Impact on air environment due to underground space construction

Renaldy, T. Amrith
Roy, Surendra
Scientist, National Institute of Rock Mechanics,
Kolar Gold Fields, India

Abstract

Developing underground space can solve the space problems, but has an adverse impact on environment as it adds on to air pollutants such as dust and gases. During construction phase of underground projects, machineries such as tunnel boring machines, road headers, continuous miners, etc and other unit operations like drilling, blasting, crushing, loading and transportation of materials are carried out. These activities emits considerable amount of dust and gaseous pollutants which pollute the environment. Mist of water and oil also contribute to air pollution. The constrained work environment arises due to use of different machineries in limited space affecting the dissipation of pollutants. Dust and gaseous sampling instruments can be used to monitor air pollutants. Real-time respirable dust monitors can collect real-time fugitive dust levels that relate to specific activities of underground operations.

This paper focuses on the various elements that affect the air environment, caused by airborne dust particles and gaseous pollutants due to the subsurface mining activities. Various means to control dust and gaseous pollutants by water sprinkler patterns, use of high expansion foams during the machine operation, modern ventilation practice and use of personal protective equipment for underground excavations are explained in this paper.

1.0 Introduction:

As mining operations in the United States (US) have become more productive, controlling the dust exposure of mine workers has become more challenging. In response, US mining operations are applying basic controls at elevated levels and are looking to emerging control technologies in an effort to better control airborne respirable dust levels.

Average longwall production as reported by mine operators during compliance dust sampling in 2006 was 4,800 tons (5,300 short tons) per shift (Niewiadomski 2007). This production has been achieved through improved machine reliability and improved operating practices. Average longwall panel size in 2002 was 287 m (940 ft) wide and nearly 3050 m (10,000 ft) long (Rider and Colinet 2007). These improvements in longwalls challenge dust control efforts. In 2006, 16% and 14% of compliance samples exceeded the applicable dust standard for the tailgate shearer operators and jacksetters, respectively.

In addition to improvements and changes being realized on US longwalls, continuous mining operations have also seen dramatic changes. Average production on the approximately 780 continuous miner sections during compliance sampling reached 690 tons (760 short tons) per shift in 2006 (Niewiadomski 2007).

The vast majority of continuous miners are now operating with flooded bed scrubbers and taking extended cuts that are greater than 6 m (20 ft). An increase in the number of mines utilizing super sections (sections with two continuous miners) has also occurred. However, utilization of super sections has increased the potential for roof bolter operators to work downwind of a continuous miner, resulting in increased dust exposure. A negative change that has occurred has been an increase in the quantity of rock that is being cut as seam conditions deteriorate. Cutting of this rock has the potential to add significant quantities of silica dust to the mine environment, resulting in 51% of mines operating on reduced dust standards. In 2005, 11% of continuous miner operator and 12% of roof bolter operator samples exceeded their applicable dust standard. This paper deals with various elements that affect the air environment during underground workings and means to control dust and gaseous pollutants.

2.0 Dust generation in underground:

In various underground projects, machineries such as tunnel boring machines, road headers, continuous miners, etc and other unit operations like drilling, blasting, crushing, loading and transportation of materials are carried out. These activities emits considerable amount of dust pollutants which pollute the environment. The machines that produce extraction dust are longwall shearers, continuous miners, tunnel boring machines, and road headers. For these, the deeper the cut and the larger the chips, the less the dust produced per pound of material removed (Ludlow and Wilson 1982). Of the factors that impact cut depth, the one under the control of the mine operator is the sharpness and the lacing pattern of the cutting tools. Lab studies on conical cutting bits have shown that significantly worn bits without their carbide tips produce much more dust (Organiscak et al. 1995). In removing and transporting mined material, the broken material is inevitably dropped. At longwall faces, the broken coal can fall 6 ft or more to the pan line. At tunnel boring machines, rock removed at the crown can drop 25 ft or more. At conveyor belts, the dropping of material from one belt to another can be a major dust source. The amount of explosive used for blasting also contributes to the dust source, the finer breaking of rocks produce more dust.

3.0 Underground dust control:

Ventilating air, water sprays and water additives are the primary controls used for protecting workers from overexposure to respirable dust. Ventilation provides reduced dust levels through dilution of generated dust and through transporting dust away before it can migrate to the breathing zones of miners. As a result, efforts must be made to maximize the quantity and quality of ventilating air that reaches the face. This is achieved by ensuring that dust levels in the intake air steam are low, that stopping and curtains are tight, and that as much of the intake air is directed down the face as possible. Out by dust sources can be controlled by wetting roadways, minimizing out by dust-producing activities (unloading supplies, removing stopping), and ensuring that sufficient coal wetting occurs before being transported out the belt entry. In recent surveys of US longwalls, the average face airflow was found to be 3.4 m/sec (665 fpm) with an estimated average air quantity of 31.6 m^3/sec (67,000 cfm). This air quantity represents a 65% increase in airflow from 10 years ago (Rider and Colinet 2007).

3.1 Dust control by ventilation:

Ventilation air reduces dust through both dilution and displacement. The dilution mechanism operates when workers are surrounded by a dust cloud and additional air serves to reduce the dust concentration by diluting the cloud. The displacement mechanism operates when workers are upwind of dust sources and the air velocity is high enough to reliably keep the dust downwind.

3.1.1 Dilution Ventilation:

The basic principle behind dilution ventilation is to provide more air and dilute the dust. Most of the time the dust is reduced roughly in proportion to the increase in airflow, but not always. The cost of and technical barriers to increased airflow can be substantial, particularly where air already moves through ventilation ductwork or shafts at velocities of 3,000 ft/min or more.

3.1.2 Displacement Ventilation:

The basic principle behind displacement ventilation is to use the airflow in a way that confines the dust source and keeps it away from workers by putting dust downwind of the workers. Every tunnel or mine passage with an airflow direction that puts dust downwind of workers uses displacement ventilation. In mines, continuous miner faces or tunnel boring machines on exhaust ventilation use displacement ventilation. Enclosure of a dust source, such as a conveyor belt transfer point, along with extraction of dusty air from the enclosure, is another example of displacement ventilation.

Displacement ventilation can be hard to implement. However, if done well, it is the most effective dust control technique available, and it is worth considerable effort to get it right. The difficulty is that when workers are near a dust source, say, 10 to 20 ft from the source, keeping them upwind requires a substantial air velocity, typically between 60 and 150 ft/min. There is not always enough air available to achieve these velocities. To compensate for the lack of air, two techniques are used. The first is to reduce the cross sectional area of the air course between the worker and the dust source. This confines the dust source by raising the air velocity. Second, the turbulence of the dust source is reduced. A turbulent dust source creates dusty eddy currents of air that back up against the airflow and push upwind toward the worker. When the dust source is less turbulent, less air is required to confine the dust cloud. The best way to illustrate displacement ventilation is to consider four specific mining examples.

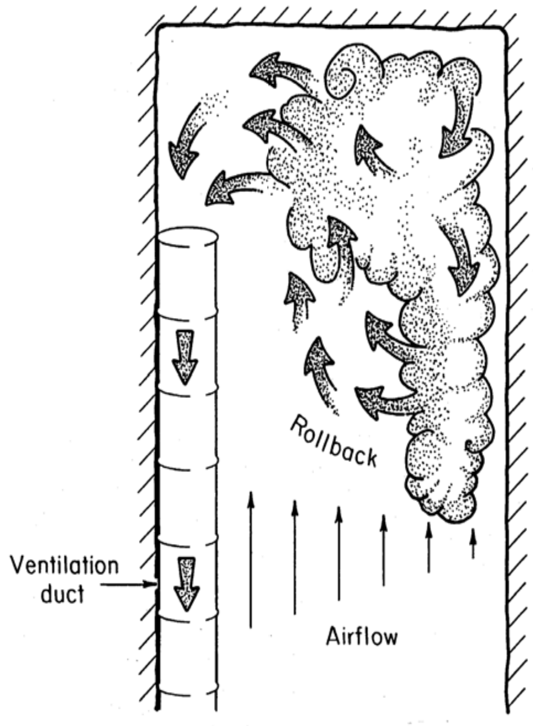

Figure 1 Rollback of dust resulting from non uniform airflow.

Example No. 1: Continuous miner faces on exhaust ventilation.—To confine the dust cloud at continuous miner faces, U.S. coal mine ventilation regulations require an average air velocity of 60 ft/min. This velocity is based on the entry cross-section without considering the area blocked by the equipment. However, 60 ft/min is a bare minimum, as it has been shown that 120 ft/min is required for good dust control (USBM 1985). This relatively high air velocity is required because a typical coal mine entry is about 18 ft wide, and over this width the air velocity is not uniform. The air velocity is much higher on the side next to the ventilation duct, as shown in figure 1.

Air turbulence created by the machine water sprays causes the dust cloud at the cutting face to expand and back up against the weaker airflow on the side opposite the ventilation duct. In mining, this is called rollback. It is surprising how far dust can roll back to contaminate the incoming air breathed by mine workers. Rollback can be reduced by increasing the airflow. The air turbulence that causes rollback can be reduced by lowering the spray water pressure and aligning spray nozzles so that they are confined only to spray on the broken coal.

Also, in high coal where the cross-sectional area is very large, a half-curtain in the entry is helpful. This curtain, shown in figure 2, is placed between the mining machine and the right or left rib, whichever is farthest from the mining machine (Jayaraman et al. 1986). A half-curtain reduces the cross-sectional area of the entry and raises the air velocity to confine the dust cloud. In addition to the half-curtain, there are many possible mining applications where a temporary curtain or screen can be used to channel airflow or raise the air velocity to keep nearby workers upwind of a dust source.

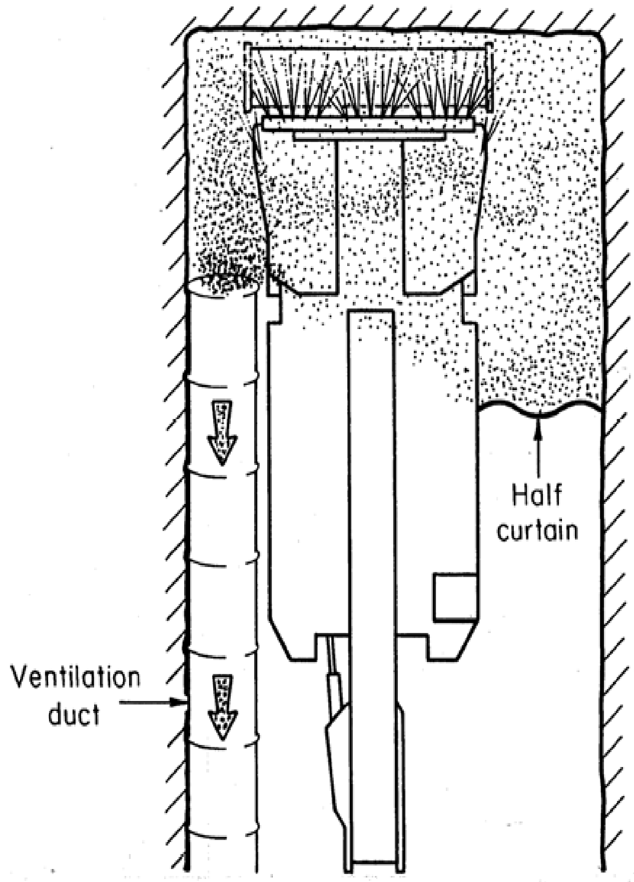

Figure 2 A half-curtain raises the air velocity to confine the dust cloud.

Example No. 2: Closed-face tunnel boring machine (TBM).—Cutter heads of hard-rock tunnel boring machines operate in what most would regard as an enclosed space. However, Myran (1985) has published recommended air quantities needed to confine dust to the cutter head space, and they are high. For example, a 20-ft-diam TBM requires 12,000 to 17,000 cfm. First, the stirring action of the large rotating cutter head creates a considerable amount of air turbulence. Second, there is far less enclosure of the cutter head than a casual inspection of a TBM would indicate. Depending on the TBM design, the entire belt conveyor access space can be open. Also, there is considerable open space when the grippers at the head expand to press out against the tunnel walls. Dust reduction efforts have focused on reducing the open space available for dust leakage by enclosing the conveyor tunnel and by installing single or even double sets of rubber dust seals between the grippers and TBM body.

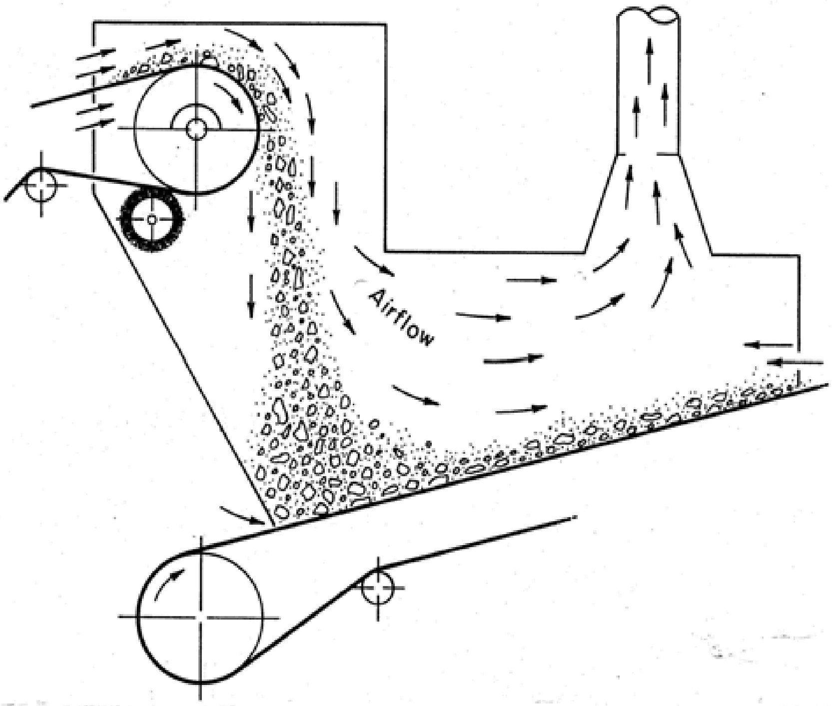

Figure 3 Conveyor belt transfer point enclosure

Example No. 3: Conveyor belt transfer point enclosure.—In addition to maintaining high airflow, sometimes it is necessary to extract the air at the right location in order to adequately confine dust. Figure 3 shows a conveyor transfer point enclosure. The design of this and similar enclosures used in materials transport has been well worked out (Goldbeck and Marti 1996; Swinderman et al. 1997). In principle, a high degree of enclosure is possible, so even moderate airflow extracted from the enclosure should keep dust inside. However, the falling material drags air with it, creating an unbalanced pressure in the enclosure that pushes dust out of the high pressure end of the enclosure. The most effective designs address this issue by locating the exhaust port at the high-pressure end and exhausting sufficient air. Other designs incorporate steps to break the fall of the rock and thus diminish the amount of air moved. However, if the dust seals along the belt and the rubber flaps at the end of the enclosure are worn or missing, even the best designs available will leak dust.

Example No. 4: Dust avoidance measures. Dust avoidance refers to moving either the dust cloud or the workers so that the workers are upwind of the dust. The use of remote control on coal mining machinery is the best example of dust avoidance in mining. On longwall shearers, remote control has enabled the shearer operators to move upwind 15-20 ft and avoid direct contact with the dust cloud coming off the head gate-end shearer drum, which reduces their dust exposure by 68% (USBM 1984). On continuous miners, remote control has enabled the operator to step back toward the intake by about 12 ft and reduce the dust exposure level by 50% or more (Divers et al. 1982).

3.2 Dust control by water sprays:

The role of water sprays in mining is a dual one: (1) wetting of the broken material being transported and (2) airborne capture. Of the two, wetting of the broken material is far more effective.

3.2.1 Wetting:

Adequate wetting is extremely important for dust control. The vast majority of dust particles created during breakage is not released into the air, but stay attached to the surface of the broken material (Cheng and Zukovich 1973). Wetting this broken material ensures that the dust particles stay attached. As a result, adding more water can usually (but not always) be counted on to reduce dust (Jankowski and Organiscak 1983; Ruggieri and Jankowski 1983; Zimmer et al. 1987). For example, coal mine operators have been able to reduce the dust from higher longwall production levels by raising the shearer water flow rate to an average of 100 gpm (Colinet et al. 1997). Compared to the amount of coal mined, on a weight basis, this 100 gpm is equivalent to 1.9% added moisture from the shearer alone. Unfortunately, excessive moisture levels can also result in a host of materials handling problems, operational headaches, and product quality issues, so an upper limit on water use is sometimes reached rather quickly. As a result, an alternative to simply adding more water is to ensure that the broken material is being wetted uniformly. Uniformity of wetting was recognized as an important issue long ago by Hamilton and Knight (1957), who measured the amount of dust generated by dropping coal. By far the best dust reductions came from pre spraying the coal with water and then mechanically mixing the coal and water together to achieve a uniformity of wetting. Subsequent mining experience has confirmed this. For example, releasing water at the cutting picks of rotating shearer drums has proven to be far more effective at suppressing longwall dust than using external sprays on the shearer body. This is because water released at the cutting picks gets mixed in with the broken coal, whereas water from external sprays usually provides just surface wetting. Increasing the number of sprays is another way to promote uniformity of wetting. Bazzanella et al. (1986) showed that dust suppression is improved by increasing the number of sprays on a shearer drum even when the total water flow and nozzle pressure were held constant with the use of smaller orifice nozzles. When 46 smaller orifice nozzles were substituted for the 17 original nozzles, dust was reduced by 60%. This is better than the dust reduction given by most dust control techniques. The benefits of improved mixing and uniformity of wetting have also been obtained with foam, with far greater effectiveness when the foam was mechanically mixed in with the coal [Mukherjee and Singh 1984] or mechanically mixed with silica sand (Volkwein et al. 1983).

The use of water for dust control is twofold. First, it is best to wet the material fully during the breakage process. This is when most mechanical mixing is likely to take place. Wetting during breakage ensures that the benefits will carry over to any downstream secondary handling operation. Second, uniformity of wetting is best achieved by using more nozzles at lower flow rates and ensuring that the nozzles are aimed at the broken material rather than just spraying into the air and wetting an adjacent metal or rock surface. While it is always best to aim sprays at broken material, circumstances dictate the impracticality of locating spray nozzles where they might be easily damaged. For example, spray nozzles under the boom of a continuous miner are more effective than those on the top of the boom (Matta 1976). However, top nozzles are more commonly used because sprays under the boom are damaged more often and are harder to maintain.

3.2.2 Airborne capture:

Under actual mining conditions, the typical water spray operating at 100 psi and 1-2 gpm gives no more than 30% airborne capture of respirable dust water blast sprays in metal mines. This is done using a combination of water and compressed air, were first used many years ago to reduce dust in metal mine headings after blasting. Brown and Schrenk (1938) saw dust reductions of 90%-99% from water blast sprays within 15 min after blasting. The reason for the difference (90%-99% instead of 30%) is that the water blast sprays had 15 min to work on a single-event dust cloud confined to the end of the heading. Most of the dust in the cloud re-circulated through the sprays again and again, whereas in most modern mining applications the dust cloud is generated continuously, and the dust only gets one pass of a few seconds through the sprays. This explains the 30% spray effectiveness in modern mining applications. In more recent years, McCoy et al. (1985) measured the effectiveness of water spray nozzles using a closed chamber in which a single-event dust cloud was re-circulated again and again through a spray. In a few minutes, the dust level was reduced by 90%, confirming the earlier observations of Brown and Schrenk, and others (Van der Bank 1977). (Courtney and Cheng, 1977). This is not as good as lab tests (Tomb et al. 1972) would lead one to believe. In lab tests, the sprays were usually confined in a duct, and all of the dust was forced to pass through the spray. However, under actual mining conditions, dust clouds are unconfined. In all sprays, the moving droplets exert drag on the adjacent air; thus, sprays act to move the air. Because of this air entrainment effect, if a spray is aimed at an unconfined dust cloud, it will carry in air that spreads the cloud, thus making capture by the spray less efficient. Aside from making sprays less efficient, the air entrainment of sprays can create other problems.

Figure 4 shows how some sprays on a longwall shearer actually raise the shearer operators dust level. For many years, it was a common practice to discharge the motor-cooling water by aiming it at the coal face under the theory that it would capture some airborne dust. Although some dust was captured, a considerable airflow toward the coal face was also created. That airflow, upon reaching the coal face, simply turned around and carried the rest of the dust cloud, formerly confined to the face, back over the operator. Perhaps one-fourth of the cloud was captured, but the remaining three-fourths were blown back over the operator, raising the operator’s dust level threefold (USBM 1981).

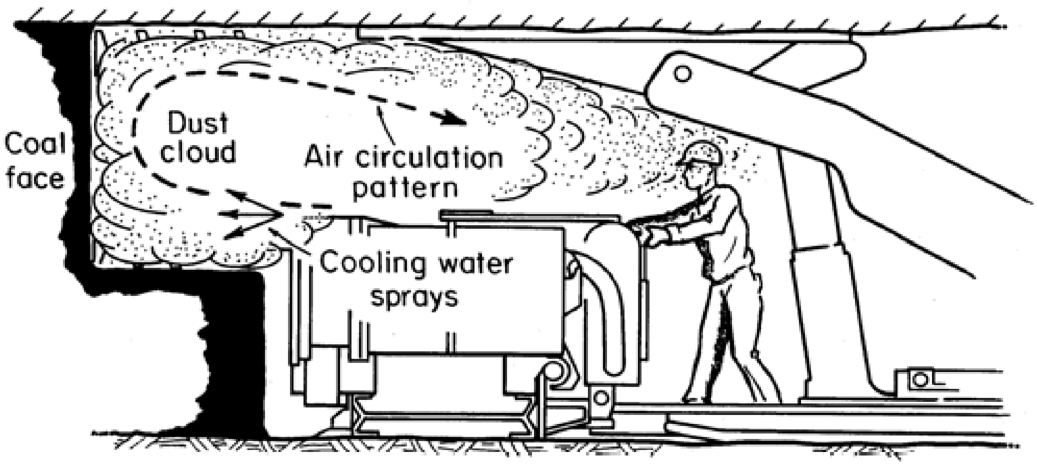

Figure 4: Spray-generated airflow carries dust back to the shearer operator.

Air entrainment of sprays can also lead to overrating their effectiveness. Figure 5 shows a conceptual example. A dust cloud is generated by a dust source, such as a belt transfer point, and the cloud surrounds much of the dust source (figure 5, left). A water spray is aimed at the cloud, and a dust sampler located on or near the source shows a substantial dust reduction when the spray is turned on. Most of this dust reduction is actually caused by the air currents induced by the water spray, which dilute and blow away much of the dust cloud (figure 5, right). Normally, this dust reduction would be misinterpreted as airborne capture by the spray droplets.

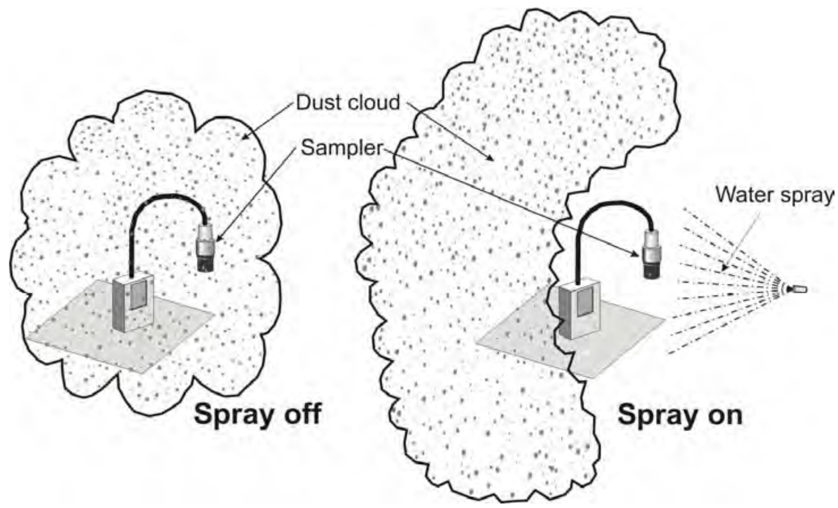

Figure 5 Water spray test that can lead to overrating spray effectiveness.

Attempts to improve the airborne capture efficiency of sprays have not met with practical success. One approach has been to reduce droplet size, based on the notion that capture by smaller droplets is more efficient. This effort has included atomizing or fog sprays, steam, sonically atomized sprays, compressed air-atomized sprays, and electrically charged atomized sprays (Bigu and Grenier 1989; McCoy et al. 1983). These methods usually offer somewhat better dust capture and some economy in the use of water, but have many disadvantages that prevent their use in mining. Nozzles with very small orifices are more prone to clogging. Fine droplets are likely to evaporate quickly and release captured dust along with the minerals that had been dissolved in the water (McCoy et al. 1983).

Despite the limitations of sprays, proper nozzle selection can enhance their use. Figure 6 shows the airborne capture performance of some common spray nozzle types at different pressures. Atomizing sprays are the most efficient. Hollow-cone sprays are a close second and are the best choice for practical mining applications because they have larger orifice nozzles and are less likely to clog. Flat fan sprays are more appropriate for spraying into a narrow rectangular space because less water is wasted by spraying against an adjacent rock or metal surface.

High-pressure sprays, one way to improve sprays is to raise the water pressure. This raises the efficiency per unit use of water, as shown in figure 6. Jayaraman and Jankowski [1988] tested the airborne capture of both conventional and high-pressure sprays at a full-scale model continuous miner face. A conventional spray system on the miner (100 psi, 19 gpm) gave 30% respirable dust reduction. A high-pressure system (2,500 psi, 3 gpm) gave the same reduction, but with much less water.

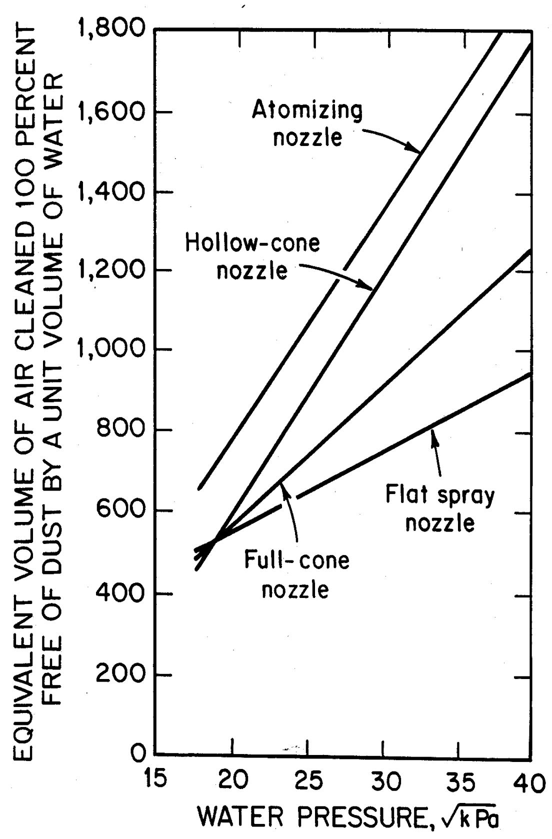

Figure 6: Airborne capture performance of four types of spray nozzles.

The two systems operating together (22 gpm) gave 59% dust reduction. The dual system would be the choice for underground use, providing both airborne capture and sufficient wetting of the broken material.

A marked disadvantage of high-pressure sprays is that they entrain large volumes of air, often leading to more dispersal of dust than is captured. Because of this secondary dispersal, their application is limited to enclosed or semi enclosed spaces, such as under the boom of a continuous mining machine.

3.3 Dust control by foam:

For dust control, foam works better than water. It provides dust reductions of 20% to 60% compared to water. Foam also can produce similar results at lower water use, that is, the amount of water needed to make the foam is less than the equivalent water spray. Seibel (1976) compared high-expansion foam to water sprays at a belt transfer point. Compared to water, the foam averaged an additional 30% dust reduction. Mukherjee and Singh (1984) found that foam released from a longwall shearer drum cut the dust an additional 50% compared to conventional water sprays on the drum. Also, the system used one-half the water of the conventional sprays. The drawback of the foam was high cost. Like water, foam works best when it is mechanically mixed with the broken material. A comprehensive review of foam for dust control in mining and minerals processing has been given by Page and Volkwein (1986).

3.4 Dust control by wet agents:

Wetting agents receive a disproportionate amount of attention, perhaps because they seem to offer an easy fix to dust problems. Most interest has been in coal mining because of the hydrophobic nature of coal. The effectiveness of wetting agents has been the subject of considerable research over the years, without much of a definitive answer on how well they work. Various studies have shown a respirable dust control effectiveness compared to plain water, averaging about 25% and ranging from zero (MRDE 1981; Chander et al. 1991) to 25%-30% (Kost et al. 1980) to more than 40% (Meets and Neethling 1987). It seems that wetting agent effectiveness depends on the type of wetting agent, type of coal, dust particle size, dust concentration, water pH, and water mineralogy (Hu et al. 1992; Kim and Tien 1994; Tien and Kim 1997). However, no general formula or methodology has emerged that would allow a mine operator to select a wetting agent appropriate for its specific coal (or rock) type. The only alternative is to try out a prospective wetting agent and discontinue its use if there is no clear benefit. However, given that the average effectiveness of a wetting agent is 25%, about the same as the accuracy of dust sampling methods, a wetting agent choice is never easy.

3.5 Dust control by various mining operations:

3.5.1 Extraction:

In machineries like tunnel boring machines, road headers, continuous miners, drilling machines, etc Aside from using sharper cutting bits, water can be applied as described above. Another application of water that reduces cutting dust is water infusion of coal seams. Although it has been largely abandoned because of high cost, water infusion of coal seams will reduce dust by about 50%. To infuse a coal seam, boreholes are drilled into the coal seam ahead of mining and large volumes of water are pumped in under high pressure to wet the coal (McClelland et al. 1987). Somewhat analogous to cutting is the grinding action of longwall shields as they are pressed against the coal mine roof. This dust is released into the air as the shields are lowered and moved forward. The factors affecting dust generated by longwall shields and the methods used to control this dust have been discussed by Organiscak et al. (1985).

3.5.2 Drilling:

In coal mines, the most common method of drill dust control is a dry collector with the intake at the tip of the drill bit. This arrangement provides excellent dust control if the collector is maintained properly (Divers and Jankowski 1987). In hard-rock mines and tunnels, water injection through the drill steel has been effectively used to control dust for many years (ILO 1965; Page 1982). Foam injection through the drill steel also can be used in those applications where excessive water can create a problem (Page 1982). Problems with wet drills usually result from maintenance difficulties such as failure to clean out clogged lines or refill water tanks. Dry dust collectors with the inlet located at the collar of the drill hole have also worked (Page and Folk 1984), but not as well as water or foam.

3.5.3 Blasting:

Blasting is done at a time when workers are not expected to enter the affected area of the mine for the next hour or so (Knight 1980). This allows some dust to settle out and the rest to be carried away by the ventilation system. Water can help control dust by wetting down the blast area.

3.5.4 Dropping:

In removing and transporting mined material, the broken material is inevitably dropped. At longwall faces, the broken coal can fall 6 ft or more to the pan line. At tunnel boring machines, rock removed at the crown can drop 25 ft or more. At conveyor belts, the dropping of material from one belt to another can be a major dust source. Where it is possible to do so, dust from falling material, whether at ore passes or at conveyor transfer points, is usually controlled by enclosure and exhaust ventilation (Marshall 1964).

3.5.5 Crushing:

Crushers in mines range from small roll types used in coal mines to large gyratory types used in hard-rock mines and mills. Whatever the size and method of crushing, dust is controlled by water sprays and local exhaust ventilation. The amount of water and air needed to do the job is hard to specify. It depends on the type of material being crushed and the degree to which the crusher can be enclosed. Jayaraman et al. (1992a) obtained substantial reductions in crusher dust at a longwall by enclosing the entire stage loader-crusher unit, using 18 gpm of water inside the enclosure, and extracting 2,500 cfm of air from the enclosure. Rodgers et al. (1978) described how dust from a 5-ft gyratory crusher was reduced by using a 75,000-cfm exhaust ventilation system and a control booth for the operators.

3.5.6 Conveying:

Conveying by railcar usually generates little dust. Rubber-tired vehicles will kick up dust if the mine floor is dry. This dust from the floor can be reduced by wetting, by calcium chloride, or by any of the chemical preparations used to control dust at surface mines (ILO 1965; Kissell 1992).

A conveyor belt can generate large amounts of dust from several sources. Dust originates at transfer points. It is also shaken from the belt as the belt passes over the idlers. Spillage of material from the belt can also be a big contributor. Further, a high velocity of ventilation air will assist the release of dust by drying the material and releasing settled particulate.

3.6 Dust Collectors:

Dust collectors can play a valuable role in dust reduction, if space is available to locate the collector and if the collector efficiency is high. Dust collectors range from low-volume filtration systems used in the cabs of mining equipment (Organiscak et al. 2000) to high-volume wet collectors used on continuous miners in coal mines (Volkwein et al. 1985).

The most difficult dust collector application occurs when the dust has a high percentage of silica and the air passing through the collector is reused. Then, any minor collector malfunction or design flaw will lead to excessive dust levels.

It is important to recognize that the efficiency of a dust collector is the filtration efficiency of the unit times the capture efficiency of its inlet. For collectors properly designed to trap respirable dust, the filtration efficiency is usually quite high, in the 90%-95% range. The inlet capture efficiency is much more variable. The inlet capture efficiency is high, 80% or better, when the collector extracts air from an enclosed or semi enclosed space, such as the cutter head space of a hard-rock TBM or the crusher on a longwall stage loader. If the coal bed is not too high, capture efficiency is also reasonable at continuous miner faces, which are dead-end spaces crammed with equipment.

However, where there is less enclosure, such as in continuous miner faces in high coal, road header faces, or longwall shearer faces, inlet capture efficiency is poor, 50% or less, unless the collector air quantity is unreasonably high. Collectors also exhibit many design and maintenance problems, as follows:

3.6.1 Design Problems:

The designers of dust collection systems take many shortcuts to cut costs and reduce the amount of maintenance required, some of which also reduce the efficiency. For example, some of the fiber filters on cab filtration systems (Organiscak et al. 2000) and the flooded-bed panels on continuous miners (Colinet and Jankowski 2000) have been found to be too porous. A porous filter permits more airflow and allows for a smaller fan, but exhibits poor collection efficiency for hard-to-trap respirable dust. Also, in recent years, continuous miner booms have been redesigned to move the collector inlets from the boom to the hinge point. This has had many benefits in cost and maintenance, but this location is farther from the dust source and thus has lowered the inlet capture efficiency (Jayaraman et al. 1992b).

3.6.2 Maintenance Problems:

Dust collectors in mines and tunnels can be high-maintenance equipment. Screens and filters clog often, sometimes more than once per shift. Gaskets disappear and access doors leak. Often, filters are not seated properly, and dusty air leaks around them. Filters also develop holes from mishandling and from abrasion by larger-sized particulate. Ductwork leading to the collector fills with coarse particulate, cutting off the airflow. Fans located on the inlet side of the collector suffer rapid erosion of their blades and are usually not designed for convenient blade replacement. High dust levels are the result. A major reason for excessive silica exposure during coal mine roof bolting is lack of maintenance on the bolting machine dust collector.

3.7 Control of Diesel particulate:

A detailed but readable review of diesel particulate controls has been written by Schakenberg and Bugarski (2000). Essentially, the technology selected depends on how much the particulate must be reduced. Moderate particulate reductions may be obtained by better engine maintenance, engine derating, biodiesel fuel, fuel-water emulsions, and oxidation catalysts in conjunction with low-sulfur fuels. Large particulate reductions (80% or better) can be obtained with ceramic particulate filters on the engine tailpipe. Also, new low-emissions engines are available. These new engines can lower the particulate level as much as 75% if the existing engine has an old design. Some reduction in diesel particulate levels can be achieved by running haulage trucks in return airways. However, since other equipment in the mine is also powered with diesel engines, the benefits of return haulage may be minimal. In many mines, the haulage truck horsepower is only a fraction of the installed diesel horsepower in the mine. Reduction in diesel particulate can be obtained with improvements in the ventilation, of jet fans and stoppings. Head (2001 a,b,c) recently wrote three helpful articles on better ventilation and reducing diesel emissions in stone mines.

4.0 Discussion:

If controlling dust were a simple matter, dust problems in tunnels and mines would have been eradicated years ago. Unfortunately, most underground dust control methods yield only 25% to 50% reductions in respirable-sized dust. Often, 25% to 50% reductions are not enough to achieve compliance with dust standards. Thus, mine operators must use several methods simultaneously, usually without knowing for sure how well any individual method is working. In fact, given a 25% error in dust sampling and day-to-day variations in dust generation of 50% or more, certainty about which control methods are most effective can be wanting. Nevertheless, over the years, some consensus has emerged on the best dust control practices. (Kissell F.N. 2003).

Dust Control Method	Effectiveness Low – 10-30% Moderate – 30-50% High – 50-75%	Cost and Drawbacks
Dilution ventilation	Moderate	High – more air may not be Feasible
Displacement ventilation, including enclosure with extraction of dusty air	Moderate to high	Moderate – can be difficult to implement well
Wetting by sprays	Moderate	Low – too much water can be a problem
Airborne capture by sprays	Low	Low – too much water can be a problem
Airborne capture by high pressure sprays	Moderate	Moderate – can only be used in enclosed spaces
Foam	Moderate	High
Wetting agents	Zero to low	Moderate
Dust collectors	Moderate to high	Moderate to high – possible noise problems
Reducing generated dust	Low to moderate	Moderate
Enclosure with sprays	Low to moderate	Moderate
Dust avoidance	Moderate	Low to moderate

Many methods have been tested to control dust in tunnels and underground mines. Poor results and difficult operating conditions have ruled out a high proportion. Those that have remained will reliably reduce dust if one makes a determined effort to deal with the problem. Inevitably, there is cost and inconvenience involved. However, the proper consideration and use of ventilation, water, and dust collectors can achieve a satisfactory result. The best practice to control dust subsurface is to control dust at the source.

Statistical and Artificial neural network tools can be applied after collecting the data from various dust generation sources so that dust concentrations can be predicted and mitigative measures can be planned well before the underground excavations. Innovative automatic dust samplers and suppression mechanism can be integrated to get the dust emissions suppressed at the source.

Acknowledgements:

The authors are thankful to Dr. G.R Adhikari, HoD, TCPMD and Environmental Engineering Department, National Institute of Rock Mechanics for his encouragement to write the paper on this topic. We are also thankful to the Director, National Institute of Rock Mechanics, for his permission to publish this paper.

References:

1. Niewiadomski G.E. 2007. Mine Safety and Health Administration, personal correspondence. NIOSH 2003. Work-Related Lung Disease Surveillance Report 2002. DHHS (NIOSH) Number 2003-111, 246 pp.
2. Rider J.P. & Colinet J.F. 2007. Current Dust Control Practices on U.S. Longwalls. 2007 Longwall USA, Pittsburgh, PA, June 5-7.
3. Kissell F.N. 2003. Handbook for Dust Control in Mining. DHHS (NIOSH) Publication No. 2003-147,Information Circular 9465. Available at: http://www.cdc.gov/niosh/ mining/ pubs/ pubreference / outputid20. htm
4. Bazzanella A, Becker H, Kemper F [1986]. Staubbekampfung in abbaubetrieben mit schneidender kohlengewinning. Gluckauf *122*(11):728-735. Also available in translation as: Dust suppression in shearer faces, Gluckauf Translation *122*(11):204-207.
5. Bennett DJ, Roberts AW [1988]. Carry-back measurements to evaluate the design, selection, and performance of belt cleaning systems. Mechanical Engineering Transactions, the Institution of Engineers, Australia. Vol. ME13, No. 4, December, pp. 215-221.
6. Bigu J, Grenier MG [1989]. Reduction of airborne radioactive dust by means of a charged water spray. AIHA J *50*:336-345.
7. Brown CE, Schrenk HH [1938]. Control of dust from blasting by a spray of water mist. Pittsburgh, PA: U.S. Department of the Interior, RI 3388. Chander S, Alaboyun AR, Aplan FF [1991]. On the mechanism of capture of coal dust particles by sprays. In: Proceedings of the Third Symposium on Respirable Dust in the Mineral Industries (Pittsburgh, PA, October 17-19, 1990). Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc. Cheng L, Zukovich PP [1973]. Respirable dust adhering to run-of-face bituminous coals.
8. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 7765. NTIS No. PB 21883.
9. Colinet JF, Jankowski RA [2000]. Silica collection concerns when using flooded-bed scrubbers. Min Eng *Apr*:49-54.
10. Colinet JF, Spencer ER, Jankowski RA [1997]. Status of dust control technology on U.S. longwalls. In: Ramani RV, ed. Proceedings of the Sixth International Mine Ventilation Congress.

11. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., pp. 345-351.
12. Courtney WG, Cheng L [1977]. Control of respirable dust by improved water sprays. In: Respirable Dust Control – Proceedings of Technology Transfer Seminars, Pittsburgh, PA, and St. Louis, MO, IC 8753, pp. 92-108. NTIS No. PB 272 910.
13. Divers EF, Jankowski RA [1987]. Maintaining filters, bits can control respirable quartz dust during roof drilling. Coal Age *Feb*:57-59.
14. Divers EF, Jayaraman NI, Custer J [1982]. Evaluation of a combined face ventilation system used with a remotely operated mining machine. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 8899. NTIS No. PB83-156794.
15. Ford VHW [1973]. Bottom belt sprays as a method of dust control on conveyors. Min Technol (U.K.) *55*(635):387-391.
16. Goldbeck LJ, Marti AD [1996]. Dust control at conveyor transfer points: containment, suppression, and collection. Bulk Solids Handling *16*(3):367-372.
17. Hamilton RJ, Knight G [1957]. Laboratory experiments on dust suppression with broken coal.
18. London, U.K.: National Coal Board, Mining Research Establishment Report No. 2083.
19. Hartman HL, Mutmansky JM, Ramani RV, Wang YJ [1997]. Mine ventilation and air conditioning. Third Edition. New York: John Wiley & Sons, Inc.
20. Hu Q, Polat H, Chander S [1992]. Effect of surfactants in dust control by water sprays. In: Proceedings of the Symposium on Emerging Process Technologies for a Cleaner Environment. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., pp. 269-276.
21. ILO [1965]. Guide to the prevention and suppression of dust in mining, tunneling, and quarrying. Geneva, Switzerland: International Labour Organization.
22. Jankowski RA, Organiscak JA [1983]. Dust sources and controls on the six U.S. longwall faces having the most difficulty complying with dust standards. Pittsburgh, PA: U.S. Department of the Interior, IC 8957. NTIS No. PB84-142058.
23. Jayaraman NI, Jankowski RA [1988]. Atomization of water sprays for quartz dust control. Applied Hyg *3*:327-331.
24. Jayaraman NI, Divers EF, Derick RL, Babbitt C [1986]. Evaluation of a new half-curtain technique for continuous miner faces. In: Proceedings of the Symposium on Respirable Dust. University Park, PA: The Pennsylvania State University.
25. Jayaraman NI, Jankowski RA, Organiscak JA [1992a]. An update on stageloader dust control. In: Proceedings of Longwall USA (Pittsburgh, PA).
26. Jayaraman NI, Jankowski RA, Whitehead KL [1992b]. Optimizing continuous miner scrubbers for dust control in high coal seams. In: Proceedings of New Technology in Mine Health and Safety Symposium. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., pp. 193-205.
27. Kim J, Tien JC [1994]. Effect of added base on coal wetting ability of nonionic surfactant solutions used for dust control. Min Eng (London) *154*(399):151-155.

28. Kissell FN [1992]. Gas and dust control. In: SME Mining Engineering Handbook. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., pp. 1004-1020.
29. Kissell FN [1996]. How to control air contaminants during tunnel construction. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9439. NTIS No. PB96-147558.
30. Knight G [1980]. Generation and control of mine airborne dust. Canada Centre for Mineral and Energy Technology (CANMET) Report 80-27E.
31. Kost JA, Shirey GA, Ford CT [1980]. In-mine tests for wetting agent effectiveness. Bituminous Coal Research, Inc. U.S. Bureau of Mines contract No. J0295041. NTIS No. PB82183344/ XAB.
32. Ludlow J, Wilson RJ [1982]. Deep cutting key to dust free longwalling. Coal Mining and Processing *19*(8):40-43.
33. Marshall L [1964]. Dust control at ore and waste pass dumps. Canad Min J *Oct*:84-86.
34. Matta JE [1976]. Effect of location and type of water sprays for respirable dust suppression on a
35. continuous mining machine. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, TPR 96. NTIS No. PB-254-677.
36. McClelland JJ, Organiscak JA, Jankowski RA, Pothini BR [1987]. Water infusion for coal mine dust control: three case studies. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 9096. NTIS No. PB88-120514.
37. McCoy J, Melcher J, Valentine J, Monaghan D, Muldoon T, Kelly J [1983]. Evaluation of charged water sprays for dust control. Waltham, MA: Foster-Miller, Inc. U.S. Bureau of Mines contract No. H0212012. NTIS No. PB83-210476.
38. McCoy JF, Schroeder WE, Rajan SR, Ruggieri SK, Kissell FN [1985]. New laboratory measurement method for water spray dust control effectiveness. AIHA J *46*(12):735-740.
39. McPherson MJ [1993]. Subsurface ventilation and environmental engineering. Kluwer Academic Publishers. Meets EJ, Neethling AF [1987]. Some experiences in the use of wetting agents to suppress dust at Sigma colliery. J Mine Vent Soc S Afr *Oct*:126-133.
40. MRDE [1981]. Methods of reducing dust formation and improving dust suppression on longwall faces: final report on ECSC research project 7256-12/003/08. Mining Research and Development Establishment (U.K.)
41. Mukherjee SK, Singh MM [1984]. New techniques for spraying dust. Coal Age *June*:54-56.
42. Myran T [1985]. Tunnel boring machines in Norway: ventilation and dust problems. In: Proceedings of the Second U.S. Mine Ventilation Symposium (Reno, NV).
43. Organiscak JA, Cecala AB, Heitbrink WA, Thimons ED, Schmitz M, Ahrenholtz E [2000]. Field assessment of retrofitting surface coal mine equipment cabs with air filtration systems. In: Bockosh GR, Karmis M, Langton J, McCarter MK, Rowe B, eds. Proceedings of the 31st Annual Institute of Mining Health, Safety and Research. Blacksburg, VA: Virginia Polytechnic Institute and State University, Department of Mining and Minerals Engineering, pp. 57-68.

44. Organiscak JA, Khair AW, Ahmad M [1995]. Studies of bit wear and respirable dust generation. Transactions SME, Vol. 298. Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc., pp. 1874-1879.
45. Organiscak JA, Listak JM, Jankowski RA [1985]. Factors affecting respirable dust generation from longwall roof supports. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, IC 9019. NTIS No. PB85 236453.
46. Page SJ [1982]. An evaluation of three wet dust control techniques for face drills. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 8596. NTIS No. PB82-177320.
47. Page SJ, Folk M [1984]. Keystone achieves positive dust control during dry drilling. Eng Min J *185*(9):84-85.
48. Page SJ, Volkwein JC [1986]. Foams for dust control. Eng Min J *187*(10):50-52, 54.
49. Rodgers SJ, Rankin RL, Marshall MD [1978]. Improved dust control at chutes, dumps, transfer points, and crushers in noncoal mining operations. MSA Research Corp. U.S. Bureau of Mines contract No. H0230027. NTIS No. PB297-422.
50. Ruggieri SK, Jankowski RA [1983]. Fundamental approaches to longwall dust control. In: Proceedings of the Symposium on Control of Respirable Dust (Beckley, WV, Oct. 4-8, 1983). Seibel RJ [1976]. Dust control at a transfer point using foam and water sprays. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, TPR 97. NTIS No. PB-255-440.
51. Shirey CA, Colinet JF, Kost JA [1985]. Dust control handbook for longwall mining operations. BCR National Laboratory. U.S. Bureau of Mines contract No. J0348000. NTIS No. PB86178159/ AS.
52. Stahura RP [1987]. Conveyor belt washing: is this the ultimate solution? TIZ-Fachberichte *111*(11):768-771. ISSN 0170-0146. Swinderman RT, Goldbeck LJ, Stahura RP, Marti A [1997]. Foundations 2: the pyramid approach to dust control and spillage from belt conveyors. Neponset, IL: Martin Engineering.
53. Tien JC [1999]. Practical mine ventilation engineering. Chicago, IL: Intertec Publications. Tien JC, Kim J [1997]. Respirable dust control using surfactants. Appl Occ Env Hyg *12*(12): 957-963.
54. Tomb TF, Emmerling JE, Kellner RH [1972]. Collection of airborne coal dust by water spray in a horizontal duct. AIHA J *33*(11):715-721.
55. U.S. Bureau of Mines [1981]. Technology news 118: Lower dust exposure of longwall shearer operator by relocating the machine cooling water sprays. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines.
56. U.S. Bureau of Mines [1984]. Technology news 203: How to reduce shearer operators dust exposure by using remote control. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines.
57. U.S. Bureau of Mines [1985]. Technology news 220: How twelve continuous miner sections keep dust levels at 0.5 mg/m3 or less. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines.
58. Van der Bank PJ [1977]. Fog nozzle water blast. J Mine Vent Soc S Afr *Apr*:81-82.

59. Volkwein JC, Cecala AB, Thimons ED [1983]. Use of foam for dust control in minerals processing. Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, RI 8808. NTIS No. PB84-131184.
60. Volkwein JC, Thimons ED, Halfinger G [1985]. Extended advance of continuous miner successfully ventilated with a scrubber in a blowing section. In: Proceedings of the Second U.S. Mine Ventilation Symposium (Reno, NV).
61. WHO [1999]. Hazard prevention and control in the work environment: airborne dust. Geneva, Switzerland: World Health Organization.
62. Zimmer RA, Lueck SR, Page SJ [1987]. Optimization of overburden drill dust control systems on surface coal mines. Int J Surf Min *1*:155-157.
63. Head HJ [2001a]. Proper ventilation for underground stone mines. Aggregates Manager *Jan*: 20-22.
64. Head HJ [2001b]. Calculating UG mine ventilation fan requirements. Aggregates Manager *Apr*: 17-19.
65. Head HJ [2001c]. Managing diesel emissions in underground mines. Aggregates Manager *Jun*:17-18.
66. Schnakenberg GH Jr., Bugarski AD [2002]. Review of technology available to the underground mining industry for control of diesel emissions. Pittsburgh, PA: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2002-154, IC 9462.