Water separator shows potential for reducing respirable dust generated on small-diameter rotary blasthole drills

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Drilling with water has the potential to significantly reduce the respirable dust concentrations generated from small-diameter rotary drills when drilling blastholes on surface mining operations. However, water adversely affects tri-cone drill bits commonly used in surface drilling operations, causing excessive wear and premature replacement. Consequently, dry drilling with a dust collector system has the most widespread use in the industry. Tests have been conducted by the National Institute of Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory (PRL) on a newly designed device for smaller diameter drills that separates the water from the bailing air before it reaches the bit and thus provides the cost benefit of dry drilling while providing the benefit of wet drilling for dust suppression. The water that is delivered to the hole with the bailing air is separated from the air by a proprietary mechanical device that is encased in a drill sub (short section of drill rod/pipe) located immediately behind the cutting bit. A cascade cyclone and a real-time dust monitor were used to sample dust emissions from the holes. Dust concentrations and silica content were measured when drilling dry versus drilling wet. The tests show that drilling with this water separating sub can reduce both measured dust emissions from the boreholes and visible dust around the drill rig.

Keywords: Surface drilling; Respirable dust; Wet drilling; Water separator

1. Introduction

Dust generated from the drilling of blastholes by rotary drills at surface mining operations may contain harmful amounts of respirable silica dust. Overexposure to respirable (< 10 μm in aerodynamic diameter) silica dust can lead to workers developing silicosis, a debilitating and potentially fatal disease that causes scar tissue in the lungs and reduces lung capacity.

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Additionally, the International Agency for Research on Cancer (IARC) classified silica as a carcinogen (IARC 1987, 1997). The regulatory standard for coal mine dust exposure in underground and surface mines is 2.0 mg/m^3 when the silica content in a dust sample is 5% or less. When the silica content is greater than 5% in the sample, the standard is reduced by dividing the number 10 by the percentage of silica in the sample.

Between the years 1985 and 1992, the Mine Safety and Health Administration (MSHA) collected and analysed respirable dust samples for silica content on all surface mine occupations. The results show that, of all surface mine occupations sampled, the drill operator and drill helper had the highest percentage of samples containing greater than 5% silica, 81% and 88% respectively (Tomb *et al.* 1995). This is further supported by the National Institute for Occupational Safety and Health (NIOSH), which confirmed that mining machine operators accounted for the highest incidence of silicosis-related deaths from 1990 to 1999 (NIOSH 2003). More recently, drill operator samples collected by MSHA between the years 2000 to 2004 showed that 14% exceed the permissible exposure limit. Because of the threats they pose to employees' health, these occupations have been the focus of dust mitigation research.

Most blasthole rotary drill rigs use dust collectors to capture dust emissions. During drilling, dry compressed air (bailing air) travels to the bit through the drill pipe. The bailing air, which exits from the nozzles at the bit, keeps the bit cool, flushes the cuttings from around the bit, and forces the cuttings up the hole, expelling them at the surface. Large amounts of dust can be produced during the drilling process and dust collectors, operating under optimum conditions, are used to maintain dust concentrations to a safe level.

The dust collectors are vacuum systems that are mounted on the drills and consist of a fan, filters, a collector tube and a shrouded drill deck over the hole. These systems draw dust emissions from beneath the shrouded drill deck as they exit the hole. Figure 1 shows the layout of a typical dust collector mounted on a surface blasthole drill. The drill deck and shroud, which enclose the drill hole, are connected to the dust collector unit by a collector tube. The fan in the collector unit creates negative pressure within the shrouded deck area to remove the dust from

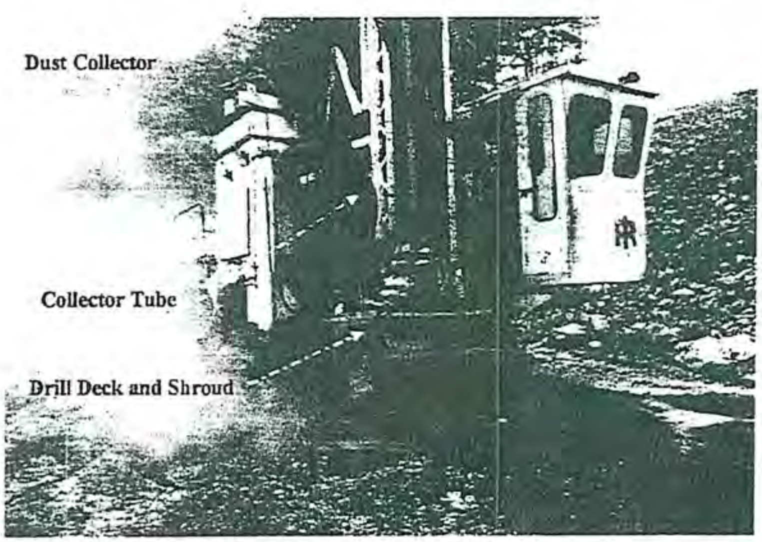

Figure 1. Dust collector on a surface mine blasthole drill.

underneath the deck into the collector as the dust is being flushed from the hole. Once inside the dust collector, the dust-laden air passes through filter media for dust removal, and the filtered air is then expelled into the atmosphere. To prevent the filters from clogging, the filters are periodically cleaned by back-flushing with compressed air. The dust that is cleaned from the filters falls into the collector dump and exits the collector unit by means of a chute onto the ground.

When new and maintained, dry dust collectors can effectively achieve greater than 95% respirable dust removal under optimum operating conditions. However, as operating parameters change and dust collection systems degrade, the effectiveness of these collectors has been shown to fall below 42% in dust removal efficiency (Zimmer and Lueck 1986). Dust escaping the dry collector unit can be traced to several sources (Organiscak and Page 2005). Damaged or non-functional filters will result in dust-laden air reaching the fan. Collector system enclosure components, whose primary purpose is to capture and contain the dust, can cause dust leakage when the components are damaged or worn. Dust leakages also can occur from the shroud and the drill table bushing, resulting in over half of the dry dust emissions from the collection system (Maksimovic and Page 1985). In figure 1, the dust shroud is not making a good seal with the ground and dust can be seen escaping from the shroud area.

Previous studies have shown the effectiveness of controlling dust from surface mine blastholes by drilling with water. A cohort mortality study of sand workers in North America (Rando *et al.* 2001) showed that a change from dry drilling to wet drilling was one of the common process changes that reduced historical exposure to silica in the sand industry. A study by the US Bureau of Mines (1988) showed the potential benefits of wet suppression drilling on large-diameter blasthole rotary drills at surface coal mines. It was reported that the water injection method of dust control showed substantial reduction in the amount of respirable dust emanating from the holes, with respirable dust control efficiencies ranging from 94 to 99%.

Despite its proven effectiveness, there are disadvantages to wet drilling with tri-cone bits. In northern regions where temperatures fall below freezing, drilling with water could be a problem during winter months. However, additives that prevent the freezing of water in tanks are available. Although not tested in this study, ethylene glycol and propylene glycol are both used in antifreeze solutions. According to the Agency for Toxic Substances and Disease Registry (ATSDR), the Food and Drug Administration (FDA) has classified propylene glycol as an additive that is 'generally recognized as safe' for use in food (ATSDR 1997). The Department of Health and Human Services, IARC and the Environmental Protection Agency (EPA) have not classified ethylene glycol or propylene glycol for carcinogenicity (ASDR 1996). Wet drilling also causes premature rotary drill bit degradation and failure as a result of the corrosive process of hydrogen embrittlement (an event that occurs with the ingress of hydrogen into a component). This process reduces the ductility and load-bearing capacity, and causes cracking and catastrophic failure at stresses below the normal yield stress of the affected material. To overcome the premature bit failure caused by wet drilling, a mechanical device to separate the water from the air was tested and shown to be effective in keeping injected water from reaching the bit (Page *et al.* 1988). The device, a drill sub located directly behind the bit, uses the high inertia of the water to separate it from the air. The air passes through the water separator sub to the bit while the water accumulates and is ejected out weep holes into the annulus of the drill hole above the bit. As the water travels up the hole to the surface, it mixes with the cuttings and reduces dust emissions at the mouth of the hole. This means of water separation works well for larger (25.4 cm (10 in.)) diameter holes. However, due to the space requirements necessary for the internal components of the device, its use on smaller diameter blastholes drills is not possible.

Recently, a new design of water separating sub was developed in Australia. The technology of this sub's components differed from the previous designs, enabling water separation in a smaller (16.8 cm (6 5/8 in.)) diameter unit. Many smaller surface mining operations drill with smaller rotary drill rigs and could possibly benefit by using this device in their drilling operations. This unit was tested and evaluated for its ability to reduce dust emissions during production drilling at a surface coal mine. This paper addresses the new design for smaller diameter blasthole drills.

2. Equipment

2.1 *Drill modifications*

A model DM 50 E Ingersoll Rand rotary drill, originally equipped with a dry dust collector system for dust control, was modified to enable water injection into the bailing air. The modifications allowed the injection of a controlled and measurable quantity of water into the bailing air on the drill. The water is introduced into the airstream at the drill masthead. The water mixes with the air as it travels down the drill string toward the bit. The mixture encounters the water separator unit before it reaches the bit and separation takes place. The water is expelled above the bit while air travels to the bit and flushes out the rock cuttings. As the air and cuttings move up the drill hole annulus, the water expelled from the water separator unit mixes with the cuttings and agglomerates dust particles while being carried to the surface. Upon reaching the surface, the dust particles have been subjected to enough moisture to prevent them from becoming airborne upon exiting the hole.

A 757 l (200 gal.) high-pressure water tank was installed on the drill carriage to provide the water to the bailing air (figure 2). The water supply for the tank was drawn from an on-site pond by a tank truck and then pumped into the water tank on the drill. An airline from the drill's air compressor to the tank enabled pressurization within the tank to force the water to the drill stem. A high-pressure 19 mm (3/4 in.) water line was connected from the tank to an airline that connected to the rotary drive at the top of the drill stem. This line supplied the water from the tank, through the rotary drive, to the drill string. To maintain control and monitoring of the amount of water, controls consisting of a valve and flowmeter were installed inside the operator's cab.

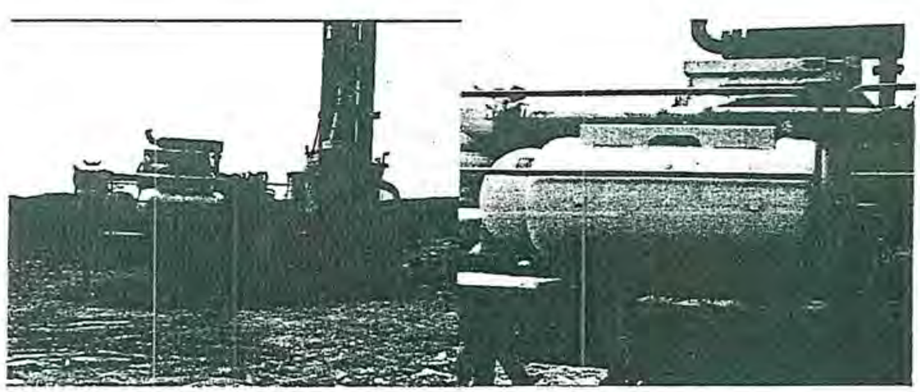

Figure 2. Water tank location on drill rig.

2.2 *DAMPA stabilizing sub*

The device tested was supplied by DTH Supplies (DTH Supplies Pty Ltd, 45 Spinnaker Ridge Way, Belmont, NSW 2280, Australia). This device, called the Dust Arresting Multi-Purpose Adapter, or DAMPA*, is a proprietary-designed, self-contained mechanical sub that uses centrifugal force to separate water from air. The DAMPA is a multi-chambered device that separates the air and water supplied to the drill stem before it enters the drill bit. The drill's cutting bit is screwed into the sub so that the separation takes place just before the bit, thus preventing water from reaching the bit. After separation, the water is ejected from three ports located 120° around the circumference of the sub. The small-diameter unit is 12.7 cm (5 in.) in diameter by 55.9 cm (22 in.) long, and is rated at 0.28 m^3/s (600 cfm). According to the manufacturer's specifications, only 4% of the bailing air is lost from the ports and 97% of the water is removed from the air. The amount of water required to suppress dust varies because of hole size, penetration rate, overburden rock and air volume. The manufacturer suggests setting water flow to a rate necessary to eliminate visible dust from the borehole. For this mining operation, 3.0 l/min (0.8 gpm) of water was adequate for dust suppression. Figure 3 shows a schematic illustration of the DAMPA unit and its location on the drill stem.

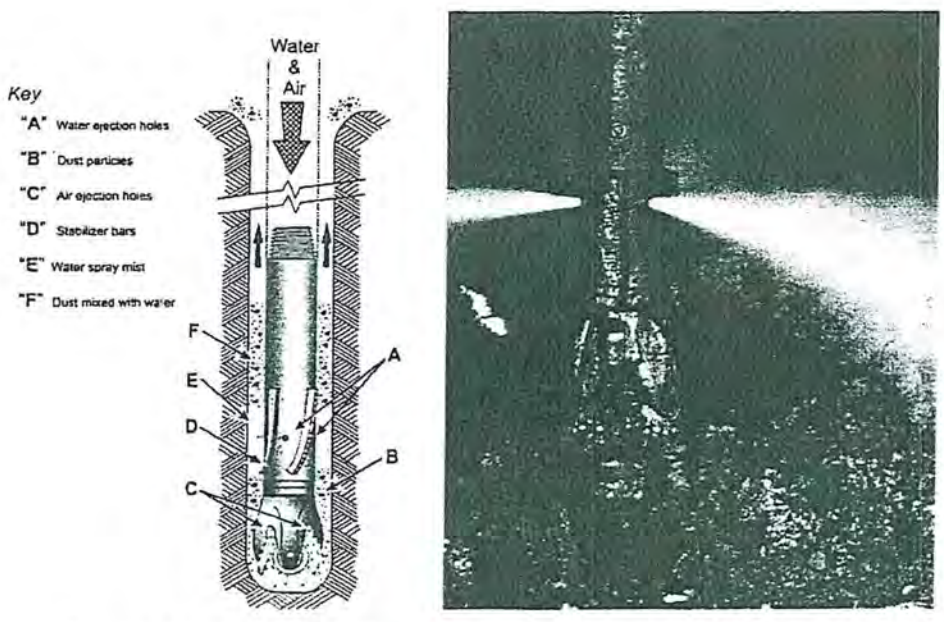

Figure 3. Schematic of DAMPA unit (left). DAMPA installed on drill (right).

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3. **Sampling methods**

3.1 *DAMPA sub trials*

Field testing of the DAMPA sub was conducted at a small surface coal mine located in northern West Virginia. During these trials the DAMPA sub was tested to evaluate its effectiveness for reducing respirable silica dust. Two sampling methods were used to measure respirable dust emissions while using the DAMPA sub. One method, which has been described previously by Listak (2003), used a cascade cyclone (Model 283-2, Grasebe-Andersen, Smyrna, GA) that sampled respirable dust inside the dust collector tube. This sample was weighed and then sent to a laboratory to determine the silica content of the airborne dust sample. The other method uses an MIE personal data ram (pDR) (Model pDR 1200, Thermo Elecron Corp., Smyrna, GA) placed adjacent to the drill deck to record respirable dust concentrations outside the drill shroud. Figure 4 shows the locations of both systems. The sampling location of the cascade cyclone is shown to the left of the drill deck next to the dust collector tube. The pDR sampler, used to record respirable dust concentrations outside the drill shroud, was located in front of the drill deck for each test. Field testing was completed over four days of testing at the mine site.

All the holes drilled and used for data analysis utilized three drill steels of 7.6 m (25 ft) length. The third drill steel was only partially drilled as drilling stopped when coal was encountered. The DAMPA was installed and used during both dry and wet drilling. During the drilling operations a time study was performed, recording the start and stop times of the hole drilling, along with the times required for adding additional drill steels.

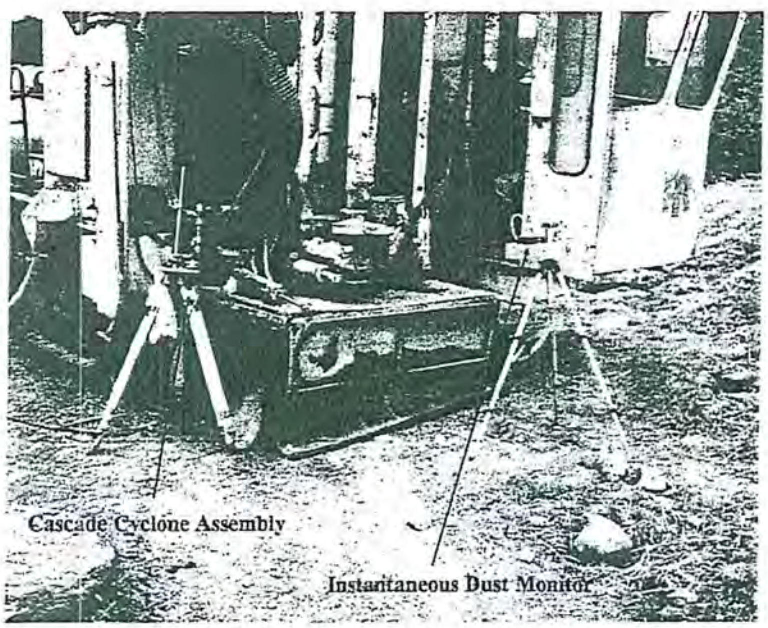

Figure 4. Location of dust sampling instruments.

3.2 *Cascade cyclone*

A component of the drill's dust collector system that draws a consistent amount of airborne dust from the hole is the collector tube. Assuming the collector system is working as designed, sampling from within the collector tube would enable a more consistent and better representative dust sample. Due to the large amounts of dust emitted during drilling, the cascade cyclone was selected as a means of sampling because it has a high particulate collection capacity (up to 10 g per stage), which permits longer sampling times. It could therefore be used for sampling in the collector tube for the entire length of the drill hole.

The sampler consists of two cyclones with particulate collector cups and a backup filter for three size classifications. The cyclone measures the aerodynamic particle size instead of its physical size. The aerodynamic size or diameter is a measure of the inertial behaviour of the particle moving in air and is defined as the diameter of a unit density (1 g/cm^3) sphere that settles with the same velocity as the particle (Lodge and Chan 1986). Therefore, the aerodynamic diameter gives information not only of the size but also of the density of a particle and indicates how the particle will behave in an environment. When sampling at a flow rate of 28.3 l/min, the cascade cyclone sampler is designed to classify dust at aerodynamic diameters of 7.5, 2.7 and 0.57 μms. The final stage (at 0.57 μm) contains a 63 mm PVC filter. Filters were pre- and post-weighed on a Mettler-Toledo microbalance (precision 5 μg) (Model UMT2, Mettler-Toledo, Columbus, OH) in a climate-controlled room after desiccation and equilibration.

In order for the cascade cyclone to collect respirable dust samples from inside the dust collector tube during drilling operations, a port was created in the dust collector tube to allow the nozzle inlet of the cyclone to be inserted into the tube. Velocity measurements were taken inside the collector tube to match the sampling velocity of the nozzle to the velocity of air in the tube so that samples could be taken isokinetically (Willeke and Baron 1993). The sampler has a range of interchangeable nozzles of varying diameters to allow for isokinetic sampling at velocities ranging from 8.0 – 50.3 m/s (1570 – 9910 fpm). An initial velocity of 9.9 m/s (1950 fpm) was measured, which is a low speed for dust collection efficiency. After opening the collector and cleaning the filters, the velocity increased to 28.2 m/s (5550 fpm).

The cyclone was set up adjacent to the dust collector tube and connected to a vacuum pump operating at a 28.3 l/min flow rate. The samples from the dust collector tube were collected from the two sampling cups, with cut points of 7.5 and 2.7 μm, and on the filter mounted in the cyclone. After every hole, the cups were emptied and the filter was removed and stored to later determine dust concentration and silica content. After each hole, the cyclone setup was removed to allow the drill to tram to the next hole and then reassembled for sampling the next hole.

3.3 *Personal data ram (pDR)*

The pDR is a real-time monitoring instrument for measuring mass concentrations of dust, mist, smoke and fumes. It was used in this study to measure the respirable fraction of airborne dust during rotary drilling. The pDR is a light-scattering nephelometer. The intensity of the light scattered over a forward angle of 50 – 90° by airborne particles passing through the sensing chamber of the device is linearly proportional to their concentration. Particle measurement is a function of the light reflected into the detector from the particles. This optical configuration produces optimal response to particles in the size range of 0.1 – 10 μm. These instantaneous sampling instruments provide relative differences in dust levels. The unit has a concentration measurement range of 0.001 – 400 mg/m^3. Time-stamped dust levels are stored at specified intervals in the unit for subsequent download to a computer. For calibration purposes, a gravimetric sampler is used with the pDR during each dust sampling survey, and then the pDR is calibrated against the gravimetric measurement to arrive at dust concentrations for the unit. The authors feel this is a more accurate way to sample with the pDR because it takes into consideration that the dust cloud may not be consistent from test to test or from survey to survey. Zeroing of the pDR units was performed after every test according to the manufacturer's specification using the zeroing bag.

Using the pDR, real-time dust measurements were taken outside the shroud area in front of the drill every 5 s while dry drilling was performed on four different holes to determine the amount of dust escaping the collector system. The DAMPA was installed and measurements were taken on four holes while drilling with water.

3.4 *Visual observations*

Surface mine operations often face opposition from nearby communities for creating large amounts of dust that propagate into residential areas. Most of this dust is created from haul roads and drilling operations, and health concerns about the dust often arise. Observations were thus made to determine the visible difference in dust in the area around the drill when drilling with each method. The differences in visible dust were documented through photographic pictures taken during testing.

4. Results

4.1 *Cascade cyclone*

The sampling plan called for drilling and sampling ten holes using the dry collector and ten holes using the DAMPA. A total of 18 holes were monitored for dust levels and visible dust during four days of testing. Various operational problems arose during testing that prevented the collection of complete data for all of the planned test holes while using the DAMPA. These operational problems caused inconsistent sampling results because of the downtime during the drilling and abandonment of holes during the wet drilling process. However, dust reductions were seen on every hole drilled while drilling with water. Although problems arose that did not allow complete sampling of the entire set of wet-drilled holes, data were collected for four complete holes while wet drilling with the DAMPA installed. Under the assumption that these four holes are representative of all wet-drilled holes, for comparative purposes, these four wet-drilled holes were compared to four holes that were sampled while using only the dry collector. The four dry holes chosen for comparison were similar in depth and proximity to the four complete holes drilled with the DAMPA, each using three drill steels and located on the same drill bench. Other dry holes were not used because they were not located near the holes that were drilled using the DAMPA.

Samples taken from the cyclone (collector tube) were analysed for dust mass and percent silica on the final filter. Drilling time is the actual time the bit was drilling and does not include the time to change drill steel or remove the drill steel and tram to the next hole. Table 1 shows the data collected from the eight holes.

The most dramatic difference between the two drilling methods was the concentration measured in the collector tube by the cyclone. An average reduction from 490.8 – 24.2 mg/m^3 was realized when using the wet drilling method (figure 5).

The advance rate (penetration rate) for each method was also recorded during dry and wet drilling—0.64 m/min (2.1 ft/min) and 0.59 m/min (1.9 ft/min), respectively. Advance rate varied little, as did the amount of silica in the cyclone samples. A bulk sample of the drill hole cuttings

Table 1. Dust levels and silica amounts measured with the cascade cyclone.

Hole	Depth m (ft)	Drilling time minutes	Dust concentration mg/m^3	Silica %
		Dry		
1	18.9 (62)	29	313.3	30.3
2	21.6 (71)	33	203.7	31.6
3	20.4 (67)	33	711.2	25.0
4	21.3 (70)	32	734.8	25.4
Avg	20.6 (67.5)	32	490.8	28.1
		Wet		
1	18.3 (60)	25	24.6	44.8
2	17.4 (57)	23	23.7	22.4
3	16.5 (54)	34	27.8	21.8
4	16.8 (55)	39	20.7	16.8
Avg	17.3 (56.5)	30	24.2	26.5

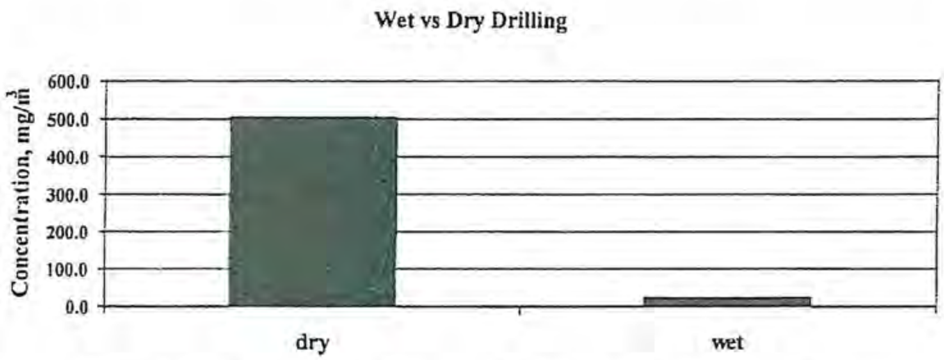

Figure 5. Dust concentration in collector tube when drilling dry versus wet.

was also collected and analysed for silica content to compare the amount of silica collected on the filter in the cyclone samples to the silica amount from the cuttings. The silica content in the cuttings taken from samples of four holes (one dry and three wet) was 59.3%, as opposed to an average of 27.3% from cyclone filter samples taken from the same holes. This result shows that the overall silica content of the rock being drilled is more than twice the silica content of the fine-sized ($>2.7\ \mu m$) airborne samples collected from the collector tube. This result suggests that silica content of the rock cannot be used as a measure of the silica content in the respirable sample. This finding concurs with an underground study of host rock silica content (Ramani *et al.* 1987).

4.2 *Visual observations*

From a visual perspective, the area surrounding the drill was much cleaner using the wet drilling method. Figure 6 shows drilling with both methods on the same bench and under the same conditions. Both pictures were taken when the drill was fully operational and drilling was underway. These pictures are typical for all holes drilled over the course of the survey.

4.3 *Personal data rams*

To measure the dust escaping the dust collection system, instantaneous respirable dust concentrations outside the drill shroud were collected in addition to the dust within the system. Area sampling of dust with these instruments outdoors can be difficult because the dust concentrations vary greatly depending on wind conditions (i.e. direction and speed). The pDRs were used in this study to give the relative differences in dust at the drill deck during each method of drilling. The pDR used in this study was positioned in front of the drill deck for each of the tests, as shown in figure 4.

The instantaneous data from the pDR are plotted in figure 7, which shows the average instantaneous respirable dust concentrations in mg/m^3 for each hole drilled for both wet and dry drilling. These concentrations consist of the averages of all concentrations measured by the pDR for the total hole length (top to bottom for each hole). Figure 7 shows that the respirable dust

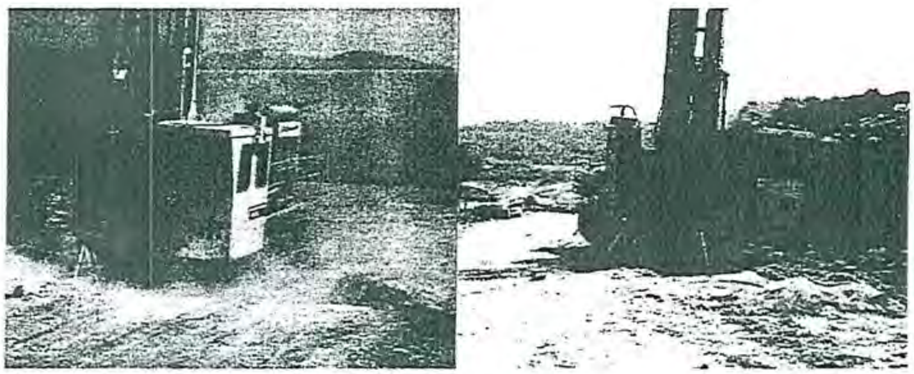

Figure 6. Dust liberated during dry drilling (left) and wet drilling (right).

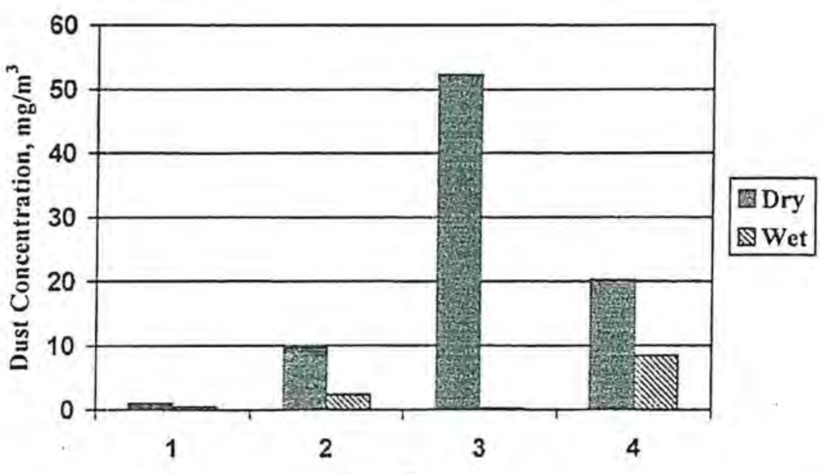

Figure 7. Comparison of dust concentrations in dry drilling versus wet drilling.

concentrations ranged from 1.042–52.297 mg/m^3 for dry drilling, while the concentrations ranged from 0.217–8.502 mg/m^3 for wet drilling with the DAMPA sub, indicating that wet drilling effectively reduced respirable dust concentrations. It should be noted that the higher respirable dust concentration of 8.502 mg/m^3 from drill hole 4 of the wet drilling was due to the large shroud-to-ground gap of approximately 30.5–61 cm (12–24 in.). This occurred because of the ground surface sloping downhill away from the drill. Other shroud-to-ground gaps for the other drill holes were not as significant, only varying from 25.4–50.8 mm (1–2 in.). Ideally, the shroud should fit tightly to the ground but because of ground undulations or grade changes, complete contact with the ground is rare. The other variations in respirable dust concentrations might have been due to changing wind directions and wind speeds (throughout most of the day the wind was calm, with slight breezes occurring often and sometimes shifting directions).

5. Discussion of results

As the results described in this paper indicate, wet drilling reduces the amount of dust generated during drilling operations. The purpose of the DAMPA is to perform wet drilling while allowing the drill bit to work under conditions that are close to dry drilling, thus enabling longer bit life. However, this study was not able to determine if there are any benefits to the drill bit life as a result of using the DAMPA. This was due to various problems encountered at the mine site, both operational and logistical.

Many of the problems encountered when using the DAMPA were due to the regulation of water flow. Specifically, constant water flow to the device was not maintained because of the method of pressurization of the water tank. Water flow from the tank varied as water levels in the tank changed during usage. A flowmeter and valve mounted in the cab did not provide enough control to properly regulate the flow to the unit. This problem could be solved by using a constant flow pump on the outflow of the tank.

The condition of the overburden at this site also had a detrimental effect on drilling performance. The overburden being drilled was highly weathered and fractured. When flows were too high the high-pressure water ejecting from the weep holes of the DAMPA caused hole-wall deterioration and spalling above the bit. This circumstance caused the holes to cave in, requiring re-drilling without water and, in some cases, abandoning the entire hole. This did not seem to occur when dry drilling with the DAMPA.

There was a significant amount of troubleshooting required to resolve these two conditions, which limited the amount of data obtained during the study. Additionally, the mine site was a very small operation where drilling did not occur on a consistent basis. However, being small did allow the flexibility for successful troubleshooting to occur without interfering with other mine operations. Moreover, this mine relied upon a drilling contractor to perform the majority of its drilling needs. Therefore, while this site provided significant resources and produced good quality dust measurement data, it was not ideal for determining long-term bit performance with the DAMPA.

For the testing completed at this mine site, there is no indication that the DAMPA had any impact upon the silica content of the dust in the cyclone samples, although this was an expected result. The silica content would vary significantly based upon the surrounding geology, rather than whether or not water was used in the drilling operation. Also, the amount of time spent drilling (advance rate) to complete the drill holes was not significantly different with or without water when using the DAMPA. However, with the limited amount of data (eight drill holes total), it is not possible to determine any impact upon the drilling rate with or without water.

6. Conclusions

Surface mine blasthole drilling generates large amounts of respirable airborne dust. When drilling through overburden, there is a high potential for this dust to contain silica, which can cause silicosis in employees in the vicinity of the drilling operation. While dust collectors are generally used to reduce airborne respirable dust surrounding the drill, water is another method that has been shown to be effective at reducing dust levels.

The evaluation of the respirable dust levels of a rotary drill while drilling overburden blastholes with the DAMPA dry versus drilling with water showed that dust levels surrounding the drill could range anywhere from 1.042–52.297 mg/m^3 when drilling dry versus 0.217–8.502 mg/m^3 when drilling wet. Dust measured in the drill's collector tube by the cyclone showed that dust levels were on average approximately 20 times higher when drilling dry (490.8 mg/m^3) versus drilling with water (24.2 mg/m^3). This shows that wet drilling with the DAMPA can reduce airborne respirable dust levels generated during drilling operations. An added benefit of drilling with water is that the cuttings that are expelled and accumulate around the holes are wetted and heavy and are thus less likely to be entrained into the air during windy conditions. This benefit could possibly reduce the respirable dust levels for the blasting preparation that occurs around the drill pattern once drilling has been completed.

Silica amounts in the respirable dust samples ranged from 25.0–31.6% for dry drilling and 16.8–44.8% for wet drilling. The silica content averages did not vary significantly. It is expected that any variations in silica contents were caused by the varying geology of the drill holes. Drilling times did not vary significantly during testing whether dry drilling (32 minute average) or wet drilling (30 minute average) with the DAMPA. The amount of data collected during this study, due to operational and logistical problems, was not sufficient to determine the long-term effects of the DAMPA on drill bit performance.

In conclusion, wet drilling with the DAMPA sub did reduce respirable dust levels during drilling operations. Problems were encountered using the DAMPA, but these were deemed to be correctable. Continued work and refinement of the process needs to be completed in order to determine any effects on long-term drill bit performance when using the DAMPA to drill blastholes at surface mining operations.

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