FIRES, EXPLOSIONS, AND COMBUSTIBLE DUST HAZARDS

Morgan Worsfold & Paul Amyotte
Dalhousie University, Halifax, NS, Canada

Manny Marta
NOVA Chemicals, Sarnia, ON, Canada
Module Basics

Scope

- Fires, explosions, and combustible dust hazards

Motivation

- While these incidents and hazards are prevalent in the process industries, practitioner knowledge gaps exist

Objective

- Achievement of specific learning objectives by the target audience of undergraduate engineering students
Learning Objectives

Remembering
- Define combustible dust
- Identify the three elements of the fire triangle and the five elements of the explosion pentagon

Understanding
- Explain how gaseous, liquid and solid fuels burn
- Describe the fundamentals of a dust explosion according to the explosion pentagon

Applying
- Calculate the airborne concentration resulting from the dispersion of a dust, given its bulk density, layer thickness and enclosure height
Learning Objectives (Continued)

- **Analyzing**
  - Identify combustible dust hazards in a given example

- **Evaluating**
  - Determine appropriate prevention and mitigation strategies for a specific case study and explain reasoning

- **Creating**
  - Formulate a dust explosion prevention plan for a given scenario, taking into account each element of the explosion pentagon
Module Outline

- Basic Fire Principles
- Basic Explosion Principles
- Dust Explosion Fundamentals
- Fuel
- Ignition Source
- Oxidant
- Mixing
- Confinement
- Dust Layer Fires
- Prevention and Mitigation
- Case Studies
- Resources
- Evaluation
Basic Fire Principles

![Diagram showing the basic fire principles with three main components: Fuel, Ignition, and Oxidant.](image-url)
Fire triangle elements

Fire definitions

- Chemical reaction (combustion) in which a substance combines with an oxidant and releases energy, part of which is used to sustain the reaction
- Process of combustion characterized by heat, smoke, flame or any combination thereof

- Fuel – gas, liquid, solid
- Oxidant – gas, liquid, solid
- Ignition source – many types widely found in industry
Flammability parameters

- Flash point: FP
- Vapour pressure: $p^{\text{sat}}$
- Lower flammability limit: LFL
- Upper flammability limit: UFL
- Flammability range: LFL $\rightarrow$ UFL
- Minimum ignition energy: MIE
- Autoignition temperature: AIT
Fire consequences

- Flame
- Heat
- Smoke

One Side of the Chevron Richmond Refinery Fire

The Other Side
Fire types

- Pool fire
- Jet fire
- Fireball
- Flash fire
- Dust layer fire

Pool Fire

Jet Fire
Fire examples

Piper Alpha

Buncefield

Deepwater Horizon
Basic Explosion Principles
Explosion pentagon elements

- Explosion definition
  - Rapid expansion of gases resulting in rapidly moving pressure or shock wave
  - Expansion can be mechanical (e.g., rupture of pressurized cylinder) or result of rapid chemical reaction
  - Explosion damage caused by pressure or shock wave that does work on its surroundings
- Fuel – as per fire triangle
- Oxidant – as per fire triangle
- Ignition source – as per fire triangle
- Mixing – of fuel and oxidant
- Confinement – for overpressure development
Explosibility parameters

- Maximum explosion pressure: $P_{\text{max}}$
- Maximum rate of pressure rise: $(dP/dt)_{\text{max}}$
- Volume normalized maximum rate of pressure rise: $K_G$ for gases and $K_{St}$ for dusts
Explosion consequences

- Overpressure
- Missile fragments

Heat Exchanger Rupture

Support Column Sheared Off Baseplate
Explosion types

General categories
- Physical
- Chemical

Speed of reaction front
- Deflagration
- Detonation
Explosion types

Explosions in process industries

Physical explosion
- Compressed gas/vapour explosion (CG/VE)
  - Rapid phase transition explosion
- Boiling liquid expanding vapour explosion (BLEVE)
  - Explosion which can occur in unconfined, but more likely in (partially) confined space

Chemical explosion
- Deflagration/detonation
  - Explosion which can occur only under substantial confinement
- Homogeneous chemical explosion
  - Exothermal explosion
  - Radical explosion
- Vapour cloud explosion
- Aerosol or mist explosion
- Gas explosion
- Dust explosion
- Condensed phase explosion
- Runaway reaction and explosion
Explosion examples

Flixborough

BP Texas City

Toulouse AZF
Fires ↔ explosions

The major distinction between fires and explosions is the rate of energy release. Fires release energy slowly, whereas explosions release energy rapidly.

Fires can also result from explosions, and explosions can result from fires.

A good example of how the energy release rate affects the consequences of an accident is a standard automobile tire. The compressed air within the tire contains energy. If the energy is released slowly through the nozzle, the tire is harmlessly deflated. If the tire ruptures suddenly and all the energy within the compressed tire releases rapidly, the result is a dangerous explosion.
# Domino effects

<table>
<thead>
<tr>
<th>Primary Scenario</th>
<th>Escalation Vector</th>
<th>Expected Secondary Scenario(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool fire</td>
<td>Heat radiation, fire impingement</td>
<td>Jet fire, pool fire, BLEVE, toxic release</td>
</tr>
<tr>
<td>Jet fire</td>
<td>Heat radiation, fire impingement</td>
<td>Jet fire, pool fire, BLEVE, toxic release</td>
</tr>
<tr>
<td>Fireball</td>
<td>Heat radiation, fire impingement</td>
<td>Tank fire</td>
</tr>
<tr>
<td>Flash fire</td>
<td>Fire impingement</td>
<td>Tank fire</td>
</tr>
<tr>
<td>Mechanical explosion(^b)</td>
<td>Fragments, overpressure</td>
<td>All(^c)</td>
</tr>
<tr>
<td>Confined explosion(^b)</td>
<td>Overpressure</td>
<td>All(^c)</td>
</tr>
<tr>
<td>BLEVE (boiling liquid expanding vapour explosion)(^b)</td>
<td>Fragments, overpressure</td>
<td>All(^c)</td>
</tr>
<tr>
<td>VCE (vapour cloud explosion)</td>
<td>Overpressure, fire impingement</td>
<td>All(^c)</td>
</tr>
<tr>
<td>Toxic release</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

\(^a\) Expected scenarios also depend on the hazards of the target vessel inventory.

\(^b\) Following primary vessel failure, further scenarios may occur (e.g., pool fire, fireball, toxic release).

\(^c\) Any of the scenarios listed in the first column (primary scenario) may be triggered by the escalation vector.
Dust Explosion Fundamentals
Dust can explode!

Methane-triggersd coal dust explosion - Westray Coal Mine (26 fatalities)

Polyethylene dust explosion - West Pharmaceuticals (6 fatalities)

Aluminum dust explosion - Hayes Lemmerz International - Huntington (1 fatality)

Sugar dust explosion - Imperial Sugar Company (14 fatalities)
Fire triangle and explosion pentagon
Hammermill – pentagon in practice
How dusts explode

- Chemical explosion
  - Propagating combustion reaction
- Reaction mechanism
  - Dust/air mixture heterogeneous; reaction may be heterogeneous (few) or homogeneous (most)
  - Most dusts explode as gas explosions
    - Volatiles from solid material
- Explosion: FUEL (dust) and OXIDANT are MIXED, ignited by IGNITION SOURCE, and sufficient CONFINEMENT results in overpressure development
How coal dust explodes
Dust explosion parameters

Laboratory-scale testing can determine dust explosion parameters for hazard/risk determination

Likelihood of occurrence
- MEC: Minimum Explosible Concentration
- MIE: Minimum Ignition Energy
- MIT: Minimum Ignition Temperature
- LOC: Limiting Oxygen Concentration

Severity of consequences
- $P_{\text{max}}$: Maximum explosion pressure
- $(dP/dt)_{\text{max}}$: Maximum rate of pressure rise
- $K_{St} = (dP/dt)_{\text{max}} \cdot V^{1/3}$
Testing standards and equipment

- ASTM E1226-12a: Standard Test Method for Explosibility of Dust Clouds
Risk control standards

- NFPA 61 – Agriculture and Food Industries
- NFPA 68 – Deflagration Venting
- NFPA 69 – Prevention Systems
- NFPA 120 – Coal Mines
- NFPA 484 – Combustible Metals
- NFPA 499 – Electrical Installations
- NFPA 654 – Manufacturing, Processing and Handling Dusts
- NFPA 664 – Wood Processing
Element 1 of 5 – Fuel
Dust and combustible dust

- **NFPA definition of dust**
  - Any finely divided solid, 500 µm or less in diameter

- **NFPA definition of combustible dust**
  - 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.
Examples of combustible dusts

- Coal and coal products
- Food products
- Metals and alloys
- Rubber and plastics
- Wood products
- Textiles
- Pharmaceuticals
- Pesticides

DeBruce Grain Elevator Explosion
Examples of process units

- Silos
- Hoppers
- Dust collectors
- Grinders
- Dryers
- Furnaces
- Mixers
- Pulverizing units
- Conveying systems

Bucket Elevator
How much layered dust is too much?

Sugar dust accumulation on steel belt drive motor

Cornstarch accumulation under cornstarch silo
Calculation of dust concentration

\[ C = \rho_{\text{bulk}} \left( \frac{h}{H} \right) \]

- \( C \) = dust concentration
- \( \rho_{\text{bulk}} \) = bulk density of dust layer
- \( h \) = thickness of dust layer
- \( H \) = height of dust cloud produced from dust layer
Example: $C = \rho_{\text{bulk}} \left( \frac{h}{H} \right)$

- $h = 1$ mm
- $\rho_{\text{bulk}} = 500$ kg/m$^3$

- $H = 5$ m
- $C = 100$ g/m$^3$

- $H = 1$ m
- $C = 500$ g/m$^3$
Particle size

- In general, as particle size of a given dust decreases, there is an increase in both explosion severity and likelihood:
  - \( P_{\text{max}} \) increases
  - \( K_{\text{St}} \) increases (potentially significantly)
  - MEC, MIE and MIT all decrease
  - Smaller particle → larger surface area → higher reactivity

- For nanomaterials, testing to date indicates an increase in explosion likelihood but no significant increase in severity:
  - Limited severity effect likely caused by particle agglomeration during dispersion
Particle shape

- Non-spherical particles can be combustible
  - Flake-like particles
  - Flocculent particles (fibers with L/D ratio)

Wood Fibers  Nylon Flock
Both of these dusts are combustible.

Spherical Polyethylene

Fibrous Polyethylene
Hybrid mixtures

- Flammable gas and combustible dust
  - May each be present in concentrations less than their individual LFL (gas) and MEC (dust), and still be explosible
- Result in increased explosion severity and likelihood
- Examples
  - Methane gas and coal dust
  - Natural gas and fly ash
  - Hydrocarbon gases and resins
Element 2 of 5 – Ignition Source
Examples of ignition sources

- Flames and direct heat
- Hot work
- Incandescent materials
- Hot surfaces
- Electrostatic sparks
- Electrical sparks
- Friction sparks
- Impact sparks

- Self-heating
- Static electricity
- Lightning
- Shock waves
MIE and MIT testing

- MIE and MIT testing can be conducted to better identify potential ignition source hazards
- MIE and MIT test results are applicable to efforts aimed at dust explosion prevention
  - Removal of ignition sources
  - Grounding and bonding
  - Control of process/surface temperatures
### MIE values of some dusts

<table>
<thead>
<tr>
<th>Material</th>
<th>MIE with inductance [mJ]</th>
<th>MIE without inductance [mJ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy coating powder</td>
<td>1.7</td>
<td>2.5</td>
</tr>
<tr>
<td>Polyester coating powder</td>
<td>2.9</td>
<td>15</td>
</tr>
<tr>
<td>Polyamide coating powder</td>
<td>4</td>
<td>19</td>
</tr>
<tr>
<td>Magnesium granulate</td>
<td>25</td>
<td>200</td>
</tr>
<tr>
<td>Flock</td>
<td>69-98</td>
<td>1300-1600</td>
</tr>
</tbody>
</table>
Ignition of titanium dust

<table>
<thead>
<tr>
<th>Size</th>
<th>With inductance</th>
<th>Without inductance</th>
<th>MIT [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;150 µm</td>
<td>10-30</td>
<td>1-3</td>
<td>&gt;590</td>
</tr>
<tr>
<td>&lt;45 µm</td>
<td>1-3</td>
<td>1-3</td>
<td>460</td>
</tr>
<tr>
<td>≤20 µm</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>460</td>
</tr>
<tr>
<td>150 nm</td>
<td>Not determined</td>
<td>&lt;1</td>
<td>250</td>
</tr>
<tr>
<td>60-80 nm</td>
<td>Not determined</td>
<td>&lt;1</td>
<td>240</td>
</tr>
<tr>
<td>40-60 nm</td>
<td>Not determined</td>
<td>&lt;1</td>
<td>250</td>
</tr>
</tbody>
</table>
Destruction at 10 mJ

ABS (Acrylonitrile-Butadiene-Styrene) Plant
Element 3 of 5 – Oxidant
Limiting oxygen concentration

- Oxygen is the most common oxidant
- Does not have to be completely removed to prevent a dust explosion
- Limiting oxygen concentration (LOC)
  - Highest oxygen concentration in a dust/air/inert gas mixture at which an explosion fails to occur
  - Value for a given dust depends on inert gas used
  - Industry application – inerting
Use of inert gas

- Inert gas examples – carbon dioxide, nitrogen argon, helium, steam, flue gas
- Inerting can introduce new hazards
  - Asphyxiation from reduced oxygen levels in air
  - Reaction of inert gas with dust
  - Electrostatic discharge when CO\textsubscript{2} is drawn from high-pressure or cryogenic tanks
  - Leakage of inert gas in systems under pressure
  - Introduction of ignition sources from inverting equipment such as vacuum pumps
## LOC values of some dusts

<table>
<thead>
<tr>
<th>Material</th>
<th>LOC with nitrogen [volume %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pea flour</td>
<td>15.5</td>
</tr>
<tr>
<td>Calcium stearate</td>
<td>12.0</td>
</tr>
<tr>
<td>Wheat flour</td>
<td>11.0</td>
</tr>
<tr>
<td>High-density polyethylene</td>
<td>10.0</td>
</tr>
<tr>
<td>Sulfur</td>
<td>7.0</td>
</tr>
<tr>
<td>Aluminum</td>
<td>5.0</td>
</tr>
</tbody>
</table>
Inert gas effectiveness

## Magnesium Dust

<table>
<thead>
<tr>
<th>Inert Gas</th>
<th>LOC [volume %]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen (diatomic)</td>
<td>6.8</td>
</tr>
<tr>
<td>Carbon dioxide (triatomic)</td>
<td>5.5</td>
</tr>
<tr>
<td>Argon (monatomic)</td>
<td>4.0</td>
</tr>
</tbody>
</table>
Effect on $P_{\text{max}}$ and $(dP/dt)_{\text{max}}$

Brown Coal Dust/Air/Nitrogen
Effect on MEC (nitrogen)

Minimum explosive concentration (g/m³)

Oxygene concentration (%)
Element 4 of 5 – Mixing

- Fuel
- Ignition Source
- Oxidant
- Confinement
- Dust Layer Fires
- Prevention and Mitigation
- Case Studies
- Resources
- Evaluation
Primary dust explosions

![Graph showing the mass of powder/dust per unit volume in g/m³ against logarithmic scales for industrial hygiene and explosive range.]
Secondary dust explosions

- Blast waves from primary explosion
- Layer of dust
- Dust cloud formed
- Another layer of dust
- Blast waves from secondary explosion
- Dust cloud ignited by primary explosion, explodes
Primary/secondary dust explosions

- Primary dust explosions generally occur inside process vessels and units
  - Mills, grinders, dryers, etc.

- Secondary dust explosions are caused by dispersion of dust layers by an energetic disturbance
  - Upset conditions/poor housekeeping practices
  - Vigorous sweeping; cleaning with compressed air
  - Blast wave from primary explosion
  - Gas or dust explosion; other explosion types
### Dustiness/dispersibility

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Influence on Dispersion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size</td>
<td>Larger diameter → higher settling velocity</td>
</tr>
<tr>
<td>Particle specific surface area</td>
<td>Larger specific surface area → lower settling rate</td>
</tr>
<tr>
<td>Dust moisture content</td>
<td>Higher moisture content → reduced dispersibility</td>
</tr>
<tr>
<td>Dust density</td>
<td>Higher density → higher settling velocity</td>
</tr>
<tr>
<td>Particle shape</td>
<td>Asymmetry and roughness → lower settling velocity</td>
</tr>
<tr>
<td>Agglomeration processes</td>
<td>Impact effective particle diameter</td>
</tr>
</tbody>
</table>
Turbulence

Some degree of turbulence will always exist in a dust cloud
- No such thing as a quiescent dust cloud within the confines of the earth’s gravitational field

Effects of turbulence
- Increased ignition requirements
  - Highly turbulent dust clouds are harder to ignite
- Heightened combustion rates
  - Once ignited, highly turbulent dust clouds yield more severe consequences
Turbulence and overpressure

![Graph showing the relationship between Niacin (g/m³) and P_max (barg) with different tv values.](image)
Turbulence and rate of pressure rise
Element 5 of 5 – Confinement
Role of confinement

- Confinement allows for overpressure development

\[ PV = nRT \quad \text{fixed } V, R=\text{const}, n\approx\text{const} \rightarrow \uparrow T \rightarrow \uparrow P \]

- Confinement does not need to be total for a dust explosion to occur
  - Semi-confined spaces
  - Unconfined spaces with high blockage ratio (congestion) and subsequent turbulence generation
Degree of confinement

- No confinement/low confinement
  - Flash fire
  - Dust explosion rare occurrence
- Partial confinement
  - Fireball with limited pressure rise and flame propagation
  - Explosion development possible
- Complete confinement
  - Full overpressure development
Partial confinement

Methane-triggered coal dust explosion with fireball emerging from mine portal
Bruceton Experimental Mine
Pittsburgh, PA
Partial confinement

- Underground mine workings
- Approximate mine gallery as a corridor with one end open, ignition occurring at opposite end
- Explosion development and flame propagation follows corridor
- Burned gases expand behind flame front and push unburned fuel/air mixture toward open end of corridor, generating turbulence
- Flame front accelerates as it reaches turbulent flow field
- Self-accelerating feedback mechanism
Obstacles can create congestion (blockage) and generate significant post-ignition turbulence.
Influence of obstacle type
Explosion relief venting

- Dust explosion mitigation
  - Overpressure is reduced by relieving confinement

Corn Flour Explosion with Relief Venting
Dust Layer Fires

Magnesium Dust Layer Fire
Ignition of dust layers

- Self-heating (self-ignition)
- External heat source
  - Pieces of metal
    - Nut or bolt (heated by repeated contact with equipment surfaces)
  - Overheated surface
    - Bearing or motor
- Layer Ignition Temperature (LIT)
  - Minimum temperature required to ignite a layer of dust of a certain thickness
Effect of layer thickness

ALOM = Aluminum Oxide; CD = Coal Dust; LP = Lycopodium; BWD = Beechwood Dust
Self-ignition
Normalization of deviance

- Dust fires are sometimes ignored or normalized
  - Accepting as normal (and then ignoring) negative events
  - Culture of risk-denial
  - Counter to concept of safety culture

- Evidence that something is not right in the workplace
  - Nothing normal about an unintentional dust fire
Prevention and Mitigation

Unacceptable region

Tolerable region

Broadly acceptable region

Increasing individual risks and societal concerns

ALARP
Hierarchy of controls

INHERENT SAFETY

PASSIVE ENGINEERED SAFETY

ACTIVE ENGINEERED SAFETY

PROCEDURAL SAFETY
Hierarchy as a continuum
Inherent safety

- Proactive approach to reduce reliance on engineered or add-on safety devices (both passive and active) and procedural measures

- Four basic principles
  - Minimization
  - Substitution
  - Moderation
  - Simplification
Minimization

Minimize amount of hazardous material in use (when use of such materials cannot be avoided – i.e. elimination)
Substitution

Replace substance with less hazardous material; replace process route with one involving less hazardous materials
Moderation

Use hazardous materials in least hazardous forms; run process equipment with less severe operating conditions
Simplification

Simplify equipment and processes that are used; avoid complexities; make equipment robust; eliminate opportunities for error.
Minimum inerting concentration
Passive engineered safety

- Add-on safety devices
  - Explosion relief vents
  - Physical barriers
- Have no function other than to act when called upon to mitigate consequences of an explosion
- Do not require event detection or device activation
- More reliable than active devices
Venting

Corn Flour Explosion with Relief Venting
Venting process
Relief panels and rupture disks
Flameless venting

Corn Flour Explosion with Flameless Venting
Flame quenching devices
Active engineered safety

- Add-on safety devices
  - Inerting (gas) systems
  - Automatic explosion suppression
  - Explosion isolation valves
- Have no function other than to act when called upon to mitigate consequences of an explosion
- Require event detection and device activation
- Less reliable than passive devices
Suppression – HRD canisters
Suppression sequence

Ignition

Nozzle

Pressure Wave

Flame
Suppression sequence (continued)
Isolation valves
Procedural safety

- Safe work practices and procedures
  - Grounding and bonding
  - Hot-work permitting
  - Permit-to-work system
  - Housekeeping
- Directly involves people
  - Human error possible
  - Training essential
- Least effective category in hierarchy
Housekeeping

- Primary line of defence against dust explosions
- Design
  - Eliminate cleaning
  - Make cleaning easier
  - Scheduling
  - All surfaces cleaned
  - Performed safely

Dust Collection to Measure Accumulation
Safety management systems

- Accountability: Objectives and Goals
- Process Knowledge and Documentation
- Capital Project Review and Design Procedures
- Process Risk Management
- Management of Change
- Process and Equipment Integrity
- Human Factors
- Training and Performance
- Incident Investigation
- Company Standards, Codes and Regulations
- Audits and Corrective Actions
- Enhancement of Process Safety Knowledge
Safety culture

- Provides the link between an organization’s beliefs and prevention and mitigation strategies

Safety culture
- Reporting culture
- Just culture
- Learning culture
- Flexible culture

Collective mindfulness
Risk awareness
Keys to success

- Hierarchy of controls
  - Inherent safety
  - Passive engineered safety
  - Active engineered safety
  - Procedural safety
- Safety management system
- Safety culture
Case Studies

To paraphrase G. Santayana, one learns from history or one is doomed to repeat it

Westray
- Coal mine
- Methane-triggered coal dust explosion

Hoeganaes
- Atomized iron production facility
- Iron dust flash fires

Imperial Sugar
- Sugar refinery
- Sugar dust explosion
Westray: what happened

Methane-triggered coal dust explosion
Plymouth, NS
May 9, 1992
26 fatalities
Westray: why

- Substandard practices
  - Poor housekeeping with respect to coal dust
  - Inadequate rock dusting
  - Continuation of mining in spite of inoperable methane detection devices
  - Storage of fuel and re-fueling of vehicles underground

- Substandard conditions
  - Inadequate ventilation system design and capability
  - Thick layers of coal dust with unacceptably high levels of combustible matter
  - Inadequate system to warn of high methane levels
Westray: lessons learned

- Poor safety culture
  - Lack of management commitment and accountability to safety matters
  - Fear of reprisal on part of workers

- Ineffective safety management system
  - Human factors
  - Training
  - Poor compliance to best industry practices and legislated safety requirements
Westray: lessons learned
Hoeganaes: what happened

Iron dust flash fires
Gallatin, TN
Jan 31, 2011
  2 fatalities
March 29, 2011
  1 injury
May 27, 2011
  3 fatalities,
  2 injuries
Hoeganaes: why

- No employee training
- Accumulations of iron dust
  - Inadequate housekeeping
  - Elevated surfaces
Hoeganaes: lessons learned

Safety Culture

- Ignoring known hazards
- Reporting culture
  - Frequent minor flash fires not reported
- Learning culture
  - Repetition of similar incidents
- Flexible culture
  - Decision-making flawed
Hoeganaes: lessons learned
Imperial Sugar: what happened

Sugar dust explosion
Port Wentworth, GA
Feb 7, 2008
14 fatalities
36 injuries
Imperial Sugar: why

- Conveyor belt: no dust removal system or explosion vents
- Inadequate housekeeping
- Inadequate evacuation plan
Imperial Sugar: lessons learned
Imperial Sugar: lessons learned

- Previous fires and near-misses
- Management knew about hazards
Resources

- Videos
- Reports
- Data Bases
- Standards
- Papers
- Books
Standards

![ASTM International logo]

![NFPA logo]
Papers
Books
Evaluation
Remembering

Define what is meant by a “combustible dust”.

Identify all of the elements of the fire triangle and the explosion pentagon.
Explain how a gaseous, liquid or solid fuel actually burns. (What is the physical state of the reacting fuel?)

Describe the fundamentals of a dust explosion according to the explosion pentagon.
Applying

Calculate the airborne concentration in an enclosure with a height of 5 m resulting from the dispersion of a 0.8-mm thick layer of corn flour having a bulk density of 0.82 g/cm³.
Analyzing

Identify the possible fuel sources that could have been involved in the explosion at the Babine Forest Products facility in Burns Lake, BC on January 20, 2012. Discuss which of these involved combustible dust hazards.

Note: This incident was investigated by WorkSafeBC; the investigation report is available on their web site: www.worksafebc.com.
Evaluating

Determine several strategies that might have been helpful in preventing and mitigating the polyethylene dust explosion at the West Pharmaceuticals facility in Kinston, NC on January 29, 2003. Be sure to justify your choices.

Note: This incident was investigated by the US Chemical Safety Board; the investigation report is available on their web site: www.csb.gov.
Formulate a dust explosion prevention plan for the scenario described below. Be sure to account for each element of the explosion pentagon.

A fine aluminum powder is being processed at a facility involving numerous physical operations such as grinding, pulverizing and sieving. Workers are largely unaware of combustible dust hazards and plant management has not shown itself to be very supportive of loss prevention efforts.