Combustible Dust Hazards

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American Foundry Society
24th EH&S Conference
August 15, 2012
Nashville, TN

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A leading engineering & scientific consulting firm dedicated to helping our clients solve their technical problems.
Who Am I?

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- Fire Protection Engineer

  - Fire & Explosion Investigation
  - Fire Suppression & Alarm Systems
  - Hazard & Risk Analyses
  - Combustible Dust Issues

- NFPA 484 Committee for Combustible Metals
  - Alternate Member
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Combustible Dust Hazard Learning Objectives

- Hazard identification
- Historical incidents
- Safety standards
- OSHA National Emphasis Program (NEP)
- Hazard evaluation
  - Sampling & Testing
  - Process Hazard Analysis (PHA)
- Hazard control
  - Prevention: defeating the dust pentagon
  - Mitigation: containment, venting, suppression
HAZARD IDENTIFICATION
What is a Combustible Dust?

- Log: Slow Combustion
- Wood Kindling: Fast Combustion
- Wood Dust: Dust Fireball or Explosion
What is a Combustible Dust?

- **Combustible Dust.** A combustible particulate solid that presents a fire or deflagration hazard when suspended in air ... over a range of concentrations, regardless of particle size or shape.  
  \[\text{[NFPA 654]}\]

- Typically 420 microns (\(\mu m\)) or smaller
  - Passes through a U.S. No. 40 Standard Sieve

- Flakes and fibers can also be hazardous

- Agglomerations that can become dispersed

- Surface area to volume ratio > 420 \(\mu m\) → Hazardous
What is a Dust Explosion?

- **Combustible Dust**
  - Particle size
- **Air**
- **Dispersion**
- **Ignition**
- **Confinement**
- **Explosion**

[Video]
What Does a Combustible Dust Explosion Look Like?

FM Global Video
Types of Combustible Dust

- **Agricultural Products**
  - Powdered milk
  - Corn starch
  - Sugar
  - Wood flour

- **Agricultural Dusts**
  - Coffee dust
  - Cotton
  - Linseed
  - Onion
  - Potato starch
  - Wheat flour

- **Carbonaceous Dusts**
  - Activated charcoal
  - Coal
  - Petroleum coke
  - Cellulose

- **Chemical Dusts**
  - Absorbic acid
  - Calcium stearate
  - Dextrin
  - Lactose
  - Methyl-cellulose
  - Sulfur

- **Metal Dusts**
  - Aluminum
  - Bronze
  - Magnesium
  - Titanium
  - Iron & Steel

- **Plastic Dusts**
  - Epoxy resin
  - Phenolic resin
  - Poly acrylamide
  - Poly ethylene
  - Poly propylene
  - Poly vinyl chloride
Secondary Dust Explosions

- Primary Explosion
  - Initiating Event
  - Pressure Wave
  - Structural Vibration

- Fugitive Dust Dispersion
  - Dust cloud formed

- Secondary Explosion
  - Larger volume
  - More hazardous
  - Higher pressures
  - Structural damage
HISTORICAL INCIDENTS
## Recent Catastrophic Dust Explosions

<table>
<thead>
<tr>
<th>Year</th>
<th>Facility</th>
<th>State</th>
<th>Dust</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>Gray Iron Casting Foundry</td>
<td>Massachusetts</td>
<td>Phenolic Resin</td>
<td>3</td>
</tr>
<tr>
<td>2002</td>
<td>Rubber Recycling Facility</td>
<td>Mississippi</td>
<td>Scrap Tire Grindings</td>
<td>5</td>
</tr>
<tr>
<td>2003</td>
<td>Rubber Drug Delivery Products</td>
<td>North Carolina</td>
<td>Polyethylene Dust</td>
<td>6</td>
</tr>
<tr>
<td>2003</td>
<td>Fiberglass Insulation Plant</td>
<td>Kentucky</td>
<td>Phenolic Resin</td>
<td>7</td>
</tr>
<tr>
<td>2003</td>
<td>Automotive Wheel Foundry</td>
<td>Indiana</td>
<td>Aluminum Dust</td>
<td>1</td>
</tr>
<tr>
<td>2008</td>
<td>Sugar Refinery</td>
<td>Georgia</td>
<td>Sugar</td>
<td>14</td>
</tr>
<tr>
<td>2011</td>
<td>Iron Powder Production</td>
<td>Tennessee</td>
<td>Iron Powder (Dust?)</td>
<td>5</td>
</tr>
</tbody>
</table>
Common Issues

- Inadequate dust collection
- Poor housekeeping procedures
- Creation of dust clouds
- Build-up of combustible dust layers
- Poor recognition or acceptance of combustible dust hazard
- Lack of ignition source control
Jahn Foundry Explosion

- February 25, 1999 – Springfield, MA
- Resin dust explosion in the shell mold area
- Extensive damage to several buildings
- 9 Injuries
- 3 Fatalities
Jahn Foundry Explosion

- Iron castings poured into shell molds
- Molds → Mixing Sand & Phenolic Resin Binder
  - Particle size ≈ 10 – 50 microns
  - $K_{St} \approx 180 – 250$ bar-m/s (Class I – II)
  - $P_{\text{max}} \approx 8$ bar-g
  - MIE ≈ 10 – 30 mJ
- Heavy Resin Deposits
  - Inside exhaust ducts for the ovens in the shell molding stations
  - On building surfaces
Jahn Foundry Explosion

- Joint Foundry Explosion Investigation Team Investigation
- Accumulated dust disturbed
- Ignition by ovens
- Flame front through the building
- Disturbed settled dust
- Secondary explosion

Conclusions:
- Inadequate design/maintenance of the gas burner system
- Inadequate housekeeping to minimize resin accumulation
- Poor maintenance practices
OSHA NATIONAL EMPHASIS PROGRAM - NEP
2006 CSB Combustible Dust Hazard Study

- 281 dust explosions
  - 1980 – 2005
  - Various industries & materials
  - 119 fatalities & 718 injuries

- Key Findings
  - Noncompliance with recognized guidelines and standards (NFPA)
  - Poor recognition of dust explosion hazards
  - Limited OSHA regulations related to dust explosion hazards
  - No comprehensive standard for the prevention and mitigation of dust explosions

- Imperial Sugar → 2008
2006 CSB Combustible Dust Hazard Study

- **Recommendations to OSHA**
  - Train inspectors to recognize dust explosion hazards
  - Require Material Safety Data Sheets to include the hazards of combustible dusts
  - Create outreach programs to educate industries about dust explosion hazards
  - OSHA should create a general industry combustible dust standard
OSHA National Emphasis Program (NEP)

- Directive Number: CPL 03-00-008
- Effective October 18, 2007
  - Reissued March 11, 2008
  - Intensified due to Imperial Sugar
- Identified combustible dust industries
- Targeted inspections
- Outreach products and activities
- Identified OSHA regulations believed to apply to dust explosions
- Identified NFPA Standards related to combustible dust
- General Duty Clause
OSHA General Duty Clause Violations (Section 5(a)(1))

- Employment free from recognized hazards
  - Industry recognized
  - Employer recognized
  - Common-sense recognition
- Hazard caused or was likely to cause death or serious physical harm
- Feasible means to correct the hazard were available
- General duty clause citations
  - Reference consensus standards
  - Most common for combustible dust issues
- Significant increase since 2008
Most Common General Duty Clause Violations

1) Dust collector located inside building without explosion protection
2) Fugitive dust emissions
3) Dust accumulation on surfaces
4) Lack of explosion isolation on conveyor system
5) Improper ventilation
6) Lack of dust collection system
Most Common General Duty Clause Violations

7) Exhaust air circulated back into the building
8) Lack of explosion suppression system
9) Lack of interlocks
10) Equipment requires bonding to prevent static discharges
11) Inadequate housekeeping
12) Use of non-bonded or unclassified tools in the vicinity of combustible dust
SAFETY STANDARDS
NFPA Combustible Dust Standards

- **NFPA 654**
  - Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids

- **NFPA 484**
  - Standard for Combustible Metals
NFPA 654 – 2006 Edition

- Fundamental provisions for combustible dusts

- Objectives:
  1. Prevent or limit formation of hazardous atmospheres
  2. Prevent ignition of hazardous atmospheres
  3. Limit the consequences of a deflagration
     - Reduce secondary explosions

- Most recent edition: 2006
  - Returned to the committee by Association
  - Debate over new equations
  - Revised edition date: 2013
  - Tentative Interim Amendment (TIA-06) → March 2011
NFPA 654 – 2006 Edition

- Process Hazard Analysis (PHA)
- Management of Change (MOC)
- Hazard area definition
- Protection of explosion and flash fire areas
- Building construction
- Deflagration venting
- Fugitive dust housekeeping
- Ignition source control
NFPA 484 – 2012 Edition

- Applies to facilities that process, finish, handle, recycle, and store combustible metals
  - Alkali Metals
    - Lithium
    - Sodium
  - Aluminum
  - Magnesium
  - Niobium
  - Tantalum
  - Titanium
  - Zirconium
  - Other Combustible Metals

- Not specific to combustible metal dusts

- Major revisions & updates in 2012 edition
- Currently being updated for 2015 edition
NFPA 484 – 2015 Edition

- Public Input Recently Reviewed
  - July 24 – 26, 2012 Committee Meeting in Salt Lake City, UT

- Flow Charts for Navigating the Standard
  - What materials does it apply to?

- Water Reactivity Requirements → Iron & Steel
  - Contact with water
  - Automatic Sprinklers

- Flash Fire Hazard Test Methodology

- Material Properties for “Limited Hazard”

- Non-listed fire extinguishing agents
NFPA 484 – 2015 Edition

- Consolidate Common Requirements
  - Housekeeping, Electrical Classification, Dust Collection

- Location of dust collectors
  - Iron and steel operations
  - Material properties ($K_{St}$, $P_{max}$, MIE, reactivity)

- Dust layer thicknesses

- Dust Sample Collection
  - Oxidation & Inerting

- Sample Testing Schedule

- Recycling & Waste Treatment Facilities
Related NFPA Standards

- **NFPA 68** Standard on Explosion Protection by Deflagration Venting
- **NFPA 69** Standard on Explosion Prevention Systems
- **NFPA 70** National Electric Code®
- **NFPA 77** Recommended Practice on Static Electricity
- **NFPA 499** Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
- **NFPA 505** Fire Safety Standard for Powered Industrial Trucks Including Type Designations, Areas of Use, Conversions, Maintenance, and Operations
HAZARD EVALUATION
Dust Sampling

- No standard method(s)
- Representative sampling
  - Material consistency
  - Different processes
- Sample location(s)
- Sampling quantity
- Sampling method/plan
- Sample preservation
  - Oxidation of metal dusts
- Selection of test methods
Combustible Dust Testing – Combustibility

- **Trough Test**
  - Flame held to one end of powder train for 5 minutes
  - Material “combustible” if flame propagates past heated zone
Combustible Dust Testing – Explosibility

- **Screening Tests**
  - Go / No Go Test
  - Modified Hartmann Tube Apparatus
  - 20-L Sphere / Chamber

- **Full Tests**
  - 20-L Sphere / Chamber
  - Dust characterization tests
  - Multiple concentrations

- **Large-scale**
  - 1 m³ sphere
  - Marginally explosible materials
  - For overdriven tests

- **OSHA SLTC versus ASTM methods**
Properties / Tests of Combustible Dusts

- Dust Deflagration Index ($K_{st}$)
- Maximum Explosion Overpressure ($P_{max}$)
- Maximum Rate of Pressure Rise ($dP/dt$)
- Minimum Ignition Energy (MIE)
- Minimum Explosible Concentration (MEC)
- Particle size distribution
- Percent through No. 40 mesh
- Moisture content
- Limiting Oxygen Concentration (LOC)
- Dust cloud ignition temperature
- Hot Surface Ignition Temperature of Dust
- Charge relaxation time
- Chargeability & Conductivity
Dust Deflagration Index ($K_{St}$)

- Indication of dust explosion severity
- Maximum rate of pressure rise
  - Normalized to 1.0 m³
  - $K_{St} = \left(\frac{dP}{dt}\right)_{max} V^{1/3}$
- 20-L Siwek Sphere
  - ASTM 1226-10
  - 10 kJ chemical ignitor
  - Various concentrations
- Can be affected by material and the apparatus
- Different from USBM procedure
  - OSHA
## Dust Classifications

<table>
<thead>
<tr>
<th>Dust Explosion Class</th>
<th>$K_{st}$ (bar·m/s)</th>
<th>Characteristic</th>
<th>Typical Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>St 0</td>
<td>0</td>
<td>No explosion</td>
<td>Silica</td>
</tr>
<tr>
<td>St 1</td>
<td>&gt;0 to 200</td>
<td>Weak explosion</td>
<td>Powdered Milk, Charcoal, Sulfur, Sugar, Zinc</td>
</tr>
<tr>
<td>St 2</td>
<td>&gt;200 to 300</td>
<td>Strong explosion</td>
<td>Cellulose, Wood Flour, Poly Methyl Acrylate</td>
</tr>
<tr>
<td>St 3</td>
<td>&gt;300</td>
<td>Very strong explosion</td>
<td>Anthraquinone, Aluminum, Magnesium</td>
</tr>
</tbody>
</table>

The actual class is sample specific and will depend on varying characteristics of the material such as particle size or moisture.
Other Dust Test Methods

- **Minimum Explosible Concentration (MEC)**
  - Lowest concentration of dust-air mixture that will propagate a deflagration

- **Minimum Ignition Energy (MIE)**
  - Minimum ignition energy of a dust cloud in air

Modified Hartmann Tube Apparatus
Other Dust Test Methods

- **Limiting Oxygen Concentration (LOC)**
  - Minimum O$_2$ concentration that can support combustion
  - Simulate a specific process

- **Minimum Auto Ignition Temperature (MIT)**
  - Lowest temperature that will auto-ignite a dust cloud

- **Hot Surface Ignition Temperature of Dust Layers**
  - Dust layer heated on a hot plate
  - Temperature rise and/or observed combustion
Which Property is Most Important?

- It’s complicated!
- The experts don’t agree
- Requires a detailed understanding of the process
Combustible Dusts & Foundries

- **Are dusts a hazard?**
  - Most dusts are non-explosible
    - Sand
  - Weakly explosible dusts
    - 20-L Sphere versus 1 m³ Sphere
  - Dust collectors located indoors
- **Pre-coated sand versus on-site mixing**
  - Combustible/explosible binders
Process Hazard Analysis (PHA)

- Systematic analysis of hazards, consequences, and safeguards
- Consider the facility, the manufacturing operations, and the fire and explosion hazards
- Define current nature and extent of hazards
- Management of Change (MOC)
- How well do you know your manufacturing operation?
HAZARD CONTROL
Hazard Control Objectives

- Prevent or limit hazardous atmosphere
- Prevent ignition of hazardous atmosphere
- Limit consequences of fire or explosion to acceptable level
Defeating the Dust Explosion Pentagon

- Dust control
- Ignition source control
- Oxidizer control
- Dispersion control
- Confinement

Hierarchy of Safeguards
- Prevention measures – Elimination
- Protection measures – Engineering controls
- Process safety
- Training & PPE
Dust Control

- **Measures**
  - Containment
  - Leak repair
  - Dust collection
  - Housekeeping

- **Dust Accumulations**
  - Consideration of Secondary Explosions
  - Allowable depth depend on the dust

- **Dust Clouds**
Potential Areas for Dust Accumulation

- Equipment
- Floors
- Ducts
- Piping
- Roof trusses & purlins
- Wall gerts
- Suspended ceilings
- Light fixtures
- Hidden spaces
Methods for Controlling Dust Accumulation

- Dust tight equipment
- Dust collection
  - Cyclones
  - Dust Collectors
- Housekeeping
- Surfaces designed to prevent dust accumulation
- Dust accumulation inspection program
Dust Collectors / Air-Material Separators Issues

- Contain explosible concentrations
- Sufficient velocity to transport dust
- Routine inspection & maintenance
- Exhaust air discharged outside
- Collectors located outside
- Restricted employee access
Housekeeping

- Access to accumulated dust
- Proper cleaning methods
  - Vacuuming with approved vacuums
  - Sweeping with proper brooms and non-sparking scoops
  - Water wash down
  - Blowing with compressed air
    - Under certain conditions only
  - Avoid dust cloud formation!

- Cleaning Schedule
  - Based on depth and frequency
Ignition Control

- Explosion-proof electrical service
  - Class II for combustible dust
  - Division 1 or 2
    - Division I for conductive dusts

- Static electricity control
  - Bonding and grounding

- Hot work safety
  - NFPA 51B

- Control mechanical sparks & friction

- Smoking materials policy
Ignition Control

- Use of non-sparking tools
- Heating systems
  - Separated from combustible dusts
  - Elimination of open flames
- Proper use and type of industrial trucks
  - NFPA 505 for Powered Industrial Trucks
- Proper use of cartridge activated tools
- Equipment inspection, maintenance and monitoring
Dispersion Control

- Housekeeping
  - Program
  - Procedures
  - Tools
  - Training
  - Supervision
  - Inspection
  - Auditing

- Prevent/repair leaks that cause clouds
- Locate pressure relief valves away from dust hazard areas
Oxidizer Control

- Inerting processes with inert gases (NFPA 69)
  - Nitrogen
  - Argon
  - Requires oxygen monitoring

- Separation from oxidizers
Confinement Control

- Explosion containment in equipment
  - Difficult to achieve

- Explosion venting
  - Facility
  - Equipment
Explosion Venting

- NFPA 68: Standard on Explosion Protection by Deflagration Venting
- Area calculations
  - Complicated
  - Based on material properties
  - Needed pressure reduction in
- Vent ducting
- Safe venting location
Explosion Prevention & Deflagration Control

- NFPA 69: Standard on Explosion Prevention Systems
  - Oxidant concentration reduction
  - Combustible concentration reduction
  - Control of ignition sources
  - Deflagration control by suppression
  - Deflagration control by active isolation
  - Deflagration control by passive isolation
  - Deflagration control by pressure containment
Explosion Detection & Suppression

- **Detection**
  - Pressure – fixed or rate of rise
  - Radiation

- **Suppression**
  - Rapid deployment
  - Pressurized suppressant tanks with explosive actuators
  - Designed for the combustible material
  - Lock-out tag-out requirements
  - Maintenance & Inspection requirements
Additional Protection Measures

- Emergency Action Plan
- Detachment of hazards in another building
- Separation of hazards within the same room
- Segregation of hazards with barriers
- Pressure resistant construction
- Deflagration isolation devices between equipment
- Automatic sprinkler systems
  - Where appropriate → Not with reactive combustible metals
- Specialized suppression systems
- Inspection and maintenance program
Training

- Workers are the first line of defense
- Hazard Communication
  - Labeling
  - MSDS
- Hazard recognition
- Routine training
  - Refresher
  - New responsibilities
  - New processes
- Understanding combustible dust hazards!
- Understanding combustible dust fire and explosion prevention!
THANK YOU!

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