Evaluation of dust exposures associated with mist drilling technology for roof bolters

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Introduction

The United States Federal Coal Mine Health and Safety Act of 1969 requires that the concentration of respirable dust in the coal mine atmosphere not exceed 2.0 mg/m^3 for a working shift (Code of Federal Regulations, 2007). This limit is measured gravimetrically as an 8-hour time-weighted average concentration of the respirable dust. If the quartz content on the dust filters exceeds 5 percent (by weight), the dust standard is reduced according to the following expression: 10/(percent quartz). For example, if the quartz content is 20 percent (by weight), the limit is reduced to a maximum of 0.5 mg/m^3 total respirable dust. Mine Safety and Health Administration (MSHA) inspectors collected 5,000 samples from roof bolting occupations during the years 2000 through 2004. More than 1,000 of these samples showed excessive exposure to respirable silica dust (MSHA, 2004).

Past research has shown that most roof bolter operator dust exposure comes from upwind sources such as the continuous miner (Colinet et al., 1985). However, with inadequate ventilation, dust generated by roof drilling operations will contribute to elevated occupational exposures. Further research is required to develop and evaluate improvements in roof drilling dust-control methods to minimize these exposures. This paper compares respirable dust levels measured around roof bolting machines equipped with either a vacuum drilling or mist-drilling system. Tests were conducted in both underground and laboratory settings.

Abstract

Overexposure to respirable dust remains a widespread health hazard to roof bolter occupations in underground coal mines. Recently implemented mist drilling technology was evaluated for its effectiveness in controlling respirable dust exposures for roof bolting personnel. This work presents the findings from NIOSH field and laboratory studies comparing respirable dust levels on mist drilling roof bolter machines to dust levels measured on machines using a conventional vacuum drilling system. Gravimetric and instantaneous respirable dust samples were collected for multiple drilling cycles. These dust measurements were used to assess the potential dust control capabilities relative to conventional drilling. Controlled laboratory tests found 0.3 mg/m^3 more respirable dust with mist drilling than with the conventional vacuum method. A separate field investigation of the two techniques observed higher dust levels around the mist bolting machine.

Roof bolting machines are typically equipped with an MSHA-accepted (Code of Federal Regulations, 2007) vacuum dust collection system to capture dust while drilling. A vacuum pump on the bolter draws the dust through the hollow bit and drill steel into a precleaner. The precleaner removes the large particles from the air stream and deposits them on the mine floor when discharged. The precleaned dust-laden air is then routed to an enclosed dust box. The box has multiple chambers and functions as a rough size classifier, removing the dust from the air stream according to its size. The typical box consists of four compartments with a single canister filter in the final chamber. Previous research has documented the effectiveness of this system if properly maintained (Thaxton, 1984).

On roof bolter machines using mist drilling technology, the mist head bolter injects a combination of water and compressed air through the drill steel and drill bit to control drill dust. Air is supplied by an onboard compressor, while the water is supplied by an onboard water tank or by a water hose attached to the machine. As a positive displacement method of flushing the drill hole, the wet drill cuttings are expelled from the hole around the outside of the drill steel.

Laboratory test design and methods

The laboratory portion of the research was conducted in a surface test facility at the Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH). All tests were performed in the Acoustical Testing Laboratory, typically used for full-scale sound power testing of mining equipment. The room has a volume of approximately 1,300 m^3 (46,000 cu ft). During testing, the doors to the room were closed to prevent dust from escaping and to prevent possible contamination from outside sources.

The test platform was a J.H. Fletcher & Co. (Huntington, WV) roof-bolting machine. This walk-through dual head bolter was outfitted with a standard vacuum collection system and a mist drilling system. The drill was outfitted with a round 25.4-mm- (1.0-in.-) diameter hollow drill steel for all tests. For vacuum tests, Kennametal (Latrobe, PA) KCV4-1-RR bits were used, while Kennametal KWH-1-400 bits were used for mist tests (Fig. 1). These are both carbide-tipped bits with a drilling diameter of 25.4 mm (1 in.). A new bit was used for each new hole.

Granite with a compressive strength of 165 MPa

FIGURE 1

Vacuum drilling bit (left) and mist drilling bit (right).

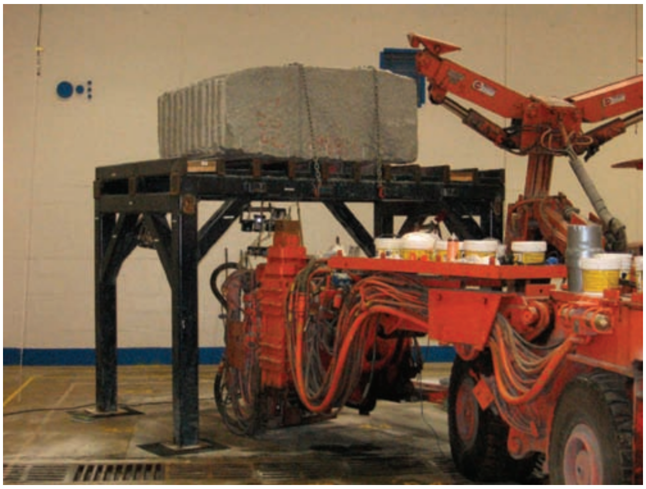
(24,000 psi) was used as the drilling test media. The high compressive strength of granite allowed for a longer drilling and sampling duration. A 0.8-m- (30-in.-) thick block of this material was secured to the steel test stand (Fig. 2). Holes were drilled to a depth of 0.5 m (20 in.) to prevent drilling through the granite block and releasing a large amount of dust and mist into the laboratory atmosphere. The thrust and drill rotation speed were held constant for all tests at 22.0 kN (4,900 lbs) and 250 rpm, respectively (Fig. 1). The bolter operator controlled the feed rate manually.

During laboratory mist drill testing, the onboard mist system supplied 2.3 L/min (0.6 gpm) of water at 700 kPa (100 psi). Compressed air was supplied at 400 L/min (13 cu ft per min) at 700 kPa (100 psi). These values correspond to drilling tests conducted by NIOSH during previous field studies (Goodman et al., 2006).

The vacuum portion of testing used a typical MSHA-accepted (Code of Federal Regulations, 2007) four-compartment dust collection system with a single canister filter (Donaldson and Co., Minneapolis, MN). The dust collection box was cleaned prior to the series of vacuum tests. The precleaner, which separates oversized material from the system before it reaches the dust box, was isolated from the atmosphere to prevent contamination of the samples. A sealed container was fitted to the precleaner outlet to contain any possible releases.

FIGURE 2

Laboratory test configuration.



Sampling was accomplished with a combination of gravimetric and instantaneous light-scattering instrumentation. Samplers were attached to the test stand in four locations (Fig. 3) to eliminate any bias due to air movements. The sampling racks were located at the midpoint of each side of the test stand, at an average distance of 1.2 m (4 ft) from the drill steel and 0.3 m (1 ft) below the base of the rock. Each sampling location consisted of two gravimetric sampling units and one instantaneous dust monitor.

For gravimetric sampling of dust, Escort ELF constant flow pumps (Mine Safety Appliances Co., Pittsburgh, PA) pulled dust-laden air through 10-mm nylon cyclone separators at a rate of 2 L/min (Code of Federal Regulations, 2007). The respirable mass was deposited onto preweighed 37 mm (1.5 in.) PVC filters that were subsequently desiccated and postweighed to determine dust levels. The filter weights were blank-adjusted to account for any variability in weighing conditions. The gravimetric samplers were operated continuously during vacuum and mist system drill tests due to safety considerations. Consequently, filter weights included dust from both drilling and non-drilling activities. For this reason, instantaneous dust sampling was used in conjunction with the gravimetric data to determine the dust level for each individual hole drilled.

Instantaneous dust sampling was performed using personal DataRAM (pDR) dust monitors (Thermo Electron, Franklin, MA). The pDR recorded dust concentrations every five seconds during testing. The pDR measurements are affected by aerosol size distribution and content. Because of this, the pDR values must be corrected by the gravimetric measurements. This is accomplished by calculating the ratio of the gravimetric concentration to the average pDR concentration for the same time period. In this study, the ratio can be calculated for each sampling location for both testing conditions. Individual pDR data points for the desired time period were multiplied by the previously determined correction ratio and averaged together to obtain a gravimetrically corrected pDR concentration. All pDR concentrations presented in the paper have been adjusted using this correction procedure.

The following test procedure was used to assess the differences in dust control effectiveness using the mist system and the conventional vacuum system. The background dust concentrations were measured in the test chamber prior to each series of drilling tests. A drilling test was conducted using either the mist or vacuum system for dust control. The duration of each drilling test was the time needed to drill 0.5 m (1.6 ft) into granite. This time varied from 100 to 300 seconds, depending on drilling technique. A two-minute period elapsed between each hole to stabilize and measure idle dust levels. A total of 60 tests were conducted, 30 using the mist system and 30 utilizing the vacuum system.

Analysis of laboratory bolter performance

There was very little respirable dust in the test chamber prior to any drilling. The corrected pDR background dust concentration before the series of 30 vacuum tests was 0.03 mg/m^3, while the dust concentration before the mist drilling tests was 0.01 mg/m^3. This indicates that nearly all dust generated during the drilling tests can be attributed to the corresponding technique.

The laboratory tests showed that mist drilling resulted in higher dust concentrations than conventional vacuum drilling. The gravimetrically corrected pDR measurements showed an average respirable dust concentration of 0.04 mg/m^3 during vacuum drilling. Sampling during mist drilling resulted in concentrations of 0.39 mg/m^3. Standard deviations between individual sampling locations were found to be 0.03 mg/m^3 for vacuum tests and 0.17 mg/m^3 for mist tests. Corrected pDR data for each sampling location are displayed in Table 1. Figure 4 shows the corrected pDR dust concentration for each hole drilled as an average of all four sampling locations.

For both test conditions, the average idle dust levels were found to be nearly the same as dust levels during drilling. Though there was no dust generated by drilling between tests, the dust generated during previous drilling tests remained in the test chamber.

During this study, elevated dust emissions were observed during the collaring of the holes. This was experienced regardless of dust control technique. Once a hole was drilled to a depth of about 50 mm (2 in.), the visible dust emissions diminished. Throughout the mist drilling tests, an appreciable stream of aerosol was emitted from the holes. In addition to water mist, this aerosol contained a respirable fraction of dust that was deposited on the gravimetric filters. On completion of each vacuum hole, a small puff of dust was observed. However, this did not appear to have a large impact on the dust levels attributed to this technique.

The visible dust emissions appeared to migrate towards sampling Locations #3 and #4 during all mist drilling tests, as was confirmed by elevated readings by the samplers in these locations. This was possibly due to small, but consistent, air currents present in the test chamber, which contributed to the variability in readings between sampling locations. The same condition was not observed for vacuum drilling. This may be due to the low dust levels documented for this technique.

Vacuum drilling was observed to have a greater penetration rate during these laboratory tests. The average time to drill a 0.5-m (20-in.) vacuum hole was 100 seconds, while it took 300 seconds to drill the same depth using the mist system. This translated into a penetration rate of 5 mm/s (0.2 ips) for vacuum drilling and 2.5 mm/s (0.1 ips) for mist drilling. These numbers were lower than those reported for previous laboratory bolter work under similar test conditions (Matetic, 2006; Peterson et al., 2006).

Field evaluation

The field portion of this study was conducted at an underground coal mine in Virginia. In this study, two separate twin-boom J.H. Fletcher & Co. roof bolting machines were sampled during production drilling and bolting. One machine was outfitted with a conventional vacuum system to control dust, while the other machine used a mist drilling system. The vacuum-equipped machine used a precleaner on each side to remove the oversized dust fraction. Each bolting arm of the vacuum bolter used a four-chamber permissible dust collection system with a single canister filter. The mist drilling system supplied water to the left and right bolting arms via a 420-L (110-gal) onboard water tank at rates of 2.6 L/min (0.7 gpm) and 1.1 L/min (0.3 gpm), respectively. Air was supplied to the left and right arms at a rate of 0.01 m^3/s (20 cfm) to each side. Both machines used round drill steels. The vacuum machine used “dust hog”-type drill bits and the mist machine used “wet” bits. These bits were both similar to those used in laboratory testing. Entry airflows were measured for each location drilled. The entry airflows averaged 5.2 m^3/sec (11,000 cfm) for vacuum drilling and 3.8 m^3/sec (8,000 cfm) for mist drilling. Because there was only one bolting crew, these machines did not operate at the same time.

Three shifts of data were collected for each bolting machine. Sampling was performed by gravimetric samplers using a combination of permissible sampling pumps operating at a rate of 2.0 L/min (0.53 gpm), with 10-mm (0.4 in.) nylon cyclones and preweighed 37-mm (1.5 in.) PVC filters. The filters were subsequently desiccated, postweighed and blank adjusted to account for any vari-

FIGURE 3

Locations of samplers around bolter for laboratory testing (not to scale).

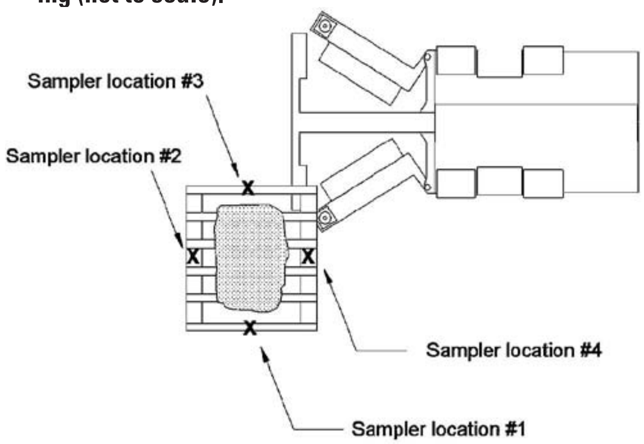


FIGURE 4

Gravimetrically corrected drilling dust concentrations for each hole drilled.

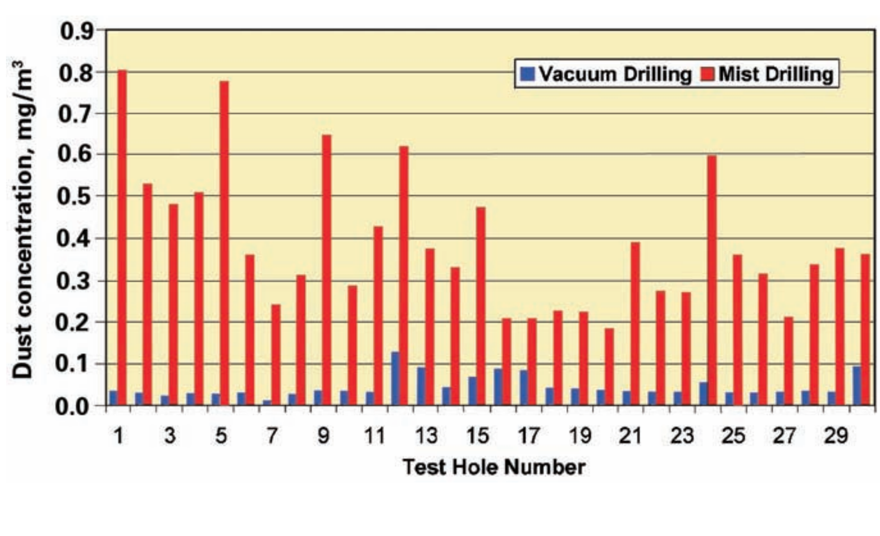
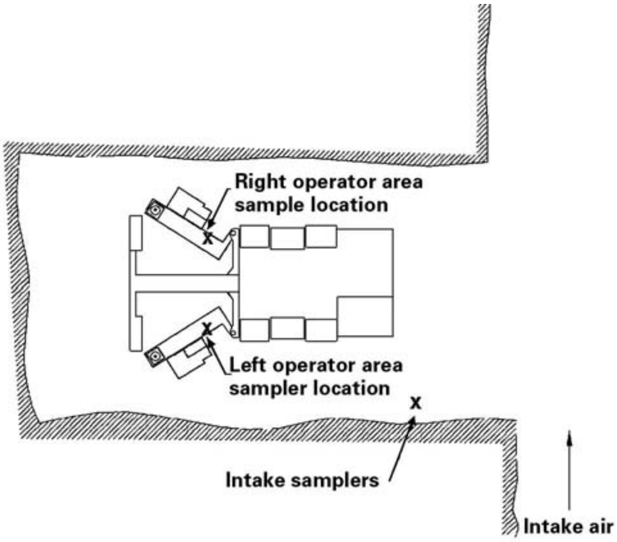


FIGURE 5

Locations of samplers around bolters for field testing (not to scale).



ability in weighing conditions. Samplers were attached near the left and right operator work locations, approximately 0.3 to 0.6 m (1 to 2 ft) outby their controls (Fig. 5). These are the preferred sampling locations when a personal sample cannot be collected on the roof bolter operator (Ondrey et al.). Separate samplers were used for the vacuum and mist drilling machines, and each set was sampled only when that specific machine operated. Thus, any dust collected on the filters could be assigned to a specific dust-control system. Gravimetric samplers were also positioned in the intake air for each bolting machine.

During the underground study, the mist bolter worked downwind of the continuous mining machine, while the vacuum-equipped bolter worked upwind. Such downwind operation of roof bolters has been shown to significantly increase operator dust exposure (Goodman and Organiscak, 2002; Kissell, 2003). This resulted in higher intake dust levels for the mist bolter than for the vacuum bolter. Also, elevated dusts levels were recorded at the left and right side operator area sampling locations for the mist bolter. With the contribution of intake dust removed from all machine samples, dust levels around the mist bolting machine still exceeded those around the vacuum machine. The overall average gravimetric dust concentration for each dust control method was 0.30 mg/m^3 for vacuum and 1.44 mg/m^3 for mist. The average dust concentration for each drilling method is listed in Table 2.

During this study, NIOSH researchers noted that dust was generated every time a hole was collared, using either the vacuum or mist system. Once the bit penetrated a depth of 20 to 30 mm (0.8 to 1.2 in.), the problem disappeared. This observation was similar to the occurrences noted during laboratory testing. During collaring, a risk exists in that the respirable fraction of this dust can be a health hazard to the operators if insufficient airflow is present.

NIOSH researchers documented a large difference in water flow rates to each bolting arm during this study. However, when comparing the dust concentrations measured between the right and left side of the mist bolting machine, this difference was not apparent. This indicated that both water flow rates resulted in similar dust generation characteristics.

Summary and conclusions

NIOSH researchers compared the dust control capabilities of a mist drilling system and a vacuum drilling system in both laboratory and underground settings. In both portions of the study, the mist drilling system was found to generate more respirable dust than vacuum drilling. In the laboratory phase of testing, sampling during vacuum drilling measured dust levels of 0.04 mg/m^3. Mist drilling tests performed under the same conditions yielded nearly ten times more dust, with area dust concentrations of 0.39 mg/m^3. Several factors, including bit selection, air/water pressures and quantities and rock composition, may have detrimentally impacted the dust capture effectiveness of the mist drilling technique.

Because the mist bolter worked downwind of the continuous mining machine for the duration of the field study, higher intake dust levels were observed for this machine. After removing the intake dust contribution, underground tests measured dust concentrations of 0.30 and 1.44 mg/m^3 for vacuum and mist drilling, respectively. Although the gravimetric dust concentrations of the field study were significantly higher than the concentrations encountered in the laboratory study, these results confirmed the laboratory results, as the dust concentrations generated during mist drilling in the field tended to be approximately five times the concentrations observed for vacuum drilling.

Conventional vacuum drilling is a negative displacement drilling technique. The system is designed to draw the drill cuttings through the drill steel and capture them in a dust collection box. The lower dust levels measured during laboratory and field testing indicate the potential effectiveness of this system at minimizing dust

Table 1

Gravimetrically corrected dust concentrations for each sampling location.

	Bolter drilling system			
	Vacuum		Mist	
Sampling location	Idle, mg/m^3	Drilling, mg/m^3	Idle, mg/m^3	Drilling, mg/m^3
1	0.05	0.06	0.22	0.23
2	0.03	0.03	0.15	0.23
3	0.03	0.03	0.49	0.48
4	0.03	0.04	0.52	0.61
Overall[1]	0.03 (0.02)	0.04 (0.03)	0.34 (0.16)	0.39 (0.17)

[1]Standard deviations are shown in parentheses.

emissions when operated under these conditions.

As a positive displacement drilling method, the mist drilling system is designed to wet the drill cuttings and expel them from the hole around the drill steel. If the drill cuttings are not completely wet, the risk exists for the respirable portion to be released into the atmosphere. Considering the elevated dust concentrations measured here, it is likely that this may be occurring during both field and laboratory mist drilling testing, indicating that additional water or a change of drilling parameters might be necessary to reduce the dust emissions for this drilling technique. Further investigation should be undertaken to better identify opportunities for improvement of this technology's performance.

Table 2

Gravimetric dust concentrations measured during field bolter testing. Values are with intake dust contribution removed.

	Bolter drilling system			
	Vacuum		**Mist**	
Shift sampled	Right side mg/m^3	Left side mg/m^3	Right side mg/m^3	Left side mg/m^3
Shift 1	0.61	0.30	1.57	1.49
Shift 2	0.36	0.36	0.95	1.43
Shift 3	0.11	0.07	1.63	1.54
Overall[1]	0.36 (0.20)	0.24 (0.12)	1.38 (0.31)	1.49 (0.04)

[1]Standard deviations are shown in parentheses.

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Disclaimers

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

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