Fundamentals of Combustible Dust

DOE Fire Protection Conference
Las Vegas, Nevada
May 15, 2012
Robert Bitter, PE
All data prepared, analyzed and presented has been developed in a specific context of work and was prepared for internal evaluation and use pursuant to that work authorized under the prime contract between the U.S. Department of Energy and Honeywell Federal Manufacturing & Technologies. LLC. Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or Honeywell Federal Manufacturing & Technologies, LLC.
Existing Facility

- 136 land acres
- 38 buildings
- 3.2M sq. ft.
- $3.0B total value
- ~50 MFL areas
- Largest MFL - $250M
- ~2510 FTES
New Facility (will be completed this year)

- Leased bldg.
- Located in south KC
- 7 miles south of current facility
- 191 land acres
- 5 buildings
- 1.5M sq. ft.
- $650M bldg. cost
- $1.2B total project cost (including move cost)
- Manufacturing Bldg. MFL
  - Manuf. – $411M
  - Stores - $1B
- ~3200 FTES
- Move –in
  - Start 1/2013
  - End 7/2014
Back to Combustible Dust
Recent Grain Elevator Explosion

- Atchison, KS
  - 50 miles NW of KC
- Oct. 29, 2011
- Bartlett Grain
- 6 killed
- OSHA fine $406K
  - Accumulation of grain dust
  - Removing dust without shutting down electrical
  - Ordinary electrical
Other Major Explosions

CTA Acoustics Corbin, KY
2/20/2003 – 7 injured
Resin dust ignited by oven

Imperial Sugar, Savannah, Georgia 2/7/08 - 14 dead – 38 injured
Accumulation of sugar dust in packaging

West Plains Pharmaceutical Kinston, NC
2/29/2003 – 6 dead – dozens injured
Plastic powder above suspended ceiling ignited

Although we don’t have this type of hazard, there can still be issues
Some Equipment Used at the KCP (and probably at your facility)

Surface Grinder Tool Room

Small Torit for Bench Grinder
Some Equipment Used at the KCP (and probably at your facility)

Plastic Media Blaster
P\text{max} = 5.24 \text{ bar}
K\text{st} = 58
\text{MIE} > 5 \text{ kJ}

Low K\text{st} with high ignition energy = pretty safe but______ ??
Some Equipment Used at the KCP (and probably at your facility)

SS White Glove box
Air abrasive jet machine
connected to a 2x2x3 Torit dust collector
Kst - 23
Some Equipment Used at the KCP (and probably at your facility)

Transverse Saw CE68074

Is this stuff combustible dust? Fire hazard but not explosion hazard
Some Equipment Used at the KCP (and probably at your facility)

- Nylon powder as fine as flour
- MIE = 7 mJ
Some Equipment Used at the KCP
(and probably at your facility)

Clean Room Central Vacuum
Is this stuff combustible dust?
Dust Explosion Basics

Dust Explosion Pentagon

Figure 2. Dust explosion pentagon
What is a Combustible Dust?

• Old definition – size matters
  – Particles < 420 micron (µm)
  – 420 micron = 0.0165 in.

• Current definition - A combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape. (no size indicated)

Ya gotta test to be sure
Characteristics of explosive dust normally fall within two groups:

1. Likelihood of an Explosion - Ignition sensitivity
   - Min Explosible Concentration (MEC)
   - Min Ignition Energy (MIE)

2. Consequence of an Explosion - Explosion severity
   - Max Explosion Pressure (Kst)

Combination of the likelihood and consequence defines the explosion risk.
<table>
<thead>
<tr>
<th>Dust Characteristic (PSI)</th>
<th>Test Symbol</th>
<th>Units</th>
<th>When the Test is Conducted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Particle size and particle size distribution</td>
<td>d</td>
<td>μm</td>
<td>To determine the size and size distribution of a sample. All four generic hazards</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(toxicity, combustibility, reactivity and instability) generally increase with decreasing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>particle size. Some ASTM dust-characterization test procedures specify a particle size</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>of 95% &lt;75 μm. Some organizations request “as received” testing to characterize the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>uniqueness of a sample.</td>
</tr>
<tr>
<td>2. Water content of a powder</td>
<td>WC</td>
<td>wt. %</td>
<td>To determine the moisture content of a given sample. Some ASTM dust-characterization</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>test procedures specify a moisture content. Some organizations request “as received”</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>testing to characterize a sample’s uniqueness.</td>
</tr>
<tr>
<td>3. Maximum explosion pressure</td>
<td>$P_{max}$</td>
<td>barg</td>
<td>To determine whether a dust is combustible and the degree of explosion hazard. One test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>determines $P_{max}$, ($dP/dt)<em>{max}$, and $K</em>{st}$.</td>
</tr>
<tr>
<td>4. Maximum rate of pressure rise and deflagration index</td>
<td>$dP/dt$, $K_{st}$</td>
<td>bar-m/s</td>
<td>Used as input in explosion-protection system design. This is typically one of the first</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>tests recommended to determine whether dust is explosive and the degree of explosion</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>hazard. One test determines $P_{max}$, ($dP/dt)<em>{max}$, and $K</em>{st}$.</td>
</tr>
<tr>
<td>5. Minimum ignition energy</td>
<td>MIE</td>
<td>mJ</td>
<td>To determine the energy required for ignition. MIE &lt;100 mJ indicates a potential for</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ignition from static discharges from personnel; MIE &lt;25 mJ indicates a potential for</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ignition from static discharges during bulking of powders. If MIE &lt;30 mJ, resistivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>testing and charge relaxation testing is typically required.</td>
</tr>
<tr>
<td>6. Surface resistivity and volume resistivity</td>
<td>$\sigma_v$, $\sigma_t$</td>
<td>ohm-cm</td>
<td>To assess electrostatic hazard. Resistivity $&gt;10^9$ Ω-cm poses a hazard.</td>
</tr>
<tr>
<td>7. Electrostatic decay and dielectric constant</td>
<td>$k(t)$, $\tau$</td>
<td>s</td>
<td>To determine if an electrostatic hazard from powder exists. Data on dielectric constant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>with charge relaxation time is needed if MIE $&lt;30$ mJ.</td>
</tr>
<tr>
<td>8. Minimum autoignition temperature of a dust cloud</td>
<td>MAIT$_{dust}$</td>
<td>°C</td>
<td>To assess a dust’s sensitivity to hot surfaces, such as dryers, bearings, and other</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>mechanical parts.</td>
</tr>
<tr>
<td>9. Limiting oxygen concentration</td>
<td>LOC</td>
<td>vol.%</td>
<td>To determine the lowest concentration of oxygen that will propagate a flame. LOC is</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>needed if inerting is the basis of safety for explosion prevention.</td>
</tr>
<tr>
<td>10. Minimum explosive concentration</td>
<td>MEC</td>
<td>g/m³ or</td>
<td>To determine the minimum concentration of dust in air that will propagate a flame. MEC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>vol.%</td>
<td>is required if dilution is the basis of safety for explosion prevention.</td>
</tr>
<tr>
<td>11. Minimum ignition temperature of a dust layer (smoldering temperature)</td>
<td>ST</td>
<td>°C</td>
<td>To determine whether a dust is sensitive to hot surfaces. ST is typically lower than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MAIT.</td>
</tr>
<tr>
<td>12. Autoignition temperature of a dust deposit</td>
<td>AIT</td>
<td>°C</td>
<td>To determine whether a dust is sensitive to hot surfaces. AIT is typically lower than</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MAIT.</td>
</tr>
<tr>
<td>13. Thermal stability</td>
<td>DSC</td>
<td>cal/g</td>
<td>To screen for self-reactivity hazards.</td>
</tr>
</tbody>
</table>
Determining Pmax

- Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dust
- ASTM E1226
- Igniter = 5kJ
- Dust concentrations are increased to achieve maximum pressure (Pex)
  
  \[ P_{\text{max}} = \text{average of 3 } P_{\text{ex}} \]
### Pmax and Kst

Maximum rate of pressure rise = Pmax

Because Pmax is volume dependent, it is converted to Kst to normalize independently of volume

$$Kst = (dP/dt)_{max} \times V^{1/3}$$

**Kst Classes and Examples**

<table>
<thead>
<tr>
<th>Dust explosion class*</th>
<th>Kst (bar.m/s)</th>
<th>Characteristic</th>
<th>Typical material</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>No explosion</td>
<td>Silica, Sodium Bicarb</td>
</tr>
<tr>
<td>1</td>
<td>&gt;0 and ≤ 200</td>
<td>Weak explosion</td>
<td>60/40 Carbon, Polyplus, sulfur, sugar and zinc</td>
</tr>
<tr>
<td>2</td>
<td>&gt;200 and ≤ 300</td>
<td>Strong explosion</td>
<td>Cellulose, wood flour, and poly methyl acrylate</td>
</tr>
<tr>
<td>3</td>
<td>&gt;300</td>
<td>Very strong explosion</td>
<td>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.

**KCP Dust Info**

<table>
<thead>
<tr>
<th></th>
<th>Kst</th>
<th>MIE</th>
</tr>
</thead>
<tbody>
<tr>
<td>D/34 Carbon</td>
<td>342</td>
<td></td>
</tr>
<tr>
<td>60/40 Carbon</td>
<td>134</td>
<td>&gt;4796</td>
</tr>
<tr>
<td>Plastic Media</td>
<td>125</td>
<td>34</td>
</tr>
<tr>
<td>Polyplus</td>
<td>30</td>
<td>&gt;4796</td>
</tr>
</tbody>
</table>

Code requires system protection for Kst >0
# Building Damage from Dust Explosion

## Table 1. Structural damage is a function of overpressure.

<table>
<thead>
<tr>
<th>Overpressure, psi*</th>
<th>Biological Damage</th>
<th>Structural Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>70</td>
<td>99% Probability of fatality</td>
<td>Total structural damage</td>
</tr>
<tr>
<td>50</td>
<td>50% Probability of fatality</td>
<td>Total structural damage</td>
</tr>
<tr>
<td>35</td>
<td>1% Probability of fatality</td>
<td>Total structural damage</td>
</tr>
<tr>
<td>15</td>
<td>Lung damage</td>
<td>Severe structural damage</td>
</tr>
<tr>
<td>7–8</td>
<td></td>
<td>Shearing and flexure of unreinforced, 8–12-in.-thick brick wall panels</td>
</tr>
<tr>
<td>5</td>
<td>Eardrum rupture</td>
<td>Shattering of unreinforced, 8–12-in.-thick concrete wall panels</td>
</tr>
<tr>
<td>2–4</td>
<td></td>
<td>Shattering of unreinforced cinderblock walls; 50% destruction of brick buildings; distortion of steel-frame buildings; rupture of light industrial buildings</td>
</tr>
<tr>
<td>1–2</td>
<td></td>
<td>Failure of wood siding, corrugated steel, and aluminum panels; shattering of asbestos siding</td>
</tr>
<tr>
<td>0.5–1</td>
<td></td>
<td>Shattering of glass windows</td>
</tr>
</tbody>
</table>
Related NFPA Codes

- NFPA 484 Standard for Combustible Metals – 2012
- NFPA 61 Standard for The Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities – 2008
- NFPA 652 – Standard on Combustible Dust – just starting
Objective of NFPA 654

4.5.1.1 The facility, combustible particulate processes, and human element programs shall be designed, constructed, equipped, and maintained to protect occupants not in the immediate proximity of the ignition from the effects of fire, deflagration, and explosion for the time needed to evacuate, relocate, or take refuge.

Code Compliance May Leave Equipment Operator at risk
4.2 Process Hazard Analysis.

4.2.1* 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.

4.2.2 The results of the process hazard analysis shall be documented and maintained for the life of the process.

4.2.3 The process hazard analysis shall be reviewed and updated at least every 5 years.
A Simplified Risk Analysis

<table>
<thead>
<tr>
<th>Likelihood of Exposible Concentration (MEC)</th>
<th>Likelihood of Ignition (ME)</th>
<th>Kst</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>B</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td>B</td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>D</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Team Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Operability Issue</td>
</tr>
<tr>
<td>A</td>
<td>High Priority Risk mitigation required to risk level D</td>
</tr>
<tr>
<td>B</td>
<td>Medium Priority Risk mitigation required to risk level D</td>
</tr>
<tr>
<td>C</td>
<td>Low Priority Risk mitigation required to risk level D</td>
</tr>
<tr>
<td>D</td>
<td>Very Low Priority No further risk mitigation required</td>
</tr>
</tbody>
</table>

Operability Issue

Risk mitigation required to risk level D

Risk mitigation required to risk level D

Risk mitigation required to risk level D

No further risk mitigation required
Air-Material Separators
(dust collectors)

• Where an explosion hazard exists, dust collectors shall be located outside unless provided with one of the following
  – Venting thru a LISTED flame-arresting device
  – Dilution with noncombustible dust
  – Explosion suppression
  – Explosion pressure containment
  – Explosion venting
  – Oxidant concentration reduction

• Or are < 8 cu. ft. (~ 55 gal) in volume
Paragraph 7.13.1.3 addressing protection requirements, states “air-material separators shall be protected in accordance with 7.1.2.”

- As the standard reads 7.13.1.3 is inclusive of all air-material separators where an explosion hazard exists.
- This includes air-material separators handling combustible dust with volumes less than 8 cubic feet, and equal to or greater than 8 cubic feet.

Protecting units with volumes of less than 12 cubic feet, with venting or suppression may not be technically feasible.

In order to meet the goals of 654, a risk analysis should be provided for air-material separators located inside that handle combustible dust.

The consensus is that the code does not specifically require protection for < 8 cu. ft.
Yet unprotected < 8 cu. ft dust collector may leave the operator at risk
Code Prescribed Fixes

- Venting
- Flameless Venting
- Explosion Suppression
- Immersion Separator
Flameless Venting

Vented explosion from a 200 Kst test with corn starch and a 24-inch vent

Vented explosion under the same conditions using a 24-inch vent and FlamQuench
Immersion Separator

- Media submerged in a liquid bath
- Good for combustible metals
Protecting < 8 cu. ft. dust collectors (if not located outside)

1. Locate the dust collector at or near roof level thus removing it from the immediate area of the operator.

2. Build a barrier to separate the unit from the operator.

3. Provide venting if No. 1 or 2 is not practical and the dust collector must be physically near the operator.

4. Use a Torit type dust collector that is designed to “shake” only if the unit is not operating and then use a timer such that the unit can only “shake” during off-shift or unoccupied times.

Explosion Suppression won’t work for Dust Collectors < 12 cu. ft.
First Steps

- Do walk-thru looking for dust-producing and collecting equipment
- Check particle size - < 420 microns?
- Do Kst and MIE test
- Do Process Hazard Analysis
  - Maybe more testing
• If you can’t clearly see thru it, you may have a problem.

• Although code is silent on this, the consensus is that dust collector (air-material separator) size is determined by measuring the volume of the dirty side (not the whole box).

• Reportedly, NASA did a study in the late 1990s of glove box blasters using a variety of plastic combustible dust and walnut shells and concluded that this is not a hazard in that the dust cloud within the glove box is particularly too lean (not enough suspended dust) to explode.

• A risk exists if:
  – Pmax > 2 bar
  – Process operates at > 25% of MEC
  – MIE < 30 mJ
  – There is a credible ignition source including static
Spent Steel Shot ignites in the Dust Collector of this Steel Shot Blaster (fire, not explosion)
Some Books to Read

• *Dust Explosions in the Process Industries*
  – Rolf K. Eckhoff
  – Gulf Publishing

• *Guidelines for Hazard Evaluation Procedures*
  – Center for Chemical Process Safety

• *Layer of Protection Analysis (Simplified Process Risk Assessment)*
  – Center for Chemical Process Safety
QUESTIONS ?