DUST CAPTURE PERFORMANCE OF A WATER EXHAUST CONDITIONER FOR ROOF BOLTING MACHINES

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Abstract

Roof bolter occupations in underground coal mines continue to experience overexposure to respirable dust. One potential source of dust in roof bolting operations is the exhaust from the roof bolter dust collection system. A wet exhaust conditioner ("water box") has been developed to reduce dust emissions from the exhaust of the vacuum dust collection system on roof bolting machines. The exhaust conditioner consists of a muffler chamber and a water chamber with four internal partitions to direct airflow over the surface of the water. The National Institute for Occupational Safety and Health conducted a series of laboratory tests to assess the respirable dust capture ability of this device as compared to the standard exhaust muffler. To determine the dust collection efficiency, both devices were placed in the exhaust stream of a simulated roof bolter dust collection system. Gravimetric samplers were operated upstream and downstream of the exhaust conditioner and muffler to evaluate the ability to capture both respirable coal and limestone dust. Researchers observed a 41 percent reduction in dust concentrations for the water exhaust conditioner in the laboratory configuration. Significant levels of dust deposition in the sampling chambers may have contributed to this effective capture rate.

Introduction

Occupational overexposure to coal mine dusts can result in coal workers' pneumoconiosis (CWP) and silicosis, both disabling and possibly fatal lung diseases. Although remarkable progress has been made in the United States (U.S.) in the years following the enactment of the Federal Coal Mine Health and Safety Act in 1969, severe cases of CWP continue to occur among coal miners. Among miners who have worked 25 or more years underground, the disease rate has increased from 4.2 percent in 1999 to 9.0 percent in 2006 (National Institute for Occupational Safety and Health [NIOSH], 2008). Similarly, for workers with 20 to 24 years of experience, the rate has increased from 2.5 percent to 6.0 percent. Coal mining also continues to be the industry most closely associated with worker-related silicosis, with the industry identified in 7.8 percent of recent silicosis deaths (NIOSH, 2008).

In order to ameliorate these occupational diseases, Title 30 CFR §70.100 limits the respirable dust exposure of coal mineworkers to a time-weighted average of 2.0 mg/m^3 for an eight hour working shift (Code of Federal Regulations [CFR], 2009). If the respirable dust sample contains more than 5 percent silica by weight, Title 30 CFR §70.101 reduces the allowable limit according to the formula 10/(percent silica) in order to maintain silica dust levels at or below 100 µg/m^3 (CFR, 2009). Data from the U.S. Mine Safety and Health Administration (MSHA) database reveals that inspectors collected nearly 13000 samples for roof bolting occupations during the years 1999-2008 (U.S. Department of Labor, 2009). Of these samples, over 18 percent exceeded 100 µg/m^3 silica and resulted in reduced dust limits. Further analysis shows that when roof bolter operators were subject to reduced dust standards, over 23 percent of inspector samples exceeded the adjusted permissible exposure limits. This indicates that many roof bolter operators continue to experience overexposure to both coal and silica dusts and suggests the need for further investigation into improved measures to control worker exposure to these harmful dusts.

In underground U.S. coal mines, Title 30 CFR §72.630 requires that any dust resulting from drilling be controlled by the use of permissible dust collectors, water, water with a wetting agent, or ventilation (CFR, 2009). A majority of roof bolting machines use an MSHA-approved vacuum dust collection system to capture drill cuttings and prevent the release of dust into the mine atmosphere. The collection systems are comprised of the following major components: pre-collector, dust tank (or dust collector box), vacuum blower, and exhaust muffler. As the drill bit advances, air transports the cuttings from the drill steel and base through a section of dust collection hose to the pre-collector. The pre-collector removes the large particles from the air stream and deposits them on the mine floor when discharged. The pre-cleaned dust-laden air is then routed to the four-chamber dust collector box where particulates are classified and removed from the air stream. Under typical operating conditions, the dust enters the collector at the top of the box and the larger, heavier particles collect in the main filter bag. The smaller, lighter dust particles pass through the woven bag surface and are carried to two cyclones that further classify the aerosol. The air stream then continues to the final chamber where it collects on a single paper canister filter. The resulting air passing through the final filter is approximately 99 percent cleaner (Thaxton, 1984). The cleaned air continues to the vacuum blower, through the muffler, and into the mine atmosphere.

Though the primary dust source for roof bolter operators comes from upwind activities (Colinet et al., 1985), the exhaust from the roof bolter dust collection system is a potential source of dust. Past research has shown that failure to properly operate or maintain the dust collection system can significantly contribute to operator respirable dust exposure. Divers (1984) observed dust concentrations as high as 20 mg/m^3 in the exhaust of machines with leaks around or through the paper canister filter. The same study showed that maintenance of the dust collection system and replacement of worn or damaged filters results in much reduced dust emissions. A recent NIOSH field study monitored the bolter exhaust and reported average exhaust respirable dust concentrations ranging from 0.31 mg/m^3 and 1.19 mg/m^3 (Listak and Beck, 2008). This suggests that dust emissions may be controlled with currently available technology.

A water exhaust conditioner (or water box) has been developed to further reduce these small dust liberations and minimize the possibility of occupational overexposure from the roof bolter exhaust. The exhaust air enters the water-filled metal container, passes through an internal muffler, and is deflected toward the surface of the water. Four internal plates act as baffles and cause the air to change direction before exiting. When filled to a depth of 13 cm (5 in.), the water box contains approximately 23.6 liters (6.2 U.S. gallons) of liquid. The water box contains an internal noise-reducing muffler and replaces the standard muffler in the exhaust stream. A schematic of the exhaust conditioner assembly showing the internal features and typical air movement is provided in Figure 1.

A prior MSHA study at an underground coal mine in West Virginia, though limited in duration, determined that there was no significant change in area dust samples or operator exposures when using a water exhaust conditioner (Fields, 1999). To address potential confounding factors and the limited scope of the previous underground study, a laboratory study was planned to isolate the water exhaust conditioner from other system components and determine any improvement in dust collection efficiency when placed in the roof bolter's exhaust. This paper details the findings of such experiments and discusses the potential impact on

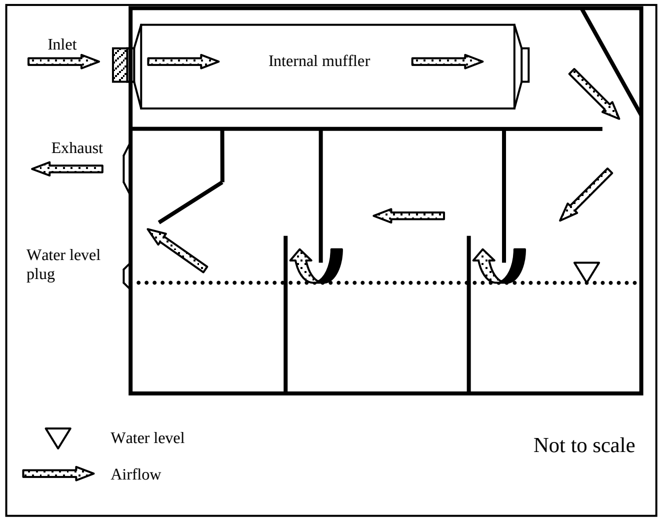

Figure 1. Schematic of Internal Exhaust Conditioner Assembly Illustrating Typical Air Flow

respirable dust exposures for roof bolting personnel in underground coal mines.

Experimental Design

Laboratory experiments were performed in a surface NIOSH facility at the Pittsburgh Research Laboratory. The test platform consisted of dust collection system components representative of the type and size found on J.H. Fletcher and Company roof bolting machines used in coal mines. The pre-collector, dust collector bag and canister filter were removed from this laboratory test system to maintain a consistent throughput of dust for all tests. Doing so eliminated potential sources of variation between individual tests caused by filter loading and corresponding changes in airflow.

Air was pulled through the Fletcher dust collection box by a Roots Frame 2504 DVJ Whispair Dry Vacuum Exhauster (Dresser Roots, Houston, TX) rated for a flowrate of 0.03 m^3/s (60 ft^3/min) at a static pressure of 68 kPa (20 in. Hg) at 3540 RPM. Utilizing an adjustable frequency drive (Dayton AC Inverter Model 3HX79, Dayton Electric Mfg. Co., Niles, IL) with an inverter duty motor (Dayton Industrial Motor Model 3KV79, Dayton Electric Mfg. Co., Niles, IL), the speed of the Roots blower was varied to maintain an airflow of 0.03 m^3/s (60 ft^3/min) for all tests. The air velocity was monitored before and after each test using a TSI thermal anemometer (VelociCalc Model 8346, Shoreview, MN) in a straight length of pipe between the collection box and the Roots blower. After traveling through the Roots blower, the exhaust air then traveled to a large sampling chamber, through the target exhaust device (muffler or water box), into another large sampling chamber, and then into the building's exhaust.

Connecting all components of the system was rubber dust collection hose with an internal diameter of 3.2 cm (1.25 in). Two 1.2 m (4 ft) lengths of hose linked each sampling chamber with the selected exhaust device. A schematic of the laboratory test layout is presented in Figure 2.

In order to test the water exhaust conditioner under ordinary operating conditions, a respirable dust concentration of 1.19 mg/m^3 was targeted (Listak and Beck, 2008). Two TSI Model 3400 fluidized bed aerosol generators (Shoreview, MN) operated simultaneously to deliver respirable dust into the test system. To avoid the potential health risks of handling quartz dust, bituminous coal dust (Keystone Filler & Mfg. Co., Muncy, PA) and limestone dust (Allegheny Mineral Corporation, Kittanning, PA) were selected as feed materials. The coal dust, Keystone Mineral Black 325A, has a relative density of 1.31 with 65% smaller in diameter than 10 μm. The selected grind of limestone dust was both denser and coarser with a relative density of 2.75 and 44.5% smaller than 10 μm. Because the interaction between dust and water may differ for limestone and coal, a separate series of tests were conducted using each material.

Painted steel drums with a nominal capacity of 208 L (55 U.S. gallons) were used as sampling chambers upstream and downstream of the target exhaust device. At 0.03 m^3/s airflow the average velocity through each chamber was slowed to approximately 0.1 m/s (20 fpm) with a residence time of 7 seconds. Two gravimetric sampling assemblies were suspended inside each chamber. Dust samples were collected by pulling dust-laden air through 10-mm nylon cyclone separators with the respirable dust fraction being deposited onto preweighed 37-mm PVC filters. A vacuum pump (Model DOA-P104-AA, GAST Manufacturing Corp., Benton Harbor, MI) drew air through a multi-port manifold (Part Number MCM20-250-10B, Polyconn Inc., Plymouth, MN), providing air flow for each of the four sampling assemblies. Critical orifices (Part Number SO0, BGI Inc., Waltham, MA) placed on each port maintained sample flow rates at 2.0 L/min for each gravimetric assembly. The vacuum pump maintained critical (or choked) flow by drawing a minimum downstream vacuum of 61 kPa (18 in. Hg) for the duration of each sampling period. After each test, the 37-mm PVC filters were subsequently desiccated and weighed with dust levels calculated. In order to ensure a sufficient mass on the sample filters, tests were conducted for durations of 180 minutes.

To measure the dust capture for the chosen feed materials and both exhaust devices, a 2x2 factorial experimental design was conducted as shown in Table 1. Each experimental factor combination was replicated for six tests with a total of twenty-four tests. Experimental tests were blocked for the feed material due to the difficulty in changing materials in the fluidized bed aerosol generators. Twelve tests were first conducted using coal dust, followed by a series of twelve tests for limestone dust. The target exhaust device was randomly selected prior to each test.

Table 1. Experimental conditions for tests of two exhaust devices with two feed materials.

Feed Material	**Exhaust Device**	
	Muffler	*Water Box*
Coal	Coal - Muffler	Coal - Water Box
Limestone	Limestone - Muffler	Limestone - Water Box

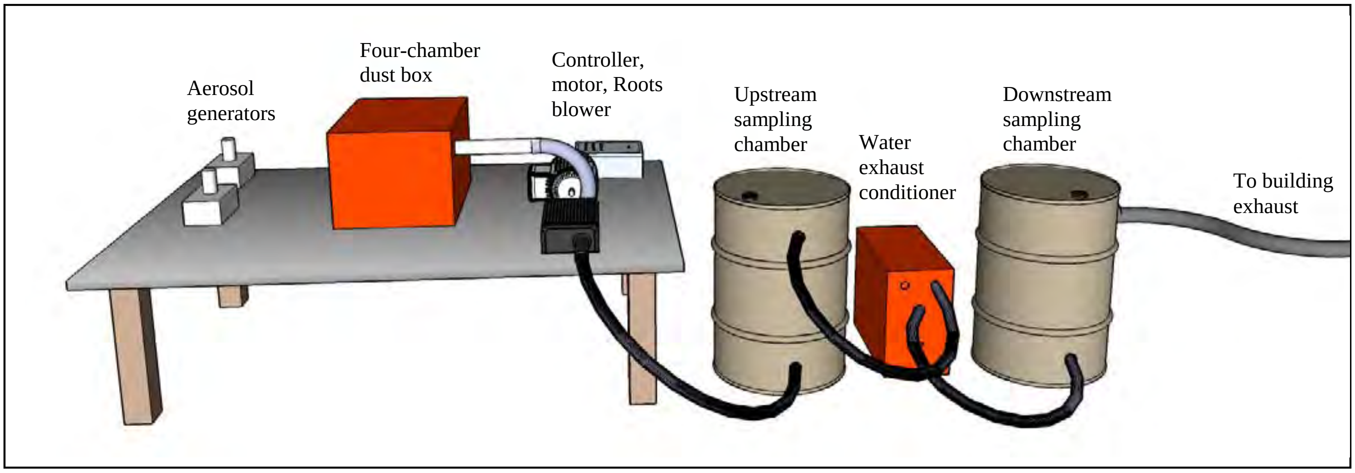

Figure 2. Schematic of Laboratory Dust Collection System and Test Apparatus

Experimental Results

After completion of these laboratory experiments, the collected data were analyzed to determine the effectiveness of the water exhaust conditioner to reduce respirable dust emissions from the exhaust of a simulated roof bolter dust collection system. The respirable dust capture efficiency was calculated for each separate test using the formula:

$$\eta = \frac{Concentration\,In\,(mg/m^3) - Concentration\,Out\,(mg/m^3)}{Concentration\,In\,(mg/m^3)}$$

Preliminary tests of the exhaust system with no device installed showed that a large proportion of the dust was lost between the two sampling chambers. Dust concentrations were reduced 16 and 18 percent for coal and limestone, respectively. This indicates that significant dust particle deposition occurred on the inside surface of the sampling chambers and dust collection hose. The slow air speed through the sampling chambers may have contributed to this effect, which presumably acted consistently for all subsequent tests.

The individual test averages for upstream and downstream sampling locations for muffler tests are presented in Table 2. These values indicate that 21 percent of the respirable coal dust measured in the first (upstream) chamber was not present in the second (downstream) sampling chamber. Similarly, the data show that 25 percent of the respirable limestone dust was lost between the two sampling locations. The observed efficiencies were fairly consistent regardless of feed material, with a range of 19 to 23 percent for coal and 24 to 27 percent for limestone. These efficiency values represent the system losses in the transport of particles through the sampling chambers, lengths of dust collection hose and muffler. Because all components are present in both test conditions, these muffler efficiencies establish the baselines to which the water box tests are compared.

The samples from the water box tests were analyzed and reported in a similar manner in Table 3. The average collection efficiency for these tests was found to be 64 percent, with 63 and 66 percent dust capture for coal and limestone dusts, respectively. Considering that an average of 23 percent of the dust loss can be attributed to the muffler and dust hose for both materials, the exhaust conditioner device was responsible for collecting 41 percent of the airborne respirable dust. As was the case for muffler tests, the efficiencies observed for limestone test were fairly consistent, with baseline adjusted values of 39 to 43 percent. The efficiencies observed for individual coal tests were less consistent, ranging from 38 to 45 percent after accounting for baseline dust losses.

Table 2. Respirable dust concentrations and efficiencies for the muffler in the exhaust stream.

Test Number	**Coal**			**Limestone**		
	In (mg/m^3)	*Out (mg/m^3)*	η	*In (mg/m^3)*	*Out (mg/m^3)*	η
1	1.55	1.21	0.22	0.40	0.30	0.25
2	1.54	1.25	0.19	1.13	0.83	0.26
3	1.31	1.01	0.23	1.50	1.11	0.26
4	1.08	0.83	0.23	1.03	0.78	0.24
5	0.89	0.70	0.22	1.40	1.03	0.27
6	0.58	0.47	0.19	0.95	0.73	0.24
Average	1.16	0.91	0.21	1.07	0.80	0.25

Table 3. Respirable dust concentrations and efficiencies for the water box in the exhaust stream.

Test Number	**Coal**			**Limestone**		
	In (mg/m^3)	*Out (mg/m^3)*	η	*In (mg/m^3)*	*Out (mg/m^3)*	η
1	1.38	0.57	0.59	0.91	0.31	0.66
2	1.36	0.51	0.63	1.36	0.48	0.65
3	1.39	0.47	0.66	1.59	0.57	0.64
4	1.01	0.35	0.65	1.68	0.58	0.66
5	0.62	0.25	0.60	1.59	0.51	0.68
6	0.95	0.36	0.63	2.07	0.68	0.67
Average	1.12	0.42	0.63	1.53	0.52	0.66

A minor difference in system throughput was observed between the selected feed materials. Coal dust tended to be better transported through the system than limestone dust in muffler tests, resulting in lower capture efficiencies. In contrast, slightly less limestone dust was captured in water box tests, when adjusted for baseline system losses. It is possible that a difference in properties between the materials may have had an impact on the dust loss and capture mechanisms present in the system. In other NIOSH research regarding dust control with wet collection systems, it has been suggested that particle density, particle size distribution, and wettability may contribute to differences in collection efficiencies (Colinet et al, 1990).

Prior to each water box test, the water level in the box was checked and replenished as needed. During this series of tests, very little water addition was needed to maintain the full level. In practice, increased loads on the Roots blower from drawing air through the many vacuum collection system components will result in increased air temperatures. These elevated temperatures would result in higher rates of water depletion through evaporation, requiring more frequent maintenance. The researchers also observed that the water box tests required a higher input frequency to maintain airflow at 0.03 m^3/sec (60 ft^3/min). A frequency of 37 Hz supplied to the motor for muffler tests while 42 Hz maintained airflow for water box tests. This represents an increase of over ten percent due to restrictions to airflow through the water box. The resulting increased load on the Roots blower presumably increased the air temperature for water box tests, though this was not measured. Lower ambient humidity would also increase water depletion. For this series of water box tests, the relative humidity in the laboratory averaged 52 percent.

Discussion

Though these experimental results indicate a potential for dust reduction in the roof bolter exhaust, it is necessary to evaluate the capacity to reduce occupational exposures in the mine environment. Title 30 CFR §75.325 requires that a minimum air quantity of 1.42 m^3/s (3000 cfm) be supplied to each working face (CFR, 2009). Using this minimum quantity and an exhaust dust concentration of 1.19 mg/m^3 for a twin-boom bolter with total exhaust airflow of 0.06 m^3/s (120 cfm), this fugitive dust would contribute 0.05 mg/m^3 to the ambient dust concentration. Even with significant reductions in respirable dust as found in this series of tests, dilution in the mine atmosphere will result in minimal impact on operator dust exposures.

The following key considerations and limitations of this series of laboratory tests should also be noted:

- These laboratory tests evaluated the performance of the water exhaust conditioner on the full range of respirable dust of size less than 10 μm Aerodynamic Equivalent Diameter (AED). Previous NIOSH research has shown that more than eighty percent of the dust particles bypassing the final paper filter and entering the bolter exhaust are smaller than 2 μm AED (Listak and Beck, 2008). It is not clear what effect variations in particle size has on the performance of the exhaust water conditioner, but it is possible that different size fractions will not perform in a similar manner.
- These laboratory tests considered only coal and limestone dusts. Cuttings captured during roof drilling in a coal mine would contain a dust with different characteristics (homogeneity, density, hydrophobicity, cohesion, etc). These differences in dust size and characteristics would affect and possibly decrease the efficiency of the water exhaust conditioner in practice.
- These tests maintained the water in the box at the full level for all tests. NIOSH field observations have documented instances of water boxes operated in a low water or even empty condition. These practices have not been evaluated for dust capture performance, but it is expected that the system would not function optimally.
- Accumulations of material in the water box were not observed during this series of laboratory tests. In field operation, depending on the size distribution and concentration of dusts in the roof bolter exhaust, build-up of material could vary and influence the operation of the water box.

Summary

NIOSH researchers conducted laboratory evaluations of the respirable dust capture ability of a water exhaust conditioner in the exhaust airstream of a roof bolter. The tests isolated the device from other components of the bolter vacuum collection system. The results indicate that the exhaust water conditioner captured 41 percent of the airborne respirable dust. It is unclear what mechanism was responsible for this significant reduction: impingement on the water surface or deposition on the inside metal surfaces of the apparatus. Considering the system losses of 17 percent, it is possible that a similar metal surface/dust particle interaction acted to reduce dust transmission through the water box.

Given these experimental observations, it appears that the exhaust water conditioner may function as a supplement to a properly maintained and functioning roof bolter vacuum collection system in an underground setting. While the use of the water box may provide a reduction in respirable dust exposure to roof bolting personnel, this effect would be minimal. As was observed by MSHA personnel, diluted in the mine atmosphere, the reduction in dust concentrations in a roof bolter exhaust is unlikely to be significant. In addition, the previously listed factors may influence the practical performance of the water exhaust conditioner in underground coal mines. The use of the water box also introduces additional maintenance measures, including periodic replenishment of the reservoir and removal of potential material accumulations. The device would not function as a substitute for regular replacement of the dust collector bag or replacement of the final paper filter.

Disclaimer

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