Effective Control of Respirable Dust in Underground Coal Mines in the United States

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ABSTRACT

The extraction and transport of coal from underground coal mines can result in significant liberation of coal and/or silica dust into the mine atmosphere. Mine operators have long used ventilating air as a primary means of diluting generated dust, removing dust from the working faces and preventing dust from reaching the miners' working environment. As production levels have increased, mine operators continue to be challenged in maintaining dust concentrations below compliance levels. The need for maximising the effectiveness of available ventilating air in conjunction with other effective controls, such as water sprays and dust collectors, continues to be critical to the long-term health of mine workers. The National Institute for Occupational Safety and Health (NIOSH) has conducted full-scale laboratory and mine-site research to evaluate improved application of dust controls for both longwall and continuous mining methods. A summary of recent research results and recommended practices will be provided.

INTRODUCTION

Exposure to excessive levels of respirable coal dust can lead to the development of coal workers' pneumoconiosis (CWP). Similarly, exposure to excessive levels of respirable silica dust can lead to silicosis. Both of these lung diseases can be disabling or fatal, depending upon the severity and duration of exposure. The Federal Coal Mine Health and Safety Act of 1969 (1969 Act) established respirable coal and silica dust exposure limits and instituted an x-ray surveillance program for underground coal miners. This voluntary program gives miners the opportunity to periodically participate in an x-ray surveillance program for detecting CWP. Figure 1 illustrates the prevalence of CWP found in underground coal miners participating in the first six rounds of this x-ray program (NIOSH, 2003). As illustrated, the percentage of miners with CWP increases as their years in mining increases. For the more experienced miners, the prevalence of CWP shows a marked decline since the passage of the 1969 Act. Established dust limits, improved dust control technologies, and greater awareness of the dangers of dust exposure have combined to produce these reduced rates, despite significant increases in average shift production over the same time period. Although these results are encouraging, the prevalence rate for examined workers with 25 years or more of experience was at 7.8 per cent in the last surveillance period. Chest radiographs collected between 1995 and 2002 under this x-ray surveillance program were combined with radiographs collected between 1999 and 2002 under a special Miners' Choice Program offered by the Mine Safety and Health Administration (MSHA). For the 6778 miners examined that had 25 years or more of underground coal mining experience, the prevalence of CWP was found to be 5.4 per cent (CDC, 2003).

Regulations in the 1969 Act limit respirable coal dust concentrations in underground US coal mines to a time-weighted average of 2 mg/m^3 over an eight-hour shift. Compliance with this regulation is monitored through the use of a personal gravimetric sampler that is periodically worn by miners in designated occupations. These compliance samples are collected by both mine operators and MSHA inspectors. MSHA also routinely analyses these compliance samples for silica content. If the per cent silica in a sample is greater than five per cent, then a reduced dust standard is calculated by dividing ten by the per cent silica. For example, if a sample contains ten per cent silica, then a reduced dust standard of 1 mg/m^3 (10 ÷ 10 per cent silica = 1) would be enforced on that mining unit.

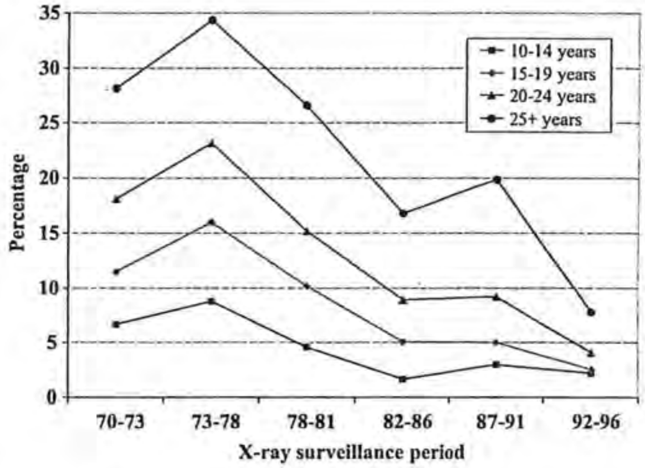

FIG 1 - Percentage of examined miners with CWP (category 1/0+) by years of experience in mining, 1970 - 1996.

Historically, compliance dust sampling results have indicated that the continuous miner operator and roof bolter operator are the high risk occupations on continuous mining sections. For longwall mining, the tailgate-side shearer operator and jack setters have historically been at greatest risk for overexposure. Compliance sampling results from 1996 through 2000 are provided in Figure 2 and show that a substantial portion of these samples are still exceeding allowable limits for these high-risk occupations. As a result, NIOSH dust control research is currently focused upon developing control technologies to protect these workers.

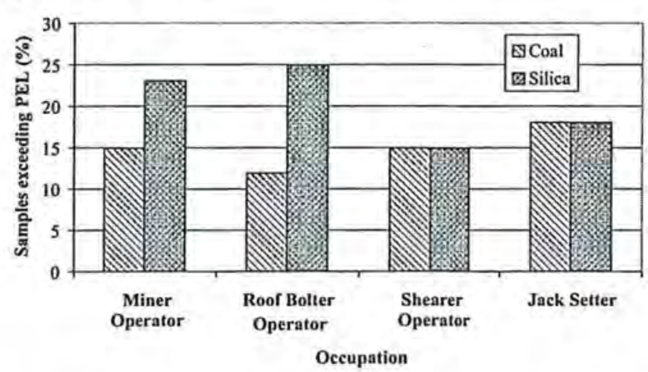

FIG 2 - Compliance samples exceeding PEL for high-risk occupations, 1996 - 2000.

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Ventilation and water are two primary controls that are utilised by mine operators throughout the US in an effort to control dust generation and worker exposure. To be most effective, these controls must be applied in an efficient manner so that they compliment one another. If these controls are improperly applied, the dust exposure of mine workers can be aggravated (Jankowski, Jayaraman and Babbitt, 1987). The Pittsburgh Research Laboratory (PRL) of NIOSH, formerly in the US Bureau of Mines, has conducted dust control research to develop controls that will minimise worker exposure to respirable coal and silica dust. Research continues in full-scale laboratories and at mine sites in an effort to develop control technologies to further reduce the dust exposure of mine workers.

CONTINUOUS MINER RESEARCH

Sprayfan and flooded-bed scrubber testing

A full-scale continuous miner gallery is available at PRL to conduct tests under controlled conditions. The gallery is equipped with the capability of releasing both dust and gas. To alleviate safety concerns, sulfur hexafluoride (SF_6) is used as a tracer gas for methane. This gas is tasteless, odourless, not found naturally in the atmosphere, and is non-toxic in the amounts used in this testing. It is also detectable in the parts per million (ppm) concentration level. Consequently, tests can be conducted to concurrently identify the impact on both dust and gas levels resulting from changes in ventilation and/or water spray parameters. The test facility simulated a cut 5.5 m wide, 2.0 m high, and up to 15.2 m deep. A full-scale mock-up of a continuous mining machine used for this testing featured a 0.9 m diameter cutting drum rotating at 50 rpm. The machine was positioned at the end of the box cut for testing. A coal slab measuring 2.4 m by 6.1 m remained to the right of the machine (Figure 3).

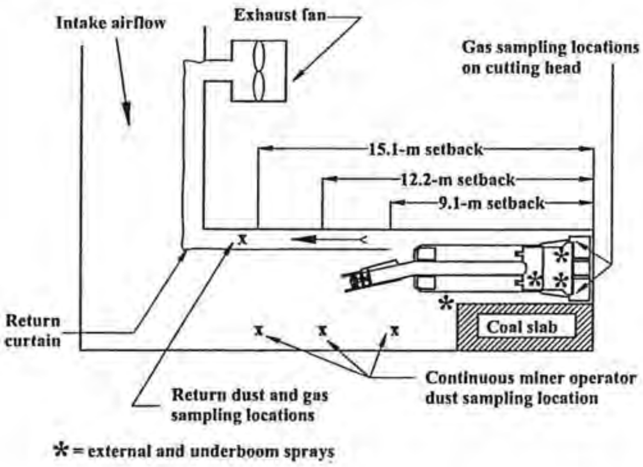

FIG 3 - Full-scale continuous miner gallery as configured for testing.

Tests were recently conducted in this gallery to compare the dust and gas control capabilities of a miner operated with either a sprayfan system or flooded bed scrubber. The sprayfan system was designed to utilise the air-moving capabilities of water sprays to sweep ventilating air across the face. The goal of this spray system was to promote mixing and turbulence to prevent the development of stagnant air zones where methane levels could rise. Unfortunately, past research has shown that this spray system may not be very effective for dust control (Colinet, Miller and Jankowski, 1994). The sprayfan was installed according to published specifications (Foster-Miller Inc, 1985) and featured 34 hollow cone spray nozzles positioned above and below the cutting boom and along the sides of the mining machine frame. The flooded-bed dust scrubber, rated at 3.3 m^3/s, used a 30-layer stainless steel filter screen. When testing with the scrubber, the mining machine used a standard water spray system consisting of twenty-four hollow cone sprays positioned above, below, and along the sides of the cutting head.

In practice, the sprayfan is used only with exhaust curtain face ventilation while the dust scrubber can be used with either a blowing or exhausting curtain arrangement. To reduce the number of tests, all evaluations used exhaust curtain ventilation which was created by drawing air via a main gallery fan through a brattice curtain positioned on the left side of the test gallery as shown in Figure 3.

Preliminary testing of the dust scrubber with the standard water spray system showed relatively high gas levels in the corner on the off-curtain side. To clear this area of gas, external spray manifolds were placed on the right side of the machine frame 2.4 m outby the hinge point of the cutting boom and on top of the cutting head at the hinge point (Figure 3). Each manifold consisted of two hollow cone sprays oriented to 'flush out' this corner of the face. These external manifolds were plumbed separately from the standard spray system to evaluate the effect of these added sprays on controlling respirable dust and face gas.

Two additional spray manifolds were placed under the cutting boom, each manifold consisting of three hollow cone sprays oriented toward the cutting drum. These underboom manifolds also were plumbed separately to assess their effects on dust and gas levels.

For dust sampling, constant flow pumps pulled dust-laden air through 10 mm Dorr-Oliver nylon cyclone separators at a rate of 2 L/min. The respirable mass was deposited onto pre-weighed 37 mm filters that were subsequently post-weighed to determine dust levels. A pair of gravimetric samplers placed on the off-curtain (right) side of the entry, opposite the mouth of the exhaust curtain, represented the typical location of the remote mining machine operator. This location moved with curtain setback distance. Two gravimetric samplers placed in the return monitored dust levels in that location.

Testing also evaluated the impact of face airflow quantity, water spray pressure, and setback distance on the removal and dilution of hazardous gas concentrations. As indicated, sulfur hexafluoride (SF_6) was used as a tracer gas. This gas was introduced at the cutting drum, where the drum rotation mixed the gas with the face airflow. A mixture of SF_6 in air (>99 per cent pure) was introduced at the cutting drum at 6 ml/s and measured real-time with a multipoint doser and sampler (California Analytical Instruments, Orange, CA). Gas was sampled at locations representing typical methanometer locations on a continuous mining machine – on the left and right sides of the cutting head approximately 0.6 m outby the cutting drum. For each test, gas was introduced into the gallery in a series of four evenly spaced pulses, each pulse lasting 12 minutes.

When testing the sprayfan, a single exhaust curtain quantity of 2.8 m^3/sec was used. Curtain setback distances were 9.1 m or 15.2 m, while water spray pressure values were 483 kPa or 1.31 MPa, measured in the line feeding the spray manifold. Measured water flow rates at low and high pressures were 76.9 L/m and 125.1 L/m, respectively.

When testing the dust scrubber, only a single curtain flow of 3.8 m^3/s was used. This ensured that the face ventilation quantity exceeded the rated capacity of the dust scrubber (3.3 m^3/s), which is typically required by MSHA. Quantities less than this were not considered, as they could lead to potential recirculation of dust and gas at the face. Curtain setback distance was either

9.1 m or 12.2 m, as physical constraints did not permit testing of the scrubber at a distance of 15.2 m. Water pressures were set at either 621 kPa or 1172 kPa. Testing with the flooded-bed scrubber evaluated the impacts of setback distance and spray pressure for the single-curtain airflow quantity. These tests also determined the effects of the external 'flushing' sprays and the underboom sprays.

The dust concentration at each sampling location was calculated using the numerical average of the concentrations for each group of samplers. The tracer gas concentration at each location was the average of the concentrations recorded for each pulse. Respirable dust and tracer gas concentrations for each series of test conditions were calculated using the average concentration for each test making up that set of conditions.

Changes in water pressure and setback distance significantly impacted miner operator dust levels when using the sprayfan. Increasing water spray pressure adversely affected exposures by increasing dust rollback levels. Increasing curtain setback distance reduced dust exposure by removing the operator from the high dust region surrounding the machine. Return dust levels varied with changes in water pressure and setback distance, although the changes were not statistically significant.

With the scrubber operating, miner operator dust levels increased with setback distance. The external sprays significantly increased dust levels, implying that these sprays may have pushed the dust cloud beyond reach of the scrubber inlets. This same mechanism also led to higher dust levels in the return airway. The underboom sprays produced insignificant changes at both sampling locations.

When the sprayfan was used, water pressure affected tracer gas levels around the cutting head. An increase in water pressure produced slight increases in tracer gas on the off-curtain side and larger reductions on the curtain side. Increasing curtain setback distance adversely affected gas levels by reducing dilution airflow to the face.

Increasing water pressure with the dust scrubber reduced gas levels on the off-curtain side of the cutting head. The greatest impact occurred with the use of external sprays. The underboom sprays increased gas in the off-curtain area by reducing airflow on this side of the cutting head. On the curtain side of the cutter head, increasing water pressure also elevated gas levels by reducing airflow to this area. A similar mechanism likely caused an increase in gas levels with the use of the external or underboom sprays.

Across the range of parameters that were tested, the scrubber was more effective than the sprayfan in controlling respirable dust concentrations at the miner operator and in the return. With the scrubber, operator dust levels did vary slightly with changes in setback distance and water pressure, although none of the levels ever exceeded 0.3 mg/m^3. In contrast, operator dust levels with the sprayfan ranged from a low of 0.2 mg/m^3 to a maximum of 1.3 mg/m^3. Similarly, return dust levels with the scrubber varied between 0.4 and 2.3 mg/m^3, while return dust levels with the spray fan were between 3.0 and 7.9 mg/m^3. Obviously, the lower return dust levels with the scrubber would offer much lower dust exposures for workers when working downwind of the mining machine.

The sprayfan was more effective than the scrubber in reducing gas levels on the off-curtain side of the cutting head. At the shortest setback distance, the scrubber plus external sprays approached the effectiveness of the sprayfan for removing gas from this area. This same spray configuration at the lowest water pressure was more effective than the sprayfan at limiting curtain-side gas levels. A detailed summary of measured dust and gas levels for all test conditions was recently published (Goodman, Pollock and Beck, 2004).

Wet-head miner

The application of a wet-head spray system with sprays in the cutting drum of a continuous miner, similar to shearer drum sprays, has been pursued over many years. The problem that has hindered the implementation of this concept has been the development of a dependable seal that reliably isolates the spray water in the cutter drum. A new seal has been offered by a miner manufacturer and mines in the US are exhibiting interest in these machines. NIOSH has recently performed an evaluation of one of these miners. The wet head miner was equipped with 73 water sprays, with each spray located behind a cutting bit. The spray nozzles provided a solid jet of water with a rated flow rate of 1.1 L/min at 689.5 kPa. To minimise spray clogging, the miner was equipped with two in-line water filters. When the wet head sprays were operated in conjunction with the required cooling water sprays, the total water usage of the miner was approximately 189 L/min. For the evaluation of the wet-head miner, NIOSH conducted sampling under three operating conditions: traditional external spray system with flooded bed scrubber, wet-head sprays with flooded bed scrubber, and wet-head sprays without the flooded bed scrubber. Data from these tests are currently being analysed and prepared for publication.

ROOF BOLTER RESEARCH

Canopy air curtain

Previous research has shown that significant dust exposure for roof bolter operators can occur when the bolter has to work downwind of the continuous miner (Organiscak, Page and Jankowski, 1990). In this position, dust generated by the miner is carried to the bolter. In an effort to protect the bolter operators, a canopy air curtain (CAC) was designed and tested. The air curtain is designed to be mounted on the underside of the canopy above the roof bolter's operator station. This air curtain is connected to a filter and blower mounted on the bolter. A portion of the air coming into the face is filtered and the clean air is blown into the canopy air curtain. Air enters this device at one side of the frame and passes along an intake plenum and through honeycomb flow straighteners before exiting through a perforated steel plate, which more uniformly disperses the air down over the bolter operator.

A series of tests was conducted in the laboratory to evaluate the performance of the CAC under different operating conditions (Goodman and Organiscak, 2001). A 432 mm square CAC was mounted to a wooden frame at a distance of approximately 1.8 m above the floor. Changes in entry air velocity and blower capacity were evaluated by placing gravimetric dust samplers under the curtain and in several areas around the air curtain. Entry air velocities ranging from 0.32 m/s to 0.64 m/s were tested along with CAC air flows ranging from 0.094 m^3/s to 0.283 m^3/s. Dust was released into the air stream upwind of this location to contaminate the entry. Comparisons between dust levels under and around the air curtain were used to determine the effectiveness for dust control. Results of these tests indicated that the air curtain performance was impacted by the mean entry air velocity and the distance below the curtain. As mean entry air velocity increased and the sampling distance below the curtain was increased, the relative dust reduction decreased. These results illustrated that the CAC had the potential to reduce dust levels under the curtain by approximately 60 per cent. This reduction was measured with mean entry air velocity of 0.32 m/s and at a distance of 305 mm below the air curtain. When the entry air velocity was increased to 0.64 m/s, the dust reduction under the curtain dropped to 25 per cent. Lower entry air velocities are however, typically found in roof bolter entries in the US.

After completion of the lab tests, an underground evaluation at a producing mine was conducted. The underground installation on a bolter is shown in Figure 4. The CAC used for this testing had to be shortened in width by 178 mm to better fit under the canopy. Dust sampling results from this survey are being analysed. Subjective results from this testing illustrate however, the potential of this technology. The roof bolter operator had favourable comments regarding the use of the CAC and the bolter manufacturer has expressed an interest in pursuing further development of this technology.

FIG 4 - Canopy air curtain being tested on a roof bolter.

It was apparent from this first evaluation that improvements in performance could be achieved, if modifications to the installation of the system can be adopted. These modifications would include utilising a bolter canopy that would facilitate installation of a full-size CAC and installing the filter and blower on the bolter closer to the drill operator's station to shorten the length of tubing needed to supply the CAC. The roof bolter manufacturer has expressed an interest in continuing this cooperative research effort, with the goal of developing a system that can be commercialised.

Mist drilling

Previous research on roof bolters has shown that wet drilling can be an effective method to control dust during drilling. In these systems, water flow rates varying from 7.6 to 22.7 L/min were utilised however. These flow rates led to operational problems and discomfort for the drill operators from getting wet. Recently, a new wet drilling system has seen introduction in the US mines. This 'mist drilling' system injects small amounts of water, approximately 1.9 L/min, into a compressed air stream that is blown into the drill hole. NIOSH has conducted an underground evaluation of this new control technique. Results of this testing will be reported in the near future.

LONGWALL RESEARCH

Longwall mining has undergone significant changes over the past 20 years. Face dimensions have been greatly increased, equipment reliability has significantly improved, and shearer power has dramatically increased. These factors have resulted in significant increases in production. MSHA data from compliance sampling results show that average production has increased from 890 tons per shift in 1980 to 5200 tons per shift in 2000 (Niewiadomski, 2003). These changes have challenged longwall operators to implement dust control technologies that are capable of controlling dust levels in spite of this five-fold increase in production.

Benchmarking surveys

NIOSH is currently conducting a series of surveys at longwall faces throughout the US in an effort to quantify dust generation from the major sources on longwall faces and identify the state-of-the-art of dust control technology. During these surveys, NIOSH personnel utilise gravimetric and instantaneous dust samplers with mobile and stationary sampling to isolate dust generation from major sources. This sampling also provides an indication of the relative effectiveness of the control technologies being used. Similar surveys were conducted by the USBM in the 1980s and 1990s (Colinet, Spencer and Jankowski, 1997). Results from these surveys indicated that the shearer, on average, accounted for approximately 50 per cent of the dust generation on the longwall faces surveyed. In the 1980s, dust from the stageloader/crusher and shields were the second and third highest sources. Emphasis was placed upon controlling dust from the stageloader through the addition of spray manifolds, enclosing the stageloader with physical barriers, and installation of fan-powered dust collectors. As a result, lower stageloader dust levels were observed in the 1990 surveys and dust from shield advance became the second highest source.

To date, NIOSH has completed evaluations of six longwalls operating in four different states. As anticipated, preliminary results from these surveys show that airflows and water flows higher than those reported in the 1990s are being applied in an effort to control dust levels. Air velocities up to 5.1 m/s and shearer water quantities up to 570 L/min have been measured in these surveys. In addition, mine operators are also placing greater emphasis on worker positioning and utilising automation to remove workers from zones of high dust concentration. All of the longwalls surveyed to date are utilising bidirectional cutting sequences and shearer activation of shield advance. The shields are being advanced within five shields of the trailing shearer drum. In the tail-to-head cutting direction, this allows the jack setters to remain within a few shields of the shearer and benefit from the protection afforded by the directional spray systems that have been observed on all of the shearers sampled in the survey.

Shield dust entrainment

As mentioned, the longwalls in these surveys are utilising bidirectional cutting with shield advance relatively close to the shearer. In the head-to-tail cutting direction, this practice places shield advance directly upwind of the shearer operators. As stated, longwall operators have also increased the amount of air being supplied to the longwall face with reported air velocities as high as 8 m/s on some faces. When these factors are combined, the potential for increased dust entrainment from shield advance has been raised by mine operators. This can lead to increased dust exposure for the shearer operators. Figure 5 shows the dust levels measured with an instantaneous, light-scattering dust sampler during one of the longwall dust surveys. As shown, dust levels at the shearer midpoint are much higher in the head-to-tail cutting direction when compared to the tail-to-head cutting direction. This increase in dust exposure is attributed to dust liberated during shield advance. Consequently, NIOSH has conducted a series of tests in a wind tunnel to evaluate dust entrainment from shield advance as air velocities are increased.

Tests were conducted in a wind tunnel at air velocities ranging from 2.1 to 10.2 m/s in 2.0 m/s increments. Figure 6 illustrates the wind tunnel as utilised for these tests. As shown, dust is dropped into the tunnel from above to simulate dust dropping off of shield canopies as the shields are advanced. Initial tests were conducted with a mixture of processed coal with a 6.35 mm top size along with a commercial coal product that is -50 microns in size. This mixture was used to simulate the respirable and oversize material that is found on top of shield canopies. Sampling was conducted with Marple personal impactors

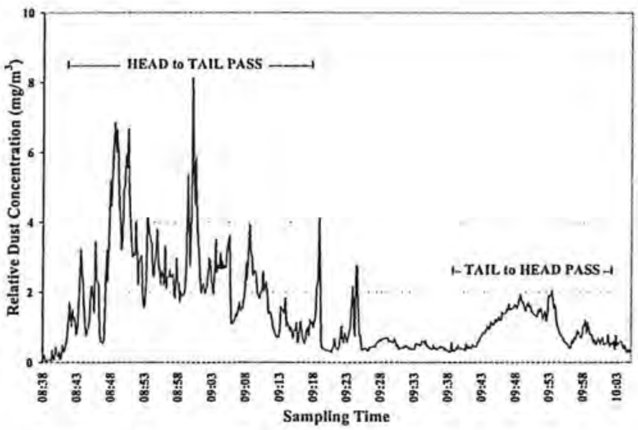

FIG 5 - Dust profile at shearer midpoint during cutting passes in each direction.

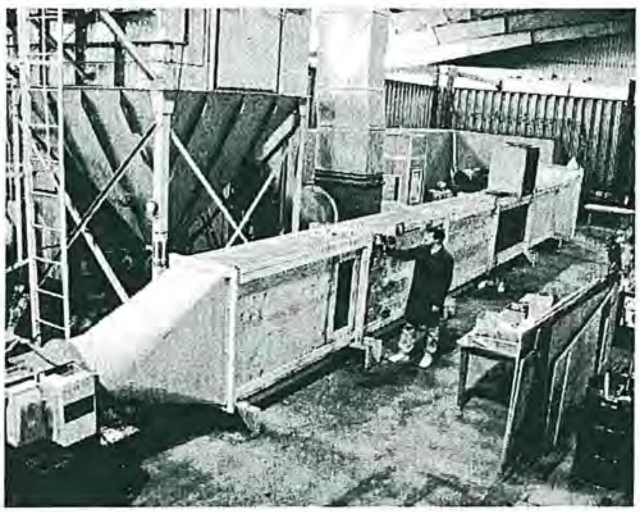

FIG 6 - Conducting entrainment tests in wind tunnel.

operated at 2 L/min in order to obtain data on the size distribution of the airborne dust. Isokinetic sampling was used for three samplers spaced evenly between the roof and floor of the tunnel. An average concentration for each test was calculated from these three samplers to eliminate bias from dust gradients that may have changed as velocities in the tunnel were changed.

The first series of tests showed that as air velocity was increased, both the total dust and the respirable fraction of the dust significantly increased (Listak, Chekan and Colinet, 2001). Figure 7 shows the trend of increasing dust levels as velocity increased and indicates that entrainment effects were greater than dilution effects. This graph also shows the amount of respirable dust at each velocity as a percentage of the total airborne dust. As the air velocity increased, the per cent of airborne respirable dust also increased.

After reviewing these results, it was suspected that the quantity of respirable dust utilised in the feed material may be saturating the air within the wind tunnel. Consequently, a second series of tests was completed in which the per cent of respirable dust in the feed material was systematically reduced. Once again, respirable dust levels continued to increase with corresponding increases in air velocity. The results from these two series of tests suggested that increased air velocities were able to free respirable dust particles that were agglomerated to one another or with oversize particles.

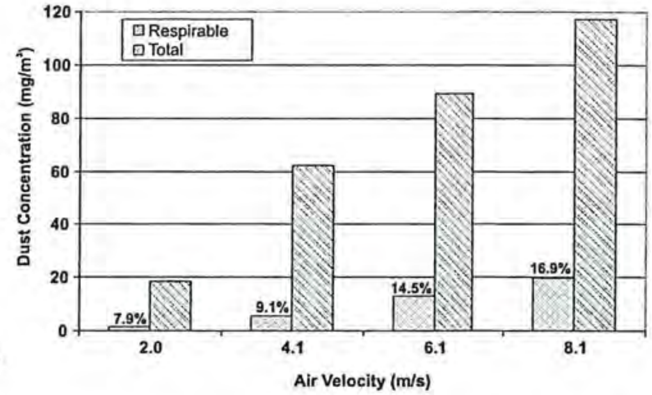

FIG 7 - Increase in respirable and total airborne dust as velocity increases.

In an attempt to evaluate this hypothesis, only the -50 micron dust was used for a series of tests and was injected into the wind tunnel through an eductor. Compressed air was blown through the eductor which is designed with a venturi section. As the air accelerates through the venturi, the dust is dropped into the airstream. Consequently, agglomerated particles are exposed to high air velocities and likely separated prior to entering the wind tunnel. Another series of tests was conducted with this injection system. Samples containing only respirable coal dust were collected with BGI GK2.69 cyclones at a flow rate of 4.2 L/min. Results of these tests showed that dilution did occur as air velocity in the wind tunnel was increased (Chekan, Listak and Colinet, 2004). These tests were completed however, as the weather conditions changed from summer to winter. Relative humidity was recorded during each test and a nearly two to one ratio in humidity was observed. Dust results indicated that this change in humidity resulted in a shift in airborne dust levels. Figure 8 shows that similar trends in dust levels were observed regardless of humidity levels; however, with the higher humidity, higher dust levels were measured.

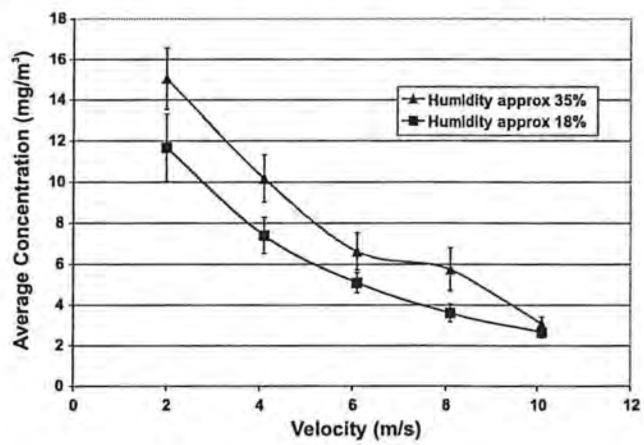

FIG 8 - Impact of air velocity and humidity on respirable dust levels.

Past research has suggested that increased moisture can reduce the static charge attraction between particles and result in higher levels of airborne dust (Page, 2000). Page's research also suggested that the critical moisture level can vary depending upon the coal itself. Additional research will be conducted in the wind tunnel to further evaluate the impact of moisture content on dust liberation in an effort to use this information to develop controls to reduce dust liberation during shield advance.

Longwall dust gallery

A full-scale longwall test gallery is available to simulate a 38.1 m length of a longwall face. As with the continuous miner gallery, air flow, water flow, water pressure, spray system design, mining height, and cutting direction can be varied to determine their impact on respirable dust levels. Figure 9 shows testing being conducted in the longwall gallery. Real-time dust samplers are used to monitor dust levels and can be observed on a computer in the control room during the test. Typically, dust sampling is conducted at a series of locations along the face to develop a profile of dust levels around and downwind of the shearer. Past testing has been conducted to evaluate the impact of changing control parameters for two different spray system designs (Rider, Colinet and Prokop, 2002). These tests showed that increases in air quantity resulted in the greatest dust reductions. Also, it was found that if external shearer sprays are not properly oriented, airborne dust was more quickly forced into the walkway and into the breathing zone of face workers as water pressure was increased.

FIG 9 - Testing in full-scale longwall dust gallery.

Upgrades to the shearer water supply system, the dust injection system, and the external shearer sprays were recently completed. A series of tests to evaluate the effectiveness of external spray systems with a mining height of 3.2 m were recently initiated. Previous research on external spray systems had focused upon mining heights of approximately 2 m. As mining height increases, the difficulty of confining and controlling airborne dust also increases. Results of this planned testing should provide longwall operators in the western US with guidance for improving dust levels around the shearer.

SUMMARY

NIOSH utilises compliance sampling results and stakeholder input to identify areas needing dust control research to address occupations at the highest risk. NIOSH has conducted research to evaluate the application of ventilating air in conjunction with water sprays to improve dust control for workers on continuous and longwall mining sections. This research has resulted in: the identification of operating guidelines for controlling dust and gas with a spray fan system on a miner, the development of a canopy air curtain for implementation on a roof bolter, benchmarking control technologies being utilised on longwalls across the United States, and defining the relationship between dust entrainment and high velocity airstreams. In addition, NIOSH has recently completed evaluations to quantify the dust reduction potential of wet-head continuous miner technology and mist drilling for roof bolters. NIOSH is also initiating laboratory research to improve the application of external spray systems for shearers operating in higher coal seams. NIOSH will continue to conduct research to identify and develop dust control technologies that will improve working conditions for miners by reducing respirable dust levels.

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