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Particle size and surface area effects on explosibility using a 20-L chamber

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ABSTRACT

The Mine Safety and Health Administration (MSHA) specification for rock dust used in underground coal mines, as defined by 30 CFR 75.2, requires 70% of the material to pass through a 200 mesh sieve (<75 μm). However, in a collection of rock dusts, 47% were found to not meet the criteria. Upon further investigation, it was determined that some of the samples did meet the specification, but were inadequate to render pulverized Pittsburgh coal inert in the National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) 20-L chamber. This paper will examine the particle size distributions, specific surface areas (SSA), and the explosion suppression effectiveness of these rock dusts. It will also discuss related findings from other studies, including full-scale results from work performed at the Lake Lynn Experimental Mine. Further, a minimum SSA for effective rock dust will be suggested.

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1. Introduction

Float coal dust, consisting of very fine aerosolized particles, presents a hazard that can contribute to a major underground coal mine explosion. In order to mitigate this risk, pulverized rock dust is required to be applied to the intake, return, and belt airways (entries). Federal safety regulations (30 CFR 75.402 and 30 CFR 75.403) require rock dust to be applied so that the total incombustible content of a mine dust sample is not less than 80 percent. 30 CFR 75.2 also defines rock dust and requires rock dust to be sized such that 100 percent passes through a 20 mesh (850 μm) screen and 70 percent or more passes through a 200 mesh (75 μm) screen.

This current particle size specification is so broad that it may not ensure that all rock dust will inert at the 80% incombustible level when uniformly mixed with coal dust. Past work (Man and Harris, 2014) suggests that rock dust particles in excess of 75 μm provide little inerting potential and, therefore, do not need to be included in the rock dust supply. A specification of 95% finer than 75 μm would ensure that the focus is on particles with the most inerting potential yet within grinding mill tolerances for rock dust manufacturers. Furthermore, members of the industrial minerals sector have indicated that such a particle size distribution (PSD) is attainable given current grinding technology. Given that the PSD of rock dust varies widely, another attribute such as specific surface area (SSA) should be considered to ensure that only the most effective dust particles are included.

2. Background

MSHA rock dusting regulations were initially based upon data generated within the Bruceton Experimental Mine (BEM) by the U.S. Bureau of Mines (BOM) which suggested that the largest-sized coal dust particle that participated in explosions was 850 μm (Rice et al., 1922). At that time, the authors stated that the following circumstances may prevent 20 mesh coal dust from propagating:

1. The 20 mesh dust will not mix readily and thoroughly with air due to the weight of the coarser particles,
2. The surface area of the coarse particles is less than that of the same weight of fine particles, resulting in less surface area for instantaneous oxidation, and
3. The number of the coarse particles is less than that of the same weight of fine particles making it probable that the distance between the particles will be greater and thus prevent propagation of the flame from particle to particle.

Since those early BOM tests, other laboratory and experimental mine testing methods were developed to determine which coal

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dust particle sizes contribute to explosion propagation and which rock dust particle sizes contribute to explosion suppression. Understanding of these relationships is critical to properly determining those characteristics of an effective rock dust for preventing coal dust explosion propagation.

One of the well-established American Society for Testing and Materials (ASTM) laboratory methods is the use of a 20-L (20-L) explosion chamber to test the explosibility of various coal dust and rock dust mixtures. Previous data from NIOSH 20-L chamber tests have shown that a coal dust (400 g/m^3 coal concentration) and rock dust mixture must contain at least 76% limestone rock dust to inert the pulverized Pittsburgh coal (PPC) dust which contains 80% minus 200 mesh particles (Cashdollar and Hertzberg, 1989). This finding was verified at coal dust concentrations of 150–700 g/m^3 Dastidar et al. (2001) also tested PPC in a 20-L chamber and reported a slightly lower value of 74% rock dust to inert the PPC dust at a dispersed coal concentration of 500 g/m^3. In an earlier study, Dastidar et al. (1997) had published an inerting value of 77% limestone rock dust associated with a 300 g/m^3 PPC concentration. The differences were described by the authors as "due to the nature of flame propagation, which is probabilistic at limit conditions." The latter observation reinforces the idea that multiple trials are needed to safely conclude that the mixture will remain non-explosive at all coal concentrations.

It is important to note that the 20-L chamber results indicate trends but cannot be directly scaled to full-scale results such as those obtained in another study performed at the Lake Lynn Experimental Mine (LLEM) (Sapko et al., 2000). The differences between the laboratory chamber results and the LLEM full-scale results include but are not limited to important differences between the dimensions and geometry of the mine and the laboratory chambers, differences in the ignition source (pyrotechnic ignitors in the 20-L chamber vs. an initiating methane-air explosion in the LLEM), and the manner in which the dust is introduced and dispersed. The chamber criterion for explosibility is based on the measured overpressure rise whereas the LLEM criterion is based on self-sustained flame propagation beyond the influence of the ignition source. Through previous research (Cashdollar, 1996; NIOSH, 2010), one can equate a 75% inerting rock dust concentration given by 20-L tests to an 80% incombustible content requirement for mine inerting (at least for Pittsburgh seam coal with a 6% ash content). The baselines in both the LLEM and 20-L chamber tests were established using PPC as the coal dust and a reference rock dust (acquired from the same rock dust manufacturer and having historically consistent PSDs).

A recent NIOSH study demonstrated that larger rock dust particles (>75 μm) are much less effective than smaller particles at inerting coal dust as indicated by the large increase in the percentage of rock dust required to inert PPC in both 20-L chamber and 1-m^3 chamber tests (Man and Harris, 2014). Results further indicated that rock dust particles between 250 and 850 μm (>60 mesh) did not inert PPC in the 20-L chamber studies. The study also showed that when rock dust particles <38 μm (<400 mesh) were removed from the particle size distribution, inerting was not possible at even a 90% rock dust level. Past research showing the dependence of inerting effectiveness on rock dust PSD suggested the need to further quantify this relationship using constant volume explosibility studies in the NIOSH 20-L explosion chamber (Man and Harris, 2014).

A previous NIOSH investigation of rock dust revealed significant concerns with the material used in mines based on the analysis of rock dust samples collected by the Mine Safety and Health Administration (MSHA) inspectors from U.S. coal mines in 2010. One concern was the frequency of rock dust material in mines not meeting the legal size criterion (70% by weight passing through a 200 mesh sieve). In a population of 393 rock dust samples from 278 underground coal mines, 47% of the rock dust samples failed to meet the minimum size criterion (NIOSH, 2011). NIOSH tested these dusts within the 20-L chamber to verify the inadequacy of the rock dust that did not meet the definition. Most importantly, some of the rock dusts that did meet the current definition did not inert PPC in the 20-L chamber.

In light of the above findings and given the need for a more definitive characterization of rock dust that is effective for inerting a propagating coal dust explosion, NIOSH researchers undertook an investigation of the rock dust particle size effects on explosibility in a 20-L chamber. The PSDs of the rock dusts vary greatly with some having multiple peaks in the distribution and although sieving can be used to characterize the PSD of rock dusts, the most effective particles for inerting lie in the respirable size range and cannot be sieved. To better characterize such wide variations, multiple and varying sized sieves would be required and the finest size to be assessed would typically be 38 μm or possibly 20 μm (635 mesh sieve not widely available commercially). However, the respirable portion of rock dust is the most effective and cannot be assessed using sieves. Therefore, in lieu of characterizing rock dust solely on the percentage finer than 200 mesh, NIOSH investigated the use of a specific surface area (SSA) designation as means to assess inerting effectiveness. The SSA is a calculation of outer surface area based upon a spherical approximation given the particle size or width. In this paper, the term "explosibility" refers to the ability of an airborne dust cloud and/or gas mixture to explode in a confined laboratory chamber or propagate flame within an experimental mine after the dust cloud or gas mixture has been initiated by a sufficiently strong ignition source. All of the full-scale LLEM explosion tests referenced earlier utilized the same limestone rock dust which is referred to herein as the Reference rock dust. Rock dust samples collected by MSHA during a survey were tested within the 20-L chamber to demonstrate their inerting abilities. The standard PPC dust and Reference rock dust were used for both laboratory and experimental mine explosions.

3. Experimental

3.1. Particle size analyzers

For a full particle size distribution and SSA, NIOSH used a Beckman Coulter (B-C) LS 13320 laser diffraction particle size analyzer equipped with a Tornado Dry Powder air dispersion system. NIOSH researchers followed the analysis procedure recommended by the manufacturer (Beckman Coulter, 2011). The laser diffraction data is analyzed by the instrument in terms of equivalent spherical scatterers using a Mie scattering algorithm. The volume fraction is determined for the various particles sizes, and a specific surface area in terms of area per unit volume (cm^2/ml) is determined. That area divided by the density of the particles then gives the specific surface area (SSA) in units of area per units of mass. The complex refractive index (RI) of $1.8 + 0.3i$ was used for the coal dust analysis and $1.68 + 0.0i$ was used for the limestone rock dusts, where i is the imaginary (absorptive) component. These were average RI values found in the B-C manual for carbon and calcium carbonate and were not determined by a separate analysis. Control samples of PPC and the Reference rock dust were tested every 30–50 samples to confirm proper B-C operation and to detect significant deviations from the typical measured average values and uncertainty in their SSAs. The B-C system was the system of choice to use for SSA determination. The system requires only a small sample for analysis, is easy to use, gives reproducible results, and is not subject to user variability. However, another option is the use of an air-jet sieve in conjunction with the Blaine Permeability