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AN EVALUATION OF METHODS FOR CONTROLLING SILICA DUST EXPOSURES ON ROOF BOLTERS

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ABSTRACT

This paper examines methods for limiting occupational silica exposures for roof bolting personnel in underground coal mining. A canopy air curtain and an air tube were evaluated as means to provide filtered air over the breathing zone of these personnel. Laboratory testing showed that dust reductions beneath the air curtain and air tube approached 60 percent and 40 percent, respectively, with low interference air velocities. The data also showed that dust reductions were highest for positions closest to the device and that these levels decreased with distance.

This paper also evaluates a metal rake, a flexible insert, and a rigid insert for cleaning the roof bolter dust collector box. Less dust was produced when using the rigid insert. Surprisingly, the flexible insert was sometimes no better than scraping or raking the dust onto the mine floor. However, little dust got on the coveralls when using either of the inserts.

INTRODUCTION

The Federal Coal Mine Health and Safety Act limits respirable dust exposures of mine workers to a time weighted average of 2.0 mg/m^3 for a working shift (U.S. Government Printing Office, 1999). If the respirable dust sample contains more than 5 percent silica by weight, the dust standard is reduced according to the formula 10) (percent silica). Compliance with the 2.0 mg/m^3 standard or a reduced standard maintains silica dust levels at or below 100 Φg/m^3.

Data from the Mine Safety and Health Administration (MSHA) revealed that more than 3400 respirable dust samples were collected at underground coal roof bolter occupations in 1999. Of these, nearly 70% exceeded 5 percent silica content on the dust samples, while nearly one-quarter of the samples exceeded 100 Φg/m^3 (MSHA, 1999). Clearly, roof bolter occupations exhibit a continued risk for overexposure to respirable silica dust. These high levels of noncompliance could result from operation of the roof bolter downwind of the continuous mining machine or from inadequate maintenance of the vacuum dust collection system.

Data collected by NIOSH researchers showed that silica dust levels in the roof bolter intake increased when working downwind of the continuous mining machine. These dust levels were measured by placing four gravimetric samplers in the bolter intake. Two samplerswere used when bolting upwind of the mining machine and the other two used when bolting downwind. Comparing dust levels from each sampling set showed the effects of bolting downwind of the mining machine.

The samplers consisted of constant-flow sampling pumps pulling dust-laden air through a 10-mm nylon cyclone at 2 lpm (liters/minute) to deposit the respirable fraction onto preweighed 37-mm PVC filters. All filters were subsequently weighed and dust levels calculated. The filters were sent to an independent laboratory for analyses of crystalline silica using the infrared P-7 Method (MSHA, 1973).

The data showed that silica dust levels in the intake airway of the roof bolter increased by nearly 70 Φg/m^3 when operating downwind of the mining machine. At another operation, silica dust levels measured in the bolter intake increased by nearly 40 Φg/m^3 when operating downwind of the mining machine. Similar results were found in Colinet et al (1985), Kok et al (1985), and Taylor et al (1986). To limit these silica exposures, many MSHA dust control plans limit the time that the roof bolter works downwind of the mining machine.

Improper cleaning of the dust collector box and dust filters is another dust source for roof bolter personnel. Although the cleaning process has the potential to produce high silica dust levels, durations for these exposures are typically low (Colinet et al, 1985). However, bolter headings can be poorly ventilated so that any dust generated by dust collector box cleaning may linger near the bolter operators, increasing the duration of their exposure (Kok et al, 1985). Miners also can get dust on their clothing when cleaning the collector boxes and filters. Future movement by these workers may generate additional dust until the clothing is cleaned. Furthermore, dust from the collector boxes is generally dumped into tramways where it can be entrained into the mine atmosphere by movement of men and equipment.

NIOSH studies also revealed that dust boxes and filters were not frequently cleaned during the shift causing dust to accumulate in the collector boxes and to eventually bypass the filters. Dust flowed from the mufflers of the bolter and formed a white haze around the machines, suggesting that immediate corrective action (cleaning collector box, changing filters) should be taken.

Eventual cleaning of the dust collector boxes and filter reduced dust levels by 10 to nearly 80 percent at two surveyed operations (figure 1). The values in this figure are averages for bolting an entire cut before andthen after cleaning the collector boxes or filters. The mini-RAM units used in this figure are outputs from this light scattering device and are representative of a dust concentration. Little differences were evident between cleaning the collector boxes or cleaning just the filters. Although cleaning the collectors and filters reduced instantaneous dust readings, some dust continued to flow from the mufflers suggesting that fine dust particles were present throughout much of the vacuum system downstream of the filters. According to a bolter manufacturer, only a thorough cleaning and purging of the dust collection system may clear this dust.

Infrequent cleaning and subsequent contamination of the vacuum dust collection system led to high silica dust levels at the roof bolter operator's sampling location. During the two studies mentioned previously, dust levels were measured by placing gravimetric samplers on the frame of the roof bolter approximately 1-1.2 m outby the controls of the return side bolter operator.

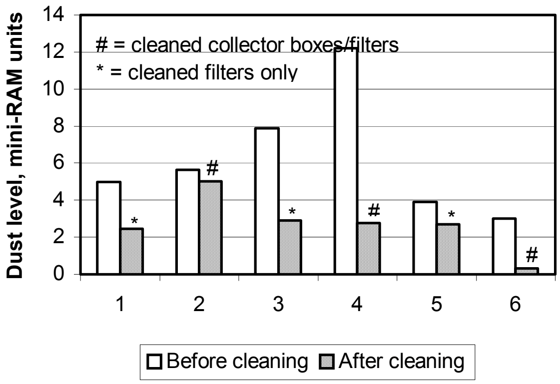

Figure 1. Dust levels before and after cleaning dust boxes and/or filters.

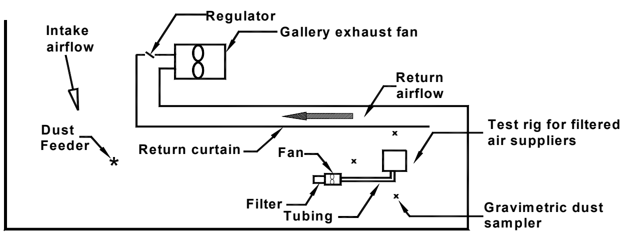

Figure 2. Test setup for filtered air suppliers.

Silica dust concentrations and percentages at these surveyed operations ranged from 103 to 327 Φg/m^3 and 9.1 to 13.7 percent. Levels were measured when operating upwind of the continuous mining machine and in clean intake air. Therefore, silica exposures arose from dust generated by the bolter and not by the mining machine.

This paper describes methods for controlling occupational silica exposures for roof bolting personnel in underground coal mines. A canopy air curtain and an air tube system are tested as a means to limit exposures by supplying filtered air over the breathing zone of these personnel. Finally, dust levels are given for various methods of cleaning the roof bolter dust box.

TESTING OF FILTERED AIR SUPPLIERS

Two filtered air suppliers, the canopy air curtain and the air tube, were tested separately in a full-scale facility at the Pittsburgh Research Laboratory. This facility simulated a bolter heading 1.9 meters high, 5.5 meters wide, and 12.2 meters deep. This heading was ventilated by an exhausting line curtain hung 0.9 m from the left side of the simulated heading. Each device was mounted 1.6 m above the floor on a wooden test rig placed 1.0 m from the return curtain and 0.9 m from the curtain mouth (figure 2).

Three gravimetric samplers each were placed 30.5 cm and 61.0 cm beneath the filtered air supplier while three samplers were placed around the device to measure environmental dust levels. One was placed 1.5 meters in front of the test rig and one sampler 0.9 m to the left and right sides of the test rig. These three samplers were positioned 1.1 m above the floor. All sampling equipment was sized and calibrated similarly to that used in the underground studies.

A 13.0 ∀ 0.9 percent mixture of silica dust in coal dust was used for this testing. This dust was introduced into the gallery 12.2 m upwind of the air curtain or air tube to simulate dust flow from a mining machine working upwind of a roof bolter. Reductions in dust levels were calculated by comparing dust levels beneath the filtered air supplier to dust levels surrounding the device. Selected filters were analyzed for silica content using the MSHA P-7 Method.

Canopy Air Curtain Testing

The canopy air curtain is constructed of a square steel frame 43.2 cm wide, 43.2 cm long, and 7.6 cm thick. Air enters this device at one side of the frame and passes along an intake plenum and through a series of aluminum honeycomb flow straighteners (figure 3). The airflow then enters another honeycomb flow straightener before exiting through a perforated steel plate. The perforations are 2.38-mm diameter holes drilled on 6.35-mm centers. The perforated plate is roughly 40.6 cm by 40.6 cm.

The tested system consisted of the canopy air curtain connected to a 5.6-kW (7.5-hp) centrifugal fan (American Fan Co., OH) by 20.3-cm (8 in) diameter metal tubing. A Donaldson Company (Minneapolis, MN) ECG11-2501 Konepac filter was mounted on the inlet side of the fan to filter dust from the air supplied to the air curtain (Goodman and Organiscak, 2001).

Tests were run with air quantities of 0.094 (200 cfm) and 0.283 m^3/s (600 cfm) supplied to the air curtain and with interference air velocities of 0.32 m/s (60 fpm) and 0.64 m/s (120 fpm). Interference airflow is the ventilation airflow moving in the bolter heading and, at higher velocities, may distort air patterns emanating from the canopy air curtain. The lower value of 0.32 m/s represents the lowest velocity permitted in bolter headings. Five tests were made at each set of canopy flow and interference air velocity to assess errors in dust reduction potentials. Test durations were 50 minutes.

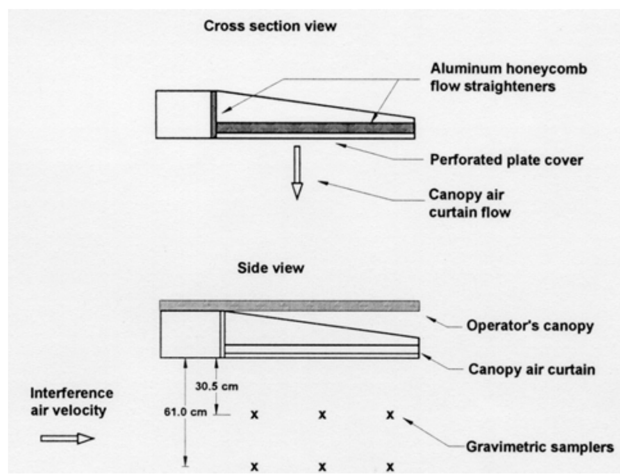

Figure 3. Canopy air curtain construction and testing.

Figure 4 gives mean dust reductions and 95% confidence levels for distances of 30.5 and 61.0 cm beneath the canopy. Positive reductions signify protection from environmental dust concentrations, whereas negative reductions show increases in dust concentrations.

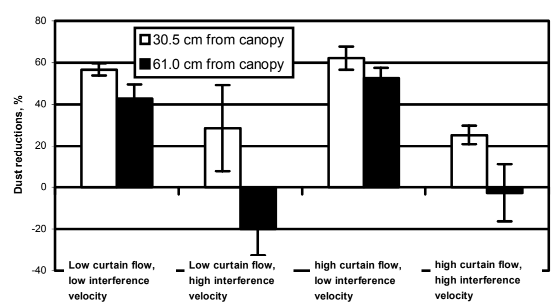

Figure 4. Canopy air curtain performance.

The data showed that efficiencies always were highest when sampling close to the canopy and that these efficiencies decreased with distance. Also, reductions were highest when interference air velocity was lowest. This suggests that dust reductions approaching 60 percent were possible in headings with low interference air velocities, a likely occurrence in many bolter headings. Increases in interference air velocity adversely affected the performance of the canopy air curtain. Detailed statistical analyses of test parameters and theirinteractions are given in Goodman and Organiscak (2001).

Silica contents averaged 6.10 ∀ 0.40 percent for samples 30.5 cm beneath the air curtain, 5.95 ∀ 0.56 percent for samples 61.0 cm beneath the canopy, and 6.13 ∀ 0.35 percent for samples outside the canopy. Statistical analyses showed that respirable silica contents beneath the canopy were not significantly affected by changes in either air curtain quantity or interference air velocity. Subsequent pair wise comparisons revealed no significant differences between silica contents measured under the canopy and those contents outside the canopy suggesting that the canopy air curtain was equally effective on both coal and silica particles.

Air Tubing Testing

Although the canopy air curtain provided adequate dust reductions, its 7.6-cm thickness could detract from its usefulness in lower seam operations. To provide more headroom for the roof bolter operator, an air tube was placed on the edge of the canopy and tested for its efficiency in reducing concentrations of respirable coal and silica dusts. The air tube was a 45.7-cm (18-in) length of 63.5 mm (2.5 in) internal diameter PVC tubing. A 90-degree section of the tubing was removed over a 40.6-cm (16-in) length and covered with a perforated steel plate. The perforations were 2.4-mm diameter holes drilled on 6.4-mm centers. Polycarbonate hexagonal flow straighteners with 3.2-mm (1/8-in) openings redirected the tubing airflow to exit from the ninety-degree section through the perforated plate (figure 5). Airflow was distributed over the tube length by means of an internal baffle.

The air tube was connected to an American Fan Company 0.6-kW (0.75-hp) centrifugal fan using 12.7-cm (5-in) diameter rigid tubing and 10.2-cm (4-in) diameter flexible tubing. A Donaldson Company G11-0120 Radial Seal dust filter was mounted on the intake side of the fan. This device was mounted on theunderside of a surface representing the bolter operator canopy. Initial testing revealed that placing the tube on the upwind side of the canopy and angling it 45 degrees downward delivered more air over the operator's breathing zone.

Air quantities of 0.057 and 0.103 m^3/s (120 and 220 cfm) and interference air velocities of 0.32 m/s and 0.64 m/s were evaluated in this testing. Again, five tests of 50 minute duration were run with each combination.

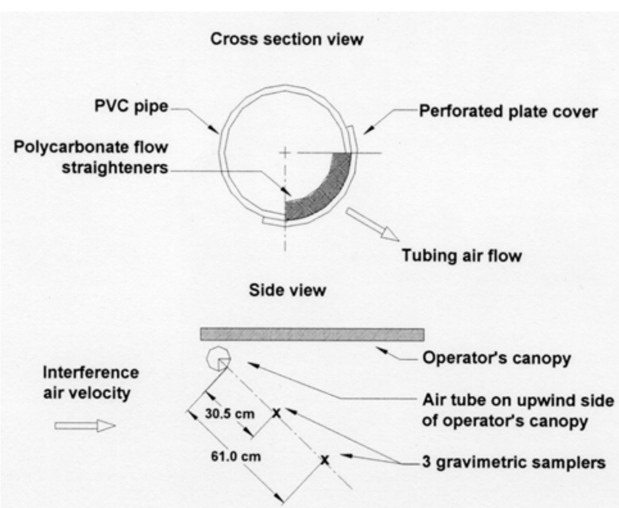

Figure 5. Air tube construction and testing.

At a distance of 30.5 cm from the air tube, dust reductions approached 40 percent with low interference velocity in the bolter heading (figure 6). Increasing interference air velocity adversely affected air tube performance, especially at the low tubing flow where negative dust reductions occurred at both 30.5 and 61.0 cm from the tubing. Like the canopy air curtain, dust reductions decreased as distance from the air tube increased.

Silica dust content averaged 6.75 ∀ 0.51 percent for those filters 30.5 cm beneath the air tube and 7.00 ∀ 0.37 percent for samples taken from the environment surrounding the air tube. Statistical analyses showed that at 95% confidence, no significant differences in silica contents existed between samples surrounding the air tube and samples beneath the air tube. Furthermore, changes in silica contents were not significantly affected by changes in tubing air quantity or interference air velocity. As with the canopy air curtain, the air tube was equally effective on both coal and silica particles.

The air tube produced dust reductions approaching 40 percent in tests with low airflow. Although the air tube was more adversely affected by higher interference airflows than the canopy air curtain, the air tube offerscertain advantages. This device is less obtrusive than the air curtain because it is mounted at the edge of the operator's canopy. Air tube operation also may require a smaller fan which will produce less heat and noise.

CLEANING THE ROOF BOLTER DUST BOX

Roof bolter personnel can reduce their occupational exposure to respirable silica dust by maintaining the vacuum dust collection system on the machine. This includes proper cleaning of the dust collector box by removing drill cuttings and placing them in the return or against the rib.

This study examined three methods of cleaning the dust collector box. These include an unacceptable, but very common, method of using a metal rake to scrape dust from the collector box onto the mine floor. Dust likely falls onto the worker's clothing. A second method inserts a rigid box with open top into the largest compartment of the bolter's dust collector box. This rigid box measures approximately 38 cm wide by 28 cm high by 32 cm deep and is constructed of 16-gauge steel with recessed handles welded on the front and top sides. When full of dust, the rigid box is carried to the rib and carefully dumped to control the dust cloud. A final method inserts a lightweight, flexible bag in the largest dust collector box compartment. This bag is sized similarly to the rigid box and is constructed of lightweight brattice-type material with handles sewn on the top. This bag also is carried to the rib and dumped when full of dust.

The different methods were evaluated on an EIMCO 300-10 (EIMCO, LLC; Bluefield, WV) single boom roof bolter. This machine uses a permissible four-compartment Donaldson vacuum dust collector with a single cannister-type filter. The bolting machine was placed in a heading ventilated by an exhausting line curtain hung 0.9 m (3 ft) from the right rib. Ventilation problems limited face airflow to 0.5 -1.0 m^3/s (1000 - 2000 cfm) behind the curtain. The dust collector box was located on the right side of the bolter chassis.

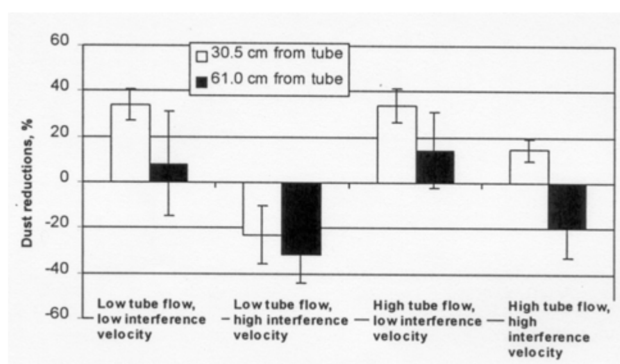

Figure 6. Air tube performance.

To avoid potential health risks of working with silica dust, limestone rock dust instead was used. Sieve analyses of rock dust and drill dust from this drill showed that the rock dust had a finer composition (table I). Two-22.7 kg (50 lb) bags of rock dust, were opened and set onthe mine bottom near the drill chuck. The vacuum hose running to the drill chuck was disconnected and, after energizing the bolter, was used to vacuum-up the rock dust pile. After de-energizing the machine, the dust collector box was cleaned using one of the methods described earlier. New rock dust was used every five tests to avoid altering the size fraction of the dust. The filter was cleaned every three tests.

Table I. Sieve analyses of drill dust and rock dust

	Cumulative Percent Finer Than Size (%)								
Sieve size	**#4**	**#7**	**#16**	**#30**	**#40**	**#60**	**#100**	**#200**	**Fines**
Opening size (Φm)	**4750**	**2800**	**1180**	**600**	**425**	**250**	**150**	**75**	**<75**
Drill dust	100	98.4	85.0	64.4	53.6	38.2	26.9	16.8	0
Rock dust	100	100	100	100	100	99.9	61.0	25.8	0

Due to the short test durations, gravimetric sampling at 2 lpm did not collect sufficient mass on the filters to permit accurate analyses. Instead, all samples were collected at 4.2 lpm. Use of this higher flow rate required a change in the cyclone preseparator from a 10-mm nylon cyclone to a Gk-2.69 metal cyclone (BGI, Inc., Waltham, MA). Constant flow pumps pulled dust-laden air through BGI cyclones at 4.2 lpm. The respirable fraction was then deposited onto preweighed 37-mm PVC filters. These filters were weighed following each test and dust levels calculated.

Accurate measurement of the respirable size fraction was not compromised by changing sampling rate and cyclone design. Work conducted by Kinney and Gussman (1997) showed that a d_{50}=4.2 Φm was obtained with the BGI cyclone sampling at 4.2 lpm. This was similar to the value obtained when sampling at 2 lpm with the 10-mm nylon cyclone (NIOSH, 1995).

For each test, only the largest compartment of the dust collector box was cleaned and this kept test durations at one minute. Five replicates of each cleaning method were made and were split between Researcher A and Researcher B. The five tests were averaged to establish an average dust concentration for each cleaning method. Dust levels were measured with two BGI gravimetric samplers in the breathing zone of the researcher cleaning the dust collector box. Separate samplers were used for each cleaning method to note any differences in dust levels.

The test results in figure 7 show that cleaning thedust collector box using the rigid box insert produced minimum dust levels compared to those measured when using the brattice bag and rake. Not only were dust levels smaller, but we observed little dust on the coveralls of the researchers.

Surprisingly, the brattice bag insert was not very effective and sometimes was less effective than raking the dust onto the mine floor. This was attributed to dust "puffing" off the bag as it flexed and bent while being pulled out of the dust collector box and while being carried to the rib. It is possible that the "puffing" problem will be smaller when used with coarser drill dust. Like the rigid box, cleaning the dust collector box with the brattice bag insert did not get much dust on the researcher's coveralls.

The rake produced much dust as the dust mass fellfrom the collector box onto the mine floor. In the process, dust got on the coveralls of the researchers. Furthermore, there was no way to get the dust to the rib without rehandling the dust. When cleaning the dust collector box using either the rigid box or the flexible bag, carefully rolling the box or bag at the rib successfully limited the size of the dust cloud.

SUMMARY

Recent field work by NIOSH researchers showed that high silica dust levels around a roof bolting machine arose when working downwind of the continuous mining machine. One means to limit exposure is the use a canopy air curtain or an air tube to provide a constant flow of filtered air over the breathing zone of roof bolter personnel. This laboratory work evaluated the effectiveness of each device for limiting exposures to respirable coal and silica dust.

The results showed that dust reductions were highest when sampling close to each device and that efficiencies decreased rapidly with distance. Furthermore, reductions with both devices tended to decrease rapidly when interference air velocities increased, although the air tube was most affected by such increases. Increases in air flow supplied to the canopy air curtain and air tube generally led to increased dust reductions. The canopy air curtain provided dust reductions approaching 60 percent in headings with a low interference air velocity, a likely condition in many bolter headings. Reductions approached 40 percent when using the air tube under similar conditions.

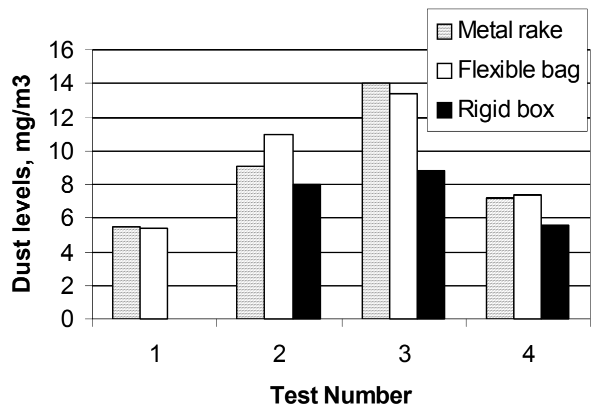

Figure 7. Results of dust box cleanings.

Silica dust contents were not affected by changes in flow quantity or interference air velocity when using the canopy air curtain or the air tube. Generally, silica contents measured under the air curtain and air tube were not significantly different from those measured outside.

Roof bolter personnel can control their exposures to respirable silica dust through proper cleaning of the dust collector box by removing drill cuttings and placing them against the rib. Three different methods were examined for cleaning this box. The first used a metal rake to scrape the cuttings onto the mine floor. The other two methods used a rigid metal box or a flexible bag inserted in the largest compartment of the dust collector box to hold the drill cuttings. When full of dust, the rigid box or flexible bag was carried to the rib and carefully dumped.

Less dust was produced when using the rigid boxinsert. Not only was less dust generated when dumping the rigid box, but we observed less dust on the clothing. The flexible bag did not do as well as the rigid box and sometimes did no better than scraping the dust onto the mine floor. This was attributed to "puffing" of dust as the bag flexed and bent while being carried to the rib. As with the rigid box, little dust got on the clothing. Much dust was present on the clothing when scraping the dust onto the mine floor. Also, there was no way to get this dust against the rib without rehandling it.

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