

Respirable dust control technology utilised in underground coal mines in the United States

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Significant improvements in production from longwall and continuous mining operations have occurred in the underground coal mining industry in the United States (U.S.) over the past fifteen years. For longwall operations, increases in panel size and equipment power, improved equipment reliability, and improved operating practices have contributed to a four-fold increase in average shift production. Similar improvements in continuous miner capabilities and the utilization of extended-cut mining procedures have allowed production from continuous mining sections to approximately double over this time period. Unfortunately, as more coal is mined, greater quantities of respirable dust can be generated and the potential for worker overexposure to harmful levels of coal dust increases. In addition, as rock partings in the coal seam or rock surrounding the coal is cut, the generation of respirable silica dust becomes a health concern for miners. A substantial number of continuous miner sections continue to experience difficulty with controlling silica dust generation.

The Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health (NIOSH) is responsible for conducting respirable dust control research for the U.S. coal mining industry. An overview of current dust control practices for longwall and continuous mining operations in the U.S. will be presented. Information regarding face ventilation practices and water spray application for longwalls, ventilation and dust control practices for extended-cut continuous miner operations, silica dust collection for flooded-bed scrubber dust collectors, and a summary of ongoing NIOSH dust control research for underground coal mining will be provided.

INTRODUCTION

Prolonged exposure to excessive levels of respirable coal dust can lead to the development of Coal Workers' Pneumoconiosis, a debilitating lung disease. Similarly, inhalation of excessive levels of respirable silica dust can lead to the development of silicosis, a potentially fatal lung disease. In an effort to prevent the development of these lung diseases in mine workers, Federal regulations (U.S. Congress 1969) were passed that limit personal dust exposure to a time-weighted-average concentration of $2\text{mg}/\text{m}^3$ over an 8-hour shift. Federal mine inspectors from the Mine Safety and Health Administration (MSHA) collect dust samples on multiple occupations at each operating section to identify the occupation of highest dust exposure, which is then classified as the designated occupation (DO). MSHA inspectors and mine operators are then required to periodically sample the DO to monitor compliance with the $2\text{mg}/\text{m}^3$ dust standard. Gravimetric samples are also analyzed for silica content and if the quantity of silica in a sample exceeds 5 per cent, the $2\text{mg}/\text{m}^3$ standard is reduced. The reduced dust standard is computed by dividing 10 by the percent silica. For example, if a sample contains 10% silica, the reduced dust standard becomes $1\text{mg}/\text{m}^3$ [$10/(10\% \text{ silica})$]. The dust exposure of the DO must then be maintained at or below the reduced dust standard.

Historically, longwall mining operations have had difficulty in maintaining compliance with the respirable dust standard. In the early 1980s, 31% of all DO dust

samples collected by MSHA inspectors (Niewiadomski & Jankowski 1993) exceeded the permissible exposure limit (PEL). Since this time, average shift production and productivity for longwall units in the U.S. have dramatically improved to the point where longwall mines now account for approximately 50% of the coal produced underground in the U.S. Average shift production for longwalls has increased from 890 metric tons per shift in 1980 to 3,544 tons per shift in 1995. Despite this substantial increase in production, MSHA dust sampling results for fiscal year 1995 show that 19% of DO samples exceeded the PEL (Niewiadomski 1996). Improved dust control and operating practices have allowed U.S. longwall operations to dramatically increase production and at the same time, reduce the number of dust samples that exceeded compliance levels. In the early to mid 1990s, NIOSH conducted dust surveys on 13 longwall operations throughout the U.S. to identify the types of control technologies being used and assess areas of future need. A summary of U.S. longwall control technologies will be discussed, along with a discussion of current NIOSH research and potential areas of future research.

Historically, continuous miner operations in the U.S. have extracted 6.1 metre (20 feet) deep cuts in an entry before moving out of the cut to allow roof bolting to take place. More recently, continuous miner operations have been approved to extract extended cuts up to 12.2m deep (40 feet). Utilization of these extended-cuts increases the time available for mining by minimizing the number of entry changes that need made during any

given shift, thereby improving production potential. As a result, over 50% of continuous miner operations in the U.S. have applied for and received approval to utilize extended-cut mining. However, each operation, on a case-by-case basis, must demonstrate to MSHA that roof integrity, methane levels, and dust levels can be successfully controlled at the extended-cut depth.

The most popular means of ventilating the face and controlling dust levels in extended-cut operations is through the utilization of blowing face ventilation and a flooded-bed scrubber on the continuous miner. Flooded-bed scrubbers are fan-powered dust collectors that draw dust laden air from near the cutting heads into the scrubber, which utilizes a wetted filter and mist eliminator to remove dust from the airstream. The "cleaned" air is then discharged back into the mine environment. Research conducted by NIOSH has indicated that flooded-bed scrubbers can remove over 90% of the respirable coal and silica dust drawn into the unit. However, over the last several years, the density of the filter media utilized in flooded-bed scrubbers has been reduced by as much as 75% to improve the air-moving capacity of flooded-bed scrubbers. Unfortunately, the impact on respirable dust collection, particularly silica dust, was not known. NIOSH conducted laboratory evaluations to identify the respirable silica collection efficiency of these reduced density filter panels and found significant differences in performance. Results of this research and insight into silica research for continuous miner operations will be discussed.

LONGWALL DUST CONTROL TECHNOLOGY

A series of dust surveys was conducted from the early to mid 1990s on 13 longwall operations located throughout the U.S. to quantify the levels of dust generated by the major sources on each longwall and to identify the control technology being utilized. Sampling results from these surveys were used to calculate average dust generation from major sources with results presented in Figure 1. As shown, the shearer remains the largest source of dust generation and accounts for

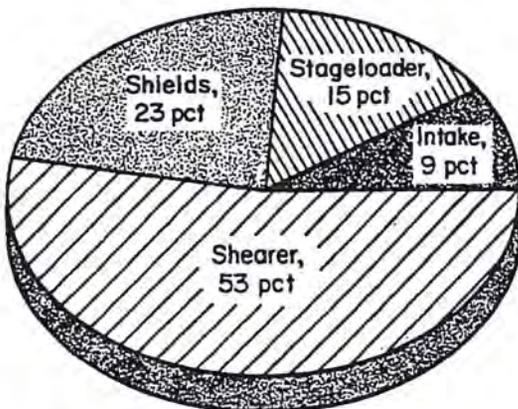


Figure 1 Dust contributions from major sources on longwall faces.

over half of the dust generated on the longwall section. Significant levels of dust were also generated by shield movement and the stageloader/crusher. Data from these surveys also showed that ventilation, physical barriers, and water sprays are the primary means used on U.S. longwalls to control dust from these sources.

Ventilating air supplied to the longwall face is important in that the air dilutes dust as it generated and also carries dust away from personnel required to work near major dust sources. All mines in the survey were ventilating from the headgate to tailgate. The average air velocity calculated from spot velocity measurements taken along the longwall faces was 2.5m/s (500fpm), with measured values ranging from 1.0 to 7.6m/s (200 to 1500fpm). The average velocity on the faces of the surveyed longwalls represents an increase of over 0.5m/s (100fpm) when compared to the average air velocity data reported in a 1983 USBM study (Jankowski & Organiscak 1984). Utilizing a rough estimate of the area under the shields for each face, an average air quantity of 19.2m³/s (40,700cfm) was calculated. Figure 2 illustrates the average quantity of air measured on each longwall, with the maximum air quantity of 50.0m³/s (106,000cfm) found at Mine A. It should be noted that Mine A was utilizing such a large quantity of air because of high methane liberation rates on the longwall face. This data illustrates a wide range of application but on average, U.S. longwall operators are supplying more air to longwall faces than ever before.

One method used to improve the airflow on the face was the installation of a gob curtain at the headgate, Figure 3. The gob curtain is hung between the first shield and the pillar rib to reduce air loss into the gob and increase the amount of air flowing down the face (U.S. Bureau of Mines 1981). Ten of the 13 mines in the survey were using gob curtains at the headgate. Several of these mines also extended curtain along the back of the first five to ten shields to further minimize air loss into the gob.

Six of the longwalls were utilizing the belt entry to bring intake air to the longwall face. In these operations, the dust liberated in the belt entry would be carried to

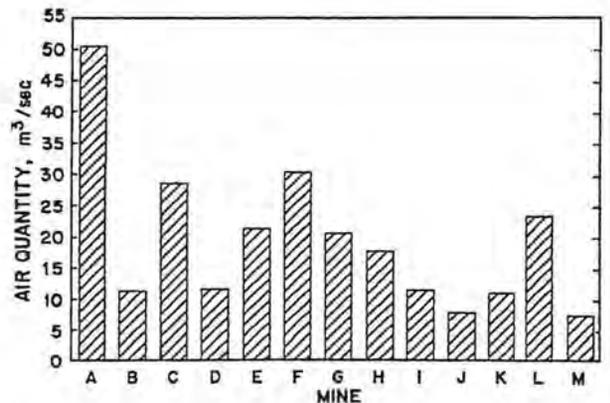


Figure 2 Air quantities found on U.S. longwall faces.

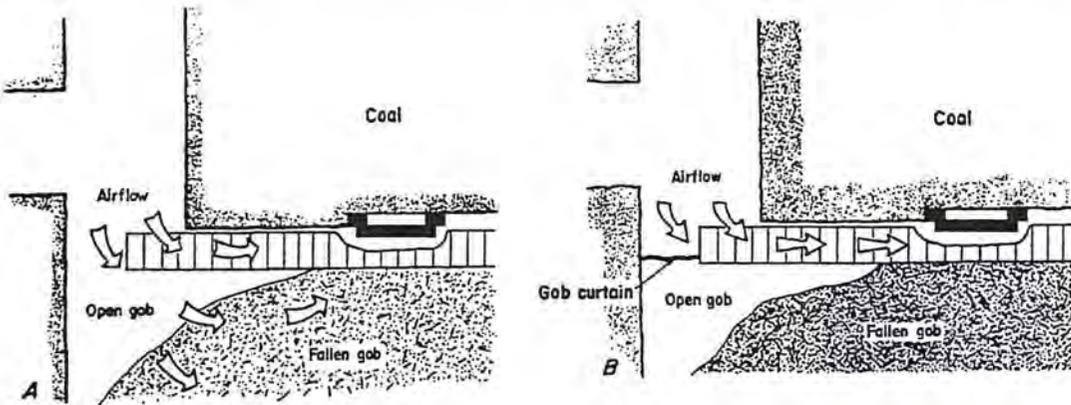


Figure 3 Gob curtain utilized to increase airflow down the longwall face.

the face. For the six longwalls utilizing belt air, the average dust level in the belt entry just outby the stageloader was found to be $0.6\text{mg}/\text{m}^3$, while the average concentration in the main intake entry for these mines was $0.5\text{mg}/\text{m}^3$. On average, the belt entry has the potential to add to face dust levels. However, this increase in intake dust levels appears to be negated by the potential for increased dilution that can be obtained with additional air brought up the belt entry (Potts & Jankowski 1992). The average air quantity found on the face for the mines utilizing belt air was $26.0\text{m}^3/\text{s}$ (55,000cfm). For the other seven mines, the average air quantity on the face was $13.2\text{m}^3/\text{s}$ (28,000cfm). At the mines utilizing the belt entry as an intake, the additional quantity of air available on the face would negate the average $0.1\text{mg}/\text{m}^3$ increase in dust generated in the belt entries.

The impact of ventilating air on face dust levels was evaluated by comparing dust levels measured approximately 15.2m (50 feet) downwind of the shearer as the shearer was cutting across the face to the average quantity of air measured on each face. When bi-

directional cutting was utilized at a mine, time study data was used to calculate a weighted downwind concentration. For example, if the head-to-tail cut took 60% of the time required to make a complete pass across the face, then the average dust level from the head-to-tail pass would receive a 60% weighting while the tail-to-head dust level would receive a 40% weighting. Regression analysis was completed using a number of models and the multiplicative model provided the best fit to the data. Figure 4 shows the plot of face air quantity and corresponding downwind dust level for each mine. The fitted line generated with the multiplicative model and the resulting equation are also provided on the graph. This model resulted in an R-squared value of 0.50, which indicates that changes in face air quantity account for approximately half of the variation observed in downwind dust levels. Considering the vast differences in mining conditions and dust control systems between each mine surveyed, an R-squared of 0.50 represents a substantial impact for one parameter and highlights the importance of ventilation on longwall faces for dust control.

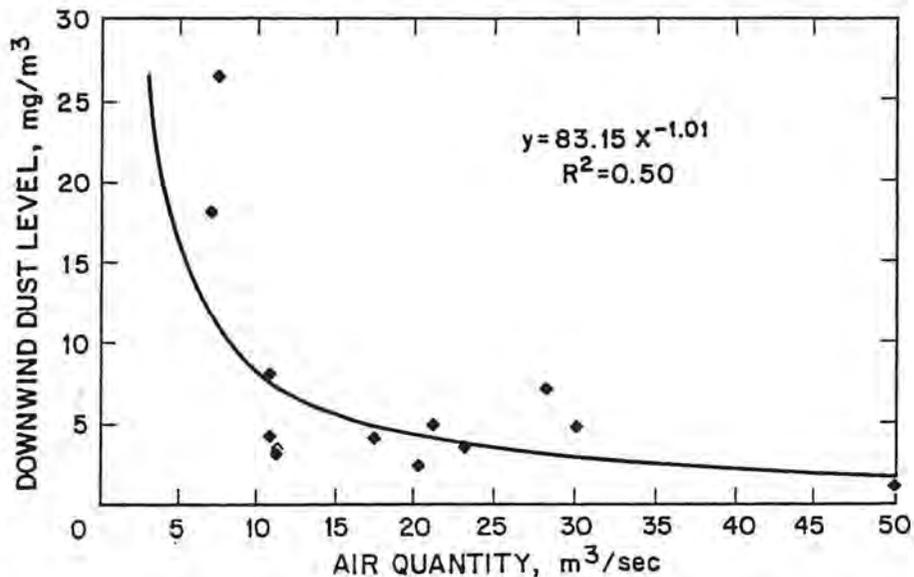


Figure 4 Relationship between airflow and dust levels downwind of shearer.

In addition to ventilating air, all longwalls were applying large quantities of spray water at the shearer in an effort to minimize the quantity of respirable dust that is liberated and prevent the dust from reaching the breathing zone of face workers. Total water application at the shearer showed an average increase of approximately 67% above water application levels observed in the mid 1980s. The majority of this water is being supplied through water sprays installed on the cutting drums. Past research (U.S. Bureau of Mines 1986) has indicated that the water applied through the cutting drums should be supplied at nozzle operating pressures that are at 689kPa (100psi) or less. If higher pressures are used, the water sprays tend to force air and dust out into the walkway and increase operator exposure. Most of the longwalls visited during these surveys were operating with drum spray pressures above 689kPa (100psi) with one mine operating at 2068kPa (300psi). It was suggested to these operations that the pressure at the drum sprays be lowered by utilizing nozzles with larger orifices. This would effectively reduce operating pressure but would not reduce the wetting capabilities of the sprays.

In addition to drum sprays, all shearers were equipped with a shearer-clearer external spray system. The objective of this external spray system is to direct dust generated by the shearer drums toward the face and keep the dust confined near the face until it passes downwind of the shearer operators, Figure 5. These shearer-clearer sprays are oriented with the face airflow and should be operated at approximately 1034kPa (150psi) in an effort to move a portion of the air toward the face. A clean air split then passes over the shearer operators. A steel splitter arm, extending from the shearer body over the face conveyor, is used to help divide the air near the headgate drum. Sprays are mounted on the splitter arm and conveyor belting is hung vertically from the arm to assist in splitting the ventilating air.

Shield movement and the stageloader/crusher units can also generate substantial quantities of dust. With the higher production levels found on today's longwalls, the need to advance a larger number of shields during a given shift has increased and thus increased the poten-

tial dust exposure from this source. Similarly, with more coal and rock being processed through the stageloader and crusher during a given shift, the quantity of dust liberated at this source can also be significant. On average, shield advance accounts for 23% of the dust-generation, while the stage loader/ crusher contributed nearly 15%. The contribution from these sources on today's longwalls represent a reversal from what was observed for the stageloader and shield dust sources in the early 1980s. Dust contribution from the stageloader has been reduced by approximately 50%, while dust generation from shield movement has nearly doubled. This reversal indicates that improvements in stageloader dust control have been realized in that dust contributions have been lowered even though higher tonnages are being processed. Conversely, dust generated from shield movement appears to be adding to face dust levels and no control technology for shields have been successfully applied to abate the dust generated by the increase in the number of shields being moved.

The keys to successful control of dust in the stageloader/crusher is to ensure that the units are totally enclosed and that water is applied in an appropriate manner (U.S. Bureau of Mines 1985b). The units were enclosed with a variety of material ranging from line brattice to conveyor belting to steel plate. The units need to be enclosed along the entire length of the stageloader and also at the inlet to the crusher and the stageloader-to-section-belt discharge. Typically, a section of conveyor belting is hung at the crusher inlet to prevent ventilating air from flowing through the unit.

In addition, all units were equipped with spray manifolds designed to wet the material and reduce the quantity of dust liberated from the crushing/transport operations. The key to the water application is that quantity is more important than pressure. The goal is to wet the broken coal and/or rock to prevent respirable dust from becoming airborne. Also, the stageloader/crusher has been enclosed in an effort to separate dust generated from this operation from the ventilating air traveling to the longwall face. If high operating pressures are utilized on the water sprays, the high pressure tends to force dust out of the enclosed stageloader/crusher where it can be entrained in the

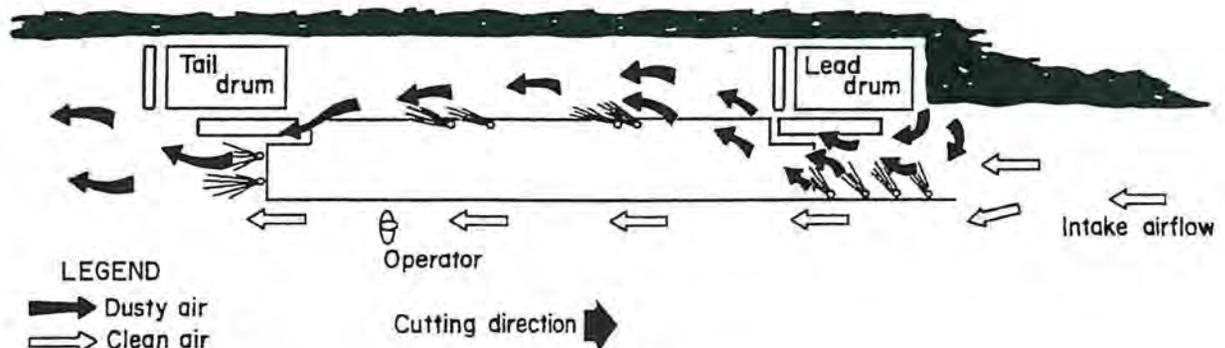


Figure 5 Shearer clearer water spray system confines dust near face.

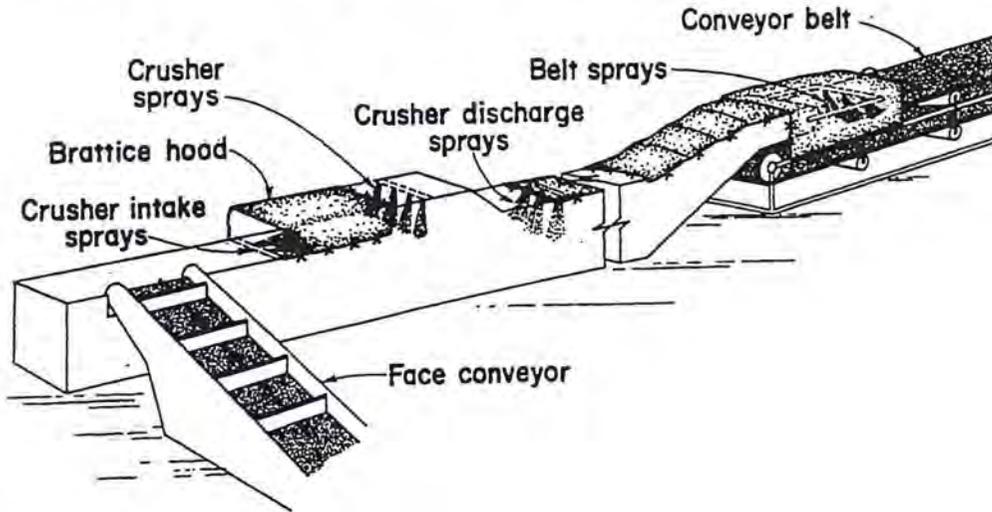


Figure 6 Dust controls applied at the stageloader/crusher.

ventilating air. Therefore, water sprays located throughout the stageloader/crusher and operated at pressures less than 483kPa (70psi) are desired. Figure 6 illustrates the principles that were just presented.

In addition to enclosing the stageloader/crusher and installing water sprays, a few longwalls had installed either a fan-powered or water-powered scrubber at the crusher. These units were utilized to improve the dust capture at the crusher and discharge "clean" air back into the mine environment. With the use of these scrubbers, a negative pressure zone is created within the stageloader/crusher which reduces the chance of respirable dust from leaking out of these units.

Mobile dust sampling was conducted upwind of the shearer so that shield generated dust could be isolated from dust liberated by the shearer. In two mines, shields were advanced downwind of the shearer during the tail-to-head pass so that no shield dust measurements were made at these mines. Average dust generation attributed to shield movement was found to be $1.5\text{mg}/\text{m}^3$. A regression analysis was completed to evaluate the relationship between shield dust levels and the quantity or velocity of air on the face, but no statistically significant relationship was found. However, another factor was identified that exposed a relatively clear-cut division in shield generated dust. Five of the mines had shield dust levels below $1.2\text{mg}/\text{m}^3$, with an average concentration of $1.0\text{mg}/\text{m}^3$. The shield dust concentrations from the other six mines were all above $1.8\text{mg}/\text{m}^3$, with an average concentration of $2.0\text{mg}/\text{m}^3$. Four of the five mines with low shield dust were located in the eastern U.S., while five of the six with high shield dust were located in the west. Previous research (Organiscak *et al.* 1985) had indicated that those mining operations that leave coal at the roof typically generate higher quantities of shield dust than those operations leaving only rock at the roof. Dust results from these longwall surveys support this trend in that the mines in the west were operating in high coal seams and typically left some coal at the roof. In the eastern mines no coal

was left at the roof. A number of U.S. longwall operations have begun utilizing water sprays mounted on the shield canopies in an effort to wet the broken material on top of the shield and prevent respirable dust from being liberated during shield advance. NIOSH is currently planning an evaluation of a shield spray system to assess the effectiveness of these sprays.

Individual mine workers can also have a significant impact on their personal dust exposure. Numerous operating practices were observed at the different mines, particularly for the tailgate shearer operator. At some operations, the tailgate shearer operator would be positioned parallel to or upwind of the tailgate cutting drum. At other operations, the tailgate operator would routinely travel downwind of the cutting drum to observe the cutting horizon and/or to assist the shield movers in their efforts to advance shields. As previously indicated, the shearer clearer spray system is designed to confine shearer generated dust near the face but the effectiveness of these sprays diminish as the distance from the shearer increases. Consequently, the tailgate shearer operators are increasing their dust exposure when they travel downwind of the shearer to observe the cutting drum or assist in moving shields. Likewise, at most operations, the dust exposure of the shield movers can be reduced by having the shield movers stay as close to the shearer as possible when advancing shields downwind of the shearer. Figure 7 contains data from one of the mines surveyed and illustrates a typical profile of dust levels around the shearer with a shearer clearer spray system. This data shows how dust levels can be minimized in the walkway around the shearer.

CONTINUOUS MINER DUST CONTROL TECHNOLOGY

Similar to longwall operations, ventilating air and water sprays are the primary controls used on continuous miners for controlling dust liberation and worker

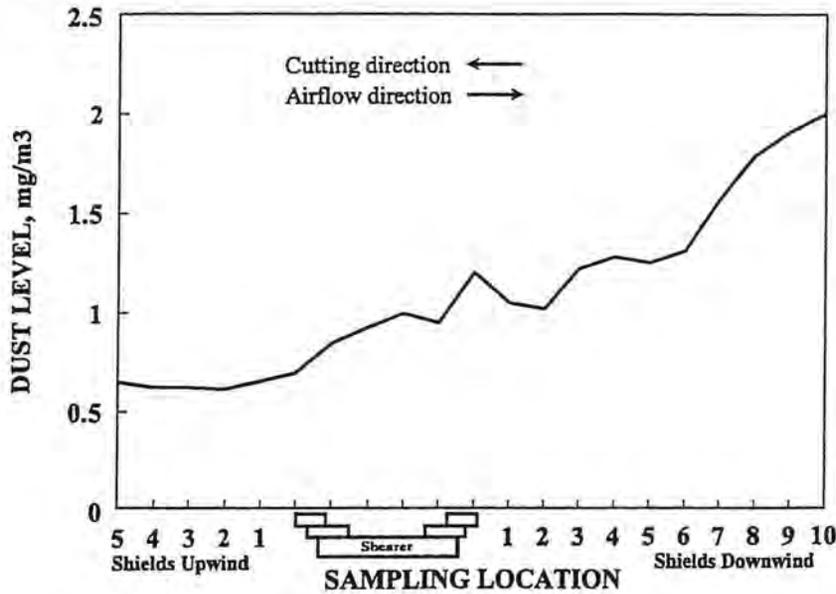


Figure 7 Dust levels around shearer with shearer-clearer spray system.

exposure. Previous research has indicated that flat fan sprays mounted across the top of the boom behind the cutting drums of the miner are the most effective sprays to utilize at this spray location (U.S. Bureau of Mines 1985a). These sprays provide wetting at the cutting drums while also minimizing the amount of turbulence and dust rollback that occurs. Research has also indicated that the greatest dust capture with water sprays on continuous miners occurs under the cutting boom. Water sprays mounted on the underside of the boom are utilized to control dust in this location (U.S. Bureau of Mines 1989). Operation of these sprays should be focused upon applying water at relatively low operating pressure in order to provide wetting without

forcing the dust out from under the boom.

In miner cuts of traditional 6.1m (20 feet) depth, exhaust ventilation systems have been shown to be most effective for dust control (Kost *et al.* 1981), while blowing ventilation is thought to be more effective for controlling methane. Extended-cut mining is now approved for over 50% of the continuous miner sections operating in the U.S. A primary concern in extended-cut mining is ensuring that sufficient ventilation air reaches the face to control methane and dust liberation. The most popular ventilation system used in extended-cut mining is blowing face ventilation in conjunction with a flooded-bed scrubber. The scrubber assists in increasing airflow into the extended-cut (Thimons *et al.* 1999) and

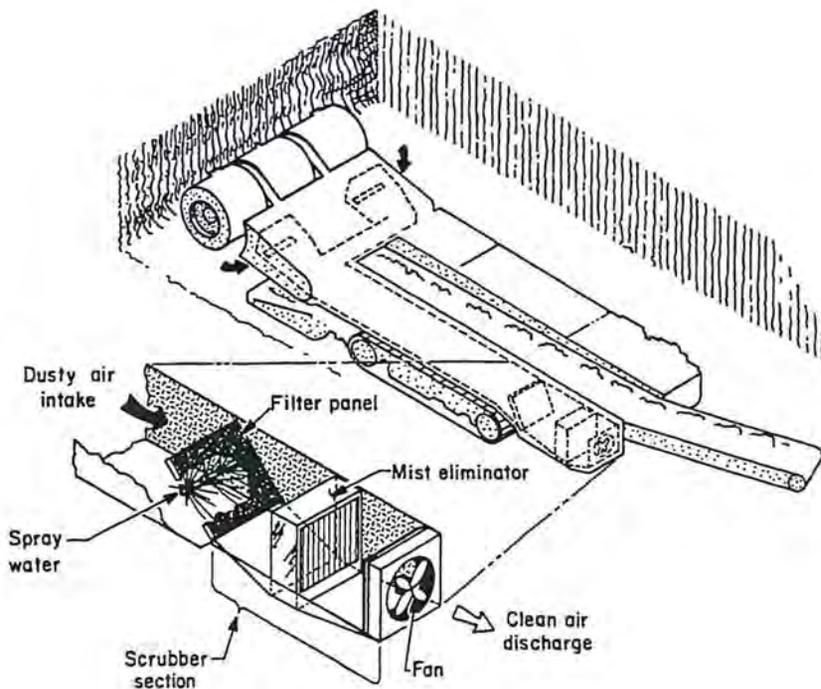


Figure 8 Flooded-bed scrubber on continuous miner.

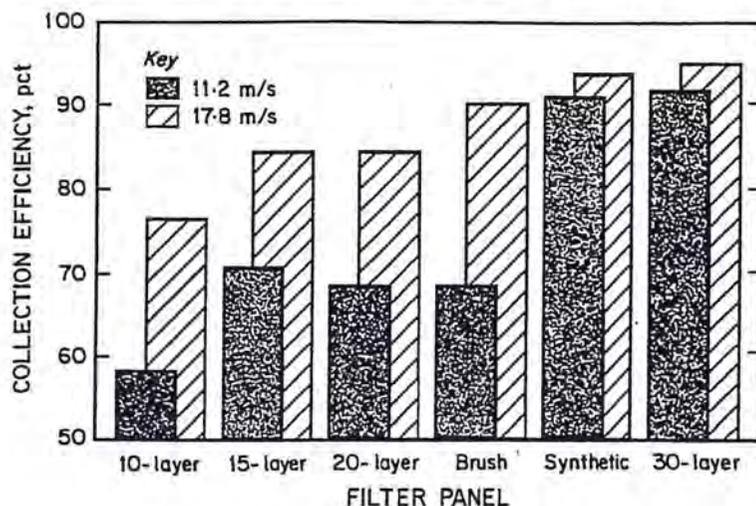


Figure 9 Silica collection efficiency for scrubber filter panels.

also is a very effective dust collector. Flooded bed scrubbers are fan-powered dust collectors that capture dust-laden air from the cutting face, carry this air through ductwork on the miner, and pass the air through a filter panel that is wetted with water sprays, Figure 8. As dust particles impact and travel through the filter panel, they mix with water droplets and are removed from the airstream by a mist eliminator (Campbell 1983). The cleaned air is discharged from the scrubber back into the mine environment. Overall effectiveness of a flooded bed scrubber is a function of the amount of ventilating air from the face that is drawn into the scrubber (capture efficiency) and the quantity of dust removed from the captured air (collection efficiency).

Flooded-bed scrubbers have traditionally been utilized with stainless steel filter panels that were constructed of 40 layers of fine stainless steel mesh. Previous research (Colinet *et al.* 1990) has shown that these scrubbers were capable of removing over 90% of the respirable coal and silica dust that is drawn into the unit. Over the last several years, two changes in the flooded bed scrubber operation have occurred that have the potential to impact scrubber effectiveness:

- (1) the density of the filter media utilized in scrubber filter panels has been reduced by as much as 75%, and
- (2) the internal air velocity in scrubbers has increased by as much as 100%. These changes have occurred as the need for higher capacity scrubbers has increased as more operations are seeking extended-cut approval. The impact on dust collection resulting from these changes had not been determined.

A series of full-scale tests were conducted at the Pittsburgh Research Laboratory to evaluate the silica collection efficiency of six different scrubber filter panels. The panels included: 30-, 20-, and 10-layer stainless steel panels from Manufacturer A, 15-layer stainless steel and synthetic fabric panel from Manufacturer B, and a nylon brush filter panel from Manufacturer C. Each filter panel was evaluated at scrubber air velocities of 11.18 and 17.78 m/s (2200 and 3500 fpm). Results of respirable dust sampling and subsequent silica analysis indicate that collection

efficiency improved for all filter panels at the higher scrubber air velocity, Figure 9. The 30-layer and synthetic panels were the most efficient and removed between 91-95% of the respirable silica dust drawn into the scrubber. The 10-layer panel was the least efficient and only removed 58% of the silica at low scrubber airflow and 77% at high airflow. Utilization of the 10-layer panel will allow approximately 25-40% of the silica drawn into the scrubber to be discharged back into the ventilating air, and as such, reduces the scrubber unit to more of an air mover rather than an efficient dust collector.

The use of filter panels with greater density was shown to improve dust collection efficiency but also was found to reduce scrubber airflow capacity. Optimum flooded-bed scrubber performance occurs when all of the face ventilating air is drawn into the scrubber (100% capture efficiency) and over 90% of the respirable dust is removed by the scrubber. Relative performance of the scrubber with each filter panel was calculated for the low and high airflow test conditions, when assuming a 100% capture efficiency for each filter, using the collection efficiencies shown in Figure 9, and assuming a scrubber intake dust level of $2\text{mg}/\text{m}^3$. It should be noted that in order to realize a 100% capture efficiency the quantity of air ventilating the face would need to be adjusted to match the air moving capacity of the scrubber with each of the different filter panels. Figure 10 contains the silica levels calculated for the scrubber discharge and indicates that the lowest dust levels were obtained with the 30-layer stainless steel filter and the synthetic filter panels. The 10-layer panel was once again the poorest performing filter of those evaluated. Relative dust concentrations were also calculated for the assumption that a 100% capture efficiency could not be obtained because face ventilation air quantity would remain constant, regardless of the filter panel being used. For these conditions, the 30-layer and synthetic panel again provide the lowest silica levels at the low scrubber airflow test condition. At the high scrubber airflow, the brush filter resulted in the lowest silica levels, while the differences in silica collection for the remaining panels were minimal. In general, the 30-layer and synthetic

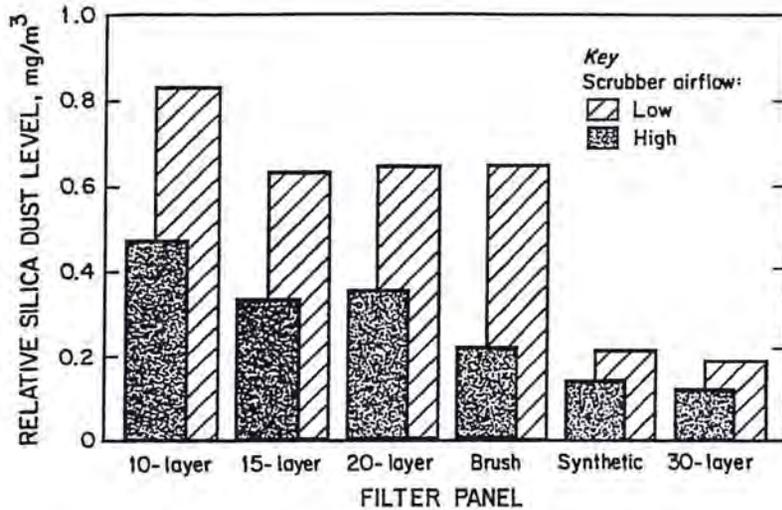


Figure 10 Relative silica levels in scrubber discharge with 100% capture efficiency.

filters were the most consistent performing filters regardless of test conditions and are recommended for those operations experiencing difficulty in controlling silica dust levels. The 10-layer panel typically allowed the highest quantities of silica to be discharged from the scrubber and is not recommended for use where respirable dust collection is an important goal.

FUTURE RESEARCH

Longwall operators in the U.S. anticipate further production gains and have indicated that the traditional controls that are being used may be reaching practical limits. As a result, future NIOSH research for longwall dust control will examine more advanced, more complex control technologies. This may include developments such as water-powered scrubbers on the shearer, the use of foam through the shearer cutting drums, application of high-pressure water sprays, and/or other nontraditional types of controls.

Future research for continuous miner operations is looking at means to reduce silica dust generation by the continuous miner and/or roof bolter and is also focusing upon the development of control technology to reduce the dust exposure of roof bolter operators. Similar to longwall research, more advanced, more complex controls are being considered for research and includes items such as wet-head miners, alternate bit designs, and wet drilling. In addition, the use of coanda air curtains or filtered air sources are being evaluated to provide protection for roof bolter operators when working downwind of the continuous miner.

SUMMARY

Significant advances in dust control technology have been developed over the past two decades and have reduced the dust exposure of miner workers. However, as production and productivity from both longwall and continuous miner operations increases, the ability of these traditional dust controls to successfully limit

worker exposure is constantly being challenged. A review of current dust control practices in the U.S. indicates that successful longwall and continuous miner operations use a multitude of controls in an effort to limit worker exposure. Some of these control technologies are designed to limit the amount of respirable dust that is generated and entrained in the ventilating air, while other controls are designed to prevent the dust from reaching the breathing zones of the workers after the dust becomes airborne. The use of both types of controls along with the mine workers recognition of proper operating practices are needed to successfully minimize worker exposure.

In addition, a key to long-term protection of mine workers is the maintenance of the dust control systems that have been found to be effective at any particular mine. The lag time between excessive dust exposure and contracting lung disease tends to diminish the urgency that is associated with other mining hazards that may have immediate impact on the safety of the mine worker. For example, roof bolter operators would not be willing to continue bolting operations if the temporary roof support system was not working on the roof bolter. However, these same bolter operators would likely operate the bolter even if they were aware of problems with the dust collection system on the bolter. By operating the bolter with an ineffective dust collector, the potential for exposure to high levels of silica dust increases. Mine workers and mine management must recognize the importance of dust control technology and its relationship to the long-term health of the mine workers. Both parties must stress the importance for maintaining dust controls with as much attention as is given to systems that provide protection from injury.

Although the overall incidence of Coal Workers' Pneumoconiosis and silicosis has decreased in the U.S. mining industry, mine workers continue to contract these diseases and the need for more effective control technologies is apparent. NIOSH continues to conduct research in an effort to develop control technology to improve working conditions for underground coal miners.

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