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Examination of classified rock dust (treated and untreated) performance in a 20-L explosion chamber

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ABSTRACT

Mine explosions are caused by the ignition of excessive accumulations of combustible dust and/or flammable gas mixed with air in the presence of an ignition source. Rock dusting (limestone dust) is a primary measure to prevent propagating coal dust explosions in underground coal mines in the United States.

Although rock dust is considered a nuisance dust, Continuous Personal Dust Monitors (CPDMs) do not distinguish between the coal dust and rock dust and assess the total dust exposure. During application, the $< 10\,\mu m$ limestone particles and coal dust particles can become suspended and carried by the ventilating air for long distances and can be measured by the CPDMs. There is a concern in the mining industry that rock dust can be included in the CPDM measurements and make the samples noncompliant.

Research conducted by the National Institute for Occupational Safety and Health (NIOSH) has found that all rock dust (RD) cakes after being wetted and then dried. To prevent rock dust from caking, several rock dust manufacturers have developed anti-caking rock dusts. The anti-caking additives used are typically fatty acids that make the rock dust hydrophobic and are added in very low quantities ($< 1\%$). While this development will add to the rock dust fluidity, an inevitable problem may be the increased airborne re-entrainment of rock dust due to vehicle movement and foot traffic in the area. Thus, one consideration to reduce such exposure from rock dust is to remove the respirable size fraction ($< 10\,\mu m$) of the applied rock dust. This paper presents the results of experiments that were conducted to determine if a rock dust can still inert a coal dust explosion when the respirable ($< 10\,\mu m$) or inhalable ($< 20\,\mu m$) component of the particle size distribution is removed. Three different untreated rock dusts (untreated A, B, and C) with their treated counterparts (treated A, B, and C) were classified using mechanical sieves into several different-sized fractions, including < 10, 10–20, 20–38, 38–53 and $> 75\,\mu m$. The relative inerting effectiveness of these size fractions were determined using the United States Bureau of Mines (USBM) 20-L explosion chamber.

1. Introduction

Current strategies for explosion prevention in underground coal mines use a multilayered approach which consists of: 1) controlling methane gas concentrations, 2) regulating the use of potential ignition sources, and 3) rock dusting airway surfaces (ribs, roof, and floor) to prevent dust explosion propagation, and 4) elimination or reduction in the amount of float coal dust produced and the inerting of any float dust deposited. In the event of an explosion, when sufficient quantities of rock dust are lifted in conjunction with the coal dust, the coal dust is inerted and the propagating explosion is mitigated. The precise mechanism by which limestone rock dust quenches the flame has not been fully understood, but it 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 (Sapko et al., 2000).

In September 2011, the National Institute for Occupational Safety and Health (NIOSH) analyzed several rock dust samples being used in underground coal mines and determined that many of the samples did not meet the rock dust size requirements set forth in CFR 30 Part 75 Section 75.2. Almost half of the samples did not contain the minimum of 70% passing through a 200-mesh ($75\,\mu m$) sieve (NIOSH, 2011). Upon investigation of other requirements included in 30 CFR part 75 section 75.2, NIOSH found that all of the samples caked after being wetted and then dried. Anti-caking additives were then developed to prevent rock dust from caking, but this development will increase the rock dust

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fluidity.

Current research conducted at NIOSH with applications of a treated rock dust in wet mine conditions has shown that anti-caking rock dust, when applied to rib and roof surfaces, continues to be dispersible even after several years. Adjacent applications of an untreated rock dust under similar conditions became non-dispersible immediately after application and currently remain non-dispersible (Harris et al., 2017). But the enhanced fluidity of the respirable-sized treated rock dust particles may be a concern for respirable dust exposure for miners working downwind during the application of rock dust or due to movement of men and machinery through rock-dusted areas. Additionally, with lowering the respirable dust maximum from 2.0 mg/m^3 to 1.5 mg/m^3 per 8-h shift (effective August 1, 2016), there is a concern that dust monitors may give inaccurate exposure readings as the CPDMs measure the total respirable dust concentration of "mine dust." A CPDM does not differentiate between the coal dust and rock dust. Based on these concerns, one recommendation is to reduce or remove the respirable-size fraction (less than 10 μm) of the supplied rock dust to eliminate CPDM readings that may be associated with limestone dust.

The 20-L chamber is a well-established ASTM laboratory test method to evaluate the explosibility of various coal dust and rock dust mixtures (ASTM, 2007, 2010). Previous data from NIOSH 20-L chamber tests have shown that a coal dust (400 g/m^3) and rock dust mixture must contain 75% 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. It is important to note that the 20-L chamber results indicate trends but cannot be directly scaled to full-scale test results conducted at the Lake Lynn Experimental Mine (LLEM) (Sapko et al., 2000). There are multiple differences between the laboratory chamber results and the LLEM full-scale experiment results. The dimensions and geometry of the mine and the laboratory chambers are different. Also, the ignition source (pyrotechnic ignitors in the 20-L chamber versus an initiating methane-air explosion in the LLEM) and the manner in which the dust is introduced and dispersed are different in the chamber versus the LLEM tests. The chamber criterion for explosibility is based on the measured overpressure rise (as described in the Experimental Methods section), whereas the LLEM criterion is based on self-sustained flame propagation beyond the influence of the ignition source. Despite such differences, NIOSH research has revealed that the Pittsburgh coal seam, with a 6% ash content, is historically inerted at 75% RD concentration in a 20-L explosions chamber. This 75% inerting limit in a 20-L chamber can be equated to an 80% incombustible content in large-scale explosion tests that were conducted at the Lake Lynn Experimental Mine (Cashdollar, 1996, 2000).

Therefore, a series of 20-L explosion tests were conducted to determine if a rock dust can still inert a coal dust explosion when the respirable (< 10 μm) or inhalable (< 20 μm) component of the particle size distribution is removed. The current research classified three different untreated rock dusts (untreated A, B, and C) with their treated counterparts (treated A, B, and C) into several different size fractions, including < 10, 10–20, 20–38, 38–53 and > 75 μm, to test the inerting effectiveness using a 20-L chamber. In order for the rock dust to effectively quench a propagating explosion, properly sized rock dust particles should be lifted into the air to absorb the thermal energy from the initial explosion wave front. Hence, a key attribute of the rock dust is its dispersibility. Therefore, the relative dispersibility of the classified rock dusts were evaluated using the NIOSH-designed dust dispersion chamber and qualitative caking tests. The details are stated in the Experimental Methods section that follows.

2. Experimental Methods

Most of the rock dusts were classified in the NIOSH laboratory using a Ro-Tap and an air jet sieve. The < 10 μm size fraction was air-classified by an outside vendor. These size fractions were analyzed by a Beckman Coulter (B–C) particle size analyzer before the other physical characterizations were assessed. All classified rock dusts were assessed for inerting effectiveness using the 20-L explosion chamber, and the dispersibility was evaluated using the dust dispersion chamber. Qualitative caking tests were conducted with the classified treated rock dust to determine the dispersibility of rock dust after wetting.

2.1. Particle size analysis

The particle size distributions, mean rock dust particle sizes, and specific surface areas (SSA) were obtained using a Beckman Coulter LS 13 320 optical particle sizing analyzer. NIOSH researchers followed the procedure recommended by the analyzer manufacturer (Beckman Coulter, 2011). The index of refraction (RI) used was $1.8 + 0.3i$ for coal dust analysis and $1.68 + 0.0i$ for limestone rock dust analysis, where i is the imaginary component. The Beckman Coulter (B–C) relies on laser scattering and is capable of particle size measurements as small as 0.3 μm (Beckman Coulter, 2011). The software for the B–C calculates the SSA cm^2/cm^3 and is converted to cm^2/g by dividing by the particle density of the material tested (2.7 g/cm^3 for rock dust and 1.3 g/cm^3 for coal dust).

2.2. The 20-L explosibility chamber

The dust explosibility experiments were conducted in the USBM-developed 20-L explosibility chamber shown in Fig. 1 and Fig. 2 (Cashdollar, 1996, 2000). This is the standard laboratory test chamber used previously at the U.S. Bureau of Mines (USBM) and now by NIOSH for studying the explosibility and inerting of combustible dusts. The software program allows for variable smoothing, rescaling, peak searches, expansion of the time scale, etc. The ignition sources used for the 20-L chamber inerting tests were 5000 J electrically activated pyrotechnic igniters manufactured by Sobbe of Germany. The 5000 J energy is a nominal calorimetric value based on the mass of pyrotechnic powder. The 5000 J igniter by itself produces a pressure rise of about 0.55 bar in the 20-L chamber. This igniter pressure contribution is subtracted from the explosion pressure in determining the pressure ratio (PR = explosion pressure/initial pressure) of the ignition.

In this paper, the term explosibility refers to the ability of an airborne dust cloud mixture to deflagrate when exposed to a defined ignition source. The standard pulverized Pittsburgh coal (PPC) dust and

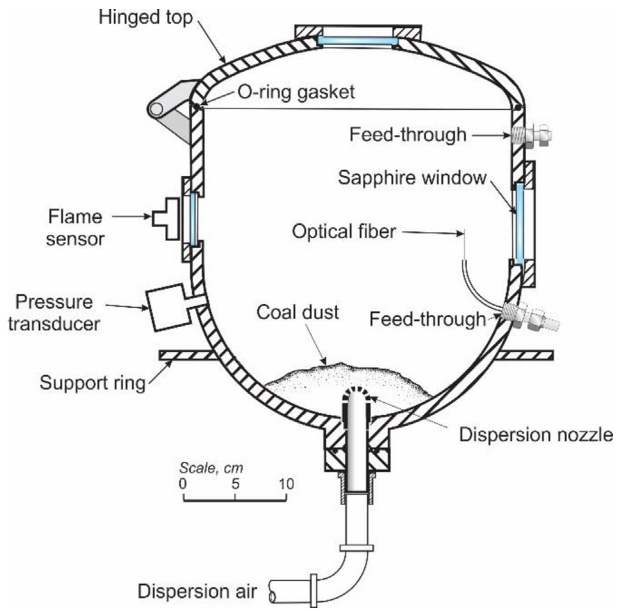

Fig. 1. Side view of the NIOSH 20-L explosibility chamber.

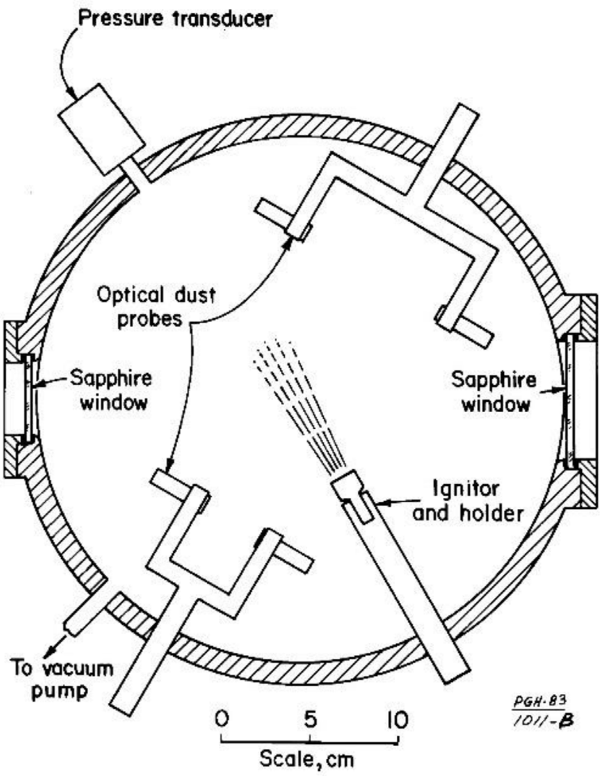

Fig. 2. Top view of the NIOSH 20-L explosibility chamber.

Table 1
Proximate analyses and heating value of PPC used in the 20-L explosibility chamber.

PPC Property	Value
Moisture, %	1
Volatility, %	37
Fixed Carbon, %	56
Ash, %	6
Heating Value, Cal/g	7720

the reference rock dust have been used extensively in both laboratory and experimental mine explosions. The proximate analyses and heating values of the PPC are listed in Table 1.

A pressure ratio (PR) calculation is used to determine the inerting effectiveness of a particular rock dust when mixed with explosible concentrations of PPC in the 20-L chamber. The PR is the final maximum chamber pressure obtained during the test divided by the initial chamber pressure just prior to ignition (atmospheric pressure or approximately 14.5 psia or 1 bar).

Criteria for an explosion:

- The maximum explosion pressure ≥ 2 bar and
- The volume normalized rate of pressure rise, $(dP/dt)\ V^{1/3} \geq 1.5\ \text{bar m s}^{-1}$.

For each rock dust percentage, five tests were run with PPC concentrations of 200, 400, and 600 g/m^3 to determine the reactivity of the mixture. Tests were conducted with rock dust increments of 5%, and the final amount to inert was interpolated for values reported therein.

2.3. The dust dispersion chamber

The dispersibility of the classified rock dusts were measured using a NIOSH-designed dust dispersion chamber. All test samples were subjected to the same reproducible 0.3-sec air pulse from a 2.8-bar (40-psi) compressed air source, providing a peak dynamic pressure of 0.3 bar (4.2 psi). An optical dust probe downwind of the pressure pulse measured the obscuration resulting from the concentration of the dispersed dust cloud. Details of the dust dispersion chamber construction and protocol are presented elsewhere (Perera et al., 2016a). In general, a uniform level layer of dry dust fills a tray. The tray is inserted into the chamber where the air nozzle supplying the pressure pulse is horizontal to the surface of the dust layer (see Fig. 3). Sample dust trays were weighed before and after each air pulse to determine the mass of dust dispersed. The attached optical dust probe measures the obscuration resulting from the concentration of the dispersed dust cloud. Between the mass loss of the dust tray and the dust probe measurements, the relative dispersibility of the dust is determined (Perera et al., 2016a).

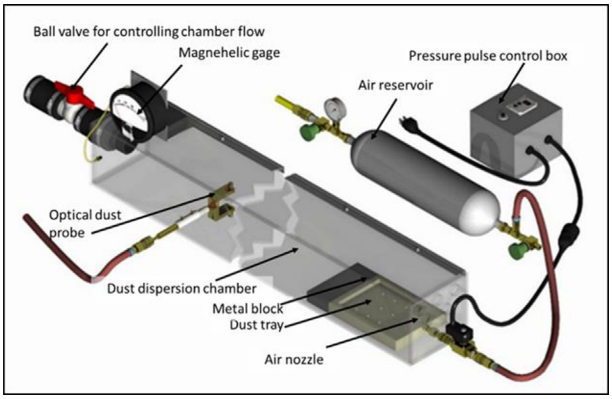

Fig. 3. Schematic of the dust dispersion chamber with the dust tray.

2.4. Qualitative caking test

The qualitative caking test is a pass/fail assessment of the rock dusts' ability to cake when exposed to moisture and then dried. Twenty (20) ml of water is added to 20 g of rock dust in a weigh boat or container. The rock dust and water are then mixed with a spatula for approximately 10 s and left to dry in ambient laboratory conditions until a constant weight (for approximately 24–48 h). After the sample dries, a visual assessment of caking is made. A rock dust that cakes will look like a dried-up lake bed while a non-caking rock dust will look nearly the same as when first placed in the boat (Perera et al., 2016b).

3. Results and discussion

Federal safety regulation 30 CFR 75 part 75.2 defines rock dust and requires rock dust to be sized such that 100% passes through a 20-mesh (850-mm) screen and 70% or more passes through a 200-mesh (75-mm) screen and disperse into particles with a light blast of air.

The 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. Previous NIOSH research (Man and Harris, 2014) suggests that rock dust particles larger than 75 µm provide little or no inerting potential to prevent a propagating explosion and, thus, do not need to be included in the rock dust supply. In this view, NIOSH research recently introduced the SSA of rock dust as a better parameter to characterize the rock dust size. The differential volume percentage versus the particle diameter of reference rock dust or the rock dust A in this study is shown in Fig. 4A. The cumulative size percentage of reference rock dust versus the particle diameter is shown in Fig. 4B. This reference limestone rock dust shows a bimodal size distribution (Fig. 4A). It is interesting to note that ~30% of the volume contributes to < 5% of the rock dust's surface area. Hence, removing the larger size fraction of rock dust will not greatly affect the overall specific surface area of the rock dust. But, when removing the inhalable

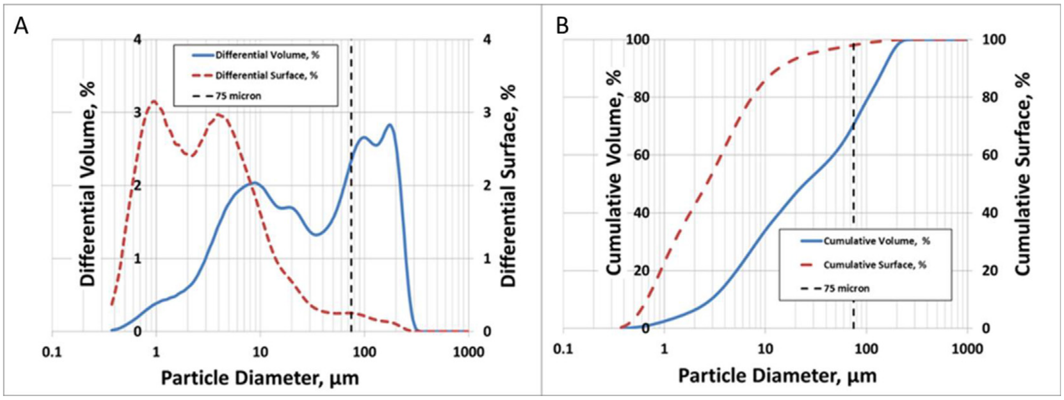

Fig. 4. A: The differential volume and surface area percentage of rock dust versus the particle diameter and B: The cumulative volume and cumulative surface area percentage versus the particle diameter of whole reference rock dust used in this study.

or the respirable portion of the rock dust size fraction, a proper balance of the SSA should be achieved in order for the rock dust to be effective in preventing a propagating explosion, especially since the smaller particles are proven to be more effective in inerting an explosion.

3.1. 20-L chamber results

According to past 20-L chamber results, PPC with the reference rock dust (untreated A, historically used in NIOSH large-scale experiments) will inert at 75% rock dust at 400 g/m^3 PPC coal dust concentration (NIOSH, 2010). This is compared to the 80% rock dust required to inert in LLEM studies using the same dust sources. Therefore, as a screening test, when examining the inerting limits of the rock dust, if the dust is non-explosible at or below 75% rock dust, the dust is expected to meet the inerting requirements in a large-scale experiment. Before classifying the three treated and untreated rock dusts, 20-L experiments were conducted on all six rock dusts to determine the inerting limits, and the data is presented in Fig. 5. It was found that all six rock dusts inerted at 75% rock dust concentration with PPC at 400 g/m^3.

3.2. Treated and untreated reference rock dust A

Untreated rock dust A is also the reference rock dust, which was used to establish the 80% Total Incombustible Content (TIC rule). The exact concentration of the treated A is unknown due to proprietary issues. Summarized in Table 2 are the explosion results of the 20-L measurements for the reference rock dust. The red "**E**" indicates an explosion where the pressure ratio is above 2 and the green "**I**" indicates a non-explosion where pressure ratio is less than 2. Experimental results indicate that the unclassified rock dust A (< 840 µm) inerted at a 73% rock dust concentration using 400 g/m^3 PPC (Table 2 and Fig. 4). The size distribution of the PPC is reported elsewhere (Harris et al., 2015). When the larger particles > 75 µm were removed, the rock dust inerted PPC at 70% rock dust. However, when the respirable particles and the inhalable particles (< 20 µm) were removed, the percentage of rock dust, which is required to inert the PPC in the 20-L chamber, increased significantly to ~85%. Finer rock dusts having larger SSAs, such as the < 10 µm and 10–20 µm size fractions, inerted at a 70% rock dust concentration. The larger classified size fractions (38–53, 38–75, 53–75, and > 38 µm) all required 85% or more rock dust to inert PPC in the 20-L chamber. The only fraction of rock dust that inerted the PPC at 75% rock dust with the finer material removed was a narrow size range of 20–38 µm. It is interesting to note that the SSA of the 20–38 µm size fraction was only 1093 cm^3/g, but it is increased to 2373 cm^3/g in the smaller size fraction of 10–20 µm, reducing the amount of dust needed to inert an explosion from 75% to 70%. This indicates that rock dust SSA plays a crucial role in defining inerting limits of coal dust explosions.

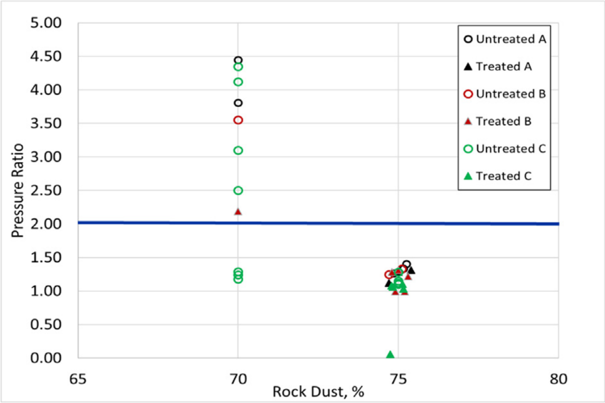

Fig. 5. Pressure ratio versus the rock dust concentration.

Table 3 summarizes the 20-L explosion results for the treated reference rock dust (treated rock dust) A. Experimental results indicate that the treated rock dust A inerted at a 75% rock dust concentration using 400 g/m^3 PPC (Table 3). Similar to the untreated rock dust A, a narrow size range of 20–38 µm treated RD inerted at 75%. Size fractions of < 75 µm and < 38 µm inerted at 70% RD concentration, confirming that the finer rock dusts having larger SSAs need less RD to inert an explosion in the 20-L chamber.

Table 4 summarizes the overall results of the treated and untreated reference rock dust (A). It is worth noting that some of the dust fractions of the treated rock dust A were unable to obtain due to time constraints. Classifying dust in a laboratory scale is both time consuming and labor intensive. The detailed differential volume percentage size distributions and the inerting limit of each fraction determined from the 20-L chamber studies are shown in Table 4.

These artificial distributions were manufactured to help experimentally clarify the relative effectiveness of various rock dust particle size fractions for inerting PPC dust explosions in the 20-L chamber. The < 75 µm size fraction, < 38 µm size fraction, and 20–38 µm size fractions inerted at 75% RD concentration for both treated and untreated rock dust A.

Interestingly, both the treated and untreated rock dust B inerted at 75% rock dust concentration using 400 g/m^3 PPC. Unlike the rock dust A, the rock dust B 20–38 µm size fraction did not inert an explosion at 75% RD concentration but needed more rock dust (80% rock dust concentration) to do the same. Also, the < 75 µm and < 38 µm size fractions inerted at 75% RD, unlike the reference RD which inerted at 70% RD concentration. This may be due to the characteristic dispersion differences in the 20-L chamber.

Table 2
The 20-L chamber explosion results for classified untreated reference rock dust A. An "E" represents an explosion and an "I" represents a non-explosion.[a]

Rock Dust Size, μm	Untreated A (0–840)	< 10	10–20	20–38	20–75	< 38	38–53	38–75	53–75	< 75
% Rock Dust needed to inert at 400 g/m^3										
60		E	E							E
65		E	E							E
70	E	I	I	E						I
73	I			E		E				
75	I			I	E	I	E	E		
80					E		E	E	E	
85					I		I	I	E	
90									I	
Average SSA cm^3/g	2530	5252	2373	1093	589	4001	480	394	277	4130

[a] At least 3 tests were conducted to confirm a non-explosion or "I."

Table 3
The 20-L chamber explosion results for classified treated rock dust A. "E" represents an explosion and an "I" represents a non-explosion.

Rock Dust Size, μm	Treated A (0–840)	< 38	20–38	20–75	< 75	38–75
% Rock Dust needed to inert at 400 g/m^3						
60		E				
65		E			E	
70	E	I	E		I	
75	I	I	I	E		
80				E		
82				I		
85				I		E
90						I
Average SSA, cm^3/g	2828	5365	782	567	4388	467

*At least 3 tests were conducted to confirm a non-explosion or "I."

Table 4
A summary of 20-L chamber explosion results for classified treated and untreated reference rock dust.[a]

Size Fraction, μm	Untreated A	Untreated A	Treated A
	Particle Size, cm^3/g	Inert at 75%	Inert at 75%
53–75	277	no	N/A
38–75	394	no	yes
38–53	480	no	no
20–75	589	no	yes
20–38	1093	yes	N/A
10–20	2373	yes	N/A
< 840 (as received)	2530	yes	N/A
< 38	4001	yes	yes
< 75	4130	yes	N/A
< 10	5252	yes	N/A

[a] At least 3 tests were conducted to confirm a non-explosion or "I." N/A: Size fraction was unavailable to test.

3.2.1. Treated and untreated rock dust B

Tables 5 and 6 represent the 20-L chamber tests conducted with treated and untreated rock dust B. The treated RD B is comprised of a fine limestone dust blended with 1% stearic acid. This dust passes almost completely through a 325-mesh screen (99.96% < 45 μm). Its size distribution is characterized by 90% < 8.6 μm, 50% < 2.9 μm, and 10% < 1.0 μm. It has distribution peaks at 1.3 and 3.5 μm.

3.2.2. Treated and untreated rock dust C

Tables 7 and 8 show the results of the 20-L chamber tests conducted with untreated and treated rock dust C. Similar to the reference RD or the untreated rock dust A, both treated and untreated C inerted at 75% rock dust using 400 g/m^3 PPC. Also similar to the untreated A (reference RD), the 20–38 μm size fraction inerted an explosion at 75% RD concentration. The < 75 μm and < 38 μm size fractions inerted at 75% RD concentration and not at the 70% RD concentration as it did with the untreated RD A.

Table 5
The 20-L chamber explosion results for classified untreated rock dust B[a].

Rock Dust Size, μm	Untreated B (0–840)	20–38	20–75	< 38	38–75	< 75
% Rock Dust needed to inert at 400 g/m^3						
65				E		E
70	E			I		E, I
75	I	E	E	I	E	I
80		I	E		I	
85			I			
Average SSA (cm^2/g)	2662	661	535	3117	1531	2481

[a] At least 3 tests were conducted to confirm a non-explosion or "I."

Table 6
The 20-L chamber explosion results for classified treated rock dust B[a].

Rock Dust Size, μm	Treated B (0–840)	20–38	20–75	< 38	38–75	< 75
% Rock Dust needed to inert at 400 g/m^3						
65				E		E
70	E	E		I	E	E, I
75	I	E	E		E	I
80		I	E		E	
85		I	E		E	
90			I		I	
Average SSA (cm^2/g)	4348	601	518	5038	592	4331

[a] At least 3 tests were conducted to confirm a non-explosion or "I."

Table 7
The 20-L chamber explosion results for classified untreated rock dust C[a].

Rock Dust Size, μm	Untreated C (0–840)	20–38	20–75	< 38	38–75	< 75
% Rock Dust needed to inert at 400 g/m^3						
60						
65				E		
70	E	E		I		E
75	I	I	E		E	I
80			I		E	
83					E, I	
85					I	
90						
Average SSA (cm^2/g)	3556	648	509	4331	385	3387

[a] At least 3 tests were conducted to confirm a non-explosion or "I."

3.2.3. A summary of ideal rock dust size fraction

Fig. 6 represents the particle diameter versus the differential volume

Table 8
The 20-L chamber explosion results for classified treated rock dust C[a].

Rock Dust Size, μm	Treated C (0–840)	20–38	20–75	< 38	38–75	< 75
% Rock Dust needed to inert at 400 g/m^3						
60				E		
65				E		
70	E	E		I		E
75	I	I	E		E	I
80			E		E	
83			I		E	
85					I	
Average SSA (cm^2/g)	3556	652	772	4568	537	3717

[a] At least 3 tests were conducted to confirm a non-explosion or "I."

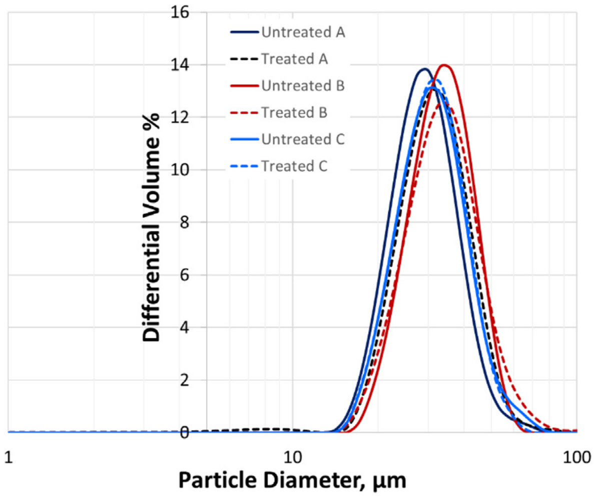

Fig. 6. Particle diameter versus the differential volume of the 20–38 μm size fraction of all tested rock dusts used in the experiments in the study.

of the 20–38 μm size fraction of all tested RD. It is evident that the size fraction is clean and has a similar surface area for all six dusts. Based on the 20-L experiments conducted, the 20–38 μm size fraction of dust A and C inerted at 75% rock dust using 400 g/m^3 PPC. Both treated and untreated rock dust B needed 80% rock dust to inert PPC at 400 g/m^3. Due to laboratory limitations, the lowest size fraction attainable for testing was 20–38 μm. It is important to note that in an event where laboratory techniques allow rock dust classification to include smaller material and attain a size fraction of 15–38 μm, this would allow more surface area and the resulting dust may be able to inert an explosion at 75% rock dust concentration. Based on the current 20-L results, it can be inferred that, if we eliminate the respirable or the inhalable portion of the rock dust, only the narrow 20–38 μm rock dust size range offers the protection to prevent an explosion. It is also important to note that large-scale experiments should be conducted to obtain an in-depth knowledge on dust scouring and lifting of classified rock dust to determine if this narrow size fraction will still lift in time to act as a heat sink and prevent a propagating explosion.

3.3. *Dispersibility of classified rock dust*

It is well known that rock dust must be dispersible with the coal dust to effectively prevent a propagating dust explosion. In order to determine the dispersibility of classified rock dust, the untreated rock dust A was classified into different size fractions, as noted above, and dispersed in the NIOSH-designed dust dispersion chamber to determine the relative dispersibility of the different size fractions. Due to laboratory limitations, not all six rock dust samples were classified and tested for dispersibility. The relative dispersibility of classified rock dust A as a function of particle size is shown in Fig. 7. A more detailed description of the dispersion chamber and rock dust dispersibility is presented elsewhere (Perera et al., 2016a). The optical density, D_L, decreases with increasing particle size with a maximum of 5.3 ± 0.3 m^{-1} for the < 10 μm particle size fraction, compared to only 0.3 ± 0.2 m^{-1} for the > 75 μm particles. It is evident that the 20–38 μm size fraction disperses as well as the untreated reference rock dust A. As discussed above, large-scale experiments are needed to evaluate the lifting of this size fraction in an explosion. However, these results suggest that particles more than 75 μm are less likely to be dispersed and entrained

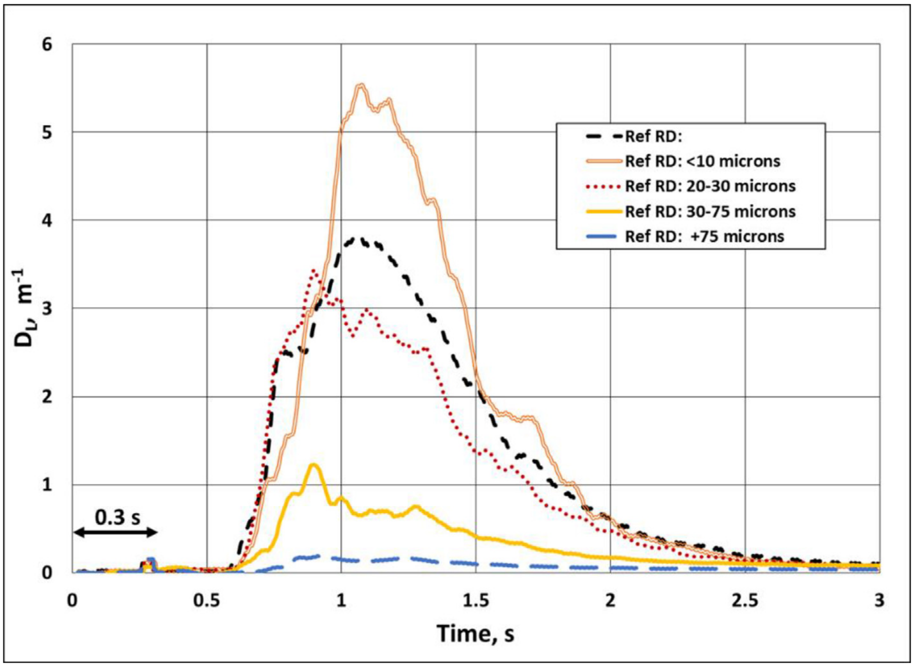

Fig. 7. The relative dispersibility of classified limestone rock dusts (average of 5 samples).

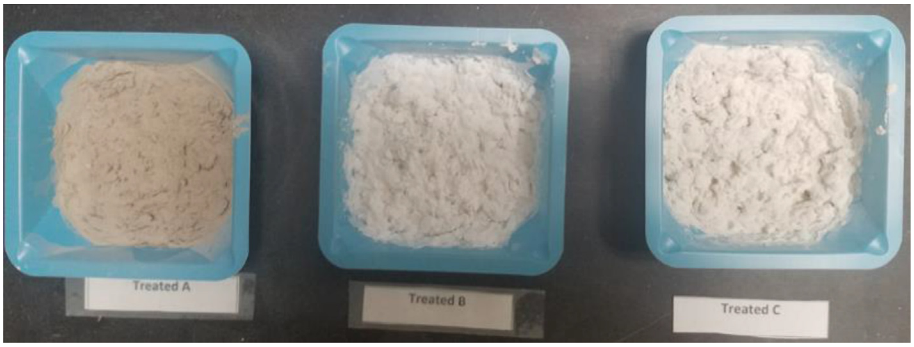

Fig. 8. The 20–38 μm size fraction of the treated rock dust 24 h after mixing with water.

during a developing coal dust explosion.

3.4. Dispersion of treated and untreated rock dusts after moisture exposure

Past NIOSH research demonstrates that all untreated rock dusts cake when in contact with moisture (Perera et al., 2016b). In addition, experiments conducted over the last few years have shown that when rock dust is treated with anti-caking agents, it becomes hydrophobic and dispersible and remains so several years after application. Some of the stearic acid based anti-caking agents available on the market contain larger amounts of respirable dust ($< 10\,\mu m$). The stearic treatment predominantly resides in the respirable size fraction (treatment is blended with the bulk rock dust to make the hydrophobic rock dust). Hence, there was a concern that if the $< 20\,\mu m$ coated particles are removed, the hydrophobicity of the treated rock dust may be impacted as well. In order to test this hypothesis, the 20–38 μm fraction was tested for caking tendency. As indicated in the Experimental Methods section in this paper, 20 g of rock dust was mixed with 20 g of water and dried on a bench top. After 24 h (Fig. 8), a spatula was used to test the caking tendency. Further, a "can of air" was used to qualitatively determine the dispersibility of the rock dust. It was observed that the 20–38 μm fraction visually remained dispersible. This result suggests that much of the $< 4\,\mu m$ treated rock dust particles were not removed with sieving and may be adhering to the larger particles, preventing a cake formation after contact with water.

The hydrophobicity of rock dusts A and C occurred by spraying the anti-caking treatment over the raw untreated rock dust product. The simple caking test did not indicate a difference in dispersibility between the total dust distribution versus the 20–38 μm fractions. All three treated rock dust samples and all three 20–38 μm size fractions were dispersible and did not cake after contact with water.

4. Summary

NIOSH conducted research to determine if a rock dust can still inert a coal dust explosion when the respirable ($< 10\,\mu m$) or inhalable ($< 20\,\mu m$) components of the particle size distribution were removed using a series of laboratory-scale experiments. Previous NIOSH research findings indicate that the rock dust particles $> 75\,\mu m$ offer almost no protection as an inhibitor against coal dust explosions. Experimental results indicate that when the specific surface area (SSA) decreases, the amount of rock dust needed to inert an explosion increases, especially because the respirable size fraction or $< 10\,\mu m$ size fraction provides a larger surface area. When it is removed, more rock dust would need to inert a propagating coal dust explosion.

Results from the 20-L explosion chamber demonstrate that rock dust A and C of a 20–38 μm size fraction can inert a coal dust explosion at 75% rock dust concentration using 400 g/m^3 coal dust concentration. If only the $< 15\,\mu m$ size fraction instead of the $< 20\,\mu m$ size fraction is eliminated, more surface area would be provided. Hence, it is anticipated that the 15–38 μm size fraction would have a better inerting effectiveness in preventing an explosion. When dispersibility tests were conducted using the NIOSH-designed dispersion chamber, the relative dispersibility of the 20–38 μm size fraction was similar to that of the reference rock dust which was used to establish the 80% Total Incombustible Content (TIC) rule. However, large-scale experiments still need to be conducted to better evaluate the preferential dispersion of a classified rock dust when mixed with coal dusts. It is important to note that classifying rock dusts on a laboratory scale is a labor-intensive, tedious task. Even though the results indicate a technical success to reduce the exposure to respirable rock dust, the manufacturing costs may be prohibitive when considering deployment of this rock dust in coal mines.

Disclaimer

Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health. The findings and conclusions in this paper are those of the authors and do not necessarily represent the views of NIOSH.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jlp.2019.103943.

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