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Fundamentals of Combustible Dust

DOE Fire Protection Conference

Las Vegas, Nevada

May 15, 2012

Robert Bitter, PE

Existing Facility

- 136 land acres
- 38 buildings
- 3.2M sq. ft.
- $ 3.0B total value
- ~ 50 MFL areas
- Largest MFL - $250M
- ~2510 FTES

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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

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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

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Some Equipment Used at the KCP
(and probably at your facility)

Plastic Media Blaster
Pmax = 5.24 bar
Kst = 58
MIE > 5 kJ

Low Kst with high ignition energy = pretty safe but______ ??

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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

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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

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Some Equipment Used at the KCP
(and probably at your facility)

- Nylon powder as fine as flour
- MIE = 7 mJ

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Some Equipment Used at the KCP
(and probably at your facility)

Clean Room Central Vacuum
Is this stuff combustible dust?

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Dust Explosion Basics

Dust Explosion Pentagon

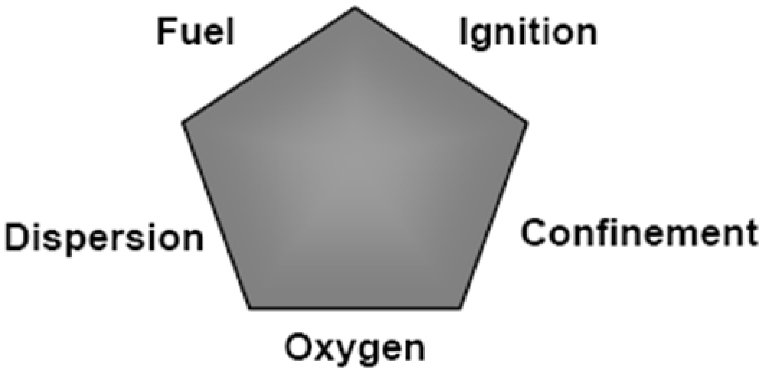
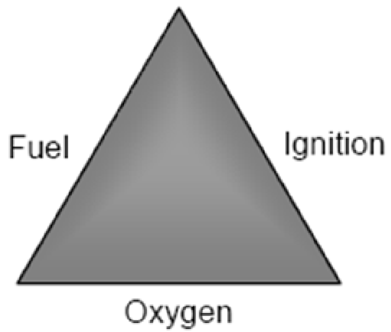


Figure 2. Dust explosion pentagon



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

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Explosion Characteristics of Dust
(Basic Dust Test)

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

All Possible Test
(initial test indicated)

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Table 2. Typical tests for dust characterization.

Dust Characteristic (PSI)	Test Symbol	Units	When the Test is Conducted
1. Particle size and particle size distibution	d	µm	To determine the size and size distribution of a sample. All four generic hazards (toxicity, combustibility, reactivity and instability) generally increase with decreasing particle size. Some ASTM dust-characterization test procedures specify a particle size of 95% <75 µm. Some organizations request "as received" testing to characterize the uniqueness of a sample.
2. Water content of a powder	WC	wt.%	To determine the moisture content of a given sample. Some ASTM dust-characterization test procedures specify a moisture content. Some organizations request "as received" testing to characterize a sample's uniqueness.
3. Maximum explosion pressure	P_{max}	barg	To determine whether a dust is combustible and the degree of explosion hazard. One test determines P_{max}, $(dP/dt)_{max}$, and K_{st}.
4. Maximum rate of pressure rise and deflagration index	dP/dt, K_{st}	bar-m/s	Used as input in explosion-protection system design. This is typically one of the first tests recommended to determine whether dust is explosive and the degree of explosion hazard. One test determines P_{max}, $(dP/dt)_{max}$, and K_{st}.
5. Minimum ignition energy	MIE	mJ	To determine the energy required for ignition. MIE <100 mJ indicates a potential for ignition from static discharges from personnel; MIE <25 mJ indicates a potential for ignition from static discharges during bulking of powders. If MIE <30 mJ, resistivity testing and charge relaxation testing is typically required.
6. Surface resistivity and volume resistivity	γ_s, γ_v	ohm-cm	To assess electrostatic hazard. Resistivity $>10^9$ Ω-cm poses a hazard.
7. Electrostatic decay and dielectric constant	$k(\varepsilon_T)$, τ	s	To determine if an electrostatic hazard from powder exists. Data on dielectric constant with charge relaxation time is needed if MIE < 30 mJ.
8. Minimum autoignition temperature of a dust cloud	$MAIT_{dust\ cloud}$	°C	To assess a dust's sensitivity to hot surfaces, such as dryers, bearings, and other mechanical parts.
9. Limiting oxygen concentration	LOC	vol.%	To determine the lowest concentration of oxygen that will propagate a flame. LOC is needed if inerting is the basis of safety for explosion prevention.
10. Minimum explosive concentration	MEC	g/m^3 or vol.%	To determine the minimum concentration of dust in air that will propagate a flame. MEC is required if dilution is the basis of safety for explosion prevention.
11. Minimum ignition temperature of a dust layer (smoldering temperature)	ST	°C	To determine whether a dust is sensitive to hot surfaces. ST is typically lower than MAIT.
12. Autoignition temperature of a dust deposit	AIT	°C	To determine whether a dust is sensitive to hot surfaces. AIT is typically lower than MAIT.
13. Thermal stability	DSC	cal/g	To screen for self-reactivity hazards.

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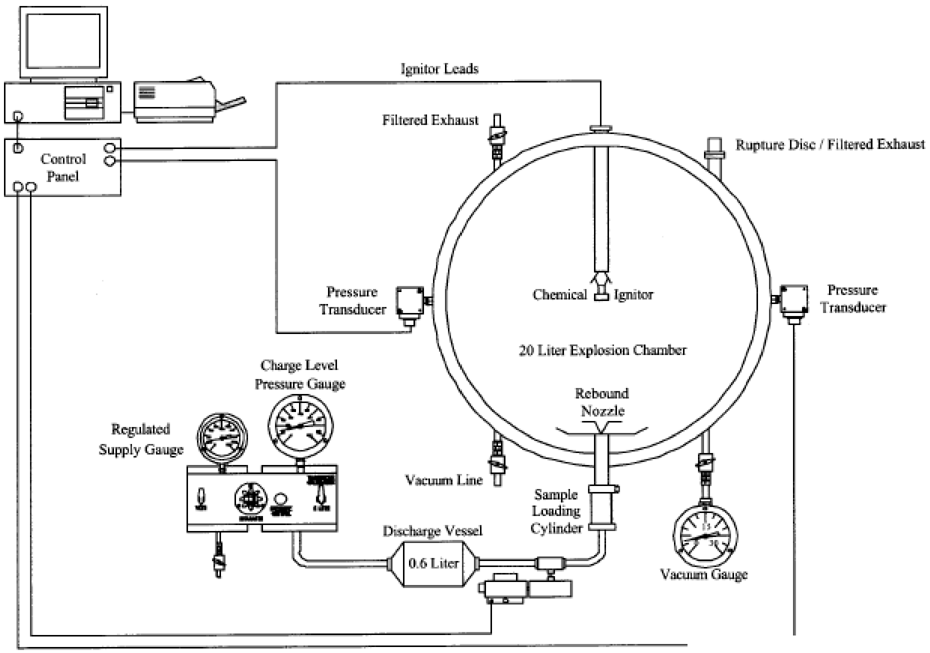
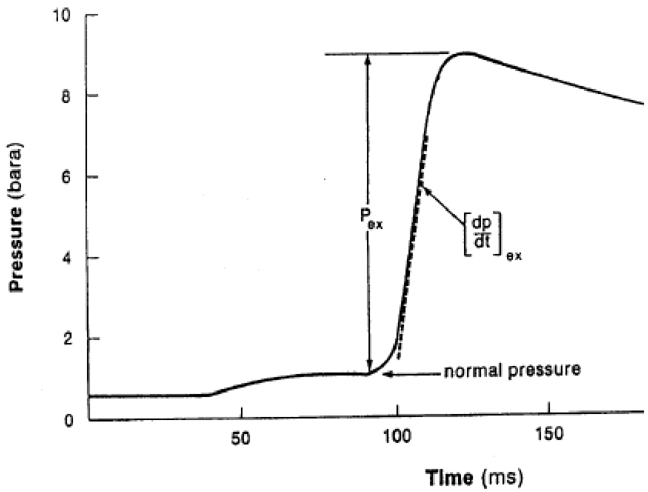
Determining Pmax





- 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)

Pmax = average of 3 Pex

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Pmax and Kst

Kst Classes and Examples			
Dust explosion class*	Kst (bar.m/s)	Characteristic	Typical material
0	0	No explosion	Silica, Sodium Bicarb
1	>0 and ≤ 200	Weak explosion	60/40 Carbon, Polyplus, sulfur, sugar and zinc
2	>200 and ≤ 300	Strong explosion	Cellulose, wood flour, and poly methyl acrylate
3	>300	Very strong explosion	aluminum, magnesium

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

Maximum rate of pressure rise = Pmax

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

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

KCP Dust Info

	Kst	MIE
D/34 Carbon	342	
60/40 Carbon	134	>4796
Plastic Media	125	34
Polyplus	30	>4796

Code requires system protection for Kst >0

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Building Damage from Dust Explosion

Table 1. Structural damage is a function of overpressure.

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

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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 664 Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities – 2012
- NFPA 655 Standard for the Prevention of Sulfur Fires and Explosions – 2007
- NFPA 654 Standard for the Prevention of Fire and Explosions from Manufacturing, Processing and Handling of Combustible Particulate Solids – 2006
- NFPA 652 – Standard on Combustible Dust – just starting

Objective of NFPA 654

4.5.1.1The 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

Process Hazard Analysis (PHA) required

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

Likelihood of Exposible Concentration (MEC)
Likelihood of ignition (MIE)

C	B	A	A
D	C	B	A
D	D	C	B
D	D	D	C
D	D	D	D

Kst

Risk Level		Team Action
O	Operability	Operability Issue
A	High Priority	Risk mitigation required to risk level D
B	Medium Priority	Risk mitigation required to risk level D
C	Low Priority	Risk mitigation required to risk level D
D	Very Low Priority	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

8 cu. ft. Controversy in NFPA 654

- 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

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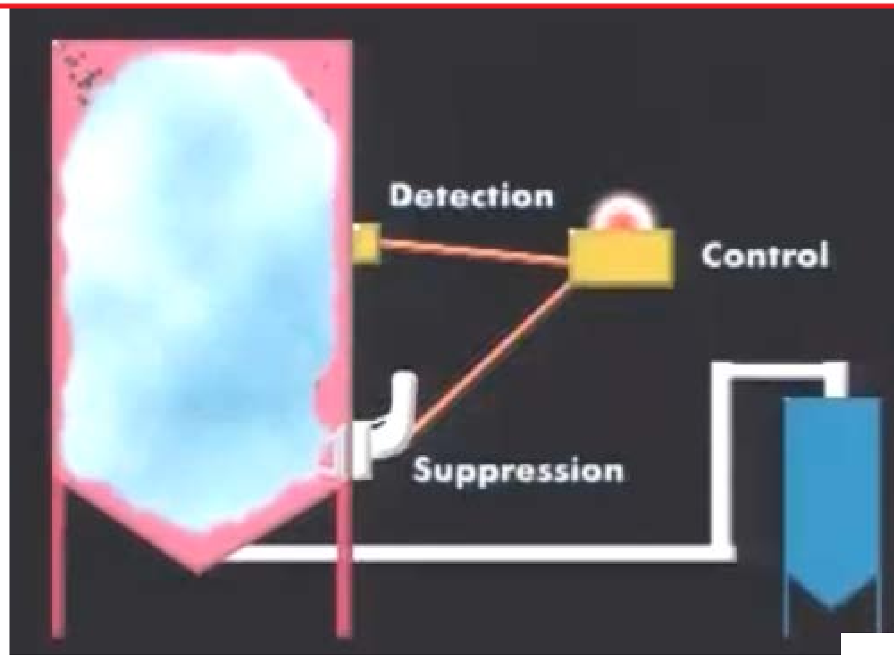
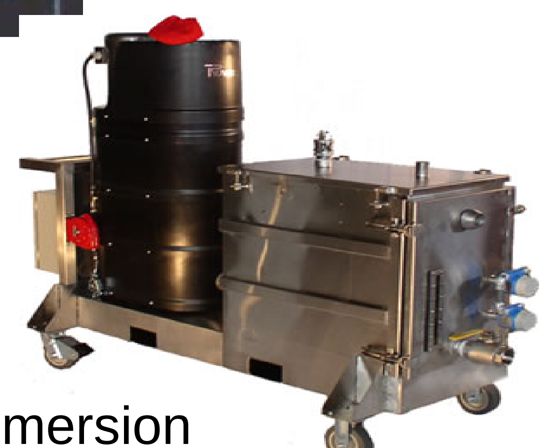
Code Prescribed Fixes



Explosion
Suppression

Venting

Flameless
Venting



Immersion
Separator

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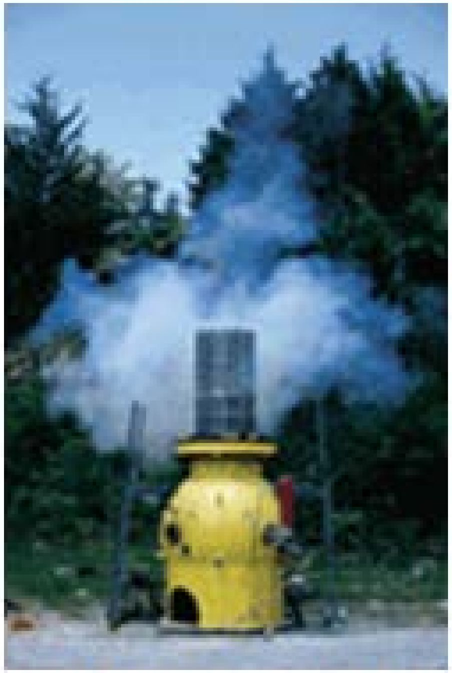
Flameless Venting

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

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Immersion Separator

- Media submerged in a liquid bath
- Good for combustible metals

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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

Miscellaneous

- 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

3/10/2012 Dust Fire

Spent Steel Shot ignites in the Dust Collector of this Steel Shot Blaster
(fire, not explosion)

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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

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QUESTIONS ?