Dust Explosion Hazard Assessment

Presentation Outline

- Conditions for a Dust Cloud Explosion
- Management of Dust Cloud Explosion Hazards
  - Explosion Characteristics of Dust Clouds
  - Control of the Spread of Combustible Dust Atmospheres
  - Elimination/Control of Potential Ignition Sources
  - Application of Explosion Safeguards
Conditions Required for Dust Cloud Explosions to Occur

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

- Dust must be explosible (combustible, Flammable)
- 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
Explosibility Screening

Use a Hartmann Bomb, 20L sphere, or 1m³ 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”
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Management of Dust Cloud Explosion Hazards

- Site Audit:
  - Understand process operations and review of all available information (drawings, specifications, process/operation descriptions)
  - Identification of locations where combustible dust cloud atmospheres are or could be present during normal and abnormal operating conditions
  - Identification of potential ignition sources that could be present under normal and abnormal conditions
  - On-site electrostatic measurements (electrical field, electrical continuity measurements, etc.), where applicable

- Understanding of the explosion characteristics of the dust(s)

- Proper process and facility design to prevent and/or minimize the occurrence of dust explosions and protect people and facilities against their consequences

- Regular inspection and maintenance of equipment to minimize ignition sources and dust releases
Industries handling and processing explosible dusts must be fully aware of Best Industry Practices as described in pertinent dust Codes and Standards, and follow these recommendations. Relevant codes and standards include:

- NFPA 61, “Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Products Facilities”
- NFPA 77, “Recommended Practice on Static Electricity”
- NFPA 484, “Standard for Combustible Metals, Metal Powders, and Metal Dusts”
- NFPA 499, “Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas”
- NFPA 654, “Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids”
- NFPA 655, “Standard for Prevention of Sulfur Fires and Explosions”
Laboratory Testing to Understand Explosion Characteristics of Dusts

- How easily will the dust cloud ignite?
  - Minimum Ignition Energy (dust cloud)
  - Minimum Ignition Temperature (dust cloud and dust layer)
  - Thermal Instability

- What will happen if the dust cloud does ignite? (Consequences of Ignition)
  - Maximum Explosion Pressure
  - Maximum Rate of Pressure Rise

- Ensuring Safety by Avoiding/Controlling Flammable Atmospheres?
  - Minimum Explosible Concentration
  - Limiting Oxygen Concentration

- Electrostatic Properties
  - Electrostatic Chargeability
  - Resistivity / Conductivity
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:
- Electrostatic discharges
- Mechanical friction and sparks
- Hot surfaces and equipment
- Thermal decomposition
- Electrical arcs (sparks)

Application of explosion safeguards:
- Explosion protection (containment, relief venting, explosion suppression)
- Explosion isolation
- Inert Gas Blanketing
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.

![Graph showing the relationship between explosible dust cloud concentration and explosion violence.](image)
Control of the Spread of Combustible Dust Atmospheres

Illustration of the potential hazard of even thin dust layers. A 1mm layer of a dust of bulk density 500Kg/m³ will generate a cloud of average concentration 100g/m³ if dispersed in a room of 5m height. Partial dispersion up to only 1m gives 500g/m³ (Eckhoff)

\[ C = P_{\text{bulk}} \times \frac{h}{H} \]

- \( C \) is dust cloud concentration
- \( P_{\text{bulk}} \) is powder bulk density
- \( h \) is dust layer thickness
- \( H \) is dust cloud height in the room
Control of the Spread of Combustible Dust Atmospheres

- Equipment should be maintained and operated in a manner that minimizes the escape of dust.

- Continuous local exhaust ventilation should be provided for processes where combustible dust is liberated in normal operation so as to minimize the escape of dust. The dust should be conveyed to dust collectors.

- Regular cleaning frequencies should be established for floors and horizontal surfaces, such as ducts, pipes, hoods, ledges, and beams, to minimize dust accumulations within operating areas of the facility.
Surfaces should be cleaned in a manner that minimizes the generation of dust clouds. Vigorous sweeping or blowing down with compressed air produces dust clouds and should be permitted only if the following requirements are met:

- Area and equipment should be vacuumed prior to blow-down
- Electrical power and other sources of ignition should be shut down or removed from the area
- There should be no hot surfaces capable of igniting a dust cloud or layer
- Only low gauge pressure [15psi (103kPa)] compressed air should be used

Vacuum cleaners should be listed for use in Class II hazardous locations or should be a fixed pipe suction system with remotely located dust collector.
Management of Dust Cloud Explosion Hazards

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Elimination / Control of Potential Ignition Sources

- Electrostatic Discharges
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.
MIE and the Effect of Dust Cloud Concentration

![Graph showing the relationship between Minimum Ignition Energy (mJ) and Dust Concentration (g/m³). The graph indicates a decrease in Minimum Ignition Energy as Dust Concentration increases from 0 to 500 g/m³, after which it increases sharply.]
### Factors Affecting Minimum Ignition Energy

<table>
<thead>
<tr>
<th>Some Influencing Factors</th>
<th>Effect</th>
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<tbody>
<tr>
<td>Increasing Particle Size</td>
<td>![Up arrow]</td>
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<tr>
<td>Increasing Moisture Content</td>
<td>![Up arrow]</td>
</tr>
<tr>
<td>Presence of Flammable Vapor (even if below LFL)</td>
<td>![Down arrow]</td>
</tr>
<tr>
<td>Increase in Ambient Temperature</td>
<td>![Down arrow]</td>
</tr>
</tbody>
</table>
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

Tank farm

Reactors

Centrifuge

Vacuum Dryer

Mill
Electrostatic Discharges and Their Control

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 = \( \frac{1}{2} CV^2 \)

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

- **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
Electrostatic Discharges and Their Control

- **Discharges from Human Body**
  Maximum energy of about 25mJ to 30mJ

  - Personnel should be grounded so that their resistance-to-ground $<1\times10^8$ ohm
  
  - Static dissipative footwear may be used
  
  - Resistance of the floor/surface on which the operator is standing should also be $<1\times10^8$ ohm
Electrostatic Discharges and Their Control

- **“Bulk”/”Cone” Discharge** - Discharges on the surface of the powder during filling of vessels/bins/containers
  
  - Discharge energy depends on powder Volume Resistivity, Electrostatic Chargeability, particle size, and vessel dimensions
  
  - Maximum discharge energy about 25mJ
Electrostatic Discharges and Their Control

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

  - **Volume Resistivity < 10^9 Ohm.m**
    No electrostatic charge accumulation and hence on “Bulk” discharge if powder is handled in grounded conductive plant

  - **Volume Resistivity > 10^9 Ohm.m and Minimum Ignition Energy >25mJ**
    No electrostatic ignition hazard in grounded conductive plant

  - **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
Elimination / Control of Potential Ignition Sources

- Mechanical friction and sparks
- Hot surfaces and equipment
- Thermal decomposition
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.
Relevant Laboratory Test

**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
Thermal Instability (Self-Heating)

- 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 Instability Testing

- 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
Thermal Instability (Self-Heating)

Bulk Powder (Diffusion Cell) Screening Test

![Graph showing temperature versus time with different sample positions and oven temperature.]

- Oven temp
- Sample top
- Sample upper
- Sample lower
- Sample base
Control of Heat Sources and Frictional Sparks

- If the material is subjected to heat as part of the normal process (e.g. during drying), the temperature should be maintained below the self-heating temperature.
- 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
Elimination / Control of Potential Ignition Sources

- Electrical arcs (sparks)
Incorrectly specified electrical equipment is a potent ignition source for flammable gases, vapors and dusts

- Sparks
- Hot surfaces

In facilities handling flammable materials the electrical equipment used must be suitable for the environment in which it is to be used

In order to determine the type of equipment it is necessary to define hazardous (classified) locations
Electrical Area Classification

- Electrical area classifications defined under Article 500 of the National Electrical Code (NFPA 70)

- The intent of Article 500 is to prevent electrical equipment from providing a means of ignition for an ignitable atmosphere

- Two classes of hazardous locations:
  - Class I  Flammable gases or vapors (NFPA 497)
  - Class II  Combustible dusts (NFPA 499)

- Two divisions of hazardous locations:
  - Division 1  Normally or frequently present
  - Division 2  Not normally present, but possible
Factors influencing the extent of Class II locations include:

- Combustible material involve
- Bulk density of the material
- Particle sizes of the material
- Density of the particles
- Process or storage pressure
- Size of the leak opening
- Quantity of the release
- Dust collection system
- Housekeeping
- Presence of any flammable or combustible gas
Extent of Class II Locations

- Dust-tight equipment and good maintenance reduces the extent of classified areas

- Effective dust removal (ventilated hoods and pickup points) and excellent housekeeping reduces the extent of a classified area

- Where there are walls that limit the travel of the dust particles, area classifications do not extend beyond the walls
Selection of Electrical Apparatus

Division 1

- Dust Ignition proof
- Intrinsically safe
- Pressurized

Division 2

- Any suitable for Division 1
- Dust-tight
- Non-incendive
- Hermetically sealed

In addition the maximum surface temperature must be considered
- determined by MIT (dust cloud and layer)
- usually stated as temperature classes
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:
  - Electrostatic discharges
  - Mechanical friction and sparks
  - Hot surfaces and equipment
  - Thermal decomposition
  - Electrical arcs (sparks)

- Application of explosion safeguards:
  - Explosion protection (containment, relief venting, explosion suppression)
  - Explosion isolation
  - Inert Gas Blanketing
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) $K_{st}$

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

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

<table>
<thead>
<tr>
<th>Dust Explosion Class</th>
<th>$K_{st}$ (bar.m/s)</th>
<th>Characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>St 0</td>
<td>0</td>
<td>Non-explosible</td>
</tr>
<tr>
<td>St 1</td>
<td>$0 &lt; K_{st} &lt; 200$</td>
<td>Weak to moderately explosible</td>
</tr>
<tr>
<td>St 2</td>
<td>$200 &lt; K_{st} &lt; 300$</td>
<td>Strongly explosible</td>
</tr>
<tr>
<td>St 3</td>
<td>$K_{st} &gt; 300$</td>
<td>Very strongly explosible</td>
</tr>
</tbody>
</table>

Note:
- Any explosion can cause burn injuries
- Any explosion can cause structural damage if the structure is not strong enough
Explosion Protection Techniques – Containment

- Must withstand the maximum pressure that is expected
- All parts of the plant made strong
  - includes pipes, ducts, flanges, covers, etc.
- Maintain strength over lifetime
- Strong plant is expensive to build and can be difficult to operate
Explosion Protection Techniques – Explosion Suppression

Relies on early detection of an explosion and rapid injection of suppressant. Typically at moment of detection, explosion pressure is 35 to 100 m bar g. Suppressant extinguishes the flame within approximately 50msec.

To achieve explosion suppression, the following are required;

- Explosion Detector
- Control Unit
- Suppressor
- Suppressant

Diagram:
- 1. Ignition - 0.000 Seconds
- 2. Detection - 0.020 Seconds
- 3. Control - 0.025 Seconds
- 4. Suppression - 0.060 Seconds
Explosion Protection Techniques – Venting

Relies on rapid opening of panel(s) or door(s) hence allowing the release of hot gases and unburnt product from within a process component or room

Advantages and disadvantages

- Relatively low cost
- Simple to install in most cases
- Not suitable for toxic materials
- Venting to inside of buildings is usually unacceptable
An explosion, initiated in one plant item should be prevented from propagating along pipes, chutes, conveyors etc. and starting a subsequent explosion in other plant items.

The simplest isolation method is avoidance of unnecessary connections. If this is not possible, special measures should be taken to create barriers to avoid propagation of an explosion.

- Mechanical Isolation (Barriers)
- Chemical Isolation (Barriers)
Inert Gas Blanketing Techniques - NFPA 69

An explosion (or fire) can be prevented by reducing the oxidant concentration below a level that will no longer support combustion through the addition of an inert gas to the vessel where the flammable/combustible atmosphere exists.

There are 3 commonly used inerting techniques:

- **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.
Relevant Laboratory Test

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 type of fuel and the inert gas used

- Nitrogen gas is the most commonly used inert gas. Carbon dioxide and argon are also used
Influence of Oxygen Content in Gas on MIE (Eckhoff)

Minimum Ignition Energy, MIE (mJ)

Oxygen Content in Gas (vol. %)

Lycopodium

Melamine

Pea Flour

Pyrotechn. Ignitors

Capacitive Electric Sparks
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)

<table>
<thead>
<tr>
<th>Dust Concentration</th>
<th>$P_{\text{max}}$ (barg)</th>
<th>$\frac{dP}{dt}_{\text{max}}$ (bar/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>21% O$_2$ (air)</td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>14%</td>
<td>6</td>
<td>50</td>
</tr>
<tr>
<td>11%</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>11.5%</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>11%</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>6420</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0.1</td>
<td>0</td>
</tr>
<tr>
<td>50</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

![Graph showing influence of oxygen content on explosion pressure and rate of pressure rise](image-url)
About Chilworth Global
Chilworth Technology 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
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
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
Chilworth Technology, Inc.

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 Technology, Inc.

Our Clients

Chilworth Technology 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
Dust Explosion Hazard Assessment

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