Dust Explosion Hazards Management
Requirements of NFPA 652: Standard on the Fundamentals of Combustible Dust

AIHA NE Regional Conference
December 1st, 2017
Princeton, NJ

Executive Vice President
DEKRA Process Safety
Dust Explosion Hazard Management

Requirements of NFPA 652: Standard on the Fundamentals of Combustible Dust

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Presentation Outline

• Introduction
  o Conditions for Dust Explosions
  o Codes & Standards for Combustible Particulate Solids

• NFPA 652 - Standard on the Fundamentals of Combustible Dusts
  o Compliance Options
  o Combustibility Characteristics
  o Dust Hazard Analysis (DHA)
  o Hazard Management - Mitigation and Prevention
  o Written Management Systems

• Basis of Safety
  o Avoidance of flammable atmospheres
  o Elimination of ignition sources
  o Provision against consequences of ignition

• Discussion
Conditions for Dust Cloud Deflagrations

1. Dust must be explosible (flammable, combustible)
2. Dust must be airborne
3. Particle size distribution capable of propagating flame
4. Concentration must be within explosible range
5. The atmosphere must support combustion
6. An ignition source must be present

- Condition 1-5 often exist at some point during the handling, transport, processing, storage, dust collection, and packaging operations.
- In the presence of an incendive ignition source a flash fire or explosion will occur.
Formation of Explosible Dust Cloud

- 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
Secondary Dust Cloud 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 (Eckhoff)
Potential Ignition Sources

- Lightning strikes
- * Open flames
- Hot surfaces
- Electrostatic discharges
- * Electric arcs and sparks
- Exothermic chemical reactions
- Self-heating / decomposition / spontaneous combustion

- * Welding [torch or arc]
- * Cutting [torch or arc]
- Grinding
- Frictional heating
- Mechanical impacts
- Smoking [rule violation]

* Electrical Classification or Hot-Work Permit required
Codes & Standards - Combustible Solids

- EPA Risk Management Rule
- OSHA PSM Regulation
- Facility Design
  - NFPA 68
  - NFPA 69
  - NFPA 77
  - NFPA 91
- National Electric Code
  - NFPA 70
  - NFPA 499
- Life Safety Code
  - NFPA 101
- ACC Responsible Care
  - OSHA General Duty Clause
  - RAGAGEP
- Building Codes
  - IBC, NFPA 5000
- State Fire Protection Codes
  - IFC, NFPA 1
- Combustible Dusts
  - Special Dusts
    - NFPA 652
    - NFPA 654
    - NFPA 655
    - NFPA 664

Best Industry Practice
Codes & Standards - Combustible Solids

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”
NFPA 652: Standard on the Fundamentals of Combustible Dust

• Provides general requirements for management of combustible dust fire and explosion hazards and directs the user to appropriate NFPA industry or commodity-specific standards

• Establishes relationship and hierarchy with industry or commodity-specific standards, ensuring that fundamental requirements are addressed consistently across industries, processes, and dust types
Industry or Commodity-Specific NFPA Standards

• For the purposes of NFPA 652, the industry or commodity-specific NFPA standards shall include the following:
  o NFPA 61, *Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities*
  o NFPA 484, *Standard for Combustible Metals*
  o NFPA 655, *Standard for Prevention of Sulfur Fires and Explosions*
  o NFPA 664, *Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities*
  o NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*
## NFPA 652 - Conflicts

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<td>Requirement in an industry or commodity-specific NFPA standard differs from the requirement in NFPA 652</td>
<td>Requirements in industry or commodity-specific NFPA standard shall be permitted</td>
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<tr>
<td>Industry or commodity-specific NFPA standard specifically prohibits a requirement specified in NFPA 652 standard</td>
<td>Prohibition in the industry or commodity-specific NFPA standard shall be applied</td>
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<tr>
<td>Industry or commodity-specific NFPA standard neither prohibits nor provides a requirement</td>
<td>Requirement in NFPA 652 shall be applied</td>
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NFPA 652 Compliance Requirements

- Owner/operator of facility with potentially combustible dust shall be responsible for:
  - Determining combustibility and explosibility hazards of materials (Chapter 5)
  - Conducting a Dust Hazard Analysis (DHA) - Identifying and assessing fire, flash fire, and explosion hazards (Chapter 7)
  - Managing identified fire, flash fire, and explosion hazards
    - Prescriptive Approach (Chapters 5, 7, 8, 9)
    - It shall be permitted to use performance-based alternative designs for a building, equipment, ignition source control, and explosion protection in lieu of prescriptive requirements in Chapter 8 (Chapter 6)
  - Establishing Safety Management Systems (Chapter 9)
Combustibility / Explosibility of Dusts

• Determination of combustibility or explosibility shall be permitted to be based on the following:
  o Historical facility data or published data that are deemed to be representative of current materials & process conditions
  o Laboratory analysis of representative samples
    ➢ Permitted to test a sample sieved to <75μm
    ➢ Permitted to test the as-received sample
  o Permitted to assume a material is explosible, forgoing the laboratory analysis

• Absence of previous incidents shall not be used as basis for deeming a particulate non-combustible or non-explosible

Note:
• Test results are strongly influenced by particle size, moisture content, presence of contaminants
• Be sure test results are appropriate for your material!
Explosibility Screening (ASTM E1226)

- 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”.
- If the dust cloud does not ignite in the Hartmann Bomb, additional tests in a larger volume (20L or 1m³) with stronger ignition source will be conducted.

Modified Hartmann Apparatus
20L Sphere
Chilworth 1m³ Vessel
Combustibility / Explosibility Characteristics of Dusts

• Explosibility, ignition sensitivity, and explosion severity of dusts shall be determined in accordance with applicable test standards such as ASTM

• Typical tests that might be considered include:
  - Go / No Go test
  - Minimum Ignition Energy
  - Minimum Ignition Temperature (Cloud and Layer)
  - Self-Heating
  - Minimum Explosible Concentration
  - Limiting Oxygen Concentration
  - Maximum Explosion Pressure (Pmax) and Kst
  - Electrostatic Chargeability and Volume Resistivity
Confidence in Explosion Characteristics Data

- Specific powder testing
- Prior material testing
- Manufacturer SDS
- Generic SDS
- Literature sources
  - NFPA
  - Internet sites
  - Other

Increasing Level of Confidence in Data
Dust Hazards Analysis (DHA)

• **DHA** is required if materials handled and processed have been identified as combustible and/or explosible.

• **DHA** is a systematic review to identify and evaluate potential fire, flash fire, and explosion hazards associated with the presence of combustible particulate solid(s) in a process or facility.

• **DHA** must be conducted by an expert with demonstrated ability to deal with hazards related to processing and managing combustible particulate solids.

• **DHA** does not need to comply with the Process Hazards Analysis (PHA) requirements of the OSHA regulation, 29 CFR 1910.119 (e).
Dust Hazards Analysis (DHA)

- For existing processes the owner/operator shall schedule the DHA to be completed within three years of the issue date of NFPA 652 (September 2015)
  - Reasonable progress in each of the three years must be demonstrated
- For new construction or modifications in excess of 25% of original cost, DHA shall be completed as part of the project
DHA Target Areas

• Can dust clouds be created?
  o Routinely during operations such as within powder transfer systems, blenders, mills, and dust collection systems
  o Machining of Combustible Materials (sawing, sanding, drilling, routing)
  o Foreseeable abnormal conditions

• Are dust deposits managed?
  o Floors and equipment surfaces, and
  o Overhead surfaces including HVAC ducting, piping, light fixtures and steel structural elements
DHA Target Areas

- Hazardous properties of materials
  - Ignition Sensitivity and Explosion Severity
  - Self-heating and Reactivity
- Smoldering of materials in a pile or layer
- Flaming fire in a layer or pile
- Flash-Fire Deflagration*
- Explosive Deflagration* within equipment
- Explosive Deflagration* within rooms and buildings

* Dust Cloud Event
DHA Target Areas

• How are fire and explosion hazards managed? What are the Safeguards?
  o Preventions and/or Mitigations

• Are Safeguards appropriate and reliable?
  o Consider:
    ➢ Life Safety,
    ➢ Mission Continuity, and
    ➢ Mitigation of fire and explosion propagation
Hazard Management - Mitigation & Prevention

- Owner/operator of facility with potentially combustible dust shall be responsible for managing identified fire, flash fire, and explosion hazards. Consideration shall be given to:
  - Building design
  - Equipment design
  - Housekeeping
  - Ignition source control
  - Personal protective equipment
  - Dust control
  - Explosion prevention/protection/Isolation
  - Fire protection
Hazard Management - Performance-Based Design Option

- A documented risk assessment acceptable to AHJ shall be permitted to be conducted in lieu of prescriptive requirements to determine level of:
  - Design and protection features for the building
  - Protection for the equipment
  - Ignition source control
  - Explosion protection

- Shall be acceptable to AHJ
Hazard Management - Performance-Based Design Option

• Shall meet life safety requirements
  o Including combustible dust fire, deflagration, and explosion scenarios

• Shall be completed by a person with qualifications acceptable to the owner/operator
  o Technical References & Resources and Building Design Specifications shall be acceptable to AHJ
Hazard Management - Performance-Based Design Option

- Performance-based Design will achieve the Life-Safety (fire and explosion) objectives if:
  - Ignition has been prevented
  - OR
  - No person, other than those in the immediate proximity of the ignition, is exposed to untenable conditions due to the fire and/or explosion, and
  - No critical structural element of the building is damaged to the extent that it can no longer support its design load during the period of time necessary to effect complete evacuation.

Most US companies would not accept injury or fatality of even the most exposed individual.
Written Management systems

• Owner/operator shall establish written management systems for operating its facility and equipment to prevent or mitigate fires, deflagrations, and explosions from combustible particulate solids, including:
  o Operating Procedures and Practices
  o Inspection, Testing, and Maintenance
  o Training and Hazard Awareness
  o Contractors qualifications and training
  o Emergency Planning and Response
  o Incident Investigation
  o Management of Change
  o Documentation Retention
  o Management Systems Review
  o Employee Participation

• Management system requirements shall apply to new and existing facilities and processes
Hazard Management - Mitigation & Prevention

Basis of Safety

- Avoidance of flammable atmospheres
- Elimination of ignition sources
- Provision against consequences of ignition
Hazard Management - Mitigation & Prevention

• Avoidance/Control of flammable atmospheres:
  o Proper plant design (containment / source reduction)
  o Maintaining fuel below its minimum explosible concentration (dust cloud) or lower flammable limit (vapors & gases)
  o Management of liquid spills and dust deposits (housekeeping)
  o Exhaust ventilation
  o Inert Gas Blanketing

• Elimination/control of potential ignition sources including:
  o Electrostatic discharges
  o Electrical Arcs / Sparks
  o Mechanical friction and sparks
  o Thermal decomposition

• Application of Explosion Safeguards:
  o Explosion protection (containment, relief venting, explosion suppression)
Control of Combustible Dust Atmospheres

- Equipment should be designed, operated, and maintained 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
Control of Flammable Atmospheres

• Inert Gas Blanketing, NFPA 69
  
  o Safety may be based on reducing the Oxidant concentration below a level that will no longer support combustion (LOC), by adding an inert gas
  
  o Limiting Oxidant Concentration (LOC) for combustion is dependent on the material and type of inert gas used
  
  o Nitrogen gas is the most commonly used inert gas. Carbon dioxide and argon are also used
Hazard Management - Mitigation & Prevention

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Electrostatic Charge Generation

- Electrostatic charges are usually generated when any two materials make and then break contact, with one becoming negative and the other positive.
- The build up of the charge on electrically isolated conductors and/or on insulating materials, can give rise to electrostatic discharges.
- Depending on the incendivity (energy) of the discharge, a flammable atmosphere can be ignited.
Controlling Electrostatic Hazards - Summary

• Metal Plant
  o Resistance to ground should be checked. If $R > 10$ ohm, direct ground connection is required
  o Ground connections should be checked regularly

• Personnel
  o During normal activity, the potential of the human body can reach 10kV to 15kV, and the energy of a possible spark can reach 20mJ to 30mJ
  o Personnel should be grounded so that their resistance-to-ground $< 1 \times 10^8$ ohm

• Non-Conductive (Insulating) Materials (e.g. plastic hoses, bags, liners, drums)
  o Grounding of non-conductive materials would not facilitate the relaxation of electrostatic charges to ground
  o Consider conductive or static dissipative materials
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.

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 (for solids).
Control of Friction and Impact Sparks

• 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
  o Consider use of screens, electromagnets, pneumatic separators, etc.

• Floor sweepings should not be returned to any machine

• 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:
  o Formation of dust clouds should be prevented, and dust deposits should be removed
  o A gas/vapor detector may be used to ensure flammable vapors/gases are not present
Why a Concern with Electrical Apparatus?

- Arcs and sparks occur during normal operation of many electrical equipment
- Consumption of energy produces hot surfaces
- Malfunction creates (more) potential ignition sources
- Electrical apparatus must be selected and installed carefully to ensure there is no risk of ignition
- Hazardous Area Classification was developed as a means to optimize equipment selection
  - Electrical area classifications is 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
## Hazardous Area Classification

- **Electrical Area Classification**

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<tr>
<td><strong>Class – Division</strong></td>
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<tr>
<td><strong>Class I – Gas or vapor</strong></td>
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<tr>
<td><strong>Class II – Dust</strong></td>
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<tr>
<td><strong>Class III – Fiber or flying (No Group Designation)</strong></td>
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</table>
Determination of Extent of Divisions

- Extent of division affected by:
  - Working methods
  - Ventilation
  - Housekeeping
  - Maintenance
  - Plant structure and layout

Dust deposits are sources of release
Selection of Electrical Apparatus

### Division 1
- Dust Explosion 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
Explosion Protection

Basis of Safety

• Avoidance of flammable/explosible atmospheres
• Elimination of ignition sources
• Provision against consequences of ignition
  o Preventative measures alone may not ensure adequate level of safety. Protective measure should be taken as well
  ➢ These measures are:
    ✤ Containment by explosion resistant construction, Design based on ASME Boiler and Pressure Vessel Code, Section VIII, Division I
    ✤ Explosion suppression by injecting a suppressant, NFPA 69
    ✤ Explosion venting to a safe place, NFPA 68
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 - 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.

Components of explosion suppression system:
  - Explosion Detector
  - Control Unit
  - Suppressor
  - Suppressant

1. Ignition - 0.000 Seconds
2. Detection - 0.020 Seconds
3. Control - 0.025 Seconds
4. Suppression - 0.060 Seconds
Explosion Suppression - Examples

Fluid bed Dryer

Dust Collector
Explosion Protection Techniques - Venting

• Relies on rapid opening of panel(s) or door(s) hence allowing the release of hot gases and un-burnt 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
Explosion Protection Techniques - Venting

- Commonly used to protect
  - Dust collectors
  - Silos and hoppers
  - Dryers
  - Cyclones
  - Sack tipping stations
  - Pipelines
Explosion Protection Techniques - Venting

Volume of fireball is many times the volume of the dust collector
Explosion Relief Venting and Ducting to a Safe Place
Flameless Venting Devices
Explosion Isolation

• 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.
  o Mechanical Isolation (Barriers)
  o Chemical Isolation (Barriers)
Mechanical Explosion Isolation

- Automatic Fast-Acting Shut-off Valve
Chemical Explosion Isolation

- Chemical Barrier
Concluding Remarks

Effective management of flash fires and explosions often involves:

• Establishing a sound process safety-management system and competency within the organization, including:
  o Having appropriate data for the understanding of the combustibility, ignition sensitivity, electrostatic properties, and explosion characteristics of the fuel(s)
  o A thorough understanding of all operations and processes
  o Identifying locations where explosible atmospheres could be present
  o Identifying potential ignition sources that could be present under normal and foreseeable abnormal conditions
  o Defining one or more “Basis of Safety”
Concluding Remarks

Effective management of flash fires and explosions often involves:

- Regular review and maintenance of process data and information, process-control systems, processing equipment, and the facility to ensure the continued safety of people, the community, and the business.
- Establishing a safety culture that starts at the top but pervades consistently through the whole organization.
About Chilworth Technology

A DEKRA Insight Company

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Legacy Chilworth Technology - An Overview

- Leading provider of **specialist process safety services** in the world - since 1986
- Over 150 staff including engineering professionals, scientists and laboratory technicians with specialist process safety expertise
- Objective, practical advice
- Chilworth Technology was acquired by **DEKRA SE** in July 2011
## DEKRA Insight - Process Safety Centers of Excellence

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Process Safety - Definition

- **Process Safety** - The prevention and control of fires, explosions, and accidental chemical releases in chemical & process industries
- Such incidents may result in serious injury, property damage, lost production, and environmental impact

2015 - Warehouse Fire & Explosion, Tianjin, China
173 killed and 797 injured *(as of September 12th, 2015)*

2008 - Imperial Sugar, Georgia
14 Killed, > 40 injured
DEKRA Insight - Process Safety Business

• We help process industries understand and avoid fire, explosion, and loss of containment events and improve performance.

• We combine specialist process safety management (PSM) and process safety engineering expertise, with generation and use of process safety data to help our clients achieve the most effective and practical approaches to safe and efficient operations and processes, globally.

• We are the “Trusted Advisor” - Always keeping our Client’s Needs/Wants in focus as we evaluate their process hazards and propose solutions.
# DEKRA Insight - Process Safety Portfolio

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**Process Safety Engineering**

- Dust Flash Fire & Explosion Hazards
- Gas & Vapor Flammability Hazards
- Electrostatic Hazards
- Chemical Reaction Hazards
DEKRA Insight - Process Safety Client Industries

- Bulk & Fine Chemicals
- Agro-Chemical
- Energy / Power
- Food & Drink
- Flavor & Fragrance
- Machine/Equipment Mfg
- Government Agencies
- Engineering / Consultants
- Legal/Insurance/Risk

- Primary Metals & Machining
- Automotive & Aviation
- Personal & Household Products
- Oil & Petrochemical
- Pharmaceuticals
- Plastics & Rubber
- Pulp & Paper
- Wood / Forestry
- Consumer Electronics