# Moisture variance of mine dust samples and the inclusion of moisture as incombustible content

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**Full text: Headnote**

Abstract

Coal dust produced during the mining process is a prime explosion hazard in underground coal mines. To inert the coal dust and prevent a catastrophic propagating dust explosion, rock dust is applied to the roof, ribs, and floor surfaces of mine entries. Currently, one determination of whether a mine is adequately protected from the coal dust explosion hazard is made by analyzing collected mine dust samples for percent total incombustible content (% TIC). A minimum of 80% TIC is required per 30 CFR 75.403. The as-received moisture of the dust sample is included in the % TIC. Moisture and humidity within a coal mine vary greatly with the seasons, with explosions occurring more frequently during dry winter months. This paper will discuss the fluctuations of the as-received moisture content of the mine dust samples collected by U.S. Mine Safety and Health Administration inspectors in 2010 and the observed fluctuations of the moisture content of rock dust within the U.S. National Institute for Occupational Safety and Health Office of Mining Safety and Health Research Bruceton Experimental Mine and the Safety Research Coal Mine over a one-year period.

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Abstracto * El polvo de carbón producido durante el minado es uno de los principales peligros de explosión en minas de carbón subterráneas. Con el fin de volver inerte el polvo de carbón y evitar una explosión catastrófica propagante por polvo, se aplica polvo de roca a la superficie del techo, paredes y piso de las entradas de mina. En la actualidad, una forma de determinar si una mina está adecuadamente protegida contra explosiones por polvo de carbón es mediante la recolección y análisis de muestras de polvo para medir el porcentaje del contenido incombustible total (% TIC por sus siglas en inglés). Se requiere un mínimo de 80% TIC por 30 CFR 75.403. La humedad tal como se recibe en la muestra de polvo es incluida en el % TIC. La humedad varía bastante al interior de la minas de carbón según la estación, con mayor frecuencia de explosiones durante los meses secos de invierno. Este estudio abordará las fluctuaciones del contenido de humedad tal como se recibe en las muestras de polvo de mina recolectados por inspectores de la Administración de Salud y Seguridad en Minas de los Estados Unidos (MSHA por sus siglas en inglés) el 2010, y las fluctuaciones observadas del contenido de humedad del polvo de roca en los laboratorios del Instituto Nacional de Salud y Seguridad Ocupacional de los Estados Unidos y la Administración de Salud y Seguridad en Minas ubicados en la Mina

Experimental en Bruceton y la Mina de Carbón para Investigación en Seguridad (SRCM por sus siglas inglés) durante el periodo de un año.

## Introduction

Explosions in underground mines and surface facilities such as processing plants are caused by confined accumulations of combustible dust and/or flammable gas mixed with air in the presence of an ignition source. Underground explosions can be prevented by minimizing methane concentrations through methane drainage and ventilation, by adding sufficient rock dust to inert the coal dust and by eliminating ignition sources.

The effectiveness of rock dust in arresting explosion propagation was proven by experiment and practice (Rice, 1911; Rice et al., 1927; Cybulski, 1969; Richmond et al., 1975; Michelis et al., 1987; Reed and Michelis, 1989; Lebecki, 1991, Cashdollar and Hertzberg, 1989, Weiss et al., 1989, NIOSH, 2010, Sapko et al., 2000). The precise mechanism by which rock dust (generally pulverized 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.

One measurable aspect of explosibility is incombustible content. In order to determine whether enough rock dust is applied, 30 CFR §75.403, Maintenance of Incombustible Content of Rock Dust, requires at least 80% incombustible content on the roof, ribs and floor of underground coal mines. 30 CFR §75.403-1 further defines the incombustible content as follows: "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."

In order to determine the incombustible content of the mine dust, samples of deposited dust from specified areas in a mine must be collected, analyzed and then compared with the minimum standard of 80%.

The traditional low-temperature ashing (LTA) approach to determine if a coal and rock dust mixture is compliant with the inerting requirement consumes the coal dust and considers the remaining material to be inert. Compliance with the law is then determined by comparing the measured percentage of inert material of the representative band sample with the pre-established requirement of 80%. The incombustible content of the sample includes rock dust, the amount of moisture as received at the lab and the inherent ash in the coal. The LTA method is not itself a direct measure of explosibility, but is a surrogate that calculates a single parameter associated with large-scale Bruceton Experimental Mine (BEM) explosion test results conducted with dry rock dust. This method assumes a homogenous mixture with no layering of rock dust and coal dust. Float coal dust is a serious explosion hazard if it accumulates on top of the rock dust and is not mixed with the rock dust (NIOSH, 2006).

Mitchell and Nagy (1962) studied the effectiveness of water as an inerting agent for 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 the 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. However, if the mine depends upon the moisture content as part of the incombustible content, fluctuations in the dust surface moisture within a mine can render moisture content an ineffective and inconsistent measure of safety. Additionally, if sufficient moisture is absorbed and subsequently relinguished by rock dust, a cake can form and render the rock dust ineffectual.

The trend has long been recognized that mine explosions occur primarily during the winter season when the humidity is low for long periods of time (Mannakee, 1910; Scholz 1908; Kissell, 2006). In light of this trend and due to the potential variability of the moisture content of the dust, it may not be prudent to include variable surface moisture in the total incombustible content of the sample. Instead, surface moisture should be viewed as an additional safety measure as long as the rock dust is dispersible. However, moisture limits the ability of the rock dust to disperse and can significantly reduce its capacity to effectively inert propagating explosions (Rice et al., 1927; Owings et al., 1940; Greenwald, 1938; Hartman and Westfield, 1956; Hartman et al., 1956; Mitchell and Nagy, 1962; Cybulski, 1975; Harris et al., 2010).

Given the methods by which the as-received moisture and incombustible content are determined, dust samples from the 2010 U.S. Mine Safety and Health Administration (MSHA) database were assessed to determine the variability of the moisture content throughout a year and how often the measured as-received moisture might have affected the dust explosibility determination if removed. The findings were then verified by observation in laboratory studies and within the National Institute for Occupational Safety and Health (NIOSH) Office of Mining Safety and Health Research (OMSHR) Safety Research Coal Mine (SRCM).

## Methods

Low-temperature ashing: LTA is the incombustible analysis procedure used to determine the total incombustible content reported in the MSHA database. It begins by passing the <10 mesh sample (< 2 mm particles) through a 20-mesh sieve (850-pm) and then oven drying the minus 20 mesh material for 1 hr at 105° C (221°F) (Montgomery 2005). The weight lost during drying constitutes the asreceived-moisture in the sample. Next, the dried sample is heated in an oven that is ramped up over 1.5 hour and held at 515° C (595°F) hour for about 2.5 hour to burn off the combustible coal fraction, thereby leaving the ash and incombustible material. This LTA burns off the coal, but does not decompose the limestone rock dust. The amount of the remaining ash material plus the as-received-moisture divided by the initial weight is reported as % total incombustible (TIC).

Database analysis: NIOSH OMSHR examined a database file containing MSHA laboratory analyses for quarterly band sample surveys with moisture data during 2010. Less than 0.5% of the samples (209) contained negative moisture values or values >100% moisture. These errone- ous data points, having values outside of the 0-100% moisture range, were not considered in this study.

SRCM measurements: Rock dust was placed within the SRCM in several locations in March 2011 (Fig. 1) to evaluate potential moisture values of rock dust when in contact with ambient air. At each location, one bag was opened with the plastic bag liner intact to prevent wicking moisture from the floor. This rock dust should have acquired moisture from the ventilation air only. A second bag was dumped onto the floor, providing contact with moisture from the floor surface. In August, a third bag was added with the liner intact because several locations were under active roof drips that allowed condensed moisture and ground water to fall onto the rock dust (Fig. 2).

Samples were taken monthly for one year from March 2011 through March 2012. Samples were collected by scraping 50 g of rock dust material into a sealable plastic bag. After researchers exited the SRCM, the samples were taken to the laboratory for immediate moisture analysis to prevent loss of moisture through the bag or to the drier laboratory atmosphere. In the laboratory, 3 g of each collected sample were placed in a CompUTrac moisture analyzer and dried at a temperature of 105° C.The percentage of moisture was calculated from the difference in weight loss.

## Data analysis

Database analysis: Table 1 is a summary of MSHA moisture analysis of dust samples collected during the 2010 quarterly band sample surveys. It displays the ranges of moisture content and the number of samples that fell within the associated ranges as well as the associated percentages of the overall database. More than half of the samples from the 40,263 data sets in the 2010 database contained less than 1% as-received moisture. This would be expected since the inherent moisture of the rock dust as shipped from the manufacturer is expected to be approximately 0.2-0.5%. Approximately 99% of the samples contained less than 10%.

Figure 3 displays the distribution of as-received moisture analysis from the MSHA 2010 quarterly surveys.The brush and pan sampling collection technique used to obtain these samples is designed for dry dust and cannot effectively sample dust mixtures that are pastes or liquids. Thus, areas too wet to be sampled are avoided. In addition, 30 CFR 75.402-1 states: "The term 'too wet' means that sufficient natural moisture is retained by the dust that when a ball of finely divided material is squeezed in the hands water is exuded" and excludes samples in those areas. Additionally, sample areas tend to be chosen as the drier areas so that the collected dusts can be sieved, which may bias the in situ moisture of mine dust. In the OMSHR laboratory, when a rock dust was mixed with 21 % water, it was observed that the consistency of the water/rock dust mixture was slightly thick, yet able to be stirred. The actual percentage of moisture required to convert the rock dust into this thick mixture is dependent on the particle size distribution of the particular rock dust. An overall finer rock dust size distribution with a higher surface area measurement requires more water, compared with a coarser rock dust with a lower surface area measurement. Nonetheless, the moisture data points indicated as 20% or more should be considered suspect since it would be extremely difficult to collect samples of that nature with the brush and pan technique and then pass those samples through a 20-mesh sieve for subsequent analysis.

The sample preparation and handling prior to the LTA analyses in the laboratory likely result in moisture loss. Moisture will evaporate from the dust samples if the samples are not maintained in air-tight sample containers and if the samples are exposed for any lengths of time to drier atmospheric conditions prior to the analyses. Therefore, the moisture within the dust sample at the time of sample collection is likely not the same as the moisture reported from the LTA analysis, hence the term "as-received moisture."

Figure 4 illustrates the seasonal moisture trend due to large variations in humidity in dust samples. These samples were collected from mines in numerous MSHA districts. Each of these mines had a high number of samples collected throughout the year, which allowed for evaluation of these seasonal moisture trends. The dust samples obtained during the humid summer season contain a larger percentage of as-received moisture compared with the samples collected during the drier winter season. Figure 4 shows a general trend for each of these specific mines.

The 40,263 database samples represent 1,396 individual events or surveys. There were 4,798 individual samples that did not meet the required total incombustible and resulted in 1,122 citations for noncompliance with 30 CFR 75.403 in 2010 (MSHA, 2013). Another 1,324 samples would have failed if the as-received moisture had not been considered as part of total incombustible. In other words, if the moisture within the dust sample in these 1,324 instances evaporated, there would not be enough incombustible material to inert the coal dust. Each of the 1,324 samples represents 500 ft of entry at the time that these samples were taken, or approximately 125 miles of coal mine entries that were potentially rock dust deficient.

SRCM measurements: Figure 5 shows the change in the moisture content of rock dust piled directly on and in contact with the mine floor in a relatively dry room in the SRCM during a one-year period. As seen, the rock dusts start out dry, with 0.2-0.5% moisture, which is the typical moisture content of rock dust as received from the manufacturer. The maximum moisture content of this rock dust was 20%. During the winter, when the outside air temperature is normally lower than the air temperature in the mine, the water content decreased but did not dry out completely. Rock dust isolated from moisture on the floor, rib or roof strata did not appear to take on any significant amounts of moisture from the ventilation air (Fig. 6). Even rock dust located under water drips or piled in standing water did not take on more than 20% surface moisture in the humid summer months. Rock dust in direct contact with the mine surfaces appears to wick or absorb moisture, from either the ground strata or condensation, much more readily than rock dust that is only in direct contact with ventilation air with humidity as the source of moisture.

Figure 7 shows the difference in moisture content of the rock dust samples within 50 ft of each other in 12 Room of the SRCM, a relatively wet area. As seen here, the wet conditions did not allow the dust to dry to depth of sample during the less humid winter months. Some samples at the 20% or more moisture level displayed free water in the sample bag before laboratory analysis. Other researchers have reported that drying rates are dependent on the relative humidity of the mine or room in which the dusts are located. Early mine tests of wet rock dusting by U.S. Steel (Snell, 1958) reported that a 35% moisture content dropped to less than 1 % in four days at 75% RH, while a 17% moisture rock dust only dropped to 7% in six weeks at 88-97% RH. OMSHR testing in the SRCM found similar results to Snell, where the rock dust in wet or +95% RH areas did not dry significantly. Samples were weighed wet, dried in an oven overnight at 90° C and reweighed to obtain the % moisture over a two-week period (July 30 to Aug. 14,2012). Initial moisture readings of wet rock dust applied to the ribs and roof of three areas of the SRCM ranged from 20% to 31%. After one week, only 16% of these samples were less than 15% moisture; after two weeks, 35% were below 15% with one sample less than 10% moisture.

## Conclusions

Mine dust samples from the 2010 MSHA quarterly band sample surveys database exhibited the seasonal trends that have been previously observed. Although the majority of the samples contained less than 2% moisture, seasonal (summer) samples of various individual mines shown in Fig. 4 contained upwards to 10% moisture. Also, 1,324 individual samples that were considered as compliant would contain less than 80% incombustible if the moisture were removed.

In experimental testing, these same trends were observed in the rock dust located on the floor of the NIOSH OMSHR Safety Research Coal Mine. Although rock dust bags that were isolated from the floor only gained less than 0.5% moisture, rock dust samples that were in direct contact with the floor gained upwards to 20% moisture in the summer months, then lost considerable moisture again in the winter months. This would be more indicative of rock dust that is applied and is in direct contact with the roof, ribs and floor of a mine. Any moisture that seeps from the local coal or rock strata or condenses on the mine surfaces would be immediately wicked by the rock dust.

Currently, when determining the incombustible content of mine dust samples, the as-received moisture is analyzed and classified as incombustible, although it has been recognized in this recent OMSHR study and for many years that the humidity and moisture within a mine vary greatly with seasonal changes. As has been previously demonstrated and proven here again, rock dust can gain as much as 20% moisture in the humid summer months and then lose much of that moisture during the dry winter months. Therefore, given the inconsistent nature of the moisture content within a mine dust sample, the asreceived moisture should not be considered and depended upon as a reliable incombustible material to inert coal dust. Instead, moisture should be considered as part of a safety factor in the incombustible determination. *

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