Field evaluation of the coal dust explosibility meter (CDEM)

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Introduction

Experimental studies by the Pittsburgh Research Laboratory of the National Institute for Occupational Safety and Health [1] (PRL) and similar agencies in other countries have shown that mixing a sufficient quantity of inert rock dust (usually limestone) with coal dust will prevent coal dust explosion propagation (Nagy, 1981). The rock dust particles act as a heat sink, lowering the flame temperature below the value needed to continue explosion propagation. Previous full-scale explosion studies have illustrated the importance of particle size in relation to explosibility (Nagy, 1981; Weiss et al., 1989). As these studies demonstrate, the finer the coal dust particle size, the more rock dust required for inerting. The U.S. requirement specified in Title 30, Code of Federal Regulations, Part 75, Section 403, mandates that the nation's coal mines must maintain an incombustible content of at least 65 percent in the nonreturn (intake) airways and at least 80 percent in the return airways, where finer float coal dust is more likely to accumulate.

Abstract

In underground mines, coal dust explosions are prevented by the addition of rock dust sufficient to render the coal dust inert. The National Institute for Occupational Safety and Health (NIOSH) developed a hand-held instrument that uses optical reflectance to measure the explosibility of a rock dust and coal dust mixture. This instrument is called the Coal Dust Explosibility Meter (CDEM). In this study, NIOSH personnel accompanied Mine Safety and Health Administration (MSHA) inspectors on their routine band surveys in five underground coal mines in MSHA District 2 (Pennsylvania) and three underground coal mines in MSHA District 11 (Alabama). While underground, NIOSH personnel and MSHA inspectors used the CDEM to assess the explosibilities of the dust samples. The values of percent incombustible content (percent IC) determined by the CDEM agreed well with those obtained later by low-temperature ashing (LTA) in both MSHA and NIOSH laboratories. Further, the meter identified some samples as potentially explosible that LTA analysis had found to possess sufficient rock dust for inerting. The CDEM provides more information on the hazards in the mine. Rapid identification of areas with explosible dust mixtures using the CDEM allows for immediate intervention rather than a wait of several weeks for laboratory analysis.

The current procedures for determining compliance with rock dusting requirements begin with an MSHA inspector visiting a mine quarterly to perform a rock dust survey. The dust samples are then submitted to the Mine Safety and Health Administration (MSHA) laboratory at Mt. Hope, WV, for low-temperature ashing (LTA) analysis, which will be described below. The MSHA laboratory determines the total incombustible content of each sample and sends the results to the inspector. This process, from obtaining the samples to reporting the analytical results, typically takes several weeks.

The Coal Dust Explosibility Meter (CDEM) gives real-time results in the mine during the rock dust surveys instead of waiting weeks for laboratory results from the MSHA survey (Sapko and Verakis, 2006). With real-time results, the potential for a disaster can be mitigated immediately. The CDEM is a hand-held instrument that uses optical reflectance to determine the explosibility of a rock dust and coal dust mixture. The CDEM displays the percent incombustible content as well as a color indicating the relative explosibility of the coal and rock dust mixture. A red-color readout indicates that more incombustible material is required to inert the coal and rock dust sample, while a green readout indicates that the dust sample is sufficiently inert. When the mixture is marginally explosible, yellow is indicated.

In addition to the problem of waiting weeks for the results of MSHA inspections, the MSHA regulations are based on two sizes of coal — a coarse size in mine intakes and a finer size in returns. However, these MSHA rock-dusting regulations are based on coal particle size surveys conducted in the 1920s and experimental mine measurements of the amount of incombustible required to inert those sizes of coal (Rice and Greenwald, 1929; Nagy, 1981). A recent coal dust particle size survey indicates that current mining methods generate finer particles; therefore, more inert material is required (Sapko et al., 2007). One advantage of the CDEM is that it accounts for the coal particle size in its determination of explosibility. The CDEM color readout takes the various sizes of coal into account when determining the explosibility of the dust mixture. Details regarding the design and operation of the CDEM can be found in Sapko and Verakis (2006).

To field test the effectiveness of the CDEM, NIOSH researchers accompanied MSHA inspectors on their rou-

FIGURE 1

Sample tube containing molecular sieves.

tine rock dust surveys in eight underground coal mines. While underground, NIOSH and MSHA inspectors used the CDEM to assess the explosibility of the dust samples. A complete description of the procedures and results from these field studies is reported in the following sections.

Field evaluation procedures

To measure percent incombustible contnet (IC), the CDEM is calibrated for each mine using a dried sample of mine dust with a known percent incombustible, preferably between 63 percent and 75 percent, as determined by prior LTA analysis. This sample is considered to be representative of that particular mine and is used as a midpoint calibration sample. Prior to each mine visit, the meter is calibrated using a sample of the mine's rock dust, coal dust and midpoint calibration sample. The explosibility function of the meter only requires a sample of pure rock dust and pure coal dust for calibration. The explosibility mode (red, yellow or green color) indicates the level of explosion protection based on the fineness of the coal dust and is preset in the CDEM.

In this study, to determine the incombustible content of the dust mixtures in the entries, MSHA inspectors gathered dust samples per procedures outlined in the *MSHA Handbook Series* titled "General Coal Mine Inspection Procedures" (MSHA, 2006). The band sample method was used, meaning that dust was collected from around the perimeter (roof, ribs and floor) to a depth of 25 mm (1 in.) in a mine entry. When the roof was too high, only rib and floor samples were collected. The band samples were collected every 152 m (500 ft) along the entries. Part of the band sample was bagged, labeled and sent to the MSHA Mt. Hope laboratory for analysis, while part was analyzed in situ using the CDEM. The MSHA inspector collected the band sample into a metal pan using a brush, and the dust was then sifted through a 10-mesh screen to remove particles larger than 2 mm (0.08 in.). The minus 10-mesh dust sample was then mixed by a combination of using fingers to mix it in the tray and by shaking the tray. Mixing continued for about five seconds until the dust appeared to be homogeneous. However, this method of mixing was not always sufficient, as will be shown and discussed later.

NIOSH personnel used tubes (45 mL or 1.5 oz) to collect a small dust sample from the tray and to prepare the dust for CDEM measurement (Figs. 1 and 2). The tubes were about half-filled with molecular sieve material (Grace Davison, Columbia, MD[2]), which was used to dry the dust. The remainder of the dust within the MSHA inspector's tray was placed in a plastic bag and labeled for subsequent MSHA LTA analysis. The dust sample was added to the molecular sieves in the sample tube until the tube was mostly filled. The tube was shaken for at least one minute so that the dust sample would mix with the sieves and dry. With the moisture removed from the dust sample, a funnel with a 20-mesh screen was attached to the end of the tube. The CDEM sample cup was then fitted onto the end of the funnel and a dust sample was shaken from the sample tube into the sample cup (Fig. 3). The 20-mesh screen inside the funnel prevented the molecular sieves from entering the sample cup. The MSHA Mt. Hope laboratory similarly sieves all dust samples through a 20-mesh screen before determining the incombustible content.

Once the dry dust was in the sample cup, the CDEM probe was inserted into the cup. The CDEM returned a reading of percent IC and the corresponding red/yellow/green indicator readout (Fig. 4) was recorded. The re-

FIGURE 2

Collecting a sample into a sample tube.

FIGURE 3

Transferring dust to a sample cup.

FIGURE 4

Sampling the dust with the CDEM, displaying "65Red."

FIGURE 5

Comparison of MSHA and NIOSH incombustible measurements.

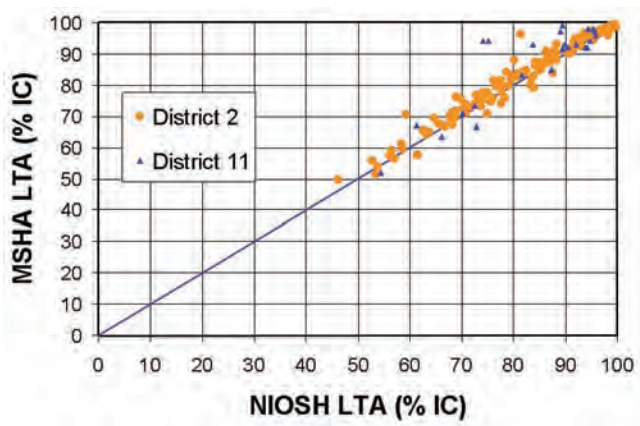
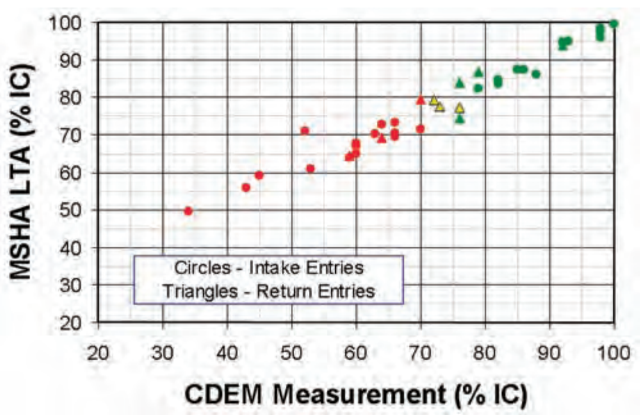


FIGURE 6

Mine D measurement comparison.



maining sample within the tube was capped and retained for later NIOSH laboratory analysis.

The MSHA Mt. Hope laboratory analysis consisted of sieving the sample through 20 mesh and then oven drying the minus 20-mesh material for one hour at 105°C (221° F)and recording the weight change (Sapko and Verakis, 2006). This value would be the percent moisture. LTA analysis was done by heating the dried sample in an oven, which was ramped up over 1.5 hours and held at 515° C (959° F) for about 2.5 hours to burn off the combustible coal fraction, thereby leaving the incombustible ash. This temperature is chosen because it is high enough to burn off the coal but not high enough to decompose the limestone rock dust. The weight of the remaining ash and weight of the as-received moisture are combined and reported as total incombustible content (TIC).

The NIOSH lab analysis procedure used only LTA analysis because the molecular sieves had already removed the moisture during the collection process. The NIOSH LTA procedure included a similar ramp time of 1.5 hours to 515° C (959° F), which was maintained for 20 hours (Cashdollar et al., 2007).

Results and discussion

Figure 5 shows a comparison of the incombustible content as measured by both the MSHA and NIOSH LTA analyses. There is a linear relationship between the percent IC measured at the two facilities. The average difference between samples processed at the two sites was about 2 percent, with the largest difference being 20 percent. It should be noted that MSHA reported to NIOSH both the total IC percentage (including moisture) and the moisture percentage. To determine the percent IC on a dry basis, a correction was made for the MSHA moisture percentage. A few samples had large differences between the analyses at the two laboratories. These could be due to how adequately the dust was mixed before division. To determine if these large differences were associated with mixing or with differences in ashing time, the Mt. Hope laboratory sent the remainder of its portion of the original sample to NIOSH for 20-hour ashing. NIOSH testing confirmed that the MSHA and NIOSH methods actually produced almost the same percent IC. This result indicates that more care needs to be taken in the mine to more thoroughly mix the bulk sample before extracting a portion for CDEM analysis.

Figures 6 and 7 show the in situ CDEM measurement of percent incombustible compared to the MSHA Mt. Hope LTA measurements for the five mines from District 2. For the MSHA data, the percent moisture values were subtracted from the total incombustible percent values because the CDEM values were on a dry basis. The data points are shown as red, yellow or green, corresponding to the explosibility color reading from the CDEM. Red denotes an explosible dust mixture, yellow denotes a marginally explosible mixture and green denotes an inert mixture. Figure 6 displays the data for Mine D. There is a linear relationship between the MSHA analyses and the CDEM incombustible readings. The CDEM color readings show red for the samples with the lowest incombustible contents, meaning they need more rock dust to be rendered inert. The CDEM green readings show samples with sufficient rock dust. Note that there were 10 intake samples that met the current 65 percent IC requirement by the MSHA laboratory analyses but were identified as red by the CDEM, meaning that they were potentially explosible. The reason for this difference is probably that the actual coal dust size in the mine was finer than the size basis for the regulation. Figure 7 shows the combined data for Mines A, B, C and E. There appears to be good agreement between the Mt. Hope percent IC (LTA analysis) and that measured by the CDEM. As indicated above, the data that appear to be major outliers were found to be the result of inadequate in-mine sample mixing before the sample was subdivided.

Among District 2 intake entry samples, 92 out of 104 had ≥65 percent IC, as required by current regulations. However, the CDEM indicated that 27 of those samples were within the red or yellow bands, indicating that about a quarter of the samples may be deficient in incombustible content. Mine areas represented by these samples would most likely not receive additional rock dust because they are compliant with current regulations. Yet, according to CDEM analysis these samples represent areas of the mine where a risk of explosion propagation is present and more rock dust is required. The reason that the CDEM shows these samples as potentially explosible is probably because the coal dust in the samples is finer in size than the basis for the regulation (Sapko and Verakis, 2006; Sapko et al., 2007).

Figure 8 displays the CDEM percent IC measurements and the MSHA results for three mines within District 11. The CDEM IC percentages agree reasonably well with the MSHA results for Mines F and G but not as well for Mine H. However, Mine H values are all very high in incombustible content. The rock dust used in District 2 mines is composed of limestone that is light gray in color, while the rock dust used at the District 11 mines is a marble dust that is bright white. Figure 9 is a visual comparison of the marble dust and limestone dust. The normalized reflectance takes these reflectance differences into account for the CDEM percent IC readings. However, the red/yellow/green explosibility boundaries that had been preset in the CDEM for District 2 using limestone dust did not apply to the District 11 marble dust. Based on the explosibility color settings for District 2 using the limestone, most of the District 11 sample readings were red, which was obviously in error. The color settings of the CDEM for the marble dust were further studied to address the issue.

Figure 10 shows the normalized reflectance of the limestone and marble dust mixed with Pittsburgh coal dust of different sizes. The coal size is identified by the percent by weight of minus 200 mesh. The data points show the mixtures at the explosibility limits, which correspond to the yellow-green boundaries for the CDEM (Sapko and Verakis, 2006). As can be seen, the normalized reflectance remains relatively constant for both sizes of coal dust, but the normalized reflectance at the explosibility limit is higher for the limestone than for the marble. Therefore, mines that inert with marble dust will require a different normalized reflectance value at the explosibility limit to be programmed into the CDEM for the correct color output. The difference in the normalized reflectances for the two rock dusts is most likely due to a difference in the particle sizes of the limestone and marble. More study on the effects of rock dusts from different districts will be undertaken to determine the appropriate color output settings for the CDEM.

Conclusions

After calibration with a mine sample of known incombustible content, the CDEM can give real time measurements of the percent IC in a mine during a rock dust band survey. Rapid determination of percent IC allows for immediate remedy of inadequate rock dusting. Previous large-scale explosion studies illustrated the importance of particle size in explosion hazard. The color indicators of red, yellow and green output of the CDEM take this coal dust size variation into account when determining the level of protection present. During the current survey, the CDEM color indications determined that about a quarter of the intake samples meeting the MSHA requirements (incombustible content) fell into the possibly explosible range requiring more rock dust.

FIGURE 7

Measurement comparison of Mines A, B, C and E.

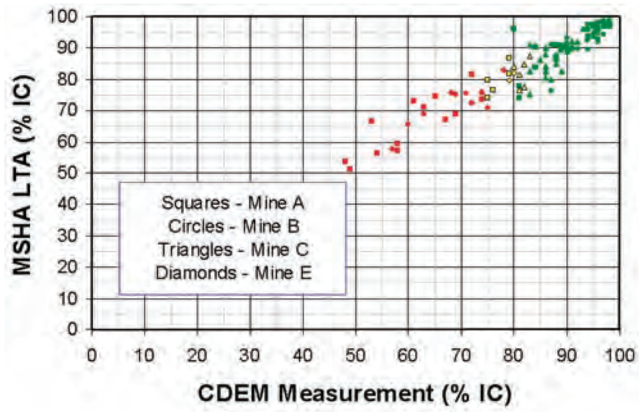


FIGURE 8

Measurement comparison of Mines F, G and H.

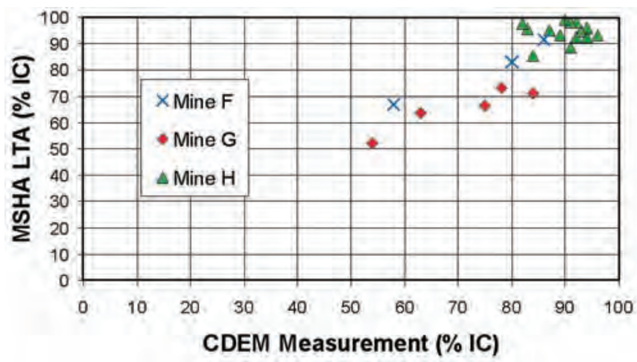


FIGURE 9

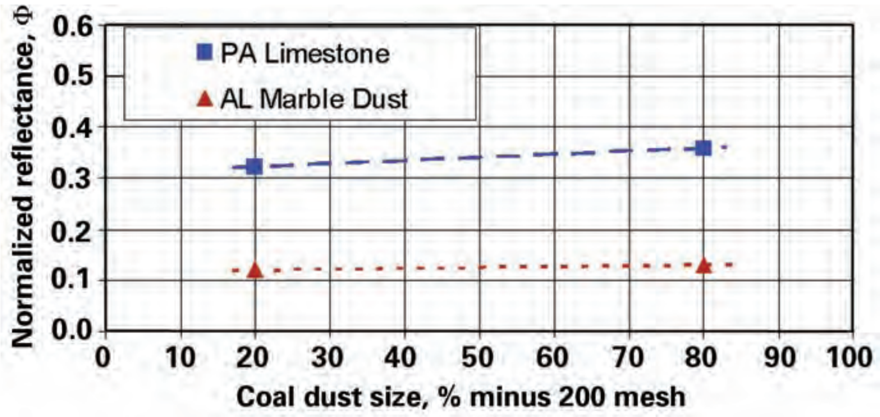
Different rock dusts used.

Acknowledgments

The authors acknowledge Terry Montgomery with the MSHA laboratory for supplying LTA and moisture analyses for the District 2 and 11 mine samples. The au-

FIGURE 10

Comparison of normalized reflectance using different rock dust mixtures.



thors also acknowledge the MSHA Ruff Creek, PA, field office and the MSHA Bessemer, AL, field office for allowing NIOSH investigators to accompany its inspectors on their routine rock dust surveys. The authors wish to thank Greg Green of NIOSH PRL for his assistance with the LTA data.

Footnotes:

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

[2] Mention of any company or product does not constitute endorsement by NIOSH or MSHA.

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