Rock dusting considerations in underground coal mines

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ABSTRACT: Rock dusting to prevent coal dust explosions has been in widespread use in U.S. underground coal mines since the early 1900s. Underground coal mining technology has changed significantly over this same time period, becoming highly mechanized and produces finer coal dust particles which are more explosive. Despite the advances in mining technology, mine-wide dust sampling practices have remained essentially unchanged. There are many factors associated with the practice of rock dust sampling that, if not properly considered, can adversely impact the effectiveness of the rock dust and the potential explosibility of the coal dust. Dust on elevated surfaces is dispersed and entrained by the developing explosion much more readily than dust on the floor. The increased use of meshing to control roof and rib spall provides elevated surfaces for coal dust to collect which significantly increases the potential for dust explosion propagation if not adequately inerted. In addition to holding more coal dust, the meshing makes the collection of representative dust samples by using current band sampling equipment inadequate. This paper discusses these and other related factors that could result in a potential undetected dust explosion hazard, when using current dust sampling procedures, in an area that otherwise appears to be adequately protected with rock dust. Recommendations are made for further investigation into how these and other factors affect explosion propagation and the need for sampling procedure changes.

1 Introduction

A coal dust explosion can generate sufficient air pressure and associated turbulence to disperse dust from entry surfaces and draw it into the expanding combustion zone. Heat transfer to the coal dust particles results in the production of volatiles and tars. These products react with the oxygen in the air at high temperatures, and the heat released from this exothermic reaction is converted into work of expansion of the semi-confined air. Similarly entrained rock dust acts as a heat sink, drawing energy out of the system. As the explosion progresses, surrounding dust is fluidized and dispersed into the propagating explosion. The magnitude of the explosion is related to the relative amounts of coal, rock, and other dust entrained at the flame front. The amount of dust entrained depends on the size of the explosion-produced aerodynamic disturbance.

In underground coal mining, coal dust is produced at the face, at conveyors, at transfer points, and by the normal movement of machines. Coarse coal dust settles rapidly while finer coal particles remain airborne. Fine dust can be moved relatively long distances by ventilating air before settling. Although water sprays are effective for removal of dust particles at the face and along the conveyor, rock dust distribution is still required to render the residual coal dust accumulations inert in order to protect against a propagating explosion.

2 Rock Dust Sampling Procedure

The Mine Safety and Health Administration (MSHA) inspectors conduct rock dust surveys in each advancing working section to determine compliance with the regulations (30 CFR 75.403). If the working section has advanced and the loading point has moved 150 m (500 ft) or more since the last survey, a new survey is conducted. Samples are gathered every 150 m (500 ft) (MSHA, 2008).

MSHA inspectors collect dust samples according to established procedures (MSHA, 2008). These procedures dictate that the band or perimeter method be used to collect dust samples from the roof, ribs, and floor creating one “band” sample. This band sample includes 25 mm (1") deep material from the floor. Once collected, the sample is thoroughly mixed, coned, and quartered to take a portion for analysis. This sampling essentially assumes a homogeneous mixture of coal, rock, and other dust on all surfaces. Underlying this assumption is that in the event of an explosion, the aerodynamic disturbance ahead of the flame front will scour dust from all surfaces and will tend to either enhance or inhibit propagation depending on the incombustible content (% IC) (Owings *et al*, 1940).

Once the sample is gathered, the collected dust is sieved through a 10-mesh screen (1.7 mm) and a portion of the sample is bagged and labeled. The survey samples are sent to the MSHA Mt. Hope laboratory for moisture and low temperature ash analysis to determine % IC of the minus 20 mesh fraction.

If a sample location is too wet to take a dust sample, the location is tracked and inspected for one year. If during the year, the sample location is dry enough to take a dust sample, then a survey is conducted in that location.

3 Issues Associated with Rock Dusting

Current mining technologies have created a need to review and revise sampling procedures and hence corresponding rock dusting practices.

3.1 Current Rock Dust Requirements

Currently, generalized rock dusting is the primary means of defence against coal dust explosions in U.S. mines. Code of Federal Regulations, 30 CFR 75, Subpart E (Combustible Materials and Rock Dusting) requires the use of rock dust in bituminous coal mines (30 CFR 75.402) to abate the hazard of accumulated coal dust. Regulations state rock dust shall be distributed upon the top, floor, and sides of all underground areas of a coal mine in such quantities that the percent of incombustible content (% IC) of the combined coal dust, rock dust, and other dust shall be not less than 65%. In the return aircourses where the dust is expected to be finer, the % IC shall be no less than 80% (30 CFR 75.403).

The current requirements are based on a 1920s coal dust particle size survey. As a result of the 1920s research, “mine size” coal dust was defined as coal dust that passes through a U.S. Standard No. 20 sieve (850 µm) with 20% passing through a 200-mesh sieve (75 µm) (Rice & Greenwald, 1929). Float coal dust was defined as minus 200-mesh coal dust particles that may be deposited on the roof, ribs, and timbers in a mine (Nagy, 1981). Current rock dust regulations mandating a 65% IC dust mixture provide no margin of safety since the NIOSH Lake Lynn Experimental Mine (LLEM) tests have shown that even a ~68% IC dust mixture with the “mine size” Pittsburgh seam coal dust will propagate dust explosions (Sapko *etal.,* 1989; Weiss *et al.,* 1989; Greninger *et al.,* 1990). The LLEM entry geometries are typical of current U.S. coal mines (Triebsch & Sapko, 1990).

The mining methods that produced the 1920s survey data have changed dramatically throughout the last century. A particle size survey of US coal mines recently conducted by NIOSH concluded the old definition of “mine size” dust is no longer applicable or representative (Sapko *et al.,* 2007).

MSHA divides U.S. coal mines into 11 districts (Figure 1). The intake airway dust samples were examined and compared according to these MSHA districts. The fractions of minus 200-mesh (75 µm) ranged from 27% in District 9 to 37% in District 11. Minus 70-mesh (212 µm) fractions ranged from 59% in Districts 2 and 6 to 73% in District 11. The median diameter of the samples ranged from 128 µm in District 11 to 172 µm in District 9. The overall averages are 31% minus 200-mesh, 61% minus 70-mesh, with a median dust particle diameter of 156 µm. These samples are significantly finer than those of the 1920s survey (Cashdollar *et al.,* 2009; Sapko *et al.,* 2007).

The same information was analyzed for the various coal seams sampled. The Blue Creek (District 11, Figure 1) and Hazard #4 (District 6, Figure 1) coal seams have the finest sized particles with a median diameter of 98 µm and 104 µm respectively. For these seams, the finer particle sizes were found in the Blue Creek coal seam containing about 40% dust particles minus 200-mesh (75 µm) and 76% minus 70-mesh (212 µm) and in the Hazard #4 seam containing 40% minus 200 mesh and 69% minus 70-mesh (Cashdollar *et al.,* 2009; Sapko *et al.,* 2007).

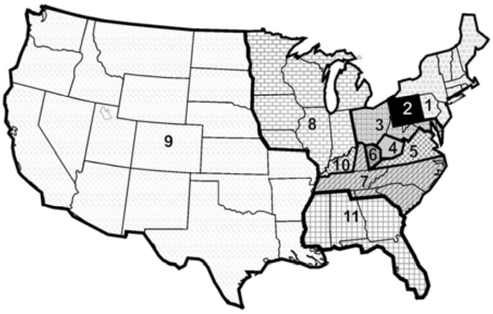

Figure 1 MSHA districts (Sapko *et al.,* 2007).

Since the average particle size is significantly different than that on which current regulations are based, current %IC requirements are also different. Based on recent large-scale inerting experiments conducted within the LLEM (Figure 2), at least 76.4% IC is required to prevent explosion propagation for medium-size coal dust (37% < 75 µm); i.e., an average of the finer coal dust found in current intake areas. NIOSH recommends 80% IC in both intake and return airways in order to prevent flame propagation (Cashdollar *et al,* 2009).

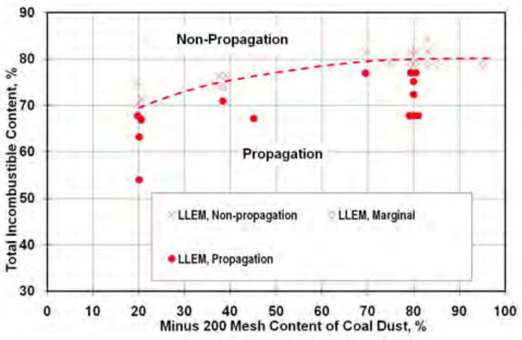

Figure 2 Effect of particle size of coal dust on the explosibility of Pittsburgh seam bituminous coal. (Cashdollar *et al.*, 2009).

3.2 Sample Depth

As a part of the recent large-scale dust explosion testing at the LLEM in 2008, 13 sets of dust scouring measurements were collected. The dust scoured is indicative of the depth of dust participating in an explosion. Two parallel rails were filled with a coal dust mixture and positioned in the entry with the dust leveled between the rails. Using a displacement gauge mounted on a portable aluminum bar, measurements were taken of the dust levels before and after the explosions (Figure 3). The dust scoured during an explosion ranged from 0.7 mm (0.03") to 2.6 mm (0.1 in) with an average of 1.7 mm (0.06") and a standard deviation of 0.5 mm (0.02"). This is much less than the 25 mm (1 in) that is specified in the MSHA band sampling procedures. Therefore, the current 25 mm (1") sampling depth of dust does not represent the dust that actually contributes to initial explosion propagation. If there is a layer of coal dust, the band sample can be diluted with rock dust by sampling to a full depth of 25 mm (1"), thereby giving a false sense of safety. A sample depth of 3 mm (1/8") appears to better represent the level to detect potential deficiencies in rock dust (Sapko *et al.,* 1987; Harris *et al.,* 2009).

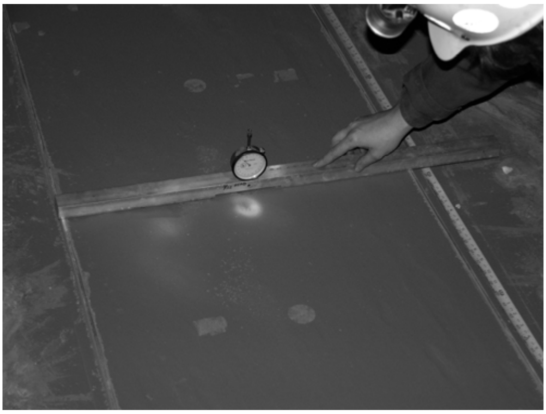

Figure 3 Measuring the amount of dust scoured during an explosion.

3.3 Use of Mesh

The position of the coal dust along the perimeter of an entry is a more important factor affecting explosion propagation than is commonly recognized. Dust on the ribs, roof, or elevated surfaces is dispersed by the explosion wind much more readily than dust on the floor. If the overhead dust is disproportionally coal dust, the explosion hazard is intensified. If the dust is primarily rock dust, the explosion hazard is reduced (Hartman *et al.* 1956)). It is obvious that roof and rib sampling procedures are critical.

Wire mesh is commonly used in mines to prevent skin failure from the ribs and roof. When material spalls from the ribs or roof, it can fall on miners or create slipping and tripping hazards. The installed meshing contains the spalled material to minimize the risk of injuries to miners. For control of roof skin failure, wood planks, steel straps or channel, and various meshes such as welded wire, chain link fencing, or synthetic grid materials are being used (Bauer & Dolinar, 2000). As seen in Figure 4, the mesh is placed as close to the roof and ribs as possible using bolts but is not completely flush which creates areas for coal dust to accumulate.

The use of mesh prevents adequate band sampling of the ribs and roof. With the mesh on the ribs, it is difficult for inspectors to brush the dust from the ribs into a pan for sample collection. The space between the mesh and strata allows the dust to fall behind the mesh or to be blown away by the ventilation airflow rather than to be collected. Also, the dust on the roof is sampled only in mines with a low roof that can be accessed without the aid of a ladder or extended sampling equipment. In mines where the roof is beyond reach and cannot be practically or safely sampled, a sample from the roof is not collected. It is currently acceptable to take a sample of the floor and ribs to the maximum height that it can be done safely and practically (MSHA, 2008). Therefore if coal dust were present on the mesh support, in these instances, it would not be collected for analysis and a potential explosion hazard may go undetected. Also, when combining a limited quantity roof and rib sample with a 25 mm (1 in) deep floor dust sample, the potential coal dust explosion hazard can easily go undetected.

Diligently applying rock dust to these elevated surfaces with roof and rib mesh will reduce the dust explosion hazard. Nevertheless, improved sampling methods and procedures are needed to better assess the dust explosion hazards in view of these new technologies that prevent skin failure.

Figure 4 Synthetic mesh supporting roof and rib. (Photo courtesy of Tensar Earth), (Bauer and Dolinar, 2000).

3.4 Distance Between Samples

Current sampling practices for determining compliance requires samples be collected at least every 150 m (500 ft) of mine entry (MSHA, 2008). Limited experiments were conducted in a single entry at the Bruceton Experimental Mine (BEM) to determine the effect on explosion propagation of alternate zones deficient in incombustible content. Alternate zones contained 9% less than and 9%

more than the limiting incombustible content (Nagy 1981). When alternate zones were 18 and 27 m (60 and 90 ft) in length, flame propagation was arrested. When the alternate zones were 36 m (120 ft) in length, explosion propagation was obtained. These limited trials indicate with approximately 30 m (100-ft) length of entry, 9% deficient in incombustible has a significant effect on explosion propagation even though the rock dust deficient zones are compensated by excess incombustible in adjacent zones. It can be presumed that if the deficiency in incombustible were greater than 9%, a zone of less than 30 m (100 ft) would affect explosion development.

Results from one recent large-scale explosion experiment conducted within the LLEM (Test #511) indicates that a propagating explosion can significantly increase in intensity while propagating through a 64 m (210 ft) zone of nearly 68% IC and jump over (through) and well beyond an adjacent 100 m (330 ft) zone containing over 81% IC. This preliminary result indicates that the minimum requirement of 150 m interval between band sampling locations within an entry needs to be reassessed.

3.5 Particle Size of Rock Dust

MSHA specifies rock dust as pulverized limestone, dolomite, gypsum, anhydrite, shale, adobe, or other inert material, preferably light colored, 100% of which will pass through a sieve having 20 meshes per linear inch (840 μm) and 70% or more of which will pass through a sieve having 200 meshes (75 μm) per linear inch (30 CFR §75.2). The research supporting the rock dust particle size effects on coal dust explosion propagation was performed in 1933 and reported in Bureau of Mines Bulletin 369. Preliminary sieve analysis of field samples of rock dust indicated that the rock dust meets the (30 CFR) specification of 100% less than 20-mesh (840 μm) and 70% less than 200-mesh (75 μm). However, the integrated surface mean particle size showed considerable variation.

In small-scale laboratory tests, the larger the rock dust particle size, the more rock dust is required to inert and prevent an explosion from propagating. It has been shown in various small chamber tests that by reducing the size of the rock dust particles, the surface area of the rock dust increases and promotes greater radiant heat absorption (Dastidar *et al.,* 1997).

In view of current results from the NIOSH coal dust particle size survey in US mines and preliminary size analyses of rock dusts, the effect of rock dust particle size in preventing coal flame propagation should be re-examined through large-scale explosion tests.

3.6 Effectiveness of Different Rock Dust Types

The effectiveness of rock dust in arresting explosion propagation has been proved by experiment and practice. The precise mechanism by which rock dust (generally limestone dust) quenches flame has not been fully explained, but is believed to be absorption of thermal energy from the heated gases and absorption of radiant energy which reduces the preheating of unburned coal particles ahead of the flame front. Even though limestone is not considered a chemical inhibitor some decomposition does take place which absorbs additional energy.

Man & Teacoach (2009) have shown that the limestone acts more than a simple heat sink. Calcium carbonate does not only act as a physical heat sink in the prevention of a coal dust explosion, but also absorbs some energy in a calcination process to convert the calcium carbonate to calcium oxide or calcium hydroxide.

Laboratory explosion inerting experiments conducted in the 20 liter chamber (Cashdollar & Hertzberg, 1989) also indicate that not all commercial rock dusts are equally effective in inerting Pittsburgh pulverized coal dust (80% < 75 μm). For example, marble dust was less effective than limestone even though both dusts fulfill the 30 CFR size specifications. The marble dust has a higher percentage of mass below 75 μm but less below 200 μm than other rock dusts. The smaller amount of very fine particles reduces the effectiveness of the rock dust as a heat sink and any rapid energy absorption in the flame front through the decomposition process.

Currently limestone, dolomite, gypsum, anhydrite, shale, adobe, or other inert material are permitted by 30 CFR for use in intake and return airways for preventing coal dust explosion propagation. The only size requirement is that 70% by mass be less than 200 mesh (75 μm) and 100% be less than 20 mesh (840 μm).

In view of these results, there is a need to re-examine the particle size specifications for rock dusts and determine the material specific requirements relevant to the incombustible content needed to prevent explosion propagation.

3.7 Moisture Fluctuation in a Mine

Mitchell *et al.* (1962) studied the effectiveness of water as an inert for neutralizing the coal dust explosion hazard. The study emphasized that surface water evaporates readily from dusts. Thus, in a passageway where the dust is wet, changes in weather or ventilation system could dry the dust and make it unsafe in a relatively short period of time. Where adequate rock dust has been applied, this drying effect is not a factor. According to 30 CFR § 75.403-1 “moisture contained in the combined coal dust, rock dust and other dusts shall be considered as a part of the incombustible content of such mixture.” However, dust surface moisture within a mine can fluctuate making moisture content an ineffective measure of safety.

It has long been recognized that the trend shows mine explosions occur primarily during the winter season when the humidity is low for long periods of time (Mannakee, 1910: Scholz;, 1908; Kissell, 2006). Due to the potential variability of the moisture content of the dust, it may be prudent to not include surface moisture in the total incombustible content of the sample.

4 Summary

Dust sampling studies were conducted by NIOSH researchers to evaluate the amount of mine floor dust involved in an explosion, to evaluate the explosion hazard of collected samples in terms of coal dust particle size, and examined the current rock dust inerting levels to prevent explosion propagation hazards. The sampling procedures and techniques essentially described by Owings *et al.* (1940) are still being used.

Dust explosion assessment procedures developed many years ago have not adequately kept pace with advances in mining methods and the implementation of new ground control technologies. Results from preliminary experimental mine explosion dust scouring experiments and dust particle size surveys indicate that the current dust sampling procedures are not fully adequate for identifying potential dust explosion hazards and should be reassessed in view of recent research findings and current mining practices.

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