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## CONTINUOUS MINING DUST LEVELS IN 20-FOOT CUTS WITH AND WITHOUT A SCRUBBER OPERATING

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## ABSTRACT

Flooded-bed scrubbers on continuous miners have been shown to be an effective respirable dust control technology, traditionally used during the extraction of extended cuts of up to 12.2 m (40 ft). To effectively use scrubbers in faces that employ exhaust ventilation, the return ventilation curtain or tubing should be located outby the scrubber discharge on the continuous miner, which results in a setback distance from the face of approximately 12.2 m (40 ft). The goal of this research was to compare respirable dust levels generated in 6.1 m (20 ft) cuts when using extended curtain setbacks with a scrubber operating to dust levels in 6.1 m (20 ft) cuts when using traditional exhaust face ventilation without a scrubber operating.

Dust surveys were completed at three mines with area and personal sampling conducted to quantify respirable dust concentrations on a cut-by-cut basis. Sampling results did not show a statistically significant difference in respirable dust at the continuous miner or shuttle car locations with and without the scrubber operating. However, with the scrubber operating, respirable dust concentrations in the return airstream downwind of the miner showed reductions of 91%, 86%, and 40% at Mines A, B, and C, respectively. The reductions at Mines A and B were statistically significant. Likewise, reductions in respirable quartz dust levels in the miner return were observed at all three mines, with statistically significant reductions of over 80% observed at Mines A and B. Consequently, operation of the flooded-bed scrubber did not impact respirable dust levels in the face area but did significantly reduce respirable and quartz dust levels downwind of the continuous miner. These results were obtained with the mines operating at or above the minimum operating levels specified in their ventilation plans.

## INTRODUCTION

During the mining and transport of coal, respirable dust is generated and can be liberated into the air ventilating the mine. If mine workers inhale excess amounts of this respirable airborne dust, it can result in the development of coal workers' pneumoconiosis (CWP). Likewise, if rock within or adjacent to the coal seam is extracted, respirable silica (quartz) dust can be liberated into the ventilating air. Inhalation of excess amounts of silica can lead to the development of silicosis. CWP and silicosis are disabling and potentially fatal lung diseases that cannot be cured [Cohen and Velho 2002], so it is critical to prevent mine workers from contracting these lung diseases.

The Federal Coal Mine Health and Safety Act of 1969 (Public Law 91-173) established a respirable coal mine dust standard of 2 mg/m$^3$ over an eight-hour shift. This Act also required periodic respirable dust sampling with a personal gravimetric sampler on each mechanized mining unit (MMU) to demonstrate compliance with the dust standard. When the quartz content in a respirable dust sample collected by a Mine Safety and Health Administration (MSHA) inspector exceeds 5%, a reduced dust standard is calculated by dividing the percent quartz into 10. For example, if a sample contains 11% quartz, the reduced dust standard for that MMU would be 0.9 mg/m$^3$ (10 ÷ 11% quartz = 0.9).

In an effort to limit the respirable dust exposure of coal mine workers, MSHA requires each mine operator to establish an acceptable ventilation plan that details how the mine proposes to control worker respirable dust exposure by defining ventilation parameters and dust control technologies that will be used [30 CFR[1] 75.371]. This plan must be submitted to the appropriate MSHA district manager and approved by MSHA before mining can begin [30 CFR 75.370]. Also, MSHA personnel assess the status of the dust controls during inspections to ensure that the plan parameters control respirable dust levels to or below the applicable dust standard. Typically, the mine will be permitted to exceed the minimum specified plan parameters by 120% and still be considered to be operating under the existing dust control plan [MSHA 2012a]. In addition, mine operators must verify on each production shift that the plan parameters are being maintained [30 CFR 75.362 (a)(2)].

In order to extract cuts extending beyond 6.1 m (20 ft), mine operators must apply to MSHA for approval. Historically, MSHA has granted approval if the mine has successfully demonstrated the ability to control the roof, methane, and respirable dust while extracting extended cuts. However, MSHA does not grant approval until after completing an on-site evaluation of the proposed extended cut system. Initially, MSHA will only allow for extraction of extended cuts while MSHA personnel are present at the mine site conducting their evaluation. At all other times, the mine operator must follow the standard cut plan included in the MSHA-approved ventilation plan, which "should require that the ventilation curtain/tubing be maintained to not more than 6.1 m (20 ft) from the deepest point of penetration the face has been advanced" [MSHA 2012b].

In underground coal mines in the United States, the majority of continuous mining machines in use today are equipped with a flooded-bed scrubber, which is a fan-powered dust collector. The scrubber pulls dust-laden air from the face and passes it through a wetted filter panel. Past research [Colinet et al. 1990] has shown that scrubbers can remove over 90% of the respirable dust that is pulled into the unit. Although MSHA does not consider the scrubber to be a ventilation device, it has been shown to assist in moving ventilating air to the face [Taylor et al. 1996]. As a result of these dust collection and air-moving capabilities, flooded-bed scrubbers have become a key component for mines in receiving MSHA approval to take extended cuts of up to 12.2 m (40 ft) as part of their approved ventilation plan.

In order to realize the maximum effectiveness of scrubbers in mines using exhausting face ventilation, the mouth of the brattice curtain should be outby the discharge of the scrubber so that the scrubber exhaust can be directed into the return airway [Jayaraman et al. 1990]. This would require the curtain to be approximately 12.2 m (40 ft) from the face. In extended cut approvals, MSHA grants a variance to the mining operation to allow for this extended curtain setback distance. Historically, mines have not requested and MSHA has not granted this curtain setback variance for use in 6.1m (20-ft) cuts. However, the use of a flooded-bed scrubber in 6.1 m (20-ft) cuts along with an extended curtain setback could be advantageous for controlling dust.

Researchers from the Office of Mine Safety and Health Research (OMSHR) of the National Institute for Occupational Safety and Health

[1] Code of Federal Regulations. See CFR in references.

(NIOSH), in partnership with MSHA and Alpha Natural Resources, completed a research project to evaluate the impact on respirable dust levels generated in 6.1 m (20-ft) cuts with and without a flooded-bed scrubber operating. An extended curtain setback was used in cuts when the scrubber was operated. Respirable dust surveys were conducted at three Alpha underground coal mines (referred to here as Mines A, B, and C). Two of these mines did not have approval to operate a flooded-bed scrubber in their current ventilation plans. For these mines, mine management submitted a temporary plan to MSHA, which was approved by MSHA for use only during the NIOSH testing period. The third mine had the capability of operating a flooded-bed scrubber with an extended curtain setback to extract 12.2 m (40-ft) cuts in its current plan, so no temporary plan was needed. However, the mine restricted the depth of the cuts taken during the NIOSH sampling to 6.1 m (20 ft) to accommodate the test protocol.

Prior to NIOSH initiating each of its dust surveys at the individual mines, MSHA personnel visited the mines to ensure that the plan parameters specified in the approved ventilation plans for Mines A, B, and C were in use and adequate to control respirable dust levels. Dust levels measured by MSHA during the baseline surveys were within allowable levels. MSHA also examined the scrubbers to document their proper operation and quantify the air quantities produced. In addition to these baseline surveys, an MSHA representative participated in the subsequent NIOSH dust surveys at each mine and verified that minimum plan parameters were present during the NIOSH sampling.

## MINE SITES TESTED

Each of the mines included in these surveys used line brattice to implement an exhausting face ventilation system. For the cuts with the scrubber off, the ventilation curtain was set back from the face a maximum of 6.1 m (20 ft) For the cuts with the scrubber operating, the ventilation curtain was set back a distance of up to 12.2 m (40 ft).

All of the continuous miners sampled were located on super sections—i.e., where two sets of mining equipment operate simultaneously within the same working section, and each set is ventilated by a separate split of intake air—with the sampled mining machine responsible for completing the development of entries on one side of the super section. Two shuttle cars were used to transport coal from the face to the section feeder. A twin-boom bolter was used to complete the installation of roof bolts. In the approved ventilation plans for each of the MMUs sampled, the bolting machine was permitted to travel downwind of the continuous miner once during each production shift. Table 1 provides a brief summary of the equipment and operating conditions present at each mine during the NIOSH dust surveys, with more detailed information provided in an upcoming publication [Colinet et al., forthcoming].

As noted in Table 1, all three mining machines used 30-layer filter panels in their respective flooded-bed scrubbers; however, the other parameters showed substantial variation across the three mines. For example, mining height varied by over 0.76 m (30 in), while scrubber airflow varied by nearly 1.42 $m^3/s$ (3,000 cfm). Consequently, the mines sampled during these surveys represent a range of operating conditions.

## SAMPLING PROTOCOL

Respirable dust measurements were made using the following instruments: (1) Thermo Scientific Model pDR-1000AN Personal Data Rams (pDRs); (2) Thermo Scientific Model PDM3600 Personal Dust Monitor (PDM); and (3) Mine Safety Appliances (MSA) Escort ELF sampling pumps (gravimetric samplers). The pDR samplers use light-scattering technology to provide real-time measurements of dust levels, which are stored in an internal data logger. Dust measurements were recorded by each pDR at five-second intervals throughout the sampling shift. The PDM sampler is a mass-based, real-time dust sampler that was operated at 2.2 l/min with a Higgins-Dewell cyclone. The PDM sampler recorded dust measurements at one-minute sampling intervals. Each MSA pump was operated at 2 l/min while connected to a Dorr-Oliver 10-mm nylon cyclone fitted with a 37-mm-diameter PVC filter. All filters were pre- and post-weighed at the OMSHR Pittsburgh lab, with the gain in dust mass and sampling time used to calculate the average respirable dust concentration for the sampling period. These time-weighted average dust concentrations were not converted to Mining Research Establishment (MRE) equivalent concentrations as described in 30 CFR 70.206 because they were not collected as compliance dust samples.

Because light-scattering instruments can be impacted by changes in dust composition and size distribution, the pDR manufacturer recommends that individual dust readings be corrected with a ratio calculated from adjacent gravimetric samplers [Thermo Scientific 2008]. Consequently, two gravimetric samplers were located side-by-side with a pDR sampler on area sampling racks. The average gravimetric concentration from the two samplers was divided by the pDR concentration for the entire sampling period to calculate a correction factor. The individual five-second dust readings recorded by the pDR were then multiplied by this correction factor. The corrected pDR concentrations were used in all subsequent calculations.

Area sampling packages as described above were placed at multiple sampling locations, as illustrated in Figure 1. In addition, a gravimetric-only sampling package was operated in the miner return, with the filters from this package used for quartz analysis. A PDM sampler was worn by the continuous miner operator to assess his dust exposure. Each of these sampling locations will be discussed below in greater detail.

NIOSH researchers collected time study information related to the operation of the continuous miner. The start and stop times for each miner cut were used to calculate the average dust concentration during each cut. The times when each shuttle car entered and exited the active face were also recorded and used to calculate dust levels at each shuttle car while being loaded. When the continuous miner was not loading for periods of three minutes or longer, these down-periods were removed from the dust calculations so that the reported data would represent dust generated during mining and loading.

**Table 1.** Summary of conditions observed during NIOSH sampling at three mines.

| Mine parameter | Mine A | Mine B | Mine C |
|---|---|---|---|
| Continuous miner model | Joy 14 CM 15 | Joy 12 CM 15 | Joy 14 CM 15 |
| Average mining height, m (in) | 1.57 (62) | 2.39 (94) | 1.65 (65) |
| Average face airflow, $m^3/s$ (cfm ) | 3.92 (8,300) | 3.75 (7,943) | 3.10 (6,565) |
| Average scrubber airflow, $m^3/s$ (cfm) | 3.02 (6,400) | 3.41 (7,218) | 2.02 (4,288) |
| Scrubber filter panel density | 30-layer | 30-layer | 30-layer |
| Number of water sprays operating | 51 | 42 | 33 |
| Spray type | BD3-5 hollow cone | BD3 hollow cone | BD3-5 hollow cone |
| Average water pressure, kPa (psi) | 682.6 (99) | 468.8 (68) | 689.5 (100) |
| Roof bolter model | Fletcher Roof Ranger II | Fletcher DDR-13 | Fletcher Roof Ranger II |
| Average vacuum pressure, mm Hg (in Hg) – left | 406.4 (16) | 355.6 (14) | 381.0 (15) |
| Average vacuum pressure, mm Hg (in Hg) – right | 330.2 (13) | 431.8 (17) | 330.2 (13) |

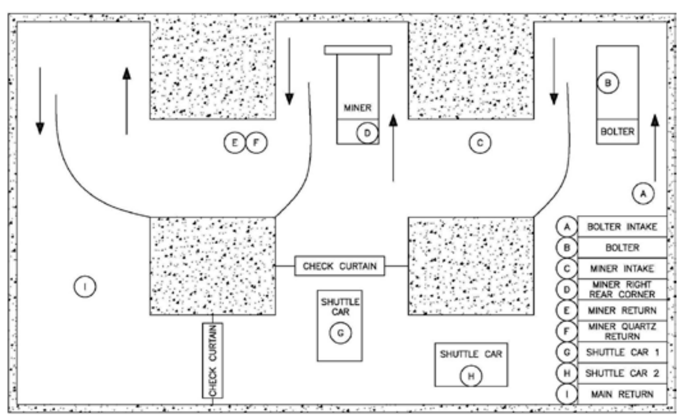


**Figure 1.** Schematic of typical dust sampling locations at each mine.

Isolation of miner-generated dust was accomplished by placing area sampling packages in both the immediate intake and return (locations C and E in Figure 1) for the continuous miner. Intake dust levels were subtracted from return dust levels to calculate the quantity of dust attributable to the miner. An area sampling package was also located on the right rear corner (RRC) of the continuous miner (location D). This sampling location assisted in monitoring dust rollback from the face. After the survey at Mine A was completed, an additional area sampling package was placed in the main return entry (location I) to expand the information obtained on differences in dust levels downwind of the miner.

An area sampling package was placed in each shuttle car cab (locations G and H) to monitor face area dust concentrations. The shuttle car dust concentrations are important for this study because their position with respect to the mining machine is consistent during mining and loading operations at the face. These data allow for a direct comparison of dust concentrations in the face area for the scrubber-on and scrubber-off test conditions.

The roof bolting machine was operated downwind of the continuous miner on several occasions during the survey. Because miner-generated dust can significantly impact the exposure of downwind personnel [Jayaraman et al. 1988], NIOSH monitored dust concentrations with sampling packages placed in the bolter intake (location A) and on-board the bolter (location B). Because of differences in operating practices and bolter designs, the bolter-mounted sampling package could not be placed at identical locations for all three surveys. A detailed time study documented the bolter's location and position with respect to the continuous miner (upwind or downwind) for each bolting cycle. Figure 2 illustrates representative locations for the sampling packages on the shuttle cars and roof bolters.

Miner-generated dust was analyzed for quartz content for both the scrubber-on and scrubber-off conditions. This was accomplished by using two sets of cyclones/filters on the same area sampling rack, which was placed in the immediate miner return (location F). If the scrubber was being used (scrubber-on), the hoses for two filters were connected to the sampling pumps and the pumps were activated just before mining commenced. The pumps were placed on hold at the end of the cut and the hoses were removed from the pumps. A similar procedure was followed with the other two filters during scrubber-off cuts. The quartz content of these filters was determined by the MSHA analytical lab in Pittsburgh through the use of the MSHA P7 analytical method [MSHA 1989]. Sampling times were recorded for the scrubber-off and scrubber-on operating conditions to allow for the calculation of respirable quartz dust concentrations.

**Figure 2.** Dust sampling packages located on a shuttle car (left) and on a roof bolter (right).

During normal mining operations, a buildup of material can occur in flooded-bed scrubbers, diminishing their air-moving effectiveness [Potts et al. 2011]. This possibility was monitored by using a pitot tube and differential pressure gauge to measure velocity head in order to calculate scrubber air quantity prior to the start of each 6.1 m (20-ft) scrubber-on cut configuration. At the beginning of each mine survey, a full traverse of velocity measurements (15 to 21 points depending upon the cross-sectional area of the scrubber ductwork) was completed and used to calculate scrubber air quantity. During subsequent scrubber measurements, three center-line velocity head measurements were obtained and compared to the three center-line readings from the full traverse to ensure appropriate airflow through the scrubber prior to each cut. As specified in the ventilation plans, the 30-layer scrubber screen was removed and cleaned with water after each cut. Additional maintenance included cleaning the scrubber inlets and ductwork at the beginning of each shift. In a few instances, the demister also had to be removed and cleaned in order to obtain the required scrubber airflow.

Air velocities in the entries and behind the exhaust line curtains were measured with a vane anemometer. An airflow measurement was taken at the face-side end of the ventilating curtain prior to the start of each cut. For cuts where the scrubber was going to be operated, this airflow measurement was taken before activation of the scrubber. Curtain configuration and length were also recorded. The exhaust brattice curtain was positioned just outby the scrubber exhaust for the scrubber-on tests and within 6.1 m (20 ft) of the face during the scrubber-off tests. The scrubber discharged airflow either from the left or from the right rear corner of the miner, with that choice dictated at each mine by the location of the exhaust line brattice within the entry.

Past research has shown that the mining machine's external water spray system can have a dramatic impact on dust levels at the face [Organiscak and Beck 2010]. Therefore, the number of sprays operating and the operating pressure on the left and right side of the cutter head were monitored throughout the survey for adherence to the specifications in the ventilation plan for each MMU. Similarly, vacuum measurements were taken on the left and right drill heads of the roof bolting machine to ensure that the bolter dust collector was meeting the required operating levels.

## DATA ANALYSIS

In order to evaluate the impact of the flooded-bed scrubber in 6.1 m (20-ft) cuts, the real-time sampling data and time study information were used to calculate dust concentrations on a cut-by-cut basis. Seven cuts were sampled for each of the scrubber-off and scrubber-on test conditions at Mines A and B, and four cuts were sampled for each of the test conditions at Mine C. Given the small sample sizes and the possibility that the dust data would not be normally distributed, it was necessary to use a nonparametric or distribution-free statistical test to analyze for differences between mean dust levels for each test condition.

The Wilcoxon two-sample test (exact form) was used with a level of significance of $\alpha = 0.05$ to test the null hypothesis that the mean ranks of the two groups of dust data from the two test conditions were equal. Because the dust levels with the scrubber operating could be higher or lower than with the scrubber off, a two-tailed test was selected to identify any statistically significant differences between the two test conditions. If the computed probability (p-value) from the statistical test was less than 0.05, the observed difference between the mean ranks for the two test conditions was considered to be statistically significant. The average dust concentrations from the individual cuts were used to analyze the data for each sampling location at each mine. However, for ease of interpretation and presentation, the mean dust concentrations for the scrubber-off and scrubber-on test conditions at each mine and the calculated p-values from the Wilcoxon test are provided in Tables 2, 3, and 5 to identify statistical significance.

### Continuous Miner Results

The miner operator dust concentrations were calculated from the PDM data, while dust concentrations from all other sampling locations were calculated from pDR data. The dust concentrations for the miner operator, RRC, immediate miner return, and main return sampling locations had the intake dust levels subtracted out. Because increases in production can generate more dust [Webster et al. 1990] and increases in airflow can dilute dust levels [Hartmann 1973], the intake-adjusted dust levels were then normalized for differences in production and face airflow between cuts, assuming a linear relationship between these parameters and dust levels. For example, if average productivity for all cuts sampled during a mine survey was 0.28 shuttle cars per min and productivity for an individual cut averaged 0.36 shuttle cars per min, then the average dust level for this cut was multiplied by a factor of 0.78 (0.28 ÷ 0.36) to adjust for the higher-than-average productivity observed in the cut. The adjustments for differences in airflow were made in a similar manner. A summary of the average normalized respirable dust concentrations around the continuous miner and in the return from the three surveys is provided in Table 2.

**Table 2.** Average respirable dust concentrations around the continuous miner and in the section return.

| Mine | Scrubber status | Continuous miner dust concentrations, mg/m³ | | | | Section return†, mg/m³ |
|---|---|---|---|---|---|---|
| | | Intake | Operator | RRC+ | Return | |
| A | Off | 0.08 | 0.30 | 1.27 | 23.86 | na |
| | On | 0.07 | 0.26 | 1.02 | 2.05 | na |
| | *Calculated p-value* | | *0.3310* | *0.6439* | *0.0005** | *na* |
| | Dust reduction with scrubber on | | 13% | 20% | 91% | na |
| B | Off | 0.12 | 0.55 | 7.53 | 12.13 | 4.81 |
| | On | 0.13 | 0.46 | 5.20 | 1.66 | 0.74 |
| | *Calculated p-value* | | *0.6352* | *0.6200* | *0.0005** | *0.0005** |
| | Dust reduction with scrubber on | | 16% | 31% | 86% | 85% |
| C | Off | 0.09 | 0.25 | na‡ | 14.37 | 6.73 |
| | On | 0.05 | 0.32 | na‡ | 8.64 | 4.80 |
| | *Calculated p-value* | | *0.8000* | *na‡* | *1.0000* | *0.4000* |
| | Dust reduction with scrubber on | | -28% | na‡ | 40% | 29% |

+ Abbreviation: RRC – right rear corner.
† Section return sampling location added after completion of survey at Mine A.
* Statistically significant difference.
‡ Water exposure of dust samplers invalidated data at this mine.

Intake dust concentrations to the continuous miner faces were well controlled at all three mines and averaged 0.09 mg/m³. Average dust concentrations at the miner operator were 0.55 mg/m³ or lower and exhibited a maximum difference of 0.09 mg/m³ between scrubber-on and scrubber-off test conditions. These differences were not statistically significant. Average dust concentrations at the RRC of the mining machine were somewhat variable from mine to mine, with no statistically significant difference despite the lower levels observed with the scrubber operating. However, major reductions in dust concentrations were observed in the immediate miner return when the scrubber was being operated. The reductions in average dust concentrations in the miner return at Mine A (21.81 mg/m³) and at Mine B (10.47 mg/m³) were statistically significant when evaluated using the Wilcoxon two-sample test with α = 0.05. At Mine C, difficult geologic mining conditions resulted in the fewest cuts sampled for any of the surveys. In addition, the variability in measured dust concentrations observed between the cuts was greater than that observed at Mines A and B. When combining these two factors, the 5.73 mg/m³ reduction in average miner return dust concentration with the scrubber operating at Mine C was not statistically significant.

For the average dust concentrations measured in the section return at Mine B, the 4.07 mg/m³ reduction in dust concentration with the scrubber operating was statistically significant. A reduction of 1.93 mg/m³ in the average section return dust concentrations was measured at Mine C, but this difference was not statistically significant due to the sampling issues previously identified for Mine C.

**Shuttle Car Results**

Time study data were collected to identify when each shuttle car entered the mining face to be loaded and when the car left the face. These time periods were used to calculate dust concentrations for each shuttle car while being loaded at the face. The individual dust concentrations were then used to calculate an average shuttle car dust concentration for each cut. The miner intake dust level was subtracted from the shuttle car dust level for each cut. These cut concentrations were then used to calculate the average dust level with the scrubber off and the scrubber on at each mine, which are summarized in Table 3.

As shown in Table 3, operation of the scrubber during these surveys did not have any practical impact on dust concentrations at the shuttle car cab locations. The largest observed difference between scrubber-on and scrubber-off was an increase of only 0.08 mg/m³, which was not statistically significant. The observed dust levels were 0.43 mg/m³ or lower, indicating that dust was not escaping the miner face and was not exposing the shuttle car operators to elevated levels under either test condition.

**Table 3.** Average respirable dust concentrations at shuttle car cabs.

| Mine | Scrubber off, mg/m³ | Scrubber on, mg/m³ | Difference with scrubber on, mg/m³ | *Calculated p-value** |
|---|---|---|---|---|
| A | 0.27 | 0.28 | **-0.01** | *0.9272* |
| B | 0.03 | 0.07 | **-0.04** | *0.4272* |
| C | 0.35 | 0.43 | **-0.08** | *0.5429* |

* No statistically significant differences.

**Roof Bolter Results**

Time study information was collected on the roof bolter to identify when the bolter was operating and the relative position of the bolter with respect to the continuous miner. Average dust concentrations were calculated for the intake and on-board sampling locations for each roof bolter place and are summarized in Table 4 for each mine.

**Table 4.** Average respirable dust concentrations around the roof bolter.

| Mine | **Bolter intake dust concentrations, mg/m³** | | | | ***On-board dust concentrations, mg/m³**** | | | |
|---|---|---|---|---|---|---|---|---|
| | Bolter upwind of miner | Bolter downwind of miner | | | Bolter upwind of miner | Bolter downwind of miner | | |
| | | Miner scrubber off | Miner scrubber on | **Reduction with scrubber on** | | Miner scrubber off | Miner scrubber on | **Reduction with scrubber on** |
| A | 0.04 | na† | 3.29 | **na†** | 0.12 | na† | 3.62 | **na†** |
| B | 0.12 | 5.97 | 0.92 | **85%** | 0.30 | 5.65 | 0.94 | **83%** |
| C | 0.09 | 11.23 | 7.38 | **34%** | 0.16 | 12.26 | 6.06 | **51%** |

* Sampling package located near return-side-operator at Mine A, in the center of the walk-through bolter at Mine B, and in the operator's cab at Mine C.
† No data available.

When the bolter was positioned upwind of the miner, the intake air delivered to the bolter contained low levels of respirable dust and was 0.12 mg/m³ or lower at these mines. Because the bolter is only permitted downwind of the miner once per shift, only a limited amount of downwind data was obtained. At Mine A, the bolter was only operated downwind of the miner once during the entire survey, so no scrubber-on/scrubber-off comparison could be made. However, the data from Mines B and C illustrate substantial reductions in dust levels when the bolter was downwind and the scrubber was operating on the miner. Reductions of 34%–85% were measured at the bolter intake sampling location, with reductions of 51%–83% observed on the bolter. Because of the limited amount of data, statistical analysis was not completed.

In addition to dust generated by the continuous miner, bolter operators can be exposed to dust generated from installing bolts. However, when comparing the concentrations measured at the bolter intake location when upwind of the miner to those measured on the bolter, increases in dust concentrations of only 0.07 to 0.18 mg/m³ were observed, indicating that the vacuum collection systems on these bolters were effective in capturing bolter-generated dust. NIOSH personnel measured the vacuum pressure at each drill head multiple times during each shift. All of the measured vacuum readings provided in Table 1 exceeded the minimum vacuum pressure required by MSHA.

**Quartz Results**

A gravimetric sampling package was placed in the immediate miner return and collected dust samples that were analyzed for quartz content. The quartz analysis provided the mass of quartz on each filter, which allowed for calculation of the quartz percent and concentration. In order to address the differences in production rates for the various cuts, the quartz concentrations from each cut were normalized based upon the average number of shuttle cars per min of sampling time. These values were used to calculate an average quartz concentration for the scrubber-off and scrubber-on test conditions. Table 5 summarizes the average quartz data from samples collected at each of the three mines.

The percent quartz found in the samples with the scrubber on showed mixed trends in that the percent was higher in Mines A (0.3%) and C (2.3%) and lower in Mine B (-0.9%). However, operation of the scrubber lowered the quartz mass and adjusted concentrations in all three mines. Results from Mines A and B were very similar with reductions in mass and concentration greater than 80%, which were found statistically significant with the Wilcoxon test. At Mine C, the highest quartz percentages of all mines were observed. However, the reductions in mass (55%) and concentration (14%) with the scrubber on were not as great at Mine C and these differences were not statistically significant.

**Table 5.** Quartz content in the immediate miner return with the scrubber off and on.

| Mine | Quartz percent | | Quartz mass, µg | | | Adjusted quartz concentration, µg/m$^3$ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Scrubber off | Scrubber on | Scrubber off | Scrubber on | **Reduction** | Scrubber off | Scrubber on | **Reduction** | *Calculated p-value* |
| A | 6.8 | 7.1 | 202 | 31 | **86%** | 1282 | 177 | **86%** | *0.0022** |
| B | 3.7 | 2.8 | 38 | 7 | **82%** | 255 | 45 | **82%** | *0.0022** |
| C | 14.3 | 16.6 | 387 | 175 | **55%** | 1602 | 1385 | **14%** | *0.3939* |

* Statistically significant difference.

## SUMMARY

Respirable dust samples were collected from continuous miner sections at three underground coal mines to evaluate the impact of operating a flooded-bed scrubber in 6.1 m (20-ft) cuts with exhaust face ventilation and an extended curtain setback. The dust levels observed with the scrubber operating were compared to dust levels measured in 6.1 m (20-ft) cuts without a scrubber operating and the exhaust ventilation curtain advanced to within 6.1 m (20 ft) of the face. Area dust sampling with gravimetric and light-scattering instrumentation was conducted in the intake and return airways of the continuous miner, on the continuous miner, in the shuttle car cabs, and at the roof bolting machine. A personal dust monitor (PDM) was worn by the continuous miner operator to measure the dust exposure at the operator's position. Time study information was collected by NIOSH researchers so that the dust data could be analyzed on a cut-by-cut basis, with extended downtimes removed from the calculations. MSHA personnel participated in the dust surveys and monitored operating parameters specified in the individual mine ventilation plans to ensure that minimum plan parameters were present during each survey. Three days of sampling were conducted at each of the mine sites. When sufficient data were available, the Wilcoxon two-sample test ($\alpha = 0.05$) was used to determine the statistical significance of differences in mean dust levels between the two test conditions.

Analysis of the data from the three surveys supports the following findings:

- Intake dust concentrations to the continuous miner faces were well controlled at all three mines and averaged just under 0.10 mg/m$^3$.
- There were no statistically significant differences in dust concentrations between test conditions for the continuous miner operator at each mine, with a maximum difference in average dust concentration of only 0.09 mg/m$^3$.
- With the scrubber operating, dust concentrations at the right rear corner of the miner were 22% lower at Mine A and 31% lower at Mine B. However, these reductions were not statistically significant.
- Dust concentrations in the return immediately downwind of the miner were at least 40% lower when the scrubber was operating. At Mines A and B, statistically significant reductions of 91% and 86% were observed, respectively.
- A sampling package was added in the section return for the surveys conducted at Mines B and C. A statistically significant reduction of 85% was observed in section return dust concentrations at Mine B with the scrubber operating, and a reduction of 29% was observed at Mine C.
- There were no statistically significant differences in dust concentrations measured at the shuttle cars between test conditions. The maximum difference measured at the shuttle cars between test conditions at any of the mines was 0.08 mg/m$^3$.
- When the roof bolter was operating downwind of the continuous miner, intake dust concentrations to the bolter were reduced by 85% at Mine B and 34% at Mine C when the scrubber was operated. Limited data for these conditions prevented statistical analysis. At Mine A, the bolter was only downwind of the miner one time during the survey, so no comparison could be made.
- Quartz mass and concentrations in the continuous miner return were reduced at all three mines when the scrubber was operating. At Mines A and B, statistically significant reductions of over 80% were measured.

Results from the surveys at these three mines show that there were no statistically significant differences in dust concentrations at the continuous miner operator, the right rear corner of the miner, or in the shuttle car cabs when the flooded-bed scrubber was operated. However, statistically significant reductions in respirable and quartz dust levels in the miner and section return were measured during the surveys. As a result, dust exposures for personnel located downwind of the miner would be reduced through operation of the flooded-bed scrubber, with no adverse impact to workers located in the face area. Therefore, from a dust control perspective, operation of the flooded-bed scrubber would be beneficial.

It should be noted that these results were achieved with the 30-layer scrubber filter panels being cleaned after each 6.1 m (20-ft) cut, which was found to be necessary in order to maintain scrubber airflows at the required levels. To illustrate, airflow measurements were taken in the scrubber after completion of one 6.1 m (20-ft) cut during which the scrubber was operated but before the filter panel had been cleaned. On three different occasions during the survey at Mine B, measurements were taken after completion of one cut with the scrubber operating. An average drop in scrubber airflow of 0.94 m$^3$/s (2,000 cfm) was observed, which represented an average reduction of 29% when compared to the quantities available at the beginning of each of these cuts. At Mine C, a scrubber airflow reading was taken after one cut and before the filter panel was cleaned. A drop in airflow of 0.71 m$^3$/s (1,500 cfm) was measured, which represented a reduction of 35%. These numbers emphasize the critical need to clean the 30-layer filter panel after each cut. Previous research [Potts et al. 2011] recommended the cleaning of scrubber filter panels after every 12.2 m (40 ft) of advance when using a 20-layer filter. In addition, the minimum operating parameters specified in the ventilation plans were present prior to the start of each cut and contributed to the results observed during these surveys.

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## DISCLAIMER

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