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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.

Keywords

Dust dispersibility; Mining; Explosion prevention; Particle size

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

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> 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 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.

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 152.4-cm (60-in) long clear methacrylate plastic box (Figs. 3 and 4). The front side of the chamber is hinged so that the chamber can be opened to insert dust-filled trays for testing and to easily clean it afterwards. The 0.32-cm OD (~⅛-in) stainless steel tubing with 0.14-cm ID (~0.06-in) with the exit hole is positioned 3.2 cm (1.25-in) from the leading edge of the dust layer.

The tubing is mounted such that the wall of the tubing is adjacent horizontally to the top of the plastic tray and thereby parallel to the top of the dust layer. The air nozzle and tray arrangement of the dust dispersion chamber is shown in Fig. 5.

All test samples were subjected to the same 0.3-s air pulse from a 2.8 bar (40-psi) compressed air source which provides a peak dynamic pressure of 0.3 bar (4.2 psi). This air pulse has the same integrated area as that seen in Fig. 1. The air pressure is pre-established in the pressurized reservoir that feeds the air nozzle. The timing of the air-jet pulse is controlled by a time-delayed relay that opens and closes a solenoid valve. To test samples, a uniform layer of dry dust is added to a NIOSH-designed tray as seen in Fig. 6.

The outside tray dimensions are: 14.5 cm wide, 19.25 cm long, and 2.54 cm deep. It has a 4.6-cm long and 14.5-cm wide front ledge. The inside compartment which contains the dust is 13.6-cm long, 12.3-cm wide and 1.34-cm deep with nine equally spaced 0.64 cm (¼-in) diameter holes on the bottom of the tray. The depth of the dust layer was chosen to be 1.3 cm (½ in) deep or twice the thickness of the measured scouring depths during large-scale near limit explosion tests conducted at LLEM which were a maximum of ~0.64 cm (¼ in) (Harris et al., 2009). The holes serve as the means of water absorption when the trays are placed in water inside closed conditioning chambers. The tray is lined with Grade 4 Whatman cellulosic filter paper to contain the dust and to provide a rough bottom surface. Aerated dust is then heaped on the shallow sample area, gently leveled while avoiding dust compression, and the tray is placed in the dust dispersion chamber. A 14.5-cm by 4.9-cm by 2-cm metal block is placed in front of the tray to secure it. It is then subjected to the air pulse directed across the top of the dust tray (Fig. 5). The depth of the dust layer was chosen to be 1.3 cm (½ in) deep or twice the thickness of the measured scouring depths during large-scale

near limit explosion tests conducted at LLEM which were a maximum of ~0.64 cm (¼ in). The dimensions of the trays will affect the mass loss from the tray and may affect the magnitude of the measured $D_{L.}$ It should not, however, change the overall relative ranking of the dust when compared to the reference rock dust under the same conditions.

The dynamic pressure at the leading edge of the dust-filled tray was measured using a SenSym (ASCX30AN) pressure transducer mounted at the leading edge of the dust cavity 1.25 in downstream of the nozzle exit. Sample dust trays were weighed before and after each air pulse to determine the mass of dust dispersed. The attached optical dust probe, as shown in Fig. 3, measures the obscuration resulting from the concentration of the dispersed dust cloud (a detailed discussion related to the operation of the dust probe will be presented in the Theory subsection). The optical path length of the dust probe is 3.8 cm and the center of the path is located in the geometric cross section of the tunnel 129.5 cm from the exit of the nozzle and 13.5 cm from the chamber exit. The current position of the dust probe was chosen so that the dust probe was placed far enough downstream to be away from the initial dust cloud dispersion and far enough upstream from the exit to avoid the influence of the flow transitions from the 15.2 cm square cross-section to into the 2 in diameter exit hole. Between the mass loss of the dust tray and the dust probe measurements, the relative dispersibility of the dust is determined. The magnitude of the D_L measurements will most likely vary with the positioning of the dust probe. However, since the D_L for the reference rock dust is measured at the same location, the overall relative ranking may not be different that those found at the current location. While this apparatus and test procedure cannot duplicate the dust dispersal mechanism in advance of an actual propagating mine explosion, it does provide a repeatable dynamic pressure source and quantitative measure of the mass loss and relative dispersibility of dusts under controlled dispersion conditions. Current results are based on the 0.3-s air pulse from a 1.5 L pre-pressurized tank to 2.76 bar compressed air source which provides a peak dynamic pressure of ~0.29 bar (4.2 psi.).

A vacuum cleaner attached to the dust dispersion chamber outlet is used to impose a ventilation flow rate of 1.52 m/s. The flow through the dust dispersion chamber was set at 0.75 mbar (0.3 in WG) using a differential Magnehelic pressure by adjusting an exit ball valve and was held constant for all tests. Dispersed dust entrained in the ventilating air is carried across the optical dust probe and exits the chamber to the vacuum. Dust trays were weighed before and after each air pulse to determine the amount of mass loss. A detailed discussion of the operating procedures for the dust dispersion chamber will be presented in the Experimental Procedure section. It is worth noting that the D_L and the dispersion results may vary if the dust probe was placed at a different location but we have not conducted dispersion tests using different dust probe locations.

1.2. Theory of dust probe measurements

The optical dust probe used in the dust dispersion chamber was developed by the BOM (Cashdollar et al., 1981). The dust probe consists of a vertical U-shaped probe that is positioned along the central axis of the long chamber and close to the outlet. One arm contains the 0.95 ± 0.05 μm gallium arsenide (GaAs) LED light source and the other contains the silicon photodiode detector that is directly across from the light source, with an

optical path length of 3.8 cm and restricted field of view of 0.48°. The probe's use of optical density measurement is based on the Beer-Lambert-Bouguer Law of light transmission through a collection of scatterers/absorbers. The light loss across a cloud of rock dust particles is given by the following relationship:

$$\frac{I}{I_0} = e^{-\sigma_{ext} ML/V} \quad (1)$$

where I_o = intensity of the transmitted light beam when no particles are present in the path between the light source (0.95 μm GaAs LED) and the light detector (silicon photodiode),

I = intensity of the light transmitted by the suspension of particles in the light beam,

σ_{ext} = specific extinction of the dust (m^2/g), which depends on an average particle size or specific surface area and the complex refractive index at the incident wavelength

L = path length (m).

M = mass (g) of dust in the volume,

V = volume (m^3) passing through the light beam.

Therefore, M/V is the mass concentration (g/m^3) of the dust cloud at the probe. To compare the relative amount of dispersed rock dust, Equation (1) can be rearranged to obtain the optical density D_L (m^{-1}):

$$D_L = -\left(\frac{1}{L}\right) log \frac{I}{I_0} = \frac{(\sigma_{ext} M/V)}{2.303} \quad (2)$$

In general, the specific absorption varies with particle size; however, for particles significantly larger than the wavelength (0.95 μm), σ_{ext} varies approximately with the inverse of the particle density and surface mean diameter. The GaAs LED used in the dust probe emits near-infrared radiation with a central wavelength of 0.95 μm and a bandwidth of 0.05 μm. The linear output from the photodiode was fed directly into an operational amplifier circuit. The output was recorded using a WINDQ 720 data acquisition system. Light transmission data was collected at 250 samples/s for 7 s (including the 0.3-s pulse period) and stored for subsequent processing.

2. Experimental Procedure

In order to quantify the "light blast of air" as described in 30 CFR 75.2, this paper details the initial dispersion results of eight different rock dusts. Limestone rock dust (the same source dust used in LLEM testing and referred to herein as the Reference rock dust), spray-treated Reference limestone dust, white limestone dust, stearic acid treated white limestone dust, and different size fractions of the Reference rock dust (≤10 μm, 20–30 μm, 30–75 μm, ≥75 μm) were examined using the NIOSH-developed dust dispersion chamber. Tests were conducted with dry dust and dried dust after exposure to moisture for 24 h. All experiments

were conducted at least five times with each dust to facilitate statistical analysis and to ensure reproducibility. For each test, the following steps were conducted.

2.1. Tray preparation

To prepare a dust tray, approximately 350 g of dust were placed in a 1-gallon plastic bag and shaken vigorously for 1 min to achieve a homogeneously size-distributed dust mixture. Then the dust was spooned onto a pre-weighed plastic tray where a Whatman filter paper (Grade 4; 185-mm diameter; No. 1004-185) covered the inside bottom to prevent loss of dust from the wicking holes and to provide a rough bottom surface area. Starting at the front edge of the tray (large ledge) and using an 8-in drywall knife at an approximate 20° angle to the horizontal, the excess dust was removed so that the dust was level with the top of the tray. The process was repeated twice to ensure removal of all excess dust from the trays. The above procedure was found to provide relatively consistent bulk dust tray densities. The untapped bulk tray densities are determined by dividing the mass of the dust loaded into the tray by the nominal tray volume.

2.2. Dust dispersion test procedure

Once the differential pressure was established at 0.75 mbar (0.3-in WG) within the dispersion chamber using the vacuum cleaner and ball valve flow control, the pre-weighed plastic tray filled with rock dust was placed in the chamber. The filled tray was carefully positioned in the chamber so that the distance between the end of the air pulse nozzle and the leading edge of the dust was 1.25 in. After the chamber was closed, the pressure within the air reserve tank was set to 2.8 bar (40 psi) to deliver the desired 0.3 bar (4.2-psi) dynamic pressure. The WINDQ data acquisition system was used to record the dust probe data. The time-delay relay was set at 0.3 s and activated to deliver the controlled pulse of air. After the dust settled, the chamber was opened and the remaining mass of the dust within the tray was weighed. The remaining mass in the tray was compared to the original mass and the difference was recorded.

2.3. Moisture exposure

In order to expose the dust filled sample trays to moisture, pre-weighed trays were placed in larger 9.65-cm by 8.3-cm by 1.5-cm deep plastic trays.[1] Distilled water (900 ml) was added so that the water was almost level with the height of the trays and in contact with the dust through the wicking holes (Fig. 7). The trays were then placed inside a sealed cabinet for 24 h. Data loggers were placed in the cabinets to monitor the temperature and relative humidity (RH) (Lascar Electronics-model EL-USB-2-LCD+). Inside humidity was at least 95% RH after a day of storage and at least 99% RH thereafter. It is important to note that the rock dust within the tray was exposed to standing water from beneath (wicking action) and moisture on the top surface of the tray from the high relative humidity within the sealed cabinet. Once the dust-filled sample trays were exposed to moisture for 24 h, the sample trays were removed from the cabinet and allowed to air dry on a bench top until the post-exposure weight was equal to the initial weight (~24–48 h). The unprotected rock dust

[1]The dust trays, water trays, and the dust dispersion chamber are available from Vandiver Enterprises, Zelienople, PA.

wicked water from the bottom of the layer to the top surface in 3–6 min while no moisture was observed on top of the dust layer when using the protected rock dust. The sample trays were then placed in the dispersion chamber and the dust was dispersed per the procedure detailed in Section 3.2.

3. Results and discussion

In order to determine the number of repetitions required to obtain a representative dispersion average using the dust dispersion chamber, ten samples of each rock dust (Reference rock dust, white limestone dust, and the treated white rock dust) were prepared and dispersed according to the above described procedures.

Fig. 8 shows a typical optical density diagram obtained for the ten dispersion tests with the Reference rock dust. The average for the ten tests is indicated with the dashed black line. The average area under the D_L curves is 3.4 ± 0.3 s/m. There are no significant differences between the data obtained from ten sample runs versus five sample runs when the data is statistically analyzed using the *t-test* method ($p = 1$ for the Reference rock dust). Therefore the subsequent dust dispersion chamber tests were conducted in sets of five tests with the average values reported.

Table 1 compares the D_L integrated results and the dispersed mass (tray mass loss) of the three dusts of interest. Results indicate that the D_L measurements are more reproducible with a smaller standard deviation and relatively low coefficient of variation whereas the mass measurements have a relatively large standard deviation and a higher coefficient of variation. It was observed that large particles of material which exits the tray quickly settles on the bottom of the chamber and do not remain airborne for a sufficient time to reach the downwind dust probe. Hence, D_L is a better measurement to quantifying the relative dispersibility in terms of airborne concentrations of rock dust (the key measure of its inerting ability).

3.1. Dispersibility comparisons of reference rock dust with and without anti-caking spray additive

After obtaining the dispersion data with the dry Reference rock dust, a series of dispersion experiments were conducted with the Reference rock dust after exposure to moisture for 24 h. As discussed in the “Experimental Procedure” section, all dust trays were dried on a bench top until a constant weight was obtained. Early research conducted by Cybulski (1975) has shown that the use of hydrophobic agents in conjunction with conventional limestone-based rock dusts greatly lessened their tendency to cake when exposed to moisture and enabled their dispersibility even in wet mining conditions. Currently, NIOSH and the rock dust manufacturers are jointly working on developing rock dusts with anti-caking agents to meet the dispersibility requirements of 30 CFR 75.2. In this study, two such treated rock dusts (a blended product of stearate-treated white limestone dust and a hydrophobic spray-treated Reference rock dust) were tested for their relative dispersibility with respect to the untreated dry Reference rock dust.

Fig. 9 elucidates the average D_L (optical density) data of the dry Reference rock dust, the Reference rock dust after exposure to water, spray-treated anti-caking rock dust, and spray-treated anti-caking rock dust after exposure to moisture for 24 h. The average relative dispersibility of the dry Reference rock dust was 3.4 ± 0.3 s/m compared to the water-exposed and caked Reference rock dust, which was 0.2 ± 0.3 s/m (i.e., barely visible in the figure). The relative dispersibility of the dry spray-treated product, 15.2 ± 1.9 s/m, indicates that the relative dispersibility has improved over that of the Reference rock dust. The D_L of the spray-treated rock dust after exposure to moisture is 6.7 ± 1.2 s/m, which is higher than that of the dry untreated Reference rock dust.

Coal dust is not easily wetted and can remain dispersible in the presence of water. Conversely, all rock dust tested caked when in contact with moisture and then dried and offered little to no dispersibility compared to the reference rock dust. Fig. 10 indicates the visual observations of wet and dry rock dust after the dispersion air pulse. When the dry Reference rock dust is tested in the dust dispersion chamber, a conical crater forms (Fig. 10A). However, when the dry Reference rock dust is exposed to moisture for 24 h dried and then dispersed, no crater forms (Fig. 10B). The extensive cracking noted in the moisture-exposed dust is due to uneven shrinkage during the drying of the dust — not from the air pulse.

3.2. Relative dispersibility comparisons of white limestone with and without anti-caking blended additive

NIOSH research determined that when rock dust was coated with 1.0% calcium stearate, the calcium stearate prevented the calcium carbonate from wetting and, therefore, prevented it from caking. This blended product was developed using the white limestone dust as the base product. The relative dispersibility of this product was also tested using the dust dispersion chamber and then compared to the relative dispersibilities of the untreated base rock dust and also to the dry Reference rock dust. The results are shown in Fig. 11. The relative dispersibility value of the treated dolomitic limestone dust was 12.6 ± 1.2 s/m which was greater than that of the dry Reference rock dust. It is also worth noting that the average relative dispersibility value of the treated white limestone rock dust was significantly greater than that of the dry Reference rock dust even after being exposed to moisture for 24 h. Relative dispersibility values of the treated white limestone rock dust after exposure to moisture is 14.6 ± 1.2 s/m which is slightly higher than that of the dry treated rock dust which is 12.6 ± 1.2 s/m. Similar to the Reference rock dust, the base untreated rock dust cakes when exposed to moisture, resulting in a very low relative dispersion of 0.8 ± 0.6 s/m.

3.3. Relative dispersibility comparisons of various size fractions of the reference rock dust

Inerting studies conducted in NIOSH's 20-L explosibility chamber have shown that rock dust particles greater than 75 μm are less effective in inerting explosion propagation (Man and Harris, 2014). Furthermore, air entrainment as a function of particle size is an issue in a coal mine where the air pulse from an explosion is scouring particles from surfaces. Thus, it is of interest to examine the relative dispersibility (air entrainment) of rock dust as a function of particle size. For this evaluation, the Reference rock dust was classified into the following targeted size fractions: <10 μm, 20–30 μm, 30–75 μm, and >75 μm. Results of optical

density measurements for the dispersed differential size distributions are shown in Fig. 12. There were finer and larger particle tails on each of the targeted size ranges. It is interesting to note that D_L decreases with increasing particle size, with maximum of 5.3 ± 0.3 s/m for the <10 μm particles compared to only 0.3 ± 0.2 s/m for the >75 μm particles. These results suggest that particles >75 μm are less likely to be dispersed and entrained during a developing coal dust explosion than particles less than 75 μm in size.

Table 2 shows the measured D_L and tray mass loss from the various size fractions. It is interesting to note for these samples that D_L is inversely proportional to the bulk density (R^2= 0.97). However, there is no correlation between dispersed mass and bulk density (R^2 = 0.28). Except for the <10 μm size fraction, there is an excellent correlation between D_L and the mass dispersed (R^2 = 0.99) for these size dust fractions.

4. Summary and conclusion

30 CFR 75.2 requires rock dust to be dispersible into separate particles by a light blast of air. Rock dust must be dispersible in order to effectively inert the coal dust entrained or made airborne during an explosion and to be effective in extracting heat and quenching the combustion reaction. Coal dust is not easily wetted and can remain dispersible in the presence of water. Conversely, rock dust is hygroscopic and forms a cake when wetted and dried, offering little to no dispersibility. Such rock dust is much less dispersible than the dry Reference rock dust that was used in the research recommending 80% total incombustible content in intake airways.

Ongoing NIOSH research has specified the most desirable attributes for a rock dust to effectively inert coal dust and thereby prevent or suppress a propagating coal dust explosion. This paper builds on that research and quantifies the “light blast of air” specified in 30 CFR 75.2 using a laboratory-scale dust dispersion chamber. Data obtained using this apparatus is reproducible, particularly when relative dispersibility is measured rather than total mass loss from a tray. To establish sufficient dispersibility levels for rock dusts, all dust probe dispersion data were compared to that of the dry Reference rock dust used for the LLEM full-scale explosion tests (NIOSH, 2010). Results of this study also demonstrate that a spray-treated additive and a blend additive, both commercially available, can maintain the dispersibility attribute of rock dust, even when exposed to water, which is essential to prevent coal dust explosion propagations.

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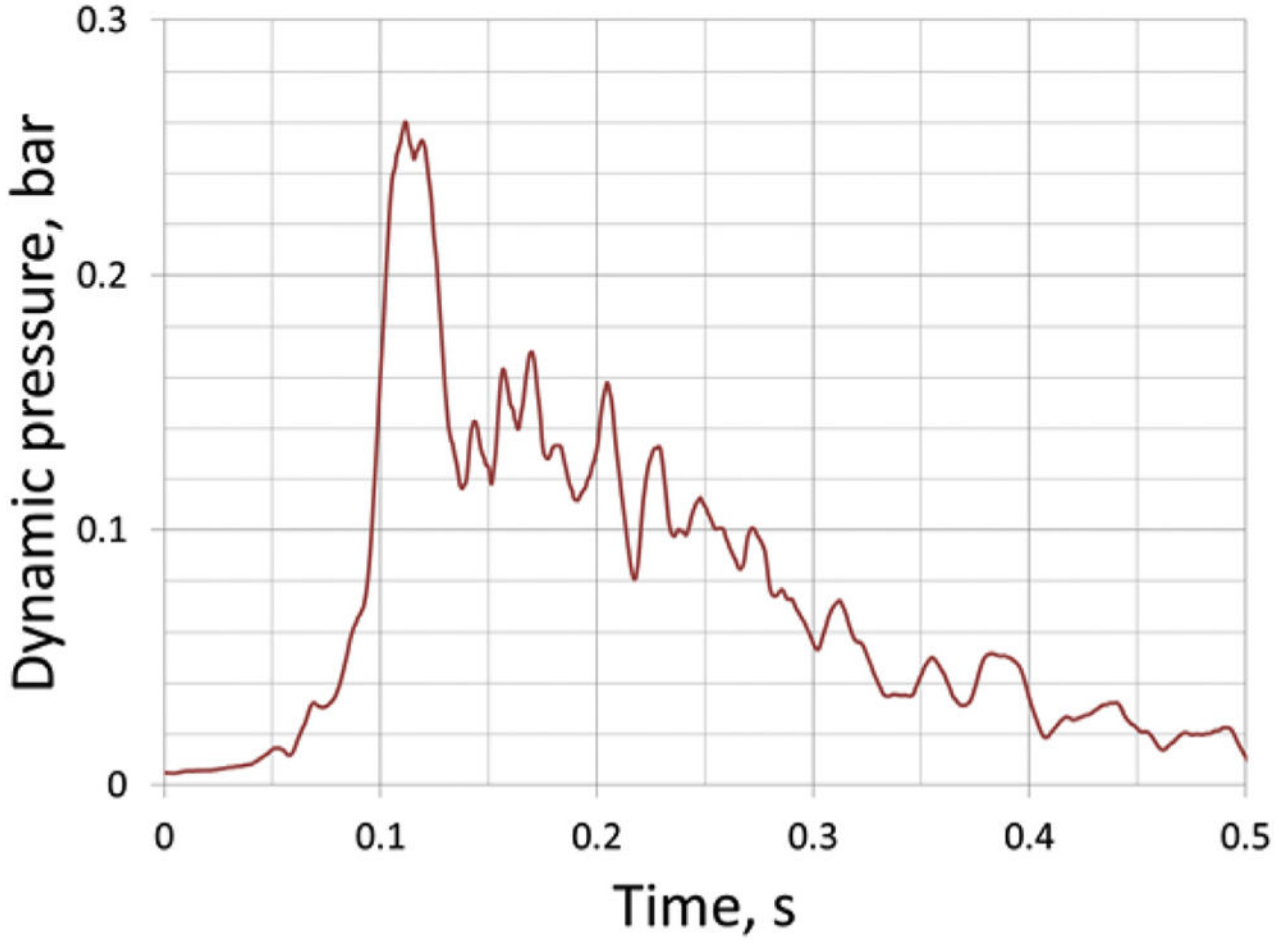

Fig. 1.
Dynamic pressure history measured during LLEM Test #517.

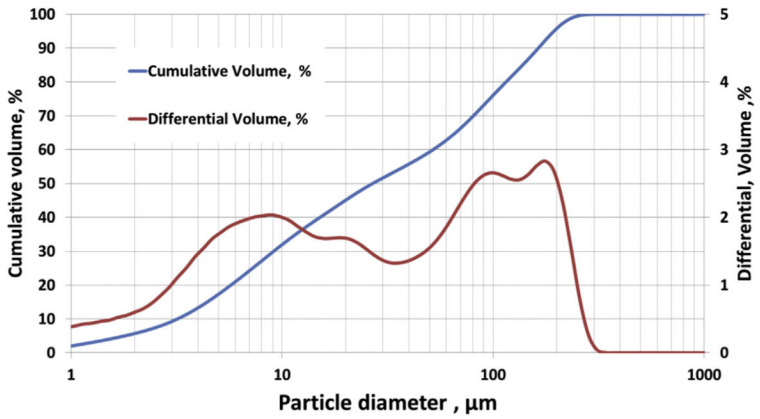

Fig. 2.
Cumulative and differential size distribution of this Reference rock dust.

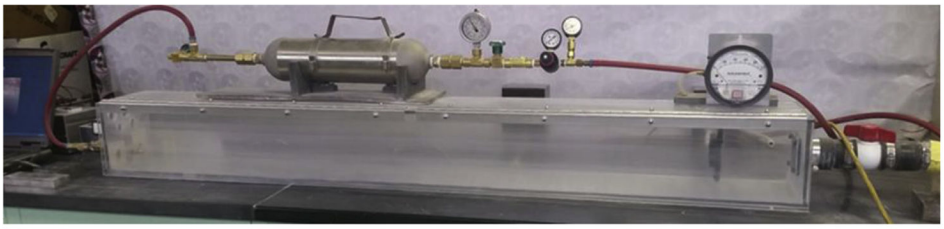

Fig. 3.
NIOSH-designed dust dispersion chamber.

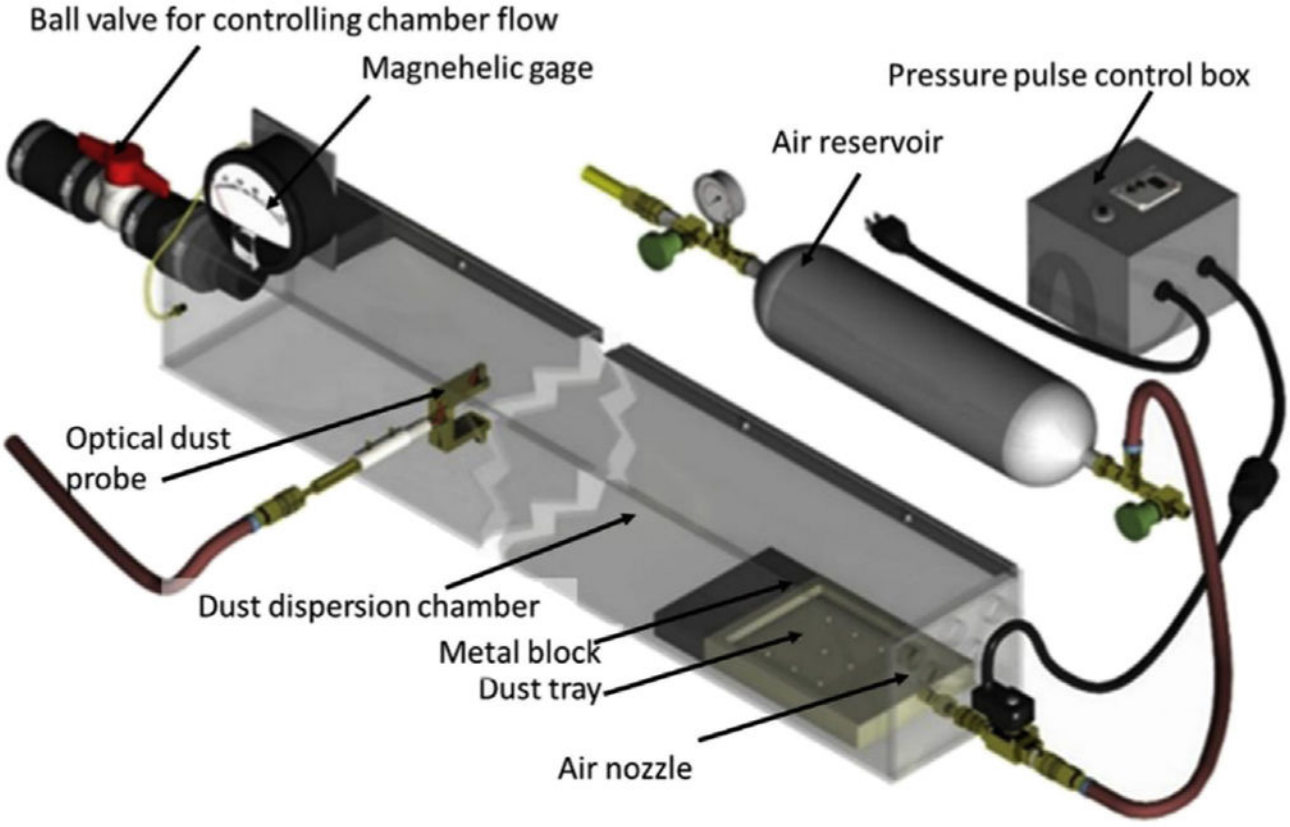

Fig. 4.
Schematic of the dust dispersion chamber.

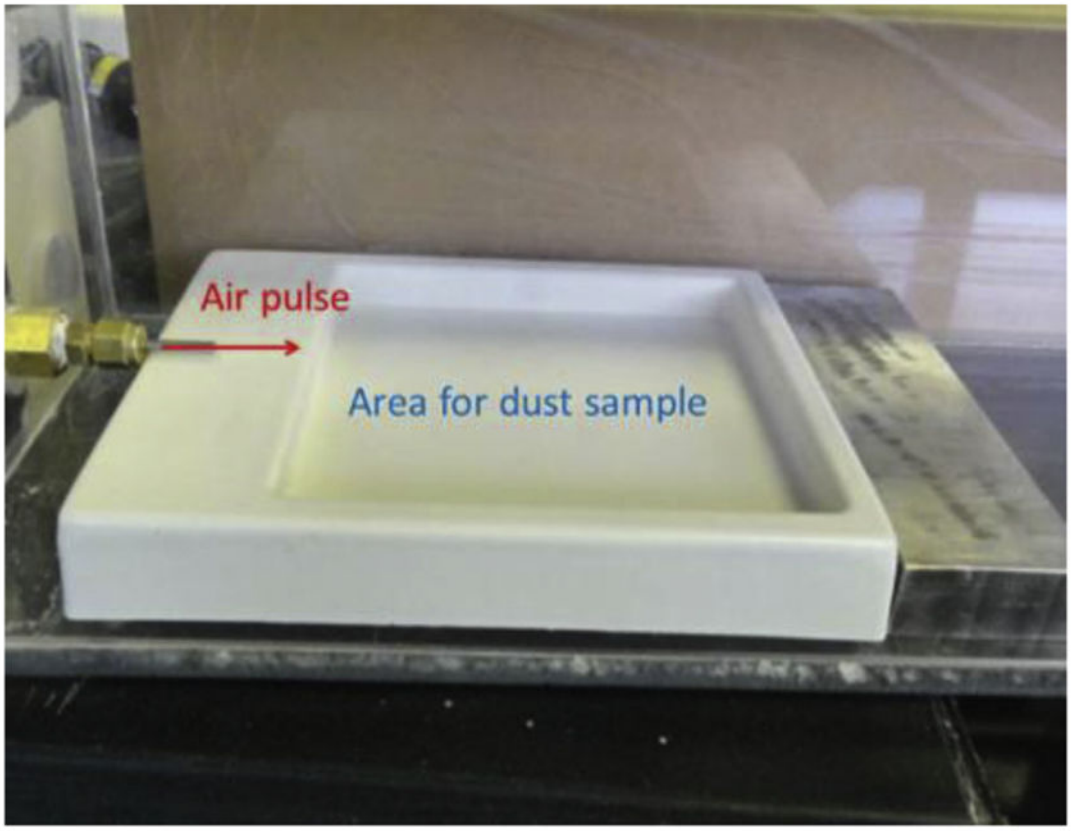

Fig. 5.
The air nozzle and tray arrangement within the dust dispersion chamber.

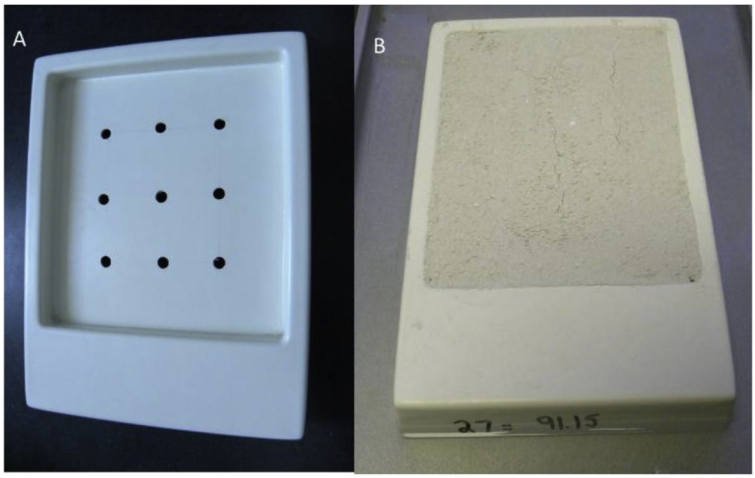

Fig. 6.

A dust tray used within the dust dispersion chamber: (A) an empty dust tray showing the bottom holes for moisture exposure from the bottom, (B) the tray filled with a rock dust.

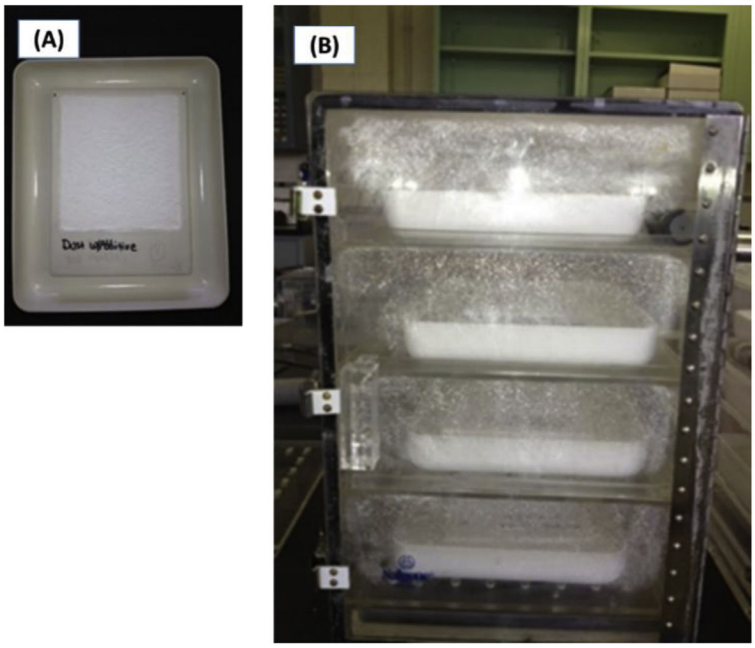

Fig. 7.
(A) Dust tray placed in a larger tray with 900 ml of water, (B) The tray set is then placed in a sealed cabinet for 24 h.

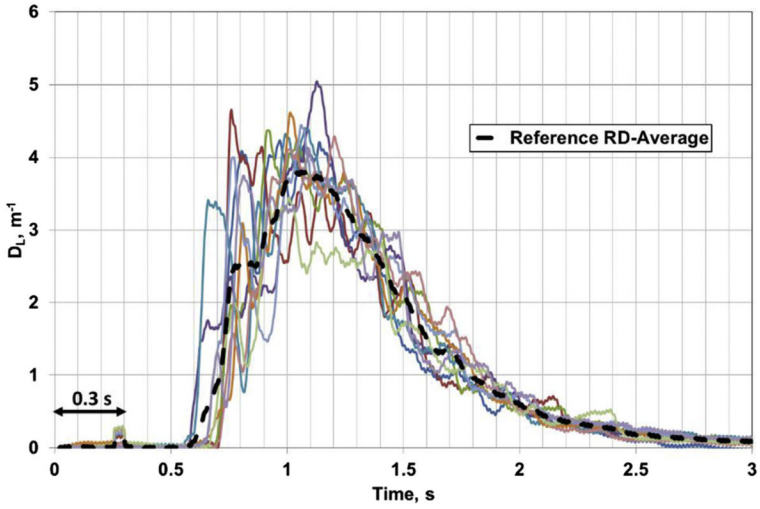

Fig. 8.

Dust dispersion chamber data for the Reference rock dust (average dispersion data from ten tests is depicted as the black dashed line).

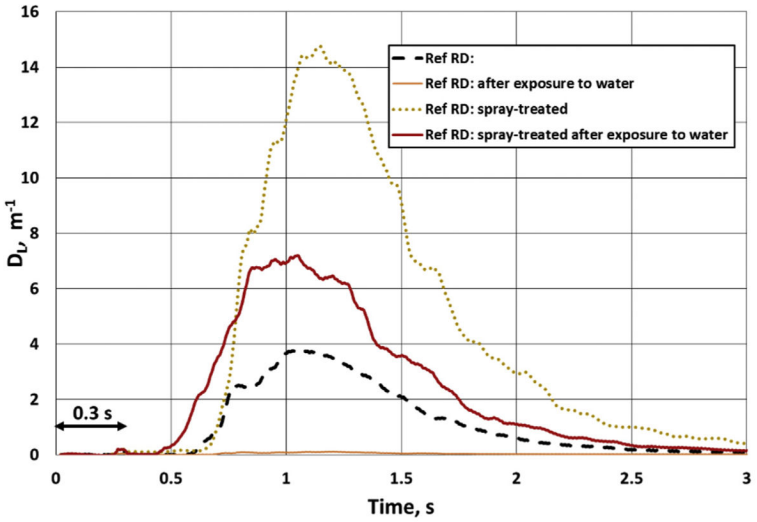

Fig. 9.

Relative dispersibility, average D_L of the dry Reference rock dust with and without moisture exposure compared to the relative dispersibility of a spray-treated anti-caking Reference rock (average of 5 samples).

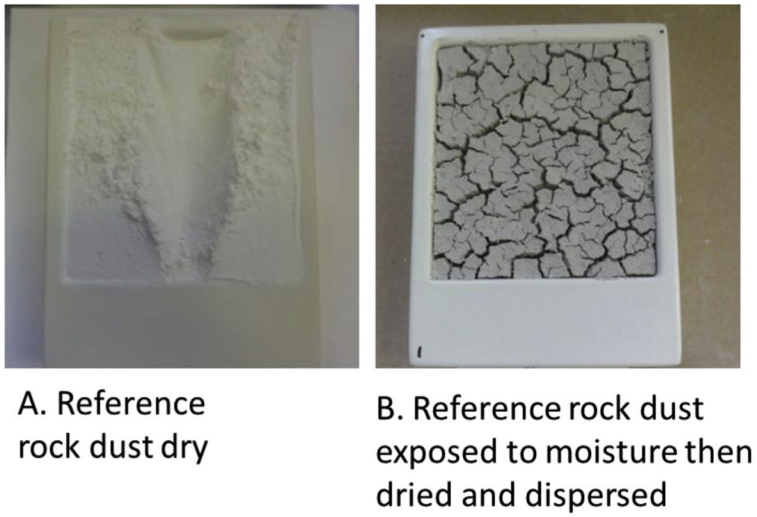

Fig. 10.

Comparison of the post-test dispersion from a tray of dry Reference rock dust with the Reference rock dust after being exposed to moisture then dried.

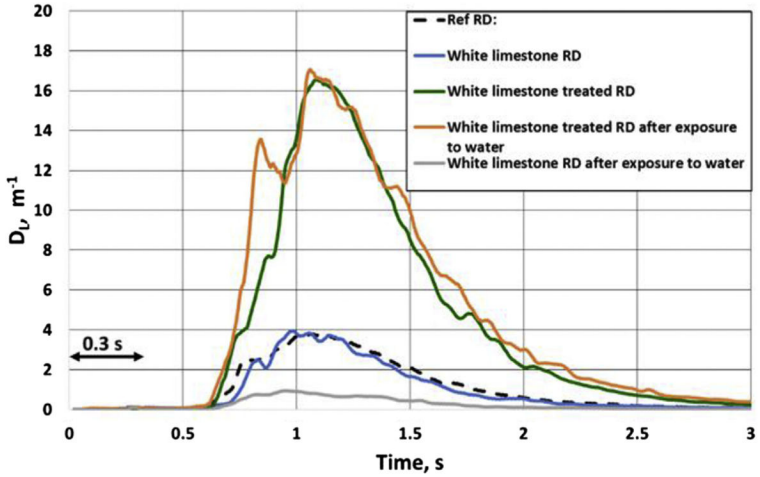

Fig. 11.

The relative dispersibility of treated and untreated white limestone rock dust before and after exposure to moisture (average of 5 sequential dispersion tests).

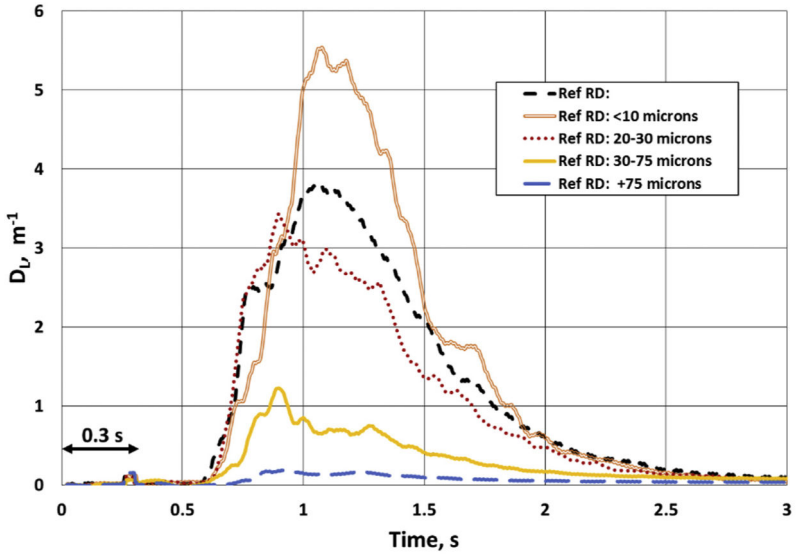

Fig. 12.

The relative dispersibility decreases with increasing particle size of classified fraction of Reference rock dust (average of 5 samples).

Table 1

D_L and mass dispersion data for Reference rock dust, white limestone, and treated white limestone rock dust.

Test number	Reference rock dust		Dolomitic limestone dust		Treated white limestone dust	
	D_L (s/m)	Mass dispersed (g)	D_L (s/m)	Mass dispersed (g)	D_L (s/m)	Mass dispersed (g)
1	2.9	11.7	2.9	9.4	12.2	24.3
2	3.5	13.7	2.9	14.8	12.1	20.3
3	3.5	10.3	2.7	12.3	12.1	22.5
4	3.5	10.3	2.4	9.3	13.5	19.2
5	3.9	11.8	2.8	10.3	11.3	13.8
6	3.5	10.9	3.2	11.1	11.9	16.5
7	3.6	19.1	2.4	28.4	15.6	22.7
8	3.2	7.9	2.6	15.2	12.9	17.7
9	2.9	10.4	2.3	12.0	12.5	24.0
10	3.6	11.2	2.8	9.2	12.3	18.7
Average relative dispersion	**3.4**	**11.7**	**2.7**	**13.2**	**12.6**	**20.0**
Std. deviation	**0.3**	**3.0**	**0.3**	**5.7**	**1.2**	**3.4**
Coefficient of variation	**9.4%**	**25.5%**	**10.8%**	**43.6%**	**9.3%**	**17.2%**

Table 2

Average D_L and the mass dispersion of different size fractions of Reference rock dust.

Size fraction of the dust, μm	Average optical density (D_L, s/m)	Average mass dispersed (weight difference of the tray, g)	Bulk density, g/cm^3
<10	5.3 (±0.3)	22.4 (±8.5)	0.76
20–30	2.8 (±0.4)	15.3 (±2.0)	1.20
30–75	1.1 (±0.2)	25.7 (±1.9)	1.33
>75	0.3 (±0.2)	30.2 (±1.6)	1.51
Reference dust	3.4 (±0.3)	11.7 (±2.9)	1.01