Control of Respirable Dust

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LUNG DISEASES OF MINERS

The two major lung diseases of miners are "blacklung" and silicosis. Blacklung, or pneumoconiosis, was first recognized as a disease of British coal miners in the 1600s. However, investigations into the cause of blacklung disease did not begin until the 1900s. The causative agent of pneumoconiosis in coal miners was thought to be silica until studies in the United Kingdom provided evidence that exposure to coal dust containing minimal silica could also cause pneumoconiosis. In the Federal Coal Mine Health and Safety Act of 1969, coal workers pneumoconiosis (CWP) was defined as "a chronic dust disease of the lung arising out of employment in an underground coal mine."

Diagnosis of CWP is generally based on chest x-ray findings and a patient's history of working in coal mines, usually for 10 or more years. In its early stages, CWP is called "simple CWP." Miners with simple CWP are at increased risk of developing an advanced stage of the disease, called "progressive massive fibrosis" (PMF) or "complicated CWP."

PMF (complicated CWP) is associated with significant decreases in lung function and oxygen-diffusing capacity. PMF is also associated with breathlessness, chronic bronchitis, recurrent chest illness, and episodes of heart failure. Coal miners with silicotic lesions or PMF have an increased risk of tuberculosis and other mycobacterial infections. PMF may progress even in the absence of further dust exposure. This disease is also associated with increased mortality (National Institute of Occupational Safety and Health [NIOSH] 1995).

The most recent study to determine the prevalence of CWP in coal workers was in the mid-1990s. The average prevalence of CWP was 2.8%, but for those with 30 or more years in the industry it was 14%. For the 10-year period from 1987 to 1996, 18,245 deaths were attributed to CWP. The most frequently recorded occupation on the death certificate (70%) was mining machine operator (NIOSH 1999).

Silicosis may develop when inhaled respirable crystalline silica (quartz) is deposited in the lungs. The clinical diagnosis of silicosis is based on (1) recognition by the physician that the level of silica exposure is adequate to cause the disease, (2) the presence of chest radiographic abnormalities consistent with silicosis, and (3) the absence of other illnesses (e.g., tuberculosis or pulmonary fungal infection) that may mimic silicosis. The radiographic patterns are often the same for CWP and silicosis; thus, these diseases are sometimes distinguishable only by work history or pathological examination.

Chronic silicosis commonly involves 15 or more years of exposure to silica. The characteristic microscopic feature is the silicotic nodule. Chronic silicosis is often asymptomatic and may manifest itself as a radiographic abnormality with small, rounded opacities of less than 10 mm in diameter, predominantly in the upper lobes. Lung function may be normal or show mild restriction. Chronic silicosis is also associated with a predisposition to tuberculosis and other mycobacterial infections and with progression to complicated silicosis.

Complicated silicosis, also called PMF, occurs when the nodules coalesce and form large conglomerate lesions. Complicated silicosis is characterized radiographically by the presence of nodular opacities greater than 10 mm in diameter on the chest x-ray. Complicated silicosis typically causes respiratory impairment. Recurrent bacterial infection may occur, and tuberculosis is a concern (NIOSH 1995).

For the 10-year period between 1987 and 1996, 1,054 deaths occurred in the United States from silicosis. About 40% of these were in mining and construction. The most frequently recorded occupation on the death certificate (14.7%) was mining machine operator (NIOSH 1999).

PERMISSIBLE EXPOSURE LIMITS

In coal mines, dust samples are collected by both coal mine operators and the Mine Safety and Health Administration (MSHA) using a size-selective sampling device (cyclone) that separates out dust in a way that reflects the efficiency of deposition in the gas-exchange region of the lungs. This so-called "respirable size fraction" has a lung deposition efficiency of 100% at 1 μm or below, 50% at 5 μm, and zero efficiency for particles of 7 μm and upward (NIOSH 1995).

The permissible exposure limit (PEL) is 2 mg/m^3 for respirable coal mine dust, which is measured gravimetrically as an 8-hour time-weighted average (TWA) concentration. This limit is reduced when the respirable silica (quartz) content exceeds 5%. A formula of 10 divided by the percentage of respirable silica is used to determine the reduced PEL for respirable coal mine dust. For example, a sample with 10 pct silica would have a dust PEL of 1 mg/m3 (*Code of Federal Regulations,* 30 CFR 70.101 and 71.101). For the 10-year period from 1987 to 1996, 7.4% of coal mine inspector samples exceeded the PEL.

A respirable dust PEL has not been established for noncoal mines, but a nuisance dust standard of 10 mg/m^3 is regulated. The nuisance dust sample is comprised of "total dust," which represents airborne particles that are not selectively collected with regard to their size. However, respirable dust sampling is conducted in non-coal mines if potential exposure to silica dust is suspected. If the silica content of the respirable dust sample exceeds 1%, the formula used to establish the dust PEL is 10 divided by (the percentage of silica + 2). Thus, a sample with 8 pct silica would have a dust PEL of 1 mg/m^3.

For the 10-year period between 1987 and 1996, 15.6% of the dust samples in the metal mining industry taken by MSHA inspectors exceeded the PEL because of silica. For coal mining, it was 23.4%, and for stone products, it was 22.5% (NIOSH 1999).

DUST CONTROL TECHNOLOGY AND PRACTICES

In underground coal mining operations, ventilating air and water sprays are the primary controls used to limit respirable dust generation and worker exposure. The quantity of ventilating air supplied has a direct impact on the dilution of the dust cloud as it is generated, while the velocity of the ventilating air determines the rate at which dust can be moved away from the mine workers. Water is applied to coal as it is being mined or crushed to wet the coal particles and minimize the quantity of dust that becomes airborne. After dust is entrained in the ventilating air, water sprays are also used to direct dust-laden air away from workers and/or remove dust particles from the airstream. In addition to these basic controls, mine operators use more advanced control technologies (such as dust collectors, scrubbers, and enclosed cabs) and improved operating practices/administrative controls to further reduce the dust exposure of mine workers.

Dust Control Practices in Room and Pillar Coal Mining

Face Ventilation To ventilate the working face, line brattice (plastic curtain) is installed along the coal rib, or tubing (fiberglass ductwork) is hung from the mine roof and used to supply fresh air. Federal regulations require a minimum of 1.4 m^3/s (3,000 cfm) of air to be directed to each working face to provide protection from dust and methane gas. In today's high-production mining operations, significantly larger quantities of air are often supplied to the working face. Exhaust and blowing ventilation systems are the two types of face ventilation techniques commonly used in room and pillar operations.

With exhaust ventilation, fresh air is forced up the mine entry to the face to dilute and entrain dust. Dust-laden air is then pulled from the face area and carried behind the curtain or into the tubing and out of the face area. The quantity of air and the distance from the end of the line brattice or tubing to the face are critical, particularly with exhaust ventilation. Studies have shown that dust levels are lower when the brattice or tubing is located close to the face. For this reason, the end of the exhaust brattice or tubing should be maintained within 3 m (10 ft) of the face. Also, when using exhaust ventilation, mean entry air velocities above 0.3 m/s (60 fpm) have been shown to minimize dust. Both of these criteria—3-m setback and 0.3 m/s velocity—are required by MSHA coal mine regulations (30 CFR 75.326 and 75.330).

Historically, continuous miner operators were positioned on the back corner of the mining machine. In this situation, dust exposure could be reasonably controlled with exhaust ventilation. However, if the dust cloud rolls back toward the operator, remote control can be used to lower the operator dust exposure. Operator positioning when using remote control can have a significant impact on dust exposure. For exhaust ventilation, an operator using remote control should be positioned on the off-curtain side of the entry and stand as far outby as practical (Colinet and Jankowski 1997).

Recently, room and pillar coal mining has adopted blowing ventilation in conjunction with dust scrubbers and remote control. This technological development does a better job of clearing out methane gas, and so it has allowed for the extraction of extended cuts up to 12 m (40 feet) in depth. When using blowing ventilation, fresh air is directed behind line brattice or in tubing and then discharged from the end of the curtain/tubing toward the face. This fresh air dilutes and entrains dust at the mining face and the dust-laden air then passes out of the immediate face area and into the dust scrubber. For operations with blowing ventilation, the operator should be positioned at the discharge of the line curtain or tubing in the fresh air stream to minimize dust exposure.

As a general rule, especially in older mines, reducing stopping leakage is the most cost-effective technique to get more air to the face. Varying degrees of airtightness can be realized with different stoppings and the quality of construction used to erect the stoppings. Step-by-step instructions for building three types of stoppings are available in a U.S. Bureau of Mines (USBM) handbook (Timko 1983).

Water Spray Systems for Continuous Miners Continuous miners are equipped with water supply systems designed to suppress dust, cool motors and bits, and serve as emergency fire-suppression systems. Spray nozzles mounted on the machine body deliver water to strategic areas for dust control. The purpose of these sprays is to wet the coal as it is cut. Once the liberated dust has been entrained in the ventilating air, the dust capture or "knockdown" afforded by the sprays is moderate. Ideally, all spray systems are turned on before cutting and left on for a short period after cutting. Tests have shown that the best spray systems can reduce respirable dust by 60%; typical reductions average 30% (Courtney and Cheng 1977).

Continuous miners utilize three general types of spray systems: conventional, anti-rollback, and spray fan. The conventional spray system is recommended for all blowing ventilation sections and for exhaust ventilation sections with high airflow. The quantity of water needed depends upon the operating conditions of the individual section. Flow rates usually range from 1.3 to 1.9 L/s (20 to 30 gpm). Nozzles are typically located on top of the boom (directed at the top of the drum), beneath the boom (directed at the bottom of the drum and at the gathering arms), and in the conveyor throat. Sprays can also be located on both sides of the boom. Either full- or hollow-cone nozzles are typically used on the top to provide adequate coverage across the total width of the drum. These types of nozzles should also be used below the boom and should be uniformly spaced to maximize coverage of the area between the sprays and the bottom of the drum. Sprays are suggested for the conveyor throat to prevent dust dispersion from the conveyor to the operator.

When exhaust ventilation is used and air velocities are low, turbulence created by the sprays can roll the dust cloud back toward the operator. This is called rollback. High spray pressure (over 692 kPa or 100 psi) and the use of wide-angle top and side sprays that overspray the drum or are set too far from the drum promote this condition. Whether rollback exists can usually be determined by temporarily shutting off the sprays. If the rollback is reduced when the sprays are shut off, one or more of the following measures is taken: (1) face airflow is increased; (2) extension and tightening of brattice or tubing; (3) a reduction in spray pressure; (4) removal of any nozzles pointed outby; or (5) installation of an anti-rollback spray system if the mine is not gassy.

The anti-rollback water spray system (USBM 1985a) is particularly suited for exhaust ventilation faces without a methane problem, with low face airflow, and where dust standards are more stringent because of silica. With this system, a moderate spray pressure of 692 kPa (100 psi), measured at the nozzle, is a practical maximum. Although higher pressure sprays have the potential to knock down more dust, they can also increase the dust blown back to the operator. However, water-flow rates should be as high as possible, within a 1.6- to 2.2-L/s (25- to 35-gpm) range.

As shown in Figure 20.1, the top and side nozzles of the anti-rollback system are arranged for "low" reach (about 300 mm or 12 in.) from the cutting head. This location prevents overspray that would increase rollback. Flat spray patterns, as opposed to cone spray patterns, are better because the entire flow from the nozzle can be directed to the cutting head. On the boom top, horizontal flat spray patterns near the cutting head cause the least air disturbance; on the sides, vertical flat spray patterns are best.

The dust collection efficiency of the anti-rollback system can be greatly improved by using under-boom sprays. These are located on the rear corners of the shovel at the sides of the machine and they are aimed towards the front of the gathering arms (Figure 20.2). Pressures can be as high as 1380 kPa (200 psi) with flow rates of 0.25 to 0.31 L/s (4 to 5 gpm) (USBM 1989).

Another water spray system, designed for use with exhaust ventilation, is the spray fan system (Ruggieri et al. 1984; Ruggieri et al. 1985). The spray fan system is designed to reduce face methane concentrations by using the air-moving properties of ordinary water sprays. A series of water sprays working in concert directs the main ventilation flow to the face and sweeps contaminated air and gas across the face toward the return. The spray fan system should only be used with good face ventilation (mean entry air velocities above 0.3 m/s (60 fpm). It is also effective with curtain setback beyond 3 m (10 ft). Proper operation of the spray fan system requires a minimum pressure of 1034 kPa (150 psi) measured at the spray nozzles. This usually requires that the pressure loss in the supply hose be minimized by the selection of a supply hose with an inside diameter of at least 38 mm (1.5 in.).

The spray fan system was designed for use with exhaust ventilation only. A different system, designed for use with blowing ventilation, was designed by Volkwein and Wellman (1989). It also uses directional sprays to induce air movement around the cutter head. The authors report an improvement in ventilation by a factor of 2 to 3.

A major problem associated with water spray systems is the frequent clogging of spray nozzles caused by particulate matter in the water line. Nozzle blockage can be minimized by using fewer nozzles, but with larger orifice diameters of at least 1.6 mm (1/16 in.). The USBM developed a simple, nonclogging, water filtration system to replace conventional spray filters (USBM 1981a). The system consists of an in-line Y-strainer to remove the plus 3.2-mm (1/8-in.) material, a hydrocyclone to remove virtually all of the remaining particulates, and a polishing filter to remove traces of particulates that are carried over the hydrocyclone overflow during the startup and shutdown of the spray system.

Flooded-Bed Scrubbers Flooded-bed scrubbers are fan-powered dust collectors installed on continuous miners to collect dust-laden air through an inlet(s) near the front of the miner and discharge cleaned air at the back of the miner. The dust-laden air passes through a filter panel that is being wetted with water sprays, which allows the dust particles to be captured by the water. After passing through the filter panel, the airstream then enters a demister, which removes the dust-laden water droplets from the airstream. The cleaned air is then discharged at the back of the scrubber unit and typically can be directed toward either side of the entry with a louvered discharge on the miner. Approximately 90% of miners now being fabricated are equipped with flooded-bed scrubbers (Armour 1999).

The overall effectiveness of a flooded-bed scrubber is determined by the proportion of face air that is drawn into the scrubber (capture efficiency) and the proportion of respirable dust removed from the captured air (collection efficiency). Scrubbers are primarily used on continuous miner sections employing extended cuts with blowing face ventilation. The scrubber assists in pulling the ventilating air into the face as the miner moves deeper into the cut and away from the line brattice/tubing. In these operations, the face airflow is typically matched to the capacity of the flooded-bed scrubber in an effort to allow 100% capture of the air ventilating the face. Today, scrubbers are also being used

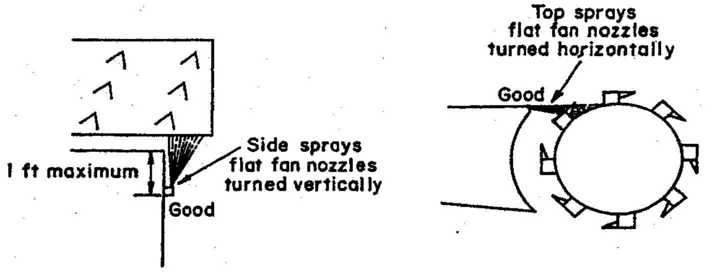

FIGURE 20.1 **Top and side nozzles arranged for low reach. Overspray causes rollback**

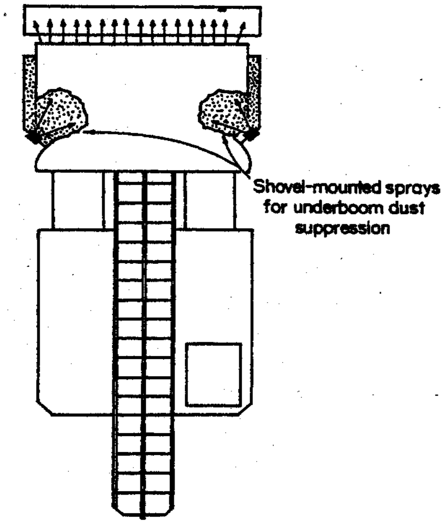

FIGURE 20.2 **Underboom sprays**

in conjunction with exhaust face ventilation in an effort to further reduce the dust exposure of face workers.

Research has shown that flooded-bed scrubbers can remove more than 90% of respirable-sized coal and silica dust (Colinet et al. 1990). However, the collection efficiency is affected by the density of the filter panel. The original filter panel was fabricated with 40 layers of fine stainless steel mesh. Filter panels containing 30, 20, and 10 layers of stainless steel mesh are now available. The reduced filter density allows larger quantities of air to be moved by the scrubber, potentially improving capture efficiency, but can reduce the collection efficiency. In one study, the 30-layer panel was shown to maintain respirable dust collection efficiency above 90% but the collection efficiency dropped when less dense panels were used (Colinet and Jankowski 2000). When using flooded-bed scrubbers, the balance between the capture efficiency and collection efficiency must be optimized to minimize dust levels.

Bit Replacement The condition of the cutting bits, design of the cutting drum, and sump rate have a major impact on the quantity of dust of respirable size that will be generated. Routine inspection of the cutting drum and replacement of dull, broken, or missing bits improves cutting efficiency and helps to minimize dust. Also, research results indicate that bits that are designed with large carbide inserts and smooth transitions between the carbide and steel shank typically produce less dust over the life of the bit (Organiscak et al. 1995).

Modified Cutting Cycle Studies have shown that cutting rock can contribute five times the respirable dust compared with cutting coal. When roof rock has to be cut, an alternative to the usual cutting pattern is to sump into the face 0.3 to 0.6 m (1 to 2 ft) below the roof and to shear down to the floor. This should be continued for at least two sump-shear sequences (more if roof conditions and seam and/or miner height requirements allow). Then the machine is pulled back to cut the remaining top coal and roof rock. This procedure reduces respirable dust levels by allowing the roof rock to be cut to a free face, which generates less respirable dust (USBM 1985).

Roof Bolting Systems to control dust from roof bolting machines use either a dry collector or water injection to achieve lower dust levels. In either case, a problem with the system can be easily detected and remedied with a few simple maintenance procedures.

If a dry collector is used, dust in the blower exhaust is the most common problem encountered, a sign that dust is bypassing the filters. Common causes of this are damaged or improperly seated filters. Cloth-bag-type filters are less efficient dust collectors than the pleated-paper cartridge-type and allow dust to bleed through the system and escape through the exhaust. Accumulations of dust between the filters and the blower (clean side) are a result of filter leaks. Finally, a visible dust plume from the collar of the drill hole is a sign of inadequate airflow to the chuck or bit and is often a result of air leaks within the system. These occur primarily through loose connections (especially at the chuck hose), air-pressure relief valves, poorly fitting dust-collector access doors, and worn and damaged hoses. Replacement of overloaded and clogged filters will generally increase airflow at the bit by more than 30% (Divers et al. 1987).

Studies have shown that a roof bolter's dust exposure can be substantially reduced by changing from a shank-type bit to a "dust hog" bit (air inlet port located on the bit instead of on the drill steel) (USBM 1985b). Generally, this difference can be attributed to the initial few centimeters of bit penetration when the shank-type bit allows far more dust to become airborne. Underground evaluations of the two bit types showed that the dust hog bit reduced bolter dust exposure by more than 80%, and it also drilled faster and cooler.

In wet systems, hollow drill steels are used to deliver low-pressure water (0.13 L/s or 2 gpm per chuck) to the bits. These systems offer improved bit life, faster drilling, and excellent dust control. However, wet drilling can create problems in sections that cannot tolerate additional water accumulation on the mine floor. Also, use of wet drilling may aggravate the working conditions for the roof bolter operators. As a result, good maintenance of all seals is important to minimize leakage.

Double-Split Ventilation The roof-bolter operator's dust exposure frequently derives from upwind dust sources, particularly the continuous miner. The use of a double-split ventilation system to provide the bolter operator with a clean split of air is the most effective way to combat this problem. In single-split sections, the mining-bolting cycle must be carefully designed to keep the roof bolter upwind of the continuous miner whenever possible.

Conveyor Belts The first step in minimizing the amount of dust generated during coal conveyance is to ensure that the coal is wetted adequately at the face. Rewetting the coal at intervals along the belt may also be necessary. This is best accomplished by uniformly wetting the coal stream with flat-fan sprays operating at 280 to 350 kPa (40 to 50 psi). The accumulation of coal and dust particles on the top and bottom sides of the returning belt can be controlled by mounting belt scrapers or wipers near the drive, or by spraying the belt with a low-quantity water nozzle. Maintaining the conveyor system (alignment, rollers, and splices) in good working condition will also reduce dust.

Transfer Points Transfer points can be the greatest source of dust in outby areas; transfer points include shuttle-car-to-belt, belt-to-belt, and belt-to-mine-car. A major cause of dust at transfer points can be the dislodgment of dust adhering to the underside of the belt. Nozzles projecting a flat, fan-type spray directly at the underside of the belt have been shown to reduce dust levels in this area by as much as 60% (Kost et al. 1981); water quantities of 0.019 to 0.032 L/s (0.3 to 0.5 gpm) are typical for this application. It is also important that the coal be wet prior to its reaching the transfer point. Hoods and chutes may also be used to prevent the ventilating air from agitating dust and to reduce the amount of coal fragmentation and breakage associated with excessive free-fall distances.

Haul Road Dust Control Good housekeeping practices—such as scooping up excess coal when a cut is finished, shoveling coal along the ribs to the middle of the entry where the machine can readily reach it, and minimizing shuttle car spillage—form a basic and effective approach to the problem of haul road dust control. Another method is to wet the roadway with water. However, this is usually a temporary measure because the water can rapidly evaporate. To keep the moisture content of the roadway dust at a desired 10% level, the use of a hygroscopic salt, such as calcium chloride, is frequently required. It should be spread in two applications: three-quarters applied 1 hour after wetting the dust with water, and the remaining one-quarter applied about 1 week later. Depending upon mining conditions, retreatment of the roadway should not be necessary for about 6 months, but spraying the roadway with water after 3 months is recommended.

Dust Control in Longwall Coal Mining

The number of operating longwall faces in the United States has decreased from more than 90 ten years ago to 59 in the year 2000, yet production from longwall mines now accounts for more than 50% of the coal produced in underground U.S. mines. Advancements in equipment design, equipment reliability, operating practices, and longwall layout have allowed U.S. longwall mining operations to steadily increase production. In 1980, average shift production as reported to MSHA was equal to 890 metric tons, and production has increased to an average of 4,600 metric tons per shift in 1999 (Niewiadomski 2000). High production longwalls are capable of producing more than 15,000 tons per shift on a recurring basis.

Two factors that have contributed to increased production are the increase in longwall face lengths and the widespread adoption of bidirectional cutting sequences. These combine to increase the cutting time during a shift. Currently, about 90% of operating sections use a bidirectional cutting sequence where the shearer extracts full-face cuts in both directions. Typically, the lead drum takes a full cut in the raised position, while the trailing drum cuts the remainder of the coal along the floor. For unidirectional cutting, a full-face cut is only taken in one direction across the face (cutting pass). For the clean-up pass, both shearer drums are lowered to "clean" the coal remaining along the floor, with minimal additional cutting. However, the increase in face length that has occurred in the last 15 years has made the use of unidirectional cutting less popular because of the low production that results during the clean-up pass. The substantial improvement in longwall production provides the potential to increase the quantity of respirable dust generated and thus the dust exposure of mine workers.

However, despite the substantial increase in production, compliance with the 2 mg/m^3 dust standard for longwall mines has actually improved. In the early 1980s, 31% of MSHA dust samples collected for the designated occupations (DO) from longwalls were out of compliance; in 1999, 18% of the DO samples were out of compliance (Niewiadomski 2000). This improvement can be attributed to dust control research that has identified a number of successful control technologies and to longwall operators that have adopted multi-faceted approaches to dust control. Successful dust control in the U.S. longwall industry has been achieved by the following practices: minimizing the quantity of dust liberated into the airstream, preventing airborne dust from reaching the breathing zone of mine workers, removing airborne dust from the ventilating air, and providing workers with the knowledge to protect themselves from excessive dust exposure.

Shearer-Clearer A poorly designed external water spray system on the shearer body can actually raise operator dust levels. Poorly designed systems have nozzles directed upwind at the cutting and loading zone of the intake-side drum. Airflow generated by these sprays pushes dust away from the face and upstream of the drum. Here, dust mixes with the clean intake air and is carried out into the walkway over the shearer operators.

To prevent this, the USBM has developed a novel shearer spray system, called the shearer–clearer. It takes advantage of the air-moving capabilities of water sprays. The system consists of several shearer-mounted water sprays, oriented downwind, and one or more passive barriers, that split the airflow around the shearer into clean and contaminated air (Figure 20.3).

The air split in the shearer–clearer system is initiated by a splitter arm, with conveyor belting hanging from the splitter arm down to the panline. This belting extends from the top gob side corner of the shearer body to 460 mm (18 in.) beyond the cutting edge of the upwind drum. A spray manifold mounted on the splitter arm confines the dust cloud generated by the cutting drum, further enhancing the air split. The dust-laden air is drawn over the shearer body and held against the face by two spray manifolds positioned between the drums, on the face side of the machine. The air is then redirected around the downwind drum by a set of sprays located on the downwind splitter arm. Operating pressure must be about 1034 kPa (150 psi), measured at the nozzle, to ensure effective air movement. Total water flow rate with all sprays operating is about 0.76 L/s (12 gpm). In underground tests, the shearer–clearer reduced operator exposure from shearer-generated dust by at least

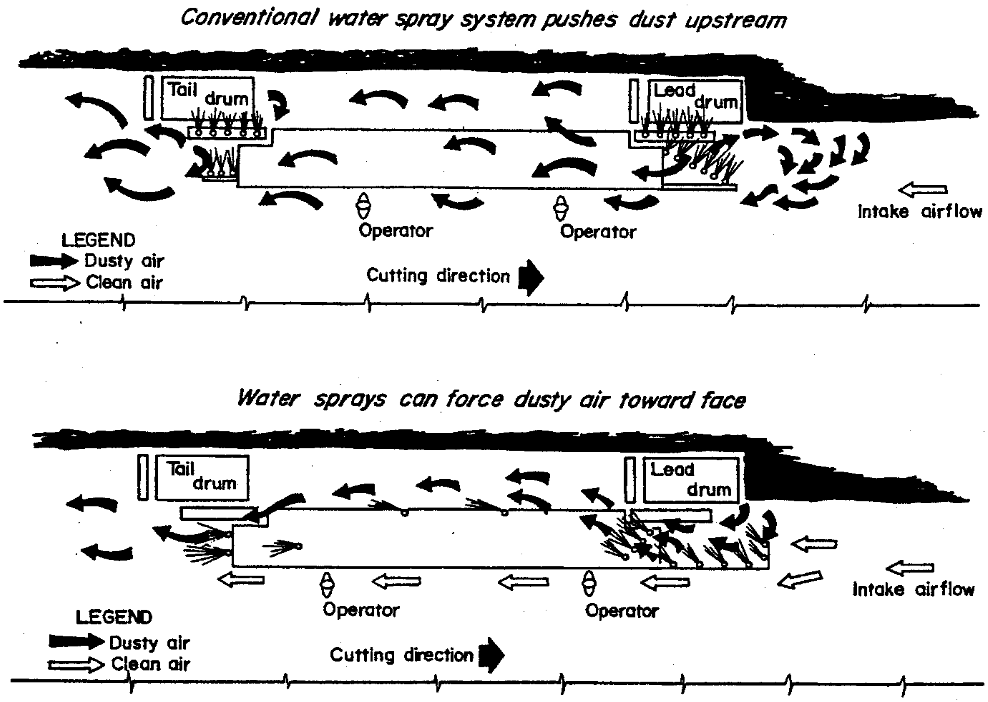

FIGURE 20.3 Air currents with conventional sprays (top) and shearer-cleaner system (bottom)

50% when cutting against the ventilation, and 30% when cutting with the ventilation (Shirey et al. 1985; Ruggieri and Babbitt 1983).

Spraying Water on Shearer Drums Dust generated by the shearer is reduced by increasing the quantity of water supplied to the shearer drums, so it is important to supply as much water as possible. In two separate studies, water flow to the shearer was increased about 50% and dust levels at the shearer were reduced about 40% (Shirey et al. 1985).

Dust exposure of the shearer operators may be affected by the operating pressure of the water supplied to drum sprays. In two separate studies (Piemental et al. 1984; Kok and Adam 1986), water pressure of the drum sprays was increased from 517 to 793 kPa and 552 to 1,034 kPa (75 to 115 psi and 80 to 150 psi), respectively. In both instances, dust exposure of the shearer operators increased by 25%. Thus, the maximum drum spray pressure to optimize dust control appears to be in the range of 483 to 690 kPa (70 to 100 psi). Also, the water flow rate should be increased by increasing the nozzle orifice size rather than the operating spray pressure.

The type of spray nozzle chosen is important for optimum performance (Kost et al. 1985). The pick-point flushing system with solid-stream (jet) nozzles is the most effective at suppressing respirable dust near the shearer operator's position. The pick-point system with cone-type sprays has been shown to be only 70% as effective. In the Kost study, downwind concentrations were essentially the same for all systems.

Remote Control Use of remote control on shearers can significantly reduce dust exposure of the machine operators. With remote control, operators control the machine from positions along the face less contaminated than their normal work positions. A survey shows that exposure was reduced 68% by moving the operator just 6 m (20 ft) upwind of the shearer body (USBM 1984).

Controls at the Headgate State Loader and Crusher Dust generated at the headgate can have a significant impact on the full-shift dust exposure of all face personnel. The major source of dust in the headgate entry is the stage loader/crusher. A basic approach to dust mitigation is to mount water sprays in the stage loader/crusher. Several sprays are mounted in spray bars, which usually span the width of the conveyor to ensure uniform spray coverage of the coal stream.

Recommended spray bar locations include the mouth of the crusher, the discharge of the crusher, and at the stage loader-to-belt transfer point (USBM 1985c). The dust capture efficiency of these sprays may be enhanced by enclosing the stage loader, either with steel plates or strips of conveyor belting. The enclosure also isolates the conveyed material from the airstream, thus reducing dust entrainment. The goal of the water sprays and the enclosing of the stage loader is to wet the coal and confine generated dust. Consequently, water quantity is more critical than water pressure. High-pressure water sprays may actually force dust out of the stage loader/crusher and into the intake air. Water pressure should be maintained below 60 psi. During underground trials with a fully covered stage loader and additional water-spray manifolds, improvements at the headgate operator and at support 20 locations were 80% and 45%, respectively (Jayaraman et al. 1992).

Ventilation Ventilation is one of the principal methods used to control dust on longwalls. Face air velocities of 2.0 to 2.3 m/s (400 to 450 fpm) are minimum levels appropriate for effective longwall dust control. Adequate longwall panel ventilation involves more than supplying the required volume of air to the headgate entry. Maintaining that airflow along the entire face is just as critical. Air leakage is greatest in the headgate area because there is often a large gap between the first shield and the adjacent rib. Also, the gob behind the first few shields remains open because the headgate entry is supported with roof bolts. This air loss prevents maximum use of the air available to ventilate the face. In addition, dust generated during gob falls may be entrained by this airflow and carried back into the face area. A gob curtain, installed from the roof to the floor between the first support and adjacent rib in the headgate entry, forces the ventilation airflow to make a 90° turn and stay on the face side of the supports (Figure 20.4). During underground trials, the average face air velocity with the curtain installed was 35% greater than that without the curtain (USBM 1981b). The most significant improvement was seen for the first 25 to 30 supports.

Despite the above success, misapplication of the primary ventilation airflow can increase dust exposure. Shearer operators are often exposed to very high concentrations as the headgate drum cuts into the headgate entry. The high-velocity primary airstream passing over and through the drum entrains and carries large quantities of dust out into the walkway and over both operators. An effective solution is to install a wing curtain between the panel-side rib and the stage loader (Figure 20.5). This curtain shields the headgate drum from the airstream as it cuts out into the headgate entry. It is typically located 1.2 to 1.8 m (4 to 6 ft) back from the corner of the face to provide maximum shielding without interfering with the drum. The curtain is only in place during the cutout operation and is generally advanced every other pass. The curtain can reduce operator dust exposure by 50 to 60% during the headgate cutout (USBM 1982a). Shearer operators can further reduce their dust exposure by moving as far upwind at the headgate as possible as the shearer cuts out at the headgate.

Site-Specific Longwall Controls

There are several control techniques that are site-specific, and therefore, cannot be successfully applied at every longwall installation.

Deep Cutting Reducing drum speed is one of only a few changes a longwall operator can make to increase output, reduce respirable dust, and decrease machine power consumption (Ludlow and Jankowski 1984). Deep cutting is a function of drum speed and machine advance rate. Pick spacing must be increased and gauge length must be adjusted to take full advantage of deep cutting. The rotational speed of the drum is reduced (typically to 30 to 40 rpm). The depth of cut is increased by using large bits with wider spacing of the bit lines while maintaining the same advance rate used at higher rpm.

Field tests have confirmed the benefits of slow-speed deep cutting (Ludlow and Wilson 1982). A 60% reduction in dust generation was achieved by reducing the drum speed from 70 to 35 rpm. This effectively increased bit penetration from 43 to 86 mm (1.7 to 3.4 in.).

Drum Water Proportioning Increasing the water flow to the drums usually reduces airborne dust levels produced by the shearer. Some operations, though, cannot tolerate an increase in water flow because of clay floors. Excess water in the coal reduces the run-of-mine Btu value. It can also cause problems in the coal transport system and in the coal preparation plant. For operations with these conditions, supplying larger quantities of water only to the upwind cutting drum can have a significant impact on the amount of water used while still reducing the operator dust exposure (USBM 1982b).

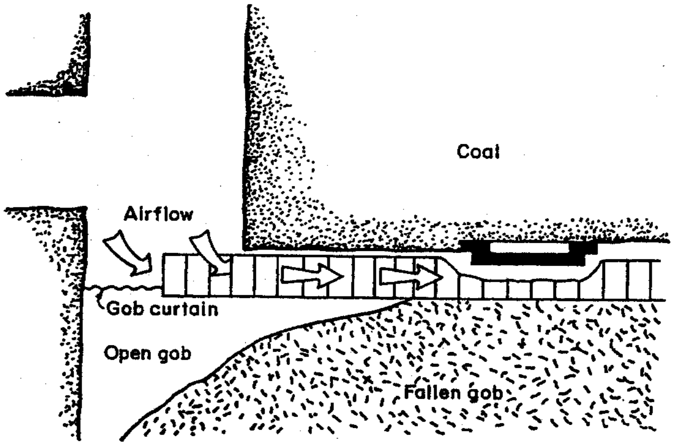

FIGURE 20.4 Gob curtain forces air to stay on longwall face

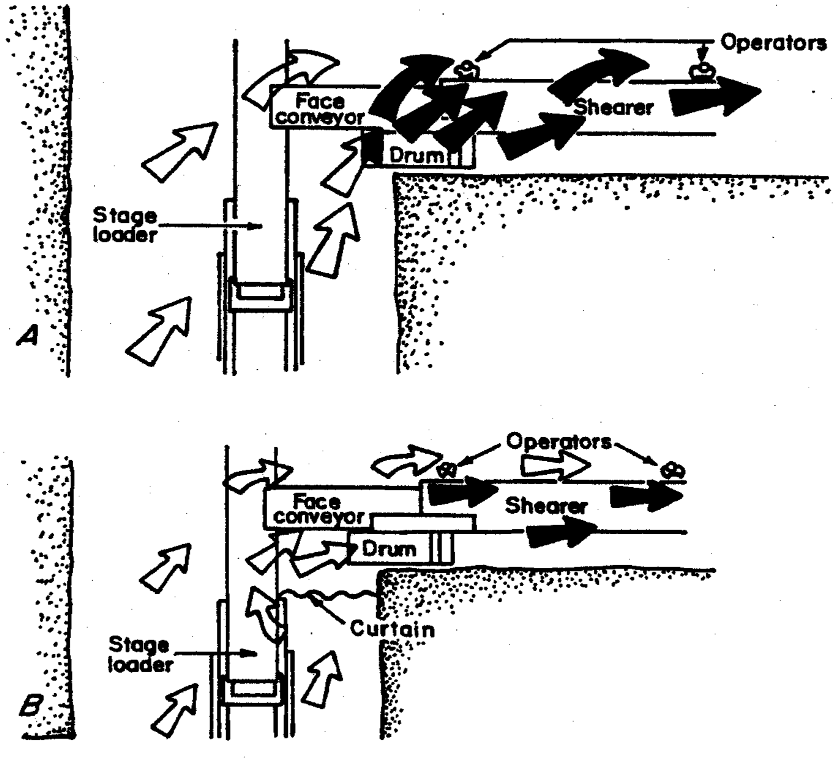

FIGURE 20.5 Airflow at longwall headgate without (a) and with (b) a wing curtain

Support Movement Practices During bidirectional cutting, shield advance will occur in both cutting directions. In these cases, supports are moved on the intake-air side of the shearer as it cuts head-to-tail (downwind). Shearer operators are then exposed to any dust generated by support movement. Under these circumstances, some mine operators find that support-generated dust can be effectively diluted before it reaches the shearer operators by increasing the distance between support advance and the shearer from 6 to 15 m (20 to 50 ft).

Water application on the immediate roof may also help to suppress some of the support dust generated during lowering, advancing, and resetting the roof supports. The immediate roof can be wetted by: (1) spraying the roof with one or more water sprays mounted on top of the shearer body, directing water downwind, at an upward 45-degree angle; (2) supplying enough water at the shearer drum sprays to wet the roof while the face is being cut.

In addition, shield supports can now be equipped with water sprays in the shield canopy that are used to wet the roof material on top of the shields. Typically, these sprays are automatically activated during the shield advance cycle. The shield spray systems have the potential to reduce dust liberation during shield advance, but require diligent maintenance and upkeep to ensure proper operation.

Finally, roof support automation can contribute to reduced dust exposure. Automation allows jacksetters to minimize their time downwind of dust sources.

Personal Protection Devices

The Federal Coal Mine Health and Safety Act of 1969 mandated that approved respiratory equipment be made available to personnel when exposed to respirable dust concentrations greater than 2.0 mg/m^3. However, this equipment cannot be used in lieu of achieving the 2.0 mg/m^3 standard.

Air Helmet The air helmet is a redesigned hard hat equipped with a battery-powered fan, filtering system, and face visor, thus providing protection for the head, lungs, and eyes within one unit. Although the air helmet is slightly larger and heavier than conventional hard hats, weighing approximately 1.4 kg (3 lb), wearer acceptance has been favorable in high coal seams.

A small fan is mounted in the rear of the helmet to draw dust-laden air through a filtering system; the resulting cleaned air is directed behind a full-face visor and over the wearer's face. Seals are provided along both sides of the visor so that exhaled air and excess clean air are allowed to exit the helmet at the bottom of the visor. Also, these face seals and additional seals inside the helmet limit contamination from unfiltered air. The fan is externally powered by a rechargeable battery smaller than a conventional cap-lamp battery to be worn on the miner's belt.

The air velocity outside of the helmet and the direction of air impact on the helmet can have a major impact on the effectiveness of the helmet (Cecala et al. 1981). For example, at a longwall face with an air velocity less than 2.0 m/s (400 fpm), the air helmets reduced respirable dust by an average of 84%. However, at another longwall with an air velocity of 6.0 m/s (1200 fpm), the air helmet was not as effective, with an average reduction of 49%. The sampling included periods when the face visor was lowered and periods when it was raised, according to normal underground use; this would tend to minimize differences between inside and outside samples, thus reducing the apparent effectiveness of the helmet.

Replacement Filter Respirators The replacement filter respirator consists of a filter-holding unit, typically fabricated from plastic, metal, or hard rubber, which also contains intake and exhaust valves. Soft rubber or cloth is used to form a face piece around the filter-holding unit, forming a seal against the wearer's face in an attempt to prevent dust-laden air from bypassing the filter. With a reasonably leak-tight face piece fit, the respirator should remove up to 95% of the respirable dust. During one respirator evaluation program (Cole 1984), two models of face-mask respirators were tested on four longwall sections. The dust exposure of workers was reduced by 80% to 92%.

Although the replacement filter respirator does an excellent job of dust removal when properly fitted, some personal discomforts may arise, including increased breathing resistance, aggravated by dust loading on the filter, facial irritation caused by the face seal, inference with normal voice communication, and interference with eye glasses or goggles.

Single-Use Respirators The single-use respirator employs a much lighter and simpler design than the replacement filter respirator. The entire mask is fabricated from filter material and covers the mouth and nose, similar to a surgical mask. Single-use respirators offer some advantages when compared to the replaceable-filter respirators. They are more comfortable and require no maintenance. However, single-use respirators usually do not form as tight a seal against the wearer's face as replaceable-filter types, thus allowing more leakage. As a result, they are much less effective than replacement-filter types.

Underground Metal Mine Dust Control

The exposure of workers to respirable dust in hard-rock mines, including both metal and nonmetal mines, may be reduced by a systematic approach that includes all or some of the practices discussed in this section.

Proper Use of Water in Drilling and Blasting Adequate water suppresses drilling dust. Enough must be provided to keep the rock surface wet all the time, so that the rock is actually broken under a film of water. This does not, however, prevent dust from entering the air during the initial collaring period. Various means have been tried to prevent the escape of dust during collaring, ranging from simple hand-held sprays to elaborate types of suction traps around the end of the drill steel, but no single method has been found to be very efficient.

If some of the compressed air operating the drill leaks into the front head of the drill and escapes down the drill steel, it will cause dry drilling and carry dust out of the hole. Also, compressed air escaping through the front head release ports will atomize some of the water in the front head. This atomized water, which forms a fog at the front head release ports of many rock drills, evaporates rapidly; if the water gets dirty, as it often is, many dust particles will remain in the air.

Water is also important in controlling dust generated by blasting. The first step in controlling blasting dust is to ensure that the area surrounding the blast (walls, floor, and back) is thoroughly wetted beforehand. This precaution will prevent dust settled out during previous operations from becoming airborne. Furthermore, some of the dust created by the blast will adhere to the wet surfaces in the area, thereby reducing the concentration in the airstream. To improve the effectiveness of water when wetting down the area, a spray nozzle ensures an adequate spread of water over a greater area and prevents the settled dust from being stirred up. An alternative is to use a two-phase fog spray nozzle that employs both water and compressed air. These nozzles are effective at reducing dust and the amount of nitrous fumes (because of their solubility in water).

A moisture content of the rock of only 1% produces a very significant reduction in dust production when compared with dry rock. As it is difficult to maintain a uniform moisture content of 1% under conditions encountered underground, the optimum moisture content should be maintained at about 5%. The water used for dust suppression, particularly in drilling and in blasting, should be as clean as possible, in that the evaporation of dirty water can release considerable quantities of dust.

Preventing Dispersal of Dust The dispersal of respirable dust from crushers, conveyors, and similar equipment can be eliminated in most instances by confining the dust-producing operation within an enclosure and controlling the air contained therein. The air from within the enclosure can be exhausted directly to the upcast airway or, if this is not feasible, it can be filtered. The section of this chapter entitled "Minerals Processing Dust Control Devices and Systems" gives guidelines for dust collection systems.

Ore and waste passes produce large quantities of airborne dust. The broken rock delivered to the passes contains a considerable amount of inherent dust as a result of the preceding operations, which include blasting and loading. Furthermore, the autogenous grinding action of the rock as it is dumped and falls down the pass produces more dust. The first line of defense is to ensure that the rock is thoroughly wetted before delivery to the dump. More wetting can be obtained at the dump site by installing a mist-type atomizer to spray the rock as it falls into the pass. However, excessive use of water at the orepass can be objectionable for many reasons: (1) adverse impact on crushing and milling, (2) a large quantity of water may accumulate on top of the material in the chute, creating a hazard for workers on the lower levels, and (3) plugging of clay minerals.

The second step in lessening dust at ore and waste passes is to prevent its escape and dispersal into working areas by confining it within the passes. This can be accomplished by a system of stoppings and airtight doors over the dumps or "tipping" points. The maintenance of these doors is of prime importance.

A third step in lessening dust, difficult to accomplish in practice, is providing means to keep the confined ore or waste pass under negative pressure to ensure that all leakage paths are in draft, and to capture the air displaced when rock enters the raise. A suitable fan is used to exhaust air from a convenient point in the raise. The contaminated air is filtered or sent via a direct untraveled route to the return air raise.

Dilution Ventilation Ventilation is the best method for controlling contaminants at underground operations. Ventilation is undertaken in producing areas, such as stopes or scraper drifts, by directing an air split from the main ventilating stream through the workings. The design criterion is 0.15 to 0.25 m/s (30 to 50 fpm), depending upon the type of operation and other local conditions. Volume may have to be increased greatly in some instances—for example, high-speed drives or scraper drifts, where the severe dust-producing operations may require as much as 0.75 m/s (150 fpm).

In headings and raises, the design volume also is based on providing an air velocity of 0.15 to 0.25 m/s (30 to 50 fpm). In most cases, an overlap system will provide a satisfactory environment in most headings. An overlap system consists of a main ventilating duct that exhausts dusty air and a small fan and blowing line kept to within 6 to 9 m (20 to 30 ft) of the face. The length of the overlap of the exhaust and blowing lines depends upon the size of the drift and, in any case, should be at least 9 m (30 ft). The blowing volume should not exceed approximately 60% of the exhaust volume to avoid recirculation. The exclusive use of exhaust systems for auxiliary ventilation should be discouraged, since it is impractical to keep the end of the duct near the dust-producing operation, particularly when blasting.

Proper ventilation is critical since water alone is inadequate. Blasting dust and fumes should be diluted and exhausted to surface via an untraveled route, preferably an upcast raise designed for that purpose. If this is not feasible, the blasting schedule should be arranged so that the contaminated air will pass through working places when the miners are absent.

Avoiding Dust Dust avoidance is often the best way to prevent exposure to respirable dust. It is applied mainly after blasting by requiring a minimum reentry period, by arranging a fixed blasting time for each working place so that other workers are not exposed to the blasting dust and fumes, and by ensuring that blasting takes place only at the end of the shift when most other workers have already been withdrawn.

Other ways in which workers are kept out of dusty air are by arranging that they travel downcast shafts and by locating all underground waiting places in fresh air. Also, work may be scheduled in such a way as to reduce dusty operations upstream of a designated location.

Dust Control in Water Soluble Ores

This section reviews strategies to suppress and collect dust on cutter machines and face drills, where water usage must be restricted to very low flow rates because the ore is water-soluble. Typical flow rates are 0.063 L/s (1 gpm).

Cutting Machine Dust Control Achieving effective dust control on cutter machines can be difficult because there are five major dust sources. These are (1) the cutter chain during cutting, (2) the star wheel, (3) the cutter chain reentering the kerf, (4) the bug duster, and (5) a recirculation loop that develops within the kerf. The cutter chain during cutting and the recirculation loop are probably the most severe dust sources.

Wet-bar type cutting techniques are used to help control mine dust by keeping the cutting chain wet. As the chain cuts the kerf, it dampens the dust produced by the cutting action at the point of generation.

Three basic wet-bar techniques are used (Figure 20.6). Water-trickle system A uses a gravity-feed or low-pressure (less than 345 kPa or 50 psi) pump to send water through the bar and to discharge it at the bar tip. Water-spray system B uses a low-pressure spray nozzle located at the front of the cutter head. For protection, the nozzle can be located within the cutter head. Water-trickle system C used a gravity-feed or low-pressure pump to discharge water onto the cutter chain on either or both sides of the cutter head.

Tests on all three wet-bar designs conducted in two salt mines revealed no significant difference in their dust control performance. While there are many variations of the three designs, it is not expected that any one type will be more effective at controlling dust. Also, the performance of the three systems is independent of water flow rate when operated between 0.016 and 0.063 L/s (0.25 and 1.0 gpm). At these water flow rates, the average total dust reduction of the three systems is 60% to 70%.

Dust control efficiency deteriorates significantly when water flow is less than 0.016 L/s (0.25 gpm). Higher water flow rates (more than 0.032 to 0.063 L/s or 0.5 to 1.0 gpm) are not likely to improve the performance of the wet-bar system. Also, excess water causes the dust to cake and solidify on the bit

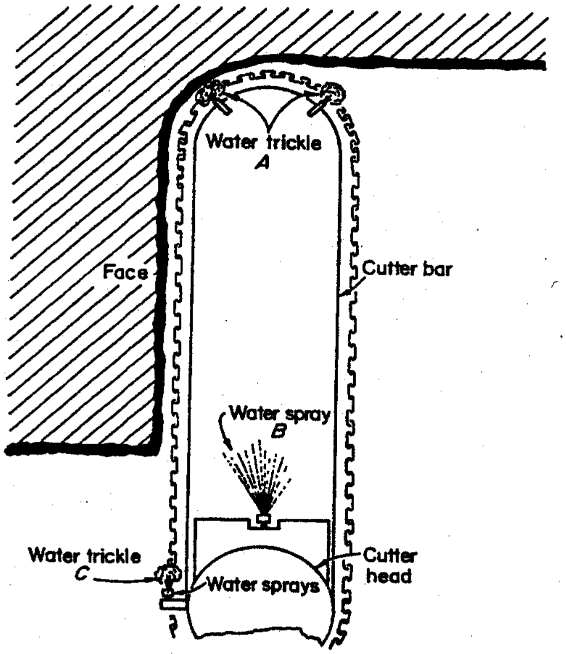

FIGURE 20.6 Wet-bar water spray systems

blocks, increasing bit-changing times. However, cutting the last few feet (meters) of the kerf dry helps to clean the bit blocks without producing a significant amount of dust.

Several dry collection systems on cutter machines have been tried but have been generally unsuccessful. The reasons are (1) they involve a large number of nonlocalized dust sources, (2) the tremendous amounts of dust produced are more than a machine-mounted collector can handle, and (3) the size of a suitable collector is not practical for machine mounting. More information on cutter machine dry collection systems is available in the literature (Page 1983).

Face-Drill Dust Control Dust control on face drills used in water-soluble ores is generally easier to accomplish than on cutter machines because there are fewer sources. Techniques include both wet and dry systems.

Wet dust suppression systems include external water sprays, water injection through the drill, and foam injection though the drill. External boom-mounted systems are typically homemade and reduce dust by about 50%. Water-mist injection through the drill is available from several manufacturers. The resulting dust reduction is much better, typically 90% or more. A homemade foam system has also been used successfully (USBM 1982c). It achieved 95% dust reduction at lower water flow rates.

Dry collection systems are generally inferior to wet suppression systems. This is due primarily to the inability of dry collection systems to maintain effective intake dust capture because of face irregularities. The overall dust reduction is a product of the inlet capture efficiency and the filtration efficiency of the collector. Therefore, high filtration efficiency is pointless unless the inlet dust capture efficiency is also very high.

An additional reason why dry systems are generally inferior to wet systems is maintenance. Dry systems require that the dust collected be disposed of in some convenient manner. Wet systems require no material handling; the wetted material merely dribbles down the face. One dry collector tested has shown 76% respirable dust efficiency (Page 1983).

Surface Mine Dust Control

Personal exposure to respirable dust at surface mines primarily results from overburden drilling. Both wet and dry methods are available to suppress dust from this source. Haul road dust control is also important.

Overburden Drilling/Wet Suppression Wet drilling systems consist of a water tank mounted on the drill from which water is pumped into the downhole airline. The water droplets in the bail air conglomerate dust particles as they travel up the annular space of the drilled hole, thus controlling dust as the air bails the cuttings from the hole.

In wet drilling systems, typical water flow rates are 0.0063 to 0.126 L/s (0.1 to 2.0 gpm) depending upon the size and type of drill, as well as the condition of the material being drilled. Flow rate is controlled manually by the drill operator by means of a control valve located in the cab. Some drills may also be equipped with a flow meter to give the operator a visual indication of the flow rate. The operator simply watches the cuttings as they are bailed from the hole and adjusts the flow rate according to how moist the cuttings appear to be. This technique can be effective; however, the delay between the time the valve is opened and the time the cuttings are expelled from the hole can be several seconds. This makes it difficult for the operator to find the proper flow setting. This is especially true when drilling through alternating dry and wet strata.

Too much water pumped into the bail air wets the drill cuttings to a point where they are too heavy to be bailed up the hole. This can result in undesirable regrinding of the cuttings as well as the drill string becoming seized in the hole. Excessive water in the hole may also result in plugging the air orifices of the bit and hastening bit degradation. The most obvious drawback to wet system drilling occurs when the outside temperatures drop below freezing. The entire system must then be heated while the drill is in operation, and during downtime the system must be drained.

Tests show that wet suppression systems can effectively control respirable dust (USBM 1987). Control efficiencies for 200-mm (8-in.) holes varied from a low of 9.1% at a flow of 0.013 L/s (0.2 gpm) to a high of 96.3% at a flow of 0.076 L/s (1.2 gpm). The most significant increase in efficiency is generally between 0.013 and 0.038 L/s (0.2 and 0.6 gpm). The rate of increase of efficiency then decreases until the drill's upper flow limit is reached. In the case of the drills tested, a flow rate approaching 0.063 L/s (1.0 gpm) began to cause operational problems.

To operate at close to the optimum water flow rate, the operator slowly increases the amount of water just to the point where visible dust emissions abate. Due to the initial sharp increase of dust control effectiveness, the visible dust abatement point is easy to identify. Increasing water flow beyond this point does not yield any significant improvements in dust control, but will most likely cause increased bit degradation and possible seizing of the drill stem.

Overburden Drilling/Dry Collection The use of a dry system involves enclosing the area where the drill stem enters the ground. This enclosure is usually accomplished by hanging a rubber or cloth "shroud" from the underside of the drill deck. This enclosure is ducted to a dust collector, the clean side of which is equipped with a fan. The fan creates a negative pressure inside the entire system, thus capturing dust as it exits the hole during drilling. The dust is removed in the collector device and clean air is exhausted through the fan.

The integrity of the drill stem shroud, including how well it seals to the ground, is probably the single most important factor contributing to the effectiveness of a dry collection system. The shrouded volume under the drill deck should be at least 1.8 times the volume of the hole and should be at a negative pressure of at least 50 Pa (0.2 in. of water). The air is ducted out of the drill stem shroud either from the top of the shroud near the outside edge or from the side of the shroud near the top. Varying the open area of the shroud changes the shroud's dust capture efficiency. As the open area is reduced, the velocity in the open area increases. The most common open area is the gap between the bottom of the shroud and the ground, which is called the shroud height. With a shroud height of 150 to 225 mm (6 to 9 in.) or lower, it is apparent that the control system works well. However, as the height increases, the control efficiencies decrease.

During drilling, it is sometimes necessary to raise the drill shroud. This is done for two reasons: (1) the driller/helper needs to shovel the cuttings to prevent them from falling back into the hole, and (2) the operator must be able to observe when the coal seam has been reached and stop drilling. As a result, there are times when a broken seal between the shroud and the ground or cutting cannot be avoided. Therefore, it is important for the driller to keep the open area to a minimum. This involves raising the drill shroud frequently.

Dust collection efficiency also decreases if significant leaks are present from gaps or holes in the shroud. Most deck shrouds are rectangular and constructed from four separate pieces of rubber belting attached to the deck. Consequently, leakage can often occur at the corner seams as the individual pieces of belting separate from one another.

Testing was completed by NIOSH (Page et al. 1998) to evaluate a circular drill shroud design that was capable of being hydraulically raised and lowered. The circular shroud is attached to the drill deck with steel banding, which is also used to seal the one seam in the sheet rubber material used to fabricate the shroud. A steel band is also attached to the bottom of the shroud to maintain shape and provide weight for lowering the shroud to the ground. The shroud can be raised and lowered through activation of a hydraulic cylinder and guide wires attached to the bottom steel band. The cylinder is controlled by a hand valve located near the drill controls. The shroud is also equipped with a small trap door that can be manually opened to allow cuttings to be shoveled from inside the shroud without having to raise the shroud above the ground. Sampling results indicated that, when drilling with the shroud lowered to the ground, this type of shroud design maintained dust levels below 0.5 mg/m^3.

Enclosed Cabs Enclosed cabs on mining equipment can also offer substantial protection for the drill operator from outside dust sources. The most effective protection is achieved when filtered air is blown into the cab and all cab seals are well maintained. Filtered air conditioning/heating units are available to control the working environment in the cab. The filtered air units provide a clean air source and, if adequate seals are in place, the positive air pressure will prevent dust leakage into the cab. To ensure the effectiveness of filtered air units, the operator must minimize the time that cab doors and windows are opened.

Haul Road Dust Control Many methods are available for haul road dust control. Water is the most obvious, but there are many others, including:

- **Salts**—hygroscopic compounds, such calcium chloride, magnesium chloride, hydrated lime, and sodium silicates
- **Surfactant**—substances capable of reducing the surface tension of the transport liquid, such as soaps, detergents, and dust-set monawet
- **Soil cements**—compounds that are mixed with the native soils to form a new surface; for example, calcium lignon sulphonate, sodium lignon sulfonate, ammonium lignon sulphonate, and portland cement
- **Bitumens**—compounds derived from coal or petroleum, such as coherex peneprime, asphalt, and oils
- **Films**—polymers that form discrete tissues, layers or membranes, such as latexes, acrylics, vinyls, and fabric

Salts increase roadway surface moisture by hygroscopically extracting moisture from the atmosphere. Surfactants decrease the surface tension of water, which allows the available moisture to wet more particles per unit volume. Soil cements, bitumens, and films generally form coherent surface layers that seal the road surface and thereby reduce the quantity of dust generated.

A study by Rosbury and Zimmer (1983) showed that the highest control efficiency measured for a chemical dust suppressant, 82%, was for calcium chloride two weeks after application. Generally, however, the control efficiencies hovered in the 40% to 60% range over the first 2 weeks after application, then decreased with time. After the fifth week beyond application, the limited number of data points suggests a control efficiency of less than 20%. Composite watering data were fairly uniform. Watering once per hour resulted in a control efficiency of approximately 40%. Doubling the application rate increased the control effectiveness by about 15% to 55%. The study also showed that chemical dust suppressants (primarily salts and lignons) can be more cost-effective than watering under some conditions.

The cost of using a dust suppressant is very site-specific. Certain types of dust suppressants work better in certain types of road aggregate. Recommendations are:

- **Gravel.** In road surfaces with too much gravel, only watering will be effective. Chemical dust suppressants can neither compact the surface because of the poor size gradation, nor form a new surface, and water-soluble suppressants will leach.

- **Sand.** In compact sandy soils, bitumens, which are not water-soluble, are the most effective dust suppressant. Water-soluble suppressants such as salts, lignons, and acrylics will leach from the upper road surface. However, in loose, medium, and fine sands, bearing capacity will not be adequate for the bitumen to maintain a new surface.
- **Good gradation.** In road surfaces with a good surface graduation, all chemical suppressant types offer potential for equally effective control.
- **Silt.** In road surfaces with too much silt (greater than about 20% to 25% as determined from a scoop sample, not a vacuum or swept sample), no dust suppression program is effective, and the road should be rebuilt. In high silt locations, the chemical suppressants tend to make the road slippery and are not able to compact the surface nor maintain a new road surface because of poor bearing capacity. Further, rutting under high moisture conditions requires that the road be regraded, which almost completely destroys chemical dust suppressant effectiveness. If the road cannot be rebuilt, watering is the best program.

All chemical dust suppressants (with infrequent watering) share one common failing as compared with frequent watering. Material spillage on roadways is very common, and the material spilled is subject to reentrainment. With frequent watering, newly spilled material is moistened at close intervals. With chemicals and infrequent watering, newly spilled material could go for long periods before being moistened. Therefore, in mines where spillage cannot be controlled, watering is more effective for dust control.

In locations where trackout from an unpaved road to a paved road is a problem, chemical suppressants are generally a good choice. Watering aggravates the trackout problem with moisture and mud, whereas chemical suppressants, particularly bitumens and adhesives, leave the road dry. Finally, some mines have a dust problem in winter when temperatures are subfreezing but little moisture is present. The case for chemical suppressants over water in this case is clear.

Minerals Processing Dust Control Devices and Systems

Belt Conveyors Belt conveyors can be a major source of dust. To minimize dust emissions, the material being carried should be loaded onto the center of the belt. Ideally, the belt conveyor should be designed to operate at 75% of its full rated capacity. Closely spaced impact idlers (0.3-m or 1-ft centers) should be located at transfer points. These absorb the force of impact and prevent deflection of the belt between the idlers, thus preventing dust leakage under the skirting rubber seal. Skirtboards are used to keep the material on the belt after it leaves the loading chute. They are equipped with flat rubber strips that provide a dust seal between the skirtboards and the moving belt. Improved skirtboard designs are also available (Mody and Jakhete 1987).

Muckshelves can be installed in the belt conveyor's material impact zone to load the material centrally on the belt. A belt scraper should be installed at the head pulley to dislodge fine dust particles that may adhere to the belt surface. A scrapings chute should also be provided to redirect the material removed by the belt scraper into the process stream or a container. A V-plow installed on the noncarrying side of the belt will clean the belt and prevent buildup of material and dust on the tail pulley, thus keeping the belt properly aligned.

Water applied to the belt can go a long way in reducing dust. A small quantity sprayed onto the noncarrying side of the return belt will reduce dust (Ford 1973). Water washing belt scrapers are used to clean the carrying side of the return belt (Planner 1990).

A good general reference on conveyor belt dust control is *Foundations 2—The Pyramid Approach to Control Dust and Spillage from Belt Conveyors* (Swinderman et al. 1998).

Transfer Chutes Transfer chutes transport ore from one piece of equipment to another. The following specifications should be used when designing a transfer chute: (1) the chute depth should be at least three times the maximum lump size to avoid jamming; (2) the chute should be designed so that the material falls on the sloping bottom of the chute and not on the succeeding equipment; (3) wherever possible, the material should fall on a local rockbox or stonebox rather than on the metal surfaces; (4) abrupt changes of direction must be avoided to reduce the possibility of material buildup, material jamming, and dust generation; (5) curved, perforated, or grizzly chute bottoms should be used when the product stream consists of fines and lumps—placing a layer of fines ahead of the lumps on the belt helps prevent heavy impact of material on the belt, which reduces belt wear and dust generation; (6) spiral chutes should be used to prevent breakage of fragile or soft material; and (7) bin-lowering chutes should be used to feed bins and hoppers without generating large amounts of dust.

Enclosures Enclosures are used to contain dust emissions around a dust source. When designing an enclosure for a dust source, the following parameters should be employed: (1) enclosures should be spacious enough to permit internal circulation of the dust-laden air; (2) enclosures should be arranged in removable sections for easy maintenance; (3) a hinged access door should be provided to aid routine inspection and maintenance; and (4) dust curtains should be installed at the open ends of the enclosures to contain dust and reduce airflow.

Crushers Crushers emit dust primarily from two points, the discharge and the feed. Dust control measures are not usually considered in the design of a crusher. However, the use of shrouds or enclosures for crushers can contain the dust so that a dust control system can operate more efficiently. In installing crushers, the following measures are recommended: (1) a crusher feedbox with a minimum number of openings should be installed, and rubber curtains should be used to minimize dust escape and airflow; and (2) the crusher should be choke-fed to reduce air entrainment and dust emission. Dust escape at the crusher discharge end can be minimized by properly designed and installed transfer chutes.

Screens The rate of dust generated by screens cannot be altered. However, properly enclosing the screen can reduce dust emissions. A complete enclosure that can be easily removed for maintenance and inspection should be used. Some screen manufacturers provide sheet-metal covers to enclose the top of the screen. These covers are effective when properly maintained. However, they do not provide a dust seal between the moving screen surfaces and the stationary chutes.

Storage Bins and Hoppers Dust emissions during feeding operations can be minimized by installing a bin-lowering chute and by completely enclosing the bin or hopper. Also, dust emissions can be minimized by installing a telescopic chute or by installing a loading spout. Loading spouts are sophisticated versions of the telescopic chute and are used to load and stack ore into barges, trucks, and railroad cars. The falling material is enclosed by a flexible duct, acting as a chute, which retracts as the height of the material pile increases. The duct also prevents airflow during free fall of material between the chute and stockpile. The generated dust is captured by the same flexible duct and is conveyed, countercurrent to the material flow, to a dust collector.

Bucket Elevators Bucket elevators emit dust from two points, the boot where material is fed and the head wheel where material is discharged. The steel casing that encloses the buckets and chain assembly contains dust effectively unless there are holes or openings in the casing. Emissions at the boot of the bucket elevator can be reduced by proper design of a transfer chute between the feeding equipment and the elevator. Dust production can be reduced significantly by keeping the height of material fall to a minimum and by gently loading material into the boot of the elevator. Proper venting to a dust collector will control dust emission at the discharge end of the bucket elevator.

Screw Conveyors Normally, screw conveyors are totally enclosed except at the ends, where emissions can be controlled by proper transfer chute design. To maintain a proper dust seal, a neoprene rubber gasket should be installed on the trough cover. Many manufacturers provide two-bar flanges and formed-channel cross members that make a continuous pocket around the trough. The flange-cover sections are set in this channel. Once the channel section is filled with dust, an effective dust seal is created.

Stockpiles All types of stockpiles can be a significant dust source. Generation of dust emissions from stockpiles is due to the formation of new stockpiles and wind erosion of previously formed piles. During formation of stockpiles by conveyors, dust is generated by wind blowing across the stream of falling material and separating fine from coarse particles. Additional dust is generated when the material hits the stockpile.

Dust from stockpiles can be reduced by:

- Minimizing height of free fall of material and providing wind protection using:
  - Stone ladders, which consist of a section of vertical pipe into which stone is discharged from the conveyor. At different levels, the pipe has square or rectangular openings through which the material flows to form the stockpile. In addition to reducing the height of free fall of material, stone ladders also provide protection against wind.

- Telescopic chutes, in which the material is discharged to a retractable chute. As the height of the stockpile increases or decreases, the chute is raised or lowered accordingly. Proper design of the chute can keep the drop to a minimum.
- Stacker conveyors, which operate on the same principle as telescopic chutes.

- Minimizing wind erosion of the stockpile by locating stockpiles behind natural or manufactured windbreaks, locating the working area on the leeward side of the active piles, and covering inactive piles with tarps or other inexpensive materials.
- Minimizing vehicle traffic on or around the stockpile.
- Using specialized equipment such as a reclaimer to minimize the disturbance of the stockpile or providing a tunnel underneath to reclaim the material.

Dust Collection Systems A dust collection system is one of the most effective ways to reduce dust emissions. The rate of airflow through the exhaust hood is the most important factor for all types of hoods. For local, side, downdraft, and canopy hoods, the location is also important because the rate of airflow is based on the relative distance between the hood and the source. The shape of the exhaust hood is another design consideration.

Ductwork design includes the selection of duct sizes based on the velocity necessary to carry the dust to the collector without settling in the duct. To prevent dust from settling and blocking the ductwork, transport velocities should range from 17.5 to 20 m/s (3,500 to 4,000 fpm) for most industrial dust (such as granite, silica flour, limestone, coal asbestos, and clay) and from 20 to 25 m/s (4,000 to 5,000 fpm) for heavy or moist dust, such as lead, cement, and quick lime.

Recommended minimum transport velocities for different types of dust are shown in Table 20.1.

Wet Dust Suppression Systems These systems fall into three categories:

1. **Plain water sprays.** This method uses plain water to wet the material. Advantages are low cost and simplicity of operation. However, large quantities of water may not be tolerable.
2. **Water sprays with surfactant.** This method uses surfactants to lower the surface tension of water. The droplets spread further and penetrate deeper into the material pile.
3. **Foam.** Water and a special blend of surfactant make the foam. Less water is necessary to achieve a given level of dust control. However, operating costs can be high.

Background Dust Sources Background dust sources can expose workers at mineral processing facilities to more significant dust concentrations than from their normal job functions. These background dust sources include such things as soiled work clothes, blowing clothes off with compressed air, broken bags of product material both at the fill station and during the conveying process, bag hoppers overflowing with product, improper housekeeping techniques such as dry sweeping of floors, and dusty makeup air that may flow into mill buildings from outside sources.

The best way to detect background dust sources is to use an instantaneous dust monitor with data logging capability. By monitoring the worker's exposure throughout the entire workday, significant dust-producing events can be identified and controlled.

Research has shown that total mill ventilation systems (Cecala et al. 1993) can be a cost-effective means of reducing background dust levels found in mineral processing operations. Fans are placed near the top of the mill and air intakes are strategically placed on lower levels to provide desired airflow movement through the structure. Test results indicated that dust reductions of 40% to 60% were achieved.

A good general reference for minerals processing dust control is the *Dust Control Handbook for Minerals Processing* (Mody and Jakhete 1987).

TABLE 20.1 Recommended minimum transport velocities

	Minimum Design Velocity,	
Material	m/s	fpm
Very fine, light dusts	10	2,000
Fine, dry dusts and powders	15	3,000
Average industrial dusts	17.5	3,500
Coarse dusts	20 to 22.5	4,000 to 4,500
Heavy or moist dust loading	>22.5	>4,500

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