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Emerging technologies control respirable dust exposures for continuous mining and roof bolting personnel

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ABSTRACT: This work presents the findings from a number of NIOSH studies evaluating the impacts of emerging technologies that may reduce dust exposures for continuous mining and roof bolting personnel. These technologies include use of a wet head cutting drum on a continuous mining machine that places water sprays on the cutting drum instead of placing them on a manifold outby the drum. Evaluations at two separate operations showed that the use of the wet head sprays reduced dust levels at the miner operator in the return air, although these reductions were quite variable. NIOSH also assessed the effectiveness of a canopy air curtain for protecting roof bolting personnel. The data showed that dust levels were lower beneath the air curtain than outside the air curtain. This study also suggested several future modifications to the air curtain to increase its effectiveness. Finally, NIOSH evaluated mist drilling technology for its effectiveness in controlling respirable dust exposures of bolting personnel. A recent study showed that higher dust levels existed around a machine using the mist system compared to a machine using a conventional vacuum system for dust control. Unfortunately, the true impact of mist drilling was confounded by this machine operating downwind of the continuous miner for much of the study.

1 INTRODUCTION

The Federal Coal Mine Health and Safety Act requires that the concentration of respirable dust in the coal mine atmosphere not exceed 2.0 mg/m^3 for a working shift. If quartz content on the dust filters exceeds 5% by weight, the dust standard is reduced according to the following expression: 10/(% quartz). Compliance with the standard or a reduced standard maintains quartz dust exposures at or below 100 μg/m^3.

Over 17,000 samples collected by Mine Safety and Health Administration (MSHA) inspectors during the period 2000–2004 (MSHA 2004) were analyzed for both respirable coal and quartz dusts. This included over 12,000 samples at the miner operator occupation and 5,000 samples at roof bolter occupations. Nearly 2,000 samples of the miner and bolter showed excessive occupational exposure to respirable coal dust while 3,000 samples at the same occupations showed quartz exposures in excess of 100 μg/m^3.

Such levels present unacceptable health risks to the U.S. coal miner. The high incidences of coal and quartz overexposures suggest that existing control systems do not consistently limit respirable quartz dust exposures at roof bolter and miner operator occupations. Research must, therefore, focus on evaluation and improvement of these needed controls.

Continuous mining machines typically are equipped with external water spray systems and a fan-powered dust collector (scrubber), while roof bolting machines are equipped with vacuum (dry) dust collection systems. Novel technologies have been developed that offer the potential to further reduce dust exposures. A "wet head" continuous mining machine (water sprays situated in the cutting drum), a filtered air supply (canopy air curtain) for a roof bolting machine, and mist drilling technology are available for implementation on continuous mining operations. Each of these technologies offers the potential for reducing the dust exposures of underground coal miners.

This paper documents NIOSH evaluations of these emerging technologies for controlling worker exposures to respirable dust. Recommendations are provided for effective use of these methods.

2 CONTINUOUS MINER DUST CONTROL

2.1 *Wet head cutter drum*

Water sprays are the most widely used technique for limiting worker exposure to respirable dust in underground coal mining. Water sprays wet surfaces to prevent airborne dust generation, which is most effective when the water sprays are placed as close as possible to these surfaces. Typical mining machines place water sprays approximately 30–40 cm away from cutting bits to protect the spray manifolds. Wet head cutting drum designs, on the other hand, introduce water via sprays located directly behind each cutting bit on the cutting drum. This places water at each cutting bit and in the region where the dust cloud forms, a significant advantage for limiting formation and growth of this cloud.

Early studies of a prototype wet head machine showed 25–40% reductions in respirable dust levels at the mining machine operator (Strebig 1975, Kost et al. 1976). Return dust levels showed similar reductions, an important consideration for miners working downwind of the continuous miner. However, comprehensive studies of wet head machines were not conducted to evaluate the impacts of external spray and scrubber use on dust reduction potentials.

Poor mechanical reliability and high maintenance requirements of the wet head drum delayed its initial acceptance by the underground coal mining industry (Belle et al. 2002). A major manufacturer of underground mining equipment has recently introduced a redesigned version of the wet head cutting drum that improves both reliability and maintenance.

NIOSH conducted two multi-shift studies of this new design to evaluate the effectiveness of the wet head cutting drum for limiting respirable dust exposures for the miner operator and downwind personnel. Pairs of gravimetric samplers were hung in the intake and return air of the continuous mining machine while the miner operator wore a single sampler. These samples were not collected for a full shift; hence the results could not be correlated to compliance sampling.

2.2 *Wet head study at Mine A*

This study compared dust levels around a single machine that could be configured with either a wet head spray system or a regular spray system. The machine ran with three configurations: (1) with the regular drum sprays and with the flooded-bed dust scrubber, (2) with the wet head sprays and with the scrubber, and (3) with the wet head sprays but without the scrubber. NIOSH evaluated the first and second configurations for five shifts each and the third configuration for two shifts.

Mining height averaged 2.0 m for all test configurations with rock partings accounting for half of the height in some entries. A combination of a flooded-bed dust scrubber rated at 3.3–3.5 m^3/s and an exhaust line curtain hung along the right rib ventilated the face. Exhaust curtain flow averaged 7.1 m^3/s for configuration 1, 6.2 m^3/s for configuration 2, and 5.6 m^3/s for configuration 3. Shift production averaged 500 tons (range 290–575 tons) for configuration 1,620 tons (range 360–810) for configuration 2, and 420 tons (range 330–500 tons) for configuration 3.

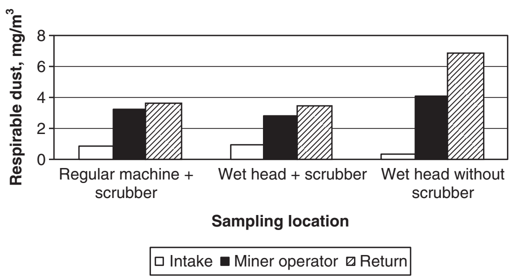

Figure 1. Gravimetric dust levels for Mine A, with and without wet head sprays.

The regular spray system consisted of twenty-seven hollow-cone water sprays for dust control mounted externally on the frame of the continuous miner, with an equivalent number located on the cutting boom. Water spray pressure on the external sprays varied from 1,034 to 1,276 kPa measured with a dial gauge on a right-hand end-ring spray. The wet head drum contained 73 small orifice solid stream sprays (each delivering 1.1 liters/min at 689 kPa) oriented to spray directly on the 73 cutter bits. These sprays could be turned on or off depending on required test conditions. Wet head spray pressures varied from 448 to 655 kPa when measured by company personnel prior to testing. Water flow rates on the continuous miner were 174.3 liters/min with the wet head sprays operating and 181.9 liters/min with the regular sprays. In addition to the wet head sprays, several sprays on the cutting boom remained open to provide cooling water to the cutting motors and contributed to the total flow measured for the wet head spray system.

Average gravimetric dust levels measured at the miner operator and in the return airway were slightly lower using the wet head cutting drum and the dust scrubber (Fig. 1). Removing the contribution of intake dust from miner operator and return dust levels showed that operation of the wet head sprays reduced dust levels by 0.5 and 0.3 mg/m^3, respectively at these two locations. However, the true impact of these sprays on respirable dust levels was likely hidden by the variability of the gravimetric data collected at these locations. For instance, miner operator dust levels ranged from 2.20 to 4.52 mg/m^3, 0.94 to 4.26 mg/m^3, and 1.94 to 6.15 mg/m^3 for configurations 1, 2, and 3, respectively. Gravimetric dust levels in the return exhibited similar variations.

Relatively high quartz dust levels in the intake airway were observed for configurations 1 and 2 (Table 1). These levels tended to be higher when rock was being crushed in the feeder breaker and its dust entered the intake air. This and the cutting of a sandstone rider above the coal seam elevated miner operator

Table 1. Quartz dust levels for three configurations during wet head study, Mine A.

	Respirable quartz levels, Average (range), μg/m³		
Configuration	Intake	Miner Operator	Return
1	103 (0–262)	356 (140–613)	413 (230–739)
2	82 (0–192)	311 (89–753)	359 (161–579)
3	20 (0–39)	372 (191–553)	621 (436–806)

quartz dust levels on several shifts. The highest quartz exposures for configuration 1 were recorded at the miner operator and in the return while cleaning up a roof fall from the previous shift.

The data showed much higher dust levels for configuration 3, indicating that the wet head sprays could not control dust levels without the dust scrubber. The large amount of dust around the continuous miner made it difficult for the operator to see the cutter head. Based upon the sampling results, NIOSH recommended that the wet head machine not operate without the scrubber.

2.3 *Wet head study at Mine B*

This study compared dust levels around two continuous mining machines: one equipped with wet head sprays and the other equipped with a conventional spray system. Cutting height varied with face location but averaged 1.8 m for the regular machine with an average rock thickness of 0.5 m. Cutting height and rock thickness averaged 1.7 m and 0.3 m, respectively, for the wet head machine. Evaluation of the regular and wet head machines took place over four shifts.

Section ventilation was single split with the wet head continuous miner operating upwind of the regular mining machine during the study (operation was not simultaneous). Blowing face ventilation for both machines was provided by an intake line curtain hung along the right rib and by a flooded-bed dust scrubber rated at 3.2 m^3/s on the wet head machine and 3.0 m^3/s on the regular mining machine. Airflow quantities behind the intake curtain averaged 4.6 m^3/s for the wet head mining machine and 4.4 m^3/s for the regular machine. Production for the wet head averaged 610 tons (range 430–740 tons) and 680 tons (range 580–910 tons) for the regular miner.

The wet head continuous miner contained a total of 89 sprays, 63 of which were small orifice sprays located on the cutter head. The wet head sprays (each delivering 1.5 liters/min at 689 kPa) were oriented to spray directly on the 63 cutting bits. Wet head spray pressure was approximately 621 kPa as measured by company personnel prior to testing. With the scrubber operating, water flow on the wet head machine varied from 144 to 159 liters/min measured by a flow meter on the right side of the machine frame. External spray pressure was 1,034 kPa measured with a dial gauge on this machine. Six sprays were open on the cutting boom to provide cooling water to the cutting motors.

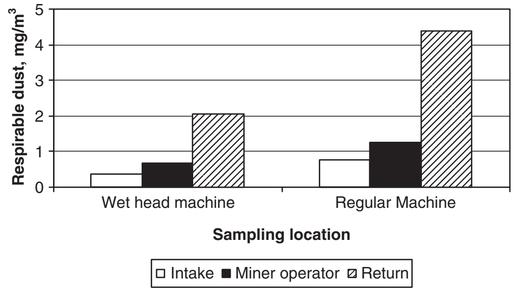

Figure 2. Gravimetric dust levels for Mine B, with and without wet head sprays.

The regular machine contained a total of 41 dust control sprays, each delivering 2.6 liters/min at 689 kPa. Water pressure on the sprays was 1,034 kPa when measured by a dial gauge on the mining machine. A flow rate measurement was not possible on this machine because of a broken flow meter.

The intake and return samplers assigned to each machine ran only when that mining machine operated. The results of this study indicate lower dust levels at the three sampling locations when using the wet head (Fig. 2). After removing the intake dust contribution, the reduction at the miner operator location was only 0.2 mg/m^3 when operating the wet head sprays. Interestingly, the reduction in the return was nearly 2 mg/m^3 when using the wet head sprays.

Respirable quartz dust levels varied between the wet head and regular mining machines. Measurable levels were not detected on the intake airway or miner operator samples of the wet head machine. The return airway showed a respirable quartz level of 81 $\mu g/m^3$ on the first shift, while return airway samples from other shifts showed no detectable quartz mass. Measurable levels of respirable quartz were not found in the intake airway samples of the regular mining machine. Quartz dust levels for the miner operator of the regular machine averaged 70 $\mu g/m^3$ (range 42 to 97 $\mu g/m^3$) while return airway levels averaged 143 $\mu g/m^3$ (range 108–193 $\mu g/m^3$).

The true impacts of the wet head sprays on respirable coal and quartz dust levels were likely confounded by excessive variability in production, ventilation, and geologic factors between the two machines. It is the contention of the authors that dust reductions shown in figure 2 and quartz reductions described earlier may not have been due solely to the wet head sprays, but also to these variations.

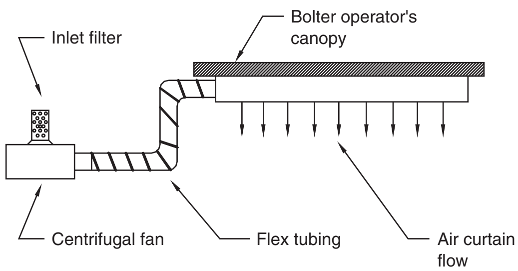

Figure 3. Schematic of canopy air curtain.

3 ROOF BOLTER DUST CONTROL

3.1 *Canopy air curtain*

Previous work by NIOSH researchers showed that dust levels for roof bolter operators could increase when working downwind of the continuous mining machine (Goodman et al. 2002). A canopy air curtain system was developed by NIOSH researchers and tested as a means for reducing these exposures. This device consists of a hollow metal plenum with a perforated surface on one side. The plenum is connected by flexible tubing to the output of a small centrifugal fan. A filter is placed on the intake side of the fan. Placed on the underside of the operator's canopy, filtered air flows from the perforated plate and over the breathing zone of the person working beneath the air curtain (Fig. 3).

Laboratory testing of this device showed that its effectiveness in limiting dust levels beneath the canopy was mostly a function of the velocity of the air moving across the face of the air curtain. Higher velocity air disrupted the air flowing from the air curtain, thus reducing its effectiveness. Testing of the air curtain showed dust reductions of 40% to 60% at a low air velocity of 0.3 m/s, a typical value in the bolter headings of many underground coal mines (Goodman et al. 2001).

An underground study by NIOSH evaluated the canopy air curtain for its effectiveness in controlling respirable dust exposures for the bolter operators. Respirable dust levels were measured around a twin boom roof bolting machine equipped with a canopy air curtain mounted on the underside of the canopy of the downwind operator (Fig. 4). The canopy air curtain was constructed of 14-gauge steel and measured 61 cm long, 25 cm wide, and 5 cm thick. The underside of the air curtain was a section of perforated plate steel (2.4 mm diameter holes, 4.8 mm staggered spacing). The inside of the air curtain contained a 3.2 mm cell polycarbonate honeycomb material to straighten and baffle the air flowing into the air curtain. A small centrifugal fan (American fan, model AF-10-R12327-6) supplied 0.11 m^3/s to the air curtain and was mounted at the rear of the roof bolting machine adjacent to the tramming cab. A 6.1 m length of 10.2 cm diameter spiral tubing connected the air curtain to the centrifugal fan. Airflow to the air curtain was cleaned by an EPG model G110120 filter (Donaldson, Inc., Minneapolis, MN) mounted on the intake side of the fan. The canopy air curtain system provided a steady stream of filtered air over the operator's breathing zone.

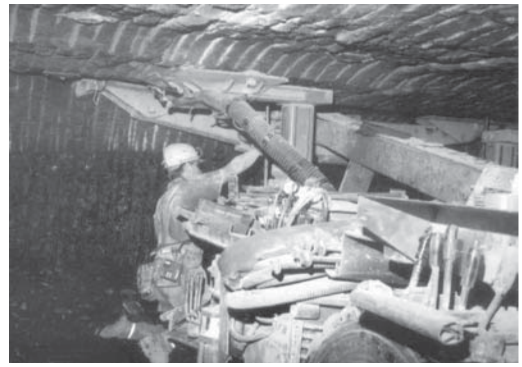

Figure 4. Canopy air curtain installed on roof bolter.

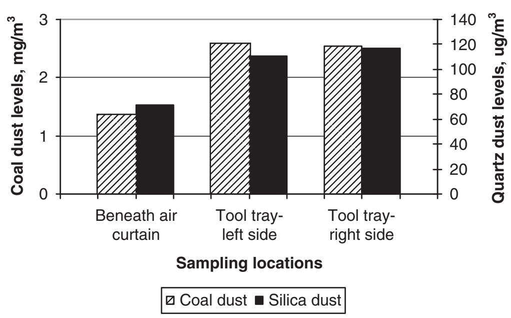

Figure 5. Respirable coal and quartz dust levels beneath air curtain and around roof bolter.

Dust sampling was conducted for three shifts beneath the air curtain and on the left and right sides of the bolting machine on the tool trays. Coal and quartz dust levels beneath the air curtain were 1.2 mg/m^3 and 40 μg/m^3 lower than dust levels on the tool trays (Fig. 5). However, these samples were collected close to the perforated plate of the air curtain because of headroom constraints and, as such, represent an "optimum" scenario for dust protection effectiveness. Data collected during this study suggested several ways to improve the efficiency of the canopy air curtain, such as increasing air curtain size to increase coverage area and reducing tubing lengths from the fan to the air curtain (requiring positioning of the fan closer to the drill head).

3.2 *Mist drilling*

A mist head bolter injects a combination of water and compressed air through the drill steel to the drill bit to

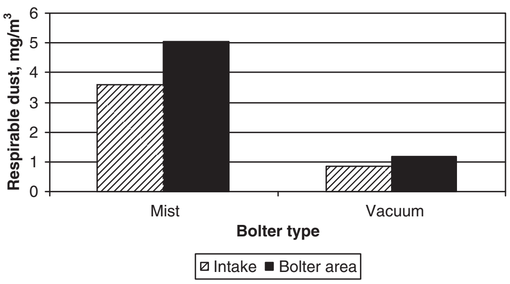

Figure 6. Impact of mist drilling on gravimetric dust levels.

control drill dust, instead of using a conventional vacuum system with canister or bag filters. Air is supplied by an on-board compressor while the water is supplied by an on-board water tank or by a water hose dragged behind the machine.

An underground study compared dust levels around two roof bolting machines, one using a mist system and the other using a conventional vacuum system to control drill dust. The mist bolting machine injected water and compressed air to the left bolting arm at rates of 2.6 liters/min and 75.8 liters/min, respectively. Water and air were supplied to the right arm at rates of 1.1 liters/min and 75.8 liters/min, respectively. The vacuum bolter used a four-compartment permissible vacuum dust collection system with a single canister filter to collect drill dust. These machines did not operate simultaneously.

Two gravimetric samplers were attached near the left and right operator's work location on each machine approximately 30–60 cm outby their controls. The bolter area dust level for each machine was the average of the dust concentrations from the left and right samples. Gravimetric samplers were also hung in the intake air of each machine. The sampling pumps on each machine operated only while that machine ran. Three shifts of data were collected for each bolting machine.

For much of this study, the mist bolter worked downwind of the continuous mining machine, resulting in higher intake dust levels for this bolter than the vacuum bolter that typically worked in the clean air upwind of the continuous miner. As a result, gravimetric dust levels measured around the mist bolter were significantly elevated compared to dust levels around the vacuum machine (Fig. 6). Even after removing the contribution of intake dust, dust levels around the mist bolting machine still exceeded those around the vacuum machine.

Quartz contents on the intake filters averaged 10.6% (range 10.3 to 10.9%) at the vacuum machine and 9.5% (range 7.7 to 11.1%) at the mist machine for a three-shift study. Quartz contents averaged 12.3% (range 9.6 to 16.3%) around the mist machine and 9.0% (range 7.6 to 10.4%) around the vacuum bolter. The higher quartz content around the mist bolter was likely a result of this machine working downwind of the continuous miner as it cut rock (rock thickness varied with face location, but ranged from 0.6 to over 1.0 m out of a mining height of 1.7 m). This high quartz dust content coupled with the high gravimetric dust levels led to higher quartz dust concentrations around the mist bolter.

4 CONCLUSIONS

NIOSH evaluated emerging technologies that limit respirable dust exposures for operators of continuous mining and roof bolting equipment. These technologies include use of a wet head cutting drum on a continuous mining machine that places water sprays on the drum and closer to the dust cloud. An evaluation at one operation showed that use of the wet head sprays reduced dust levels 0.5 mg/m^3 at the miner operator and 0.3 mg/m^3 in the return when adjusted for intake dust levels. Dust reductions at a second operation were about 0.2 and 2.0 mg/m^3 at the miner operator and in the return airway, respectively. In both studies, the true impacts of the wet head sprays were likely confounded by variations in gravimetric data, production, ventilation, and geologic factors. NIOSH also assessed the protection afforded roof bolter personnel by use of a canopy air curtain, a device that blows filtered air over the operator's breathing zone. The data showed a reduction in dust levels of over 1.2 mg/m^3 beneath the air curtain compared to levels around the bolter. This study also revealed several ways to improve the efficiency of the air curtain, including increasing air curtain size to increase coverage area and reducing tubing lengths from the fan to the curtain. Mist drilling controls dust by injecting a combination of water and compressed air through the drill steels to the drill bit, instead of using a conventional vacuum system to draw dust back through the steel. A recent NIOSH study compared two bolting machines, one using a mist system and the other using a conventional vacuum system. The mist bolter worked downwind of the continuous miner for much of the study causing higher intake dust levels for this bolter. As a result, dust levels averaged 1.1 mg/m^3 higher around the mist machine than around the vacuum machine, even after removing the intake dust contribution.

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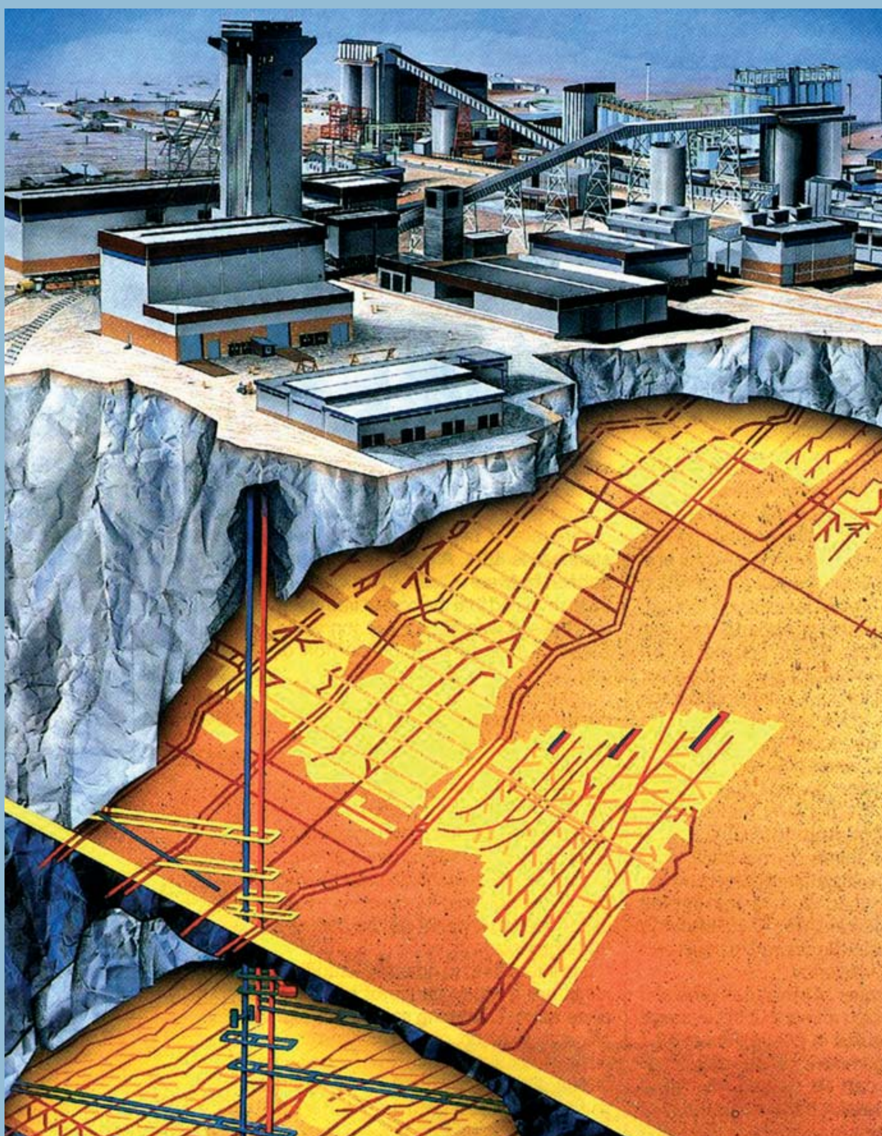

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