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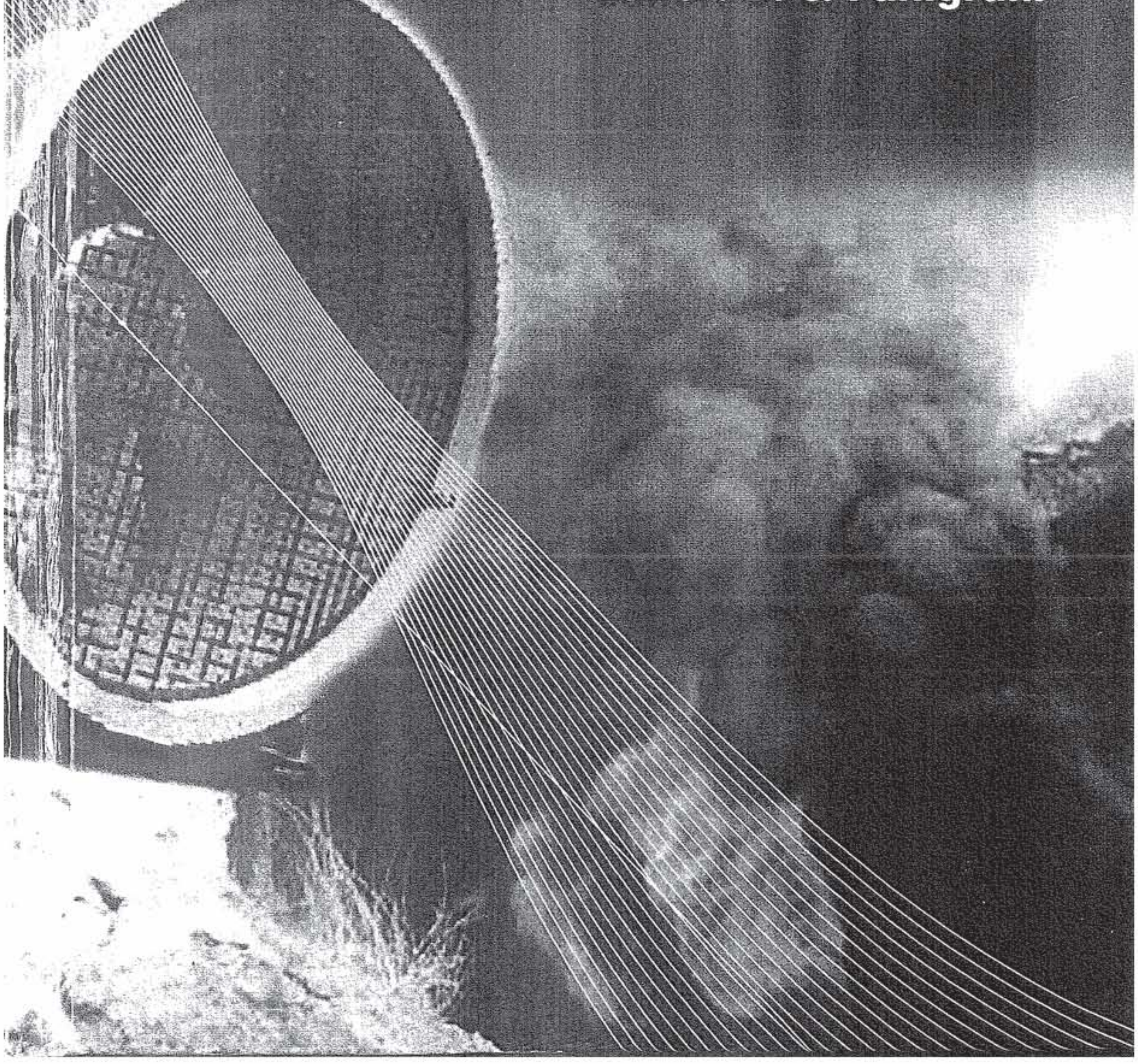

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AN OVERVIEW OF FUNDAMENTAL AND EMERGING TECHNOLOGIES TO MONITOR AND CONTROL RESPIRABLE DUST IN UNDERGROUND COAL MINES IN THE UNITED STATES

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ABSTRACT

As production levels continue to increase in underground coal operations in the United States, greater quantities of respirable dust are generated with the potential to increase worker exposure. Ventilating air and water spray systems continue to be the primary means of controlling respirable dust for both continuous mining and longwall mining operations. Mine operators are applying these fundamental control technologies at elevated levels and are looking to new and emerging control technologies to better control respirable dust. New monitoring technologies are also being developed to improve the real-time measurement of worker dust exposure; so that corrective action can be taken before workers' become overexposed.

The Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) conducts research to develop and improve control technologies and monitoring instrumentation that can be used to reduce the respirable dust exposure of mine workers. An overview of fundamental dust controls technologies being utilized in underground US coal mines will be presented. Also, updates on emerging technologies such as the personal dust monitor (PDM), wet head spray technology for continuous miners, and a roof bolter canopy air curtain will be provided.

KEYWORDS: *Dust; control technology; pneumoconiosis; coal mining; monitoring*

1. INTRODUCTION

In an effort to prevent lung disease, the Mine Safety and Health Administration (MSHA) enforces a respirable dust standard of 2.0 mg/m^3 averaged over five 8-hour shifts for the underground coal mining industry in the United States (US). If the silica content of the collected sample exceeds 5%, the 2.0 mg/m^3 dust standard is reduced according to the equation of $10 \div$ % silica. For example, if the sample contains 10% silica, the reduced dust standard would be 1.0 mg/m^3 ($10 \div 10$% silica). Currently, mine operators are required to collected dust samples on a bimonthly basis and MSHA samples each mechanized mining unit (MMU) four times a year.

Improvements in longwall mining equipment and mining practices have led to substantial gains in longwall production levels, resulting in longwall mining accounting for 51% of the coal produced underground in the US (EIA, 2006). Average longwall production as reported by mine operators during compliance dust sampling in 2008 was 5,000 tons (5,500 short tons) per shift (Lindahl, 2009). Although significant gains in longwall dust control have been made, they have been challenged by these increases in production. In 2006, 11.1% and 8.8% of compliance samples exceeded the applicable dust standard for the tailgate shearer operators and jacksetters, respectively.

Along with major changes on longwalls in the US, continuous mining operations have also seen dramatic changes. Average production on the approximately 850 continuous miner sections during compliance sampling reached 700 tons (770 short tons) per shift in 2008 (Lindahl, 2009). The majority of continuous miners are operating with flooded bed scrubbers and taking extended cuts greater than 6.1 meters (20 feet). The number of mines utilizing super-sections (sections with two continuous miners) has increased in recent years. This has resulted in the potential for roof bolter operators to work downwind of a continuous miner and be exposed to increased amounts of respirable dust. Another significant change that has occurred is an increase in the quantity of rock that is being mined as seam conditions have deteriorated. Cutting of this rock has the potential to add significant quantities of silica dust in the mine environment. In 2008, 17.9% of continuous miner operator and 7.1% of roof bolter operator samples exceeded their reduced dust standard.

Medical studies have shown that prolonged exposure to excessive levels of airborne respirable coal dust can lead to coal workers' pneumoconiosis (CWP), progressive massive fibrosis (PMF), and chronic obstructive pulmonary disease (COPD). These diseases are irreversible and can be debilitating, progressive, and potentially fatal. Coal workers' pneumoconiosis contributed to the deaths of 10,406 miners during the period of 1995 through 2004 (NIOSH, 2008). Pneumoconiosis continues to be a very serious health threat to underground coal mine workers. Recent x-ray surveillance data have uncovered cases of rapidly progressing CWP and also revealed an upturn in the prevalence rate (CDC, 2006).

The continued development of CWP in underground coal mine workers and the magnitude of respirable dust over exposures in the US illustrate the need for NIOSH and the US mining industry to improve existing dust control technology and develop new control methods.

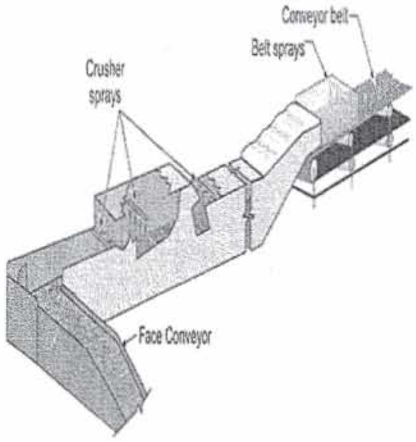
2. LONGWALL MINING DUST CONTROL

Outby dust sources can contribute significantly to worker dust exposure at the longwall face. Dust generated by these sources enters the ventilating airstream and remains airborne across the entire face, which can have a significant impact on the dust exposure of all face personnel. Efforts must be made to maximize the quantity and quality of ventilating air that reach the face area. Outby dust sources such as vehicle movement, removing stoppings, and delivering/unloading supplies can elevate intake dust levels. If at all possible, these activities should be limited during production shifts. Operators must be diligent in monitoring moisture content of the dust on intake roadways. The moisture content of the haulage floor should be approximately 10% (Kissell, 2003) to minimize dust entrainment. Properly maintaining the belts is one of many vital components needed to keep respirable dust levels low along the belt entry. Dry belts could become a major source of dust in ventilation airstream. Missing rollers, belt slippage, and worn belts can cause belt misalignment and create spillage. With the substantial increase in airflow, rewetting of the coal may be necessary at intervals along the belt. Flat fan sprays and full-cone nozzles are typically used for coal wetting along the belt. Water application usually ranges from 3.8 to 15.1 lpm (1 to 4 gpm) at operating pressures at or greater than 348 kPa (50 psi) (Bituminous Coal Research Inc).

The stageloader/crusher is the most significant source of respirable dust in the headgate area. The breaking action of the crusher on the coal and rock generates large quantities of dust, which can mix with the ventilating airstream and be carried the entire length of the longwall face. In the US, all stageloader/crushers are fully enclosed; however, there is not a universally applied technique for enclosing the stageloader/crusher. The common practice is to enclose the stageloader and crusher through a combination of steel plates, strips of conveyor belting, and/or brattice. With the quantity of coal being transported through the stageloader/crusher, it is imperative that all seals and skirts be carefully maintained to ensure that dust stays confined within the enclosure. At a minimum, water sprays should be placed on both sides of the crusher and at the stageloader-to-section-belt transfer (Figure 1A). The objective of these sprays is to wet the coal product and prevent respirable dust from becoming airborne. Consequently, water quantity is more critical than water pressure, so larger orifice, full-cone sprays operating at water pressures below 414 kPa (60 psi) are recommended. In an effort to keep fugitive dust from escaping from the stageloader/crusher area, fan-powered scrubbers located close to the crusher discharge and/or stageloader to belt transfer area are being utilized more often, according to the latest longwall surveys (Rider and Colinet, 2007).

Adequate ventilation of the longwall panel involves supplying the required volume of air to the headgate and maintaining that airflow along the face. Often, loss of air into the gob in the headgate area prevents the maximum utilization of the intake air. A gob curtain (Figure 1B) installed between the first support and the rib in the headgate entry, can force the ventilating airstream to make a 90 degree turn down the longwall entry, rather than leaking into the gob (Jankowski and Colinet, 2000). The brattice curtain can be extended behind hydraulic support legs along the first five to ten shields to further reduce leakage into the gob area and thus increase airflow down the face.

To accurately assess face airflow, ventilation measurements should be taken at every 10^{th} support. The resulting profile could be used to determine the "average" face airflow, along with the effective utilization of the primary intake air, and the loss of air into the gob. Higher air velocities provide greater air quantities for better dust dilution, improved diffusion of dust from stagnant areas, and rapidly removes dust from the breathing zones of the face workers. In recent surveys of US longwalls, the average face airflow was found to be 3.4 m/sec (665 fpm) with an estimated average air quantity of 31.6 m^3/sec (67,000 cfm). This air quantity represents a 65% increase in airflow from 10 years ago (Rider and Colinet, 2007).



(a)

(b)

Figure 1 (a, b): Dust control practices to reduce respirable dust in the headgate area

Water spray application is the primary control being used to substantially reduce dust liberation during longwall mining. In the US, all shearer-cutting drums are equipped with drum-mounted water sprays. The intent is to apply water directly at the point of coal fracture to maximize dust suppression and add moisture to the product to minimize dust liberation during the transport of the coal off of the longwall face. Once respirable dust becomes airborne and is entrained by the primary airstream, it is then carried throughout the entire cross-sectional area of the longwall face. In general, water spray pressure to the shearer drums should be limited to a maximum of 690 kPa (100 psi) to prevent dust from being blown into the walkway by the sprays. Also, past research has shown that full-cone or jet sprays are the most effective type of spray patterns to use in the shearer drums. These sprays increase wetting without inducing substantial air movement around the drum.

Water sprays are very effective air-moving devices and when mounted on the shearer body can act very much like small fans that move air and entrain dust in the direction of the spray. Poorly designed shearer-mounted spray systems with the water sprays oriented upwind into the primary ventilation can cause high levels of dust to be transported away from the face area and into the walkway. If applied properly, water sprays can be used to augment the primary airflow and reduce the amount of shearer-generated dust. A technique used on longwall operations in the US is to hold the dust-laden air near the face by splitting the ventilating air as it reaches the headgate side of the shearer. This air split is facilitated through the use of a "splitter arm," which is a steel arm that extends from the headgate side of the shearer body parallel to the headgate ranging arm. Sprays are mounted on this splitter arm and oriented in the direction of the airflow and angled toward the face. A section of conveyor belting is also hung from the splitter arm to form a physical barrier between the face conveyor and walkway. Additional spray manifolds are mounted along the body of the shearer to further promote the movement of the dust-laden air along the face. Figure 2 illustrates a directional spray system operating on a shearer. Spray manifolds on the back side of the shearer help to maintain this dust near the face and move the dust cloud past the shearer. Since the sprays in these directional spray systems are attempting to move air, the operating pressure is critical and pressures of at least 1035 kPa (150 psi) should be utilized. Hollow cone sprays and/or venturi sprays are effective in this application.

Figure 2: Directional spray system on a longwall shearer

3. CONTINUOUS MINER DUST CONTROL

The greatest source of respirable dust at continuous mining operations is generated by the continuous mining machine. Continuous miner dust affects the operator as well as anyone working downwind of the active mining area. In the US, two types of ventilation systems are used to supply fresh air to the face of a continuous mining section. Typically, the most effective method from a dust control standpoint is exhaust ventilation. Fresh air is brought to the face in the working entry and line brattice or tubing is installed within the entry to create an air separation. Dust-laden air is then drawn from the face through the tubing or behind the curtain. This method keeps the continuous miner operator and shuttle car operators in clean air. The second system is blowing ventilation, where clean air is brought to the face behind the brattice or in tubing and discharged toward the face. Dust-laden air is then carried out of the face through the entry. This type of ventilation typically penetrates deeper toward the face and is more effective for methane control. From a dust control standpoint, the miner operator can position himself at the discharge of the line curtain/tubing and work in clean air. However, the shuttle car operators are exposed to dust-laden return air.

In the US, water spray manifolds are typically mounted on top of the miner boom within 30-38 cm (12-15 inches) of the cutting drums. These sprays wet the coal as it is being cut and prevent dust from becoming airborne. High volume, cone sprays or flat-fan sprays operating at less than 690 kPa (100 psi) should be located across the boom as close to the cutter head as possible to provide uniform coal wetting across the cutter head during mining while limiting rollback (Figure 3A). Dust rollback can occur when cone type sprays are used at higher pressures and force dust back over the continuous miner (Jayaraman *et al.*, 1984). Large-orifice, low-pressure sprays should be utilized under the boom of the miner and in the conveyor throat area. These sprays usually operate at 412 kPa (60 psi) or less with a flow rate of approximately 18.9 lpm (5 gpm). Broken material is wetted as it is gathered and conveyed (Figure 3C). For dust containment under the boom, flat-fan sprays with a vertical orientation at 30 degrees are mounted 0.3 meters (1 foot) back from the cutter head outby the scrubber inlets on both sides of body of the machine (Figure 3B). Because sprays are oriented vertically they act as a water barrier along side of the miner boom and give the scrubber and external sprays an improved opportunity of capturing the dust. The operating pressure of these sprays can be higher than 690 kPa (100 psi) to increase the impact zone of the sprays.

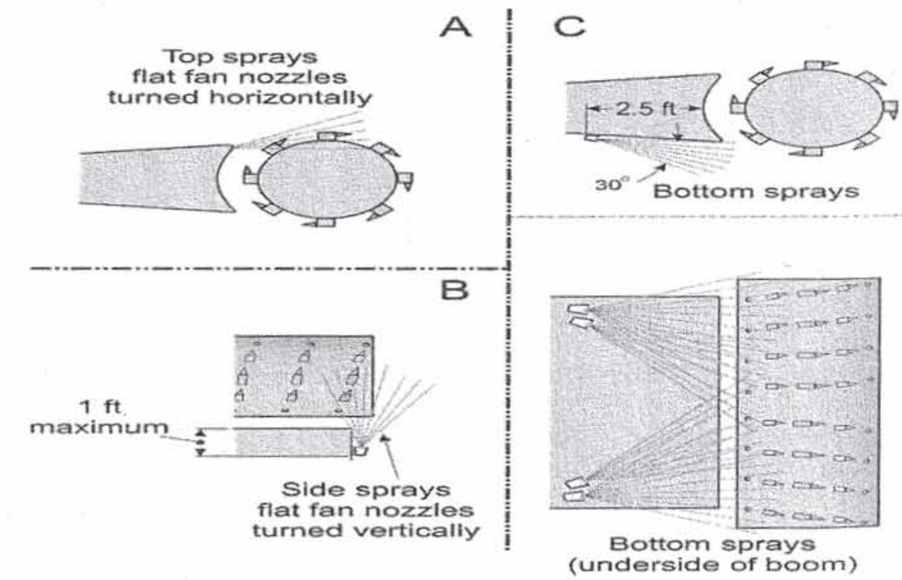


Figure 3: Orientation of sprays to prevent dust rollback

Currently, most mining operators are using fan-powered, flooded bed scrubbers to assist in moving fresh air toward the face and to capture dust-laden air generated by the miner's cutter heads. Airborne dust is pulled through one to three inlets located on the miner's boom and passes through a wetted filter panel. Water sprays impact the filter panel and the dust mixes with the water droplets. The dust is removed from the airstream when the droplets are captured by a demister located behind the filter panel. The cleaned air is discharged from the back of the miner and is directed toward the return. If operated properly, over 90% of the respirable dust can be removed by a scrubber. It is critical that sufficient water is applied to the entire filter panel area to extend the effectiveness and performance of the scrubber. Usually, full cone sprays operated at 415 kPa (60 psi) are used to wet the scrubber filter. Periodic removal and cleaning of the filter and demister are also necessary to maintain optimum performance of these dust collectors. Research has shown that the selection of the scrubber filter can have a significant impact on dust collection efficiency. If dust control is a concern, the more efficient filters (30-layer stainless steel or bottle brush filter) can be utilized to maximize dust capture (Colinet and Jankowski, 2000).

4. ROOF BOLTER DUST CONTROL

The largest source of roof bolter operator's dust exposure can occur when working downwind of the continuous miner. The mining pattern should be designed to eliminate or at least minimize the need for the bolter to work downwind of the continuous miner. Other sources of dust exposure for the bolter operators are the drilling process and maintaining the dust collector. The majority of the roof bolters in the US utilize a dry vacuum dust collector system that pulls dust through the drill to a dust collector box. The dust is removed from the airstream and deposited in chambers of the collector box or captured by a filter cartridge. Properly maintaining the dust collector system is critical; checks should be made for loose hose connections and damaged compartment door gaskets. Vacuum pressure at the drill head should be checked periodically by using an approved pressure gauge to maintain manufacturer's vacuum specifications for proper airflow. Frequent cleaning of the main dust compartment is necessary to ensure proper operation of the dust collection system. As the collector box fills, it is necessary for the operator to empty the box and change. the filter cartridge. The operator should maintain an upwind position when removing dust from the dust box to reduce exposure.

Utilization of a collector bag has shown to reduce dust exposures to bolter operators when emptying the dust box. These collector bags contain the dust and reduce loading on the filter cartridge. Operators can easily remove the filled bags from the dust box and deposit the bag against the rib. Dust loading on the filter cartridge is significantly reduced and the filter does not need to be replaced as often. Laboratory and field testing of the collector bags has shown that they reduce dust loading on the filter cartridge by approximately 80 % (Listak and Beck, 2007). It should be noted that the dust collector must be fitted with an automated pre-cleaner that separates and captures larger particles prior to the material reaching the collector. This minimizes the loading of the collector bag and extends its usable time. If the bolting machine's dry dust collector is properly maintained, and if the bolter is not working downwind of the continuous miner, very little dust should be measured in the air around the bolter (Goodman and Organiscak, 2002).

5. WET HEAD SPRAY TECHNOLOGY

Continuous miner manufacturers in the United States have started offering a miner that is equipped with water sprays in the cutting drums. Spray nozzles are located directly behind each cutting bit on the drum, while conventional technology places the water sprays on the boom approximately 30-38 cm (12-15 inches) away from the cutting bits. The initial intent of locating spray directly behind the cutting bit was to offer improved control of frictional ignition with the potential to reduce dust levels. This allows water to be introduced at point of coal fracture and immediately adds moisture to minimize dust where the dust cloud forms. Figure 4 illustrates the wet head miner and spray nozzle location.

Currently, NIOSH is evaluating this technology to determine the effectiveness of the wet head cutting drum for limiting respirable dust exposures for miner operator and downwind personnel. Two studies conducted by Goodman et *al.,* (2006) compared dust levels around continuous miners that were operated with either a conventional spray system located on top of the miner's boom or a wet head spray system. One study was conducted with exhaust ventilation, while the second study used blowing ventilation. Measured dust reductions at the miner operator ranged from 0.2 to 0.5 mg/m^3. During these studies, each wet head spray was limited to 1.5 lpm (0.4 gpm) in order to maintain overall water flow to the miner at an acceptable level. Additional work is planned to further explore the dust reduction potential of the wet head design.

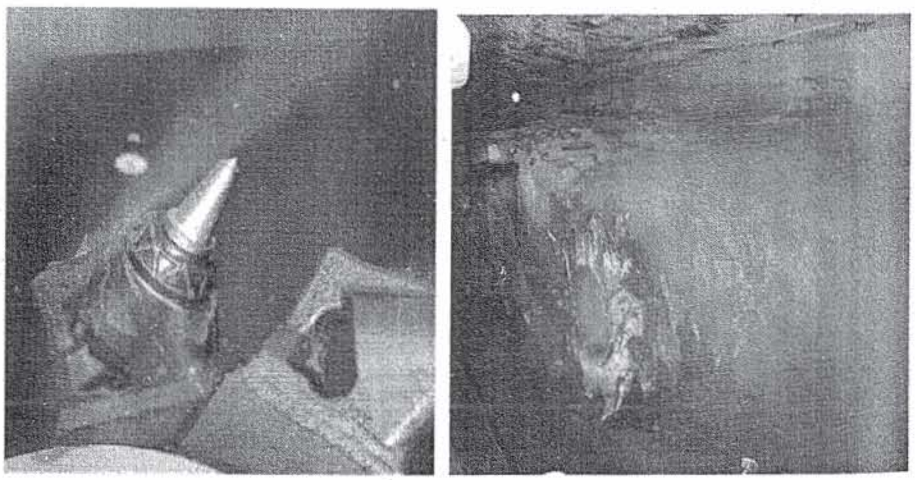


Figure 4: Wet head miner and spray location behind bit

6. CANOPY AIR CURTAIN

NIOSH is currently developing and testing a canopy air curtain for installation on a roof bolter to deliver filtered air over the operator's breathing area. This device is mounted on the underside of the bolter canopy and consists of a hollow metal plenum with a perforated plate on the bottom. A fan located at the rear of the bolter draws in ventilating air from the entry and passes it through a filter. Tubing carries the air from the fan to the plenum. A stream of filtered air is discharged from the perforated plate and passes over the operator. This filtered air prevents dust from drilling or dust generated upwind by the miner from reaching the bolter operator. Laboratory testing has shown a 50% reduction of dust under the air curtain and was followed by an underground study (Goodman et *al.,* 2006). Data collected during this study showed promise and suggested several ways to improve the efficiency of the canopy air curtain, such as increasing air curtain size to increase coverage area. A computational fluid dynamics (CFD) model has been utilized to optimize the flow of air underneath the canopy as it relates to the position of the operator. NIOSH is currently evaluating a second-generation air curtain in the laboratory. Figure 5 shows the canopy air curtain being test underground and a CFD model illustrating airflow patterns of the redesigned air curtain.

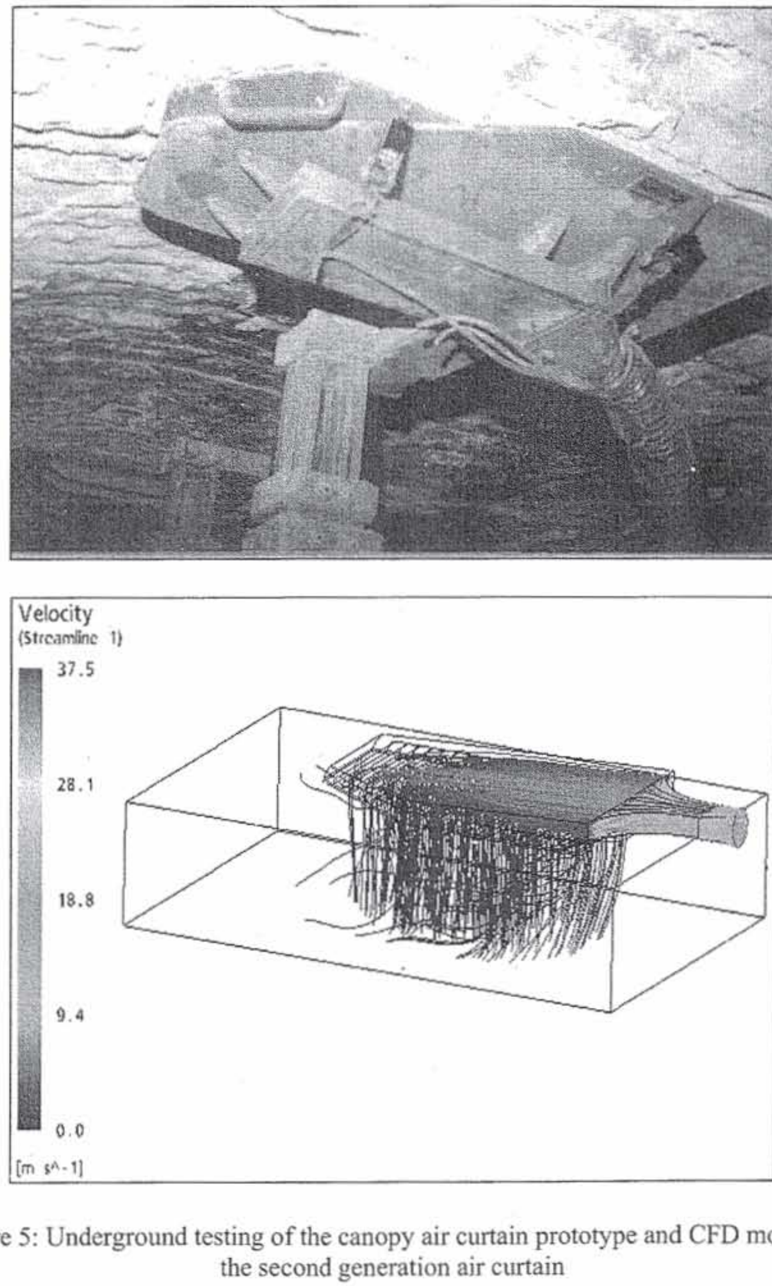


Figure 5: Underground testing of the canopy air curtain prototype and CFD model of the second generation air curtain

7. PERSONAL DUST MONITOR

To date, dust monitoring in the US has relied upon collection of a gravimetric sample with a coal mine dust personal sampler unit (CMDPSU). The CMDPSU utilizes a pre-weighed 5 μm pore size polyvinyl chloride (PVC) filter preceded by a 10 mm Dorr-Oliver nylon cyclone operated at a flow rate of 2.0 lpm to collect a respirable sample of airborne coal mine dust. The CMDPSU is operated over an 8-hour (portal to portal) sampling period to determine the average dust exposure of the wearer. Unfortunately, the dust exposure can not determined until the filter has been mailed to MSHA and processed, which can take up to 10 days. In the interim, the mine worker may continue to be exposed to elevated dust levels.

In an effort to provide real-time measurement of dust exposures, NIOSH developed the Personal Dust Monitor (PDM) (Figure 6). The PDM utilizes the Tapered Element Oscillating Microbalance (TEOM) technology to convert a mass-based measurement into real-time dust concentrations (Volkwein *et al.,* 2004). A data processor in the PDM utilizes these real time measurements to calculate and display a cumulative dust exposure to that point in the shift, as well as, a projected dust concentration for the end of the shift. The mine worker and management can monitor these levels throughout the shift and make improvements to the dust controls, if it appears that an overexposure will occur. The TEOM sensor is incorporated into a cap lamp housing, while the sampling inlet is mounted on the cap lamp light. Figure 6 presents a schematic identifying the key components of the PDM.

NIOSH completed extensive laboratory and in-mine testing of the PDM and found that the PDM dust measurements closely correlate with the CMDPSU (Volkwein et *al.,* 2006). PDM measurements are multiplied by 1.05 to be equivalent to dust concentrations measured with the CMDPSU (Page *et al*., 2008). A manufacturer is producing a commercial version of the PDM that is expected to be available by the summer of 2009.

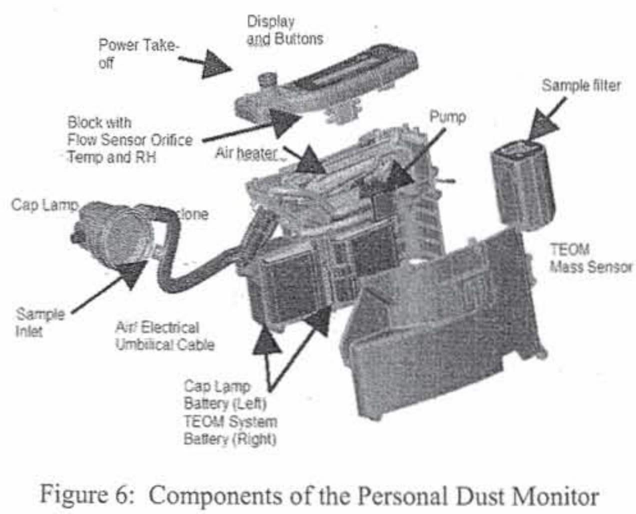


Figure 6: Components of the Personal Dust Monitor

8. DISCUSSION

Control technologies that maximize the potential to limit dust exposures to operators of continuous miners, roof bolters, and longwall operations were presented in this paper. Also discussed were emerging technologies and included a wet head miner, canopy air curtain and a person-wearable dust monitor that provides accurate real-time respirable dust concentration data to miners. However, this paper only touched upon a limited number of control technologies to reduce or eliminate harmful respirable dust. A more comprehensive discussion of dust control principles and possible solutions to respirable dust concerns is summarized in a NIOSH handbook (Kissell, 2003).

It is imperative that maintenance of these dust control technologies become a routine part of operating practices to realize their maximum potential. Mine managers must encourage mine workers to routinely inspect the control technologies and provide the mechanism to properly maintain the installed dust control equipment. An effective dust control program must contain an education and training component along with appropriate control technologies. Also, workers must be made aware of the potential health risks associated with breathing excess respirable dust and be encouraged to suggest possible solutions to dust concerns.

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