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Evaluations of bit sleeve and twisted-body bit designs for controlling roof bolter dust

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Abstract

Drilling into coal mine roof strata to install roof bolts has the potential to release substantial quantities of respirable dust. Due to the proximity of drill holes to the breathing zone of roof bolting personnel, dust escaping the holes and avoiding capture by the dust collection system pose a potential respiratory health risk. Controls are available to complement the typical dry vacuum collection system and minimize harmful exposures during the initial phase of drilling. This paper examines the use of a bit sleeve in combination with a dust-hog-type bit to improve dust extraction during the critical initial phase of drilling. A twisted-body drill bit is also evaluated to determine the quantity of dust liberated in comparison with the dust-hog-type bit. Based on the results of our laboratory tests, the bit sleeve may reduce dust emissions by one-half during the initial phase of drilling before the drill bit is fully enclosed by the drill hole. Because collaring is responsible for the largest dust liberations, overall dust emission can also be substantially reduced. The use of a twisted-body bit has minimal improvement on dust capture compared with the commonly used dust-hog-type bit.

Introduction

Occupational overexposure to respirable coal and quartz dust can cause coal workers' pneumoconiosis and silicosis, respectively, which are debilitating and deadly respirable lung diseases. Respirable dust exposures in U.S. coal mines are regulated by the 1969 Federal Coal Mine Health and Safety Act and enforced by the Mine Safety and Health Administration (MSHA). The Act established respirable dust standards (currently 2.0 mg/m^3) intended to reduce and ultimately eliminate the incidence of coal workers' pneumoconiosis and silicosis. Beginning August 2016, the average concentration of respirable dust in the coal mine atmosphere to which each miner in the active workings may be exposed may not exceed 1.5 mg/m^3 for a full working shift (Federal Register, 2014). These dust exposures are measured gravimetrically as time-weighted average concentrations. A quartz dust limit of 0.1 mg/m^3, beginning August 2014, has been established by the same rule. In order to maintain quartz exposures below 0.1 mg/m^3, the applicable respirable coal dust standard is reduced by the expression: 10 divided by percent

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quartz. For example, if 20% quartz were present in the respirable coal dust sample, the reduced coal dust standard would be 10 divided by 20, or 0.5 mg/m^3.

Upon implementation of these new regulations, roof bolting personnel may experience difficulty achieving compliance. MSHA inspectors collected more than 74,000 respirable dust samples for roof bolting occupations for the years 1997–2012 (Operator codes 012, 014 and 046). Excessive levels of respirable coal dust are evident, with 8.1% of these samples exceeding a 1.5 mg/m^3 concentration. For the nearly 14,000 MSHA inspector samples analyzed for quartz over the same period, 22.5% exceeded 0.1 mg/m^3 respirable quartz dust (MSHA, 2013).

Previous studies by the U.S. Bureau of Mines (USBM) identified the largest sources of respirable coal and quartz dust exposure to roof bolting personnel. When operating in a section with a continuous miner equipped with a scrubber unit, the roof bolting machine was found to contribute 42 and 55% of the bolter operator's dust and quartz exposure, respectively (Colinet et al., 1985). Subsequent NIOSH research found that the primary causes for roof bolter overexposure to quartz dust in underground coal mines were infrequent maintenance and cleaning of the vacuum dust collection system and operating the roof bolter on the return (downwind) side of the continuous miner (Goodman and Organiscak, 2003). While recent research has confirmed that working downwind of the continuous miner continues to be a major concern, roof bolting activities alone may pose a significant hazard, especially when performed improperly (Colinet et al., 2010). With the U.S. mining industry installing more than 60 million roof bolts in underground applications annually (Tadolini and Mazzoni, 2006), this potential dust source and continued evidence of overexposure indicates a need for further investigations of improved dust control measures on roof bolting machines.

Most roof bolting machines use MSHA-approved on-board dry dust collection systems to collect drill cuttings and prevent their release into the mine atmosphere (Dust Collectors for Use in Connection with Rock Drilling in Coal Mines, 2011). These systems satisfy U.S. regulations requiring that dust generated during drilling be controlled through the use of permissible dust collectors, water, water with wetting agents, or ventilation (Health Standards for Coal Mines, 2011). A blower on the roof bolting machine draws dust and drill cuttings from the drill hole through the bit and hollow drill steel into the dust collection system. The various components work together to remove the dust from the air stream before it is exhausted to the mine atmosphere. Prior research has detailed the specific components and shown the ability of this system to successfully clean the air when both properly operated and maintained (Listak and Beck, 2008).

Dust-hog-type bit

The dust-hog-type bit, with two debris collection ports on the lateral side of the cylindrical bit body, is a widely used bit design for reducing both dust liberations from roof drill holes and drilling times. Capturing the cuttings near the cutting edge had been shown to reduce escaping drill-hole dust by 80% compared with shank-type bits (Divers, 1985). Colinet et al. observed that this difference in dust generation is largely due to the initial phase of drilling, or collaring, where the shank-type bit allowed the release of more airborne dusts (1985). In-mine studies have also observed a 63% increase in penetration rate compared with shank-type bits (Divers et al., 1986). An example of a typical dust-hog-type bit with length of 6 cm (2.5 in.) is shown in Fig. 1. One debris collection port is highlighted with the other port located on the opposite side of the bit body.

Bit sleeve

During the collaring phase, the inlets of a dusthog- type bit are not fully encased by rock and a portion of the dust and cuttings may escape the dry collection system. To address this issue, Kennametal Inc. (Latrobe, PA) has developed a cylindrical bit sleeve intended to improve the dust-hog-type bit's ability to capture drill cuttings during this critical phase. The prototype device, shown in Figs. 2, 3 and 4, is 9 cm (3.5 in.) in length and surrounds the bit, confining the cuttings as the bit advances far enough to be fully encapsulated by rock. One or more spring clips are attached to the drill steel to support the bit sleeve, holding the sleeve flush against the mine roof until the hole is completed. Upon completion, the large washer, placed under the sleeve, may be slid up the drill steel's length to reposition the sleeve and clip combination over the drill bit for the next hole.

Twisted-body bit

A "twisted-body" (Kennametal product name ProBore) bit has two tapered inlets on the lateral side of the cylindrical bit body. The manufacturer has observed that these inlets allow drill cuttings and visible dust to more easily enter the collection system. The bit is designed to also reduce clogging and lower cutting forces ("Safer productivity with ProBore, ProPoint," 2010). In operation this bit is used in the same manner as the standard dust-hog-type bit. An example of this bit design is presented in Fig. 5.

The objective of this National Institute for Occupational Safety and Health (NIOSH) study is to compare respirable dust generation using (1) the typical dust-hog-type bit; (2) a newly developed drill bit sleeve with the dust-hog-type bit; and (3) a newly developed twisted-body drill bit. This study evaluates the quantity of respirable dust liberated in the collaring process as well as that generated over a full drilling depth.

Methods

To obtain results that would be applicable to the underground mining environment, drill-hole dust emissions were measured during the drilling of overhead, vertical holes. These tests were conducted in a surface facility of NIOSH's Office of Mine Safety and Health Research (OMHSR) in Pittsburgh, PA. A test stand supported a block of unreinforced concrete into which holes were drilled. Concrete with fully cured strength of 41.4 MPa (6,000 psi) was selected to simulate the compressive strength of the shale and siltstone roof rock found in many coal mines (Rusnak and Mark, 2000). The concrete mix contained 55% aggregate and 45% combination of mortar, sand and water. The 1.1-m-thick (42-in.-thick) block of concrete permitted the drilling of 0.9-m-deep (36-in.-deep) holes without the risk of drilling through. The drilling medium was allowed to cure for a minimum of 28 days before drilling tests commenced.

Holes were drilled with a J.H. Fletcher and Co. (Huntington, WV) walk-through dual-head roof bolting machine (Model HDDR-13-C-F) with on-board vacuum dust collection system. The dust collection system was cleaned prior to this study. The system was allowed to exhaust into the building atmosphere. The dust collector vacuum was monitored between holes at the drill chuck and maintained at 0.58 bar (17 in. Hg). The maximum rotational speed of the drill head was set to 400 revolutions per minute for all tests while the drill thrust was maintained at 15.6 kN (3,500 lbs). Holes were drilled to a depth of 0.9 m (36 in.) using a 25.4-mm-diameter (1-in.-diameter) drill bit fitted to a 22.2-mm-diameter (7/8-in.-diameter) round drill steel. A new bit was used for each hole drilled.

A containment and sampling duct was used to confine and sample the dust that escaped from the drill hole. A 15.2-cm-diameter (6-in.-diameter) inlet was mounted beneath the test block, immediately adjacent to the contact area between the drill steel and concrete. The collection inlet was moved in concert with the drilling apparatus to maintain proximity to the dust source as new hole locations were selected. A centrifugal fan, mounted at the exhaust end of the duct, induced airflow to collect and transport dust to a sampling portion of ductwork (Fig. 6) before being exhausted from the building. Air flow in the sampling portion of the ductwork was maintained at 0.047 m^3/s (100 cfm) for an air velocity of 0.76 m/s (150 ft/min), as measured by a TSI thermal anemometer (VelociCalc Model 8346, Shoreview, MN). This air velocity was well below the critical range for Dorr–Oliver cyclone sampling errors due to orientation and velocity effects as identified by Cecala et al. (1983), but provided positive air movement and ensured capture of fugitive dusts from the drilling zone. Respirable dust sampling was accomplished with a combination of instantaneous and gravimetric instrumentation.

For the gravimetric sampling of dust, two coal mine personal dust sampling units were placed in the duct. Escort ELF constant flow pumps (Mine Safety Appliances Co., Pittsburgh, PA) pulled dust-laden air through 10-mm Dorr–Oliver cyclone separators at a rate of 2.0 L/min. The respirable mass was deposited onto pre-weighed 37-mm PVC filters that were subsequently post-weighed to determine dust concentrations. Filters were desiccated before both pre- and post-weighing and adjusted by control filters to account for any variability in weighing conditions. The gravimetric samplers were operated continuously during these drill tests to ensure sufficient mass accumulation on the filters. The average concentration of the two gravimetric samplers was used in the analysis.

Instantaneous dust measurements were made every 1 second using a personal DataRAM (pDR) light scattering dust monitor (Model pDR-1000AN, Thermo Scientific, Franklin, MA) placed inside the sampling duct. Because the pDR measurements are affected by aerosol size distribution and content, the pDR values must be corrected by the gravimetric measurements. This was accomplished by calculating the ratio of the pDR average concentration and the gravimetric concentration for the same time period (Thermo Scientific, 2008). This field calibration procedure is presented in closer detail by Colinet et al. (2010). All pDR concentrations presented in this paper have been adjusted using this gravimetric correction.

The study included 48 trials of the following three drilling conditions:

1. Drilling with the dust-hog-type bit alone
2. Drilling with the dust-hog-type bit and prototype bit sleeve
3. Drilling with the twisted-body bit alone

The first test condition was considered to be the baseline against which the other conditions were compared. Sixteen holes were drilled for each condition in a randomized order. Measurements were recorded three times for each hole: (1) at the start of drill rotation with the bit contacting the drilling medium surface (2) at a bit depth of 0.3 m (12 in.), and (3) at the end of drill rotation at a full depth of 0.9 m (36 in.). For the purposes of this study, the period of time from the initial start of drilling to a bit depth of 0.3 m (12 in.) was considered to be “initial,” while the final 0.6 m (24 in.) was termed “final.” Penetration rates were determined based on the elapsed time from the beginning of drill rotation to the end of drill rotation. The penetration rate for each trial was calculated by dividing the total depth drilled by the elapsed drilling time.

Results

Table 1 details drilling times for the three conditions. The time to drill 0.9 m (36 in.) deep into concrete ranges from 16 to 35 seconds, averaging 20.9 seconds for all trials. The standard deviations observed for the dust-hog-type bit and bit sleeve combination are significantly higher than for the other conditions due to a 35-second trial, though there was no immediately observable cause for the extended drilling time. Overall average drill times of 20.4, 21.1 and 21.3 seconds are similar for each test condition. Because the drilling depth was identical for each case, average penetration rates of 4.52, 4.45 and 4.32 cm/sec are also similar for the three test conditions. The time to complete each individual phase of drilling is likewise consistent among test conditions, with a range of 6.4 to 6.9 seconds for initial stages and 13.7 to 14.6 seconds for final stages.

The average gravimetric dust concentration in the sampling duct during both drilling and non-drilling activities is 0.54 mg/m^3. The pDR average concentration for the same time period is 1.37 mg/m^3, for an adjustment factor of 0.394.

The time-dependent nature of the drill-hole dust emissions is demonstrated in Fig. 7. The figure shows that the dust concentrations for each condition quickly rise at the start of drilling and then quickly return to a low concentration once the bit is fully inserted into the hole. For the remainder of the drilling time there is very little dust emitted from the drill hole. This finding is consistent with the observations from similar roof drilling tests conducted by BCR National Laboratory for the USBM (Colinet et al., 1985). The behavior is observed for all three test conditions, though the peak dust concentration is considerably lower for tests of the prototype bit sleeve.

A summary of the gravimetric-adjusted respirable dust monitoring results for the three test conditions is presented in Table 2. The change values in the table compare the specific method with the baseline use of a dust-hog-type bit alone. Drilling vertical holes into concrete using a typical dust-hog-type bit results in an average concentration of 1.30 mg/m^3 for the full duration of the 16 trials, while mean concentrations of 2.76 and 0.38 mg/m^3 are observed for initial and final phases, respectively. Drilling holes using the same parameters with the addition of a prototype bit sleeve reduces the full-duration dust generation by 49% to 0.66 mg/m^3, with the largest reduction occurring during the initial phase (57%). The 16 tests of the twisted-body bit do not result in a large change in fugitive dust emissions, though there is an increase of 7% during the initial collaring phase. The previously mentioned 35-second trial of the dust-hog-type bit and bit sleeve has average dust concentrations of 1.79 mg/m^3 and 0.35 mg/m^3 in the initial and final periods, respectively, for an overall average of 0.67 mg/m^3. These values are consistent with the average for this test condition, showing no abnormal dust effects associated with the single extended duration test. The mean dust concentrations for each set of test conditions were tested for normality by one-sample Kolmogorov–Smirnov tests. Each test condition produces a distribution of values consistent with the null hypothesis of normality. Student's t-tests were performed to compare the mean dust concentrations for each phase between the baseline and both experimental test devices. The results of these tests are presented in Table 3. When comparing the dust emissions for the baseline test condition to the bit sleeve over initial and full periods, two-sided t-tests for equality of means results in t statistics of 3.191 and 3.725 and p-values of 0.003 and 0.001, respectively. At a significance level of 0.05, the null hypotheses of equal means between test conditions are rejected, and it is concluded that the bit sleeve combination produces lower dust concentrations than the dust-hog-type bit alone during both initial and overall drilling periods. Similar t-tests comparing the initial and overall dust concentrations of the twisted-body bit with the baseline result in t statistics of −0.352 and −0.092 for p-values of 0.727 and 0.927, respectively. At a statistical significance level of 0.05, there is not enough evidence to reject the null hypothesis that the average dust concentrations observed during baseline conditions and twisted-body are significantly different. Tests comparing the penetration rates for the tested configurations result in p-values exceeding 0.05 for no significant difference in the mean value between conditions.

Discussion

These laboratory tests monitored drill-hole dust emissions while drilling into a block of concrete with controlled parameters. Several considerations may have impacts on the translation of this study's findings to the underground coal mining environment:

- When using the bit sleeve device in laboratory tests, the flat surface of the concrete allowed the sleeve to sit flush against the drilling medium. Rough and uneven roof surfaces typically found in underground mines may create gaps along the sleeve/roof interface, hindering optimal dust capture ability.
- The drilling parameters of rotational speed and thrust force were selected to maintain consistent drilling advance rates across test conditions and to prevent premature failure of the test bits. Drilling at different rates has been shown to significantly affect fugitive dust generation (Divers and Jankowski, 1987) and may alter the dust collection capabilities of the bit sleeve and twisted-body bit.
- This study evaluated normal events during drilling and did not consider potential dust release events that may occur during temporary clogging of the dust collection

system. The twisted-body bit may present fugitive dust reductions if the bit design prevents debris from clogging the inlets, leading to dust release events.

- This study focused exclusively on dust from the drill hole and did not consider potential effects on dust collector emissions.
- A separate version of the prototype bit sleeve device is designed to be used with hexagonal drill steels. This study investigates the device for use with round drill steels. Consequently, the dust capture performance of the alternative version has not been evaluated and similar reductions may not be realized.
- Drill-hole emissions were collected adjacent to the drilling region and were not permitted to migrate to the operator's breathing zone. Due to the nature of the dust sampling methods used in this study, it is impossible to directly determine an operator's exposure with the various configurations.

Even taking into consideration these potential limitations, it is apparent that drilling performed with the bit sleeve and dust-hog-type bit combination presents a statistically significant reduction in drill-hole respirable dust emissions. Laboratory drilling with the twisted-body bit does not present the same reductions, but use of the bit in underground settings may produce some benefits.

Summary

Recent data collected by MSHA show that roof bolting occupations are at risk of overexposure to coal and quartz dusts. While much of this overexposure may be attributed to dusts generated by upwind activities, roof bolter drill hole dust emissions, simulated in these NIOSH laboratory drilling tests, may contribute to this hazard, especially in the presence of inadequate ventilation.

NIOSH researchers compared the dust emissions from the use of newly developed drilling tools to the baseline of dust emissions produced by a typical dust-hog-type bit during laboratory drilling tests. Based on the results of these vertical drilling tests, the bit sleeve device and dust-hog-type bit combination is capable of eliminating up to one-half of the respirable dusts escaping while drilling. The reductions occur during the initial phase of drilling, where the highest dust concentrations are observed, regardless of drilling configuration. A twisted-body bit, though possibly reducing bit clogging and improving the collection of larger cuttings, is found to have no impact on drill-hole respirable dust emissions while drilling. The penetration rate is found to be unchanged by the choice of configuration. Though not planned at this time, further tests of the devices in an underground setting would help to test the validity of these findings and also quantify the potential impact on roof-bolter-operator respirable dust exposures.

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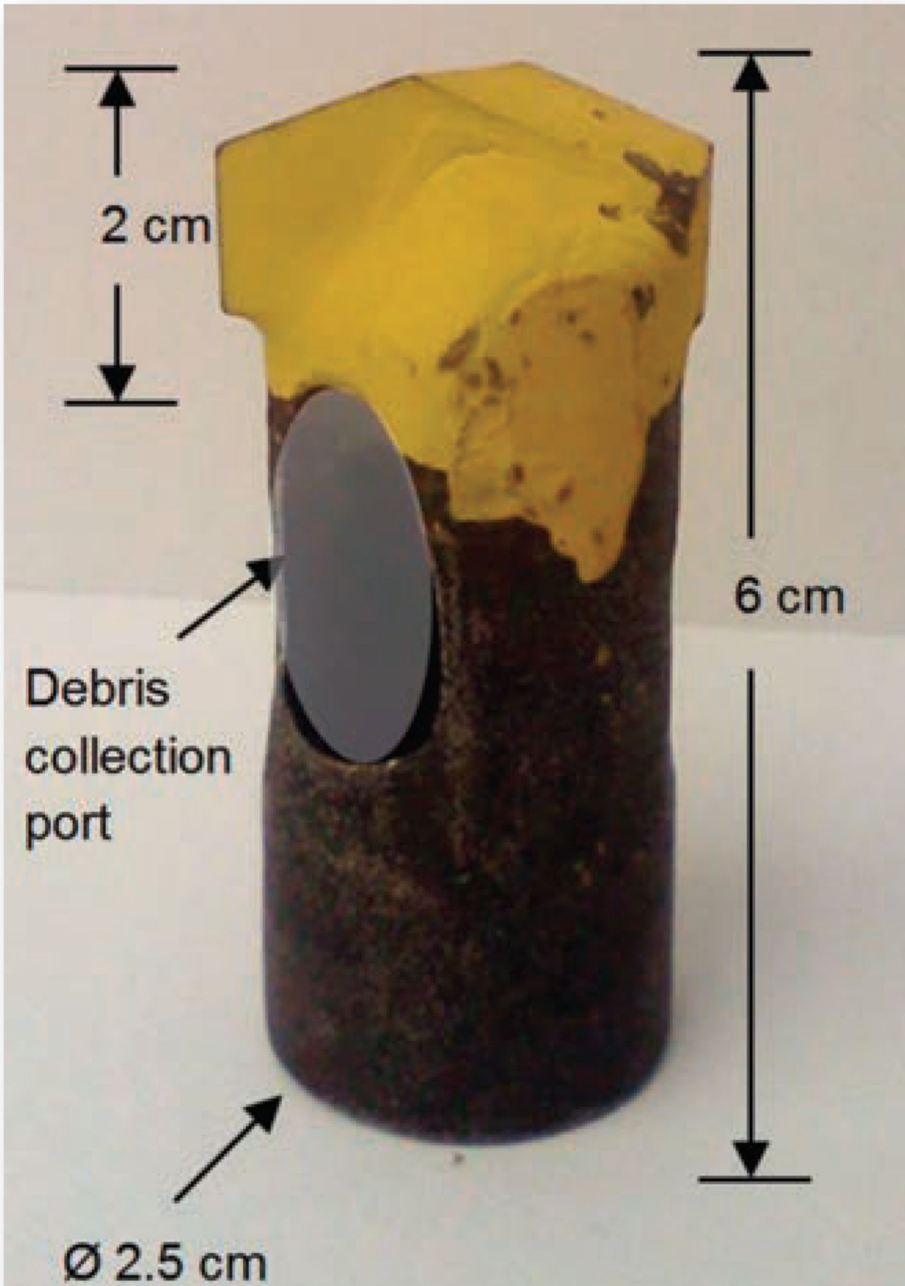

Figure 1.
Detailed view of a typical dust-hog-type bit.

Figure 2.
Detailed view of a prototype bit sleeve, spring clip and washer.

Figure 3.
Prototype bit sleeve and spring clip installed on a 22-mmdiameter (7/8-in.-diameter) round drill steel prior to drilling.

Figure 4.
Prototype bit sleeve, spring clip and washer at the base of a 22-mm-diameter (7/8-in.-diameter) round drill steel after drilling.

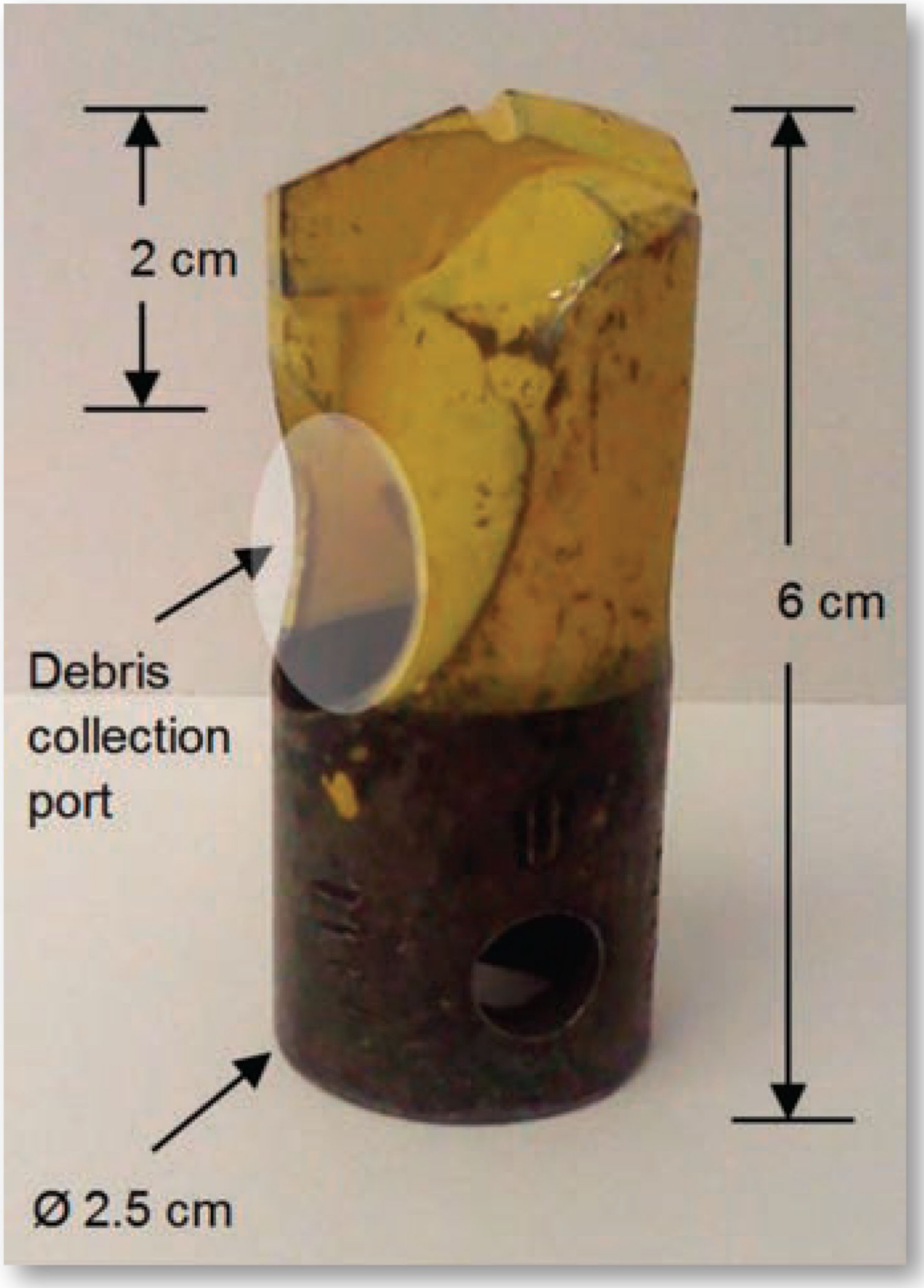

Figure 5.
Detailed view of a twisted-body bit with tapered dust collection port inlets.

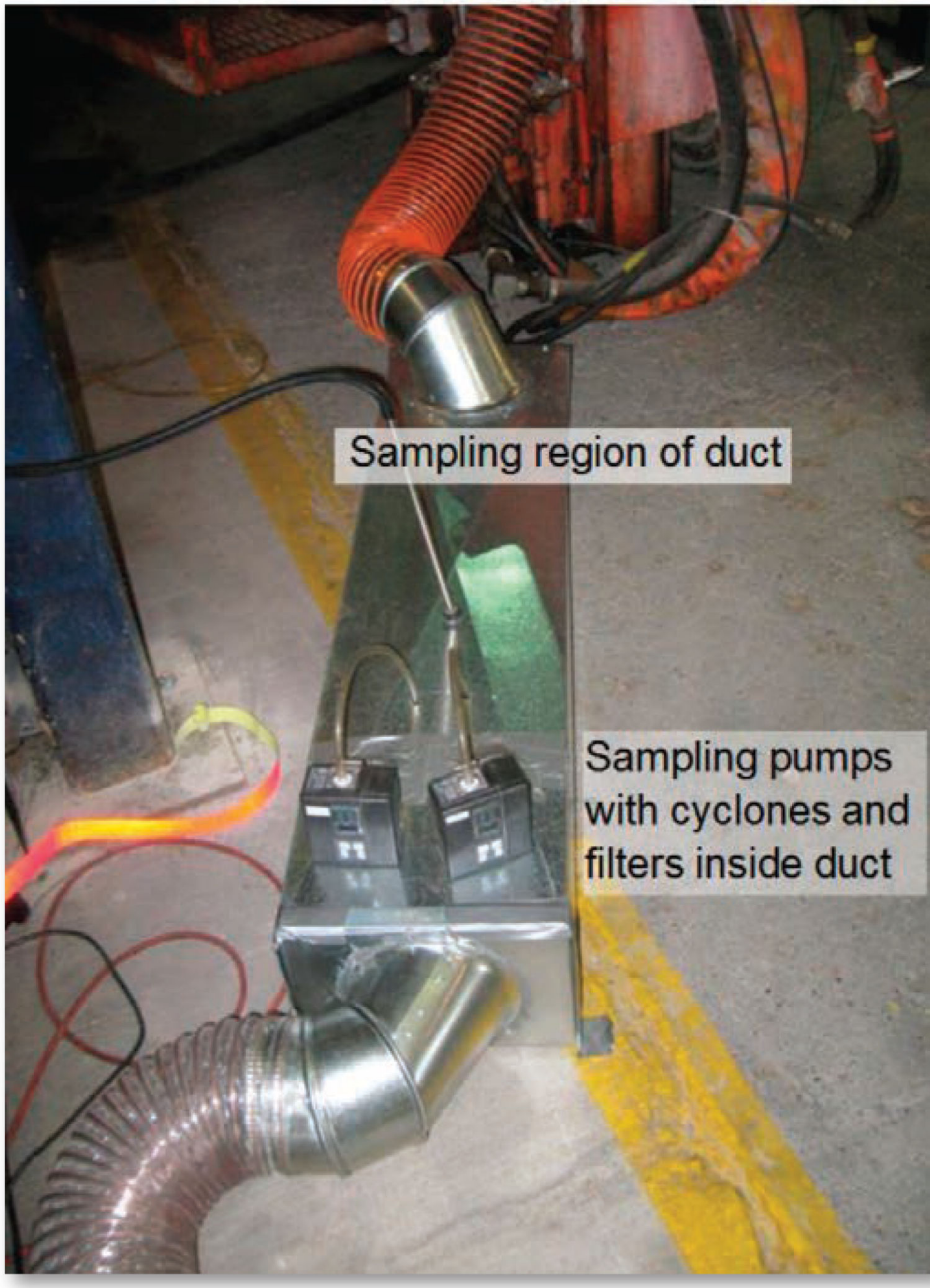

Figure 6.
Sampling portion of the dust containment and sampling duct.

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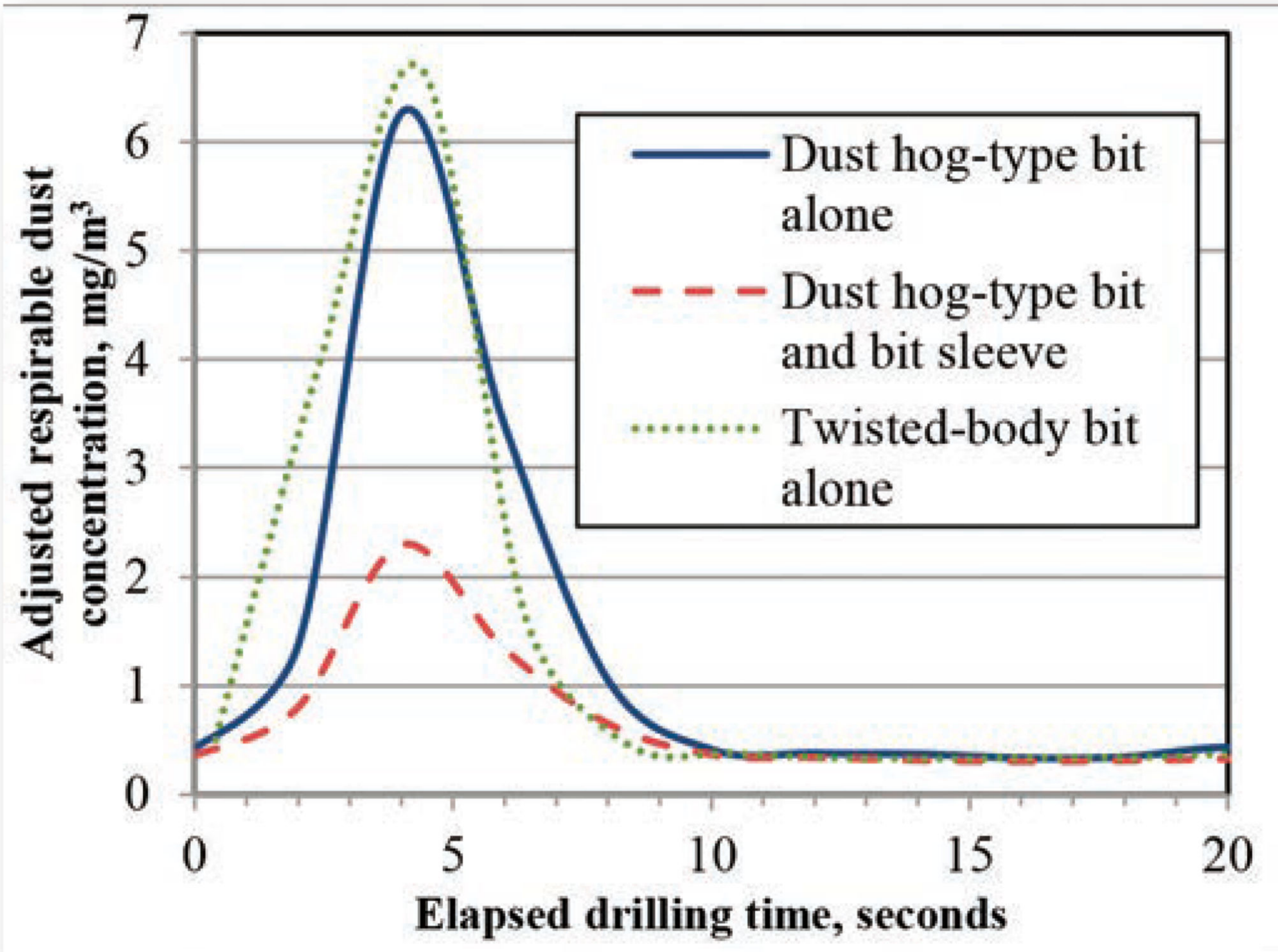

Figure 7.
Adjusted respirable dust concentration over time.

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Table 1

Elapsed drilling times and penetration rates by test condition and phase of drilling.

Test condition		**Initial (sec)**	**Final (sec)**	**Full (sec)**	**Pen. rate (cm/sec)**
Dust-hog-type bit alone	Mean	6.9	13.7	20.4	4.52
	SD	0.8	1.9	1.8	0.43
Dust-hog-type bit and bit sleeve	Mean	6.4	14.6	21.1	4.45
	SD	1.0	3.9	4.0	0.61
Twisted-body bit alone	Mean	6.8	14.5	21.3	4.32
	SD	0.5	1.8	1.7	0.33
All conditions	Mean	6.6	14.3	20.9	4.42
	SD	0.8	2.7	2.7	0.48

SD = standard deviation

Table 2

Gravimetric-adjusted dust concentrations by test condition and phase of drilling.

Test condition		**Initial (mg/m^3)**	**Final (mg/m^3)**	**Full (mg/m^3)**
Dust-hog-type bit alone	Mean	2.76	0.38	1.30
	SD	1.61	0.09	0.53
Dust-hog-type bit and bit sleeve	Mean	1.19	0.37	0.66
	SD	1.15	0.08	0.43
	Change	−57%	−3%	−49%
Twisted-body bit alone	Mean	2.95	0.36	1.31
	SD	1.35	0.10	0.50
	Change	7%	−5%	1%

SD = standard deviation

Table 3

Comparison of dust emissions for each test condition with the dust-hog-type bit, with t statistic values and two-sided p-values

Test condition		Initial	Final	Full	Pen. Rate
Dust-hog-type bit and bit sleeve	t	3.191	0.226	3.725	0.412
	p-value	0.003*	0.823	0.001*	0.683
Twisted-body bit alone	t	−0.352	0.604	−0.092	1.509
	p-value	0.727	0.551	0.927	0.142

(* significant at $p < 0.05$).