MITIGATING COAL DUST EXPLOSIONS IN MODERN UNDERGROUND COAL MINES

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ABSTRACT

The National Institute for Occupational Safety and Health (NIOSH), as part of its continuing research program for evaluating coal dust explosion hazards, has investigated several areas in which current practices may need to be updated in order to adequately protect mines against coal dust propagated explosions. In the United States, current rock dusting requirements remained largely unchanged since 1969. US Title 30 Code of Federal Regulations Section 75.403 is based on a coal dust particle size survey performed in the 1920s and later was supplemented by full-scale testing of the rock dust ability to inert a coal dust explosion. NIOSH recently conducted a comprehensive survey of US underground coal mines to determine the range of coal particle sizes found in dust samples collected from the mine entries. Due to advancements in technology and modern coal mining techniques, the current coal dust particles in intake airways are significantly finer than those found in the mines in the 1920s. According to past full-scale dust explosion test results, the current rock dusting practices used in today's mines to inert a coal dust explosion may not be adequate. Other closely related issues such as rock dust testing methods and sampling procedures are discussed.

1. INTRODUCTION

It has long been known that fine coal dust particles laying in an entryway can propagate an explosion down an entry. A coal dust explosion can generate sufficient air pressure to disperse dust from entry surfaces and draw it into the expanding combustion zone. Heat transfer to coal dust particles results in the production of volatiles and tars from these particles. At high temperatures, the product reacts with the oxygen in the air and the heat released from this exothermic reaction is converted into work of expansion of the semi-confined air. Conversely, entrained rock dust acts as a heat sink, drawing energy out of the system.

In the United States (U.S.), the current rock dust requirements were established by the Federal Coal Mine Health and Safety Act of 1969 which mandated 65% incombustible content (IC) be present in non-return airways and 80% IC in return airways. These values were derived from coal dust particle size research performed in the 1920s (Rice and Greenwald, 1929; Nagy, 1981). Mining methods have drastically changed since the early 20th century. As the industry moved towards increased mechanization and less conventional blasting, the size of the coal dust found in the entries of modern coal mines has changed (Sapko *et al*, 2007).

Finer coal dust requires more incombustible material to inert it (Rice *et al*, 1922; Rice and Greenwald, 1929; Nagy, 1981; Cashdollar and Hertzberg, 1989; Weiss *et al*, 1989). Figure 1 illustrates the effect of coal dust particle size on the explosibility of the mixture (Sapko *et al*, 2007). Large scale dust explosion experiments conducted at the NIOSH-PRL Bruceton Experimental Mine (BEM) and the Lake Lynn Experimental Mine (LLEM) show that dust mixtures with finer coal particles require more inert material to render the finer coal dust non-explosible.

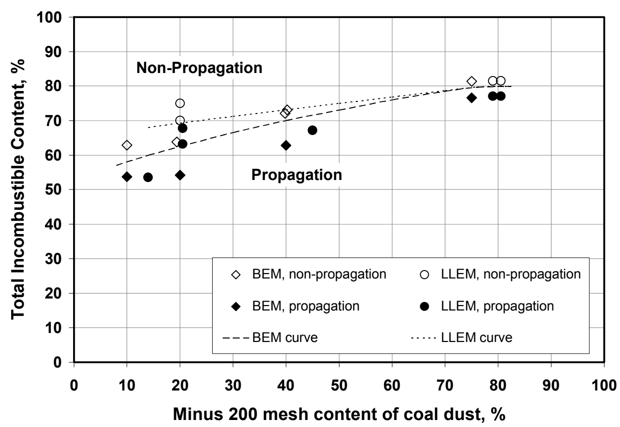

Figure 1: Effect of particle size of coal dust and IC on the explosibility (Sapko *et al.*, 2007).

In the U.S. incombustible material is typically pulverized limestone rock dust. In compliance with Federal Regulations 30 CFR 75.403, the Mine Safety and Health Administration (MSHA) performs quarterly surveys in every mine (MSHA, 2008). Dust samples are gathered and sent to MSHA's laboratory in Mt. Hope, West Virginia, for determination of moisture and incombustible content. No particle size analysis is performed. The typical wait time for results is approximately two weeks after sample collection. A recent NIOSH research project has determined the current size of coal dusts found in modern US coal mines and developed an instrument to screen samples almost instantly to determine when hazardous conditions may be present (Sapko *et al.*, 2007).

2. MSHA SAMPLE COLLECTION AND TESTING

When MSHA performs their quarterly surveys, the dust is collected in a band sample at 152 m (500 ft) intervals from the last survey sample point in a new development. The band is a 15 cm (6 in) swath collected from the roof, ribs, and floor (up to 2.54 cm or 1 in deep). The collected dust is sieved through a 10 mesh screen (1.7 mm) and a portion of the sample is bagged and sent for analysis (MSHA, 2008).

3. COAL DUST PARTICLE SIZE

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 and 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). NIOSH recently conducted a particle size survey of US coal mines which concluded that the old definition of "mine size" dust is no longer applicable or representative (Sapko *et al.*, 2007).

Dust samples were routinely collected by MSHA inspectors and sent to the Mt. Hope Laboratory. Once the Mt. Hope laboratory performed their testing of the samples, the remaining samples were sent to NIOSH for coal particle sizing analyses.

At NIOSH, the limestone fraction of the samples was leached using hydrochloric acid (Sapko *et al*, 2007). Dilute hydrochloric acid was added to the dust sample in a beaker and heated. The acid reacted with the rock dust producing foam and releasing carbon dioxide. More acid was added until the foaming stopped. The resulting slurry was cooled and the residue was filtered from the slurry. The residue consisting of coal was rinsed with isopropanol and dried.

Using a sonic siever, the remaining samples were classified into different size fractions. The sonic siever utilizes a repetitive mechanical pulse and a vertical oscillating air column to provide particle separation. The sample amount on each sieve was recorded once the sieving process was complete.

MSHA divides U.S. coal mines into districts (Figure 2). The intake airway dust samples were examined and compared according to these MSHA districts. The fractions of minus 200 mesh (75 µm) ranged from 26% in District 8 to 39% in District 11. The minus 70 mesh (212 µm) fractions ranged from 59% in District 8 to 77% in District 11. The median diameter of the samples ranged from 116 µm in District 11 to 169 µm in District 8. The overall averages are 32% minus 200 mesh, 64% minus 70 mesh, with a median dust particle diameter of 147 µm. These samples are significantly finer than those of the 1920s survey (Sapko *et al.*, 2007).

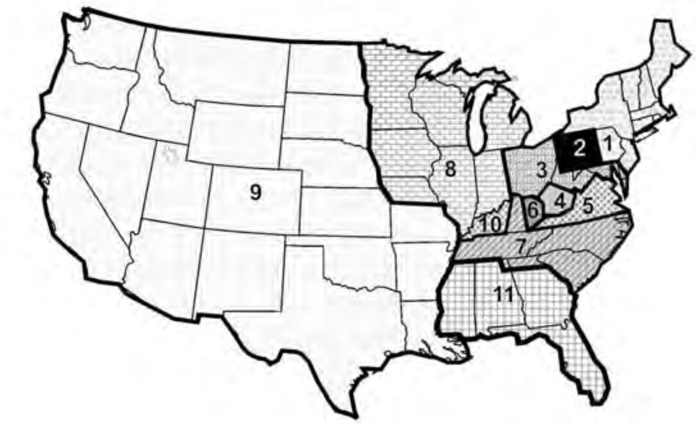

Figure 2: MSHA districts (Sapko *et al.*, 2007).

The same information was analyzed for the various coal seams sampled. The Blue Creek (District 11, Figure 2) and Hazard #4 (District 6, Figure 2) 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 43% dust particles minus 200 mesh (75 µm) and 83% minus 70 mesh (212 µm) and in the Hazard #4 seam containing 40% minus 200 mesh and 69% minus 70 mesh (Sapko *et al.*, 2007).

4. INERTING REQUIREMENTS

Coal dust explosibility is strongly dependent on its particle size. Since the average particle size is significantly different than that on which current regulations are based, current IC requirements may also be different. Based on early BEM data shown in Figure 1, more than 72% incombustible material is required to prevent a flame propagating explosion with a dust mixture containing roughly 40% minus 200 mesh (75 µm) coal particles. It would appear better to maintain 75% incombustible material in these entries in order to protect against a propagating explosion.

5. DUST SCOURING

As a part of the recent full-scale dust explosion testing at LLEM, dust scouring measurements were also collected. The dust scoured is indicative of the depth of dust participating in an explosion. Two parallel rails filled with a coal dust mixture were positioned in the entry. The dust was 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 in) to 2.6 mm (0.1 in) with an average of 1.5 mm (0.06 in). This is much less than the 2.54 cm (1 in) that is specified in the MSHA band sampling procedures. Therefore, the current 2.54 cm (1 in) sampling depth of dust does not portray what actually participates in an explosion. If there is a layer of float coal dust, the dust sample can be diluted with rock dust by sampling to a full depth of 2.54 cm (1 in), thereby giving a false sense of protection. A sample depth of 0.64 cm (¼ in) appears to better represent the level of explosion protection.

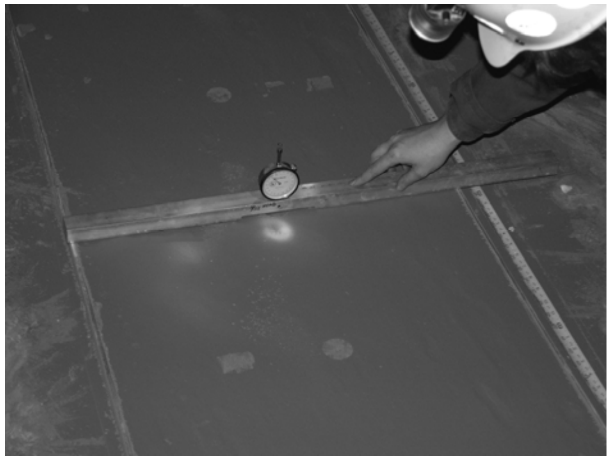

Figure 3: Measuring the amount of dust scoured during an explosion.

6. COMPLIANCE AND PROTECTION

Approximately two weeks pass before results of the quarterly rock dust band survey are received by the mine inspectors. The required remediation of potentially dangerous conditions is delayed because of this time constraint. NIOSH has developed a coal dust explosibility meter (CDEM) to address this situation.

The CDEM is a hand-held instrument that gives real-time readings of the incombustible conditions present (Figure 4). Its operation is based on optical reflectivity and takes into account the particle size of the coal dust (Sapko and Verakis, 2 006). The instrument output includes a red/yellow/green designation. Green would indicate the area is adequately protected while red would indicate an area deficient in rock dust. A yellow response indicates that the area is marginally protected.

Figure 4: The hand-held coal dust explosibility meter (CDEM)

A dust sample would be collected as per the MSHA established band sample requirements. A portion of the thoroughly mixed sample would be collected into a 45 ml sample tube containing drying molecular sieves. A small amount of the sample is shaken through a funnel that snaps onto the 45 ml sample tube and into the sample cup. The funnel is internally fitted with a 20 mesh screen which prevents the molecular sieves and larger dust particles from filling the sample cup. The sample cup containing the dust mixture is presented to the CDEM for measurement.

An earlier field study of the instrument in District 2 mines indicated that some areas were not adequately protected yet complied with the regulated 65% IC in the intake airways (Figure 5). Among the District 2 samples, 92 out of 104 had ≥ 65% IC, as required by current regulations. The CDEM indicated that 27 of these samples were within the red or yellow bands and may have been deficient in rock dust. These areas most likely would not receive more rock dust since analyses indicated compliance, however these areas represent regions where a risk of explosion propagation is present and would require more rock dust (Harris *et al.*, 2008).

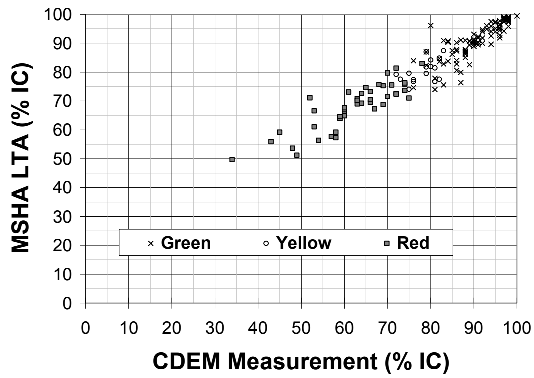

Figure 5: Coal dust explosibility meter field test results (Harris *et al.*, 2008)

7. SUMMARY

Modern underground coal mine conditions have changed since the early 20th century. The coal dust deposited in the mine intake airways is significantly finer. As such, more rock dust needs to be applied in order to prevent a propagating explosion in intake airways. New instrumentation has been developed to assess in real time the level of explosion protection that is within an entry. By accounting for varying particle sizes, the CDEM can immediately indicate whether more inert material is required to protect an entry from a possible propagating explosion. The amount of dust which participates in an explosion is less than a quarter inch deep. When assessing the rock dusting adequacy within an entry, only the top quarter inch should be evaluated.

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