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Results of Practical Design Modifications for Respirable Dust Reduction on Continuous Miners in Underground Coal Mining

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ABSTRACT

A grant provided by the National Institute for Occupational Safety and Health (NIOSH) to perform work that will reduce the amount of respirable dust generated from underground coal mining was awarded to The Western Mining Resource Center (WMRC) at the Colorado School of Mines (CSM). Based on laboratory testing and field experience, different cutter head designs, bit types and spray layouts were tested and evaluated. The first portion of this program, for continuous miners, has produced a substantial reduction in respirable dust with the cooperation of 20 Mile Coal Co., Joy Mining Machinery, and Kennametal. Test procedures, design methodologies and results will be presented.

BACKGROUND

There is a need to reduce the amount of respirable dust in the underground mining industry. This can be seen by continued presence of crippling and fatal diseases, such as pneumoconiosis (CWP, a.k.a Black Lung), progressive massive fibrosis (PMF), silicosis, and chronic obstructive pulmonary disease in underground coal workers. The Colorado School of Mines, supported by NIOSH, and the 20 Mile Coal Company have been working together on a multi-year project to reduce the amount of respirable dust.

The previous year's work, published SME 2002 pre-print, consisted of laboratory testing to help quantify the effect of cutting geometry and bit design on dust generation. This year's work focused on field testing of different cutterhead layouts, bit designs, as well as differing spray systems. A summary of the laboratory work as well of the details and results of the field testing are presented here.

INTRODUCTION

Approximately 1/3 of coal production in the United States comes from underground mines. Nearly all underground coal production is produced by continuous miners and longwall shearers. A large portion of respirable dust produced by mechanical miners is generated by material that is crushed directly under the individual bits on the cutterhead. The crush zone underneath an individual bit, and the resulting fractures in the rock that lead to production is illustrated in Figure 1. Reducing the amount of dust generated reduces the amount of dust that can become airborne in the working area and present a health hazard.

It is known that cutting geometry affects the amount of fines/dust generated under an individual cutter/bit. These cutting geometry factors include bit tip angle, angle of attack, and bit penetration. Also, reducing the number of cutters engaging the rock, which results in an increase of bit spacing, can reduce the total amount of dust generated. These variables also have a major effect on production. A full scale test program has been performed to help quantify the effects of the different variables on dust generation as well as production. A continuous miner cutterhead layout design was made based on laboratory results and geologic physical properties. A cutterhead was built to this design and tested in 20 Mile Coal Company's underground production operation.

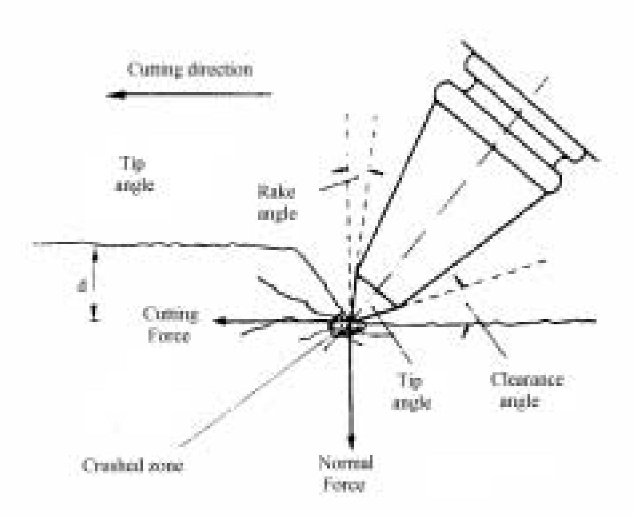

Figure 1: Crush zone, where dust is generated.

LABORATORY TEST PROGRAM

Full scale laboratory testing was performed to help quantify the effect of cutting geometry on the generation of respirable dust. This program consisted of full scale cutting tests using different bit types at differing cutting geometries in a coal measure rock, a high silica sandstone. The Linear Cutting Machine (LCM), shown in Figure 2, at the Colorado School of Mines was used for conducting the cutting tests.

The LCM forces a large rock sample through an actual bit at a preset cutting geometry, as can be seen in the schematic drawing of Figure 3. After each pass of cutting tests, muck samples were collected to determine the relative percentages of respirable dust. The linear cutting tests also measure forces acting on the cutter to ensure that the bits are operating as they would on an actual excavator while providing an acceptable level of production. This full-scale testing eliminates the uncertainties of scaling and any unusual rock cutting behavior not reflected by its physical properties. This is because the cutting action of the LCM very closely simulates the cutting action seen in the field.

Figure 2: Linear Cutting Test.

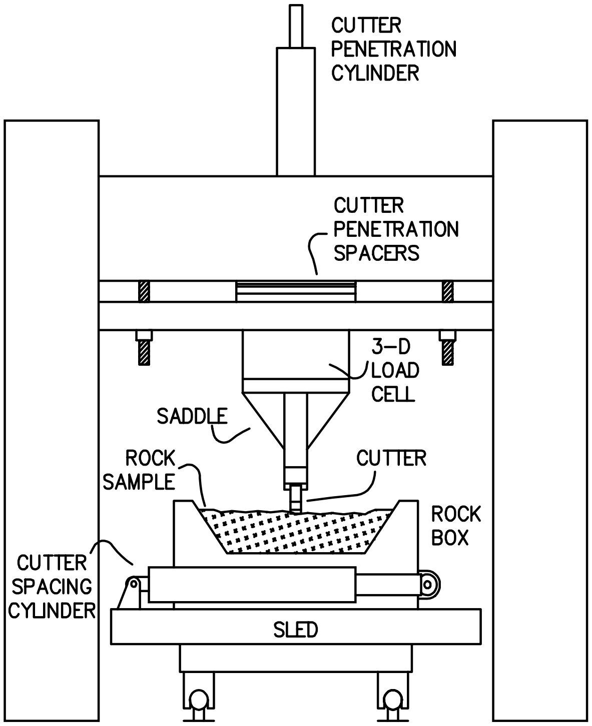

Figure 3: A schematic drawing of the LCM.

The tests performed for this program consisted of four major variables: cutter type, line spacing between cuts, penetration of cuts, and attack angle. The dependent (measured and calculated) variables were average cutter forces (normal, drag and side), specific energy and muck size distribution for determination of percentages of respirable dust. The constant variables were rock type, cutting sequence (single scroll pattern), cutting speed (10 in./sec., 254 mm/s), skew angle (0°) and tilt angle (0°).

Linear Cutting Test Results

Muck (rock cuttings) samples were collected at each matrix point to define the size distribution. In order to provide an initial evaluation of the effect of the different variables on the generation of dust, an algebraic comparison was performed on the data produced by the commercially available conical bits. This comparison simply averaged the difference in dust (5 and 25 micron particles) generation for each of the individual tests variables, while the other variables were held constant. The results were then normalized to typical increments of adjustment that would be used on continuous miners operating in a coal mine. The increments of adjustment, used for this analysis, are; attack angle, 1 degree; tip diameter, 2.5 mm (0.1 inch); cut spacing, 6.4 mm (0.25 inch); and cut penetration, 2.5 mm (0.1 inch). These results, shown in Table 1, show that spacing and penetration had a much greater affect on dust generation compared to tip diameter and angle of attack.

Test Variable	5 Micron	25 micron	Units of Evaluation
Attack Angle	0.17	0.16	% dust / degree of attack angle
Tip Diameter	0.18	0.70	% dust / 2.54 mm of tip diameter
Spacing	0.71	1.92	% dust / 6.35 mm of spacing
Penetration	1.39	3.06	% dust / 2.54 mm of penetration

Table 1: Average measured effect on dust generation.

In order to provide a more encompassing quantification of the effect of these parameters on dust generation, the statistical method of linear multiple regression was used. Multiple regression analysis was performed to provide equations relating the tip diameter, attack angle, spacing and penetration to the amounts of 5 and 25 micron particles, as well as the mean particle size. The resulting equations produced a high correlation between the test variables and the percentages of dust and the mean particle size. This can be seen by the R-squared values of 74%, 70%, and 86%, for the 5 and 25 micron particles and the mean particle size, respectively.

The resulting slopes from the best fit equations, generated by the multiple regression analysis, provide an evaluation of the effect of the independent variables. These slopes have been normalized to the same increments of adjustment used in the measured evaluation. The magnitude of these slopes, for the 5 and 25 micron particles are presented in Table 2.

Test Variable	5 Micron	25 micron	Units of Evaluation
Attack Angle	0.17	0.16	% dust / degree of attack angle
Tip Diameter	0.02	0.19	% dust / 2.54 mm of tip diameter
Spacing	0.61	1.69	% dust / 6.35 mm of spacing
Penetration	0.90	1.78	% dust / 2.54 mm of penetration

Table 2: Predicted effect on dust generation from multiple regression.

Description of Computer Model

The approach used for computer modeling of the cutting drum of a continuous miner is to program each bit individually and analyze the cutting forces acting on the bits. As for dust generation, the cutting forces (drag and normal force) depend on the rock type to be cut, the cutting geometry (spacing and penetration of the bits), the geometry of the bit (tip angle) and the attack angle. It is known that the optimum cutting geometry for cutting with drag bit, which results in minimum specific energy requirement and more efficient cutting, occurs at the spacing to penetration ratio of 1-4. This value depends on the rock type and the break out angle, which is the angle of the rock surface created by cutting on both sides of the cut. The ratio of cutting force to normal force on a conical bit depends on the rock type, rock fabric, bit shape, attack angle and depth of penetration. This ratio is typically in the range of 0.5 – 1.0.

Another factor which is important for machine production and dust generation is called spacing, which is defined as the distance between the bits. Larger spacings result in higher efficiency and lower specific energy requirements, given that the material between the bits can be cut. This tends to reduce the dust levels in the working area. However, wider spacings require stronger cutting tools, which usually signifies larger tip diameters and blunter tip angles, which can increase dust generation. Also, the increased spacing and the reduced number of bits on the cutting drum means fewer bits in contact with the cutting area at any given time, causing vibration in the cutterhead. Therefore, the balancing of the drum becomes more important to avoid excessive vibration which is detrimental to the cutting performance and the bit life. It should also be noted, that if the spacing is too large, for the given circumstances, that the coal may not break out between the cuts. This can result in more dust being generated from the bit blocks rubbing against the intact coal face.

The machine specifications, such as thrust, power and torque, are for providing sufficient amount of forces to the bits, thus supporting the excavation operation. Machine thrust is the force required to penetrate the bits into the rock surface. Also, the cutterhead torque and power requirements are the force to rotate the head at the required penetration rate, and overcome the drag force resistance of the cutters.

Figure 4 shows the schematic drawing of a cutterhead and parameters used to define the bit position on the drum that is used as input to the model. Cutterhead profile data is essential for simulating different cutting modes (sumping and shearing) of the drum and checking the availability of the thrust and power of the machine at a given sumping and shearing depth.

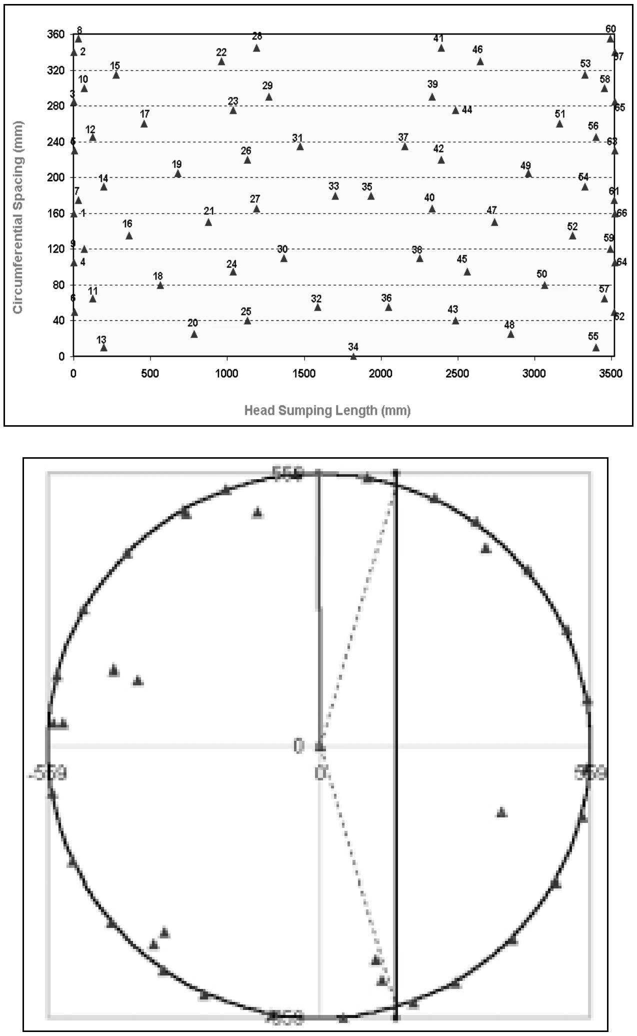

Figure 4: Cutterhead input data.

Cutting with a drum creates a continually changing cut penetration profile. If the drum is cutting downward, the cut depth starts infinitely close to zero and approaches its maximum. The model works by rotating the cutterhead 360 degrees and summing the normal and drag forces acting on the individual bits throughout the rotation, with respect to the direction of cutting and axis of drum rotation. Only the cutters engaged in the rock/coal are included in this summation. And the correct forces are used based on each bit's penetration at any given angular location.

The information generated from the computer model includes individual cutter forces, mechanical requirements of the cutterhead, production rate and dust generated. The program allows the user to monitor the variation and graphically represents these variations as the head rotates. Figure 5 illustrates a typical summary the change in power consumption for a full rotation during the shear-down mode.

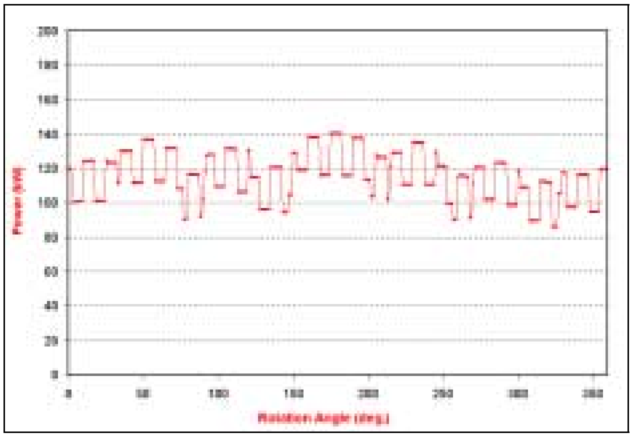

Figure 5: Sample output of the CM modeling program for a full rotation.

FIELD TESTS

Field tests were performed at RAG's Twentymile Coal mine. Twentymile Coal mine is located in northwest Colorado, about 20 miles southwest of Steamboat Springs. It is in Routt County and mines the Wadge seam. It started as a CM mine in 1983. Twentymile is now a longwall mine and uses the conventional miners sections mainly for gate road development. The miner being discussed in this paper were located in the gate road development, a 3 entry section. Currently, the average tons per shift in this section is 1400 for a ten hour shift. This is clean tons. The mine altogether will do about 6.5 million clean tons for the year of 2002. The mine work schedule is 8-10 hour shifts per week for mining and the same for bullgang. The pillar sizes are 125' by 35' on the beltline and 250' by 95' on the return. The overburden is 1200 to 1700 feet. The seam height is 8 to 10 feet. The section uses exhaust ventilation with vent tube. There are two section face fans. The last open crosscut air is around 40000 cfm. Belt air is not used to ventilate the face. There are two roof bolter machines and two shuttles cars operating in the section. The water to the section is delivered via 6" Victaulic pipe at 300 to 450 psi static.

Continuous Miner Descriptions

Three different cutterheads have been tested to date in this program. All three cutterheads were tested on Joy 12 CM 12 miners. Figure 6 shows a field test cutterhead. The first two cutterheads were tested on an older machine. The first cutterhead used 20 Miles standard cutterhead configuration, which utilized a line spacing of 57 mm (2.25 in.). The second cutterhead, provided by Joy as a stop gap drum replacement, utilized a line spacing of 76 mm (3.0in.). The third cutterhead, specified for this program used a 95 mm (3.75 in.) line spacing. This third cutterhead was tested on a new machine purchased from Joy in January of 2002 and put into service in May of 2002. This new machine also had modifications made to the dust suppression sprays. These modifications are described later.

Figure 6: Field test cutterhead.

Three different bits were tested and evaluated in this effort. The first/historical bit had a 60 degree tip and a 25 mm diameter shank. This first bit was only tested with the original cutterhead, because it would not fit the bit holder of the new cutterhead. The second bit tested utilized a multi angle tip and a 30 mm shank. This bit was tested in the 57 mm (2.25 in.) spacing cutterhead. The third bit, provided by Kennametal, used a 70 degree tip with the larger shank. This bit, tested with the 57 mm (2.25 in.) and the 95 mm (3.75 in.) line spacing cutterheads, maintained a relatively slim body profile by utilizing three ribs or flights along the bit body. These bits are pictured in figures 7, 8 and 9, in the same order they were discussed.

Figure 7: 25 mm shank with 60 degree tip.

Figure 8: 30 mm shank with multi-angle tip.

Figure 9: 30 mm shank with 70 degree tip.

Spray and Scrubber Modifications

Modifications were made to the dust suppression sprays and scrubber system for the machine that utilized the third cutterhead. A detailed description of this system follows.

Miner Dust Control System

The miner dust control system consists of 38 sprays on the main dust control-water cooler outlet circuit, 8 sprays on the side spray circuit, and the 30hp scrubber. The water enters the miner at the rear of the machine and goes through a Senior Conflow backwash filter. From the filter it goes to a distribution manifold with three high pressure 1” electric solenoids. This manifold and solenoids distribute the water to the three water circuits. We installed a bypass around each solenoid for manual testing of each circuit. The miner operator has control of the two spray circuits from his remote with switches. The scrubber water comes on when the scrubber switch is put in the auto position. It then comes on with the head.

Main Dust Control-Water Cooler Circuit

The main dust control circuit exits the solenoid with a 1” hose and splits at the rear hose tunnel. At this split, a ¾” hose runs in series along both sides of the machine through all the coolers. It exits out the cutter head motor on each side and goes through a strainer. After the strainer, it goes into a distribution manifold. From the distribution manifold, ½” hose take the water to the 38 sprays used for dust control. There are 3 spray blocks above the head with 5 sprays in each block, shown in Figure 10.

Figure 10: Modified cutterhead sprays.

There are 2 spray blocks below the head with 5 sprays in each block. There are 2 ring spray blocks with 3 sprays in each block. These blocks are located on the cutter head motor cover. There is a 3 spray block underneath the head spraying at the bottom of the cutting drum. There are 2 spray blocks with 2 sprays each pointing straight down on the conveyor just inby the belt curtain in the conveyor throat. All of these sprays are BD-3 whirljets from Spray Systems. The system pressure is 150 psi. There are pressure gauges to monitor both sides of the system and gauges to monitor the in and out condition of the backwash filter. These gauges are mounted next to the methane monitor so the operator can see them at all times. The spray blocks on the top side of the head are recessed back and flat to the head. This helps protect them better and helps with the roll back of the dust that you see in a normal Joy installation.

Side Spray Circuit

The side spray circuit has 8 sprays in it. The operator controls these with a switch on the remote. We use these sprays to help the main dust control circuit so they don’t run all the time. These sprays run at 200 psi. There is a pressure gauge mounted by the methane monitor to show the system pressure on these sprays. We used ¾” feed hoses and ½” hoses to the spray blocks. All of the hose runs are internal as are all of the hose connections. Nothing is exposed to the mining process except the spray blocks. The 8 sprays are located:

1. In the lower spot light cover on the operator side of the miner. This is a 9.5 full jet spray from Spray Systems. It sprays just underneath the head and just above the pan. This spray knocks down the dust coming off the head from the right side (Figure 11).
2. At the outside inlets to the scrubber duct. There are 2 spray blocks with 2 sprays in each block. These sprays are BD-5 whirljets from Spray Systems. These blocks are located just outby the inlet duct to the scrubber. These sprays replaced the Joy pan sprays.
3. On the off side of the machine just inby the traction sprocket cover. This is a two spray block with 2 sprays in it. The sprays are BD-3-20’s from Spray Systems. They spray towards the left hand side of the head. They help hold the dust coming off the head from that side.
4. Underneath the tail. This is a single spray, a BD-3 whirljet. This spray knocks down the dust coming from under the tail.

Figure 11: Headlamp spray assembly.

Scrubber Dust Control System

The scrubber system is a standard Joy 30hp scrubber system. We have 3 inlet duct located underneath the head. One on each side, and one over the conveyor just inby the belt curtain. We sealed up the gaps better at the hinge point just inby the filter screen. We use 3 water sprays to wash the filter screen. They are 6.5 full jets from Spray Systems. We run these sprays at 75 psi. It gives complete coverage to the screen and helps keep it clean longer. We use a 10 mesh screen. The airflow through the scrubber is 4500 to 5500 cfm. We direct the discharge air at a 45 degree angle towards the face. We have installed a 5 position gate on the off side discharge to regulate the air flow from this point. We normally discharge out both sides. We take about 70 percent of the air out the off side and the rest out the operators side. The operators side discharge has curved deflectors that turn the air to the rib towards the face. The operators almost never get scrubber air blown on them. We use the scrubber air to block the dust coming off the head into the vent tube. We use the side spray system to help push the dust from the head into the scrubber duct inlets.

Filed Test Results

Dust exposure levels, which were monitored at the at the continuous miners operator position, were taken from samples provided to and reported by MSHA during the testing required of the mine. 20 Mile also monitors the dust level in the intake air by the same method on the same shifts that are being monitored for exposure levels.

The average exposure level for the original cutterhead, which utilized the smaller bits, was 0.98 mg. This was measured over 30 shifts. The second cutterhead, with the 57 mm (2.25 in.) line spacing, produced an average exposure level of 0.78 mg, for both of the tested bit types. Each of these bit types was tested for only 5 shifts due to operational constraints. It should be noted that the leading tip of the multi angle tipped bits broke soon after use and created higher forces that made it difficult for the miner to sump into the face. The cutterhead with the 95 mm (3.75 in.) line spacing and modified spray system generated average exposure levels of 0.68 mg. This represents a 30 percent reduction in the exposure levels of respirable dust. The respirable dust exposure data is summarized in Chart 1.

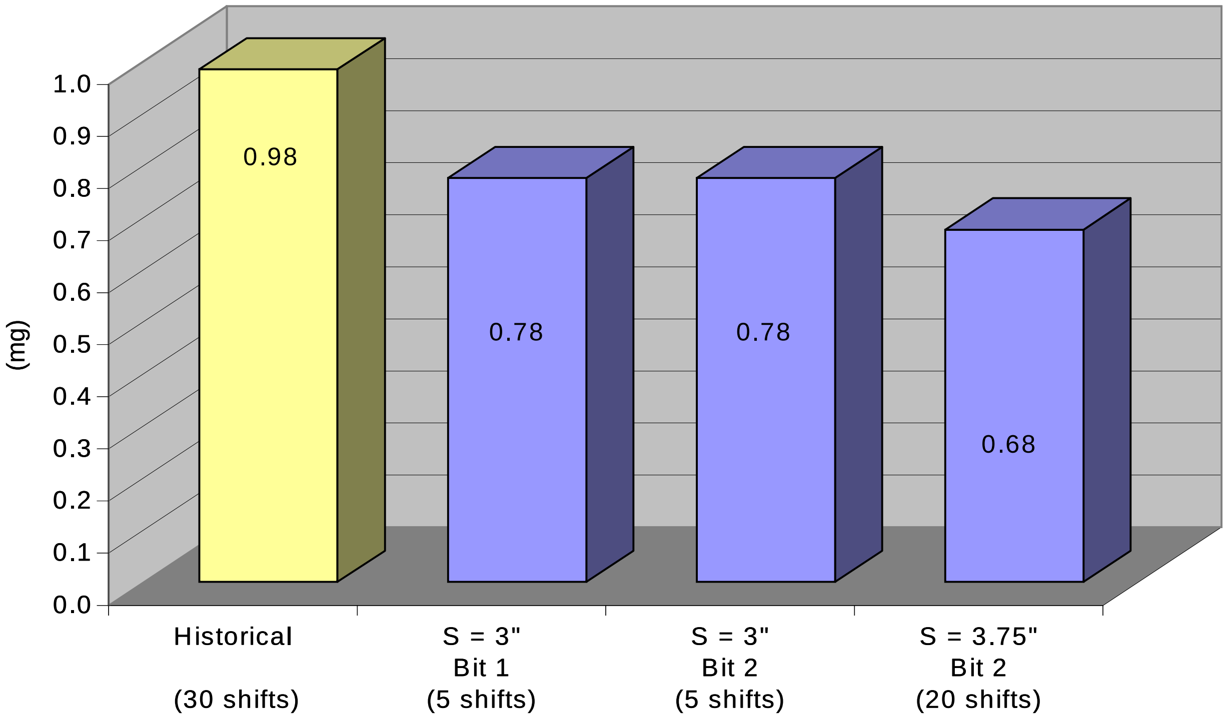

Chart 1: Dust exposure levels.

Calculations were made to determine the amount of dust added per ton mined. This was done on an individual shift bases by subtracting the amount of dust monitored in the intake air from the exposure level (at the continuous miner operator position) and then dividing that quantity by the tons mined during the shift.

The original cutterhead with the smaller bits produced 4.32E-04 mg per ton mined. The second cutterhead, while using the multi-angle tipped bits, generated an increased 4.73E-04 mg per ton mined. This is believed to be a result of the broken (and therefore very blunt) carbide tips. That same second cutterhead produced a reduced amount of dust of 3.81E-04 mg per tone mined when using the 70 degree tipped fluted bits. And the third cutterhead, with the widest spacing, fluted bits and modified dust suppression system produced 3.52E-04 mg per tone mined. This represents a reduction of 19% in the amount of respirable dust exposure per ton mined. The dust generated per ton mined data is graphically represented in Chart 2. The discrepancy in the percentile difference of the exposure level and the dust generated per ton is a function of changes in the amount of dust present in the intake air and increases in production.

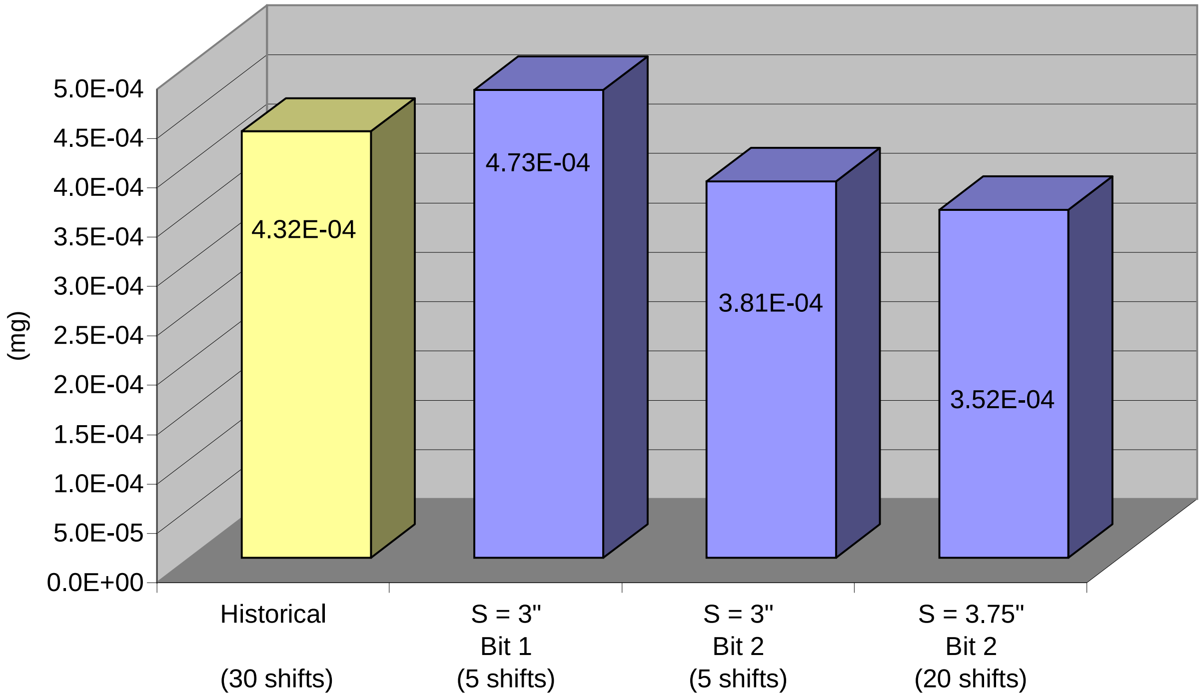

Chart 2: Levels of added per ton mined.

CONCLUSIONS

Cutterhead optimization has a substantial beneficial effect on the generation of respirable dust. Cutterhead optimization is dependent of the geology to be encountered and the capabilities of the machine driving the cutterhead. Maximizing bit spacing, while ensuring that production concerns are not adversely affected, reduces dust generation. This is true as long as the increase in spacing does not require a very different bit design (i.e. diameter and tip angle increasing more than spacing) or prevent the miner from penetrating deeply enough to provide efficient fracturing of the coal/rock.

Also, severely worn bits greatly increase the generation of dust and reduce production.

Field tests have been performed in one mine without additional cost to the operation while providing an improved work environment. Field test should be performed in different operations to confirm the validity of this process and provide additional data for calibrating the models being developed under this project.

FUTURE WORK

Additional operations are being sought out to assist in performing further field tests. These additional field test results, in conjunction with the existing laboratory and field results, will contribute to an accurate understanding of relationship between cutting geometry and respirable dust. This will provide for a better quantification of the computer models to complete the efforts to make them available to the public domain.

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