PROCESS MODERNIZATION – PROCESS SAFETY

Dust Explosion Hazards

Ashok Ghose Dastidar, PhD MBA
Vice President, Dust & Flammability Testing and Consulting Services
Disclosure

There may be references to products and/or services that are offered by Fauske & Associates, LLC (FAI) throughout this presentation.

Please note that these references are not intended as a solicitation of FAI (or other’s) products and services; but rather to provide the information and anecdotal scenarios needed to possibly prevent hazardous situations, and for your operations to be as safe as possible.
Ashok Ghose Dastidar

- B.Sc. Chemistry – Dalhousie University
- MBA – Saint Mary’s University
- Master of Applied Science – Technical University of Nova Scotia
- Ph.D. Chemical Engineering – Dalhousie University
- 22 years research in the field of dust & gas/vapor explosions
- Fauske & Associates, LLC 2007–
- Memberships – AIChE, ASTM, NFPA
- Editorial Advisory Board of Powder/Bulk Solids and Journal of Loss Prevention in the Process Industries
- Chairperson of the ASTM E27.05 Subcommittee on Dust Explosion Test Methods
Presentation Topics

- Introduction
- Review Of Recent Dust Explosions
- Hazard Identification
- Material Characterization
- Hazard Mitigation
- Questions And Answers
Dust Explosions What Are They?
Dust Fires & Explosions

Like all fires, a dust fire occurs when fuel (the combustible dust) is exposed to heat (an ignition source) in the presence of oxygen (air).

Removing any one of these elements of the classic fire triangle eliminates the possibility of a fire.
Dust explosions require the presence of two additional elements – dust dispersion and confinement.

Suspended dust burns more rapidly and confinement allows for pressure buildup; removal of either the suspension or the confinement elements prevents an explosion, although a fire may still occur.
Introduction

- Dust explosions are a serious hazard in process industries
  - Loss of land, labor and capital
- Current state – (key findings from U.S. Chemical Safety & Hazards Investigations Board (USCSB) report)
- At least 281 combustible dust fires and explosions occurred in general industry between 1980 and 2005, which
  - Caused at least 119 fatalities and 718 injuries in the United States
  - Occurred in a wide range of industries and involved many types of combustible dusts
  - Currently **NO** national standard for worker protection; OSHA has 29CFR 1910.272 (1987)
Consensus standards, developed by the NFPA, that provide detailed guidance for preventing and mitigating dust fires and explosions are widely considered to be effective, however:

- These standards are voluntary, unless adopted as part of a fire code by a state or local jurisdiction — and have not been adopted in many states and local jurisdictions, or have been modified
  - NFPA standards are part of the International Fire Code and Uniform Fire Code
  - Also, some regions have adopted NFPA 1: FIRE CODE – see Chapter 40
  - These codes are also Recognized And Generally Accepted Good Engineering Practices (REGEGAP)
Review of Historical Dust Explosions
- **Count Morozzo – Academy of Science of Turin (1795)**

- **Bakers Shop/Flour Warehouse**
  - Two injuries; one had burns from the fire, the other jumped to get away and broke his leg

- **Lessons Learned**
  - Worried about fermentation gases – known issue with flour warehouses at the time
  - Determined dust ignited
    - Fuel = flour
    - Oxidizer = air
    - Ignition source = lamp or ES
    - Dispersion = dropping flour on floor
    - Confinement = room
Grain Dust Explosions in USA

- Inland Grain Terminal, St. Joseph, MO, April 1980
  - Killed 1 person
  - Injured 4
  - $ 2 M
  - Electric arc from damaged level indicator in one of the silos. Explosion traveled though head house to other silos

- River Grain Terminal, St. Paul, MN, June 1980
  - No fatalities
  - 13 injured
  - $300K
  - Electrician working on live electrical while loading operations were taking place
  - Explosion traveled along tunnel to head house and then to bucket elevators and on into other tunnels
Grain Dust Explosions in USA (continued)

- **Train-Loading Country Grain Terminal, Fonda, IA, July 1980**
  - No fatalities or injuries
  - $30 K
  - Electrical welding on a bucket elevator. Hot work as ignition source. Traveled to other bucket elevators

- **Large Export Grain Silo Plant, Corpus Christi, TX, April 1981**
  - 9 killed
  - 30 injured
  - $30 M
  - Smoldering lumps of grain entering bucket elevator.
  - Propagated to other elevators – head house – tunnels – silos and conveyers

- **OSHA 29CFR 1910.272 in 1987**
Review of Recent Dust Explosions
North Carolina, 2003
- Plastic molding manufacturer
- Polyethylene powder
- 6 workers killed
- Hundreds of injuries
- Plant destroyed
- Facility was the major employer in area

Source: U.S. Chemical Safety & Hazards Investigations Board (USCSB)
Kentucky, 2003
Acoustic board manufacturer
Phenolic resin dust
7 workers killed
37 injuries

Source: USCSB
Hayes Lemmerz International, Inc.

- Indiana, 2003
- Aluminum casting facility
- Aluminum dust
- 1 worker killed
- Several injuries

Source: USCSB
Fugitive Dust Buildup
Cause of Secondary Explosions

Source: USCSB

Source: USCSB
Imperial Sugar

- Georgia, 2008
- Agricultural industrial facility
- Sugar dust
- 14 workers killed
- 38 Injuries
- Milling and packaging

Source: USCSB
Fugitive Dust Buildup
Cause of Secondary Explosions

Source: USCSB
The “Typical” Explosion Event

Initial Internal Deflagration

Process Equipment

Time, msec.
The “Typical” Explosion Event
(continued)
The “Typical” Explosion Event (continued)

- **Initial Internal Deflagration**
- **Process Equipment**

**Elastic Rebound Shock Waves**

Time, msec.
Explosion Types

- **Primary explosion** – usually in process equipment

- A **primary dust explosion** occurs when a dust suspension within a container, room or piece of equipment is ignited and explodes.

- A **secondary explosion** occurs when dust accumulated on floors or other surfaces is lifted into the air and ignited by the primary explosion.

*Source: USCSB*
Fugitive Dust Buildup

Source: USCSB
The “Typical” Explosion Event (continued)
The “Typical” Explosion Event (continued)
The “Typical” Explosion Event
(continued)
The “Typical” Explosion Event (continued)
The “Typical” Explosion Event (continued)

- **Secondary Deflagration Vents from Structure**
- **Process Equipment**

![Diagram showing the explosion event timeline](image-url)
The “Typical” Explosion Event
(continued)

Secondary Deflagration
Causes Collapse and Residual Fires

Time, msec.
Hazard Identification
Five elements needed to support a citation

- A hazardous condition
- A violation of an OSHA standard (or the general duty clause)
- Employee (or subcontractor) exposure
- Employer knowledge (of the condition – NOT that it was a violation of the law), and
- A feasible abatement
OSHA Has Promised Enforcement

- In a top–down fashion, using 64 SIC codes with inspections and citations utilizing the GDC
- Over 1,500 combustible dust inspections have been conducted since the NEP inception
- Over 9,000 violations! Most citations have been by way of the Hazard Communication Standard and the Housekeeping Standard
- Penalties have brought in millions of dollars
Appendix B of the dust inspection program identifies a number of questions to be asked by the OSHA inspector during an inspection focused on combustible dust.

Any inquiry into combustible dust hazards must utilize Recognized and Generally Accepted Good Engineering Practices (RAGAGEP):

- NFPA 654
- Any number of additional questions suggested by the facility operations, activities and environment.
1. What Types of Combustible Dust Does the Facility Have

- OSHA will test the dust at the lab
- Additional (less reliable) sources
  - MSDS sheets
  - Supplier data sheets and advice
  - Table 4.5.2 of NFPA 499
  - Table 1 in NMAB 353–3
2. Does the Facility Have a Housekeeping Program with Regular Cleaning Frequencies

- Is it established for floors and horizontal surfaces, such as ducts, pipes, hoods, ledges and beams to minimize dust accumulations?
- Is the dust on floors, structural members and other surfaces removed concurrently with operations?
- Is there dust accumulation of 1/32 inch thick or greater?
- What are the dimensions of
  - The room
  - The area covered with the dust
# Fugitive Dust Accumulations

<table>
<thead>
<tr>
<th>Depth of Dust Accumulation (in.)</th>
<th>Frequency</th>
<th>Housekeeping Requirements</th>
<th>Area Electrical Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1/32</td>
<td>Continuous / frequent</td>
<td>Clean up as necessary to maintain an average accumulation below 1/64 in.</td>
<td>Unclassified; however, electrical enclosures should be dust tight</td>
</tr>
<tr>
<td>1/32 to 1/8</td>
<td>Infrequent</td>
<td>Clean up during same shift</td>
<td>Unclassified; however, electrical enclosures should be dust tight</td>
</tr>
<tr>
<td>1/32 to 1/8</td>
<td>Continuous / frequent</td>
<td>Clean as necessary to maintain an average accumulation below 1/16 in.</td>
<td>Class II, Division 2</td>
</tr>
<tr>
<td>&gt; 1/8</td>
<td>Infrequent</td>
<td>Immediately shut down and clean</td>
<td>Class II, Division 2</td>
</tr>
<tr>
<td>&gt; 1/8</td>
<td>Continuous / frequent</td>
<td>Clean at frequency appropriate to minimize accumulation</td>
<td>Class II, Division 1</td>
</tr>
</tbody>
</table>
3. Are the Dust–Containing Systems Properly Designed

- Are the dust–containing systems (ducts and dust collectors) designed (so) that fugitive dusts are not allowed to accumulate in the work area?
- No fugitive dust
4. Are Dust Collectors Greater Than 8 Cubic Feet in Volume Located Inside of Buildings

- Outside location
- Engineered containment
- Venting to outside
- Suppression
5. If Dust Explosion Hazards Exist in Rooms, Buildings or Other Enclosures

- Do such areas have explosion relief venting distributed over the exterior walls of buildings and enclosures?
- Is such venting directed to a safe location away from employees?
6. Are There Isolation Devices to Prevent Deflagration Propagation Between Pieces of Equipment Connected by Ductwork

- Chokes
- Flame front diverters
- Rotary valves
- Automatic fast-acting valves
- Chemical isolation systems
7. Is There an Ignition Control Program

- Is there an ignition control program (grounding and bonding and other methods of dissipating electrostatic charge for ductwork)?
- NFPA 77 for Electrostatic Hazards
8. Are There Separator Devices to Remove Foreign Materials Capable of Igniting Combustible Dusts

- Separators
  - Magnets
    - Permanent
    - Electromagnets with power indicator
  - Pneumatic
  - Grating devices
9. Are Electrically-Powered Cleaning Devices Approved for the Hazard Classification

- Such as sweepers or vacuum cleaners used in dusty areas
- See 1910.307
- Hardware Store “Shop-vacs” are not permitted in classified locations
10. Is Smoking Permitted Only in Safe Designated Areas

- Are areas where smoking is prohibited posted with "No Smoking" signs?
- Rules followed in all locations?
- How often do you audit?
- How often do you train employees and contractors?
11. Is the Exhaust From the Dust Collectors Recycled

- NFPA 654 (2006)
  - Requires discharge to a restricted area, away from intakes
  - Recycling to the pneumatic conveying system is permitted

- Return to building air prohibited where
  - Recycle air at < 99.9% efficiency of 10 µm
  - Return of energy from a fire or explosion
  - Recycle of air where hybrid mixtures, gases or vapors are involved
  - Recycling of exhaust that reduces building air to < 19.5% oxygen
12. Does Dust Collector System Have Protection

- Does the dust collector system have spark detection and explosion/deflagration suppression systems?
- Are they sized properly?
- Do you have documentation and engineering designs?
- There are alternative measures covered later in this lecture
13. Are All Components of the Dust Collection System Constructed of Noncombustible Materials

- Big: PVC or other similar duct materials are powerful static accumulators — and combustible, as well
- Transparent view ports may
  - Disrupt electrical continuity
  - Generate static
- Temporary expedients can be a hazard

Note: Dust collector bags are typically combustible
14. Are Ducts Designed to Maintain Sufficient Velocity to Ensure the Transport of Both Coarse & Fine Articles

- Various requirements
- $\sim 18 m/s - 1068 m/min$
- 3560 ft/min
- Higher velocities may be required for denser dusts/powders
- How often do you audit?
- Alarms or warnings for low velocity?
15. Are Duct Systems, Dust Collectors & Dust-Producing Machinery Bonded & Grounded

- Conductive parts can be:
  - Grounded individually
  - Bonded together and grounded
- See NFPA 77
- How often do you audit?
- Is it mentioned on your PM schedule?
- On training documents?
16. Is Metal Ductwork Used

- Worth repeating!!!
- PVC plastic or other similar duct materials are powerful static accumulators — and combustible, as well
17. In Areas Where a Hazardous Quantity of Dust Accumulates or is Present in Suspension in the Air, Does all Electrical Wiring & Equipment Comply with (1910.307) Requirements

- ES and IS calculations
- $K_{St}$, $P_{\text{max}}$, MEC, MIE and MIT data
- Compare with PPC
- Looking at Class II Division 1 and Division 2 locations
- May wish to look at European Zone 20, 21 and 22 classification
  - ATEX requirements in place for decades – rated equipment readily available
18. Does Dust Collector System Have Protection

- NFPA 654 requires a hot work permit system for all:
  - Cutting and welding
  - Grinding, chipping
  - Other operations that produce sparks or open flame
  - Use of cartridge activated tools
19. Are Bulk Storage Containers Constructed of Noncombustible Materials

- Intent is to not exceed the capabilities of the fire protection system
- Metal bins are typical
- In corrosive environments and for some other process reasons
  - Bins may be fabricated from combustible high density plastic
    - Polyethylene or Polypropylene
  - Product must not be static generation (triboelectric)
20. Does the Company Use Methods to Dissipate Static Electricity, Such as by Bonding & Grounding

- For static generating dusts
- Small particle size
- What to do
  - Bonding and grounding
21. Are Employees Who are Involved in Operating, Maintaining & Supervising Facilities That Handle Combustible Dust Trained in the Hazards of the Combustible Dust

- Initial training
- Refresher
- Procedures — operations, maintenance and emergency
- Know about Management of Change (MOC) policies and issues
- Audit knowledge? How often?
Operations, Supervisory & Maintenance Staff Need to Know

- Hazards
- Orientation and safety rules
- Operations and upsets
- Fire and explosion protection
- Maintenance and housekeeping
- Emergency response plans
- Management of Change (MOC)
22. Are MSDS’ for the Chemicals Which Could Become Combustible Dust Under Normal Operations Available to Employees

- Must be available
- May not be accurate
- Employees trained in their use?
- Audit knowledge? How often?
Where Do Combustible Dust Incidents Happen?

Insurance Company Perspective

- Food Products: 24%
- Primary Metal Industries: 8%
- Rubber & Plastic Products: 8%
- Electric Services: 8%
- Lumber & Wood Products: 15%
- Chemical Manufacturing: 12%
- Equipment Manufacturing: 7%
- Fabricated Metal Products: 7%
- Other: 7%
- Furniture & Fixtures: 4%
- Manufacturing: 7%

Source: FM Global
What Materials Are Involved in Combustible Dust Incidents?

Source: FM Global
Components of a Combustible Dust Program

1) Management of Change Program
2) Process Hazard Analysis
3) Housekeeping Plan
4) Mitigation of the Hazard
5) Maintenance and Inspection
6) Employee Training
“Management of Change” Requirement

- Management of Change: Written procedures — to manage change to process materials, technology, equipment, procedures and facilities — shall be established and implemented

- The Management of Change procedures shall ensure that the following issues are addressed prior to any change
  - The technical basis for the proposed change
  - The safety and health implications
  - Whether the change is permanent or temporary
  - Modifications to operating and maintenance procedures
  - Employee training requirements
  - Authorization requirements for the proposed change
Process (Dust) Hazard Analysis

1. Collect Relevant Data
2. Devise and Implement Hazard Mitigation Plans
3. Conduct Facility Walk-Through
4. Risk Assessment
5. Start Hazard Evaluation

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What is Included in a Process (Dust) Hazard Analysis?

- The design of the processes and facilities shall consider the physical and chemical properties that establish the hazardous characteristics of the materials.
- The design of the fire and explosion safety provisions shall be based on a process hazard analysis of the facility, the process and the associated fire or explosion hazards.
- The results of the process hazard analysis shall be documented and maintained for the life of the process.
- The process hazard analysis shall be reviewed and updated, at least every 5 years.
Housekeeping Requirements for Dust Control

- Continuous suction, to minimize the escape of dust, shall be provided for processes where combustible dust is liberated
- The dust shall be conveyed to dust collectors
- Equipment shall be maintained and operated in a manner that minimizes the escape of dust
- Regular cleaning frequencies shall be established, within operating areas of the facility, to minimize dust accumulation
  - Dust layers on floors, walls and horizontal surfaces less than 1/32”
  - Use of safe cleaning methods and devices
- Surfaces shall be cleaned in a manner that minimizes the generation of dust clouds
Cleaning methods that produce dust clouds — such as vigorous sweeping or blowing down with steam or compressed air — shall be permitted only if the following requirements are met:

- The area and equipment shall be vacuumed, prior to blow down, with low pressure steam or compressed air.
- Electrical equipment not suited for Class II locations, and other sources of ignition, shall be shut down or removed from the area (avoid hot surfaces).
- Only a low gauge pressure steam or compressed air — not exceeding a gauge pressure of 15 psi (103 kPa) — shall be used.
- No hot surfaces or flames that are capable of igniting a dust cloud or layer shall exist in the area.
Components of a Combustible Dust Program

- Mitigation of the hazard
  - Covered in the next section

- Maintenance and inspection
  - Written schedules and logs
  - Primarily looking at ignition source control

- Employee training
  - Dust explosion awareness
  - How their operations can affect dust explosion safety
Material Characterization
Combustible Particulate Solid

- Any combustible solid material composed of distinct particles or pieces; regardless of size, shape or chemical composition (NFPA 654-2013)
- Includes dusts, fines, fibers, flakes, chips, chunks, or a mix of these
- Model building codes (e.g. International Building Code — do not have a definition)
Dust

- Traditionally defined as a solid 420 – 500 µm or smaller
- Combustible dust is a particulate solid that presents a fire or deflagration hazard when suspended in air or oxidizing atmosphere over a range of concentrations, regardless of shape or size
- Definitions are confusing because they are used interchangeably with combustible particulate solid
NFPA Dust Hazard Standards

- NFPA publishes 5 occupancy standards that are focused on dust explosion hazards
  - NFPA 652
    - NFPA 654
    - NFPA 61
    - NFPA 664
    - NFPA 484
    - NFPA 655

- NFPA publishes 7 design standards referenced in the 5 occupancy standards
  - NFPA 68
  - NFPA 69
  - NFPA 91
  - NFPA 13
  - NFPA 15
  - NFPA 72
  - NFPA 70 – NEC
    - NFPA 499
    - NFPA 77

- New overall standard covering dust explosions
- Addresses theoretical/fundamental aspects of dust explosibility and combustibility
- The “shadow” Correlating Committee then pushes down the requirements to the industry specific standard
- Industry specific standard can adopt or reject with reason
- The industry specific standard is enforced
Future Framework

NFPA 652

NFPA 68, 69, 70 etc.

NFPA 61
NFPA 484
NFPA 664
NFPA 654

ASTM
Explosion Severity
\((P_{\text{max}} \text{ and } K_{\text{St}})\) ASTM E1226

- Determined in a 20-L or 1-m³ chamber
- Indication of the severity of an explosion
- Data used in the design of explosion protection devices
  - \(P_{\text{max}} = \text{maximum pressure}\)
  - \(K_{\text{St}} = (dP/dt)_{\text{max}} \times V^{\frac{1}{3}}\)
- New addition of “Go/No Go” explosibility screening test
20-L Siwek Test Chamber

10 kJ ignition source

Source: Fauske & Associates, LLC
1–m³ FAI Chamber
Maximum Explosion Overpressure Generated in the Test Chamber

- Used to design enclosures and predict the severity of the consequence
  - The higher the number the more severe the dust deflagration will be
    - If an enclosure is constructed to withstand this pressure failure, explosion venting or suppression is not required

<table>
<thead>
<tr>
<th>Dust</th>
<th>$P_{\text{max}}$</th>
<th>Dust</th>
<th>$P_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>8.5</td>
<td>Aluminum</td>
<td>12.4</td>
</tr>
<tr>
<td>Cellulose</td>
<td>9.7</td>
<td>Magnesium</td>
<td>17.5</td>
</tr>
</tbody>
</table>
Different for every dust, and determined only by testing. NFPA and OSHA require that each dust be tested and documented; the use of industry standards or other generic data is not allowed.

- Any dust with a $K_{St} > 0$ requires a documented process analysis and explosion protection.
- The same dust can have different $K_{St}$.
- The higher the number the more “explosive” the dust is.
## Hazard Classes of Dust Deflagration – Based on $K_{St}$

<table>
<thead>
<tr>
<th>Hazard Class</th>
<th>$K_{St}$ (bar–m/sec)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>St–1</td>
<td>&lt; 200</td>
<td>Bronze 31</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bituminous Coal 129</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sugar 138</td>
</tr>
<tr>
<td>St–2</td>
<td>200–300</td>
<td>Cork 202</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cellulose 229</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phenolic Resin 269</td>
</tr>
<tr>
<td>St–3</td>
<td>&gt;300</td>
<td>Aluminum Dust 415</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnesium 508</td>
</tr>
</tbody>
</table>
Minimum Explosible Concentration (MEC) ASTM E1515

- Lowest dust concentration that will propagate an explosion
  - Analogous to the Lower Flammability Limit (LFL) for gas/air mixtures
  - The lower the number, the less dispersed dust required for a dust deflagration

<table>
<thead>
<tr>
<th>Dust</th>
<th>MEC (g/m³)</th>
<th>Dust</th>
<th>MEC (g/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar</td>
<td>200</td>
<td>Aluminum</td>
<td>30</td>
</tr>
<tr>
<td>Cellulose</td>
<td>80</td>
<td>Magnesium</td>
<td>30</td>
</tr>
</tbody>
</table>
Industrial hygiene levels lower than explosible range

Dust deposits are above explosible range, but may move down

MEC concentrations achievable if dust is present in large quantities
Limiting Oxygen Concentration (LOC) ASTM E2931

- Minimum quantity of oxygen required to propagate an explosion
  - Dust concentration independent
  - Data can be used to develop an inerting strategy
  - Start at optimal concentration
  - Once established, test several other concentrations to verify

- Limiting the oxygen concentration of the air surrounding the dust is a method of explosion control
This can be achieved by inerting the atmosphere with non-flammable gas
- (nitrogen, carbon dioxide, argon)

<table>
<thead>
<tr>
<th>Dust</th>
<th>Diameter (µm)</th>
<th>LOC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>Anthracite coal</td>
<td>17</td>
<td>14</td>
</tr>
<tr>
<td>Sulfur</td>
<td>30</td>
<td>7</td>
</tr>
<tr>
<td>Wood</td>
<td>27</td>
<td>10</td>
</tr>
</tbody>
</table>
Predicts the ease and likelihood of ignition of a dispersed dust cloud

MIE of a flammable dust is the minimum spark energy needed to ignite an ideal concentration under lab conditions

- A capacitive discharge spark is used for this test
- Test can be run with or without inductance
- Compared to typical ES ignition sources
Minimum Ignition Energy (MIE) ASTM E2019
(continued)

Source: Fauske & Associates, LLC
Examples: sugar (powdered) 30 mJ, paper dust 20–60 mJ, aluminum 50 mJ, magnesium 40 mJ

<table>
<thead>
<tr>
<th>MIE (mJ)</th>
<th>Recommended Precaution per BS 5958</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>Low sensitivity to ignition; ground plant below this level</td>
</tr>
<tr>
<td>100</td>
<td>Consider grounding personnel below this level</td>
</tr>
<tr>
<td>25</td>
<td>The majority of ignition incidents occur below this level</td>
</tr>
<tr>
<td>10</td>
<td>High sensitivity to ignition. Consider restrictions on the use of high resistivity non-conductors below this level</td>
</tr>
<tr>
<td>1</td>
<td>Extremely sensitive to ignition at this level. Handling operations should be such that they minimize the possibility of suspending the powder in air.; dissipate or discourage charge operations</td>
</tr>
</tbody>
</table>
Minimum Autoignition Temperature of a Dust Cloud (MIT) ASTM E 1491

- Measures the sensitivity to hot surfaces and environments
  - Hot surfaces in dryers, bearings and mechanical parts
  - Friction spark ignition with MIE data
  - Maximum exposure temperature

Source: Fauske & Associates, LLC
Autoignition Temperature of a Dust Layer (LIT) ASTM E2021

- Sensitivity to ignition on hot surfaces
  - Other side room temperature
- Longer exposure time (1 – 2 hr)
  - LIT is typically lower than MIT
    - Some materials melt before reacting
  - Not a true minimum since layer thickness affects results

Source: Fauske & Associates, LLC
# Typical Ignition Temperature of Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Mean Particle Size ($\mu$m)</th>
<th>MIT Cloud (°C)</th>
<th>AIT Layer (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>200</td>
<td>480</td>
<td>450</td>
</tr>
<tr>
<td>Aluminum</td>
<td>70</td>
<td>560</td>
<td>450</td>
</tr>
<tr>
<td>Iron</td>
<td>32</td>
<td>520</td>
<td>450</td>
</tr>
<tr>
<td>Melamine Resin</td>
<td>56</td>
<td>470</td>
<td>500</td>
</tr>
<tr>
<td>Coffee</td>
<td>10</td>
<td>470</td>
<td>450</td>
</tr>
<tr>
<td>Wood Dust</td>
<td>14</td>
<td>420</td>
<td>335</td>
</tr>
<tr>
<td>PVC emulsion</td>
<td>73</td>
<td>700</td>
<td>450</td>
</tr>
</tbody>
</table>

Data from BGIA
Characterizing a Dust’s Hazard

**Deposited Dust**
- Ignitability
- Flammability
- Ignition Temp. on Hot Surface
- Self-Ignition Properties
- Exothermic Decomposition
- Impact Sensitivity
- Electrostatic Properties

**Dust in Cloud Form**
- Explosible / Nonexplosible
- Min. Explosion Dust Concentration
- Minimum Ignition Energy
- Max. O₂ Conc. For Inerting
- Max. Explosion Pressure
- Max. Rate of Pressure Rise
- Properties of Hybrid Clouds (Explosible Gas Mixed w/Dust)
- Electrostatic Properties

**Smoldering Gases**
- Ignitability of Gas
- Explosibility of Gas
- Minimum Smoldering Temperature of Dust

**Chemical Composition**
- Melting Point
- Heat of Combustion

**Identification**

**Sample Modification**
- Overall Test Sample
- Sample Splitting
- Moisture Content

**Original Dust Sample**
Variables effecting output

- Dust properties
  - (type, size and exposed surface area)
- Nature of oxidative atmosphere
  - (sensitivity to oxygen or other oxidizer)
- Dispersion mechanisms
  - (lofting of powder – light or fine powders stay lofted)
- Type / magnitude and location of ignition
  - (low energy ignition or self ignition – fine powder)
- Nature of confinement
  - (volume, yield strength and initial pressure)
Hazard Mitigation
Hazard mitigation methods include
- Dust control with an effective housekeeping program
- Containment and removal of combustible dust
- Process equipment and facility design
- Ignition source control
Targeted Strategy to Handle Combustible Dust Hazards

- Equipment protection
  - Ignition source avoidance
  - Oxidant concentration reduction
  - Fuel concentration reduction
  - Deflagration venting
  - Deflagration pressure containment
  - Deflagration suppression systems
  - Isolation of equipment
Sources of Ignition

- Ignition sources that can be effective, by way of proper work practice controls
  - Smoking
  - Open flames
  - Open light (bulbs)
  - Welding
  - Abrasive cutting
  - Grinding
  - Anti-static clothing
Sources of Ignition (continued)

Ignition sources that are part of the process
- Open flames
- Hot surfaces on process and electrical equipment
- Smoldering or burning conveyed process materials
- Mechanical impact creating heat or sparks
- Electric sparks from equipment
- Electric sparks from electrostatic discharges
- Exothermic reactions
Explosion Prevention Systems: Passive Vents

Source: Fike

Source: Rembe
Explosion Protection Systems: Flameless Vent (continued)

Source: Rembe
Deflagration Chemical Suppression for a Dust Collector

Ignition Occurs
Explosion Detected
Suppression begins
Suppression continues
Total Suppression

Time: 0 msec 20 msec 30 msec 40 msec 80 msec
Deflagration Propagation
With Vent but Without Isolation

[Diagram showing a cyclone and dust collector with labels for vessel rupture, deflagration propagation, pressure and flame venting, ignition point, and vent.]
Deflagration Propagation Using Flame Front Diversion
Explosion Prevention Systems: Passive Inlet Isolation

Source: Rembe
Deflagration Propagation Using Mechanical Isolation

Diagram of a cyclone and dust collector system with an isolation valve and ignition point.
Explosion Prevention Systems: Isolation by Suppression
Deflagration Propagation Using Chemical Suppression for Isolation
The End