Brief review of dust explosion test methodologies – peaks and pitfalls

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- On NFPA Technical Committees for: 654, 61, 664, 484, 91 and 655
- On Editorial Advisory Board of Powder/Bulk Solids
- On Editorial Board of Journal of Loss Prevention in the Process Industries
Dust Explosions in Industrial Systems
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.
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)
Recent Major Dust Explosions

- February 2003 – CTA Acoustics – Corbin, Kentucky – fiberglass binder dust – 1 fatality several injured
- October 2003 – Heyes Lemmerz – Huntington, Indiana – Aluminum Dust – 1 fatality several injured
- February 2008 – Imperial Sugar – Port Wentworth, Georgia – Sugar dust – 14 Fatalities 38 Injured
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)
NFPA Dust Hazard Standards

- NFPA publishes “6” 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 “6” occupancy standards
  - NFPA 68
  - NFPA 69
  - NFPA 91
  - NFPA 13
  - NFPA 15
  - NFPA 72
  - NFPA 70 – NEC
    - NFPA 499
    - NFPA 77
Testing Methods
Screening Tests
Is My Material Combustible?

Two main tests
- Determination of Combustibility
  • UN Test N.1 (4.1) – Test Method for Readily Combustible Solids
  • Identifies if the material presents a fire hazard
- Determination of Explosibility
  • ASTM E1226 – Go/No Go Methodology
  • ASTM E1515 – Minimum Explosible Concentration
Combustibility Screening Test

- Duration of ignition source can influence combustibility
  - Metals and nonmetals have different flame-dwell times
  - What about mixtures?
- Samples could melt and pose a pool fire hazard
  - Not reflected in the method
Electric Arc versus Pyrotechnic Igniter

Electric Arc can ignite metals

Pyrotechnic Igniter may not ignite some metals

Source: Fauske & Associates, LLC
Explosibility Screening Test
Explosion Severity

\((P_{\text{max}} \& K_{St})\) 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
  - \(P_{\text{max}} = \) maximum pressure
  - \(K_{St} = (dP/dt)_{\text{max}} \times V^{\frac{1}{3}}\)
  - 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
- New addition of “Go/No Go” explosibility screening test
20-L Siwek Test Chamber

10 kJ ignition source

Source: Fauske & Associates, LLC
Pressure–Time Data From an Experiment

- Pressure is plotted as the ordinate
- Time is plotted as the abscissa
- The peak of the pressure–time plot is the highest pressure generated in the explosion for the test
- The rising slope of the pressure–time plot is the rate of pressure rise for the test
Explosion Parameters as a Function of Dust Concentration

- Peak explosion data plotted as a function of dust concentration
- The highest point is the $P_{\text{max}}$
- In this graph for niacin, the $P_{\text{max}}$ is 7.9 bar(g) at 500 g/m$^3$

- Rate of pressure rise data plotted as a function of dust concentration
- The highest point is the $(dP/dt)_{\text{max}}$
- In this graph for Niacin, the $(dP/dt)_{\text{max}}$ is 930 bar/s
Overdriving the Explosion

- Can occur in:
  - E1226 \([P_{\text{max}} \& K_{\text{St}}]\)
  - E1515 [MEC]
  - E2931 [LOC]
- Burning of the dust in the igniter flame
- Igniter flame preheats cloud
- Exacerbate explosion severity and potential

20-L Test Chamber
Underdriving the Explosion

- Can occur in:
  - E1226 \([P_{\text{max}} & K_{\text{St}}]\)
  - E1515 [MEC]
  - E2931[LOC]

- Vessel wall cools the flame

- Diminished explosion severity and potential

20-L Test Chamber
Ignition Source for Explosion Severity Test
Spherical 1–m³ Chamber

- Original ISO test vessel
  - 20–L developed to replicate results
- ~ 1000 Liters
- Uses 10–kJ ignition source
- However;
  - Uses large quantities of sample
  - Cumbersome and unwieldy to operate

Source: Fauske & Associates, LLC
These Phenomena Not Possible In The 1 m³ Chamber

Overdriving

Underdriving
Data Interpretation Tips

- Identify what apparatus is being used.
  - 20L Vessel has potential for under-driving & over-driving
  - Bureau of Mines Chamber only adequate for determining if a material is explosible

- If over-driving is suspected consider 1 m$^3$ Challenge Test
  - Low $K_{St} < 50$ bar·m/s
  - Low $P_{max} < 3$ bar
Minimum Autoignition Temperature of a Dust Cloud (MIT) ASTM E1491

- Measures the sensitivity to hot surfaces and environments
  - Hot surfaces in dryers, bearings and mechanical parts
  - Maximum exposure temperature
- Materials that do not ignite with ignition source may autoignite

Source: Fauske & Associates, LLC

Proprietary property of Fauske & Associates, LLC
Minimum Ignition Energy (MIE) ASTM E2019

- 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 electrostatic ignition sources
  - Exact method not always indicated – may lead to overly conservative strategy
Minimum Ignition Energy (MIE) ASTM E2019 (continued)
Minimum Ignition Energy Test
- 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>
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<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
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
Layer Ignition Test

- MIT values can be affected by oven geometry
  - horizontal vs vertical
- LIT can be affected by layer thickness
  - 12.5mm vs 5mm
Practical Use of MIT and LIT Data

- Can be used to determine maximum allowable surface temperatures of equipment.
  - Organic dusts that may dehydrate or carbonize
    - Maximum surface temperature must not exceed the lower of either the ignition temperature (MIT/LIT) or 165°C

<table>
<thead>
<tr>
<th>Maximum Temperature °C</th>
<th>Temperature Class °F</th>
<th>Temperature Class (T Code)</th>
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<tbody>
<tr>
<td>450</td>
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<td>85</td>
<td>185</td>
<td>T6</td>
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Dust Explosion & Fire Characteristics

- 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 & location of ignition
    - (low energy ignition or self ignition – fine powder)
  - Nature of confinement
    - (volume, yield strength and initial pressure)
The End