Laboratory Testing to Assess Explosion Characteristics of Dust Clouds

Practical Aspects

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Practical Aspects

Presentation Outline

- **Conditions for a Dust Cloud Explosion**
- **Management of Dust Cloud Explosion Hazards**
- **Explosion Characteristics of Dust Clouds**
  - Sensitivity to Ignition
  - Static Electricity
  - Thermal Instability
  - Explosion Severity
  - Minimum Explosible Concentration
  - Limiting Oxidant Concentration
- **OSHA Combustible Dust National Emphasis Program (NEP)**

Conditions Required for Dust Cloud Explosions to Occur

A number of conditions must exist simultaneously for a dust explosion to occur:

- Dust must be combustible
- Dust must be airborne
- Dust concentrations must be within explosible range
- Dust must have particle size distribution capable of propagating a flame
- The atmosphere in which the dust cloud is present must be capable of supporting combustion
- An ignition source with sufficient energy to initiate flame propagation must be present

Management of Dust Cloud Explosion Hazards

- Control of the spread of combustible dust atmospheres:
  - Proper plant design
  - Use of local exhaust ventilation
  - Management of dust deposits
- Elimination/control of potential ignition sources including:
  - Hot work
  - Mechanical friction and sparks
  - Hot surfaces and equipment
  - Thermal decomposition
  - Electrical arcs (sparks)
  - Electrostatic discharges
- Application of explosion safeguards:
  - Explosion protection (containment, relief venting, explosion suppression)
  - Explosion isolation
  - Inert Gas Blanketing

Understanding Explosion Characteristics of Dusts

- **How easily will the dust cloud ignite?**
  - Explosibility Screening
  - Minimum Ignition Energy
  - Minimum Ignition Temperature
  - Thermal Instability
- **What will happen if the dust cloud does ignite?**
  - Maximum Explosion Pressure
  - Maximum Rate of Pressure Rise
- **Ensuring Safety by Avoiding/Controlling Flammable Atmospheres?**
  - Limiting Oxygen Concentration
  - Minimum Explosible Concentration
- **Electrostatic Properties**
  - Electrostatic Chargeability
  - Volume Resistivity

Explosibility Screening (ASTM E1226)

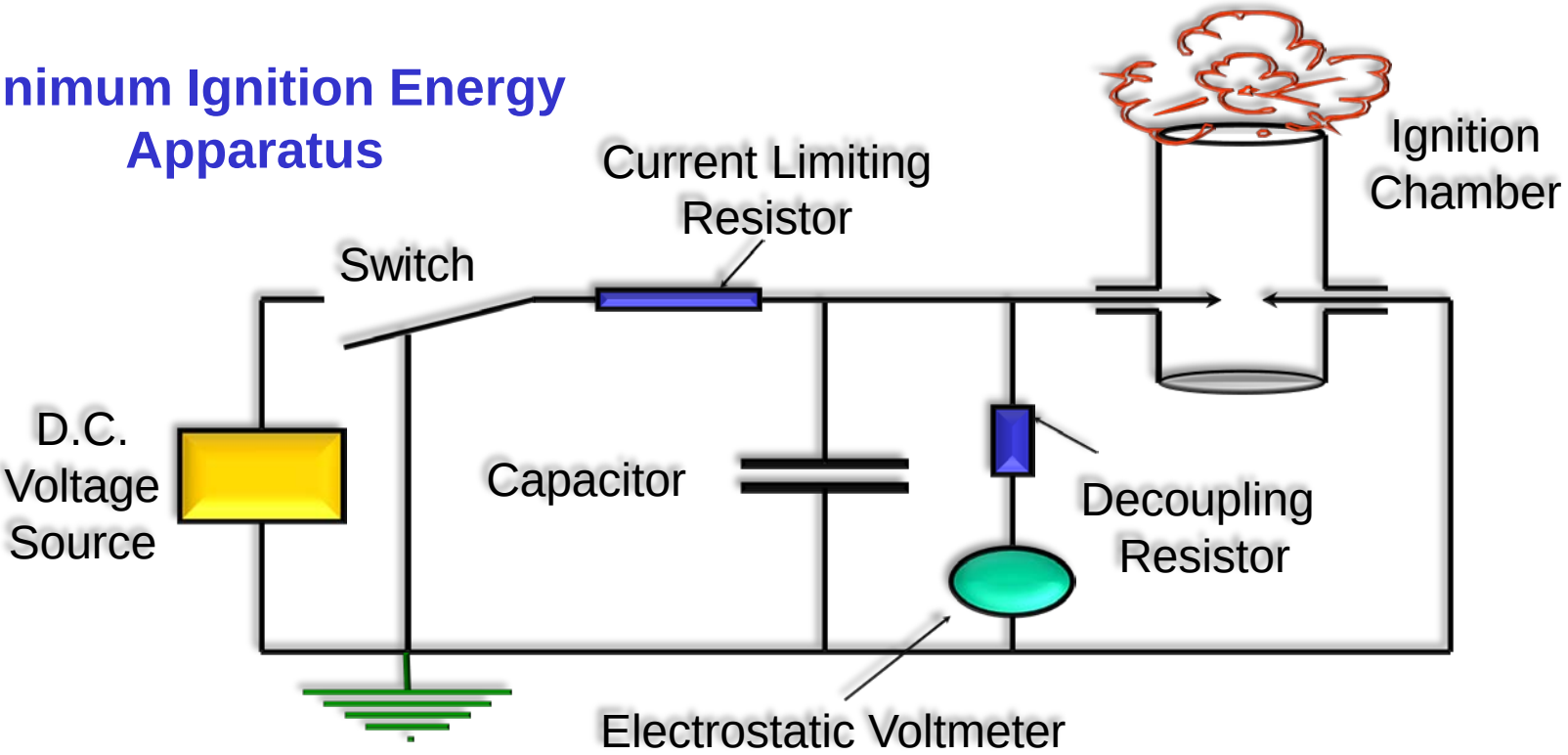
Use a Hartmann Bomb, 20L sphere, or 1m^3 sphere test vessel to determine whether the dust cloud is explosible at the dust handling/processing conditions

- Dusts which ignite and propagate away from the source of ignition are considered "explosible"
- Dusts which do not propagate flame away from the ignition source are considered "non-explosible"
- If the dust cloud does not ignite in the Hartmann Bomb, additional tests in a larger volume (20L or 1m^3) with stronger ignition source will be conducted

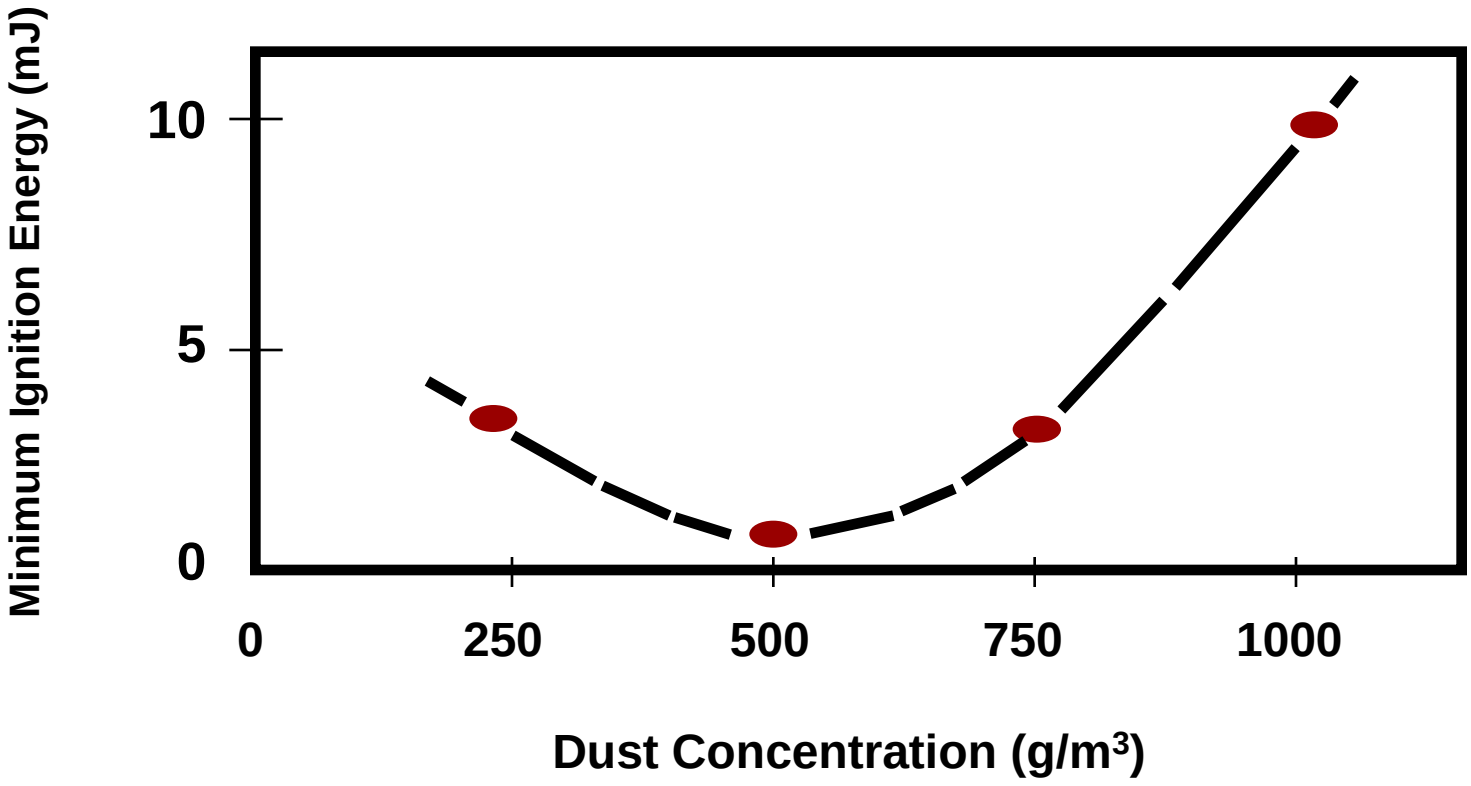
Minimum Ignition Energy (MIE) (ASTM E 2019)

MIE of a flammable material is the smallest electrostatic spark energy needed to ignite an optimum concentration of the material using a capacitive spark

Minimum Ignition Energy Apparatus



MIE and the effect of Dust Cloud Concentration



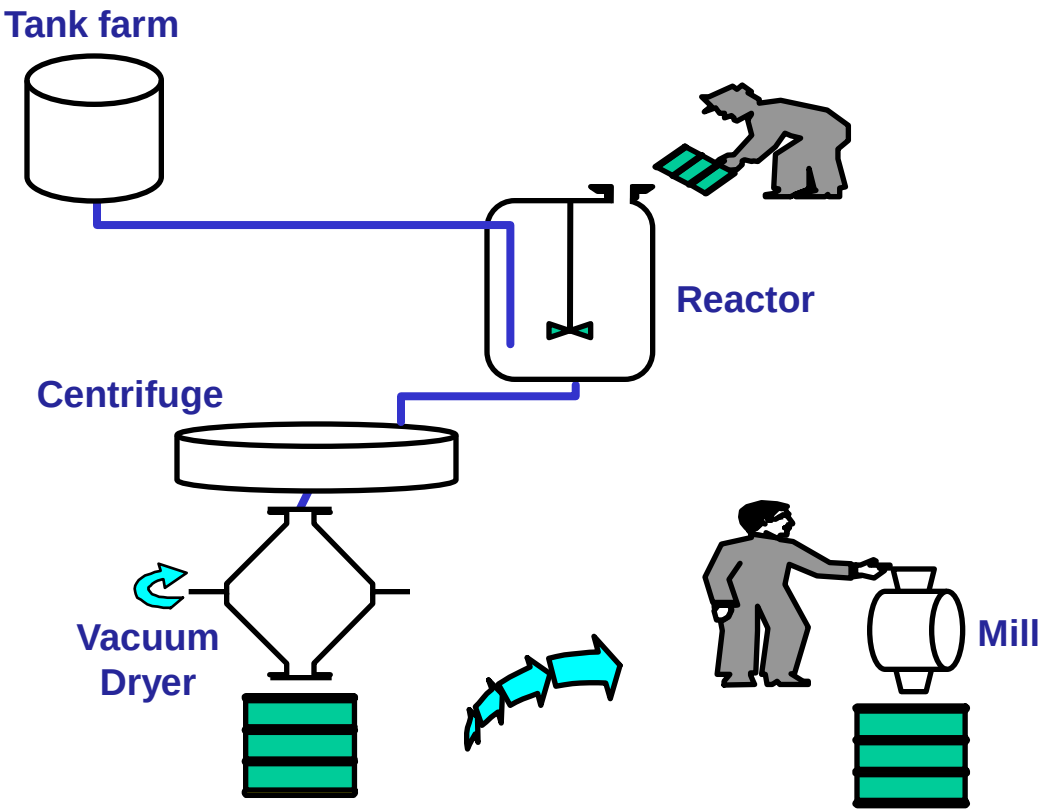
Factors Affecting Minimum Ignition Energy

Some Influencing Factors	Effect
Increasing Particle Size	↑
Increasing Moisture Content	↑
Inductance of Discharge Circuit	↓
Presence of Flammable Vapor (even if below LFL)	↓
Increase in Ambient Temperature	↓

Systematic Approach to Electrostatic Hazard Assessment

- Charge Generation
- Charge Accumulation
  - Isolated Conductors
  - Insulating Objects
  - People
  - Liquids
  - Powders
- Incendivity of Discharges
- Sensitivity of the Atmosphere to Ignition

Schematic of a Typical Chemical Processing Plant



Types of Electrostatic Discharges

Several types of electrostatic discharges are distinguished depending on resistivity and the geometric arrangement of the charged object and the geometry of the discharge initiating electrode:

- ***Spark Discharge -*** *Spark from ungrounded conductor*

  Stored (Spark) Energy = ½ C V^2

  - Resistance to ground should be checked. If R > 10 ohm, direct ground connection is required

Types of Electrostatic Discharges

Several types of electrostatic discharges are distinguished depending on resistivity and the geometric arrangement of the charged object and the geometry of the discharge initiating electrode:

- ***Propagating brush Discharge -*** *Discharge from the surface of an insulator backed by a conductor (e.g. plastic or glass-lined metal pipes and vessels) and from the surfaces of plastic pipes and hoses used for pneumatic conveying of powders*

  Maximum discharge energy of 1,000mJ to 2,000mJ

  - Avoid the use of plastic pipes and hoses for pneumatic conveying of powders
  - Avoid plastic containers/liners for powders with high charge densities

Types of Electrostatic Discharges

Several types of electrostatic discharges are distinguished depending on resistivity and the geometric arrangement of the charged object and the geometry of the discharge initiating electrode:

- ***Discharges from Human Body***

  Maximum energy of about 25mJ to 30mJ

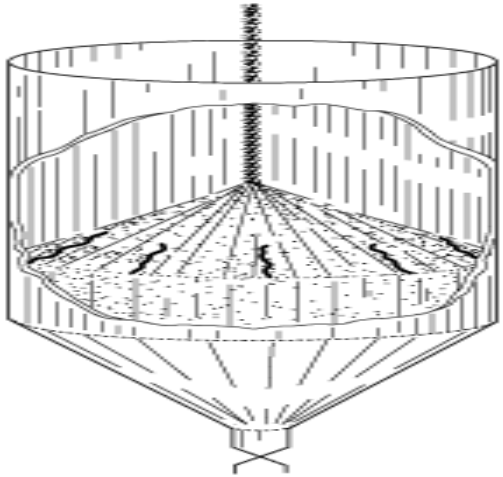
  - Personnel should be grounded so that their resistance-to-ground $<1x10^8$ ohm
  - Static dissipative footwear may be used
  - Resistance of the floor/surface on which the operator is standing should also be $<1x10^8$ ohm

Types of Electrostatic Discharges

Several types of electrostatic discharges are distinguished depending on resistivity and the geometric arrangement of the charged object and the geometry of the discharge initiating electrode:

- ***"Bulk"/"Cone" Discharge -*** *Discharges on the surface of the powder during filling of vessels/bins/containers*

  Maximum discharge energy about 25mJ (depending on powder Volume Resistivity, Electrostatic Chargeability, particle size, and vessel dimensions)



Volume Resistivity - General Accordance with ASTM D 257

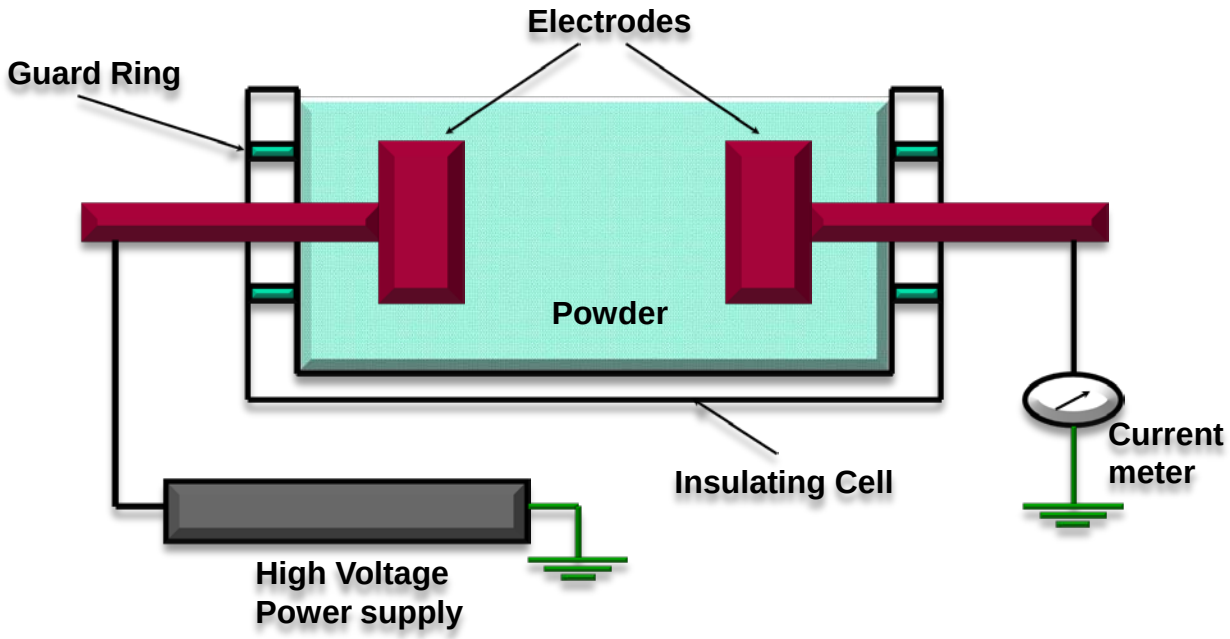
- The ability of a material (powder) to retain/dissipate electrostatic charges
- Volume Resistivity is a property of the material itself, regardless of the dimensions of the sample.
- Volume resistivity of material, is related to the resistance, R, measured when a voltage is applied across it, by the following equation

Volume Resistivity, p_v = R A/d

A *is the sample area and* ***d*** *its length*

The units of Volume Resistivity are Ohm meters (Ω.m)

Measurement of Volume Resistivity of Powders



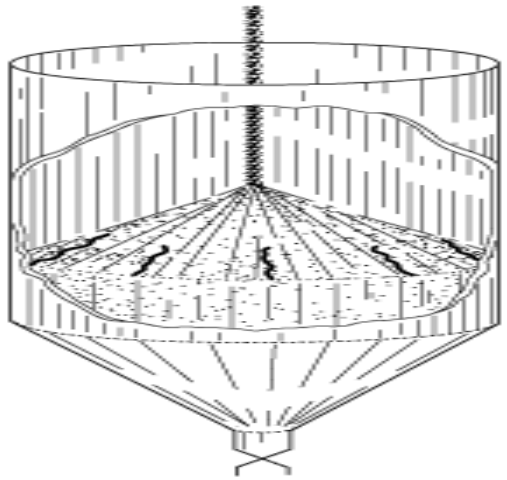
Volume Resistivity can be influenced by the moisture content of powder

Classification of Materials by their Volume Resistivity

Resistivity (Ohm.m)	Type	Examples
$<10^6$	Low Resistivity	Metals
10^6 to 10^9	Medium Resistivity	Some organic powders, Concrete, wood
$>10^9$	High Resistivity	Synthetic polymers

Control of Electrostatic Hazards - Powders

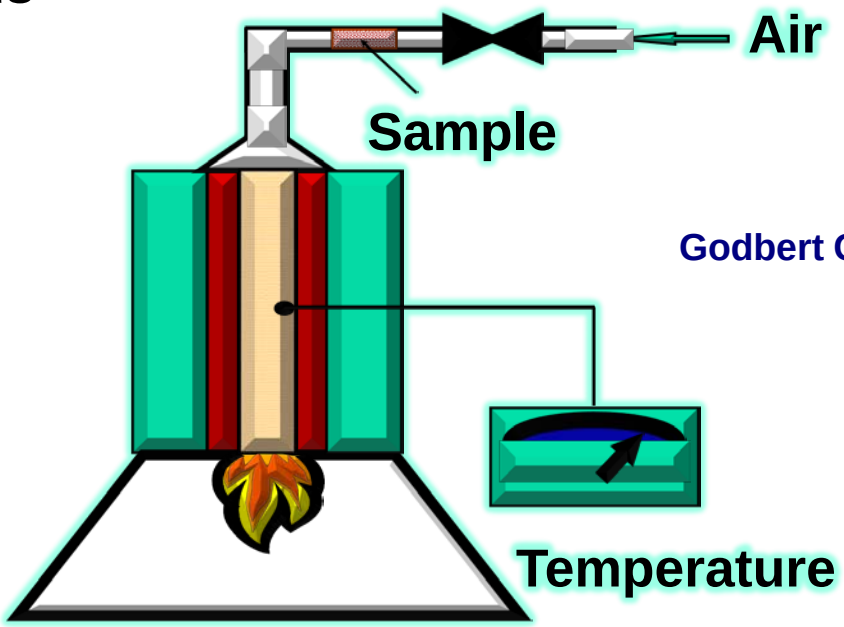
- **Volume resistivity > 10^9 Ohm.m and Minimum Ignition Energy <25mJ**
  - If the Electrostatic Chargeability test results show that the quantity of electrostatic charge on the particles is sufficient to cause discharges from the surface of the bulking powder one of the following measures is suggested:
    - Installation of inert gas blanketing, or
    - Installation of explosion protection



Minimum Ignition Temperature - Dust Cloud, (ASTM E 1491)

- Minimum Ignition Temperature of a dust cloud is a measure of its sensitivity to ignition by heated environments

- Minimum Ignition temperature is NOT a fundamental property of the dust. Factors affecting MIT include particle size, moisture content, and test apparatus



Godbert Greenwald (GG) Furnace

Minimum Ignition Temperature - Dust Layer, (ASTM E 2021)

- MIT of dust layer is the lowest temperature of a heated free-standing surface capable of igniting a dust layer (12.7mm thick)
- With thicker layers, smoldering / glowing may start at a lower temperature
- Test applicable only for materials which will not melt or evaporate before reaching the ignition temperature

Minimum Ignition Temperature

- Minimum Ignition Temperature tests provide information on:
  - Sensitivity to ignition by:
    - hot environments and surfaces of some processing equipment and plant
    - hot surfaces caused by overheating of bearings and other mechanical parts due to mechanical failure
    - frictional sparks
  - Maximum exposure temperature (Temperature Rating) for electrical equipment

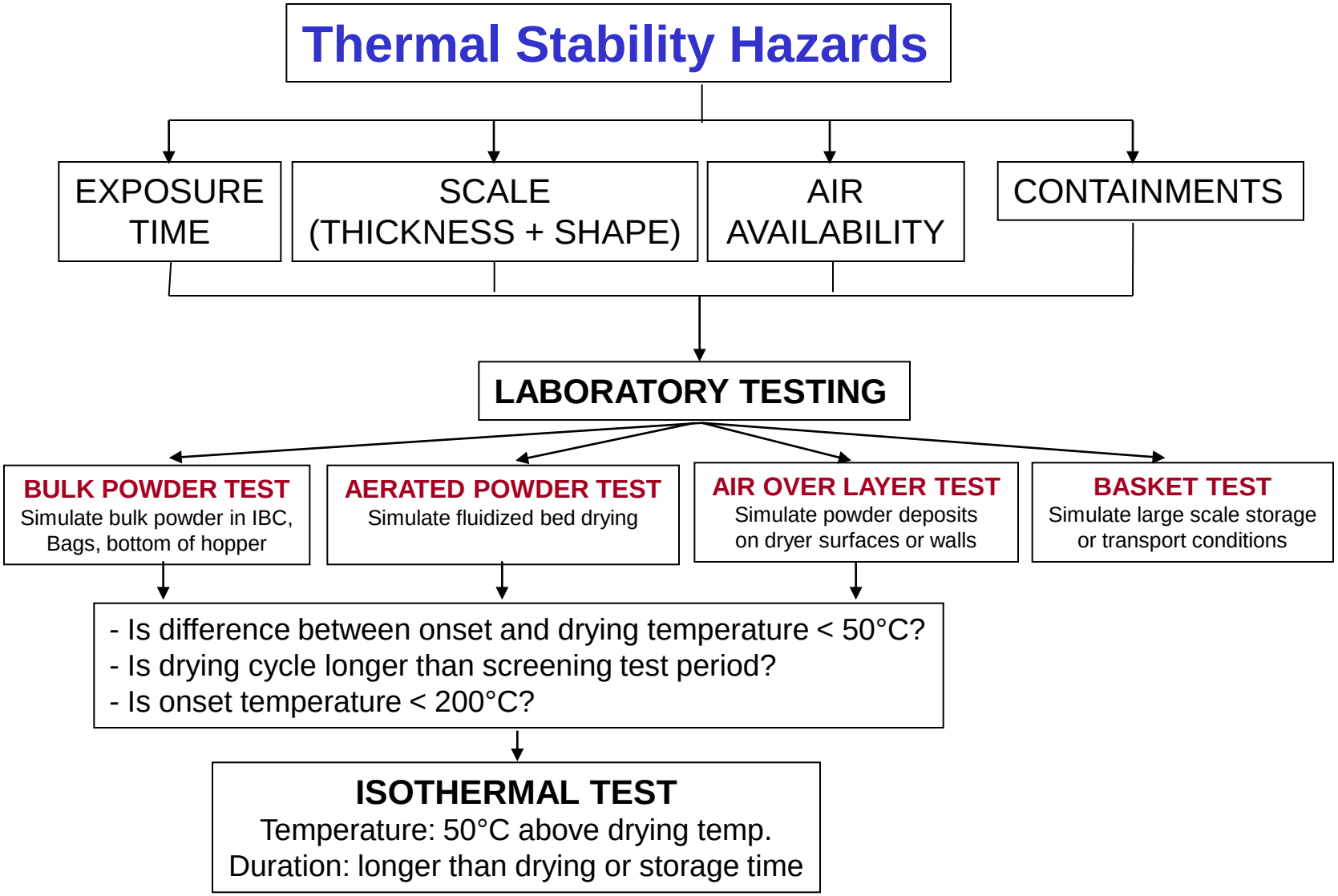
Control of Heat Sources and Frictional Sparks

- Preventing overloading of processing plant (grinders, conveyors, etc.)
- Isolation or shielding of hot surfaces
- Prevention/removal of dust accumulations on hot surfaces
- Use of approved electrical equipment (correct temperature rating)
- Prevent overheating due to misalignment, loose objects, belt-slip/rubbing etc. by regular inspection and maintenance of plant
- Prevent foreign material from entering the system when such foreign material presents an ignition hazard. Consider use of screens, electromagnets, pneumatic separators, etc.
- Hot work operations should be controlled by a hot work permit system in accordance with NFPA 51B, Standard for Fire Prevention During Welding, Cutting and Other Hot Work

Self-Heating

Prevention of Fires and Explosions in Dryers, 2nd Edition, IChem E, 1990

- Ignition of bulk powders can occur by a process of self-heating
- Ignition occurs when the temperature of the powder is raised to a level at which the heat liberated by the exothermic reaction is sufficient to exceed the heat losses and to produce runaway increase in temperature
- The minimum ambient temperature for self-ignition of a powder depends mainly on the nature of the powder and on its dimensions


Thermal Stability Hazards
EXPOSURE TIME
SCALE (THICKNESS + SHAPE)
AIR AVAILABILITY
CONTAINMENTS
LABORATORY TESTING
BULK POWDER TEST
Simulate bulk powder in IBC, Bags, bottom of hopper
AERATED POWDER TEST
Simulate fluidized bed drying
AIR OVER LAYER TEST
Simulate powder deposits on dryer surfaces or walls
BASKET TEST
Simulate large scale storage or transport conditions
- Is difference between onset and drying temperature < 50°C?
- Is drying cycle longer than screening test period?
- Is onset temperature < 200°C?
ISOTHERMAL TEST
Temperature: 50°C above drying temp.
Duration: longer than drying or storage time

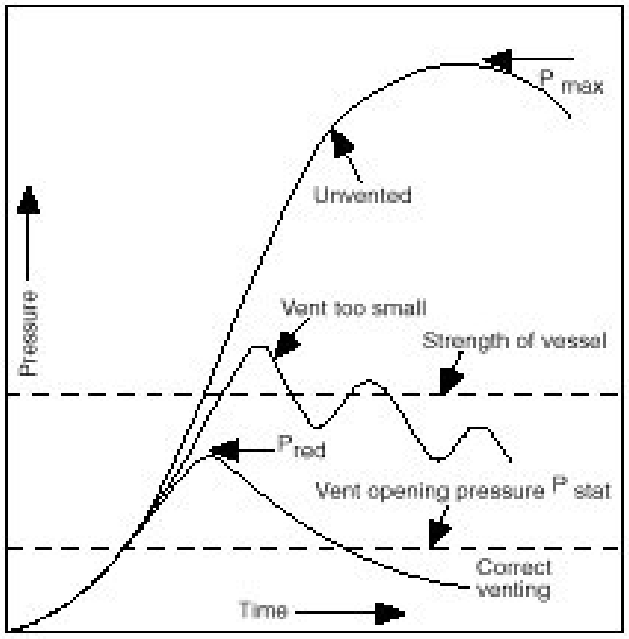
Self-Heating

Explosion Severity of Dust Cloud, K_{st} (ASTM E 1226)

- An indication of the severity of dust cloud explosion
- Data produced:
  - *Maximum developed pressure,* P_{max}
  - *Maximum rate of pressure rise,* $(dP/dt)_{max}$
- Deflagration index (explosion severity) K_{st}

$$K_{st} = (dP/dt_{max}) \,.\, V^{1/3} \quad \text{[bar.m/s]}$$

Where V is the volume of the test vessel (m^3)



- Used for the design of deflagration protection (venting, suppression, Containment)

Explosion Severity - Dust Explosion Hazard Classification

Based on test data using 1m³ and 20L Vessels and 10KJ Ignition Source		
Dust Explosion Class	K_{st} (bar.m/s)	Characterization
St 0	0	Non-explosible
St 1	$0 < K_{st} < 200$	Weak to moderately explosible
St 2	$200 < K_{st} < 300$	Strongly explosible
St 3	$K_{st} > 300$	Very strongly explosible

Note:

- **Any explosion can cause burn injuries**
- **Any explosion can cause structural damage if the structure is not strong enough**

Standard Deviation in the 20L Apparatus – ASTM E 1226

Kst (bar m/s)	Standard Deviation (±%)
50	30
100	20
200	12
300	10
≥400	5

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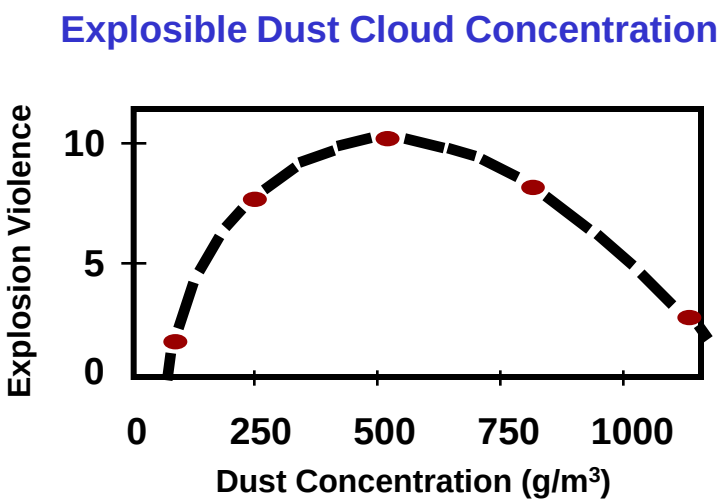
Comparison of Dust Properties Measured in $1m^3$ and 20L Vessels

Material	Kst $1m^3$ (bar-m/sec)	Kst 20L (bar-m/sec)	P_{max} $1m^3$ (bar-m/sec)	P_{max} 20L (bar)
Calcium Stearate	140	197	9.1	6.6
Lignite	138	113	7.3	6.2
Maltodextrine	205	147	9.5	6.8
Grinding Dust	36	59	4.2	2.9
Sodium Momochloroacetate	0	62	0	7.4
Lixivalt Dust	0	9	0	3.3
Metco Dust	0	13	0	1.3
Solid Sewing Residues	0	65	0	1.3
PVC Dust	64	113	8.7	7.8

Ref. **Proust, CH., et al, Journal of Loss Prevention in the Process Industries, Vol. 20, 2007**
Rodgers, S. A., et al, 6th Global Congress on Process Safety, San Antonio, TX, March 2010

Minimum Explosible Concentration (ASTM E 1515)

- When concentration of dispersed dust cloud in air is below the **Minimum Explosible Concentration**, an explosion can not propagate
- Explosion violence of the cloud increases as the dust concentration increases until an optimum concentration is reached giving the highest explosion violence



Limiting Oxidant Concentration (ISO 6184/1)

- The concentration of oxidant below which a deflagration cannot occur is referred to as the **Limiting Oxidant Concentration (LOC)**
- Limiting Oxidant Concentration (LOC) for combustion is dependent on the material and type of inert gas used
- Nitrogen gas is the most commonly used inert gas. Carbon dioxide and argon are also used

Inert Gas Blanketing Techniques - NFPA 69

- **Pressure Purging**
  Vessel is pressurized with an inert gas, then relieved to the outside. This procedure is repeated until the desired oxygen concentration is reached.

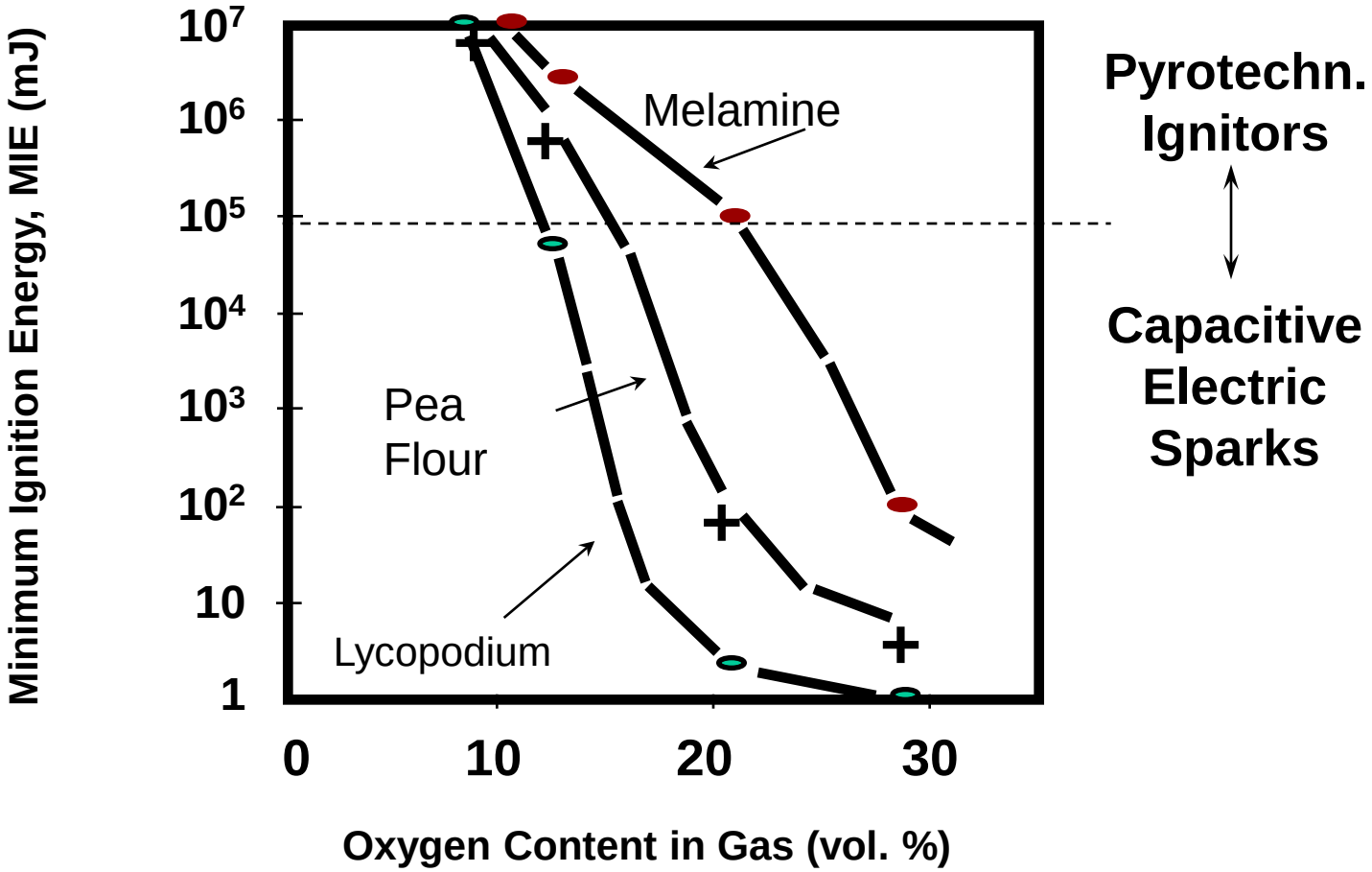
- **Vacuum Purging**
  Vessel is evacuated and then pressure is increased to atmospheric using an inert gas.

- **Flow-Through Purging**
  Vessel is purged with a continuous flow of inert gas.

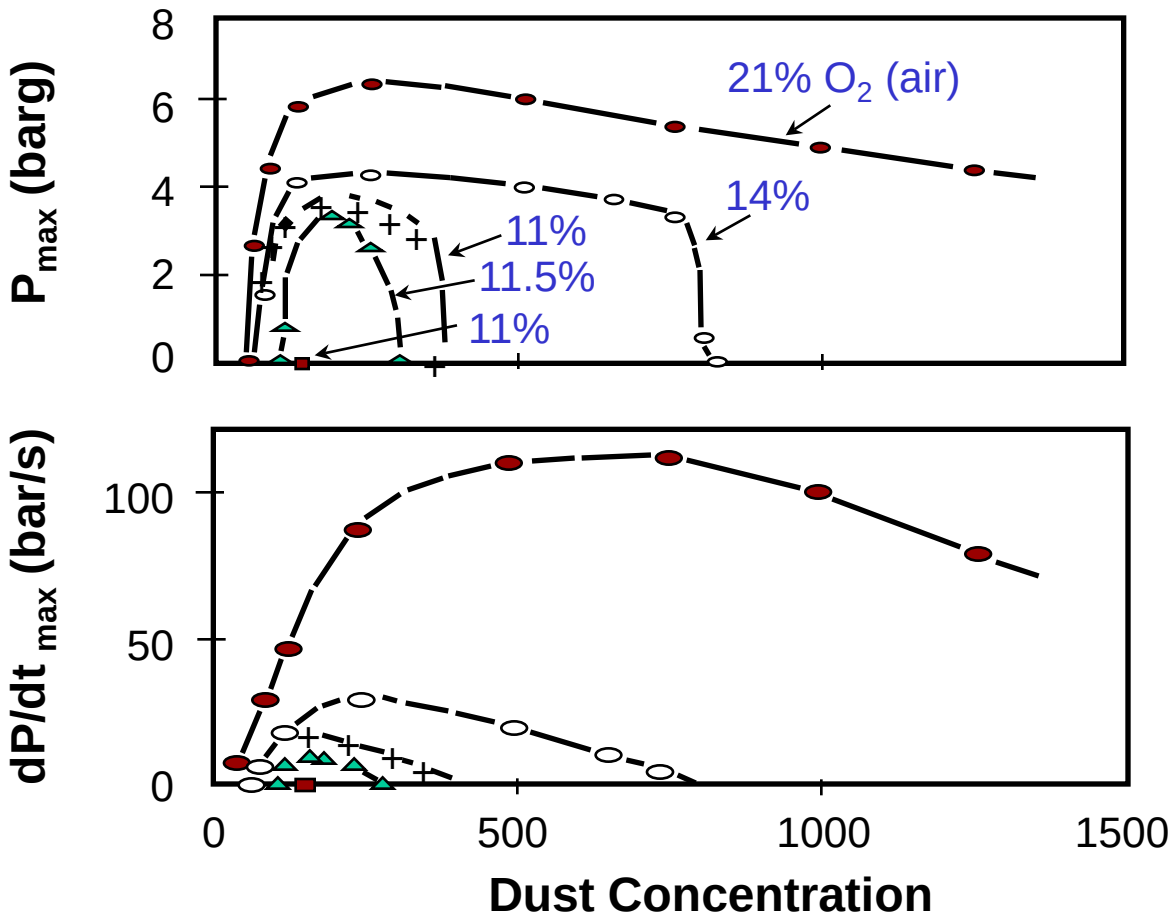
Partial Inerting

- Partial inerting is considered where:
  - It is impossible or impractical to reduce the oxidant concentration below the LOC
  - Explosion protection measures alone cannot satisfactorily provide a Basis of Safety
- Reduces the ignition sensitivity and explosion severity of the atmosphere
- Does not completely eliminate the fire or explosion hazard and must be used in conjunction with another Basis of Safety

Influence of Oxygen Content in Gas on MIE *(Eckhoff)*



Influence of oxygen content in the gas on the maximum explosion pressure and maximum rate of pressure rise of brown coal dust for various dust concentrations. Nitrogen as inert gas. ***(R. K.Eckhoff, 1997)***



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Test Data Requirements for Some Unit Operations

Unit Operation	Explosion Screening	MIE (mJ)	MIT – Cloud (°C)	MIT – Layer (°C)	Explosion Severity – Kst (bar.m/s)	LOC[2] (%)	MEC (g/m^3)	Volume Resistivity[3] (Ω.m)	Chargeability[4] (C/Kg)	Self-Heating (°C)
Manual Handling / Pouring	X	X						X	X	
Sieving / Screening	X	X						X	X	
Tumble / Double Cone Blending	X	X			X	X		X	X	
Ribbon Blending	X	X	X	X				X	X	
Milling	X	X	X	X	X	X		X	X	X
Jet Milling	X	X			X	X		X	X	
Spray, Fluidized Bed, Tumble, Flash Drying	X	X			X			X	X	X
Tray Drying	X	X			X					X
Pneumatic Conveying	X	X					X	X	X	
Screw Conveying	X	X	X	X				X	X	
Transfer to Hopper / Bin / Tote / Container	X	X			X			X	X	
Dust Collector and Exhaust Ventilation	X	X			X		X	X	X	

OSHA Combustible Dust National Emphasis Program (NEP)

CPL 03-00-008, March 11th, 2008

The purpose of this NEP is to inspect facilities that generate or handle combustible dusts which pose a deflagration or other fire hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape

OSHA National Emphasis Program (NEP)

OSHA Combustible Dust NEP Inspection Procedures Include:

- Assessment of the combustible dust threat to employees
  - *Does the MSDS indicate a dust explosion hazard?*
  - *Are dust accumulations hazardous?*
  - *What is the site history of fires involving dust?*
  - *Are the dust and management practices hazardous?*

- Collection of samples of combustible dusts for laboratory analysis
  - *From high places*
  - *From floors and equipment surfaces*
  - *From within ductwork*

  OSHA will only characterize a sample sufficiently to prove (or disprove) that the sample meets the definition for Class II dusts based on E.S or the I.S test results

- Audit of dust management practices and equipment including dust collectors, ductwork, and other dust containers.

- Audit of room safeguards

- Audit of ignition source management

OSHA National Emphasis Program (NEP)

Tests which May be Performed to Determine Explosibility and Combustibility Parameters of Dusts

Test	Particle Size	Moisture Content	Test Apparatus
% Through 40 Mesh (420µm)	As Received	As Received	40 Mesh (420µm) Sieve
% Moisture Content	Less than 420µm	As Received	Drying Oven at 75ºC for 24 hrs
% Combustible Material	Less than 420µm	As Received	Muffle Furnace at 600ºC for 1 hr
% Combustible Dust	Less than 420µm	-	(Calculation)
Max. Normalized Rate of Pressure Rise, Kst	As Received	Less than 5%	20-Liter Sphere (2500J Igniters)
Min. Explosible Concentration	Less than 420µm	Less than 5%	20-Liter Sphere (2500J Igniters)
Class II*	Less than 75µm		1-Liter Hartmann Bomb for Explosion Severity (E.S)
Resistivity	As Received	As Received	
Minimum Ignition Energy (MIE)	Less than 75µm ?	?	Hartmann Lucite Chamber
Minimum Ignition Temperature (MIT)	Less than 75µm ?	?	Godbert-Greenwald Furnace

- Classification of combustible dusts in accordance with the National Electric Code
- OSHA will only characterize a sample sufficiently to prove (or disprove) that the sample meets the definition for Class II dusts based on E.S or the I.S test results

Electrical Area Classification

Class II Test

Dust properties can be used to exempt an area from electrical area classification if it can be shown that the dust explosion hazard is not significant as defined by NFPA 499 section A.4.5.2

If

- The Ignition Sensitivity* is less than 0.2

AND

- The Explosion Severity* is less than 0.5

**As defined by the U.S. Bureau of Mines (see NFPA 499 section A.3.3.9)*

Electrical Area Classification

Class II Test

- U.S. Bureau of Mines(as referenced by NFPA 499) defines ignition sensitivity and explosion severity as follows:

$$Ignition\ Sensitivity = \frac{[MIE \times MIT \times MEC]_{Pittsburg\ Coal}}{[MIE \times MIT \times MEC]_{Sample}}$$

$$Explosion\ Severity = \frac{[P_{\max} \times \left(dP/dt\right)_{\max}]_{Sample}}{[P_{\max} \times \left(dP/dt\right)_{\max}]_{Pittsburg\ Coal}}$$

- If the ignition sensitivity is less than 0.2 **and** the explosion severity is less than 0.5, electrical area classification is not required

About Chilworth Global

Chilworth Global

Our History

- **Chilworth Global was first established in the UK in 1986**
- **Since then we have expanded and are now providing process safety and flammability services through our facilities in:**
  - **United Kingdom – Chilworth Technology Ltd**
  - **United States of America:**
    - Chilworth Technology, Inc – New Jersey
    - Safety Consulting Engineers - Chicago
    - Chilworth Pacific Fire Laboratories – Kelso, Washington
  - **Italy – Chilworth Vassallo Srl**
  - **France – Chilworth SARL**
  - **India – Chilworth Safety and Risk Management Ltd**
  - **Spain – Chilworth Amalthea SL**

Chilworth Global

Our Business

We provide services to business and industry to help **identify**, **characterize**, **prevent**, and **mitigate** potential fire, explosion, and thermal instability (runaway reaction) hazards in their processes

We achieve this by providing the following services:

- Process safety consulting and Incident Investigation
- Laboratory testing
- Training courses

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Our Services

- **Consulting**
  - Hazard Assessment
  - Incident Investigation
  - Process Safety Engineering

- **In-Company Training Courses**
  - Gas/Vapor Explosion Hazards
  - Dust Explosion Prevention & Protection
  - Understanding & Controlling Static Electricity
  - Understanding Thermal Instability Hazards

- **Laboratory Testing (ISO 17025 Certified Tests)**
  - Gas/Vapor Flammability
  - Dust Fire/Explosion
  - Electrostatic Characteristics
  - Reaction hazards and Thermal Runaway

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Our Expertise

- Gas & Vapor Flammability
- Dust Explosion Hazards
- Chemical Reaction Hazards
- Chemical Process Optimization
- Spontaneous Combustion and Thermal Instability
- Electrostatic Hazards, Problems, & Applications
- Hazardous (Electrical) Area Classification
- Transportation of Dangerous Goods
- Process Safety Management
- Flammability of Materials

Chilworth Global

Our Clients

Chilworth Global serves clients in a wide variety of industries, including:

- Basic and Specialty Chemicals
- Pharmaceuticals
- Paints and Coatings
- Petrochemicals
- Agrochemicals
- Agricultural and Food Products
- Oil and Gas
- Metals
- Soaps and Detergents
- Fragrance and Flavors
- Plastics and Resins