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A METHOD TO DETERMINE THE EFFECTS OF ROTARY DRILLING PARAMETERS AND OVERBURDEN ROCK ON SILICA DUST GENERATION

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ABSTRACT

NIOSH is conducting research to reduce the silica dust exposure of workers at surface coal mines. One goal of this research is to evaluate the relationship between drilling parameters, rock strata and silica dust generation. This study involved measuring blast hole emission dust from a rotary drill rig which required sampling high concentration dust (>400 mg/m^3) for silica content in a high velocity airstream. To measure dust initially, traditional sampling methods using personal sampling instruments were attempted in and around the shroud area of the drill with no success. Variations in the dust cloud concentrations under the shroud, the condition of the shroud and its orientation over the hole, and ambient air conditions prevented consistent and accurate dust measurements from being obtained. A more consistent dust cloud is necessary for accurate measurements. An area of the drill's dust collector system that consistently draws the emitted airborne dust from the hole is the collector tube. This tube connects the drill collector's vacuum and dust filtration system to the shroud area. Assuming the collector system is working as designed, sampling from the collector tube would enable more consistent and accurate samples to be taken. However, current personal samplers are unable to sample in the concentrations and velocities experienced in the collector tube, so another method had to be devised. To achieve the desired results, an in-stack cascade cyclone was used. Preliminary field testing shows positive results.

INTRODUCTION

Silicosis is a well-known occupational disease that causes the deaths of more than 300 people annually and cuts across a wide variety of industrial settings. Surface mine rock drillers are particularly at high risk because of the potential of being exposed to extremely high levels of respirable silica dust when drilling through rock containing silica [NIOSH, 1992]. A study of job categories was conducted by the National Institute for Occupational Safety and Health (NIOSH) to examine exposure data collected during a two year period at surface mine sites [Stauffer, et. al., 1998]. This study concluded that the highwall drill operator and helper had the two highest silica exposures and the two highest coal mine dust concentrations of all job categories examined. To address this problem, the Pittsburgh Research Laboratory of NIOSH is conducting a study to determine how rotary drilling parameters affect the amount of silica in blast hole dust emissions.

The evaluataion of airborne respirable dust generation is accomplished either by personal or area sampling in the working environment. The coal dust standard for mine workers is 2 mg/m^3 and is enforced by the Mine Safety and Health Administration (MSHA). Sampling methods for evaluating dust exposure utilize a limited number of reliable instruments from which dust can be measured, analyzed, and size classified. These instruments are designed to conform to the criteria set by the European Standardization Committee (CEN), the International Organization for Standardization (ISO), and the American Conference of Governmental Industrial Hygienists (ACGIH) for respirable aerosol sampling [CEN, 1992, ISO, 1991, ACGIC, 2001]. Typical mass concentrations of dust in work environments range from 0.1 to 10 mg/m^3 [Willeke and Baron, 1993] and personal and area sampling instruments are designed to provide measurements in these concentrations in low velocity air (0 to 4.1 m/s (0 to 800 fpm)). However, studies have shown that collection efficiencies of personal samplers drop with inlet orifice orientation and in high velocity airstreams (> 4.1 m/s (> 800 fpm)) [Cecala, 1983, Pattenden, 1977].

Typically, for respirable dust (<4 microns), these instruments are personal sampling devices consisting of a pump and cyclone assembly to separate the nonrespirable particles from the ambient air drawn into the sampler. The respirable particles are then deposited on a filter for mass determination. Since 1969, MSHA has required the use of the Dorr-Oliver cyclone as a preseparator for compliance dust sampling in underground and surface coal mines. This instrument samples at a flow rate of 2 lpm and deposits respirable dust particles < 3.5 microns (Mass Median Diameter (MMD)) on 37 mm polyvinyl chloride filters to determine dust concentration. Subsequent lab analysis can determine silica content in the sample.

Depending on its size, inhaled dust settles in different areas of the respiratory tract, which may result in different health effects. Therefore, size classification of dust is an important aspect of dust sampling methods. For size classification of dust, cascade impactors provide a means of sampling that provide a size distribution of dust particles and is used for particle size classification of dust in many industries. In use, the dust-laden aerosol is drawn into the multi-stage instrument and separated into aerodynamic size classes. The aerosol stream moves with low velocity over the upper stages and increases in velocity at each subsequent stage. The collection process is made possible through the use of Mylar substrates on each of the

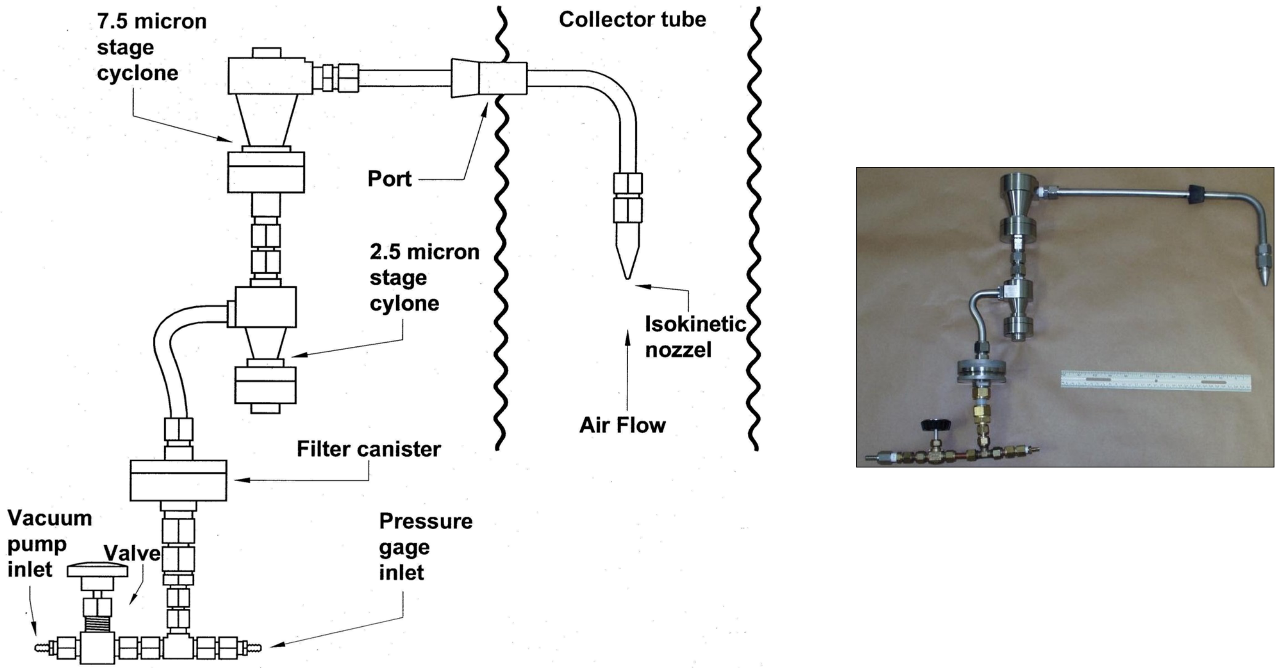

Figure 1 Schematic and photograph of the Sampler.

instrument's stages. Those particles with higher inertia (larger particles) will 'impact' the Mylar substrate and be collected on the upper stages, whereas smaller particles remain airborne and will pass through the stage and be collected on the subsequent lower stages. The Mylar substrates are coated with silicone grease to minimize particle bounce from one stage to the next. The substrates are pre- and post-weighed to determine the mass distribution on each stage of the impactor.

Personal cascade impactors have been successfully used by researchers at the Pittsburgh Research Laboratory to obtain size distribution of airborne dust particles. However, impactors can overload quickly in modest amounts of dust and sampling times may be very short. In addition, the use of silicone grease for impaction interferes with silica analysis methods and therefore complicates the determination of silica content in samples.

Personal gravimetric and impactor samplers were developed to measure worker exposure to airborne respirable dust in relatively low dust concentrations and were not a viable means to collect high concentration dust in high velocity air. Therefore, another means of collection had to be devised to measure the high concentration dust emissions from rotary blast holes. This was achieved through the use of a cascade cyclone. Originally designed for stack sampling, cascade cyclones have high particulate collection capacity (up to 10 g per stage) and allow longer sampling times. The sampler consists of two cyclones with particulate collector cups and a backup filter for 3 size classifications. When sampling at a flow rate of 28.3 lpm, 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) is a 63mm PVC filter. The sampler has a range of interchangeable nozzles of varying diameters to allow for isokinetic sampling at velocities ranging from 8.0 to 50.4 m/s (1568 to 9913 fpm). This sampler does not classify dust at the size fraction defined by MSHA (3.5 μm). However, it has been determined by the Environmental Protection Agency that inhalable particles less than an aerodynamic diameter of 2.5 μm are detrimental to worker health [USEPA, 1987]. These particles penetrate into and deposit in the deepest region of the lungs and cause the most severe respiratory problems for workers. This cascade cyclone sampler was selected to determine silica content at the size classification similar to the EPA's established standard for inhalable particulate matter.

The objective of this research is to determine the relationship between overburden rock lithology and surface mine drill parameters and the amount of respirable silica dust generated during the drilling of blast holes. The interaction of drill parameters will be evaluated, along with overburden lithology, to determine how they affect respirable silica dust generation. It has been shown that varying parameters, such as drum rotation, spray configuration, and bit type on continuous miners in underground coal mines have measurable impact on dust generation [US Bureau of Mines, 1987].

The objective of this study is to conduct dust sampling during surface drilling whereby drilling parameters (rotation and thrust) are varied and rock type is characterized to determine the effects on respirable silica dust generation. Sampling results will be evaluated to determine the interaction between silica dust generation, rock type, and drill parameters. The ultimate goal of the study is to improve air quality around drilling operations by reducing silica dust generation.

APPLICATION

Figure 1 shows a labeled drawing of the cascade cyclone assembly and photograph. The entire cyclone assembly consists of the 3-stage cyclone sampler, a 1/2 hp vacuum pump, a Magnehelic pressure gage, a flow control valve, a mounting tripod, and a power supply. The two inlet ports on the cyclone base are used for connections to the vacuum pump and a pressure gage.

Because flow rate through the sampler affects the particle cut points at each stage, initial calibration was performed with a DryCal airflow meter and Magnehelic pressure gage to determine the airflow and resistance of the sampler. In the field, flow is controlled by the valve behind the vacuum inlet port and read directly off the pressure

Figure 2. Cascade Cyclone Sampler assembly.

gage connected to the other inlet port to maintain the correct flow. For use in the field, an AC power supply is required by the vacuum pump. A power inverter was installed in a vehicle to convert DC power from the automotive battery to AC power for the vacuum pump. The entire assembly is shown in figure 2.

The cyclone itself is designed for large stack sampling and can be inserted in its entirety into a very large diameter stack at any inclination. However, the rotary drill's collector tube diameter is only 20 cm (8 in), and therefore is too small to accommodate the entire sampler. To enable the sampler to draw a sample from the tube, the cyclone was modified by adding a stainless steel extension tube with a 90 deg bend to have the correct orientation in the collector tube. This modification allowed the sampler to be mounted outside the collector tube. The isokinetic sampling nozzle was fitted to the end of the extension tube so that it could be inserted into the center line (10 cm (4 in)) of the collector tube. The extension tube of the cyclone was inserted through a port in the collector tube. The port was created by drilling a 25 mm (1 in) diameter hole in the tube and fitting it with a threaded pipe. The pipe is held in place with flat nuts on the outer and inner sides of the tube. When not in use during non-sampling periods, the pipe was capped so as not to compromise the integrity of the drill's dust collection system. Figure 3 shows the cyclone positioned in the drill's dust collector tube.

Figure 3. Sampler assembly in drill dust collector.

Table I. Laboratory Test Results.

Velocity, m/s (fpm)	**7.1 (1400)**		**21.3 (4200)**	
Time, min	15	30	15	30
Mass, mg	7.8	15.3	2.3	4.3
Concentration, mg/m^3	18.2		5.2	

LAB TEST

Extensive laboratory and field test calibration for the cascade cyclone was performed by the Southern Research Institute (SoRI) [Smith and Wilson, 1978]. The cascade cyclones used in this study were manufactured to the exact dimensions of the SoRI models. However, to ensure that the cyclone was functioning properly, cursory lab tests were conducted using respirable dust concentrations at two different air velocities and sampling for two different time periods. Because of the low concentration of dust available, the 7.5 and 2.7 mm cyclones did not collect enough dust to be measured. Therefore, the final filter of the cyclone (<2.7μm) was used to conduct the tests. The tests were conducted in an apparatus currently being used to simulate drill hole dust emissions. This test facility is ideal because it uses ductwork similar to the drill tube on the drill collector and it uses crushed limestone for simulated drill cuttings. The crushed limestone has similar density to most sandstone and shale found in surface coal mine overburden. The feed dust concentrations and the velocities can also be varied in the test facility.

The test showed that as the sampling time was increased 100%, the collected mass also increased 100%. In addition, as the test facility air velocity was increased by a factor of 3, dust concentration was decreased by more than a third. The results of the test are shown in Table I.

FIELD TESTS

Field testing at an active operation requires that measurements be taken with minimal impact on the production of the operation. Therefore, the sampling procedure has to be flexible enough for quick setup once the drill is positioned over the hole and removal from the area when a hole is completed and the drill is moved for the next hole. Using a modified surveyor tripod allowed for portability of the cyclone assembly. The cyclone was mounted with clamps on a rod so that the entire assembly could be moved into place when the drill was

Figure 4. Dust sampling survey during drilling operation.

Table II. Dust Concentrations From Test Holes.

	Concentration, mg/m^3	
Hole Number	**15.50m (51 ft) Depth**	**7.6 m(25 ft) Depth**
1	109.7	675.9
2	191.4	526.7
3	526.8	973.5
4	140.9	1344.2
5	598.5	1070.3
6	596.7	501.8

Table III. Percent Silica Content in Each Cyclone Stage.

	15.5 m (51 ft)	**7.6 m (26 ft)**
7.5 um stage	37.4	32.9
2.7 um stage	21.0	19.6
Filter	13.0	13.8

positioned over the hole and moved away quickly upon completion of the hole. This tripod arrangement also allowed for fast adjustments of the cyclone to accommodate varying height due to ground irregularities. Figure 4 shows the complete cyclone setup at the drill.

Field tests were initially conducted on the cyclone to determine if it would be able to collect the volume of dust being generated from the borehole without becoming clogged, overloaded, or damaged. In addition, the ability to safely take a sample during the production cycle without undue hindrance or obstruction to the operation was deemed important. Therefore, in these initial tests, accuracy of the measurement was not a primary concern. Twenty holes were sampled to assess the instrument. An air velocity measurement was taken in the collector tube using a pitot tube and Magnehelic pressure gage.

After determining the velocity in the tube, the isokinetic nozzle corresponding to that velocity was mounted in the cyclone. A series of 8 holes were drilled to start. These holes were drilled 7.9 m (26 ft) deep at normal drill speed (100 rpm) and an average drill time of approximately 10 minutes or 0.80 m/min (2.6 ft/min). After the first hole, the cyclone was carefully checked for nozzle obstructions, clogging, and abrasion. The stages and filter were also checked for dust amounts to determine overloading or insufficient loading. None of these problems were occurring at this depth and for this rate of drilling. After each successive hole, the cyclone stages were emptied into petri dishes and the cyclone was cleaned and remounted while the drill was repositioned over the next hole.

The next series of tests were conducted on a different bench to determine if deeper holes could be sampled without overloading the instrument. The overburden on this bench was 15.5 m (51 ft) thick. Six holes were drilled 15.5 m (51 ft) at a rate of approximately 0.85 m/min (2.8 ft/min). Again the nozzle was checked and no signs of clogging, obstructions, or wear occurred. The stage collection cups had a greater mass of dust than the first series of holes but were not overloaded. The next test, conducted on the same bench as where the previous 6 holes were drilled, sampled the upper 7.6 m (25 ft) of the 15.5 m (51ft) overburden. The overburden on this bench was comprised of a siltstone upper member and a sandstone lower member. Having only one cyclone, samples could not be taken from each rock type in the overburden within the same hole. Therefore, these six additional holes were sampled only in the upper 7.6 m (25 ft) of overburden (siltstone) to determine whether the silica content varied when compared to the samples drilled the entire 15.5 m (51 ft). Samples from each test hole were removed from the cyclone and analyzed for silica content. The final filter was used to calculate the concentration of dust particles that passed through the 2.7 mm stage and then deposited on the filter. These concentrations are shown in Table II.

Variability of dust concentration within each series of tests is high. However, comparisons of these twelve samples show that concentrations were higher on average in the 7.6 m (25ft) boreholes than in the 15.5 m (51 ft) boreholes and suggests that higher concentrations of respirable dust are being generated from the upper siltstone member. Table III shows the silica content of a single hole from each 6 hole series of tests.

Silica content of bulk samples taken from the siltstone and sandstone members are 38.8% and 43.7%, respectively and point load tests showed respective strengths of 14.9 and 40.8 Mpa (2158 and 5925 psi). Of the samples analyzed for silica content, there is little difference between the amount of silica from the15.5 m drill holes and the 7.6 m drill holes. Both holes show that there is a trend to less silica amounts at the lower stages. Average respirable silica content in the holes is about 23%, almost half the amount found in the bulk samples.

After the first tests were successfully completed, another survey was conducted to determine the effects of changing drill speed while drilling. Ten holes were sampled during the survey. Five were drilled at 100 rpm and the next five were drilled at 80 rpm. Two distinct stratigraphic members were present in the overburden. The total depth of the holes were 20.1 m (66 ft). The first 6.4 m (21 ft) was comprised of a mudstone. The next 13.6 m (45 ft) was made up of sandstone. Two cyclones were used during this survey to change sampling at the rock type interface and thus obtain samples from each member. Lump samples of each stratigraphic member were collected to determine strength and bulk silica content. Strength tests were performed using the point load method for irregular samples. The point load index for the upper and lower members was 5.6 MPa (810 psi) and 28.1 Mpa (4070 psi), respectively. Silica analyses of the lump samples were also performed and were determined to be 40.5% for the mudstone and 60.4% for the sandstone. This analysis crushes the sample to 45 mm, well above the respirable dust particle size. Table IV shows the percent silica in the stages at the two drill speeds. The trend of decreasing silica amounts in the smaller size classes is consistent with the preliminary tests for both speeds. Comparing average silica content in the samples of the two speeds shows that there are slightly higher amounts in the samples at 100 rpm and may

Table IV. Percent Silica in Samples as a Function of Drill Speed.

	Percent Silica									
	100 RPM									
Hole	**1**		**2**		**3**		**4**		**5**	
Stage	**siltstone**	**sandstone**	**siltstone**	**sandstone**	**siltstone**	**sandstone**	**siltstone**	**sandstone**	**siltstone**	**sandstone**
7.5	23.0	33.0	31.0	26.0	30.0	27.0	31.0	39.0	33.5	20.2
2.7	8.5	19	13	22	17	34	16	47	20.3	22.9
Filter	7.3	17	10	15	11	19	13	30	14.8	18.2
	80 RPM									
Hole	**6**		**7**		**8**		**9**		**10**	
Stage	**siltstone**	**sandstone**	**siltstone**	**sandstone**	**siltstone**	**sandstone**	**siltstone**	**sandstone**	**siltstone**	**sandstone**
7.5	22.0	28.0	21.0	27.0	40.0	21.0	21.0	20.0	18.4	20.8
2.7	17	21	17	28	21	20	12	17	15.4	16.5
Filter	12	17	14	16	18	16	12	19	12.4	14.7

be attributed to more regrinding of cuttings at the higher speed.

Disregarding drill speed and combining the samples for each rock type shows that average respirable silica amounts are 18.4% and 23.0%, respectively for the mudstone and sandstone and reveals that the respirable silica dust is less than half the bulk amounts (i.e., 40.5% for bulk mudstone and 60.4% for sandstone). This result indicates that not all of the silica contained in the rock is liberated as airborne respirable dust.

SUMMARY

A research study that seeks to collect and measure dust emissions from surface mine overburden blast holes required that samples be taken from the dust collector tube of a rotary drill rig. However, with tube velocities of nearly 25.4 m/s (5000 fpm) and concentrations in the hundreds of mg/m^3, the use of personal samplers is not a viable means of measuring high dust concentrations in high velocity airstreams. Therefore, a different method, the use of a cascade cyclone, had to be developed to collect and measure dust concentrations on a rotary drill rig. Results of preliminary testing and use of the cascade cyclone to measure blast hole drill emissions have been good. The assembly is portable and doesn't interfere with drilling production. Silica content in the samples is consistent from hole to hole for the type of stratum being drilled.

Sampling a greater number of holes in future surveys may decrease some of the variability in the dust concentrations. At present, variability in the dust concentrations may be attributed to the difficulty of ensuring the precise orientation of the isokinetic nozzle in the airstream. A more accurate way to mount the nozzle in the tube is being sought.

Comparing drill speeds of 100 and 80 rpm shows that there may be slightly higher amounts of respirable sized silica particles on average in the 100 rpm drilled holes. Field surveys will continue to further refine the use of the cyclone and to collect more samples for further analyses. Although these surveys are preliminary with others to follow, collected samples show that silica amounts decrease with particle size and that average silica amounts in the respirable samples are less than half those in the bulk samples. The decreasing silica amounts in the smaller sized stages are contrary to the behavior of silica particles collected in underground mines from continuous miners. Typically, underground samples show that silica particles increase at the lower size fractions and may be attributed to the difference in cutting of the two processes.

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