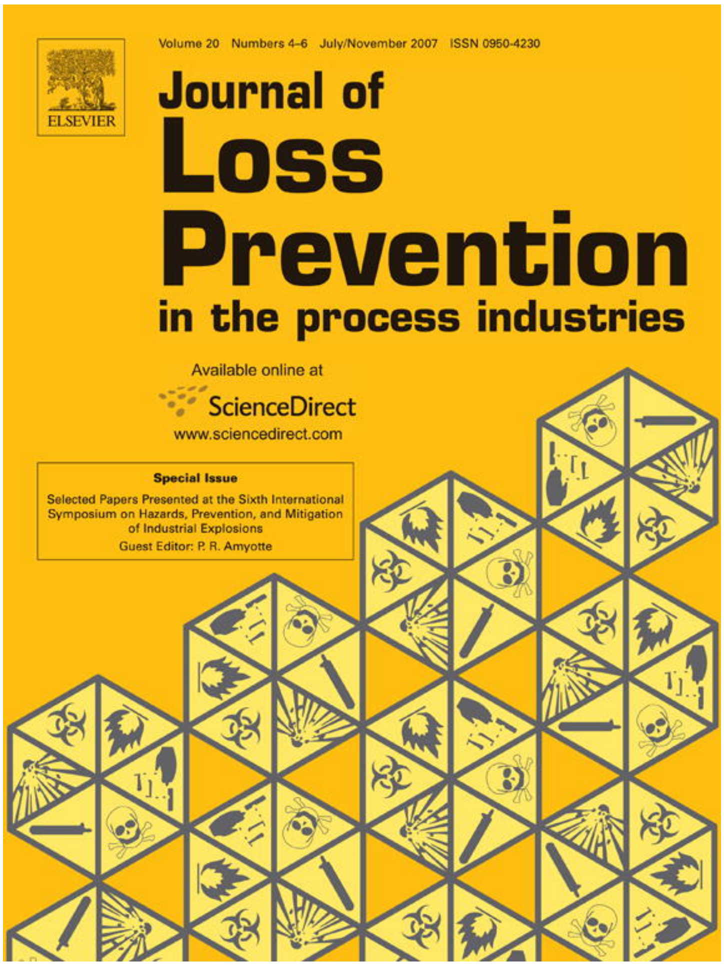
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Coal dust particle size survey of US mines

Michael J. Sapko, Kenneth L. Cashdollar*, Gregory M. Green

Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA, USA

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA) conducted a joint survey to determine the range of coal particle sizes found in dust samples collected from intake airways of US coal mines. The last comprehensive survey of this type was performed in the 1920s. The size of the coal dust is relevant to the amount of rock dust required to inert the coal dust, with more rock dust needed to inert finer sizes of coal dust.

Dust samples were collected by MSHA inspectors from several mines in each of MSHA's 10 bituminous Coal Mine Safety and Health Districts. Samples were normally collected in several intakes at each mine. The laboratory analysis procedures included acid leaching of the sample to remove the limestone rock dust, sonic sieving to determine the dust size, and low-temperature ashing of the sieved fractions to correct for any remaining incombustible matter. The results indicate that particle sizes of mine coal dust in intake airways are finer than those measured in the 1920s. This finer size coal dust in intake airways would require more incombustible matter to be effectively inerted than the 65% incombustible specified in current regulations.
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Keywords: Coal; Mine; Dust; Particle size; Explosion

1. Introduction

Despite the worldwide research on coal mine safety, coal mine explosions involving fatalities and injuries still occur. Experimental studies by the Pittsburgh Research Laboratory[1] (PRL) and similar agencies in other countries have shown that mixing a sufficient quantity of inert rock dust with coal dust will prevent coal dust explosions by acting as a heat sink. The requirements are specified in the Coal Mine Health and Safety Act of 1969 (US Congress, 1969) and in Title 30, Section 75.403 of the US Code of Federal Regulations (2006). They mandate that the nation's bituminous coal mines maintain an incombustible content of at least 65% in the non-return (intake) airways and at least 80% in the return airways where the potential for accumulation of finer float coal dust is greater. The US regulation also requires an additional 1.0% incombustible by weight for each 0.1% methane in the ventilating air in intakes and 0.4% additional incombustible for each 0.1% methane in returns.

The 65% total incombustible content (TIC) required for intake airways was based on the measured size of coal dust found in mines during the 1920s and the amount of rock dust required to inert that size of coal in full-scale experimental mine tests, as summarized by Nagy (1981). The term ''mine size coal'' was adopted in about 1925 and refers to coal dust, all of which passes a US Standard 20-mesh sieve (850 μm) and contains 20% minus 200 mesh (75 μm). The justification for adopting it is given in Bureau of Mines Technical Paper (TP) 464 (Rice & Greenwald, 1929). In the 1920s, representative dust samples were collected from mine passageways that were not rock dusted, and then they were sized using sieves. TP 464 states that these coal dust samples collected from the mine floors had 5–40% of the material less than 200 mesh. TP 464 further indicates that the values were weighted as far as possible, and for 80% of the mines, the final values ranged from 15% to 25% through 200 mesh. Therefore, coal dust

*Corresponding author. Tel.: +1 412 386 6753; fax: +1 412 386 6595.
E-mail address: KCashdollar@cdc.gov (K.L. Cashdollar).

[1]The Pittsburgh Research Laboratory was part of the US Bureau of Mines until 1996, when it was transferred to the National Institute for Occupational Safety and Health (NIOSH).

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having 20% through 200 mesh was considered to be typical "mine size dust" and was used in the experimental mine tests that determined the current 65% total incombustible requirement for intake roadways (Nagy, 1981; Rice & Greenwald, 1929). TP 464 states that dust collected from ribs, roof, and timbers was finer in size, with 40–75% finer than 200 mesh. TP 464 does not give any additional details on the total number of mines surveyed or the total number of samples analyzed for coal particle size. The 80% incombustible content required for return airways is based on the finer float coal dust that may be deposited there. Nagy (1981) defines float coal dust as dust that is finer than 200 mesh.

To comply with regulations, mine personnel periodically dust the mine intake and return airways with an inert material, such as pulverized limestone (rock) dust. The term "inert" in this sense means that the material does not support combustion. The rock dust is required to be at least 70% minus 200 mesh. In determining compliance with the regulation, inspectors from the Mine Safety and Health Administration (MSHA) periodically collect samples of deposited dust from various areas in a mine. When samples are collected in any given mine, they are usually collected at 500 ft intervals along an entry. Generally, a band sample is collected, which includes dust from the floor, ribs (walls), and roof at each location in the mine. The inspector then screens the sample through a 10-mesh sieve while in the mine, bags the sample, and sends it to MSHA's laboratory at Mt. Hope, West Virginia, for determination of the incombustible content. The fineness of the coal dust component is not measured and therefore not specifically considered in assessing the level of dust explosion protection afforded by the 65% inert requirement for intake airways.

This paper presents the results of a recent coal dust particle size survey to determine the range of coal particle sizes found in dust samples collected from intake airways in 50 US coal mines in MSHA's 10 bituminous Coal Mine Safety and Health Districts (see Fig. 1). (MSHA District 1 covers anthracite mines in Pennsylvania, which do not require rock dusting.) This research is relevant to the amount of rock dust needed to prevent coal dust explosions under current and changing mining operations.

2. Coal particle size effects

Since the amount of rock dust required to inert a mixture varies with coal particle size (Cashdollar & Hertzberg, 1989; Nagy, 1981; Rice & Greenwald, 1929; Rice, Jones, Egy, & Greenwald, 1922; Weiss, Greninger, & Sapko, 1989), the measurement of the incombustible concentration without considering the effect of coal particle size is not, by itself, sufficient to determine the possible explosion hazard. The effect of coal particle size on the explosibility is best illustrated in Fig. 2, which shows the incombustible required to prevent explosion propagation in large-scale dust explosion experiments conducted in the NIOSH-PRL Bruceton Experimental Mine (BEM) and Lake Lynn Experimental Mine (LLEM). The graph shows the amount of incombustible required to prevent propagation for Pittsburgh high volatile bituminous coal dust with 10–80% passing through a 200-mesh sieve (75 μm). Each of the data points is an individual BEM or LLEM explosion test. The lower dashed curve shows the amount to inert based on the older BEM data (Rice & Greenwald, 1929; Rice et al., 1922). The curve is the boundary between mixtures below that can propagate an explosion and mixtures above that cannot propagate an explosion. These are the data used to support the current 65% incombustible requirement for intake airways. The dotted curve shows the amount to inert based on the more recent LLEM research (Sapko, Weiss, Cashdollar, & Zlochower, 2000; Weiss et al., 1989). The LLEM data show close agreement with the BEM data for the fine size coal at 80% minus 200 mesh. For the mine size coal at 20% minus 200 mesh, the data show that somewhat more rock dust is required to prevent explosions in the LLEM than in the BEM. The reason may be that the LLEM is more adiabatic than the BEM because of the larger cross-sectional area at the LLEM.

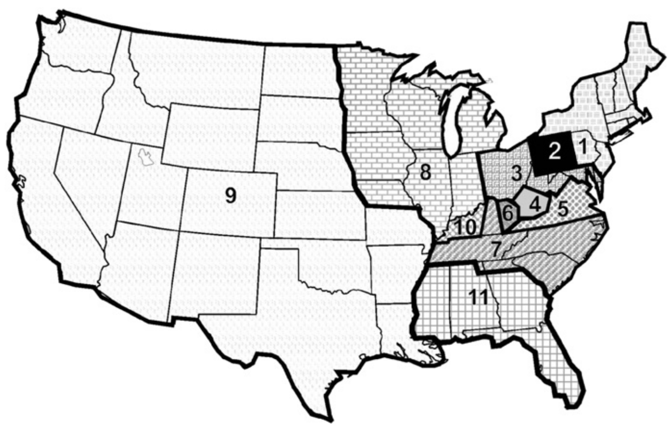

Fig. 1. MSHA Coal Mine Safety and Health Districts, identified by number.

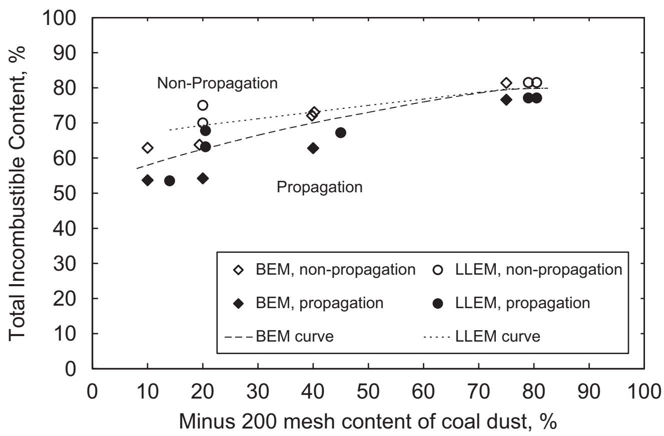

Fig. 2. Effect of particle size of coal dust on the explosibility.

3. Experimental procedures

To assess current variations in coal particle size distribution from various underground coal-mining operations, MSHA coordinated the acquisition of mine dust samples from 10 Coal Mine Safety and Health Districts. The dust samples were those collected routinely by mine inspectors for compliance with 30 CFR 75.403. The samples were sent to MSHA's Mt. Hope Laboratory in WV and analyzed for TIC. The TIC includes the moisture in the samples, the ash in the coal, and the rock dust. The incombustible analysis procedure (Montgomery, 2005) begins with passing the sample through a 20 mesh sieve (850 μm) and then oven drying the minus 20 mesh material for 1 h at 105 °C and recording the weight change. The weight loss constitutes the moisture in the sample. Next, the dried sample is heated in an oven that is ramped up over 1.5 h and held at 515 °C for about 2.5 h to burn off the combustible coal fraction, thereby leaving the incombustible ash. This low-temperature ashing (LTA) burns off the coal but does not decompose the limestone rock dust. The amount of the remaining ash plus the as-received moisture is reported as %TIC. After the MSHA laboratory completed their incombustible analyses, the remaining material of the dust samples was sent to NIOSH-PRL for the coal particle sizing analyses.

At PRL, the limestone dust was leached from the sample using hydrochloric acid, and a sieve size analysis was conducted on the remaining non-leachable residue. In the laboratory acid leaching method, dilute hydrochloric acid was added to the dust sample in a beaker and heated on a hotplate. The acid reacted with the rock dust producing foam while releasing carbon dioxide (CO_2). Additional acid was added until the foaming stopped. The hotplate kept the slurry near its boiling point for about 1 h. After the slurry cooled, the acid-insoluble residue was filtered from the acid. The solid residue was rinsed with isopropanol and then transferred to a large evaporating dish. The residue was dried at 110 °C for 3 h. Agglomerates were broken with a spatula. The residue consisted of coal plus other insoluble mineral matter (such as silica from the rock dust and shale from roof or floor rock in the mine).

The dried residue was classified into the different size fractions using a sonic siever, which combined two motions to provide particle separation: a vertical oscillating column of air and a repetitive mechanical pulse. In addition, the tops of the sieves were brushed to break up any remaining agglomerates. The sieves are 8 cm in diameter and include the following sizes: 20 mesh (850 μm), 30 mesh (600 μm), 40 mesh (425 μm), 50 mesh (300 μm), 70 mesh (212 μm), 100 mesh (150 μm), 140 mesh (106 μm), 200 mesh (75 μm), 270 mesh (53 μm), and 400 mesh (38 μm). After the sieving was completed, the weight of sample on each sieve was recorded.

Since the residue from the leaching process contained other inert mineral matter (such as clay and silica dust) that did not react with the acid, a correction to the size analysis had to be made. First, the residue was grouped into three size fractions: minus 200 mesh, 200 × 70 mesh, and plus 70 mesh. Then these three fractions were heated at 515 °C at PRL to determine the incombustible or non-coal content, using an LTA method similar to that of the MSHA laboratory at Mt. Hope. The sieve size analyses were then corrected for the non-coal content (insoluble mineral matter) in the three size groupings. The amount of this insoluble mineral matter in the samples varied greatly, but was generally in the 20–50% range. For most of the samples analyzed, the mineral matter was finer in size than the coal. Therefore, after correction for the mineral matter, the corrected minus 200 mesh amount would be less than the original minus 200 mesh amount from the sonic sieving. There was a wide range of correction values, but a value of 39% minus 200 mesh from the original sieving data might typically be reduced to ~31% minus 200 mesh after correcting for the mineral matter.

The total size analysis procedure (acid leaching, sieving, and correction for remaining incombustible matter) was verified by using prepared mixtures of coal and rock dust. First, the size of the coal sample was determined by sieving. Then, samples of coal and rock dust (usually 35% coal and 65% rock dust) were mixed together, and then the rock dust was leached from the mixture. The residue was then sieved and corrected via LTA for any remaining incombustible matter in the size fractions. For these prepared mixtures, the correction was small because amount of insoluble mineral matter was small. This verification test was done for samples of Pittsburgh seam high volatile coal, Blue Creek seam medium volatile coal, and Pocahontas seam low volatile coal. In general, the size analyses after leaching were close to the original size analyses, with agreement to within 1–3% for the amount of minus 200 mesh material.

4. Results

For this study, samples of mine dust from 50 coal mines in the 10 MSHA bituminous districts were size analyzed. For each mine, samples were usually collected from two or more entries. For most analyses, multiple samples from a mine entry were combined to give an average size distribution for that entry. Most of the samples were band samples, but some were floor and rib samples or floor and roof samples. Table 1 lists the intake coal dust size data by MSHA Coal Mine Safety and Health District. The table includes data from a total of 163 combined samples from 50 bituminous coal mines. Columns two and three of the table list the number of mines and total number of combined samples per district. The fourth and fifth columns list the average percent minus 200 mesh (75 μm) and minus 70 mesh (212 μm) with the associated standard deviations, respectively. The last column lists the average and standard deviation for the mass median particle diameter, which was interpolated from the corrected sieving data. The averages for all MSHA districts are

31% minus 200 mesh, 63% minus 70 mesh, and a mass median of ~150 μm. This is significantly finer than the size measured in the 1920s.

Table 2 lists the average sizes for various coal seams or groups of coal seams. The eastern bituminous coal seams are those in the Appalachian Mountains from Pennsylvania to Alabama. Only the seams that included samples from two or more mines are listed. The coal rank is also listed in the first column, with hvb for high volatile bituminous, mvb for medium volatile bituminous, and lvb for low volatile bituminous (ASTM International, 2006). The mid-eastern seams are those in Illinois, Indiana, and western Kentucky. These seams are known by different names in different states, as listed in the table. The western coal seams include various high volatile C bituminous (hvCb) coals in Colorado or Utah. The coal samples from the Hazard #4 seam in Kentucky and the Blue Creek seam in Alabama are the finest in size, with ~40% less than 200 mesh. These variations with coal seam may be related to the friability of the coal.

Table 1
Average coal sizes from mines in 10 MSHA Safety and Health Districts

District	No. of mines	No. of samples	−200 mesh (%)	−70 mesh (%)	D_{med} (μm)
2	5	13	29±4	60±5	161±22
3	7	19	33±10	63±9	147±45
4	4	15	31±7	62±10	156±40
5	4	10	33±10	68±13	141±40
6	4	21	32±7	60±7	155±35
7	5	16	35±10	63±8	135±48
8	4	10	27±5	58±7	172±39
9	6	12	27±4	59±5	168±26
10	4	26	29±4	61±5	151±25
11	7	21	38±9	74±15	122±42

5. Conclusions

Dust explosibility is strongly dependent on the fineness of the coal particles in a coal and rock dust mixture. Underground coal mining technology has changed significantly since the 1920s when data were collected on the particle size of coal dust distributed in mine passageways. Coal mining has become highly mechanized, and this has resulted in increased coal production rates. Particle size can vary with coal seam type, as shown in Table 2. In addition to TIC and methane concentration, the coal dust particle size should be considered as an essential part of the explosibility assessment strategy in underground coal mines. The present coal size study indicates that the coal dust in intake airways of US mines is finer than that measured in the 1920s (Rice & Greenwald, 1929). Based on the inerting data from the Bruceton and Lake Lynn Experimental Mines, the present size of coal in intake airways would require more incombustible to be effectively inerted than the 65% incombustible specified in current regulations.

A complementary study is being undertaken to collect and analyze dust samples in a selection of mines to assess the feasibility of a hand-held instrument to evaluate the explosibility hazard. NIOSH in collaboration with MSHA (Sapko & Verakis, 2006) has devised a prototype hand-held instrument, based on optical reflectivity, which can provide a direct assessment of the potential explosibility of a coal and rock dust mixture, which is independent of coal dust particle size. The field studies will be used to evaluate the practicality for in situ assessment of dust mixture explosibility with the newly developed hand-held instrument.

Acknowledgments

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Table 2
Average coal particle size from various coal seams

Coal seams	No. of mines	No. of samples	−200 mesh (%)	−70 mesh (%)	D_{med} (μm)
Eastern bituminous coal seams					
Pittsburgh, hvb	9	26	33±8	63±7	143±32
Upper or lower Kittanning, hvb	2	5	25±5	53±6	197±37
Alma, upper Elkhorn #1 or #3, hvb	3	18	33±7	61±6	149±34
Hazard #4, hvb	2	8	40±13	69±7	104±45
Pocahontas #3, lvb	2	8	35±6	64±7	138±33
Pratt coal seam, hvb	2	6	31±6	63±11	155±34
Blue Creek coal seam, mvb	5	15	41±14	79±24	109±47
Mid-eastern bituminous coal seams					
Springfield, Illinois #5, or W. Kentucky #9	3	16	29±5	62±7	150±31
Herrin, Illinois #6, or W. Kentucky #11	3	12	26±3	59±4	164±24
Western bituminous coal seams					
Various hvCb seams in Colorado	3	7	27±3	57±5	174±27
Various hvCb seams in Utah	3	5	26±5	61±7	164±29

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Disclaimer: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health or the Mine Safety and Health Administration.

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