Summary of NIOSH research completed on dust control methods for surface and underground drilling

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Abstract

NIOSH continues to conduct respirable dust control research for surface mine blasthole drilling operations. Research areas have included testing variables (shroud leakage area, drill deck cross-sectional area, shroud height, collector-to-bailing airflow ratio, etc.) that have the most impact on respirable dust control, development of a dust collector inlet hood, development of a dust collector dump point shroud and testing of a small-diameter water-separating sub. This paper summarizes the results of the aforementioned research that has been completed. Additionally, past dust control research for drilling operations of both underground and surface mines completed by the U.S. Bureau of Mines (created in 1910 and incorporated into NIOSH in 1997) is reviewed.

Introduction

Silicosis is an occupational disease caused by the inhalation of respirable crystalline silica particles that are <10 μm in diameter. There is no cure except through its prevention (Porter and Kaplan, 2007). Silicosis is classified as one of three types: chronic silicosis, which occurs after 10 or more years of exposure of relatively low respirable silica dust concentrations; accelerated silicosis, which develops within 5 to 10 years after exposure; and acute silicosis, which can occur within a time period of 5 years or within just a few weeks after exposure to high concentrations of respirable silica dust (Schulte et al., 2002). Symptoms for all three categories of silicosis are similar, with chronic silicosis being asymptomatic at first, but ultimately characterized by dyspnea or shortness of breath with exertion progressing to dyspnea at rest. Advanced cases result in pulmonary hypertension and respiratory failure. Symptoms for accelerated silicosis are similar to chronic silicosis, but occur over a shorter time period. Symptoms of acute silicosis are similar but occur rapidly and may include weight loss and fatigue with respiratory failure usually occurring within 2 years (Porter and Kaplan, 2007). Additionally, once silicosis develops, complications may arise from mycobacterial or fungal infections with tuberculosis being the most common mycobacterial infection (Schulte et al., 2002).

Definitive medical information about silicosis has evolved slowly throughout history, but the relationship between dust and health problems has long been recognized. Hippocrates, born in 460 B.C., pointed out the difficult breathing of the metal digger due to exposure. In the 16th century, Georgius Agricola, who authored the first book on physical geology, was one of the first to report on the effects of dust in miners.

Scientists eventually associated dust exposure with a disease called "consumption," which was characterized by symptoms such as slight fever, loss of appetite, cough and shortness of breath, ultimately leading to the victim being confined to a bed with great weakness, sleeplessness, fever and bloody sputnam until death (Harrington and Davenport, 1935). The process of contracting this disease was still not clearly understood during this time, but it was known to be prevalent in miners, smelters and stone masons (Harrington and Davenport, 1935).

In the early 1880s, medical science was revolutionized with the development of germ theory and Robert Koch's discovery of the tuberculosis bacillus. With these advancements, consumption was now thought to be caused by the tuberculosis bacteria. Ironically, this finding set back the understanding of silicosis, leading to the thinking that because the tuberculosis bacteria caused consumption, the dust was only the carrier and caused no harm (Rosner and Markowitz, 1991). It was not until the early 20th century that investigations were conducted into understanding silicosis, which is now known to be an occupational illness caused by a progressive fibrosis that occurs in the lungs when silica particles are ingested by macrophages (NIOSH, 1977).

The first investigation of silicosis in the mining industry in the United States occurred in 1914-1915 and examined the incidence of pulmonary diseases in the Joplin district of Missouri (Lanza and Higgins, 1915; Harrington and Davenport, 1935). From this and other observations and studies of mining and tunneling operations, it was noticed that silicosis became more prevalent and caused more worker deaths when steam-driven or compressed-air percussive drills were introduced into the tunnels (Higgins et al., 1917; Cherniack, 1986; Nelson, 2006). Because early researchers noticed that silicosis was associated with drillers, an occupation linked with high exposure to silica dust, the U.S. Bureau of Mines (USBM) initiated research on drilling dust control (Harrington and Lanza, 1921; Sayers, 1925). This research initiated with underground drilling operations, progressed to dust control research on roof bolting operations and eventually to surface mine drilling operations. The goal of the research was to determine methods to reduce the generation of respirable silica dust in the underground mine, roof bolting and surface mine drilling operations.

Figure 1 — Angle drilling in an open stope.

Although it is recognized that dust control research for drilling operations has been conducted by other public and private entities, this paper focuses on research conducted by the National Institute for Occupational Safety and Health (NIOSH) and the U.S. Bureau to Mines (USBM). The USBM was incorporated into NIOSH under the Centers for Disease Control and Prevention, U.S. Department of Health and Human Services, in 1997, and its dust control research on drilling operations continues under NIOSH.

Figure 2 — Wet drilling in an open stope with a Leyner Drill.

Underground drilling dust control research

After the investigation of pulmonary diseases in the Joplin district of Missouri in 1915, it was determined that dry drilling in unventilated underground mines was the most dangerous activity related to silicosis. As a response, the USBM began conducting research on dust control for drilling processes in underground mining facilities. From studies completed by the USBM, it was established that drilling vertical holes with hammer type drills produced the most dust (Fig. 1), with angle hole producing less.

During the 1920s, the focus was on eliminating dry drilling in underground mines and replacing this drilling method with wet drilling (Fig. 2). Measurements of dust concentrations that were recorded at this time showed a dramatic decrease in dust concentrations when wet drilling was used (Harrington, 1922).

Wet drilling. Wet drilling uses water in addition to compressed air to flush the drill cuttings from the hole. The water is forced, using the compressed air, through the drill steel, out the end of the drill bit and back through the drill hole forcing the cuttings out of the hole. This drilling method was found to be the best method of dust control with dust reductions ranging from 86% to 97%, depending on the type of drilling involved (Harrington, 1921; Johnson and Agnew, 1939). This range of dust reduction could be lower, 50% to 60%, depending on the angle of the drill hole being drilled (Brown and Schrenk, 1938a). The high dust reductions from wet drilling were confirmed approximately six decades later when studies evaluated the use of water mists and foams injected through the drill steel, resulting in reduced dust concentrations by 91% to 96%, respectively (Page 1982a ,1982b). During the early part of the 20th century, while it was conceded that wet drilling equipment was heavier and more costly to purchase and maintain, there were other advantages such as less drill steel breakage and greater penetration rate with wet drilling than with dry drilling. In fact, an example was given where a large copper mining company showed that the penetration rate with wet drilling was nearly twice the penetration rate of dry drilling (Harrington, 1921). However, it was also noted that there was resistance to wet drilling by the miners because of the fundamental working conditions it required and the large amounts of water used. They claimed that they would rather "swallow" the dust and take their chances of obtaining miner's consumption rather than become "crippled with rheumatism," as they would say, from the water of the drilling operations. Even when all drills were replaced with wet stopers, the miners would attempt to drill with them dry, with poor results. However, after the use of water with the wet stopers was compelled, eventually the men would become advocates of their use.

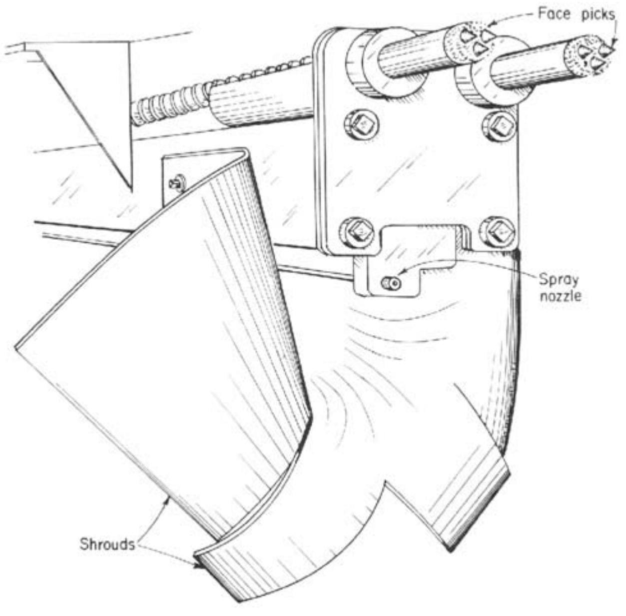

Figure 3 — External boom mounted water spray.

To help overcome this psychological resistance to change as mines were converting to wet drilling, the USBM continued research on the wet drilling dust control method. In 1938, a study was conducted drilling horizontal holes with wet drilling to determine penetration rate of drill bits. The results showed that the depths of a series of holes became progressively shorter due to the dulling of the drill bits (i.e., hole #1 was the deepest, with hole #3 being the shortest). This study also provided proof that the first 0.30 m (1 ft) or 0.60 m (2 ft) of drill hole was the dustiest when wet drilling (Littlefield and Schrenk, 1938). After the first 0.30 to 0.60-m (1 to 2-ft) were completed, the dust concentrations dropped rapidly and maintained a constant level. This study also demonstrated that collaring the hole was not responsible for the high dust concentrations, because the holes were precollared prior to testing (Littlefield and Schrenk, 1938).

The relationship of water flow to dust concentrations was tested in both stoper and drifter drills. For stoper drills, as the water flow increased to 4.9 L/min (1.3 gpm), it was found that the dust concentrations decreased rapidly. Above 4.9 L/min (1.3 gpm) the dust concentrations decreased at a slower rate. This phenomenon was also seen in drifter drills, but at a water flow rate of 3.8 L/min (1.0 gpm). Therefore, it was recommended that the minimum water flow should be 4.9 L/min (1.3 gpm) for stoper drills and 3.8 L/min (1.0 gpm) for drifter drills (Brown and Schrenk, 1938b). Eventually it was shown that different types of drill bits generated differing amounts of respirable dust when drilling dry. For example, the polycrystalline diamond compact bits generated less dust than the tungsten carbide bits. When wet drilling was tested, the differences in respirable dust generation and penetration rate were shown to be minor (Sundae et al., 1995). During this testing, it was also shown that large amounts of water are not required to produce good dust control and good penetration rate. A water flow rate of 0.41 L/min (0.11 gpm) was sufficient for dust control and good penetration rate (Sundae et al., 1995).

The use of “wetting” agents or additives to the water used in drilling was also evaluated. Results showed that wetting agent solutions applied at varying flow rates provided better dust control, reducing dust concentrations from wet drilling by an average reduction of 53.5% for each cubic inch of rock drilled (Johnson, 1943). However, the dust control provided by wet drilling was so good that the reduction from the use of wetting agent solutions was not significant in normal drilling operations. The advantage of wetting agents was in the improvement of penetration rate. When wetting agents were used, the average drilling speed or penetration rate increased slightly (+4.5%). However, this was shown to be highly variable with the penetration rate varying between -24.9% and +57.5% (Johnson, 1943).

Dry drilling with external sprays. Although previous testing showed that the use of external water sprays when dry drilling only produced dust reductions of 25% compared to dry drilling alone (Harrington, 1921), a new external water spray device was tested in the late 1930s. This device was in the shape of a ring that contained spray holes on the inside diameter for dust control on dry drilling in quarries. This device was slipped over the drill steel and sprayed water on the drill steel outside of the hole in an attempt to reduce dust concentrations. Although it was an improvement over external water sprays, results showed that this device could not be used to replace wet drilling while maintaining proper dust control during drilling operations, because it produced dust reductions that were variable, ranging from 75% to 88% dust reduction over dry drilling (Johnson and Agnew, 1939). It was stated that the water spray device could be used to assist in dust control during wet drilling and that it would aid in reducing dust during drill collaring procedures. Much later, a rubber shrouded external spray system, depicted in Fig. 3, was shown to improve dust reduction to 53% (Page, 1982b) compared to 25% (Johnson and Agnew, 1939) from earlier external spray studies. It was determined that the earlier external water spray system was not as effective because it allowed the dust to be generated and entrained prior to wetting the material. Therefore, there was little time for the water to mix with the dust to reduce its concentration.

Roof bolting dust control research for underground coal mines

A significant amount of work has been completed on roof bolting dust control (Fig. 4). In the early 1950s, a survey was conducted of underground coal mines located in three states. An evaluation of these mines showed that much of the strata above the coal contained 7% to 88% free silica, which was highly variable depending upon the type of strata (Westfield et al., 1951). At this time, it was reported that approximately 71% of the mines performed roof-bolting operations without any dust control and that dust protection relied on the use of respirators (Westfield et al., 1951). Meanwhile, Owings and Johnson (1953) reported that drilling without dust control for even short periods of times (7 minutes) presented a health hazard to the drillers and others working in the surrounding area. Their study showed that drillers were exposed to silica dust for highly variable time periods ranging from a short time period of 7 minutes to a longer period of 6 hours and 46 minutes. This time period of exposure was dependent on the rock being drilled.

Average dust concentrations were highly variable, depending on the drilling operation, and ranged from 12 to 4,531 million particles per cubic foot of air (Owings and Johnson, 1953). In 1935, it was stated that the U.S. Public Health Service declared that there was a danger in any atmosphere containing more than 5 million particles per cubic foot of fine silica particles (<10 μm) (Harrington and Davenport, 1935b). The USBM made the following recommendations for the amount of dust allowable in mine atmospheres (Owings and Johnson, 1953):

> "*In bituminous-coal and lignite mines the average full-shift concentration of atmospheric dust to which a workman may be exposed should not exceed 20 million particles per cubic foot of air, and a maximum concentration for any single operation should not exceed 40 million particles of dust per cubic foot of air. When the dust contains silica, no more than 5 million particles of silica dust per cubic foot of air should be present in the above limiting concentrations. The dust count may be multiplied by the percentage of silica concentration, and if the result is less than 5 million the dust concentration will be considered safe. The above limiting concentrations are based on impinger samples in which light-field counts are made under a microscope.*"

In 1952, the American Conference of Industrial Hygienists adopted the threshold limits shown in Table 1 for silica dust during a working shift (Owings and Johnson, 1953)

It was not until 1969 that an official legally recognized dust standard was adopted in the United States; a permissible shift exposure limit of 2.0 mg/m^3 of airborne respirable dust for coal mine workers — if more than 5% quartz mass is determined to be in the coal mine worker dust sample, then the applicable respirable dust standard is reduced to the quotient of 10 divided by the percentage of quartz in the dust (Parobeck and Tomb, 2000).

Wet drilling. Conclusions from testing were that all powered drilling produced excessive amounts of dust, best controlled at its source through dust collection or wet drilling, similar to the standard practice in metal mines using pneumatic percussion drills. It was also advised to avoid dry collaring holes — drilling the first 50 mm (2 in.) of hole with the water valve off — as this produces high dust concentrations. Additionally, proper ventilation was recommended in that wet drilling, while it reduces dust concentrations significantly, it does not completely eliminate the generation of dust. The practice of using respirators and allowing the dust to escape the drilling operation was not recommended, because workmen other than the drillers could be exposed to the dust as it was transported via the ventilation system. Additionally, it was recognized that prolonged use of a respirator would be uncomfortable to workers (Owings and Johnson, 1953).

Dust collection systems. When problems occurred with wet drilling in underground mines due to roof rock swelling when exposed to the water, resulting in roof falls and comfort issues for the operator such as the water running down from the hole onto the driller, the use of dry drilling with dust collectors was preferred. Dust collectors use some type of an exhaust ventilation system near the source of the dust. This can be a successful method of dust control for drilling, but many operational problems have been encountered that have undermined full acceptance of this dust control method. The USBM started a program in 1950 to evaluate dust-collection systems for roof drilling in underground coal mines. A typical dust collection system is shown in Fig. 5.

To properly design a dust-collection system it must:

- be capable of handling both fine and large material, as drilling in hard roof produces fine material and drilling in soft roof produces coarser material;
- take full advantage of gravity to move the drilling cuttings from the hole; and
- have a tight seal where the drill steel passes through the hood of the collector (this was found to be more important than the seal between the hood and the roof rock).

Figure 4 — Permissible roof-bolting drill capable of drilling vertical or angle holes.

Table 1 — Threshold limits for mineral dust.

Silica content	Million particles of dust per cubic foot of air
High (above 50% free SiO_2)	5
Medium (5% to 50% free SiO_2)	20
Low (below 5% free SiO_2)	50
Total Dust (below 5% free SiO_2)	50

Also, for a dust collection system to be approved, it could not allow the dust concentration to be more than 10 million particles of dust per cubic foot of air (Owings, 1956). The only drawback to using dust collectors was that they had to be properly maintained for them to work properly.

Additional research focused on the effect of the placement of the roof bolter in comparison with the entire section, on the proper cleaning of the filter boxes, and on the creation of an air canopy to provide fresh air to the bolter operator. One study showed that the roof bolter operating downwind of the continuous miner could be exposed to high concentrations of respirable silica dust (up to 204 μm/m^3 in the bolter intake), especially if the miner is cutting rock (Goodman and Organiscak, 2003). On the other hand, it was shown that when the roof bolter operates upwind of a continuous miner using poor dust control practices, then the continuous miner operator can be exposed to concentrations up to 103 μg/m^3. Proper cleaning of the filter boxes was also deemed to be necessary to reduce respirable-dust generation from the roof bolter. In fact, dust concentrations ranging from 103 to 327 μm/m^3 were observed from a roof bolter when the filter boxes were not properly maintained (Goodman and Organiscak, 2003).

Air canopy system. The air canopy is a device located above the roof bolter operator's position that directs filtered air over the

Figure 5 — Testing a Browning dust collector.

operator. Testing of the device confirmed that high air velocities were provided at a center location of the air canopy. These high air velocities also decreased rapidly as the distance away from the canopy was increased, which would result in lower protection. When using the canopy, respirable dust reductions of up to 56% to 62% were demonstrated. These reductions reduced rapidly when an interference air velocity was increased (i.e., airflow velocities of the ventilating air). When the ventilating air velocity increased then the respirable dust reductions of the canopy ranged from approximately 25% to 28% (Goodman and Organiscak, 2001). This canopy showed potential as an additional engineering control that could provide protection against respirable dust in areas of low-velocity ventilation air. Research on an improved air canopy is continuing.

Figure 6 — A Bucyrus-Erie churn drill.

Surface drilling dust control research

Drilling boreholes is an ancient activity: the Egyptians are thought to have used corundum dust or pebbles to drill holes in rock, while the Chinese are mentioned as using coupled bamboo rods for drilling deep holes for water by lifting, dropping, and rotating the rods (McGregor, 1967). Mechanized drilling was introduced in the 1800s when the first steam-driven rotary rock drill was built. In the late 1800s, compressed air was used for operating rock drills in tunnels with the pneumatic rock drill being produced by 1900. For surface operations, churn drilling — where the drill bit is picked up and dropped numerous times through a cable or drill pipe to drill the hole — was the most common drilling method continuing through mid-1950 (Fig. 6). The first roller bit was used in America around 1900. In 1910, Hughes improved rotary drilling by perfecting the tricone bit, although tungsten carbide was not in pervasive use until 1940 (McGregor, 1967). Mechanical rock drilling continued to evolve throughout the 20th century, from churn drilling to rotary and percussion drilling, to produce the diesel and electrically powered drilling rigs (both rotary and percussion) in use today.

The most common drilling methods in use in the mining industry today are percussion, rotary and down-the-hole hammer drilling. Percussion drilling is appropriate for small diameter holes (<100 mm (4 in.)) and has a limited depth of penetration into a rock formation. This type of drilling is also not suited for soft sticky material as the bit can penetrate too deeply with each impact that can impair rotation of the drill (McGregor, 1967). Rotary drilling is applicable for large-diameter drilling at considerable depths; however, rotary drilling demands large amounts of down pressure, requiring large heavy drills to maintain penetration rates (Lyons, 2001). Recently, down-the-hole hammer drilling has become more prevalent than rotary drilling, as it requires less down pressure to maintain similar penetration rates. However, this drilling method has the same disadvantage as percussion drilling when drilling in soft sticky materials (McGregor, 1967; Lyons, 2001).

Curiously, the USBM did not conduct surface mine dust control research until mid-1980, when MSHA identified the highwall driller and driller's helper occupation as those with the highest exposure to silica dust. Prior to 1960, churn drilling was a common surface drilling practice, but it had slow penetration and therefore did not generate the large volumes of dust seen in today's rotary or percussion drills. However, many of the prior research findings established for dust control in underground mining can be applied to surface mining and thus they form the basis for surface drilling research.

Dust sources and transport. The USBM's first studies on surface drilling focused on determining the locations of dust generation on a blasthole drill rig. From dust concentration measurements made on the drill, it was determined that up to 90% of the respirable dust was generated from three locations (Fig. 7): the dust collector dump (38%), leakage through the drill shroud (28%) and through the table bushing (24%) (Maksimovic and Page, 1985). The other 10% of respirable dust emanated from other nearby mining operations. Instantaneous respirable dust concentrations showed that peak concentrations could reach 68 mg/m^3 for the dust collector dump and 98 mg/m^3 for the drill shroud and table bushing (Maksimovic and Page, 1985).

Further testing was completed to determine the range of transport of respirable dust from surface drilling operations. Dust sampling systems were set up around and away from the drill at varying distances. In addition, gas samplers were used at these locations to isolate dust contamination from other nearby sources. Sulfur hexafluoride (SF_6) gas was released at the drill during drilling, and the sampling stations sampled for both the SF_6 gas and respirable dust. Results showed that within 76 m (250 ft) of the drill, the combination of dust and gas concentrations transported to downwind personnel was insignificant. Additionally, the amount of respirable dust concentrations generated from drilling decreased rapidly with distance. However, the vertical positioning of the drill may influence the downwind exposure to personnel in the surrounding area (Page and Maksimovic, 1987).

Wet drilling. As with underground drilling operations, surface mine blasthole drilling using wet drilling techniques provided the best dust control. Wet drilling provided dust control efficiencies of up to 97% at a water flow rate of 4.5 L/min (1.2 gpm). As seen in Fig. 8, the dust control efficiencies greatly increased from 0.8 L/min (0.2 gpm) to 2.3 L/min (0.6 gpm), then leveled off above this flow rate. However, for the drill tested, once the flow rate approached 3.8 L/min (1.0 gpm), operational problems were encountered such as the drill bit plugging and the drill steel rotation binding (Page, 1987).

Another disadvantage of wet drilling is that it degrades the tri-cone roller drill bits and shortens their lives by 50% or more. Therefore, the USBM tested a water separator sub for dust control efficiency and its effect on drill bit life (Fig. 9). A water separator sub uses inertia to remove the injected water from the bailing air. This removed water is then ejected out through weep holes into the annulus above the drill bit. Testing demonstrated that dust control efficiencies of up to 98% could be obtained using the water separator sub while dust control efficiencies of wet drilling without the water separator sub were 96%. Most importantly, the use of the water separator sub increased bit life. Data gathered by the USBM from a mine where drilling occurred in monzonite, sandstone, limestone and iron ore over a 14-year period showed that drill bit life averaged 590 m/bit (1,938 ft/bit) with wet drilling without water separation. With water separation, the drill bit life increased to an average of approximately 2,743 m/bit (9,000 ft/bit) (Page, 1988).

Further work on water separator subs did not continue until recently when the issue reemerged to examine the use of water separator subs in small diameter drill holes of 171 mm (6¾ in.). Testing full-production drilling with this small diameter water separator sub could not be accomplished at the test site. Therefore, an analysis of the impact this water separator sub would have on drill bit life was not possible. Nevertheless, test results and visual observations showed that dust reductions similar to those attained with previous water separator subs were achievable. However, operational problems were encountered during the testing of the sub, which included regulation of water flow and the condition of the overburden. It was difficult to maintain constant water flow because the pressurization of the water tank changed as the water level in the tank changed, requiring constant adjustment of the water flow to the sub. The ground conditions at the test site included highly weathered and fractured material. When drilling occurred, the high-pressure water ejecting from the weep holes caused deterioration and spalling of the wall material of the drill hole, which led to hole cave-in. However, in a recent study, it was determined that these problems could be overcome, in which case the small diameter water separator sub showed potential to be very effective for dust control (Listak and Reed, 2007).

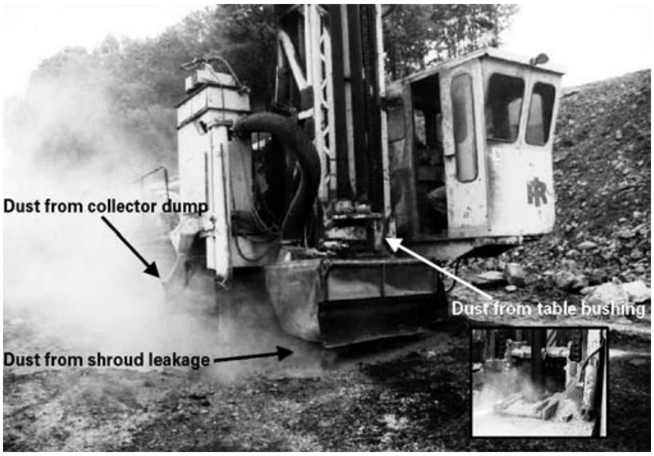

Figure 7 — Blasthole drill showing sources of dust emissions.

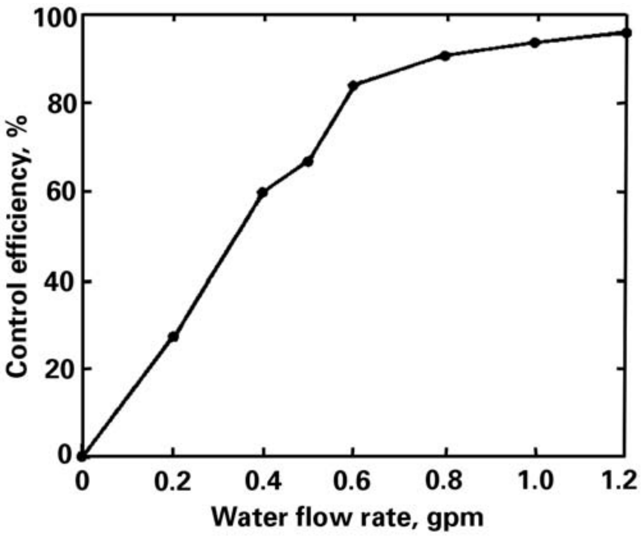

Figure 8 — Relationship of waterflow rate to dust control efficiency for surface mine drilling .

Dry Drilling. Dry dust collection systems are used when drilling dry. The collection systems tested work well and can be up to 99% efficient, but maintaining a proper seal between the ground and the bottom of the shroud is paramount, and this can be difficult due to uneven ground surfaces. Testing demonstrated that dust control efficiencies for the dust collection system became progressively worse (from 99% to 31%) as the gap between the bottom of the shroud and the ground surface increased (from 0 to 690 mm (27-in.)). Therefore, guidelines for proper shroud design were developed as follows: that its internal volume should be 1.8 times the volume of the hole, that the length and width of the shroud should be 2.5 times the shroud height, and that the dust collection system should maintain a negative pressure of 0.5 mbar (0.2 in. H_2O) underneath the shroud (Page, 1987).

It was also shown that keeping the drill deck shroud in

Figure 9 — Water separator sub with rotary bit.

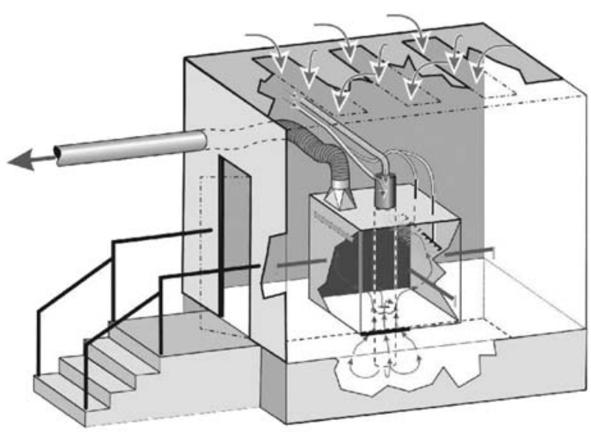

Figure 10 — Drill deck testing facility at NIOSH showing simulated drill deck inside dust chamber.

good condition, minimizing any leakage, was beneficial for dust control. By minimizing the leakage, the dust collector was able to properly perform its job of removing dust from underneath the shroud. Additionally, increasing the airflow of the dust collector improved dust control. Airflows of the dust collector that approached eight times the amount of airflow of the bailing air (air used to flush cuttings from the drill hole) significantly reduced dust leakage from the drill deck shroud (Organiscak and Page, 1995). However, common collector to bailing airflow ratios encountered in the field can be up to 3:1 with 2:1 generally being the norm when the filters are loaded (Page and Organiscak, 2004).

To determine optimum collector airflow to bailing airflow ratios, investigations were performed in an experimental laboratory of a simulated drill deck model (Fig. 10). This simulated drill deck was modeled after those decks normally found on medium-sized rock drills that drill holes ranging from 127 to 203 mm (5 to 8 in.) in diameter. It was located centrally inside a larger chamber used for dust containment. The simulated drill deck had an adjustable shroud that allowed the leakage between the bottom of the shroud and the ground to be varied. Tests were conducted by varying collector airflows and shroud leakages while maintaining a constant bailing airflow. Results showed that the most important factors for optimal dust reduction were to simultaneously minimize shroud leakage and maintain high collector airflows (>3:1) in relation to bailing airflows (Page and Organiscak, 2004).

To reduce the emissions of dust from the table bushing in the drill deck, a device called the air-ring seal was developed. This device is a donut-shaped manifold with closely spaced holes, which produce high-velocity jets of air, on the inside perimeter of the donut. It has a large inside diameter to accommodate the passing of the drill bit, steel, and table bushing through its center. The air-ring seal is housed underneath the drill deck at the location of the table bushing. Air pressure is supplied to the air-ring seal from the existing air compressor system, which produces the high-velocity air jets that impede the transport of dust through the table bushing. The air-ring seal was shown to reduce dust by 50% to 60%. It also had the advantage of preventing material from traveling through the table bushing, therefore allowing the drill deck to be kept clean of drill cuttings (Page, 1991).

Moving the inlet closer to the drill steel was also studied. The problem incurred with moving the inlet is that the larger drill cutting particles could enter the dust collection system, causing obstruction problems. Laboratory tests were conducted using a rubber deflection seal located below the new inlet location and surrounding the drill stem. This was shown to be successful in preventing large particles from entering the collection system (Organiscak and Page, 2005). However, drilling oftentimes requires high ground clearance underneath the drill shroud, and this inlet design protruded significantly below the drill deck. Therefore, a low-profile inlet hood was tested. This design was tested at different collector airflows and different shroud leakage areas. Results showed that collector airflows and shroud leakage areas had the predominant impact on dust generation. However, the newly designed inlet hood reduced dust generation by 63% to 91% for the scenarios with the higher collector airflows and also the higher shroud leakage areas, showing dramatic improvement over the original inlet location (Organiscak and Page, 2005).

The promising results above led to field evaluation of the new inlet hood design. However, because the drills tested with the new design had shrouds that were properly designed and maintained, no noticeable differences in dust concentrations were noted from the original design to the new inlet hood design. Therefore, its effectiveness in the field could not be evaluated. There was also an unforeseen problem with the new design — it eventually became obstructed from the drill cuttings entering the inlet hood. This problem could be easily rectified by designing the hood to empty the cuttings when the drill mast is lowered.

Dust collector dust control

A method of dust control for the dust collector dump that was tested early, once surface mine drilling was recognized as a silica hazard, was using a pelletizer that was attached to the drill. This apparatus used water at a rate of 0.4 L/min (0.1 gpm) to agglomerate the fine-sized dump material into pellets that ranged from 1 to 10 mm in diameter. This reduced dust levels by 65% to 73% at the collector dump. However, there were several problems encountered from having to meter the correct amount of water to the large size of the system, degrading the mobility of the drill (Bailey and Page, 1987).

Additional controls were evaluated by testing their performance on truck-mounted drill rigs. One control was to inject water into the exhaust of the dust collector. The type tested was a Rotoclone collection system. Modifying the exhaust to a level or downward position, attaching a 6-m (20-ft) length of reinforced flex tubing to relocate the exhaust port to the rear of the drill and injecting water at a rate of 0.8 L/min (0.2 gpm) resulted in a 92% reduction of respirable dust (Organiscak and Page, 1995). A disadvantage of this system is the need to supply water for injection. Another disadvantage is the bulkiness of the large amount of flex tubing required to relocate the exhaust port. Besides injecting the water into the exhaust port of the dust collector, the movement of the exhaust port itself was shown to be an effective dust control for the drill operator. The vertical exhaust port was extended vertically by adding a 2.4-m (8-ft) section of pipe. This did not reduce the dust concentrations but did allow the dust to be transported and dispersed away from the operators. Reductions in dust concentrations by 62% were seen at a 30.5-m (100-ft) distance away from the drilling operation (Organiscak and Page, 1995).

Another simplistic dust control was to shroud the dust collector discharge from the discharge opening to the ground (Fig. 11). Using a simple device as a shroud resulted in dust reductions of 80% from this source (Organiscak and Page, 1995). This shroud is easy to install. Basically, a piece of brattice cloth is attached over the existing rubber boot to the dust collector dump point using a large hose clamp. The length of brattice cloth (or similar material) should be sufficient to allow it to extend from the dust collector dump point to the ground. It should be cut so that it is only long enough to just touch the ground when the drill is lowered. When wrapping the cloth around the dust collector dump, the overlap should be placed so that it is on the outside of the dust collector dump (it should be visible as the installer looks directly at the dust collector dump). This overlap allows the cloth to expand as fine material is dumped to the ground, while containing the entrained respirable fraction within its confines. Placement of the overlap on the outside also keeps the fine material off the drill tracks, which otherwise could cause re-entrainment of the respirable size fraction of the material when the drill starts in motion.

This dust collector dump shroud is very effective in reducing the respirable dust. Respirable dust concentrations measured after installation of the dust collector shroud ranged from 0.16 to 0.24 mg/m^3, demonstrating a reduction of respirable dust of 63% to 88%. This reduction is highly dependent on wind direction and wind speed (Reed et al., 2004). Advantages of this method of respirable dust reduction are that the material is inexpensive and requires almost no maintenance. If the shroud becomes damaged, it can easily be replaced in 10 to 15 minutes, requiring little, if any, downtime for the drill.

Additional dust control measures. Further investigations revealed that the operator could reduce his exposure to dust simply by being positioned in such a way as to avoid the dust clouds. By standing away from the drill during its operation and only approaching it for operational purposes, such as maintaining drilling operations, changing steel, etc., the operator can significantly reduce the exposure (Organiscak and Page, 1995; Zimmer, 1997).

A study on the drill operating parameters was initiated to evaluate the drill bit rotation in relation to silica generation. The premise was that high-speed rotation of the drill bit may produce more silica in the dust emitted from the drill hole due to the regrinding of material in the hole. Results from this study showed that at 100 rpm (normal operating rotation), the average percent silica of all the drill holes was approximately 22.1%. When the rotation was slowed to 80 rpm, the average percent silica dropped to approximately 19.2%. This showed a slight reduction of silica generation when slowing the drill bit rotation (Listak, 2003). Additional findings were that the amount of silica in the airborne samples was generally less than half the silica amounts in the bulk material from the drill hole, demonstrating that not all of the silica in the rock is liberated as airborne respirable dust (Listak, 2003).

Figure 11 — Dust collector dump point shroud.

Conclusion

USBM research for dust control in drilling operations was initiated early after the creation of the USBM in 1910. This research was first conducted on underground drilling operations as these seemed to be associated with most cases of silicosis in underground drillers. Findings were that wet drilling is the best control method to reduce respirable silica dust. Other studies showed that the most dust was generated in the first 0.30 to 0.60 m (1 to 2 ft) of a drill hole, that water flow rates did not have to be high to successfully reduce dust generation and that external water sprays did not perform as well as wet drilling.

Later, studies of coal mine roof bolting operations were conducted that evaluated the silica content of the surrounding strata, showing that it could vary from 7% to 88%. Again, wet drilling was shown to be the best dust control measure, as dry drilling for even short time periods could expose workers to high levels of respirable silica dust. Additional research presented other methods, such as the use of dust collectors and their proper maintenance, the optimal placement of the operators with respect to the dust-generating sources and an air canopy to provide filtered air to the roof bolter operator, which could be used to provide further protection to workers against respirable silica dust.

Surface mine blasthole drill dust control research was initiated later in mid-1980. Prior to this time, the surface blasthole drill did not represent a concern for high levels of respirable silica dust. As noted above, wet drilling provided the best reduction of respirable silica dust, up to 97% reduction, but it reduced the life of the rotary bits. The first step in the research was to determine that the dust emissions were located at three sources on the drill: the deck shroud (28%), the table bushing (24%) and the dust collector dumping operation (38%).

Follow-up research focused on reducing the respirable dust concentrations at these locations. The important initiative in drill shroud design was the elimination of any shroud leakage by preventing gaps between the ground surface and the bottom of the shroud and at the corners of the drill deck. Additionally, by keeping the collector airflow at three to four times the bailing airflow, the amount of respirable dust generated at this location was significantly reduced. Other projects to reduce dust at the shroud location examined the use of a water separator sub and moving the collector inlet closer to the drill steel. The water separator sub showed potential, but problems were encountered with water control and loose material issues that were later overcome. The collector inlet relocation was also successful but required redesign to prevent large particles from collecting and obstructing airflow in the inlet area.

Research focusing on the elimination of respirable dust from the dust collector included the use of a pelletizer to agglomerate the collector fine material, injecting water at the dust collector exhaust, and the use of a dust collector dump shroud. The pelletizer was successful in reducing respirable dust by 65% to 73% but had the disadvantages of being a large, bulky and high-maintenance addition to the drill. Injecting water at the dust collector exhaust was also successful, but the required use of water introduced drawbacks, such as the need to refill and freezing issues in the winter. The dust collector dump point shroud was successful in reducing dust by 63% to 88% and was simple to install, requiring almost no maintenance.

Dust control research for drilling operations continues at NIOSH, looking for new and improved methods to reduce respirable silica dust to operators and surrounding personnel. Some of the future dust control research projects are evaluating air nozzle-assisted dust capture underneath the drill shroud and further dust control techniques for the dust collector dump material. Results from these projects should produce additional methodologies to further control dust from drilling operations, thereby, providing additional protections to the drill operators and surrounding personnel from respirable silica dust.

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