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Brief review of dust explosion test methodologies – peaks and pitfalls

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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 Fires & Explosions (continued)

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 <u>NO</u> national standard for worker protection; OSHA has 29CFR 1910.272 (1987)

Recent Major Dust Explosions

- January 2003 – West Pharmaceuticals Services – Kinston, North Carolina – Fine plastic dust – 6 fatalities many injured
- 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

Introduction
(continued)

- 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

"Framework"

NFPA 652

NFPA 68, 69, 70 etc.

ASTM

NFPA 61

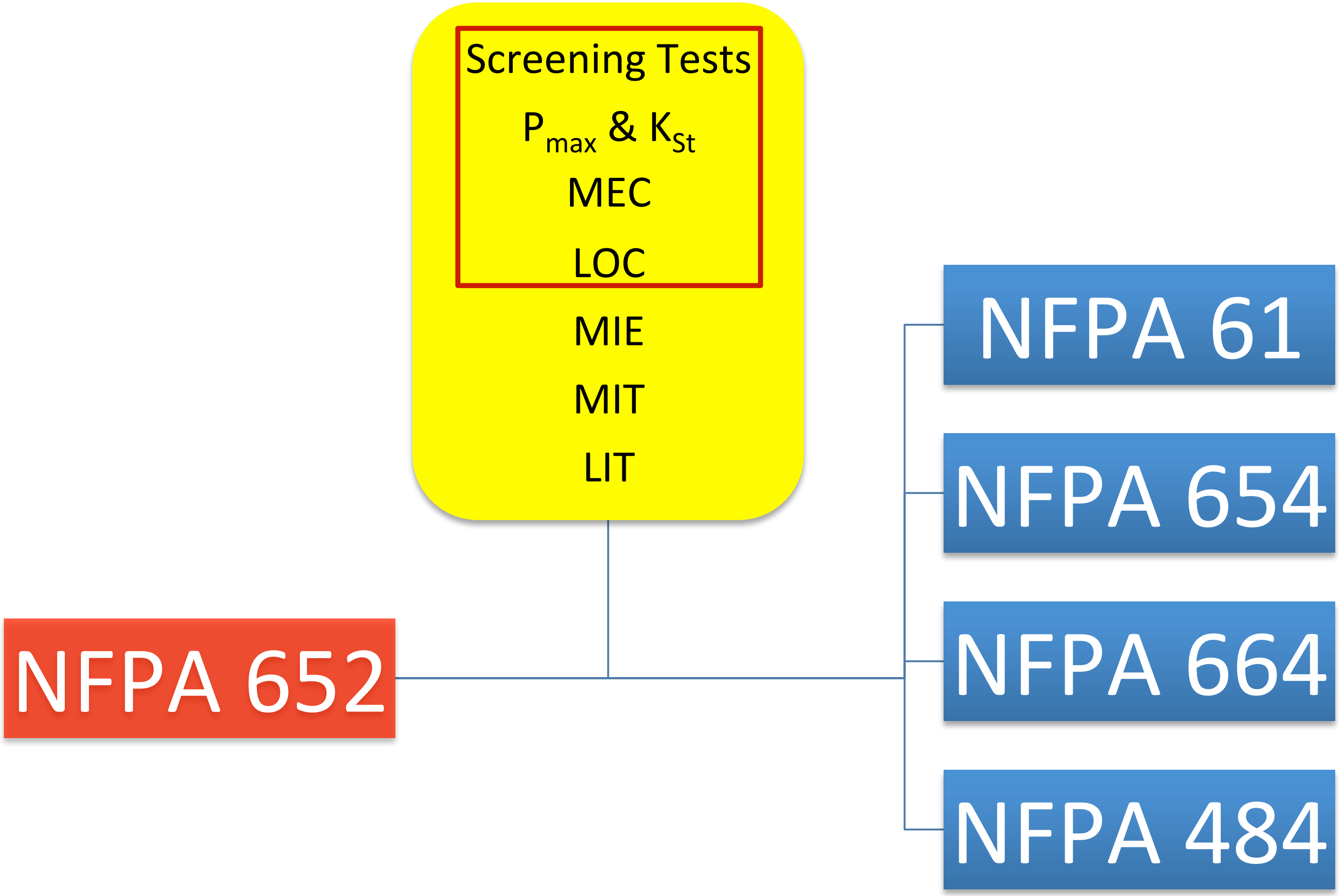
NFPA 484

NFPA 664

NFPA 654

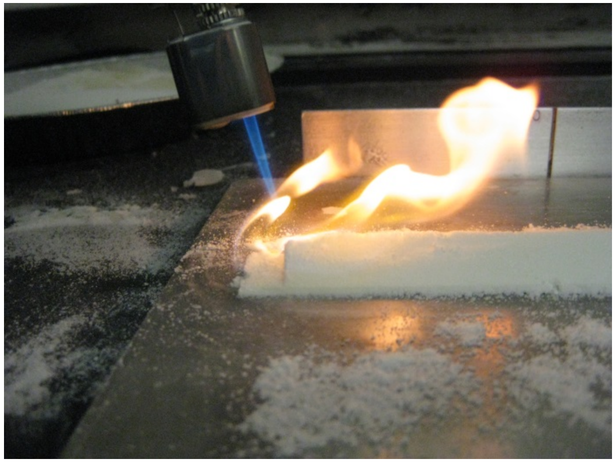
Testing Methods

NFPA Recommended Tests



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

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Electric Arc versus Pyrotechnic Igniter

Source: Fauske & Associates, LLC

Electric Arc can ignite metals

Source: Fauske & Associates, LLC

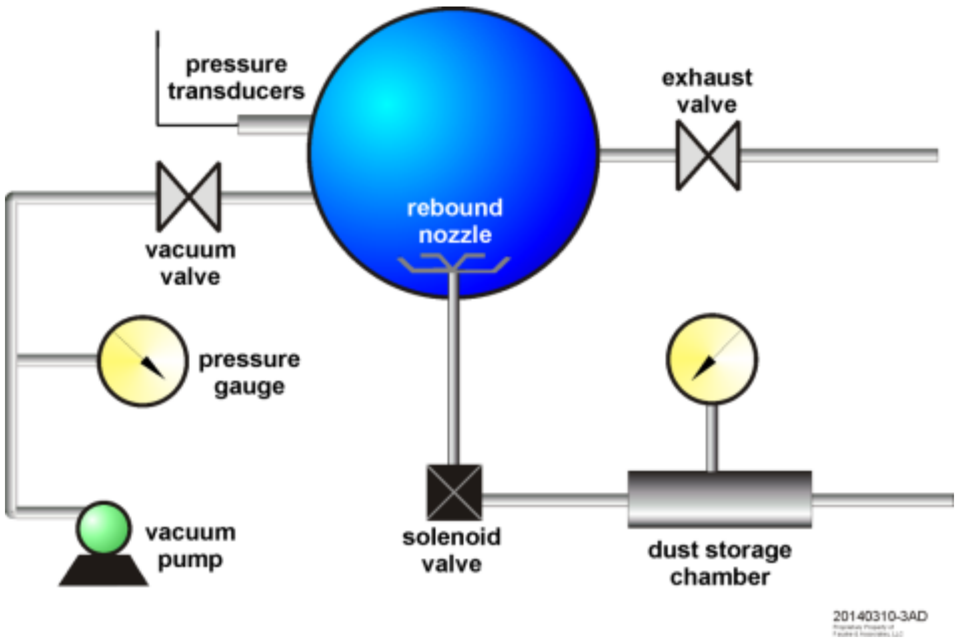
Pyrotechnic Igniter may not ignite some metals

Explosibility Screening Test

Explosion Severity (P_{max} & K_{St}) ASTM E1226

- Determined in a 20-L or 1-m^3 chamber
- Indication of the severity of an explosion
- Data used in the design of explosion protection devices
  - P_{max} = maximum pressure
  - $K_{St} = (dP/dt)_{max} \times V^{1/3}$
  - 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

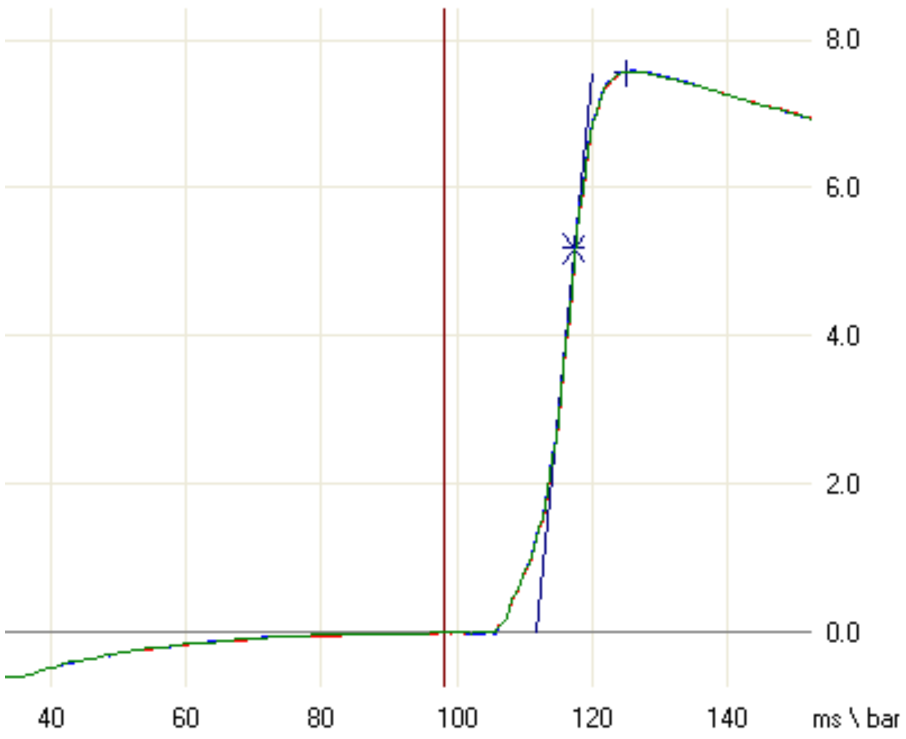


Source: Fauske & Associates, LLC

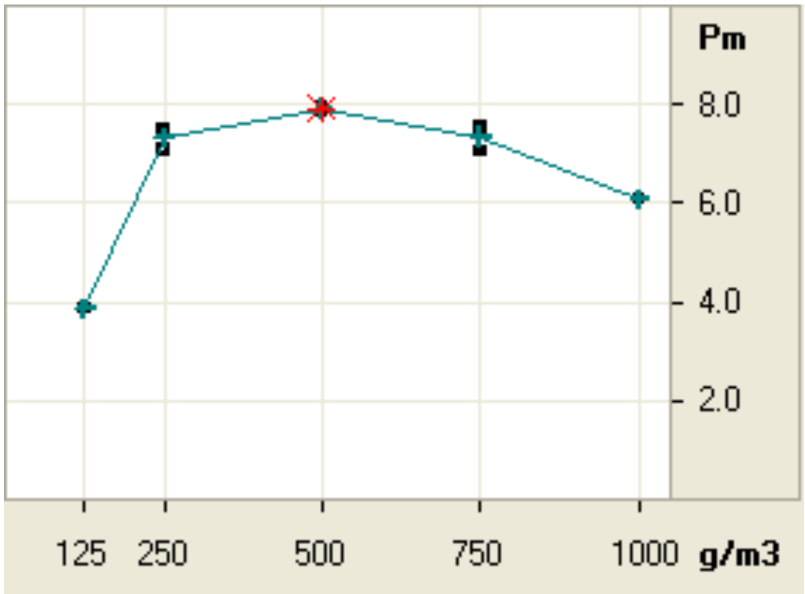
10 kJ ignition source

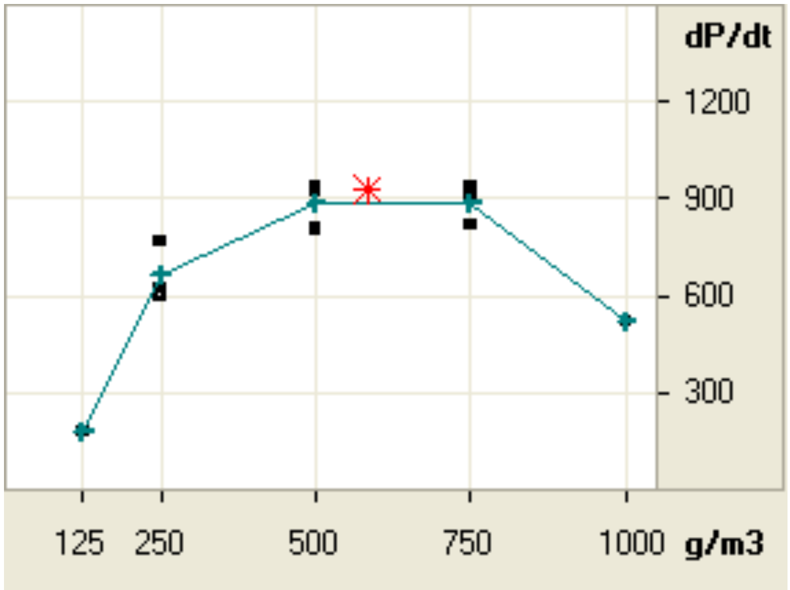
Pressure-Time Data From an Experiment

- 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_{max}
- In this graph for niacin, the P_{max} is 7.9 bar(g) at 500 g/m³

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

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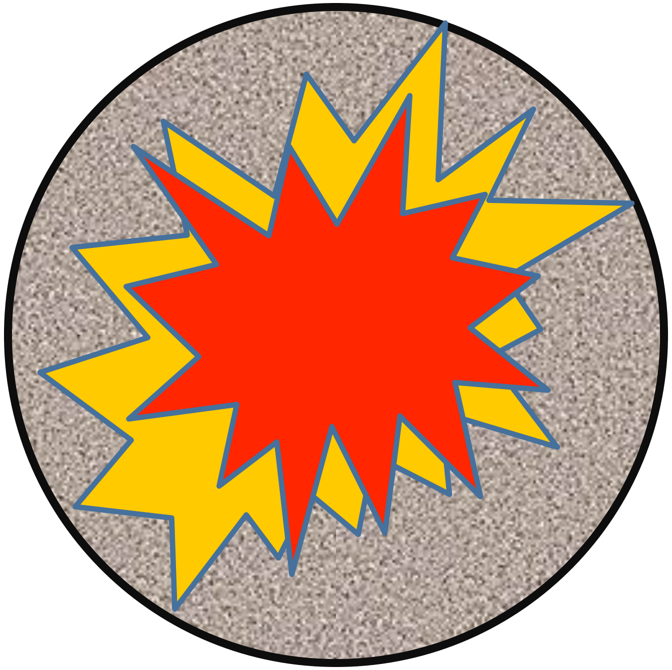
Overdriving the Explosion

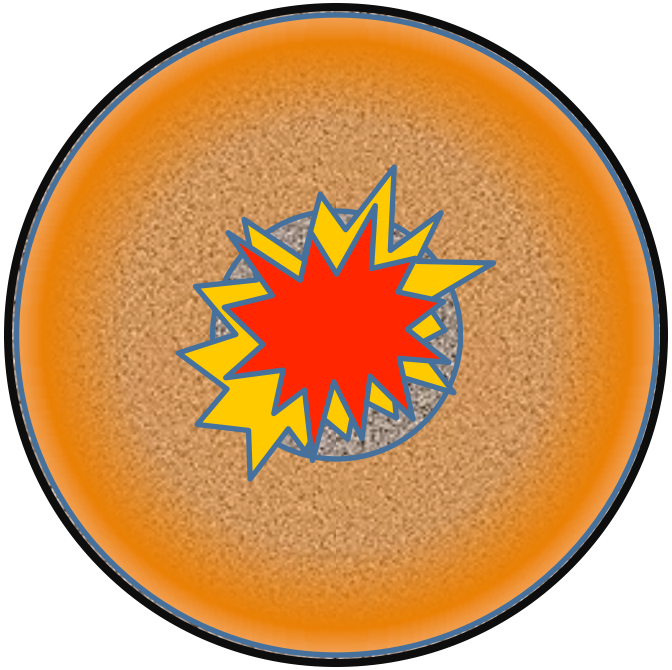
- Can occur in:
  - E1226 [P_{max} & K_{St}]
  - E1515 [MEC]
  - E2931[LOC]
- Burning of the dust in the igniter flame
- Igniter flame preheats cloud
- **Exacerbate explosion severity and potential**



20-L Test Chamber

Underdriving the Explosion

- Can occur in:
  - E1226 [P_{max} & K_{St}]
  - E1515 [MEC]
  - E2931[LOC]
- Vessel wall cools the flame
- **Diminished explosion severity and potential**



20-L Test Chamber

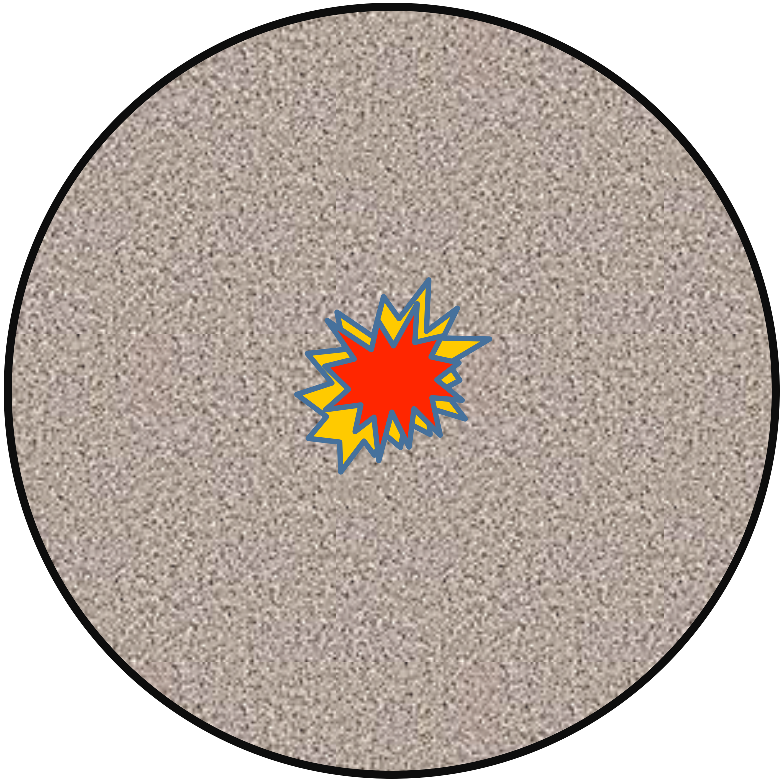
Ignition Source for Explosion Severity Test

Spherical 1-m³ Chamber

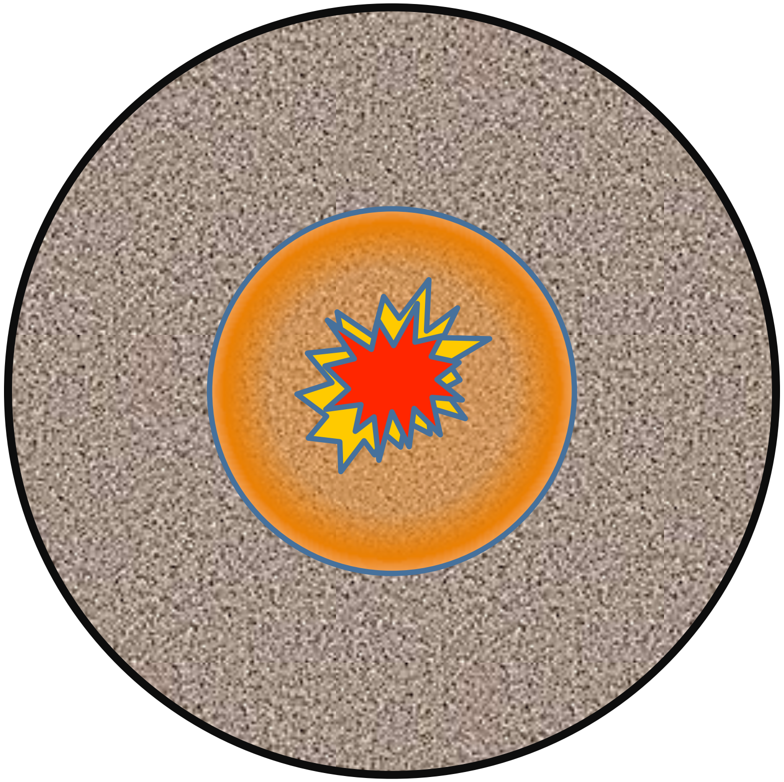
Source: Fauske & Associates, LLC

- 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

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 1m^3 Challenge Test
  - Low K_{St} <50 bar-m/s
  - Low P_{max} <3 bar

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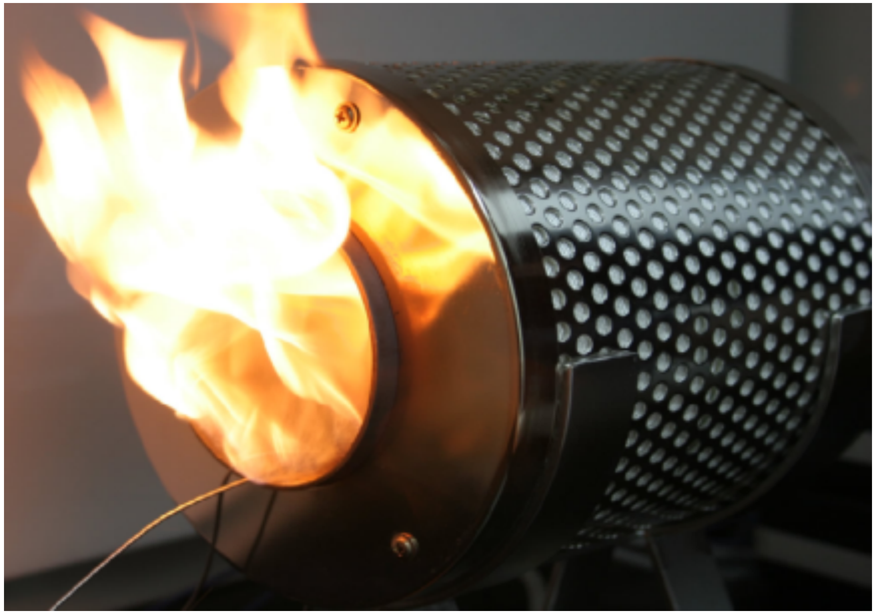
Minimum Autoignition Temperature of a Dust Cloud (MIT) ASTM E1491

- 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**

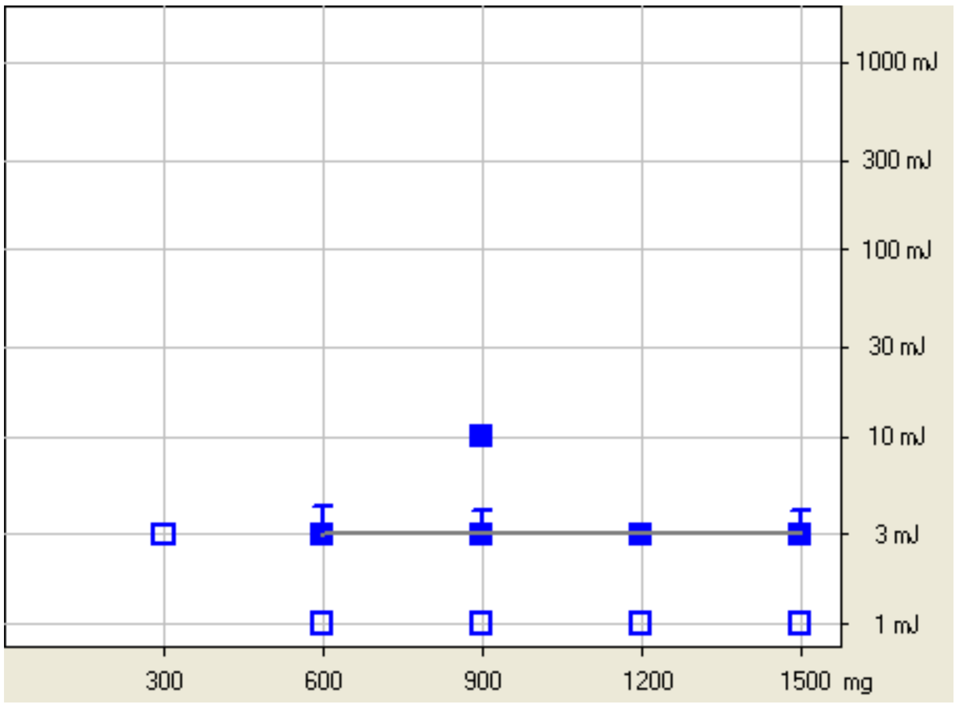


Source: Fauske & Associates, LLC

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

Minimum Ignition Energy (MIE) ASTM E2019 (continued)

- Examples: sugar (powdered) 30 mJ, paper dust 20-60 mJ, aluminum 50 mJ, magnesium 40 mJ

MIE (mJ)	Recommended Precaution per BS 5958
500	Low sensitivity to ignition; ground plant below this level
100	Consider grounding personnel below this level
25	The majority of ignition incidents occur below this level
10	High sensitivity to ignition. Consider restrictions on the use of high resistivity non-conductors below this level
1	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

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

Maximum Temperature °C	°F	Temperature Class (T Code)
450	842	T1
300	572	T2
280	536	T2A
260	500	T2B
230	446	T2C
215	419	T2D
200	392	T3
180	356	T3A
165	329	T3B
160	320	T3C
135	275	T4
120	248	T4A
100	212	T5
85	185	T6

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