Dust control methods in tunnels and underground mines

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Introduction

If controlling dust were a simple matter, dust problems in tunnels and mines would have been eliminated years ago. Unfortunately, most underground dust control methods yield only 25% to 50% reductions in respirable dust. This is the small-size, hard-to-trap dust in the crucial 1- 7 micrometer particle size range that enters the inner lungs. Often, 25% to 50% reductions are not enough to achieve compliance with dust standards, and so mine operators must use several methods simultaneously, usually without knowing for certain 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, the analysis of which control methods are most effective can be very difficult. Nevertheless, over the years, some consensus has emerged on the best dust control practices.

This paper provides a control method perspective on how dust in tunnels and underground mines can be reduced by proper use of ventilation, water, and dust collectors.

Ventilation

Ventilation air helps to control 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. Displacement ventilation is far more effective but is harder to implement, so dilution is more common.

Several good books on mine ventilation are available (McPherson, 1993; Hartman et al., 1997; Tien, 1999). The cost of various alternatives for improving airflow has also been spelled out (Engineers International, 1983). Ventilation of working faces is a separate topic from general mine ventilation and has also been covered effectively in the mining literature (Divers et al., 1987).

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 15 m/s or more.

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 difficult 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 3 to 6 meters from the source, keeping them upwind requires a substantial air velocity, typically between 0.3 to 0.7 m/s. 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 towards 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.

Example #1 - Continuous miner faces on exhaust ventilation. To confine the dust cloud at continuous miner faces, coal mine ventilation regulations in the U.S. require an average air velocity of 0.3 m/s. This velocity is based on the entry cross-section without considering the area blocked by the equipment. However, 0.3 m/s is a bare minimum, as Page has shown that 0.6 m/s is required for good dust control (BuMines, 1985). This relatively high air velocity is required because a typical coal mine entry is about 6 meters 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.

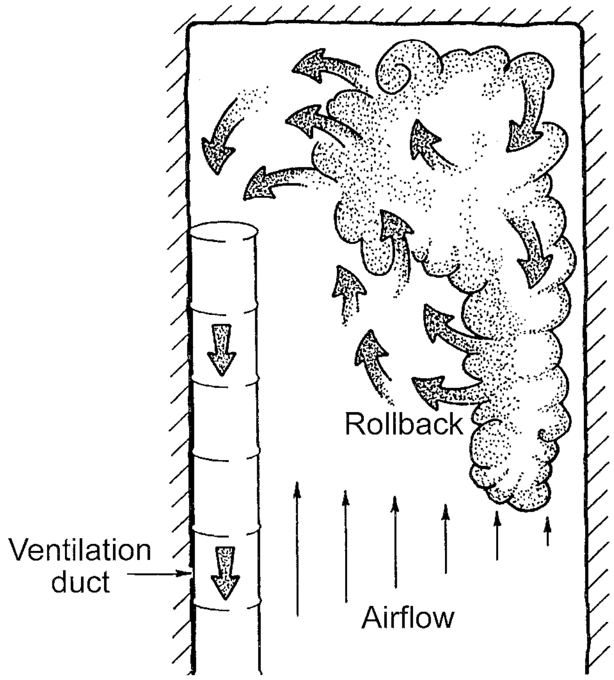

Figure 1. Rollback of dust resulting from non-uniform airflow

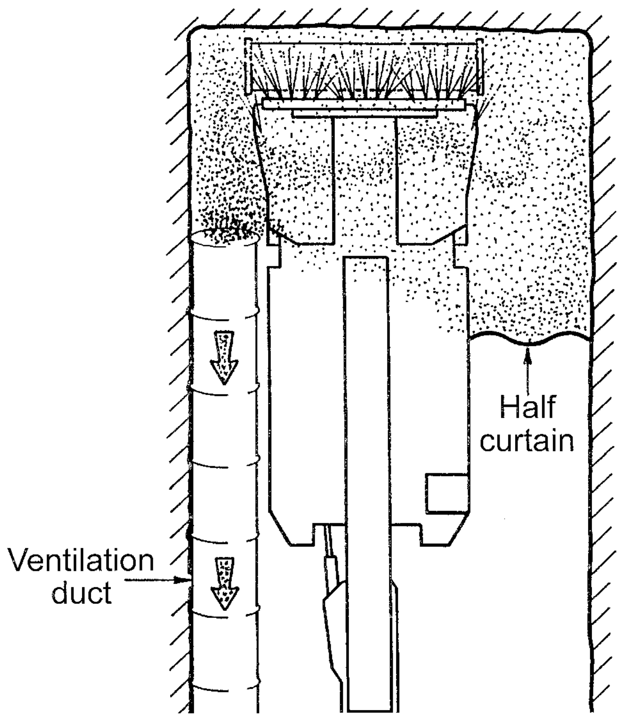

Figure 2. Half-curtain raises air velocity to confine dust cloud

Rollback can be reduced by increasing the airflow. The turbulence that causes rollback can be reduced by lowering the spray water pressure and aligning spray nozzles so they only 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). It 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.

Example #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 necessary to confine dust to the cutter head space, and they are high. For example, a 6-meter diameter TBM requires 6 to 8 m^3/s. Why such high airflow for what is presumably an enclosed space? First, the stirring action of the large rotating cutter head creates considerable source 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.

Example #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

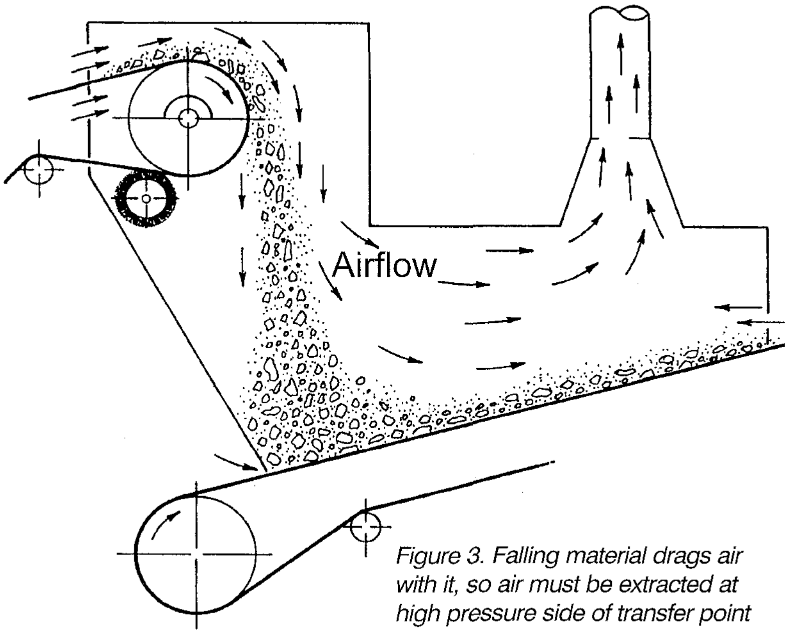

Figure 3. Falling material drags air with it, so air must be extracted at high pressure side of transfer point

and the rubber flaps at the end of the enclosure are worn or missing, even the best designs available will leak dust.

Example #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 5-6 meters and avoid direct contact with the dust cloud coming off the headgate-end shearer drum, reducing their dust exposure by 68 percent (BuMines, 1984). On continuous miners, remote control has enabled the operator to step back toward the intake by about 4 meters and reduce his dust exposure level by 50 percent or more (Divers et al., 1982).

Sometimes, it is possible to move the dust cloud or at least its outer edge. On longwall shearers, the so-called "shearer-clearer" system uses the air-moving capacity of water sprays to hold the dust cloud against the face and prevent it from moving out into the walkway. This can reduce worker dust exposure by 50 percent (Shirey et al., 1985).

When workers are at the edge of a dust cloud, a small shift in the location of the workers or the location of the cloud can yield large benefits. However, if workers are in the middle of a dust cloud, dust avoidance has less chance of success because the distance moved must be greater.

Water sprays

The role of water sprays in mining is a dual one, the first being wetting of the broken material being transported and the second being airborne capture. Of the two, wetting of the broken material is far more effective. Aside from efforts to improve sprays, one of the most helpful actions a mine operator can take is to provide some automatic feature that turns sprays on and off as needed. This allows sufficient wetting while greatly helping to avoid the problems associated with overuse of water.

Wetting. Adequate wetting is extremely important for dust control. The vast majority of dust particles created during breakage are 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 460 l/min (Colinet et al., 1997). Compared to the amount of coal mined, on a weight basis, this 460 l/min 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 just 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. For example, 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 lessons from this knowledge about the use of water are two-fold. First, it is best to wet the material fully during the breakage process. This is when most mechanical mixing is likely to take place, and 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, it is known that spray nozzles under the boom of a continuous miner are more effective than those on the top of the boom (Matta, 1976). Yet top nozzles are more commonly used because sprays under the boom are more frequently damaged and more difficult to maintain.

Airborne capture. Under real mining conditions the typical water spray, operating at 700 kPa and 5-10 l/min, gives no more than 30% airborne capture of respirable dust (Courtney and Cheng, 1977). This is not as good as laboratory tests (Tomb et al., 1972) would lead one to believe. In laboratory tests, the sprays were usually confined in a duct, and all of the dust was forced to pass through the spray. However, under real mining conditions, dust clouds are unconfined. In all sprays, the moving droplets exert drag on the adjacent air, and 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 illustrates how some sprays on a longwall shearer actually raise the shearer operator's dust level. For many years, it was a common practice to discharge the motor-cooling water by aiming it at the coal face on the theory that it would capture some airborne dust. It did capture some dust, but it also created a considerable airflow toward the coal face. That airflow, upon reaching the coal face, simply turned around and carried the remainder of the dust cloud, formerly confined to the face, back over the operator. Perhaps 1/4 of the cloud was captured, but the remaining 3/4 was blown back over the operator, raising his dust level three-fold (BuMines, 1981). Another flawed spray application that appears in all types of mines is the so-called "water curtain," based on the incorrect notion that dust particles passing across a barrier row of sprays will always be captured.

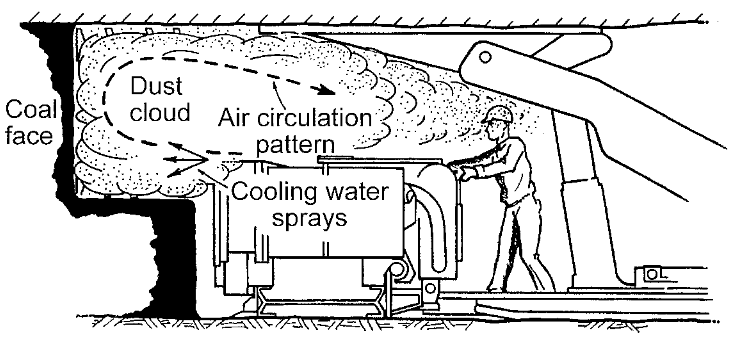

Figure 4. Airborne capture performance of four types of spray nozzles

Attempts to improve the airborne capture efficiency of sprays have not met with much 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; Foster-Miller Associates, 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. For example, nozzles with very small orifices are more prone to clogging. Fine droplets are likely to evaporate quickly and release captured dust and dissolved minerals into the air (Foster-Miller Associates, 1983). Sprays that use less water fall short in the more important role of wetting the broken material.

Despite the limitations of sprays, proper nozzle selection can enhance their use. Figure 5 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. An exception is spraying into a narrow rectangular space, where flat fan sprays might be more appropriate 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 indicated in Figure 5. For example, 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 (700 kPa, 86 l/min) gave 30% respirable dust reduction. A high-pressure system (17 MPa, 14 l/min) gave the same reduction but with much less water. The two systems operating together (100 l/min) 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

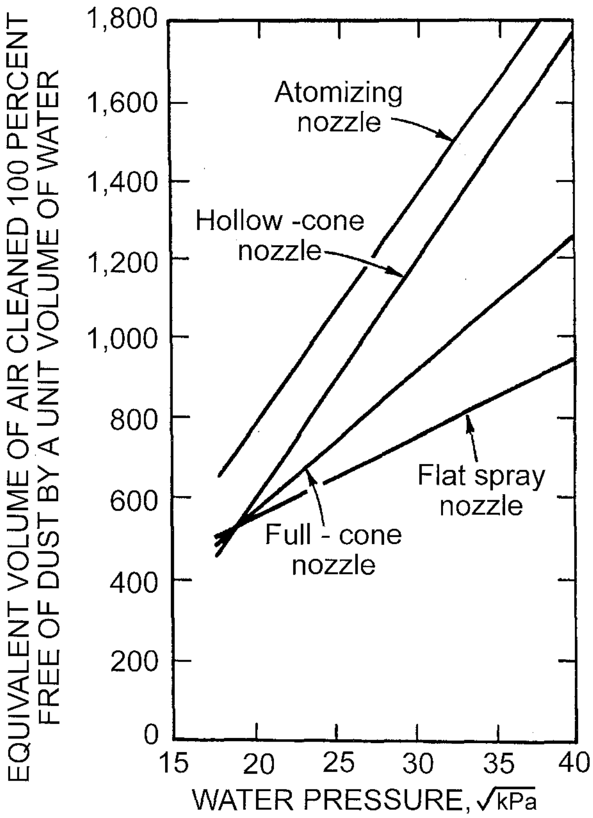

Figure 5. spray-generated airflow carries dust back to shearer operator

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.

Foam. For dust control, foam works better than water, providing dust reductions in the 20-60% range when 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% when compared to conventional water sprays on the drum. Also, the system used 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).

Wetting 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, in comparison 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 appears that wetting agent effectiveness depends on the type of wetting agent, the type of coal, the dust particle size, the dust concentration, the water pH, and the 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 his 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.

Dust collectors

Dust collectors can play a valuable role in dust reduction under the right circumstances - that is, if the collector efficiency is high and space is available to locate the collector. 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). A unique type of dust collector with some mining applications is the water-powered dust collector (Bureau of Mines, 1981a; Sandstedt and Page, 1983). This device uses high-pressure water sprays (1.7 MPa or more) to induce airflow through a short duct and remove the dust from the air. It has application at transfer points, at crushers, or at other locations where restrictions to airflow are minimal.

The most difficult application of collectors in mining occurs when the dust has a high percentage of silica and the air passing through the collector is re-used. Under these circumstances, any collector malfunction or design flaw will lead to excessive dust levels.

It is important to recognise 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 stageloader. 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, roadheader 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:

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 a 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 further from the dust source and thus has lowered the inlet capture efficiency (Jayaraman et al., 1992).

Maintenance problems. Dust collectors in mines and tunnels can be high-maintenance equipment. Screens and filters clog frequently, 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.

Reducing the amount of dust generated

Clearly, it is desirable to reduce the amount of dust that is generated, so less has to be removed from the mine air. Dust in mines and tunnels is generated by extraction, drilling, blasting, dropping, crushing, and conveying. Usually, there is some opportunity for improved dust control within these procedures.

Extraction. The machines that produce extraction dust are longwall shearers, continuous miners, tunnel boring machines, and roadheaders. 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. Laboratory studies on conical cutting bits have shown that significantly worn bits without their carbide tips produce much more dust (Organiscak et al., 1995).

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).

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, 1987a). 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. 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.

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 in controlling dust generated by blasting, either by using water bags for stemming or by wetting down the blast area.

Dropping. In removing and transporting mined material, the broken material is inevitably dropped. At longwall faces, the broken coal can fall 2 meters or more to the panline. At tunnel boring machines, rock removed at the crown can drop 8 meters 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).

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 necessary to do the job is difficult to specify because it

DUST CONTROL METHOD	EFFECTIVENESS (Low is 10-30 pct, moderate is 30-50 pct, high is 50-75 pct)	COST & 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

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 stageloader-crusher unit, by using 82 l/m of water inside the enclosure, and by extracting 1.2 m^3/s of air from the enclosure. Rodgers et al. (1978) have described how dust from a 1.5 meter gyratory crusher was reduced by using a 35 m^3/s exhaust ventilation system and a control booth for the operators.

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 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.

Methods to deal with belt dust are well known (Goldbeck and Marti, 1996; Swinderman et al., 1997). If belt dust is high, the relevant questions to address are the following:

1. Are transfer points enclosed? A simple enclosure with a spray or two inside of it may be adequate. If this is not enough, the air inside must be exhausted to a dust collector, with all of the leakage points on the enclosure sealed properly (Swinderman et al., 1997).

2. Is the material being conveyed adequately wet, but not so much that it leaves a sticky mud residue on the belt? When this residue dries, dust is released, and so an end result of excessive wetting can be an increase in belt dust.

3. Are the undersides of both the top and the bottom belts being wet (Ford, 1973) so that dust sticking to the belt is not shaken loose by the idlers? Does the belt stay wet or is it drying out and releasing dust?

4. Are the belt scrapers working properly? Is a second set of scrapers being used? Has a belt washing system been attempted (Bennett and Roberts, 1988; Stahura, 1987)?

5. Is the belt running true, and not spilling its contents (Swinderman et al., 1997)?

Summary

Methods for reducing dust in tunnels and underground mines are summarized in the table above.

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 of these methods. 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 usually achieve a satisfactory result.

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