Dust Explosion Fundamentals: Recognizing the Dust Hazard

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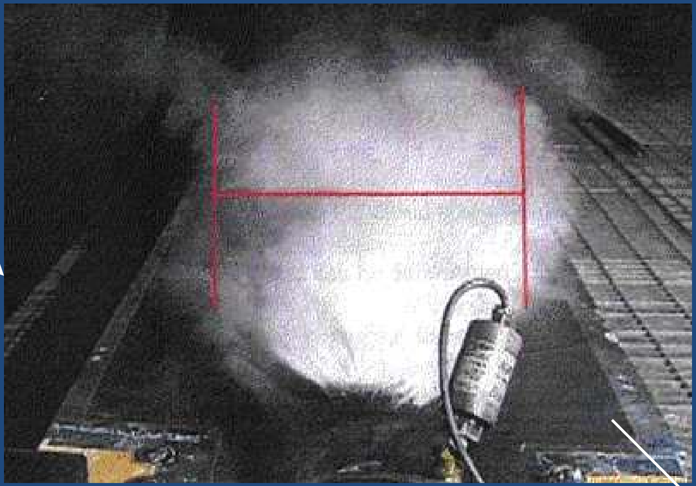
Presentation Outline

- Basic Concepts: Requirements for Dust Explosion
- Dust Cloud Concentration Criteria: MEC Data; particle size effects and pressure vs concentration
- How/where are explosive concentrations generated?
- Ignition Criteria and ignition scenarios:
  - Hot Temperatures
  - Burning Embers and Agglomerates
  - Self Heating
  - Impact/Friction
  - Electrical Equipment
  - Electrostatic Discharges

Combustible Powder/Dust Layer

+ Disturbance =



Dust Cloud

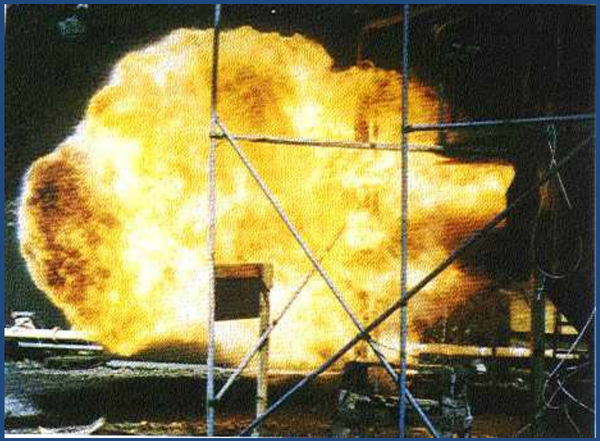
C > MEC

Minimum Explosible Concentration

+ Ignition Source

And Confinement =

Vented Explosion Fireball



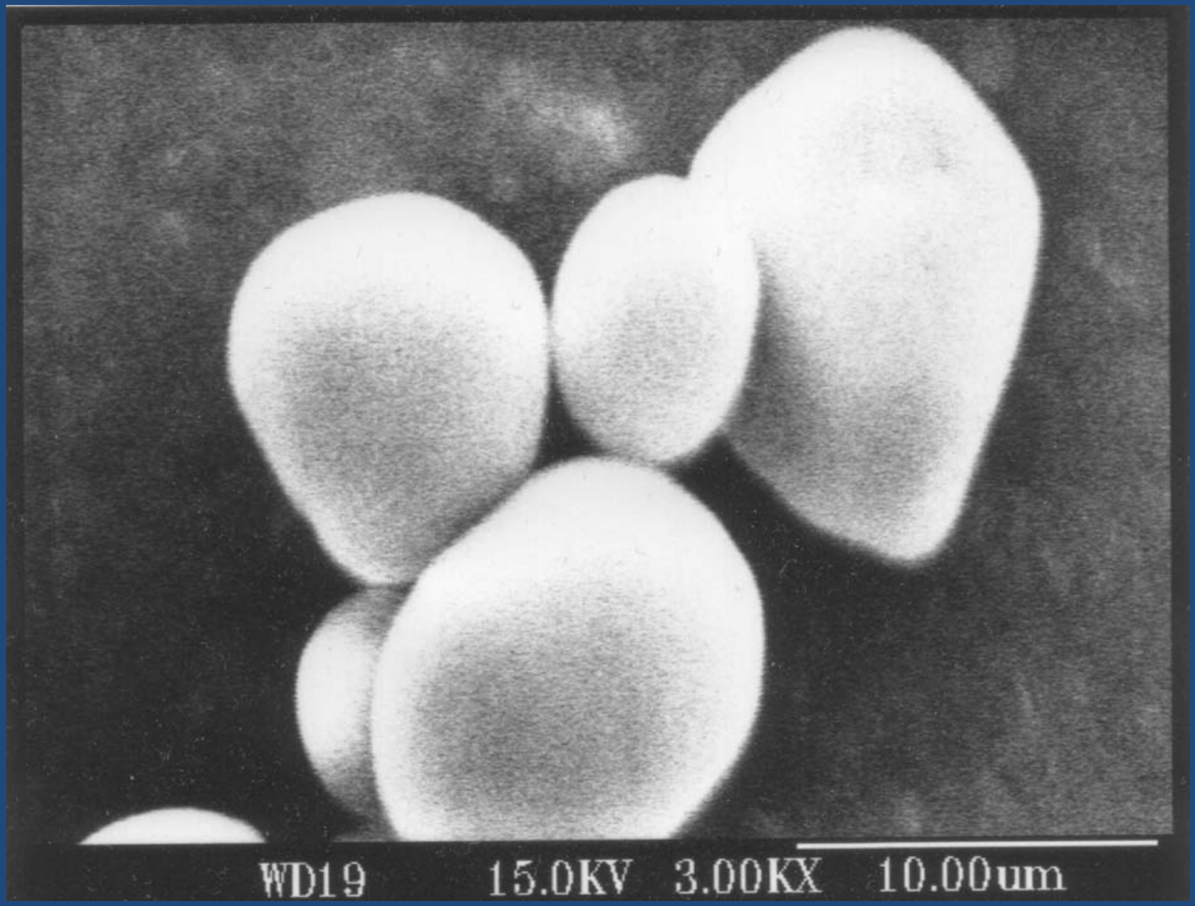
How Does Confinement Influence Dust Explosion Hazard?

- No Confinement: Ignition produces flash fire capable of producing burn injuries and igniting other combustible materials.
- Partial Confinement: Ignition produces fireball and limited pressure rise in enclosure and vented flame outside enclosure.
- Complete confinement: Ignition produces full deflagration pressure, P_{max}, which will destroy most buildings and process equipment.

How Small Does the Dust Particle Have to Be to Produce Explosion?

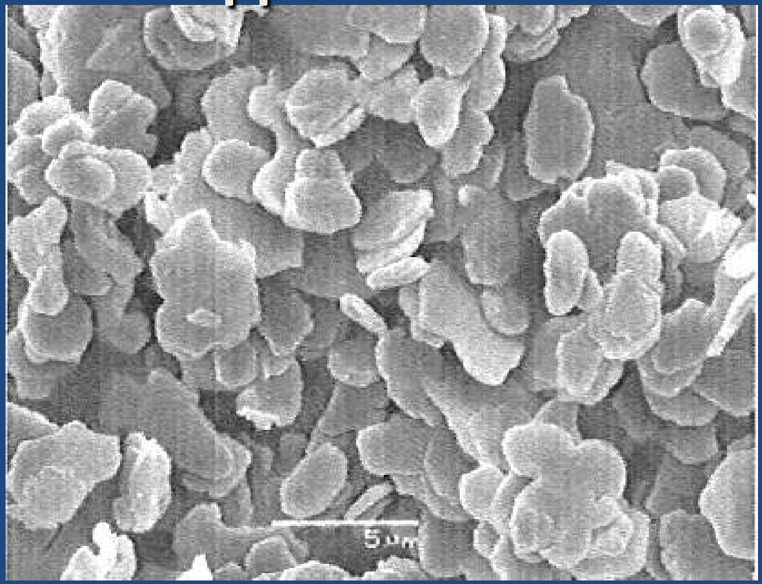
- Minimum explosible particle size depends on the material combustibility.
- Until recently, several NFPA standards defined combustible dust as “any finely divided solid material that is 420 microns or smaller in diameter (material passing a U.S. No. 40 Standard Sieve) and presents a fire or explosion hazard when dispersed in air.”
- Commercial dust testing labs now do dust explosibility screening tests based on new test method in ASTM E1226 . OSHA Salt Lake Tech Center does similar test but with slightly different test conditions.

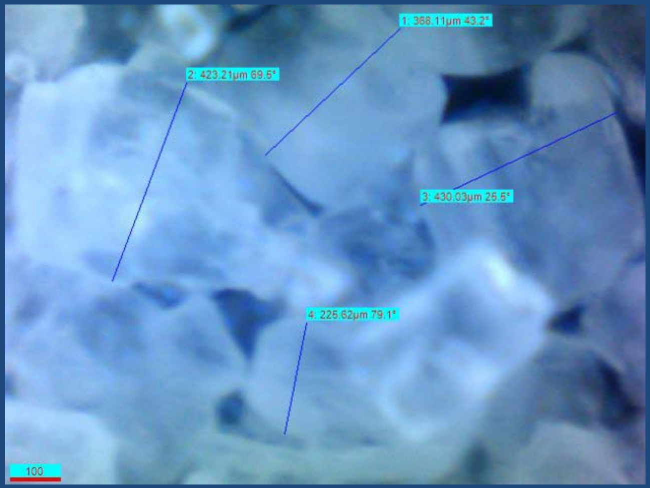
Combustible Dust Particles: Corn Starch



Combustible Dust Particles:

Copper Flakes





Granulated Sugar Crystals

Soft Tissue Papermachine Dust -400X

- Diameter: Mean = 6.5 um (1um, 50 um)
- Length: Mean = 72 um (3 um, 1700 um)
- Aspect Ratio: Mean = 13:1 (2:1, 850:1)

Dust Cloud Concentration > MEC
Opaque Cloud

Corn Starch at 110 g/m^3

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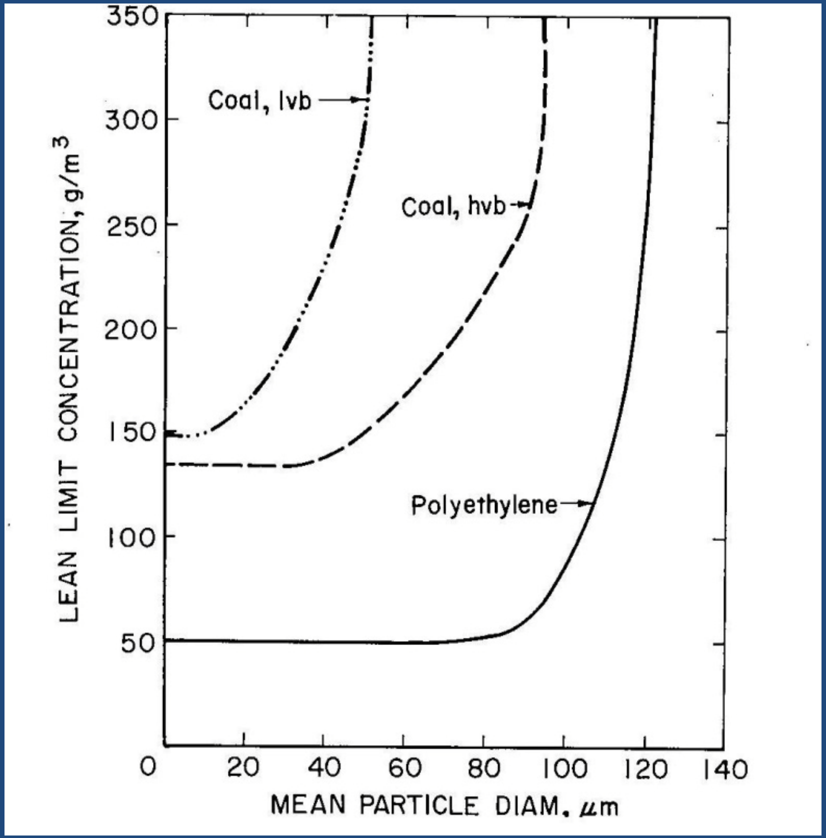
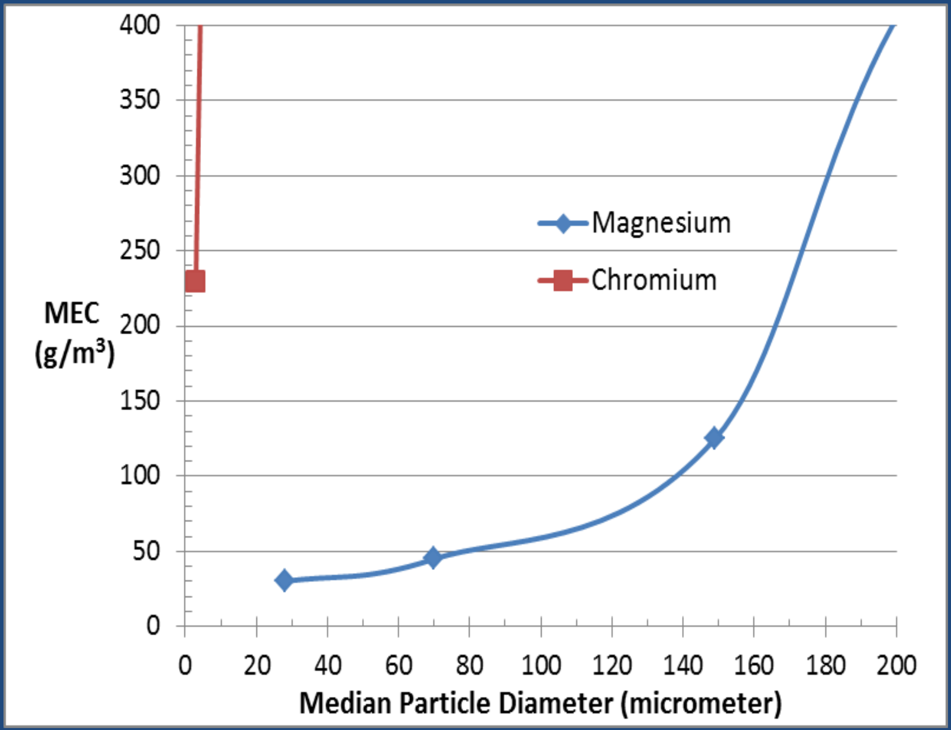
Dust Cloud in textile fiber flocking room

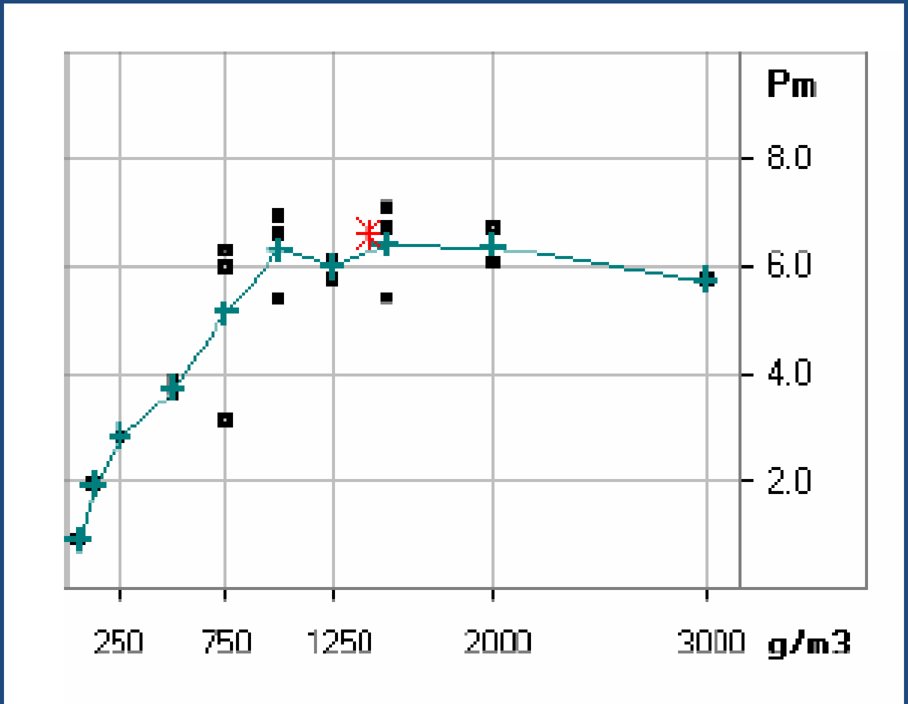
Under capacity cyclone collectors

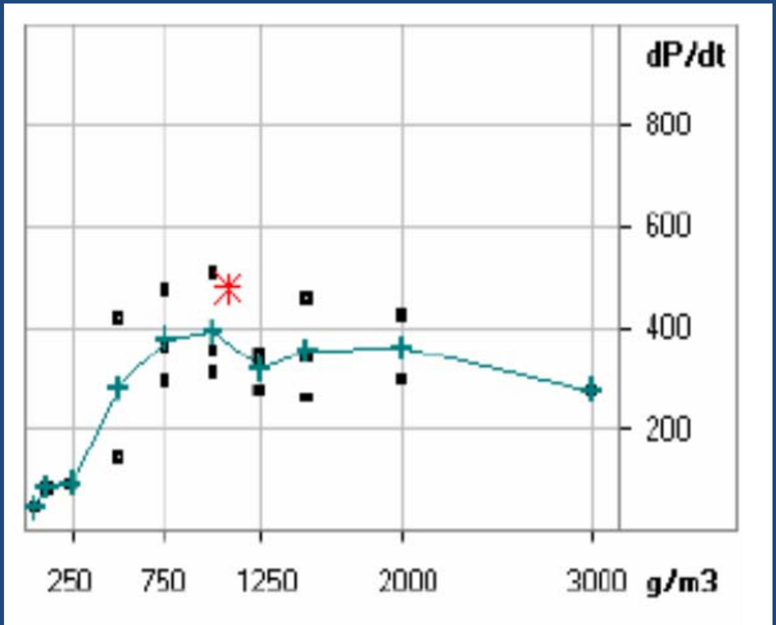
Dust Cloud MEC versus Particle Size





Effect of Dust Cloud Concentration on Explosion Max Pressure and Rate-of-Pressure Rise

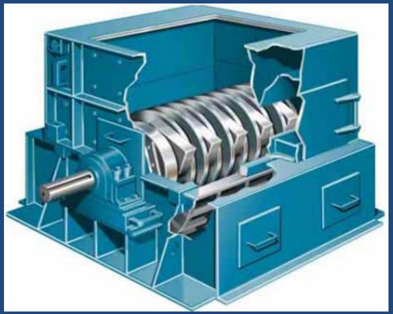




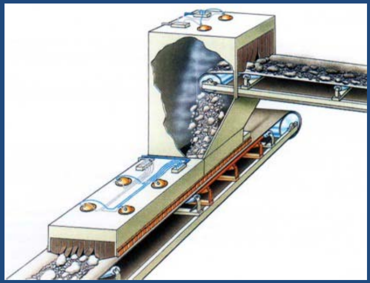
3 sets of tests in 20-liter sphere per ASTM E1226 test procedure

Where do explosible concentrations normally exist? Examples

- Dust Collectors
  - Baghouses
  - Cartridge Collectors
  - Cyclones



- Grinders/Hammermills
- Blenders



- Conveyor transfer points
- Supersack Filling and Unloading Stations

Where do explosible concentrations normally exist? More Examples

Rail car (rotary) unloader

Bag unloading stations

How are concentrations > MEC generated during housekeeping?

- Compressed air blowing

- Portable vacuum cleaners

- Vigorous sweeping

Dust Cloud Generation
in Secondary Dust Explosions

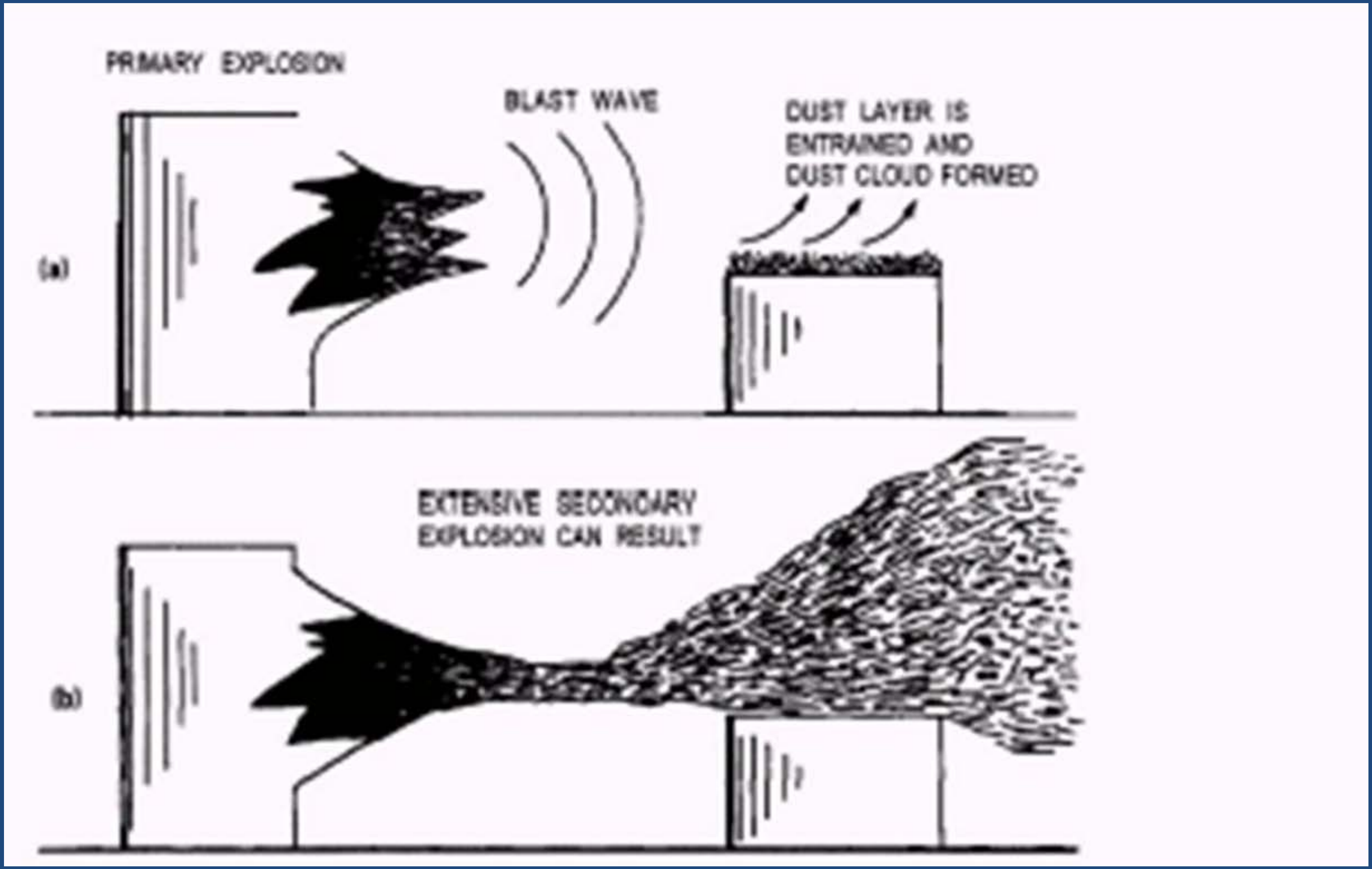


Illustration of how the blast wave from a primary explosion entrains and disperses a dust layer, which is subsequently ignited by the primary dust flame.

Ignition Sources: Hot Temperatures

- Dust Cloud Minimum Ignition Temperature
- Measured by injecting dust sample into either a horizontal or vertical oven with a pre-set air temperature.

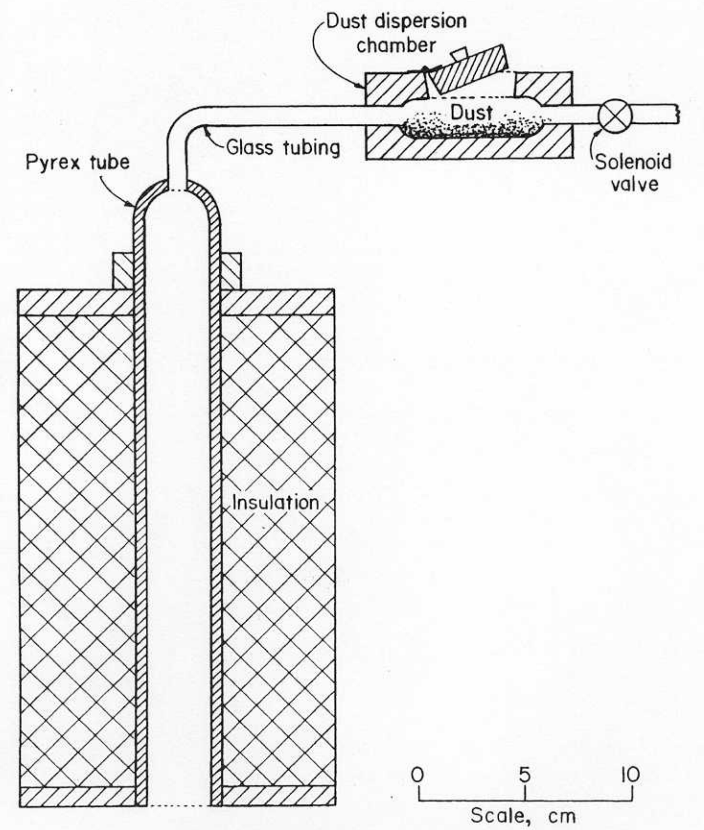


FIG. X1.1 Vertical Cross Section of the Godbert-Greenwald Furnace

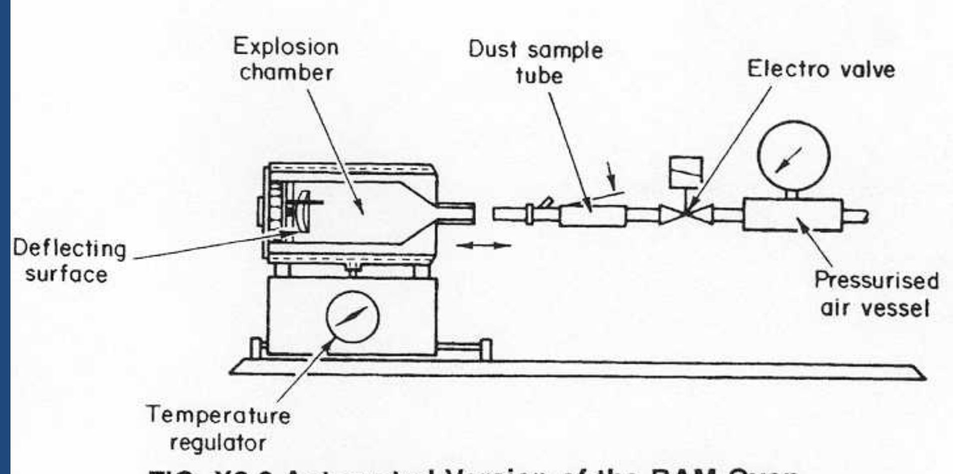


FIG. X2.2 Automated Version of the BAM Oven

Dust Cloud Ignition Temperature Data

- Most combustible dusts have a G-G dust cloud ignition temperature in the range 420^oC to 660^oC.
- BAM horizontal furnace ignition temperatures are typically 20^oC to 60^oC lower than G-G furnace temperatures because of longer residence times in BAM furnace.

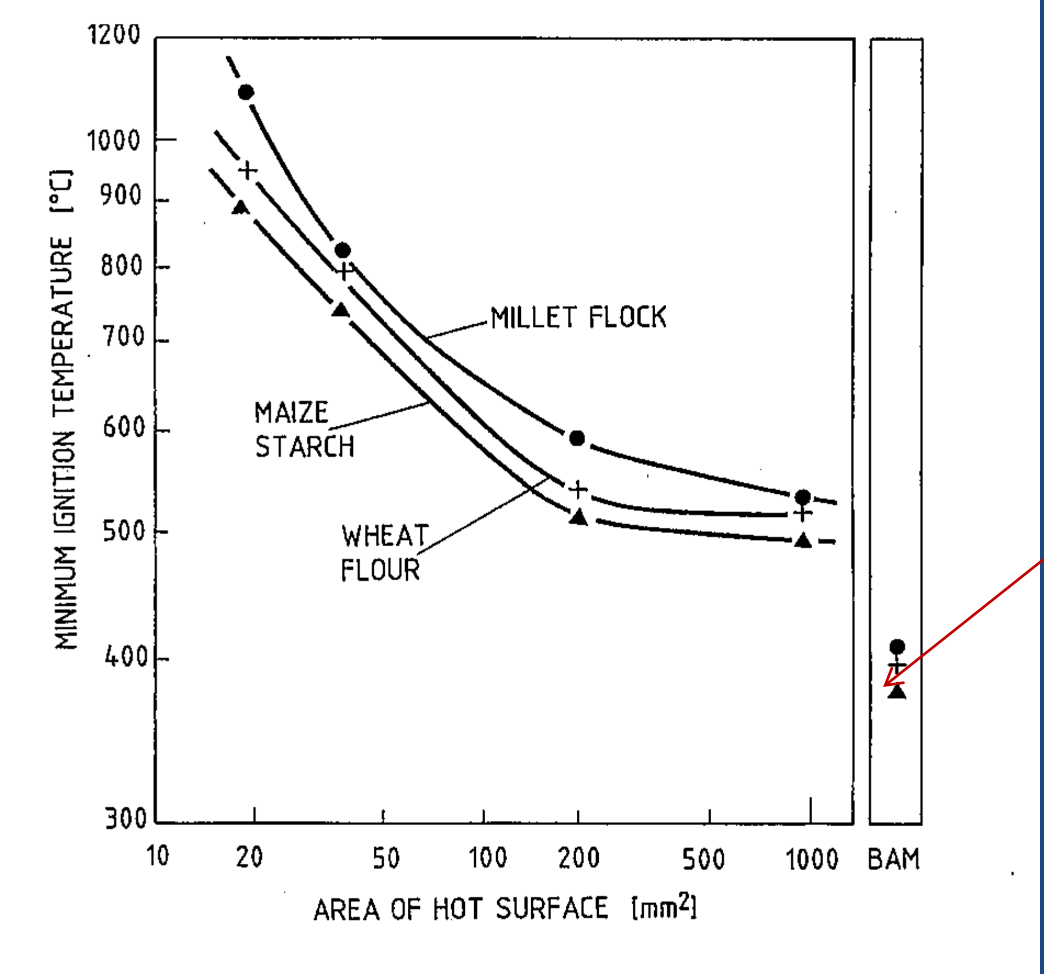
Example: Wood and Paper Dust Cloud G-G Ignition Temperature = 490 to 540^oC.

Example of Dust Explosion Ignited in Oven

- Employees "blowing down dust" in vicinity of oven
- Oven door left open to facilitate cooling between shifts and for makeshift temp control.

Figure 13. Interior of line 405 oven.

Hot Surface/Spot Ignition Temperatures

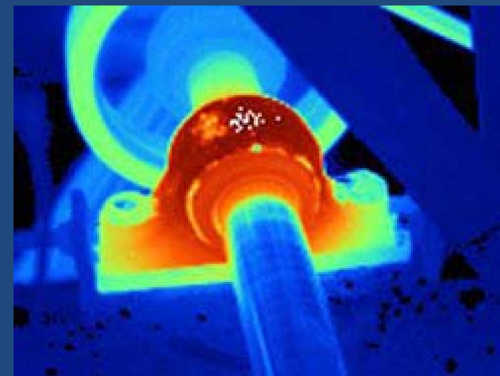


BAM Oven Ignition Temperatures

ASTM E2021 and IEC Hot Surface Ignition Temp Test Uses 7854 mm^2 Surface Area (10 cm diameter) and 5 mm deep layer

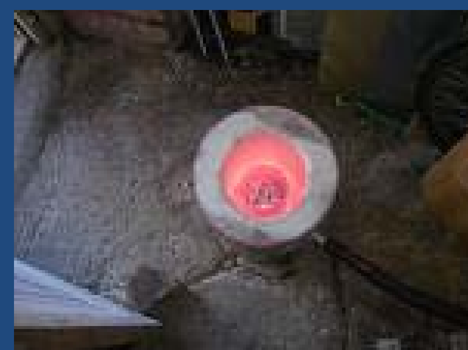
Examples of Hot Surfaces

- Hot Bearings



Failed bearing ignition source for feed plant dust explosion

- Foundry Furnace



- Hot steam pipe or heat transfer fluid pipe

More Hot Surface Ignition Examples

- Cutting & Welding

(Duct cut away while still containing aluminum dust)

- Halogen Light Bulb

Bulb recovered from debris in coal dust collector hopper after explosion

Burning Embers and Agglomerates

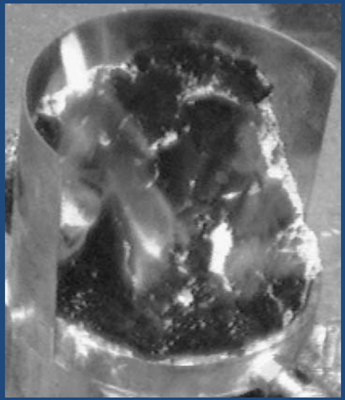
- Burning embers created by
  - Frictional heating, e.g. from sanding
  - Radiant heating, e.g. during curing of wood panels
  - Convective heating, e.g. in dryers

Dust Clouds Ignited by Burning Embers/Nests

- Direct ignition of dust clouds requires flaming embers/nests rather than smoldering.
- Can occur when embers/nests are transported downstream to dust collector or hopper

Can ignite most dust clouds

Flaming milk powder agglomerates: 960°C

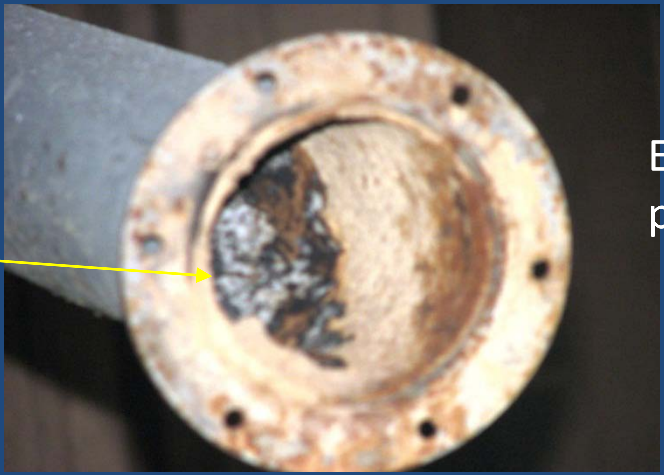


Can not ignite most dust clouds

Smoldering milk powder agglomerates: 700°C. MIT = 410°C

From Gummer & Lunn, 2003

Example of Dust Explosion Caused by Flaming Embers



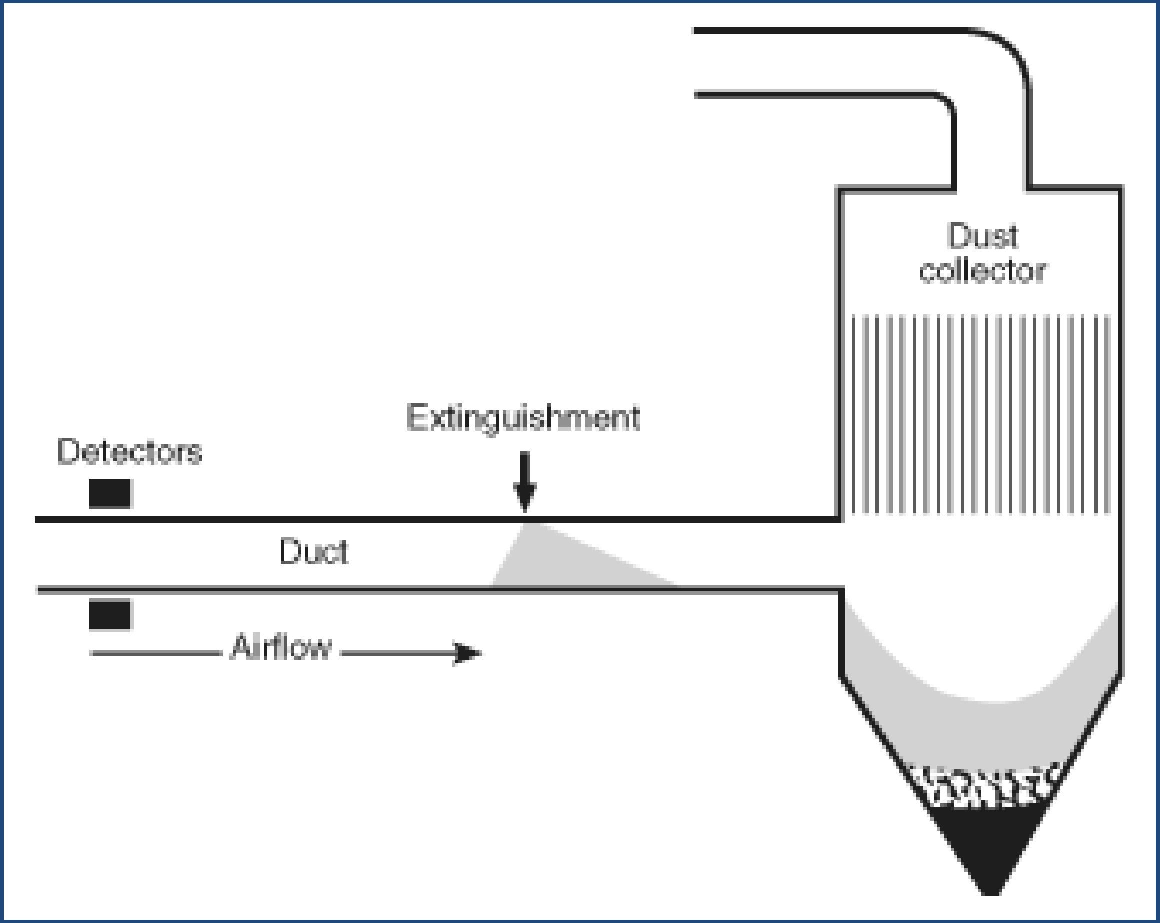
Embers in dust pickup pipe

Animal Feed Pelletizer:

Small Fire due to blockage

Dust collector explosion damages building

Prevention via Burning Ember Extinguishing System



See NFPA 654 Annex C for System Description

Dust Explosions Due to Burning Dust Piles Suddenly Dispersed in Enclosures

- Responding to dust collector fire, someone might open the collector door and allow air to rush into an oxygen-vitiated enclosure; result is a possible backdraft dust explosion.
- This has produced a fatality on a coal dust collector.

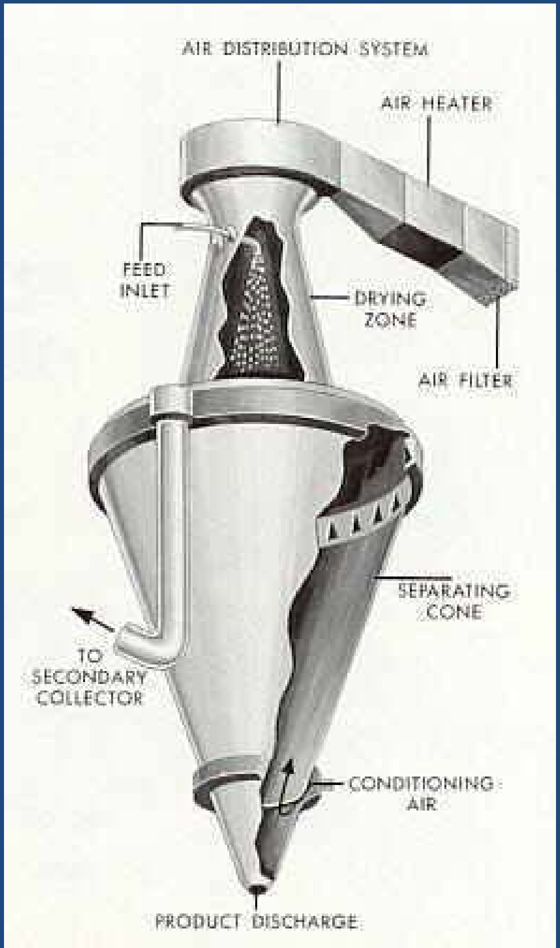
This cyclone collector was involved in a different explosion. Door was blown open. Ignition source was burning particulates from dryer.

Self-Heating Ignitions

- Self-Heating Mechanisms
  - Low level oxidation
  - Heat of condensation
  - Microbiological processes
- Pertinent Applications
  - Product accumulations in dryers
  - Extended storage in large silos or outdoor piles
  - Over-dried product suddenly exposed to moist atmosphere
- Self-ignition leads to burning, which can then ignite dust cloud if burning product is flaming.
- Critical temperature for self-heating decreases with increasing size of pile or layer.

Example of Self-Heating Explosion Scenario

- Powder accumulations remain in dryer sufficiently long for oxidative self-heating to bring powder up to ignition temperature.
- Result can be either a fire or a dust explosion in dryer or downstream dust collector.

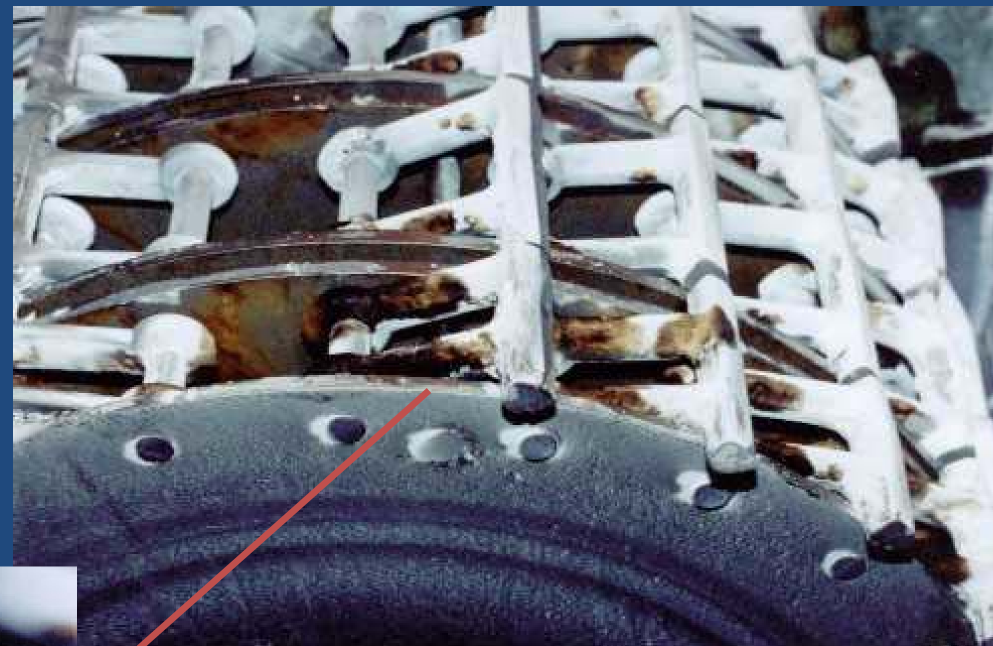


Impact/Friction Ignition

- During size reduction operations in various types of mills.
- During mixing and blending if impeller is misaligned or deformed or has inadequate clearance, or tramp metal enters mixer.
- During grinding and polishing operations.
- Tramp metal in a particle classifier or conveyor.

Example: Hammermill

Powdered Sugar Hammermill:
Ignition Evidence: broken hammer



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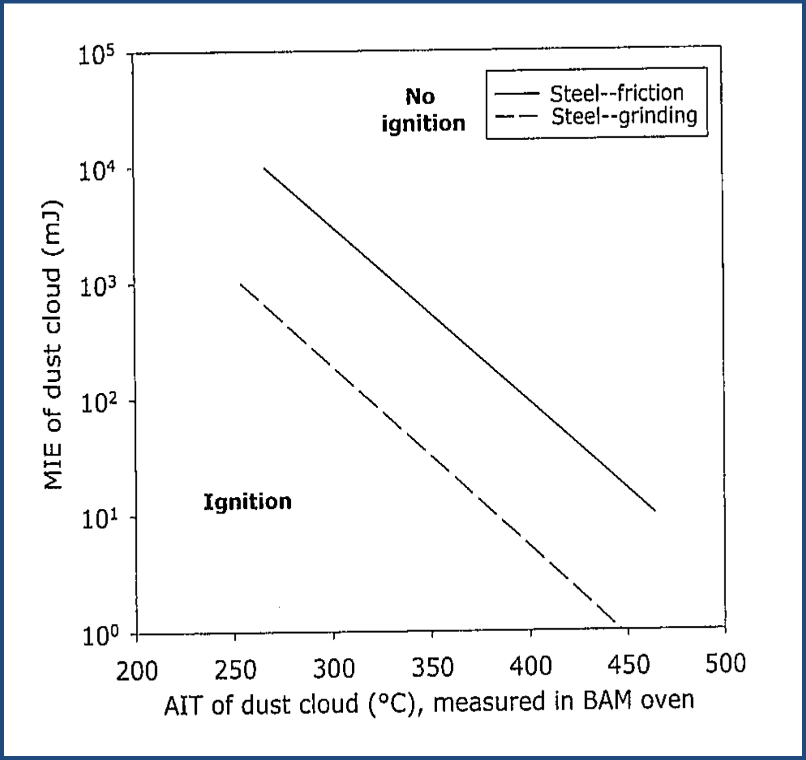
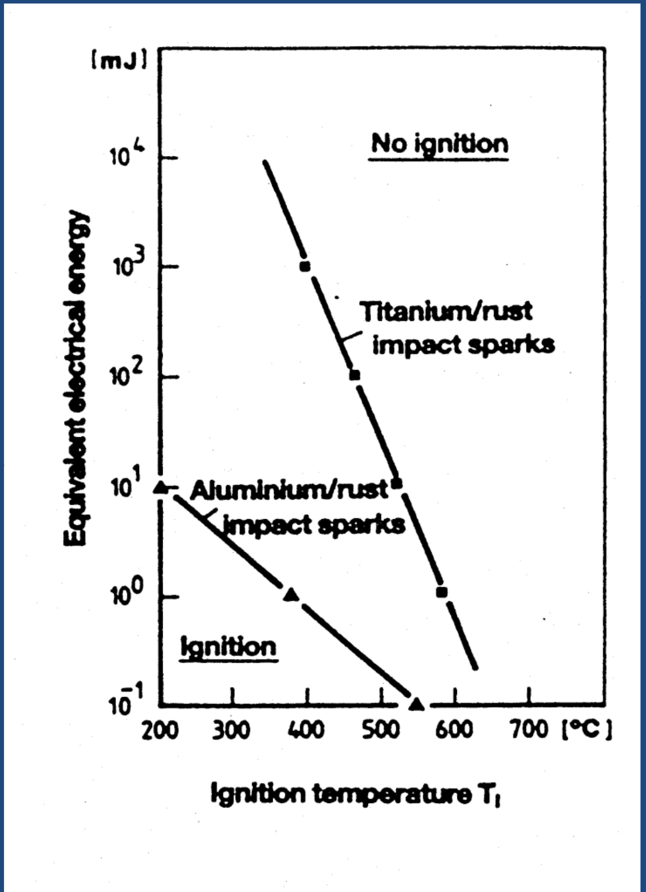
Dust Cloud Ignitability via Impact/Friction

Steel surface friction and grinding induced dust cloud ignitions

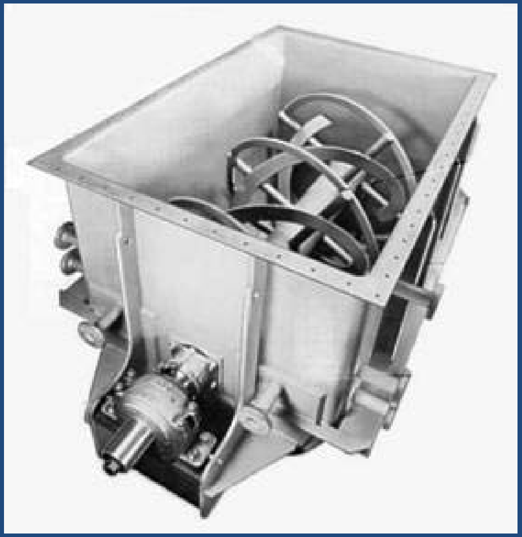




Impact sparks: relationship between equivalent electrical energy E_{Ae} and ignition temperature T_i – $F_A = 60 – 100$ N, $v_U = 25$ m · s^{-1} –

Impact/Friction Ignitions in Blenders and Grinders

Reference: Jaeger, 2001



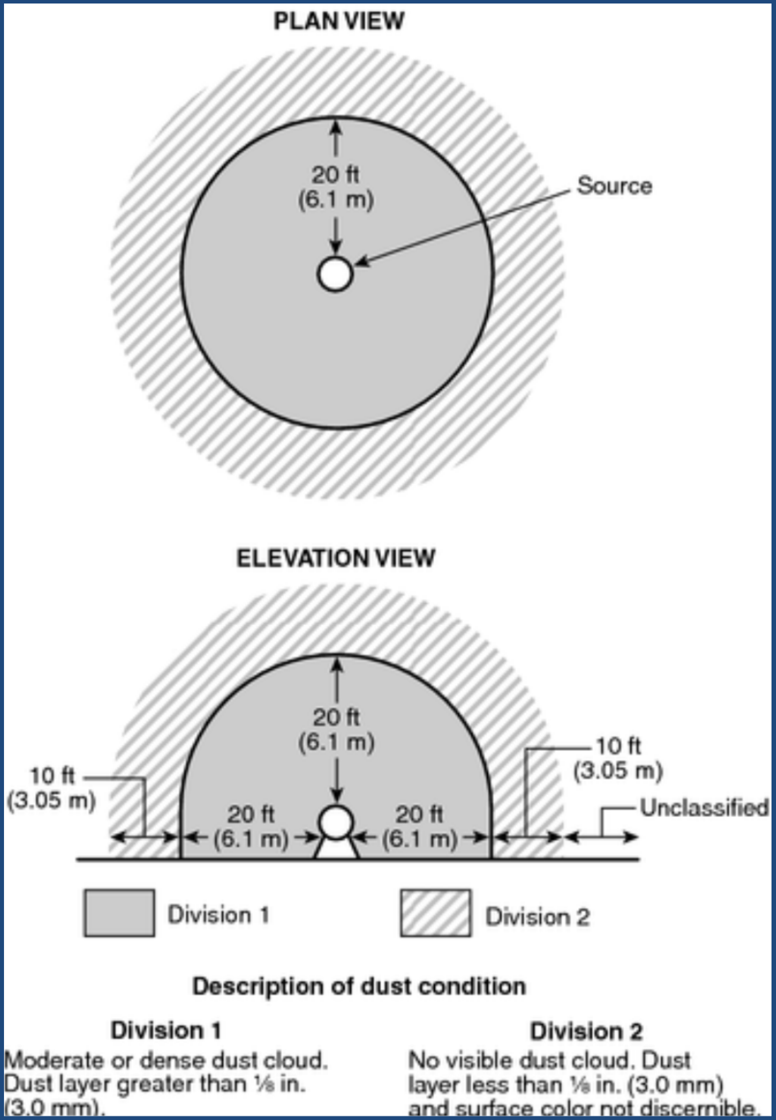
Ribbon/Paddle Speed	Friction Ignition Threat
< 1 m/s	None
1 – 10 m/s	Depends on Dust MIE and MIT
> 10	Great

No ignition threat when fill level > 70%

Ignition Sources: Electrical Equipment not Rated for Class II Areas

Dust accumulations on motor and outlet

Classification of Class II Areas per NFPA 499



NEC Article 502 Requirements for Wiring in Class II Areas

- Class II Division 1 Areas
  - Threaded metal conduit
  - Mineral Insulated (MI) cable with listed terminations
  - Fittings and boxes with threaded bosses for connections
- Class II Division 2 Areas
  - As for Division 1 areas <u>or</u>
  - _Dusttight wireways
  - Power Limited Tray Cables or Instrumentation Tray Cables in cable trays
  - Single layer Type Metal Clad or MI cables in cable trays

NEC Article 502 Sample Requirements for Equipment in Class II Areas

- Class II Division 1 Locations
  - Switches, circuit breakers, relays, etc. must be dust ignitionproof, i.e. excludes dusts and does not ignite exterior accumulations of dust (NEMA Type 9).
  - If metal dusts are present, switches and circuit breakers must have enclosures rated for metal dust exclusion
  - **Explosionproof equipment neither required nor acceptable**
- Class II Division 2 Locations
  - Motors must be either totally enclosed nonventilated or totally enclosed water-air cooled or fan-cooled or dust ignitionproof. Temperature rating < 165^{o}C for organic dusts that carbonize

IEC Electrical Equipment: Maximum Allowable Surface Temperatures Based on IEC Surface Ignition Test Data and Layer Thickness

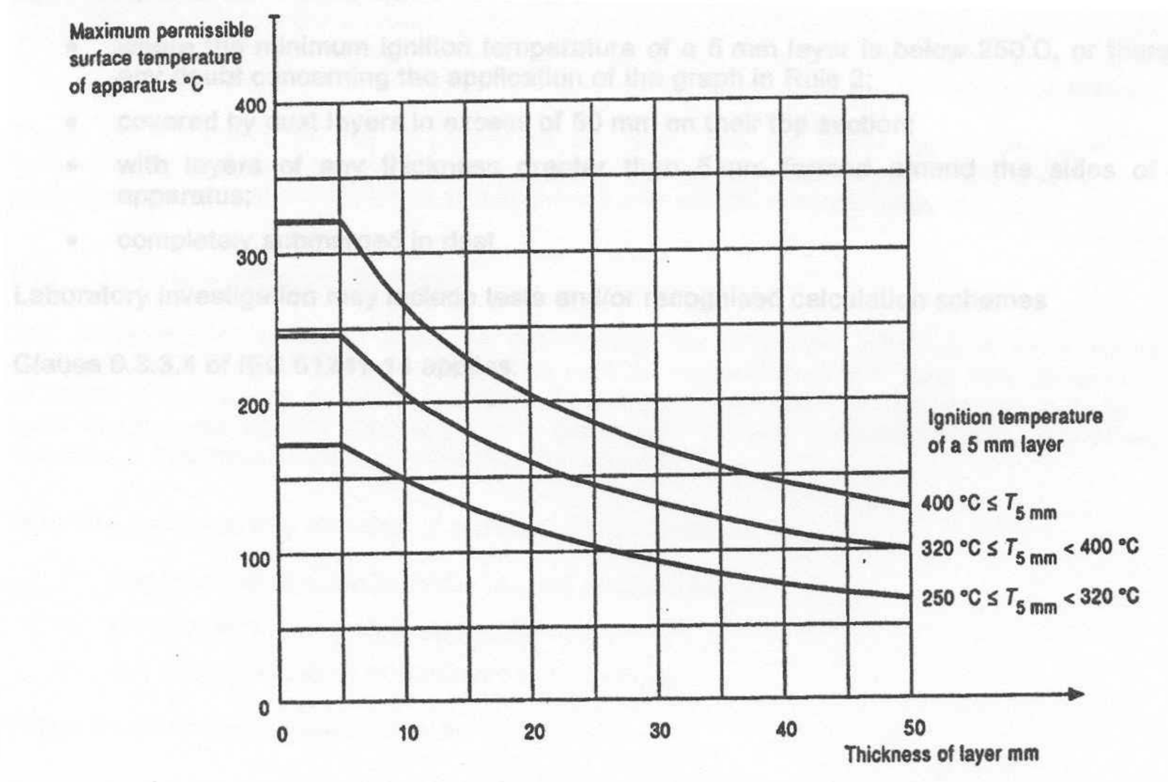


Figure B.1
Reduction in the maximum permissible surface temperature marking on apparatus for increasing depth of dust layers.

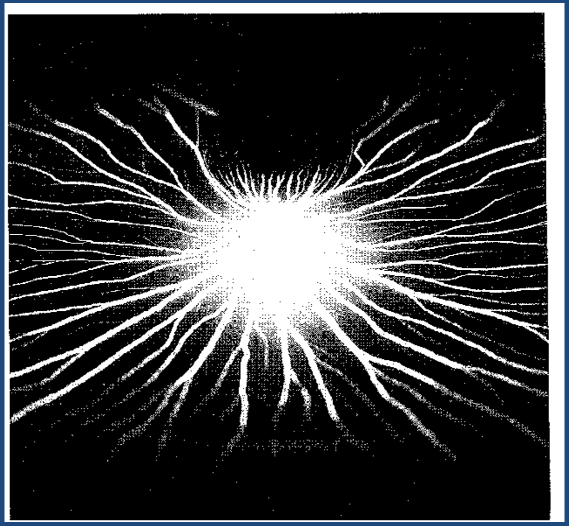
NEC Article 502 “Dustproof” Option for Class II Division 2 Electrical Equipment

- Needs to be able to prevent windblown dust from entering enclosure.
- Certification would have an Ingress Protection (IP) rating of 6x.
- IP rating of 6x corresponds to NEMA 4 rating

Dustproof light fixture

Ignition Sources: Electrostatic Discharges

- Propagating Brush Discharge from insulated layer or coating on metal surface, or from insulator with breakdown strength > 4 kV



- Sparks from ungrounded boots on pipes and ducts
- Bulking brush discharge from large piles of high resistivity powder loaded into bins or blenders

Electrostatic Ignition Sources: Flexible Intermediate Bulk Containers (FIBCs) aka Supersacks

- Used for loading, transporting, and unloading bulk powders
- Four different types with different electrostatic properties

Type A,B,C, and D FIBCs

- Type A allows high electrostatic charges and has no electrostatic controls.
- Type B has walls that cannot sustain a voltage of more than 4 kV; can be used if powder Min Ign Energy > 3 mJ.
- Type C is made with conductive fabric and must be grounded to prevent electrostatic charge accumulation.
- Type D dissipates electrostatic charges and can be used for any dust/powder.

Charging of Vessels via FIBC or Drum Unloading

- Completely opening sack spout produces a sack unloading and vessel charging flow rate of about 23 kg/s.
- High particulate flow rates produce electrostatic charges on polymeric gaskets and elastomeric boots in vessel inlet piping.
- Flow rates > 5 to 8 kg/s can charge high resistivity (> 10^{10} Ω-m) powders.

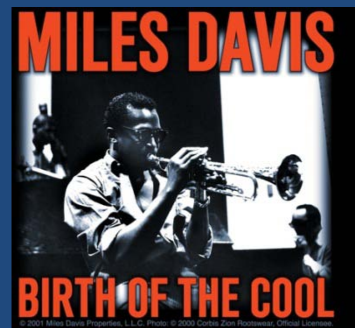
Other Electrostatic Discharge Ignition Sources

- High Resistivity Plastic pipe
- Elastomeric or Plastic Flexible Connectors, including connectors with embedded spiral wire.
- Dust collector bags

These are potential ignition sources for dusts with a Min Ignition Energies < 1 Joule (due to sparking potential) and are a particular concern for dusts with MIE < 100 mJ because of less energetic discharge mechanisms.

Alliterative Summary:
How to Prevent Ignitions and Live Longer

- Keep Cool



- Forego Friction
- Eliminate excess (electrical) energy

- Check Charging