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Design and development of a dust dispersion chamber to quantify the dispersibility of rock dust

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ABSTRACT

Dispersible rock dust must be applied to the surfaces of entries in underground coal mines in order to inert the coal dust entrained or made airborne during an explosion and prevent propagating explosions. 30 CFR. 75.2 states that "… [rock dust particles] when wetted and dried will not cohere to form a cake which will not be dispersed into separate particles by a light blast of air …" However, a proper definition or quantification of "light blast of air" is not provided. The National Institute for Occupational Safety and Health (NIOSH) has, consequently, designed a dust dispersion chamber to conduct quantitative laboratory-scale dispersibility experiments as a screening tool for candidate rock dusts. A reproducible pulse of air is injected into the chamber and across a shallow tray of rock dust. The dust dispersed and carried downwind is monitored. The mass loss of the dust tray and the airborne dust measurements determine the relative dispersibility of the dust with respect to a Reference rock dust. This report describes the design and the methodology to evaluate the relative dispersibility of rock dusts with and without anti-caking agents. Further, the results of this study indicate that the dispersibility of rock dusts varies with particle size, type of anti-caking agent used, and with the untapped bulk density. Untreated rock dusts, when wetted and dried forming a cake that was much less dispersible than the reference rock dust used in supporting the 80% total incombustible content rule.

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1. Background

30 CFR 75.2 defines rock dust as:

"Pulverized limestone, dolomite, gypsum, anhydrite, shale, adobe, or other inert material, preferably light colored, 100 percent of which will pass through a sieve having 20 meshes per linear inch and 70 percent or more of which will pass through a sieve having 200 meshes per linear inch; the particles of which when wetted and dried will not cohere to form a cake which will not be dispersed into separate particles by a light blast of air; and which does not contain more than 5 percent combustible matter or more than a total of 4 percent free and combined silica (SiO_2), or, where the Secretary finds that such silica concentrations are not available, which does not contain more than 5 percent of free and combined silica"

Coal dust explosions typically occur when a small volume of a flammable methane and air mixture is ignited. The high temperature gases rapidly expand to create a pressure wave, sometimes referred to as "pioneer wave" that may steepen into a shock wave as it propagates away from the ignition source. The shock wave produces a wind that disperses dust, from any exposed surfaces (roof, ribs, belt structure, cribbing, floor etc.). The resulting dust cloud is ignited by the propagating flame front produced by the initial methane explosion. The process continues to follow the combustible fuel source, consuming oxygen and generating large amounts of toxic combustion products. Factors that are known to affect the intensity of an explosion are the dust particle size, the location of the dust within the entry, the dust dispersibility, and the volatility of the coal dust. Coal particles less than 75 μm (minus 200 mesh) in size are most reactive and rock dust greater than 75 microns are much less effective in inerting (Man and Harris, 2014). Therefore, the application of appropriately sized and dispersible rock dust in sufficient quantities is essential to inert coal dust explosions and prevent continued flame propagation (Hartman et al., 1954; Cybulski, 1975; Sapko et al., 1987a, 1987b, 1998; NIOSH, 2010; Harris et al., 2015). The precise mechanism by which rock dust (generally pulverized limestone dust) quenches flame has not been fully explained, but is believed to involve absorption of thermal

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energy from the heated gases and absorption of radiant energy, which reduces the preheating of unburned coal particles ahead of the flame front.

Bruceton Experimental Mine (BEM) explosion research conducted in the 1950s by the US Bureau of Mines (BOM) compared wet rock dust applications to dry rock dust (Hartmann and Westfield, 1956). The caked deposits resulting from the wet rock dust applications were ineffective in preventing coal dust explosion propagation. Explosion propagation quenching resulted only if dry rock dust was distributed over the area soon after the wet application dried. These experiments indicated that dispersibility was a key controlling factor for preventing explosion propagation.

The rock dust definition (30 CFR 75.2) states in part that "… when wetted and dried will not cohere to form a cake which will not be dispersed into separate particles by a light blast of air …" A key question arising from this definition is: "What is a light blast of air and how should it be administered?" The original practices for rock dusting coal mines were approved in 1927 (Rice et al.) based on the recommendations by the American Engineering Standards Committee and again reaffirmed in May, 1960 (BOM, 1960). The phrase "a light blast of air originated in the 1960 BOM publication that referenced a caked dust as "compaction or adherence of dust particles to the extent that a light stroke with a brush or a light air blast, as from the mouth, will not cause the dust to be dispersed." Since the 1960 BOM definition can be arbitrary depending on the person applying the brush or the light blast of air, NIOSH sought to apply objective criteria to define a reproducible blast of air in a laboratory test by which the relative dispersibilities of dust can be assessed.

With the above context in mind, the mining industry has requested a quantitative test method to replace the subjective "light blast of air" for assessing the dispersibility of rock dust. In addition, the industry has also expressed the need for a quantitative method to determine whether the dispersed dust is in sufficient quantities to prevent and/or suppress a propagating coal dust explosion. This report details the NIOSH research effort and the experimental methodology developed to provide quantitative measurements associated with these rock dust dispersibility issues.

1.1. Design and development of the dust dispersion chamber

In order to conduct meaningful, quantitative laboratory-scale relative dispersibility experiments, the first step is to develop an acceptable method to produce localized wind forces (i.e., a "light blast of air") similar to those measured during full-scale dust explosions. Previous NIOSH research recorded dynamic pressure histories and dust scouring depths during full-scale dust explosion experiments conducted at the NIOSH Lake Lynn Experimental Mine (LLEM) (NIOSH, 2010, 2011). Fig. 1 is an example of the dynamic pressure history measured near the centerline of a 5.5-m (18-ft) wide by 2.1-m (7-ft) high entry 79.3 m (260-ft) from the closed end ignition source. This dynamic pressure history was produced by a near-limit propagating explosion containing a mixture of 71.4% rock dust and 28.6% pulverized Pittsburgh (PPC) coal dust. The dynamic pressure history represents the wind pressure pulse propagating at the speed of sound ahead of the flame combustion front. This pressure pulse interacts with the mine surfaces and disperses the deposited dust in advance of the flame front.

NIOSH research shows that the dust mixtures containing less than 71.4% rock dust will produce higher dynamic pressures, while increasing the rock dust content of the dust mixtures will produce lower dynamic pressures. The magnitude of the dynamic pressure is a function of the coal and rock dust particles sizes, their concentrations, the strength of the initiating methane explosion, as well as the measurement location (NIOSH, 2010; Sapko et al., 1987a, 1998). The measured dynamic pressure (Fig. 1) represents the dust-dispersing air pulse produced during the incipient stages of a methane-initiated coal dust explosion, and can therefore be considered a representative dynamic pressure pulse for quantifying the relative dispersibility and subsequent airborne concentration of rock dust within the dust dispersion chamber.

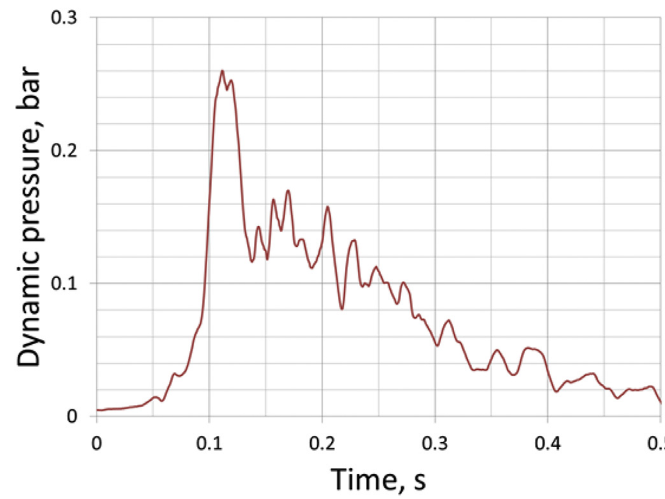

Fig. 1. Dynamic pressure history measured during LLEM Test #517.

Based on the full-scale LLEM explosion results, a laboratory-scale dust dispersion chamber was developed by NIOSH to provide a reproducible air pulse across the surface of a shallow dust-filled tray to compare the relative dispersibility of various types of rock dust samples. Both treated and untreated rock dusts exposed to wet and dry conditions were tested in the chamber. In particular, the objective was to determine if a particular waterproofed or treated rock dust formulation, after exposure to moisture, dispersed as well as the dry (Reference) rock dust used to inert full-scale explosions that were conducted in the LLEM.

Fig. 2 displays the volumetric and differential particle size distribution (PSD) of the Reference rock dust determined by the Beckman–Coulter particle size analyzer. This dust features a mass-mean diameter of 72.5 μm and an SSA of 2622 cm^2/g based on a particle density of 2.7 g/cm^2 and assuming that the particles are spherical in shape.

The assessment of dust dispersibility in the early days was very primitive and assessed by blowing on a sample of dust placed on a person's palm or equated to a puff of air for blowing out a candle. Many experiments were carried out in various countries to develop methods for a precise ascertainment of the degree of the dispersibility of coal and rock dust. Early researchers such as Greenwald at the U.S. Bureau of Mines (1938), Dawes (1952a), Dawes and Wynn (1952), Dawes (1952b) at the Safety Mines Research Establishment in England and Cybulski at the Experimental Mine Barbara (1975) understood the importance of rock dust dispersibility and conducted quantitative research to characterize the dispersibility relevant to preventing dust explosions. The concept behind the NIOSH-dust dispersion chamber was based partially on previous BOM research by Greenwald (1938) and partially on Cybulski (1975) research using optical detection techniques for assessing the dispersed cloud and then comparing these results with a "model" rock dust known to inert coal dust and prevent explosion propagations in the Polish Experimental Mine Barbara. The NIOSH approach also uses a representative air pulse based on the full-scale LLEM data and findings. The NIOSH dispersion chamber is a 15.24-cm high (6-in) by 15.24-cm (6-in) wide by