Preventing Coal Dust Explosions in Underground Coal Mines

Office of Mine Safety and Health Research
Objective

• Review the history of dust explosion research
  – Explosion principles
  – Application of explosion prevention research
  – Changing mining conditions led to new recommendations
• Coal Dust Explosibility Meter
  – New real-time hazard identification tool
  – Field validated and commercialized
• Current research tasks
  – Dust sampling practices
  – Rock dusting practices
  – Rock dust variability
Problem Definition

Presented by

Gerrit V.R. Goodman, PhD

OFFICE OF MINE SAFETY AND HEALTH RESEARCH
Problem Definition

- Explosion risk due to presence of un-neutralized coal dust
- Application of research results to development of rock dust inerting criteria
- Impact of coal dust particle size on flame propagation and inerting limits
- Impact of percent incombustible content (IC) on explosibility and development of the new 80% IC standard
Dust Explosion Elements

- Fire elements (Fire Triangle):
  - Combustible dust (fuel)
  - Ignition source (heat)
  - Oxygen in air (oxidizer)
- Additional elements for combustible dust explosion:
  - Dispersion of dust
  - Confinement of dust cloud
Anatomy of Dust Explosion

- Small volume of a methane-air mixture ignites
- Ignition produces high temperature gases
Anatomy of Dust Explosion

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- Gases rapidly expand generating shock wave
Anatomy of Dust Explosion

- Small volume of a methane-air mixture ignites
- Ignition produces high temperature gases
- Gases rapidly expand generating shock wave
- Shock wave produces wind that disperses surface dust
Anatomy of Dust Explosion

- Expanding high temperature gases
Anatomy of Dust Explosion

- Expanding high temperature gases
- Combustible dust cloud forms and is ignited by the hot gases produced by the methane explosion
Anatomy of Dust Explosion

- The flame and high temperature gases ignite the coal dust
Anatomy of Dust Explosion

- Coal combustion continues to propagate the flame
- Gas explosion consumes available fuel and oxygen
- Explosion generates large amounts of toxic combustion products
Factors Affecting the Intensity

- Four qualities of coal dust that affect the intensity of an explosion:
  - **Particle size** (particles $< 75 \, \mu m$ most reactive)
  - Location of the dust (roof, ribs, and/or floor)
  - Dust dispersibility
  - Volatile content
Review

- Turbulence from a methane ignition disperses dust from the entry surfaces into the expanding combustion zone.
- Heat transfer to the coal dust particles results in an exothermic reaction and expansion of the air in the entry.
- As the explosion progresses, the pressure wave continues to disperse entry dust, adding fuel to the explosion.
- Finer coal dust is more explosible and requires more rock dust to inert.
Application of Research

- Rock dust acts as a heat sink, drawing energy from the system.
- Development of rock dust inerting criteria
  - Based on 1920s particle size survey
  - Based on BEM explosion tests
- **Mine size coal** previously defined as coal dust that is
  - 100% minus 20 mesh (850 μm)
  - 20% minus 200 mesh (75 μm)
- **Float coal**
  - 100% minus 200 mesh (75 μm)
- Coal in returns
  - 80% minus 200 mesh (75 μm)
Past Research Findings
(Bruce ton Experimental Mine)

- Decreasing average coal particle size
- 65% IC based on average coal size found in 1920s
USBM Recommendations

As a result...

- 65% IC in intake airways
- 80% IC in return airways
Factors Affecting Inerting

- Rock dust concentration
- Fineness of the rock dust (minus 200 mesh most effective)
- Dust dispersibility
- Maintenance of rock dust within 40 ft of the face
- Distribution of coal and rock dust in the mine entry
  - Homogeneous mixture with coal dust
  - Stratified layers of coal and rock dust
  - Zones with insufficient rock dust
Assumptions thus far...

• The rock dust requirements are applicable if:
  – Homogenous mixture on floor, ribs, and roof
  – The rock dust is dry and dispersible
• Combustibility of coal dust influenced most by coal dust particle size

What if…
• A layer of float coal dust is present?
• Moisture is present?
Anatomy of a Float Coal Dust Explosion

Layered dust
- Float coal dust (0.24 mm or 0.01 in)
- Rock dust (25.4 mm or 1.0 in)

Coal combustion front
- Surface coal dust disperses first

Underlying rock dust dispersion lags behind the combustion front and unable to quench combustion front
Conditions Change...

- Over the years,
  - More mechanization
  - Less blasting
  - Finer coal dust generated
  - Larger mine geometries
NIOSH Investigation

- Coal dust particle size
  - From MSHA quarterly band sample surveys
- Blue Creek seam samples (District 11) - 43% minus 200 mesh (75 μm)
- Hazard #4 seam samples (District 6) - 40% minus 200 mesh (75 μm)
- <200-mesh fraction range
  - 27% (District 9)
  - 37% (District 11)
- Overall Average – 31%
Impact of Coal Dust Particle Size
(Lake Lynn Experimental Mine)

Decreasing average coal particle size
Survey Results Continued

80% IC requirement based on results from:
- Recent coal dust particle size survey
- Full-scale experiments conducted in the Lake Lynn Experimental Mine
- Explosion temperature thermodynamic limit models

For details of results, go to http://www.cdc.gov/niosh/mining/pubs/pubreference/outputid2825.htm
Summary of Research to Practice

• 1920s
  – Bureau of Mines recommended 65% TIC in all airways
    • 1920s coal particle size survey
    • Full-scale experiments conducted in the Bruceton Experimental Mine

• Coal mine Act 1969
  – Increased the incombustible for return entries from 65% to 80%
  – Requirements in intakes remained at 65%

• May 2010
  – Increased the incombustible for intake entries from 65% to 80%
    • Recent coal dust particle size survey
    • Full-scale experiments conducted in the Lake Lynn Experimental Mine
    • Explosion temperature thermodynamic limit models
Questions? For More Information

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Use of the Coal Dust Explosibility Meter (CDEM) to Verify Rock Dust Percentage

Presented by Marcia L. Harris
Overview of the CDEM

- Application
- Calibration
- Operation
- Discussion on use of the CDEM to improve mine safety
Current Practices

• Current compliance with CFR requires 80% incombustible in all airways in the absence of methane.
  – Collect samples at 500-ft intervals in new developments or spot checks
  – MSHA inspectors collect 6-in wide band samples up to 1-in deep
  – Samples are sent back to the MSHA laboratory for analysis
    • Sieve sample through 20 mesh sieve (841 µm or less)
    • Dry dust at 105°C for 1 hr (moisture %)
    • low temperature ashing (% IC)
    • As-received moisture credited
      – %H₂O + %IC = %TIC
  – Inspector notification on the sample ashing results can take from 1 to 4 weeks
New Alternative

A rapid in-situ instrument to measure dust explosibility based on coal and rock dust particle size
CDEM

• Immediate results
• Operation based on optical reflectance
  – light rock dust
  – dark coal dust
• Hand held
• MSHA IS approved
• Efficient method to determine explosibility of the dust mixture
• Can help mine operators
  – reduce the danger of operating under hazardous conditions
  – help provide a better balance
    o rock dust application
    o coal dust generated during mining
Operating Principle

• Based on reflectance of dust particles
• Accounts for the particle sizes of the coal and rock dust

For more in-depth discussion:
Technical development of the coal dust explosibility meter.
Sapko MJ, Verakis H [2006].

The CDEM provides a better measure of explosibility than the LTA method. Consider the following example…
Sensitive to Particle Size

65% Incombustible, 35% Combustible
Sensitive to Particle Size

65% Incombustible, 35% Combustible

20% <200 mesh
40% <200 mesh
80% <200 mesh
Sensitive to Particle Size

65% Incombustible, 35% Combustible

20% <200 mesh
40% <200 mesh
80% <200 mesh

CDEM indicates…
Non-Explosible
Sensitive to Particle Size

BEM curve

- Non-Propagation
- Propagation

- Green reading – Non-explosible
- Red reading - Explosible

Total Incombustible Content, %

Minus 200 Mesh Content of Coal Dust, %
Sensitive to Particle Size

65% Incombustible, 35% Combustible

20% <200 mesh

CDEM indicates…

Non-Explosible  Explosible
Sensitive to Particle Size

![Graph showing the relationship between Total Incombustible Content and Minus 200 Mesh Content of Coal Dust, with Non-Propagation and Propagation areas indicated. Green and red circles are marked for non-explosive and explosive readings, respectively.]
Sensitive to Particle Size

65% Incombustible, 35% Combustible

20% <200 mesh
Non-Explosible

CDEM indicates...

20% <200 mesh
Non-Explosible

40% <200 mesh
Explosible

80% <200 mesh
Explosible
Sensitive to Particle Size

![BEM curve diagram showing the relationship between Total Incombustible Content and Minus 200 Mesh Content of Coal Dust. The diagram includes two regions: Non-Propagation and Propagation. Green and red markers indicate different readings: Green for non-explosible and red for explosive.](image)
CDEM Calibration Points

- Sample of pure rock dust from the mine
- Sample of PPC (Pittsburgh Pulverized Coal)
- 80% IC mixture – Green/Red boundary
Collecting a Representative Mine Dust Sample
What is a Representative Dust Sample?

- Results are only as accurate as the sample collected.
- Current policy (BOM recommendations)
  - Band sample
  - 1-in deep
- Future???
  - Importance of including all surfaces
    - Examples: roof, mesh, timbers, etc.
  - Depth
    - Foreign practice
    - Our understanding of explosion propagation
    - We believe shallower depth is warranted
Molecular Sieve Material to Remove Moisture
Collecting the Sample
Transferring the Dried Sample into the CDEM Sample Cup
Using the CDEM to Measure the Explosibility of the Mixture

Sample cup
Mine Validation Study

- MSHA had 10 CDEMs to use – 1 for each of the bituminous districts
- December 2009 – March 2010
  - CDEMs used by district inspectors in conjunction with quarterly surveys
  - Samples analyzed according to normal procedure
  - After Mt. Hope analyzed the samples, samples were sent to NIOSH
- NIOSH evaluated the data and samples to identify any discrepancies and determine a cause
- CDEM was validated and then commercialized by Sensidyne
Results of Mine Validation Studies

• To identify and understand reasons for method differences
  – NIOSH researchers used CDEMs on the samples received from MSHA
  – NIOSH and MSHA measurements were compared
  – Measurements that did not agree were further studied
• Also compared the following results:
  – calibrated CDEMs
  – MSHA’s conventional laboratory LTA
• NIOSH numbered publication has been written and is undergoing review
Summary of Results

- CDEM and LTA results agreed in 88% of the MSHA measurements.
- Differences (12%) due to:
  - Inherent
    - Calibrate with 80% RD (equivalent to 81.6% TIC)
    - More ash contained in the coal
    - Dark IC material present in sample (such as black shale)
    - LTA insensitive to dust particle size
  - User variability
    - Dust sample not completely dry
    - Insufficient mixing of sample
- NIOSH retested samples resulted in 96% agreement between methods (CDEM results err on the side of safety)
Calibration

• Three dusts required:
  – Rock dust
    • Sets the light boundary
    • Must be from the mine!
  – Coal dust
    • Sets the dark boundary
    • Must be PPC!
  – 80% rock dust/20% coal dust mixture
    • Sets the distinction limit between red/green
Making Calibration Samples
Calibrating the CDEM
CDEM Operation
Summary of Method Differences

• LTA method is not itself a direct measure of explosibility
  – Surrogate that calculates a single parameter associated with full-scale experimental results
  – Insensitive to particle size
• CDEM utilizes a different approach
  – Uses optical reflectance
  – Determines the ratio of rock dust to coal dust surface area
  – Uses the “worst case” scenario with PPC
  – Based on full-scale experiments on flame propagation
• CDEM offers real-time measurements
  – Allows for immediate identification and mitigation of the problem
  – LTA results are not known for days or weeks after sample collection
Summary

- The CDEM is a useful tool for mine operators and safety inspectors to determine the explosible nature of coal and rock dust mixtures in real time.
- Unlike the CDEM, current laboratory (low temperature ashing) analysis does not account for variations in coal particle size needed for a true explosion hazard assessment.
- The CDEM can be used by mine operators and safety officials to manage their day-to-day rock dusting operations.
Questions? For More Information

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Update on Current Research

Presented by
Dan Alexander, PhD
Update on Current Research

• “Improving Coal Dust Explosion Hazard Assessment Strategies” Project
  – Dust sampling practices
  – Rock dust variability
  – Rock dusting practices
Current Sampling Procedure

- Performed every quarter
- Band sample
  - 500-ft intervals
  - 6-in wide swath on roof, ribs, and floor combined
  - Up to 1-in deep on floor
  - Mix, cone, quarter
  - Sieved through 10-mesh screen
- Spot sample
  - Inspector discretion
Current Analysis

- Laboratory analysis
  - Sieved through 20-mesh screen (850 µm)
  - Moisture analysis
  - Low temperature ash (LTA) analysis
- Total Incombustible Content = LTA + Moisture
Dust Sampling Practices

- Examining research questions such as:
  - Is the current band sampling method representative?
    - Distance and collection
  - Is the floor dust currently over-sampled?
  - Is the inaccessible side of a belt represented?
  - Does the 20 – 60 mesh portion of the band sample participate in an explosion?
Sample Depth

• Current sample depth of 1 in on the floor
• Scouring depths:
  – Near lower explosive limit full-scale explosion testing
  – 0.7 mm to 2.6 mm (1/32 in to ~1/8 in)
  – Average of 1.7 mm (1/16 in)
Hazard Identification

- The 1/8 in (2.6 mm) that is scoured and participates is overshadowed by the full 1 in (25 mm) that is sampled.
- An explosive layer of coal and rock dust can be deposited on top of pure rock dust.
- The top layer could be diluted and misrepresent the true explosion hazard.
Use of Mesh

• Commonly used to prevent skin failure
• Installed as close to the roof and ribs as possible
Hazard Identification

- The mesh can provide surfaces on which fine float coal dust could accumulate.
- The current sampling technique may push the dust behind the mesh rather than into the collection tray.
- Ventilation would then carry the dust away.
- Roof and ribs may be under-sampled.
- Dust from the areas of concern would be diluted in the 1 in depth of dust collected from the floor.
Moisture Fluctuation

- Surface water evaporates readily from dusts.
- Dust surface moisture can fluctuate greatly within a mine.
- 30 CFR 75.403-1
  - “... moisture contained in the combined coal dust, rock dust and other dusts shall be considered as a part of the incombustible content of such mixture.”
- Mine explosions occur primarily during winter season (low humidity)
- May not be prudent to include surface moisture in the total incombustible content of the sample.
- Observed crusting
Rock Dusting Practices

• Examining research questions such as:
  – What affects the ability to inert coal dust?
    • the methods and frequency of rock dust application
    • What are major contributors to float coal dust?
  – Should rock dust barriers be considered as supplemental protection in belt entries?
Coal Dust Generators

- CM sections
  - Without scrubbers
  - With scrubbers – little float dust observed
- Longwall faces – water sprays keep coal dust wet
  - Headgate from belts on intake air
  - Tailgate – observable dust travels hundreds of feet
- Belts
  - Rollers and transfers
  - Air checks
- Haulage
  - Rubber tired roadways – wet down to control dust or use chemical binders
  - Track spillage – may be a dust problem in very dry mines
Rock Dust Variability

- Examining research questions such as:
  - What affects the capacity to inert coal dust?
    - variability of rock dust composition
    - particle size distribution
Requirements

- 30 CFR § 75.2 Definitions
- Rock dust. 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 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 (SiO₂), 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.
Particle Size of Rock Dust

• Current requirements of rock dust
  – 100% pass through 20 mesh sieve (850 µm)
  – 70% pass through 200 mesh sieve (75 µm)
• Recent studies showed some rock dust did not meet requirements.
• When the rock dust met requirements, there was great variability in distribution.
• Larger rock dust particles require more rock dust to inert an explosion.
Rock Dust Inerting Research

- Use 20-L and 1-m$^3$ chambers to compare abilities of different materials and typical limestone rock dust to inert
- Full-scale explosion studies to determine the applicability of rock dust barriers as supplemental protection
Effect of Rock Dust Particle Size

Figure reproduced from BOM bulletin 369, 1933. Inerting experiments conducted using "mine-size-coal dust" consisting of 20% < 200 mesh.

- Incombustible in mixture, %
- Minus 200 mesh content of rock dust, %
Effect of Rock Dust Particle Size
(recently collected rock dust samples)

Explosion overpressure ratio, Pf/Pi

Rock dust field samples

Explosible

Non-Explosible

* All samples tested were 75% rock dust, 25% Pittsburgh pulverized coal

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Rock Dust Qualities

• How can we ensure wetted rock dust, when dried, is effectively dispersed?
• Method to assess caking tendencies
• Methods to reduce caking tendencies
  – such as adding compatible anti-caking agents
  – Reducing ultrafine particles
  – Controlling mineral content
Rock Dust Qualities

- Dust dispersion chamber
  - Apply a pulse of known pressure for a known amount of time to a layer of dust
  - Determine the amount of dust scoured
  - Determine the particle size distribution of the scoured dust at different intervals
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Questions?
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