# CONTINUOUS MINER SPRAY CONSIDERATIONS FOR OPTIMIZING SCRUBBER PERFORMANCE IN EXHAUST VENTILATION SYSTEMS

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## 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 complemented 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 as 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 (US) 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. 2004). 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 US 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/m$^3$ during an 8 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/m$^3$ 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 US. Over 90 % of mechanized mining units operating in US 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 and reduced dust standard was 7.2 % and 19.5 %, respectively (US 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 were used with blowing face ventilation systems in gassy coal seams to help remove dust being blown over face workers at the mining 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 being 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 remote positioning 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 don't or can't 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 the lowest dust levels at the rear corners and return of the mining machine were 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 set back 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 Occupational Safety and Health (NIOSH) conducted additional experiments in its full scale continuous miner gallery at the Pittsburgh Research Center (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.1100 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 Figure 1. The gallery entry dimensions were 5.5 m (18-ft) wide by 2.0 m (6.5 high) with a full-scale plywood mockup of a Joy CM14[1] 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 3 spraying system full cone QPH-6.5 nozzles (Spraying Systems, Wheaton, IL) at 340 kPa (50 psig) 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, 3 under boom throat sprays directed at the loading pan, and 3 sprays on each side of the cutter boom directed at the drum's end rings. Two blocking sprays were vertically mounted 3 inches 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 towards 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 grams/minute with a screw feeder (Vibra Screw, Inc., Totowa, NJ) and two LH-1/2 brass eductors (Penberthy, Prophetstown, IL) operated with 30 kPa (4 psig) of compressed air. One eductor discharged dust through a hose along the left front side of the drum and the other eductor 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

[1] Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

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 milliliters/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 Figure 1. Respirable dust concentrations were measured with coal mine dust personal sampling units (CMDPSU), comprised of an ESCORT-Elf constant flow air sampling pump pulling dust laden air through a 10-mm nylon cyclone (respirable dust classifier) and depositing the respirable fraction onto a pre-weighed 37-mm filter cassette (MSA, Pittsburgh, PA). A pair of these 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. The pairs of dust concentrations measured were averaged to determine the dust concentration at each sampling location. $SF_6$ 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 (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.

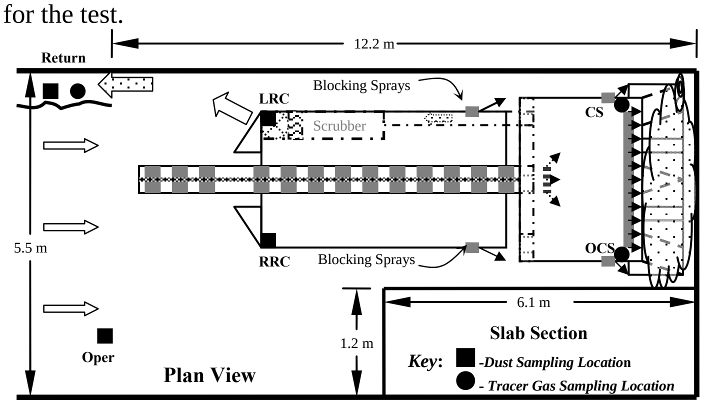


Figure 1. Plan view of continuous miner gallery test set-up.

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 traverse) 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 traverse) 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 Figure 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 $m^3$/s (4810 $ft^3$/min) and the return airflow averaged 2.90 $m^3$/s (6150 $ft^3$/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 similar water pressures. All the external sprays, including the blocking sprays, used the same nozzle type and were operated at the same water pressure during their 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 1110 kPa (161 psig), respectively. Approximately a 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 $m^3$/s (3780 $ft^3$/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 3 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. One test of spray pressure, blocking sprays, and scrubber airflow combinations was randomly conducted for each nozzle type before they were changed. The nozzle types were alternated to complete the 3 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.

Table 1. – Experimental Design

| 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 | 1100 kPa | 550 kPa | 1100 kPa |
| Blocking Sprays | Off | On | Off | On |
| Scrubber Airflow | Reduced ~ 20% | Maximum | Reduced ~ 20% | Maximum |

## Experimental Results

Test replicate averages and standard errors were determined for respirable dust and $SF_6$ 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 Figures 2-4 and for the slab cut illustrated in Figures 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 pressures 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 the 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. 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 $SF_6$ gas concentrations measured for the sump cut are shown in Figure 4. Table 2 shows the significant dust and gas relationships in these figures.

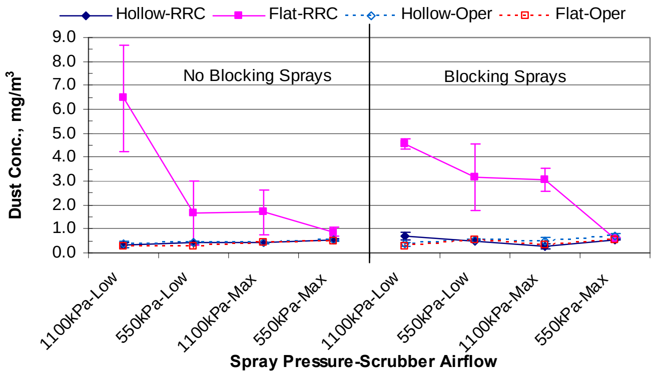


Figure 2 – Sump cut dust concentrations on the off-curtain side of the entry.

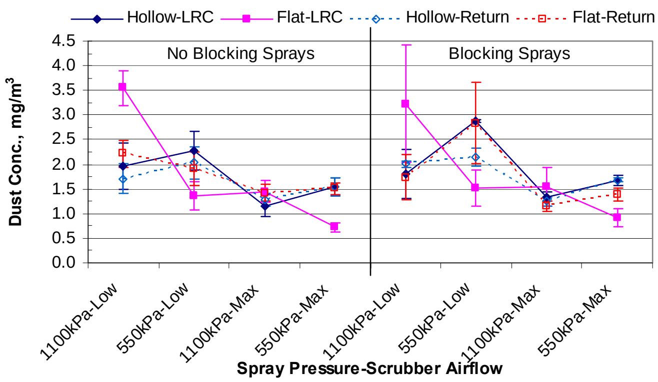


Figure 3 – Sump cut dust concentrations on the curtain side of the entry.

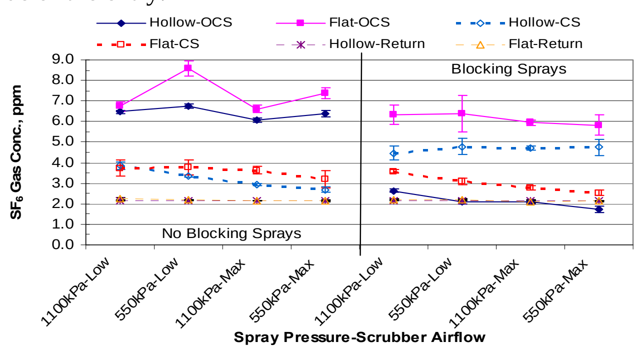


Figure 4 – Sump cut gas concentrations.

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.

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 of the machine. 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 $SF_6$ 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 as 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 OCS 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 SF6 gas concentrations measured for the sump cut are shown in Figure 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 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

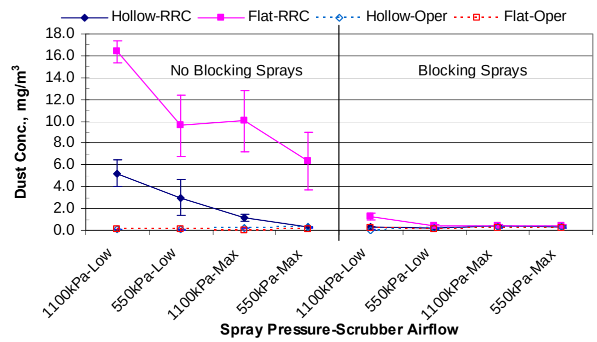


Figure 5. Slab cut dust concentrations on the off-curtain side of the entry.

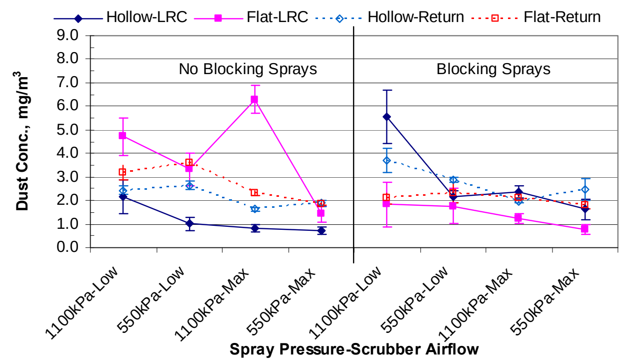


Figure 6. Slab cut dust concentrations on the curtain side of the entry.

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 hollow cone sprays achieved lower gas concentrations on both sides of the miner boom with no blocking sprays as compared to the flat sprays. Blocking sprays application again 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 on the OCS location without the blocking sprays.

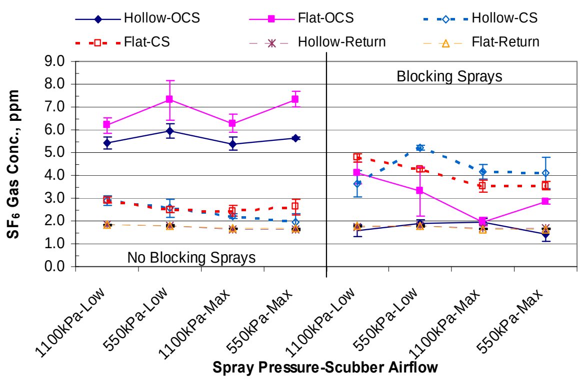


Figure 7. Slab cut gas concentrations.

## 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 were made.

- The remote operator position had the lowest and most stable dust concentrations as compared to the 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 sump cut.
- Higher water spray pressure was more detrimental in increasing dust concentrations at the back corners of the mining machine for the slab cut as 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 complemented 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 as 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.

## References

1. Antao, V.C. dos S., Petsonk, E.L., Sokolow, L.Z., Wolfe, A.L., Pinheiro, G.A., Hale, Attfield, M.D. (2005), "Rapidly Progressive Coal Workers' Pneumoconiosis in the United States: Geographic and Other Factors," Occupational Environmental Medicine 2005; 62, pp. 670-674.
2. CFR (2009), "Code of Federal Regulations," Washington, DC: US Government Printing Office, Office of the Federal Register.
3. Fields, K.G., Atchison, D.J., Haney, R.A. (1990), "Evaluation of a Combined Face Ventilation System Used with a Remotely Operated Mining Machine," In: Proceedings of the 1990 International Symposium on Respirable Dust in the Mineral Industries, pp. 349-353.
4. Colinet, J.F., Jankowski, R.A. (1996), "Dust Control Considerations for Deep-Cut Faces when Using Exhaust Ventilation and a Flooded-Bed Scubber," SME Transactions, Vol. 302, Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., pp. 104-111.
5. Goodman, G.V.R., Listak, J.M., (1999), "Variation in Dust Levels with Continuous Miner Position," Mining Engineering, Vol. 51, No. 2, pp. 53-59.

6. Goodman, G.V.R. (2000), "Using Water Sprays to Improve Performance of a Flooded-Bed Dust Scrubber," Appl. Occup. Envir. Hyg., Jul 15(7):550-560.
7. Goodman, G.V.R., Beck, T.W., Pollock, D.E. (2006), "The Effects of Water Spray Placement for Controlling Respirable Dust and Face Methane Concentrations," Journal of the Mine Ventilation Society of South Africa, April/June, pp. 56-63.
8. Jayaraman,, N.I., Stritzel, D.L., Jankowski, R.A. (1987), "Improving Health, Safety and Productivity Through the Use of Machine-Mounted Scrubbers," In: Proceedings of the 95th Annual Meeting of the Illinois Mining Institute, Mount Vernon, IL, pp. 62-75.
9. Jayaraman, N.I., Volkwein, J.C., Kissell, F.N. (1990), "Update on Continuous Miner Dust Scrubber Application," Mining Engineering, Vol. 42, No. 3, pp. 281-284.
10. Jayaraman, N.I., Jankowski, R.A., Whitehead, K.L. (1992), "Optimizing Continuous Miner Scrubbers for Dust Control in High Coal Seams, Proceedings of the 121st Annual SME Meeting, Phoenix, AZ, Feb. 24-27, pp.193-205.
11. MSHA (2009). Information provided by George Niewiadomski, Health Division, Mine Safety & Health Administration, Headquarters, Arlington, Virginia.
12. Myers, R.H., Montgomery, D.C. (1995). *Response Surface Methodology: Process and Product Optimization using Designed Experiments*. New York: John Wiley & Sons, Inc.
13. NIOSH (2008), "Work-Related Lung Disease Surveillance Report 2007, Volume1," Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Respiratory Disease Studies, DHHS (NIOSH) Publication No. 2008-143a.
14. Parobeck, P.S., Tomb, T.F. (2000), "MSHA's Programs to Quantity the Crystalline Silica Content of Respriable Mine Dust Samples," SME preprint 00-159, Littleton, CO, Society for Mining Metallurgy, and Exploration, Inc.,
15. US Department of Labor (2009), Mine Safety and Health Administration, Program Evaluation and Information Resources, MSHA Standardized Information Systems, Arlington Virginia.
16. Volkwein, J.C., Halfinger, G. Jr., Thimons, E.D. (1985), "Machine-Mounted Scrubber Helps Ventilate Face," World Mining Equipment, Vol. 9, No. 2, pp. 15-16.