentrations, especially for the hollow cone spray nozzles. The decrease in OCS gas levels were somewhat offset by an increase in gas levels on the CS of the continuous miner boom. The increased gas concentrations at the CS location

with the blocking sprays were still lower than the concentrations at the OCS location without the blocking sprays.

Slab cut

Figures 5 and 6 show the dust concentrations measured for the slab cut on the off-curtain side and curtain side of the entry, respectively. The SF_6 gas concentrations measured for the sump cut are shown in Fig. 7. Table 2 shows the significant dust and gas relationships in these figures.

All the experimental factors significantly affected dust concentrations at the RRC of the mining machine in the slab cut. Both spray nozzle types showed prominent dust rollback to the RRC of the machine with no blocking sprays operating. The flat spray nozzles exhibited significantly higher dust concentrations than the hollow cone sprays at this RRC location. Lower water pressures and higher scrubber airflows significantly reduced this rollback effect. Application of the blocking sprays appeared to eliminate all dust rollback to the RRC location, reducing these dust concentrations to nearly Oper position levels.

The dust concentrations on the curtain side of the entry were most affected by water pressure and scrubber airflow. Dust levels at the LRC were significantly increased by higher spray pressures, while higher scrubber airflows reduced dust concentrations at the LRC and Return sampling locations. Similar to the sump cut, the remote operator position again had the lowest and most stable dust concentrations for these slab cut tests.

The most significant factors affecting SF_6 gas concentrations in the slab cut were, again, nozzle type and blocking sprays. Figure 7 shows that the highest gas concentrations are at the OCS of the continuous miner boom with no blocking sprays operating. The flat sprays exhibited significantly higher gas concentrations on the OCS side of the miner boom with no blocking sprays, compared to the hollow-cone sprays. Blocking spray application again significantly reduced the OCS gas concentrations, especially for the hollow-cone spray nozzles. The decrease in OCS gas levels was somewhat offset by an increase in gas levels on the CS of the continuous miner boom. The increased gas concentrations at the CS location with the blocking sprays were still lower than the concentrations on the OCS location without the blocking sprays.

Conclusions

Laboratory experiments were conducted to examine the effect of spray type, spray pressure, machine body blocking sprays and scrubber airflow on dust and gas levels while using a 12.2-m (40-ft) exhaust ventilation curtain setback from the face. From these experiments the key observations made include:

- The remote operator position had the lowest and most stable dust concentrations compared to the

Figure 4

Sump cut gas concentrations.

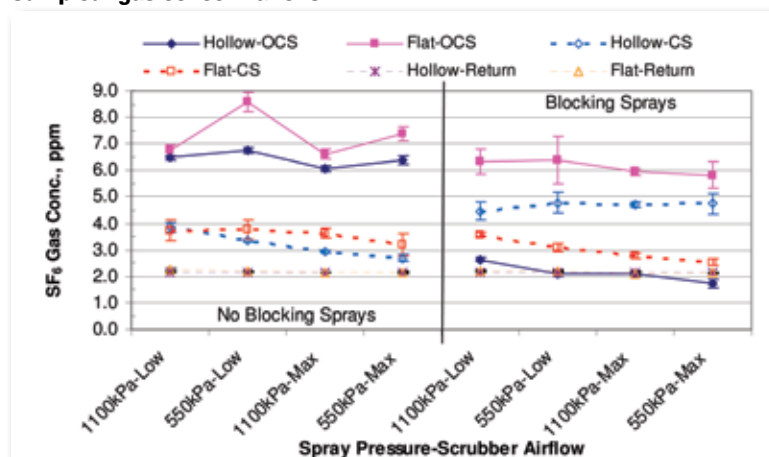


Figure 5

Slab cut dust concentrations on the off-curtain side of the entry.

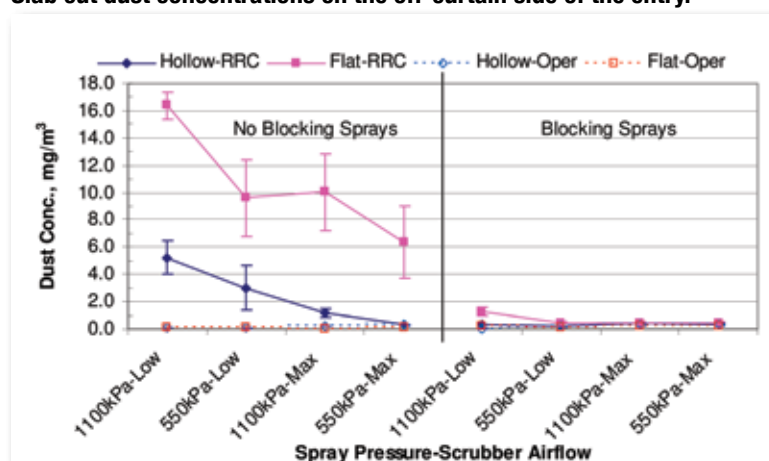
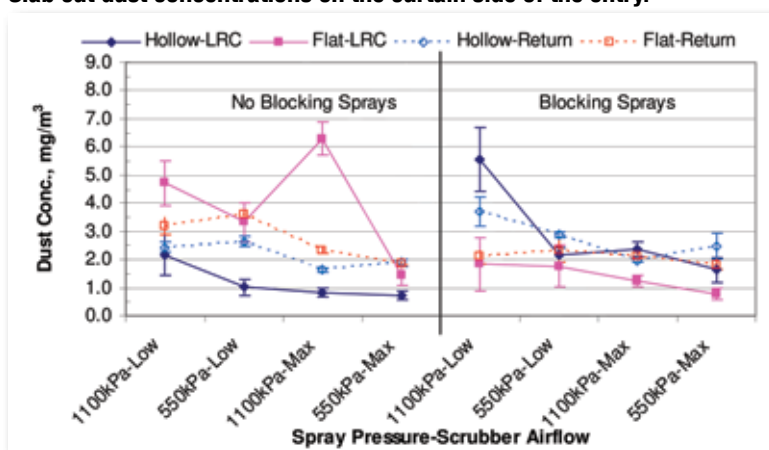


Figure 6

Slab cut dust concentrations on the curtain side of the entry.

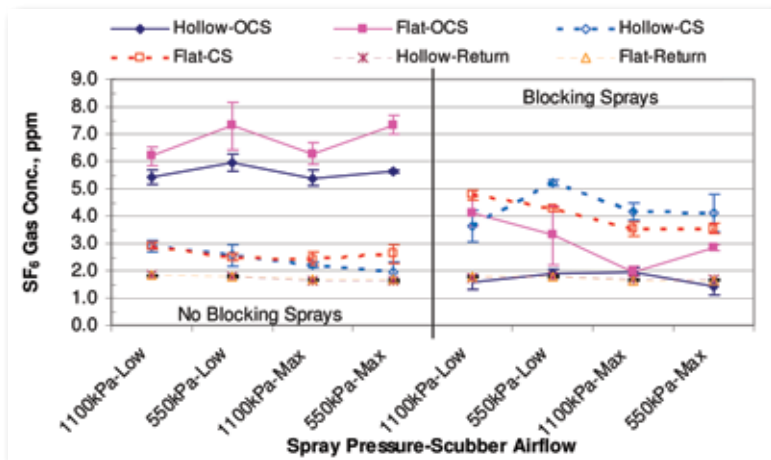


rear corners and return of the continuous mining machine.

- Hollow-cone nozzles exhibited less dust rollback than flat sprays on the off-curtain side of the mining machine for both the sump and slab cuts.
- Blocking sprays notably reduced dust concentrations on the off-curtain side of the mining machine for the slab cut, with negligible dust changes for the

Figure 7

Slab cut gas concentrations.



sump cut.

- Higher water spray pressure was more detrimental, increasing dust concentrations at the back corners of the mining machine for the slab cut, compared to the sump cut.
- Hollow-cone nozzles and blocking sprays both noticeably reduced gas concentrations at the off-curtain side of the continuous miner boom.
- Higher scrubber airflows reduced dust levels on the curtain side of the continuous mining machine, and reduced both dust and gas levels in the return.

Given these experimental observations, it appears that the hollow-cone nozzles with blocking sprays best complement the flooded-bed scrubber performance in an exhaust ventilation system. This external spray system notably reduced dust and gas levels on the off-curtain side of the mining machine for both the sump and slab cut compared to the flat spray nozzles. Using lower water spray pressures noticeably reduced dust rollback to the rear corners of the mining machine (RRC and LRC), primarily during the slab cut. Higher scrubber airflows reduced dust and gas levels on the curtain side and in the return of the continuous mining machine. Finally, the remote operator position, located on the off-curtain side and parallel to the inlet end of the exhaust curtain, sustained the most stable and lowest dust levels around the mining machine. ■

Disclosure

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

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