COMBUSTIBLE DUSTS

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1.0 SCOPE

This property loss prevention data sheet provides recommendations to reduce the frequency and severity of fires and explosions involving combustible dust, dust mixture, or fibers fires and explosions. Following the recommendations in this Standard does not eliminate the need to evaluate the processes/facilities with standards/codes that go beyond property protection. Cases where the expected property damage from a dust fire/explosion in a building do not justify corrective action from a property loss prevention standard point, still represent a significant thermal event within the building.

Guidance for the following is included in this data sheet:

- General hazard mitigation for combustible dusts; including metal, wood plastic and agricultural dusts; dust mixtures, and fiber.
- Fire and explosion protection for:
  − Dust collection equipment, including dust collectors, cyclones, electrostatic precipitators
  − Dust processing, storage and handling operations, including silos, bins and bucket elevators
- Explosion protection where combustible dusts, dust mixtures, or fibers create an equipment, room or building explosion hazard

For the following subjects, refer to the applicable occupancy-specific data sheet for loss prevention recommendations, which are **not** covered in this data sheet:

- Fire protection of spray dryers, flash dryers, ring dryers and rotary kilns and dryers. See to FM Data Sheets 6-9, *Industrial Ovens and Dryers* and 7-111A, *Fuel-Grade Ethanol*
- Specific guidance related to woodworking and wood processing occupancies – See Data Sheet 7-10, *Wood Processing and Woodworking Facilities*
- The review, design, testing and maintenance of explosion protection and isolation systems – See Data Sheet 7-17, *Explosion Protection Systems*. Such guidance should be referenced in conjunction with the guidance presented within this data sheet.
- Fire protection for processes within carbon black manufacturing plants that do not involve combustible dust – See Data Sheet 7-111B, *Carbon Black*
- Wood chip storage - see Data Sheet 8-27, *Storage of Wood Chips*

The calculation methods associated with dust explosion hazard evaluations are primarily discussed/used in metric (SI) units, and these units are used in this data sheet.

This data sheet references software called DustCalc. DustCalc is proprietary software used by FM engineers in the calculation and verification of explosion vent sizing for buildings and equipment where a combustible dust explosion hazard exists. Other vent sizing methodologies are available, but they are not used by FM.

1.1 Hazards

Combustible dust includes nearly all organic materials such as wood, paper, rubber, plastics, fiber, food and tobacco along with other materials, such as metals, that exist in the form of particles less than 500 µm in the largest dimension. Combustible dusts present both a fire and explosion hazard.

These materials can be ignited in the presence of air (oxygen). If a dust forms a low-density layer on surfaces over a large area and is ignited, the resultant fire can spread rapidly, potentially faster than automatic sprinklers can operate. This situation can result in a large and damaging event. For densely packed dusts, a fire may not spread quickly but can become deep seated. If the dust layer is disturbed, the smoldering area can become an open flame, igniting surrounding dust.

If a combustible dust is suspended in air and ignited, the resultant flame front can quickly spread through the dust particles (a deflagration) and generate a significant temperature rise within a confined volume, resulting in a fast pressure rise. If that pressure rise is not properly controlled, the confined volume will violently fail, resulting in an explosion.

Dust explosion events in buildings/rooms often begin with ignition of a small amount of suspended dust. The resulting pressure pulse may not initially damage the building/room structure but can result in the suspension and ignition of additional dust. This process will propagate through all areas where dust is present. If enough dust is available in a particular area, the developed pressure will cause the structure to fail. If not enough dust is available to create pressures that cause the failure of the room/building, it will create a spreading fireball across the roof level that produces large quantities of thermal radiation within the building/room.

Dust explosions within equipment may also involve a very small amount of the contained dust. However, due to the smaller enclosed volume, the produced pressure will often result in the failure of the equipment and the release of unburned dust into the surrounding area. The flame front then ignites this suspended dust, resulting in a secondary fireball outside the equipment which can produce damaging overpressure if confined within a building. Beyond the fireball, parts of the failed equipment can also be ejected into the building. Equipment inside a building that is vented into the building can produce significant flame jets.

The severity of a dust explosion depends on several factors such as dust composition, moisture content, particle size, ignition energy, explosibility, along with the amount and location of the combustible dust involved. Combustible particulate that is too large to be suspended in air or quickly propagate a flame front can be reduced in size within dust handling equipment, thus increasing the dust explosion hazard. When identifying where combustible dust might be present, looking at all areas within a process is important.

When located within rooms/buildings, the design and maintenance of dust processes is critical in preventing dust liberation into the building, which can create a room/building fire and/or explosion hazard. Processes that cannot be designed to prevent the release of dust into rooms/building should be isolated from other important operations and designed to control a potential explosion with the provision of damage limiting construction.

Wherever combustible dusts are present, housekeeping programs are not an acceptable alternative to containing combustible dust within the process or isolating processes where dust release cannot be prevented. However, housekeeping can be used as a supplementary method to fire and explosion protection to control the level of dust within a facility.

1.2 Changes

October 2024. This document has been completely revised and consolidates several existing documents into one. Significant changes include the following:

A. Changed title to *Combustible Dusts* (from *Fire and Prevention and Mitigation of Combustible Dust Explosion and Fire*).

B. Incorporated guidance from FM Data Sheet 7-73, *Dust Collectors and Collection Systems*. Data sheet 7-73 has been made obsolete.

C. Incorporated guidance from FM Data Sheet 7-75, *Grain Storage and Milling*. Data Sheet 7-75 has been made obsolete.

D. Added new guidance for the evaluation of combustible dust properties. This knowledge allows for better hazard evaluation and development of risk mitigation strategies.

E. Updated the guidance for determining room/building and equipment explosion hazards.

F. Provided new guidance for the testing of non-combustible dusts and dust mixtures.

G. Updated the guidance for the evaluation and treatment of fugitive dust accumulations within buildings and rooms.

H. Updated the guidance for enclosureless dust collectors to align with current FM Research guidance on explosion potentials with these devices.

I. Provided new guidance for the hazards associated with horizontal drum filters (a subset of enclosureless dust collectors).

J. Revised spray dryer fire protection guidance to reference FM Data Sheet 6-9, *Industrial Ovens and Dryers*.

K. Relocated guidance for equipment isolation to Appendix E.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Introduction

Use FM Approved equipment, materials and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals.

2.1.1 General

2.1.1.1 Apply the guidance in this data sheet to all equipment, rooms and buildings that process, handle, store and transport combustible dusts, dust mixtures or fibers, or anywhere they can be present.

2.1.1.2 Refer to FM Data Sheet 7-85, *Combustible and Reactive Metals*, for guidance on the protection of combustible metal fires and hydrogen generating (water-reactive) metals.

2.1.1.3 Evaluate the potential for room/building or equipment explosion hazard in accordance with the following:

A. A room/building explosion hazard exists when any of the following are true:

  1. Combustible dust, dust mixture, or fibers is present outside of equipment and ducting located within a room/building, despite process design and equipment upkeep.
  2. Room/building containing combustible dust, dust mixture, or fibers handling/processing equipment with a defined equipment explosion hazard that is not protected in accordance with this data sheet.

B. An equipment explosion hazard exists when any of the following are true:

  1. Combustible dust, dust mixture, or fibers is handled/processed within a piece of equipment.
  2. A piece of equipment generates combustible dust or dust mixtures as part of its operations (e.g., size reduction equipment such as hammer mills).

2.1.2 Combustible Dust, Dust Mixture, or Fibers Evaluations

Occupancies where dusts or fibers are produced or handled require a clear understanding of the material properties to properly define what hazards may exist. The most important property is a material’s ability to burn. Operations that produce or handle combustible dusts, dust mixtures or fibers have the potential for fires or explosions involving the materials. Hazard mitigation strategies require a full understanding of the materials physical properties to ensure the proper design of various protection systems.

2.1.2.1 Evaluate all dusts, and dust mixtures or fibers as follows:

2.1.2.1.1 Determine if the dust, dust mixture, or fiber is combustible.

2.1.2.1.1.1 Where known, entirely non-combustible dusts are present, initial testing of these materials is not required. Confirmation can include, but is not limited to, safety data sheets, historical test results etc.

2.1.2.1.1.2 Where dust mixtures with identified non-combustible and combustible components are present, conduct initial explosibility testing of these mixtures.

2.1.2.1.1.3 Evaluate non-combustible dusts, dust mixtures, or fibers in accordance with 2.1.3.

2.1.2.1.2 Determine if the dust/dust mixture has a particle size that is small enough to allow suspension of the material and propagation of a flame front through the suspended cloud. FM targets particle sizes less than or equal to 500 microns. There is no size target for fibers but they are larger than 500 microns in at least one dimension. They are a concern when they have a small diameter vs length and can be suspended.

2.1.2.1.3 Determine if a flammable vapor/gas is present in a concentration greater than 5% of the vapor/gas Lower Explosive Limit (LEL) within the dust handling equipment creating a hybrid mixture.

2.1.2.1.3.1 Where the vapor/gas concentration exceeds 5% of the LEL, determine the reactivity of the hybrid mixture by testing.

2.1.2.1.4 Determine if the dust, dust mixture is hard-to-ignite in accordance with Section 2.1.4.

2.1.2.2 Conduct testing of combustible dusts, dust mixtures, or fibers to determine their properties before designing explosion protection systems using recognized test standards/test methods including ISO, ASTM, European Standards, etc.

2.1.2.2.1 Determine the following properties when testing combustible dusts, dust mixtures, or fibers:

A. Composition of any pure dusts or dust mixtures

B. The deflagration index (K_{st})

C. Maximum pressure (P_{max})

D. Median particle size(s)

E. Moisture content

F. Materials subject to spontaneous heating

2.1.2.2.2 In some cases, combustible metal dust may require the use of larger scale explosion testing (e.g., use a 1 m^3 sphere instead of the 20 L sphere) to develop an understanding of the material's physical properties due to the significant flame temperatures (e.g., greater than 5972°F [3300°C]) they develop.

2.1.2.2.3 Re-test combustible dusts, dust mixtures, or fibers when a change in composition, process, handling or storage occurs.

2.1.3 Non-Combustible Dusts

Non-combustible dusts or dust mixtures do not present a fire and/or explosion hazard when exposed to an ignition source, because they do not combust. As a result, these non-combustible materials do not require specific fire and/or explosion protection. Yet, the addition of combustible components can produce an overall combustible or explosible mixture that can create a fire or explosion hazard where such hazards previously did not exist. Detection of changes (through dust explosibility testing) will allow potential hazards to be identified, and the necessary fire and explosion protection measures to be implemented promptly.

2.1.3.1 Retest non-combustible dusts or dust mixtures that have both combustible and non-combustible components and which have been previously determined to be non-combustible, every five (5) years.

2.1.3.1.1 In cases where the process contains a known dust or dust mixture, i.e., dust mixture is tied to a specific product, and the facility has a clear Management of Change (MOC) process, retesting of dust is not required except as stated in 2.1.3.2.

2.1.3.2 Retest any dust or dust mixture after a change in formulation or composition to determine the explosibility of the changed dust or dust mixture as part of the Management of Change process.

2.1.3.3 Where a change in composition or formulation of a non-combustible dust or dust mixture renders the material combustible or explosible, provide the required fire and explosion protection measures for a combustible dust, per the guidance in this data sheet.

2.1.4 Hard-to-Ignite (HTI) Dusts

FM's classification of combustible dusts as hard-to-ignite is an internal designation. This designation is not related to other codes and standards that use similar language. A hard-to-ignite dust is a combustible dust and will produce a propagating flame front when suspended in air and exposed to a strong ignition source equal to or greater than that of four 100 J (nominal) chemical ignitors. Processes that are not properly protected for a potential equipment explosion hazard are acceptable from a property loss prevention standpoint when they are only handling hard-to-ignite dusts **AND** no potential ignition sources are present. These processes will still need to be fully evaluated in accordance with local codes to assess exposures beyond property loss prevention.

2.1.4.1 If a dust is shown to be hard-to-ignite, it does not require the application of explosion protection recommendations in this document if **ALL** of the following conditions exist:

A. No possibility for a strong ignition source to be present under normal or abnormal circumstances.

B. No possibility of any flammable vapor or gas mixing with the dust, even if the vapor/gas is at a concentration below its LEL.

C. The design and operation of the dust/dust mixture containing process follow the recommendations in this document for process controls, grounding and bonding, ignition source controls, fire protection where needed, non-combustible construction, and housekeeping programs.

2.1.4.2 Retest hard-to-ignite dusts or dust mixtures every five (5) years to ensure the dust of dust mixture properties have not changed.

2.1.4.2.1 In cases where the process contains a known dust or dust mixture, i.e., dust mixture is tied to a specific product, and the facility has a clear Management of Change (MOC) process, retesting of dust is not required except as stated in 2.1.4.3.

2.1.4.3 Retest any dust or dust mixture after a change in formulation or composition to determine the explosibility of the changed dust or dust mixture as part of the Management of Change process.

2.1.4.4 Where a change in composition or formulation of a hard-to-ignite dust or dust mixture renders the material combustible or explosible, provide the required fire and explosion protection measures for a combustible dust, per the guidance in this data sheet.

2.2 Construction and Location

2.2.1 General

2.2.1.1 Construct buildings, piping, ductwork and equipment of noncombustible or FM Approved Class 1 materials. Examples of equipment include, but are not limited to:

- Dust collectors
- Cyclones
- The lining and packing materials used in wet dust collectors
- Bucket elevators
- Storage vessels containing combustible dust (e.g., silos and bins)
- Grain and malt dryers

2.2.1.1.1 If plastic ducts or ducts with plastic liners must be used, ensure they are FM Approved. If FM Approved materials are not available, protect ductwork in accordance with FM Property Loss Prevention Data Sheet 7-78, *Industrial Exhaust Systems*.

2.2.1.1.2 Where linings are added to the interior of a bucket elevator to address localized erosion issues, use non-combustible materials. Where linings are required to be non-conductive or anti-static, these properties should also be included when choosing the non-combustible linings.

2.2.1.2 Do not install combustible dust processes/operations in below-grade locations where adequate explosion venting cannot be provided.

2.2.1.3 Locate dust control equipment and bucket elevators outside buildings. Dust control equipment includes dust collectors, cyclones, electrostatic precipitators, etc.

2.2.1.4 Where dust processing and control equipment is present inside a building, and is protected by explosion venting, locate the equipment along an outside wall to permit direct explosion venting outside the building. Where vent ducts are used to direct explosion venting to the outside:

A. The ducts should be the shortest, straightest ducts practical.

B. The cross-sectional area of the duct should match the cross-sectional area of the explosion vent.

C. If a second vent panel is present where the duct exits to the exterior of the building, this panel should be factored into venting calculations to ensure the explosion vents are adequately sized.

2.2.1.5 Design dust processes to prevent the release of dust into buildings by using sealed equipment and dust collection systems at points of dust liberation.

2.2.1.6 In cases where dust liberation cannot be controlled, isolate the dust process from other areas within the facility through the use of space separation and damage-limiting construction to prevent the propagation of a dust fire or deflagration to other areas of the plant.

2.2.1.7 In rooms/buildings where some fugitive dust is likely despite process design, equipment upkeep and use of dust collection systems, reduce the likelihood and amount of dust accumulation in areas that are not easily accessible by any or all of the following, as appropriate:

A. Provide smooth interior walls with minimal ledges. Where smooth surfaces, ledges etc. should be used, they should be of non-combustible construction.

B. Provide horizontal surfaces such as girders, beams, ledges, and equipment tops with a sloped cover having a smooth finish, to shed dust settling out of the air.

C. Slope equipment covers at an angle of at least 60° from horizontal, unless a lesser slope is known to be sufficient.

D. Enclose (box in) overhead structural steel that has horizontal ledges (such as I-beams or U-shaped channels in the up or sideways position) with a noncombustible material to eliminate pockets for dust accumulation.

E. Seal doors, windows, and any other wall penetrations (e.g., cables, ducts, etc.), where applicable, to prevent dust migration into adjacent areas. Positive room pressurization can also be used to prevent dust movement into adjacent areas instead of or in conjunction with seals.

F. Provide clearance beneath and around equipment as necessary to permit sweeping or vacuum cleaning.

2.2.1.8 Use DustCalc, Appendix D of this Standard and FM Data Sheet 1-44, *Damage-Limiting Construction*, to design and install damage limiting construction in rooms/buildings with identified room explosion hazards.

2.2.2 Large Dust Collectors and Dust Collection Systems

Large dust collectors and large dust collection systems are defined as those that draw material from multiple large processes or process areas within a facility. They contain many filters/bags (several hundred or even thousands) for the collection of the dusts generated. A fire or explosion in such a large dust collection system or large dust collector can interrupt multiple process operations simultaneously. Due to their size and/or complexity, these collection systems are costly to replace.

2.2.2.1 Use a separate dust collector/collection system for each process area to minimize the process impact of a dust explosion and/or fire.

2.2.2.2 Where a large collection capacity is needed, consider the use of multiple smaller collectors, instead of one large capacity dust collection system or unit.

2.2.2.3 Where combustible filter media is present within large dust collectors or collection systems, regardless of the combustibility of the material they are handling, provide protection as follows:

A. Provide sprinkler protection for these large dust collectors/collection system units, per the guidance in this data sheet.

B. Partition the large dust collectors or collection systems into smaller fire areas using 18 ga (1.3 mm) sheet metal. The size of the partitions will depend on a number of factors, including but not limited to the size of the large system/collector, the combustible loading due to the filter media and the configuration of the sprinklers installed to protect these partitions.

C. Extend the partition from the bottom of the hopper up through the bag section of the collector, including the clean air exhaust plenum.

D. Ensure partitions have adequate abrasion resistance. This can be achieved with a sandwich panel of two ½ in. (13 mm) Type X gypsum wallboard between 18 ga (1.3 mm) steel. (Figure 2.2.2.3-1)

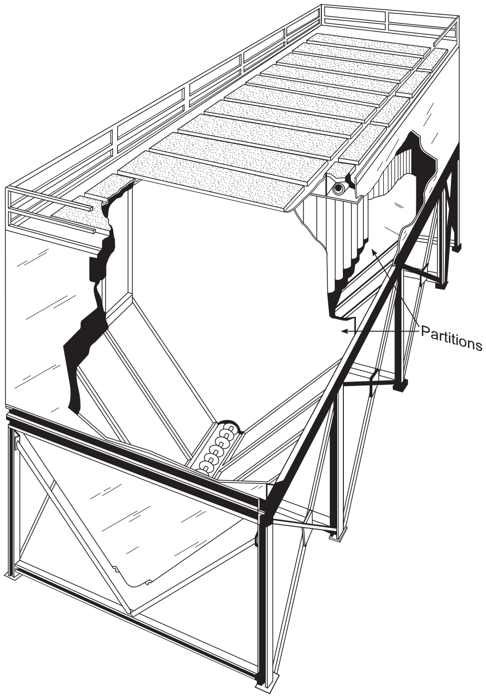


Fig. 2.2.2.3-1. Large collector showing partitions subdividing the unit

2.2.2.4 Install a spark-arrester or settling chamber in the duct between process and collector, where spark generation is common. A cyclone collector, scrubber or similar device that would deflect or extinguish heavier embers or sparks from the gas stream is acceptable.

2.2.2.5 For dust collectors or collection systems handling noncombustible dusts, substitute a low combustibility filter medium on a replacement basis for existing combustible bags/canisters.

2.2.3 Enclosureless Dust Collectors

2.2.3.1 Use dust collectors with a housing around the dust collection medium. Collectors that lack a housing around the dust collection medium (e.g., enclosureless collectors) are not to be used.

2.2.3.1.1 Locate horizontal air (drum) filters, arranged to continuously scrape and vacuum any accumulated solid particulate, as follows:

A. Isolate the air filters and associated equipment from other important operations in a cut-off area with noncombustible walls.

B. Interlock the associated process, so it cannot operate if the horizontal air filter is not fully functional. Conditions to trigger the interlock can include but are not limited to loss of air flow, non-operation of the scraper/vacuum system or a break in the fabric filter media.

2.2.4 Grain Handling Facilities

Grain handling facilities are sometimes collectively referred to as “grain elevators”. Where these grain handling facilities are present, the design and construction of these facilities should be in accordance with the guidance presented here.

2.2.4.1 Separate workhouse areas where grain is cleaned and weighed from storage silos, tanks, milling operations, loading/unloading operations and other processing areas to minimize the potential propagation of an explosion between areas.

2.2.4.2 Run conveyors connecting the workhouse to loading or unloading facilities and storage silos/tanks above ground immediately after leaving subgrade structures. Avoid the use of tunnels or conveyor enclosure galleries.

2.2.4.3 Locate elevating conveyors outside the workhouse, preferably as part of a separate structure. Inclined conveyors are preferred over vertical bucket elevators.

2.2.4.4 Design and construct all facilities out of steel or reinforced concrete framing.

2.2.4.5 Provide damage-limiting construction for all enclosed areas, including but not limited to workhouses, loading/unloading facilities, conveyor galleries and processing areas. Design the damage-limiting construction using DustCalc and FM Property Loss Prevention Data Sheet 1-44, *Damage-Limiting Construction*.

2.2.4.6 Provide explosion venting along the length of elongated enclosures such as conveyor galleries.

2.2.4.7 Provide smooth, high-gloss finishes on interior wall and ceiling surfaces in the workhouse and in bins above the maximum grain level to facilitate cleaning and to minimize horizontal surfaces where dust can accumulate.

2.2.4.8 Construct storage silos as follows:

A. Use concrete or other non-combustible materials.

B. Provide damage-limiting construction designed per Data Sheet 1-44 and verified using DustCalc. Arrange such construction so explosions vent outside and not into adjacent silos, bins or conveyors.

C. Construct the foundation in such a way that the retrieval conveyor beneath the bins is above grade to permit the use of damage limiting construction.

This guidance relates to:

1. Open belt conveyors located below ground
2. Enclosed belt conveyors

In both situations, the location of these conveyor types provides an enclosure in which an explosion can develop. Other conveyor types may present the same conditions, potentially allowing a dust explosion event.

A. Arrange breather vents for relieving dust-laden air to discharge directly to the outside. Do not vent one bin into another or into a conveyor enclosure.

B. Avoid manifolding dust collection systems from different silo groups or tank groups.

2.2.5 Grain Dryers and Malt Kilns

2.2.5.1 Construct grain dryers, including furnace rooms, of non-combustible construction.

2.2.5.2 Provide damage-limiting construction on dryers in accordance with FM Property Loss Prevention Date Sheet 6-9, *Industrial Ovens and Dryers*. Damage-limiting construction is not needed in malting kilns.

2.2.5.3 Separate grain dryers, including furnace rooms, from silos and bins.

2.2.5.4 Arrange steam coils, fins and heated surfaces to prevent dust accumulations from settling on them.

2.2.5.5 Locate air intakes in dust-free areas, and provide coarse screens to keep out debris.

2.2.5.6 Provide cleaning equipment in train lines ahead of dryers to remove debris that might clog the dryer.

2.2.6 Electrostatic Precipitators

Electrostatic precipitators collect dusts and hydrocarbon mists from gas streams by using an electrostatic charge. They may be used to condition air to meet air pollution codes or recover a product or by-product.

2.2.6.1 Locate precipitators processing oil or other hydrocarbon mists on an easily cleaned pad to prevent accumulation of combustible residues.

2.2.6.2 Extend the cleanable pad to the area below the precipitator and the transition piece from duct to precipitator.

2.3 Occupancy

2.3.1 Housekeeping

2.3.1.1 When fugitive dust is identified in a building, apply the following guidance:

A. Survey any equipment and/or ductwork where combustible dusts are generated, processed, handled, collected or transported to identify any sources of dust release.

B. Modify, repair, or replace equipment and/or ductwork to eliminate, or at least reduce, dust escape.

C. Provide permanent dust collection pickup points for a dust collection system, a ventilated hood or containment enclosure, where applicable, at the locations where dust is liberated.

D. Operate closed dust-handling systems under a slight negative pressure to reduce dust escape.

2.3.1.2 Where fugitive dust is released despite process design and equipment upkeep, apply the following guidance:

A. Develop and implement a strict dust management program that clearly identifies where dust is being released, where it is accumulating, and what the accumulation rate is. Audit the program on a regular basis.

B. Remove accumulations of dust where they are present. Prioritize the removal of accumulations in below-grade areas or areas that are not visually accessible. These areas include but are not limited to receiving tunnels near railcar and truck unloading stations, near openings for filling silos and bins, near openings adjacent to bucket elevators, within electrical rooms and areas above floor level. Areas above floor level include areas located above suspended ceilings, the tops of equipment and building structural members.

C. Use vacuum removal wherever possible with a central, portable or truck-mounted vacuum system as appropriate. Central vacuum dust collection systems are recommended for plants with inherently dusty processes to facilitate plant clean-up and minimize dust clouds. In grain handling facilities, central vacuum systems may operate from the elevator’s dust control system. Where used, these systems are to be electrically rated for the dust hazards in the area.

D. Where vacuuming is impractical, sweeping or water wash-down are other acceptable options. Where sweeping is used, soft push brooms are recommended; and pneumatic collector openings near floor level may be used to pick up sweepings.

2.3.1.3. Where compressed air blow-down is the ONLY practical method for cleanup, use the following precautions:

A. Shut down electrical equipment not suitable for Class II, Division 2 hazardous locations (or equivalent) ratings and any operations.

B. Prohibit open flames and hot work, and ensure no hot surfaces exist.

C. Provide constant monitoring when blowing down, to ensure any dust suspended by the blowdown operation does not create hazardous conditions (e.g., large dust clouds). The definition of hazardous will depend on local conditions.

D. Limit the extent of blow-down to small areas at a time.

E. Conduct blow-down operations with as low a volume and pressure of air as possible.

F. Perform air blow-down frequently enough to prevent hazardous accumulations of dust. Required frequencies and hazardous accumulations are dependent on location conditions.

2.4 Protection

2.4.1 General Fire Protection

2.4.1.1 Provide automatic sprinkler protection wherever combustible construction or occupancy is present, per the occupancy specific data sheets.

2.4.1.2 Do not attach sprinkler piping to any wall, ceiling or roof that is expected to be displaced by the pressure of a room or building explosion or allow such structures to support sprinkler piping. This provision includes any walls designated as Damage-Limiting Construction (DLC).

2.4.1.3 In grain handling, storage and processing facilities, provide appropriate wet or dry standpipes at all operating levels within elevator houses, conveyor structures, and cleaning and drying areas per FM Property Loss Prevention Data Sheet 4-4N, *Standpipe and Hose Systems*. In unheated areas within these facilities that are subject to freezing the following options are acceptable:

A. A small, approved deluge valve actuated by push buttons at each hose station. Emergency power should be provided for any deluge valve circuitry. Ordinary hose valves may be used if pressure is not maintained on piping.

B. A hose station supplied by a small dry pipe valve, separate from any dry pipe valves supplying sprinklers. Low points should have drum drips and dual valves. Hose control valves should have an automatic air device. Employees should be instructed in the operation of these devices and the need to allow air discharge to occur until water reaches the hose.

2.4.1.4 Provide automatic sprinkler protection for buildings with additive manufacturing operations in accordance with the following:

A. Design automatic sprinklers for all additive manufacturing areas (metal or plastic parts) in accordance with FM Property Los Prevention Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*, for HC-2 occupancies.

B. Design automatic sprinklers for storage areas containing plastic feed stock in accordance with FM Property Loss Prevention Data Sheet 8-9, *Storage of Class 1, 2, 3, 4 and Plastic Commodities*, in accordance to how the materials are stored (i.e., cartoned or uncartoned).

C. Design automatic sprinklers for storage areas containing metal powders in metal containers based on the surrounding occupancy. Sprinklers may be omitted in small noncombustible storage areas where no combustibles are in the room except for the metal powders in metal containers.

2.4.2 Equipment Fire Protection

2.4.2.1 Dust Collector Fire Protection

2.4.2.1.1 Provide fire protection for dust collectors handling combustible dusts, using either of the following options:

A. Automatic sprinkler protection

B. A closed-head water spray system, or open-head spray system activated by an infrared or continuous line-type detection system

When combustible dust is collected within the portions of the dust collector indicated below, (see Figure 2.4.2.1.1-1), design and install sprinkler or water spray protection for these areas as follows:

A. In the canister/bag area, install sprinklers/nozzles on a maximum spacing of 50 ft^2 (4.6 m^2) with a minimum flow of 10 gpm (38 L/min) per sprinkler/nozzle.

B. In the clean air plenum, install sprinklers/nozzles on a maximum spacing of 100 ft^2 (9.3 m^2) with a minimum flow of 20 gpm (76 L/min) per sprinkler/nozzle.

C. In hoppers that are shielded from sprinkler protection provided in either the canister/bag area or the clean air plenum, provide at least one sprinkler/nozzle per hopper using a maximum sprinkler spacing of 100 ft^2 (9.3 m^2) with a minimum flow of 10 gpm (38 L/min) per sprinkler/nozzle.

D. The use of other extinguishing systems (e.g., steam, gaseous fire suppression such as CO_2) are not to be installed as primary fire protection. Such systems are acceptable if installed as secondary protection to one of the options stated above.

The designs outlined above can be calculated independently of each other and are not needed concurrently. Use a quick-response, minimum K5.6 (K80) sprinkler for protection of the areas outlined above. See Data Sheet 2-0 for the recommended minimum design pressures for K5.6 (K80) and larger sprinklers. The sprinkler's recommended temperature rating should be approximately 50°F (28°C) higher than the maximum operating process temperature OR 212°F (100°C), whichever is higher.

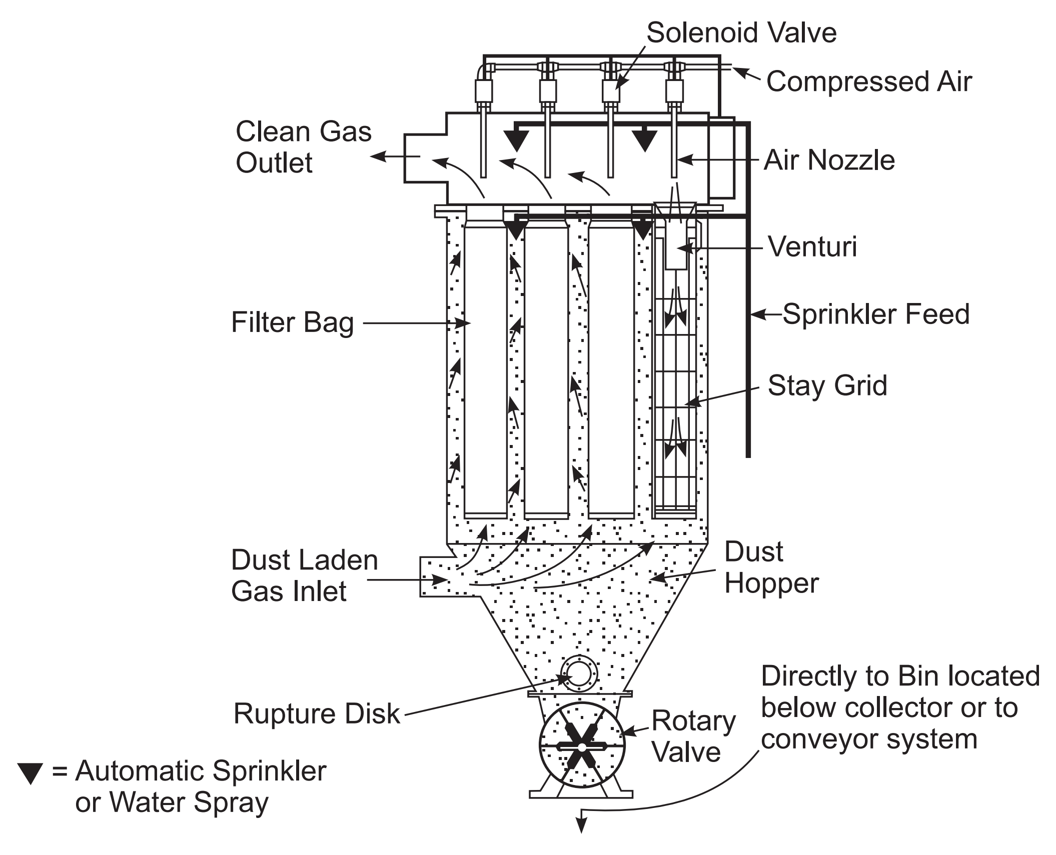


Fig. 2.4.2.1.1-1. Pulse jet collector; example of automatic sprinkler protection

2.4.2.1.2 Provide rupture disks, hatches attached with springs or other reliable devices that actuate at 1.5 psig (10 kPa, 0.1 bar) or less where water from hose streams, sprinklers or water spray systems can accumulate enough to result in structural damage to the collector. Locate these devices as close as possible to the bottom of the hopper. Ensure the location of these devices does not interfere with venting.

2.4.2.1.3 Where a rotary valve is installed, interlock the rotary valve to stop on actuation of the collector automatic water protection system.

2.4.2.1.4 In collectors handling non-combustible dusts, provide automatic water protection (see Section 2.4.2.1.1) **EXCEPT** for:

A. Collectors equipped with a fire resistive or flame-retardant filter media material

B. Small standalone collectors that, if damaged or destroyed, have only a minimal impact on business interruption

C. Small standalone collectors that have a low frequency of fires. Where a high frequency of fires (more than two or three in a year) or a high business interruption potential if the collector is destroyed or damaged exists, protect the collector in accordance with the guidance in this standard for dust collection systems.

Collectors that have combustible filter media but handle non-combustible dusts still require sprinkler protection due to the heat produced as the filter media burns.

2.4.2.1.5 Provide manual extinguishing equipment as follows when performing maintenance on a collector:

A. For small collectors: Portable extinguishers (preferably water-type units) are acceptable.

B. For larger, walk-in type collectors: Install 1-1/2 in. (40 mm) hose with a combination water spray/straight-stream nozzle near the door outside the collector.

C. Provide access ports for all areas of the collector where necessary for effective manual firefighting.

2.4.2.2 Wet Dust Collector Fire Protection

2.4.2.2.1 Provide automatic sprinkler or water spray protection inside wet collectors that are of combustible construction or have combustible lining or packing material per Section 2.4.2.1.

2.4.2.2.2 Provide interlocks to prevent operation of the system, unless the waterflow system (to wet the dust) within the wet collector is in operation.

2.4.2.2.3 Maintain the liquid level above the level of sludge or arrange for sludge to be continuously drained and disposed of properly.

2.4.2.2.4 Remove sludge that is subject to spontaneous heating from collectors as soon as they are shut down.

2.4.2.2.5 When using wet vacuum cleaners, ensure adequate water is available within the unit before starting.

2.4.2.2.6 Drain off any sludge from a wet vacuum cleaner hopper after a maximum of eight hours of vacuum cleaner operation and prior to shut down.

2.4.2.3 Cyclone Fire Protection

2.4.2.3.1. Where cyclones are handling non-combustible dusts, no fire protection is necessary.

2.4.2.3.2 Provide sprinklers within a cyclone that is handling combustible dusts if the cyclone has a high frequency of fire events or is of combustible construction. Sprinklers should be located at the top of the cyclone, have a minimum K-factor of 5.8 (K80) and provide a minimum flow of 10 gpm (38 L/min). Install one sprinkler per 100 ft^2 (9.3 m^2), using the maximum diameter of the cyclone.

2.4.2.3.3 For cyclones and cyclone collectors processing fiber or wood in woodworking or wood processing operations, (e.g., milling and drying in particle plants), see additional guidance in Data Sheet 7-10.

2.4.2.4 Vertical Bucket Elevators Fire Protection

2.4.2.4.1 Provide automatic sprinkler protection at the top of a vertical bucket elevator where the enclosure if noncombustible. If the enclosure is constructed from combustible materials, provide additional automatic sprinkler protection along the shaft (i.e. the internal vertical shaft that has the combustible sides) spaced every 10ft to 12 ft (3 to 3.7 m).

2.4.2.4.2 Combustible buckets and belts are considered combustible construction. Where these are the only combustible components, evaluate the combustible loading of these materials in a fire scenario to determine if sprinkler protection is needed.

2.4.2.4.3 Design the automatic sprinklers to deliver a minimum flow of 25 gpm (95 L/min) from the most remote sprinkler.

2.4.2.4.4 Where sprinklers are in areas subject to freezing, provide suitable protection of the installation for the temperatures expected.

2.4.2.5 Spray Dryer Fire Protection

2.4.2.5.1 Provide automatic protection for spray dryers, using sprinklers or water spray nozzles in accordance with Data Sheet 6-9.

2.4.2.5.2 Ensure spray dryer nozzles are kept free of blockage to prevent material buildup and local overheating that can lead to a fire hazard.

2.4.2.6 Large Processing Equipment

2.4.2.6.1 Install sprinklers in the interiors of large processing equipment. Examples include the lowest dry level of malting kilns in grain occupancies.

2.4.2.7 Electrostatic Precipitator Fire Protection

2.4.2.7.1 Provide automatic water spray protection at a minimum flow of 20 gpm (75L/min) per nozzle.

2.4.2.7.2 Provide automatic water spray protection in the following areas of precipitators:

A. Inside precipitators of combustible construction

B. Over precipitators of combustible construction

C. Inside precipitators collecting combustible material

D. Inside precipitators with oil-bath reservoirs

E. Over precipitator oil seals and associated oil settling tanks, reservoirs and piping, and for 20 ft (6 m) beyond

Ensure all combustible areas within the precipitator, including the collection plates where combustible residues can build up, are protected.

To be protected, the areas outlined above can be calculated independently of each other and are not needed concurrently. Use a quick-response, minimum K5.6 (K80) sprinkler for protection of the areas outlined above. See Data Sheet 2-0 for the recommended minimum design pressures for K5.6 (K80) and larger sprinklers. The sprinkler's recommended temperature rating should be appropriate for the expected temperatures inside the precipitator.

2.4.2.7.3 Automatic sprinkler protection is acceptable for precipitators where it is installed instead of water spray if the sprinklers provide a minimum density of 20 gpm (75 L/min) and are installed in all areas as stated in Section 2.4.2.7.2.

2.4.2.7.4 Automatic sprinkler or water spray protection can be omitted inside wet precipitators or precipitators of non-combustible construction collecting noncombustible material, even though combustible dry filter paper or adhesive-coated metal plates are used.

2.4.2.7.5 Special protection systems such as carbon dioxide or steam are not acceptable as primary protection.

2.4.2.7.6 Protect ducts connected to electrostatic precipitators (Figure 2.4.2.7.6-1) in accordance with Data Sheet 7-78 with the following exceptions:

A. Only use open-head water spray systems in lieu of closed-head sprinkler systems. Use a minimum flow of 20 gpm (75 L/min) per nozzle. This equates to the same protection requirement given for the precipitator.

B. Arrange the detection and control system so that all nozzles in the precipitator and all connected ductwork activate simultaneously.

C. Within the ducts, locate automatic open-head water spray nozzles as follows:

1. Space the nozzles in accordance with the guidance in Data Sheet 7-78
2. Use solid-cone, wide-angle nozzles
3. Inside each duct penetration at roof level
4. Inside the duct at each floor penetration for multi-story buildings

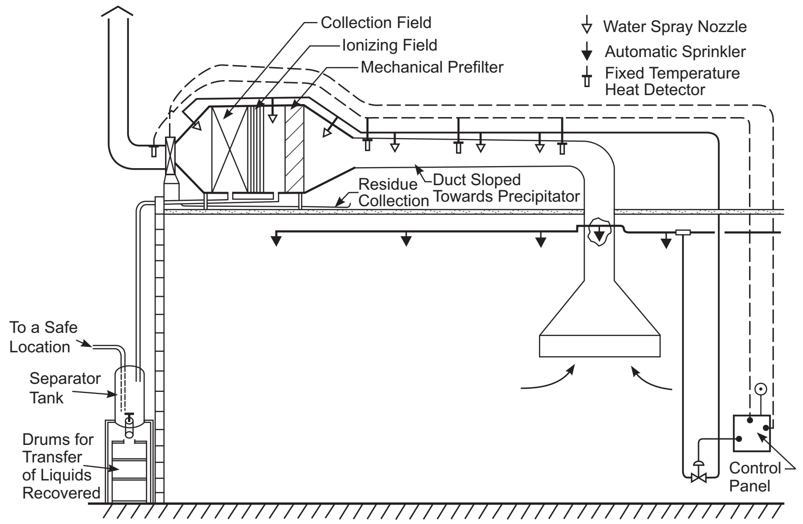


Fig. 2.4.2.7.6-1. Electrostatic precipitator with water spray protection for precipitator and ducts (only one duct shown)

2.4.2.7.7 Provide for drainage of the water originating from the protection systems. Slope ducts so that water flow is toward the precipitator. Provide a separator tank for precipitators used to collect hydrocarbon mists, so that discharge of the water spray system does not result in a release of hydrocarbon that could expose plant buildings or property.

2.4.2.7.8 Provide interlocks to automatically de-energize the precipitator and shut down the fan on the exhaust system upon actuation of the water spray systems.

2.4.2.7.9 Do not use electrostatic precipitators where dry combustible dust concentrations in air may exceed the Minimum Explosible Concentration (MEC) due to the possibility of ignition by arcing in the precipitator.

2.4.3 Equipment Explosion Protection

2.4.3.1 General

2.4.3.1.1 Protect equipment with a dust explosion hazard using one or more of the following options, unless specified otherwise in the equipment specific sections listed in Section 2.4.3:

A. Damage limiting construction. This includes explosion venting, combinations of explosion venting and pressure resistance, and explosion containment

B. FM Approved flameless venting devices

C. Explosion isolation

D. Inerting

E. Explosion suppression

Examples of equipment to be protected include but are not limited to:

- Dust collectors
- Process vessels (mixers, blenders, etc.)
- Silos and bins
- Crushing equipment (Mills)
- Bucket elevators
- Dryers

2.4.3.1.2 When using damage-limiting construction to provide explosion protection for a piece of equipment, design the damage limiting construction using DustCalc, Appendix D of this data sheet, and the following:

A. For equipment/vessel fitted with explosion vents located inside a room/building, direct the explosion vents outside to a safe location. See also Section 2.2.1.4.

B. Do not use damage limiting construction to protect equipment/vessel with an explosion hazard created by highly reactive combustible metal dusts.

C. Containment of an explosion within equipment/vessel (explosion-resistant design) is acceptable; provided the design strength of the vessel can resist a pressure of at least 87 psig (6 barg), and the initial pressure within the equipment/vessel is less than 1.5 psig (0.1 barg). Such a design should prevent deformation of the equipment/vessel.

D. Providing explosion protection on equipment/vessels operating at pressures exceeding 1.5 psig (0.1 barg) requires careful analysis. See Section C.3 for additional information.

2.4.3.1.3 When equipment/vessels located inside cannot be vented to the exterior of the building, use an FM Approved flameless venting device in accordance with the following:

A. Select and install the device in accordance with Appendix D and the *Approval Guide* listing requirements.

B. Do not use flameless explosion venting devices with metal dusts.

C. Do not use flameless explosion venting devices with fibrous dusts or melting dusts unless specifically FM Approved for such uses.

D. Do not use flameless explosion venting devices in areas where the liberation of fugitive dusts cannot be prevented. The immediate area around the flameless explosion venting device should be kept free of fugitive dusts. The size of the immediate area will be dependent upon the specific flameless vent used.

E. When using an FM Approved flameless venting device, make sure to account for the reduction in nominal venting area (i.e., the effective vent area) caused by the installation of the venting device.

F. Do not cover (or install covers on) flameless explosion venting devices.

2.4.3.1.4 To prevent a deflagration from propagating between connected equipment/vessels or buildings, use explosion isolation devices installed in accordance with the following:

A. Install the device(s) in accordance with Appendix E of this data sheet, Data Sheet 7-17 and the manufacturer's recommendations.

B. Where equipment, vessels or vessel groups are designed to contain the explosion pressure (explosion-resistant design), explosion isolation should be provided on all connections to or from such equipment.

Rotary air-lock devices, high-speed abort gates, gate valves or chemical isolation systems are all isolation systems that can be used. These should be installed per the guidance in this data sheet.

C. Long runs of ductwork, multiple bends within ductwork and changes in ductwork diameter are not acceptable methods of explosion isolation/mitigation between connected equipment. Where needed, explosion isolation should be provided per the guidance in this data sheet.

2.4.3.1.5 When a piece of equipment or vessel cannot be protected per 2.4.3.1.2 or 2.4.3.1.3 OR is critical to a production process, use an FM Approved explosion suppression system in accordance with the following and equipment specific guidance within this data sheet:

A. Design and install a FM Approved explosion suppression system in accordance with Appendix F, Data Sheet 7-17, the FM Approval listing, and the manufacturer's recommendations.

B. Where individual pieces of equipment/vessels had explosion suppression installed, provide explosion isolation devices between these individual pieces of equipment/vessels.

C. Design the explosion suppression for the full volume of the equipment/vessel. Do not exclude the clean plenum in a dust collector or the upper areas of a spray dryer.

D. Confirm that the final system pressure after the suppression system is discharged, including the pressure rise created by the system discharge, is below the strength of the protected equipment/vessel.

E. Do not use explosion suppression for highly reactive metal dusts, unless test data developed using a vessel of at least 1 m^3 is available that shows the system design will work for this hazard.

F. Do not use explosion suppression systems in conjunction with explosion venting, unless the suppression system is designed based on the assumption that venting is not provided.

G. Do not install explosion suppression systems where dusts with a K_{st} greater than 200 are used unless proven effective by full-scale explosion tests. In general, these dusts cannot effectively be suppressed due to their extremely fast rate of pressure rise.

H. Providing suppression on equipment/vessels operating at pressures exceeding 1.5 psig (0.1 barg) requires careful analysis. See Section C.3 for additional information.

2.4.3.1.6 When a piece of equipment or process is protected with inert gas (inerting), use a gas inerting system in accordance with the following:

A. Install gas inerting protection systems per the guidance in FM Property Loss Prevention Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*.

B. When inerting equipment/vessels containing combustible metals, select an inerting gas that does not react with the metal dust. See Data Sheet 7-59, and Data Sheet 7-85 for information on appropriate inerting gases for various metals.

2.4.3.2 Dust Collector Explosion Protection

2.4.3.2.1 When determining the explosion venting area for a media type dust collector, (e.g., cloth bags, paper filter sheets or cartridges), include both the clean and dirty air side to calculate the volume of the collector.

2.4.3.2.2 For media type dust collectors, locate explosion vents entirely on the dirty side of the collector volume.

2.4.3.2.3 Where installing venting on the clean side is necessary, use the following equation to calculate the minimum amount of the total explosion venting area that must be provided on the dirty side:

$$A_{v,dirty,min} \geq (V_{dirty}/V_{total})^{2/3} \times A_{v,total}$$

where:

$A_{v,total}$ is the total vent area required
$A_{v,dirty,min}$ is the minimum explosion venting area that should be on the dirty side of the dust collector
V_{dirty} is the volume of the dirty side of the dust collector
V_{total} is the total volume of the dust collector

2.4.3.2.4 Provide portable dust collection systems, such as vacuum cleaners, with appropriate protection for the material being collected. This can include adequate venting, or explosion containment.

2.4.3.3 Cyclone Explosion Protection

2.4.3.3.1 Provide explosion protection for cyclones processing combustible dusts. For cyclones processing fiber or wood (e.g., milling and drying in particle plants) in woodworking or wood processing operations, refer to Data Sheet 7-10.

2.4.3.3.2 Cyclone dust collectors can be considered to have adequate explosion relief without any additional explosion vents if they meet ALL of the following criteria:

A. The dust being processed has a K_{st} of 80 bar m/s or less, **AND**

B. The exhaust goes directly to atmosphere via the gas outlet at the top of the cyclone, **AND**

C. The gas outlet diameter is at least 45% of the diameter of the cyclone itself, **AND**

D. The free outflow of gases is not obstructed by screening.

A “rainhat” located above the gas outlet hole does not violate these criteria, as long as its distance above the gas outlet is not less than one half the diameter of the gas outlet.

2.4.3.3.3 Verify the explosion vent sizing for all other situations. These include but are not limited to higher K_{st}, a smaller gas outlet, gas outlets with an attached duct exceeding L/D = 1, a duct with a bend, etc.

2.4.3.4 Bucket Elevator Explosion Protection

2.4.3.4.1 Protect enclosed bucket elevators handling dusts with a Kst of 200 or less using explosion vents. Where explosion venting cannot be installed, explosion suppression systems are acceptable. See Section 2.4.3.4.10 for additional guidance.

Locate the explosion vents along the entire length of the bucket elevator. The vents should be spaced in accordance with Table 2.4.3.4.1-1, based on the elevator type, K_{st} and the P_{red} of the enclosure.

Table 2.4.3.4.1-1. Bucket Elevator Explosion Venting

		Maximum Vent Spacing, ft (m)$^{Note\ 1}$		
Bucket Elevator Type	K_{st} *(bar-m/s)*	P_{red} < 0.2 bar	0.2 <P_{red} ≤0.5 bar	<0.5 P_{red} ≤1.0 bar
Double casing	<100	20 (6)	None required	None required
	100-150	10 (3)	33 (10)	62 (19)
	151-175	N/A	13 (4)	26 (8)
	176-200	N/A	10 (3)	13 (4)
Single casing	<100	N/A	None required	None required
	100-150	N/A	23 (7)	46 (14)
	151-175	N/A	13 (4)	16 (5)
	176-200	N/A	10 (3)	13 (4)

Note 1. Spacing is measured from the center of one explosion vent to the center of the next explosion vent.

2.4.3.4.2 Route explosion venting for indoor elevators to the outside by short straight ducts, or provide FM Approved flameless vents. Flameless vents should be installed per the guidance in this data sheet.

2.4.3.4.3 Install explosion venting in the head section (top) equivalent to the cross-sectional area of the casing leg.

2.4.3.4.4 Install the first casing vent as close as practical to the boot (bottom) of the bucket elevator but not to exceed the spacing shown in Table 2.4.3.4.1-1)

2.4.3.4.5 Size explosion vents equivalent to the cross-sectional area of the elevator leg enclosure. The vent area can be installed as separate half-sized vents located on opposite sides of the enclosure.

2.4.3.4.6 Install explosion venting for the up and downside leg on double casing designs.

2.4.3.4.7 Explosion vents can be installed on the sides or face of the casing.

2.4.3.4.8 Set the explosion vent relief pressure (P_{stat}) to 0.1 barg (1.5 psig) or less, and construct vents of lightweight material.

2.4.3.4.9 Where the elevator head or boot feeds into equipment or areas that have an explosion hazard, provide explosion isolation (e.g., rotary air locks or chemical isolation) between the head or boot and adjacent areas or equipment.

2.4.3.4.10 Where explosion suppression systems are used in bucket elevators, these systems should be installed per Sections 2.4.3.1.5, 2.4.3.4.9 and Appendix F of this data sheet and the following guidance:

A. Where explosion suppression is used, it should be installed throughout all indoor elevator legs.

B. Within grain handling facilities where explosion venting has been installed (see Section 2.4.3.1.5), explosion suppression blocking systems should be installed in bucket elevators in the boot, the infeed and the discharge and head pulley areas to minimize the chance of an explosion propagating from one area to another.

2.4.3.5 Spray Dryer Explosion Protection

Spray dryers operate in such a way that the bulk of their volume is below the MEC, and that only the bottom conical portion of the spray dryer contains an explosive mixture. Design calculations for spray dryers typically provide this information. Where recycle streams are present, they may change the volume of the dryer that exists below the MEC and if not taken into account may render explosion protection ineffective.

2.4.3.5.1 When evaluating explosion protection for spray dryers apply the following guidance:

A. The average dust concentration within the cylindrically shaped portion should be below the MEC of the material being handled.

B. The average dust concentration within the cylindrically shaped portion should include (where present) any recycle streams introduced at the top of the spray dryer.

2.4.3.5.2 Provide explosion protection for the spray dryer. Where explosion venting is used, FM's DustCalc software should be used to confirm the required explosion venting area accounts for a combustible cloud existing within only a fraction of the total vessel volume.

2.4.3.5.2.1 Where other explosion protection systems are used (e.g., suppression and flameless venting), follow the guidance for these protection systems as stated in this data sheet.

2.4.3.5.3 Evaluate connections from the spray dryer and downstream equipment following the guidance in Section 2.4.3.1.4.

2.4.3.5.4 When explosion vents are installed on a spray dryer, distribute the explosion vents uniformly around the circumference of the dryer. Vents should be placed in or near the conical section of the dryer first, as this is the area with the greatest explosion hazard. See Figure 2.4.3.5.4-1.

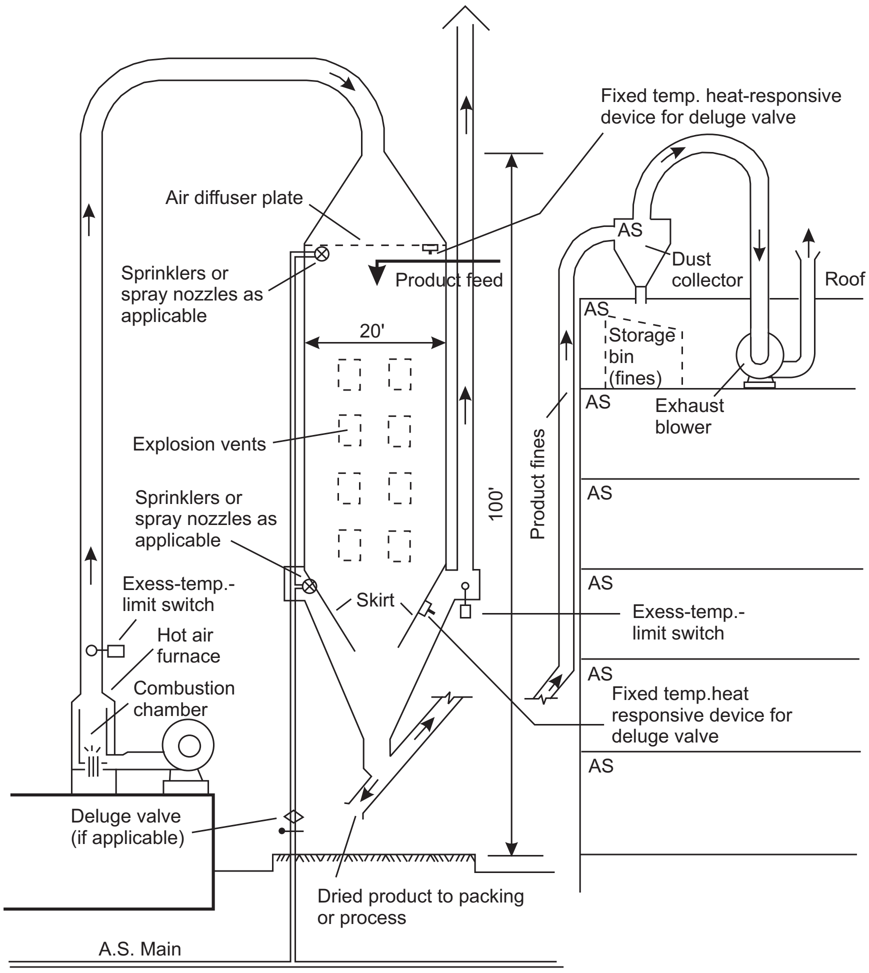


Fig. 2.4.3.5.4-1. Large spray dryer unit – location of explosion vents

2.4.3.6 Grain Dryers and Malting Kilns

2.4.3.6.1 Provide explosion vents in grain dryers, depending on design, in accordance with Data Sheet 6-9. Explosion vents are not needed in malting kilns.

The design of certain grain dryers (e.g., rotating dryers) may prevent the installation of explosion vents. Other protection options may be needed.

2.4.3.6.2 Provide automatic temperature control, coupled with an independent safety control circuit, on grain dryers and malting kilns to shut down the heating supply and fans when any of the following conditions occur:

A. Loading or unloading product when excessive temperatures within the dryer are detected

B. Stoppage of the hot air fans

C. Stoppage of the cooling air fans

D. Burner flame failure

E. A fire in the dryer or kiln

The excessive temperature limit should be set approximately 25°F (14°C) above the operating temperature of the dryer.

2.4.3.6.3 Provide a means at the dryer discharge to allow stock to be intercepted and dumped in the event of a fire within the dryer.

2.4.3.7 Connecting Ducts

Ducts connecting pieces of a process or collection system can provide a route for spreading an initial explosion and may contain enough dust to propagate an explosion of their own. This section does not apply to clean air ducts downstream of air-material separators or pneumatic transfer of process materials at rates well in excess of the MEC (dense phase transfer).

2.4.3.7.1 Avoid having multiple pieces of interconnected equipment that present a dust explosion hazard.

2.4.3.7.2 Protect ducts that carry combustible dust in concentrations that are always less than the MEC and at velocities where dust settling is unlikely as follows:

A. Provide explosion isolation devices on connections to important pieces of equipment.

B. Provide explosion protection devices on ducts running back to buildings that might contain fugitive dust and that contain expensive equipment or important processes that could be damaged.

2.4.3.7.3 Protect ducts that carry combustible dust in concentrations that are at or frequently exceed the MEC or that carry dust at velocities where dust settling is possible as follows:

A. Route the ducts outside.

B. Provide an explosion-isolation device at each point of connection between the duct and a piece of equipment.

C. Protect the duct from an explosion propagating in the explosible mixture by one of the following:

1. Provide venting for the duct.
2. Design the duct to fail at pressures as low as practical but not more than 0.3 barg (4.4 psig).

D. Convey the material within an inert atmosphere within the duct. See also guidance for inerting dusts provided in this data sheet and in Data Sheet 7-59.

For additional guidance refer to Data Sheet 7-78, *Industrial Exhaust Systems*.

2.4.3.7.4 Protect ducts that must be located indoors and carry combustible dust in concentrations above the MEC or conveyed at less than the dust-settling velocity as follows:

A. Provide an explosion-isolation device at each point of connection between the duct and a piece of equipment, AND

B. Design the duct to contain the explosion (shock resistant), OR

C. Provide venting for the duct, but route the vents outdoors.

2.4.3.7.5 Locate explosion venting along the length of a duct as follows:

A. Compute the maximum distance between explosion vents (L_{max}):

1. $L_{max} = 7.5\ D^{1/3}$, D and L in meters OR
2. $L_{max} = 16.5\ D^{1/3}$, D and L in feet

B. For noncircular ducts, calculate the hydraulic diameter for the above equation by:

$$\text{Hydraulic Diameter} = \frac{4A}{p}$$

Where:

A = cross-sectional area of vent
p = perimeter of the cross-section

C. Provide a vent area at each location at least equal to the cross-sectional area of the duct.

D. Provide a full-size vent no more than two diameters away from the point of duct connection to a piece of equipment.

E. Set the explosion vent relief pressures (P_{stat}) as low as possible with a maximum value of 0.1 barg (1.5 psig).

F. Provide an explosion vent at all elbows and end flanges (see Figure 2.4.3.7.5-1).

G. When located inside, route the explosion products outside via a short duct (L/D less or equal to 1).

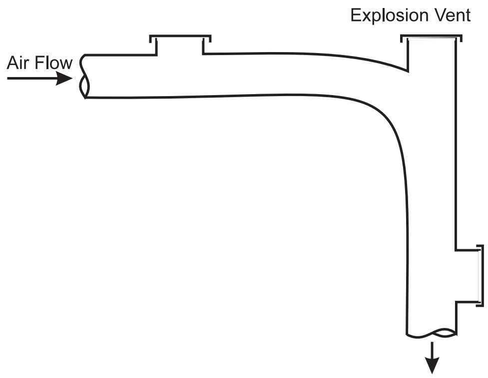


Fig. 2.4.3.7.5-1. Example of duct explosion venting at an elbow

2.4.3.7.6 Ductwork used for dense phase pneumatic conveying of combustible dusts can be installed without explosion isolation devices if the conveyed material is not metal dust or a hybrid mixture. Dense phase conveying usually presents no hazard of explosion propagation.

2.4.3.8 Dust Storage Silos

2.4.3.8.1 When a storage silo containing combustible dust has a dust collector (other than a simple vent sock) on the breather vent, treat the collector/silo combination as a single unit if either of the following conditions exist:

A. The duct connecting the silo to the dust collector has an L/D ratio less than two, **OR**

B. The cross-sectional area of the connecting duct is at least as large as the explosion-venting area needed to protect the volume of the dust collector alone.

2.4.3.8.2 Provide explosion venting for the silo/collector combination based on the total volume of the two units.

2.4.3.8.3 Install part of the explosion venting on the dust collector, if possible, not to exceed the cross-sectional area of the connecting pipe (although all of the explosion venting can be on the silo).

2.4.3.8.4 Where the dust collector/silo combination does not meet the criteria of a single unit, provide explosion venting for each component based on their individual volume; and provide explosion venting for the connecting duct itself.

2.4.3.8.5 Ensure the explosion venting area provided for a silo does not exceed its cross-sectional area ($A_{x\text{-sect}}$).

2.4.3.8.6 If calculations show the explosion venting area required is more than the cross-sectional area, use an explosion-suppression system or reinforce the silo so it can withstand the value of P_{red} corresponding to $A_{v} = A_{x\text{-sect}}$.

2.4.3.8.7 Do not use air cannons to break bridges in silos handling combustible materials, if particles smaller than approximately 500 microns exist within the material.

2.4.3.8.8 Do not use weak seam roofs or weak roof-to-shell seams as explosion vents on vessels containing combustible dusts.

2.4.3.8.9 Where turnhead distributors are used, fit the turnhead distributors with a rotating annular sleeve to seal any spouts when not in use.

2.4.3.8.10 When bins are being filled, pressurize turnhead distributors to minimize dust buildup within the equipment.

Turnhead distributors are hollow conical casings commonly found in bulk storage occupancies (e.g., grain handling and grain storage). The simplest of these has a single inlet feed at the top and multiple outlets at the bottom. The inlet feed can be rotated (turned) within the conical structure to distribute products to a specific area (such as a particular storage silo or bin).

2.5 Equipment and Processes

2.5.1 General

The following methods of dust control reduce the frequency of dust fires and explosions. Providing one or more of these methods does not preclude or remove the need for fire and explosion protection. In all cases, a thorough evaluation of the fire and explosion hazards must be undertaken.

2.5.1.1 When possible, preclean the combustible material to reduce the amount of fines (particles less than 75 microns in size) within it and/or the process equipment.

2.5.1.2 Choose dust handling and conveying processes that limit the production of fines.

2.5.1.3 If a liquid suppressant mist (water or other compatible liquid) system is used to reduce airborne dust liberation from solids being moved on a conveyor, do the following:

A. Use a non-ignitable liquid suppressant. If a non-ignitable suppressant is not available, use an ignitable liquid with a minimum closed cup flash point greater than or equal to 414°F (212°C).

B. Apply the liquid suppressant as close to the solid material surface as possible.

C. Use the lowest pressure possible for spraying the liquid suppressant to prevent the creation of a liquid mist in the air around the application zone.

D. Interlock the solids conveying system and the liquid suppressant system to shut down if:

1. The conveyor stops moving
2. The liquid suppressant system shuts down
3. A fire or explosion is detected

E. Apply the liquid suppressant at a point in the process that involves substantial turbulence (e.g., at a discharge spout), to ensure the suppressant is thoroughly mixed with the material stream.

F. Do not apply oil or other liquid suppressants to equipment, where it could lead to slipping of the rubber belts and potential friction heating.

2.5.1.4 Do the following when charging vessels/equipment having both combustible powders and ignitable liquids when the ignitable liquid is handled at or above its closed cup flash point:

A. Avoid simultaneous charging of the powders and the liquids into the equipment.

B. Arrange liquid charging operations in accordance with FM Property Loss Prevention Data Sheet 7-32, *Ignitable Liquid Operations*. Use a dip tube to fill the vessel/equipment from the bottom.

C. Arrange dust charging operations to minimize the dispersion of dust outside the equipment opening by using screw conveyors or closed shoots connected to solids charging tanks.

D. If dust can escape from the equipment opening, arrange permanent dust pickup points adjacent to the opening.

E. Ensure all equipment, including the vessel and the transfer pipes/ducts, are properly grounded and bonded.

F. If the dust has a minimum ignition energy (MIE) equal to or less than 10 mJ, provide a grounding management system that confirms all conductive elements are properly grounded before allowing the introduction of the low MIE dust.

2.5.2 Dust Collection Systems

2.5.2.1 Prohibit recycling of exhaust from a dust collection system to buildings or rooms except where either item A applies OR all items B through H apply:

A. The return air duct discharges into an area that does not contain fugitive dust, combustible equipment or storage, combustible construction, high value equipment or equipment which is critical to production, **OR**

B. Install a filter downstream of the air material separators with a minimum efficiency of 99.9% at 10 microns that prevents return of dust to the building or room, **AND**

C. Install a device to measure pressure drop across the filter with an alarm to indicate when the filter needs to be cleaned or replaced, **AND**

D. Provide support for the filter with a wire mesh screen or other method which allows the filter to withstand a pressure equal to or exceeding the value of the vented explosion pressure (P_{red}) for the piece of equipment directly upstream from it, **AND**

E. Provide fire protection (refer to Data Sheet 7-78 for ductwork) and explosion isolation between the building and the last dust collector in the system (the one furthest downstream), **AND**

F. On explosion isolation system activation, provide a controlled automatic shutdown of any connected dust collection equipment, **AND**

G. Flammable vapors, gases or hybrid mixtures are not involved, **AND**

H. The dust collection system meets the protection requirements in other sections of this data sheet.

2.5.2.2 Size any dust collection system to the maximum anticipated material flow.

2.5.2.3 Ensure the airflow (air velocity) exceeds the settling velocity of the material being transported. This condition will prevent dust from accumulating within equipment or ducts. Where the settling velocity of a material is unknown, consult Data sheet 7-78 for generic transport velocity recommendations.

2.5.2.4 Provide interlocks to prevent operation of dust-producing processes when the collection system is not operating.

2.5.2.4.1 Arrange vertical bucket elevators to empty belts and buckets as part of the process shut down.

2.5.2.5 Design a dust collection system to prevent a continuous, explosible atmosphere from developing in the duct, using the following methods:

A. For variable dust-generation rates, keep the dust below an average concentration of 25% of the minimum explosible concentration (MEC). Limit peak dust-emission rates above 100% of the MEC for only a few seconds at any time.

B. For steady dust-generation rates without significant peaks, keep the dust concentration to no more than 90% of the MEC.

2.5.2.6 For non-alkali metal dusts, use wet dust collectors.

2.5.3 Additive Manufacturing (3D Printing)

2.5.3.1 Implement basic safeguards related to the handling and storage of combustible metal powders per this standard and Data Sheet 7-85.

2.5.3.2 Locate additive manufacturing equipment that produces metal parts in areas segregated from other manufacturing or storage by either a clear space, walls or in a separate building.

2.5.3.3 Use closed conductive metal containers to store, handle, and transport metal powders.

2.5.3.4 Provide an inert atmosphere in additive manufacturing printers and the associated dust collectors. Design and install the inert gas system as follows:

A. Use Data Sheet 7-59 and Data Sheet 7-85 to determine the appropriate inert gas to use based on the types of metal powder being printed.

B. Use an FM Approved, continuous, automated inerting system to monitor the oxygen level in the equipment; and interlock as follows:

1. Interlock to prevent equipment function until the needed inert atmosphere is developed.
2. Interlock to shut down the printing operations if the inert atmosphere is lost.

C. Provide a safety factor on the limiting oxygen concentration (LOC) design based on the following:

1. Where the LOC is greater than or equal to 5%, set the oxygen design to 2% by volume below the worst credible LOC.
2. Where the LOC is less than 5%, set the oxygen design to 60% of the LOC.

Do not exposed the collected metal dust to air. Maintain the inert atmosphere around the collection medium until the metal dust can be passivated, using an acceptable liquid medium.

2.5.3.5 Process the completed product (harvesting) in a manner that minimizes or controls the release of the entrained powders as follows:

A. Ensure operators are properly grounded prior to opening the print enclosure.

B. Conduct cleaning of excess dust from the product in a suitably ventilated hood or enclosure with a properly designed dust collection system.

2.5.3.6 Use portable vacuums for cleanup of excess powder that are:

A. Certified by a reliable third-party agency (e.g., a recognized testing laboratory)

B. Are rated, at a minimum, for use in a Class II, Division 2 or Zone 22 area

C. Should be rated for Class II, Division 1 or Zone 20 if used within enclosures containing collected combustible dust.

2.5.4 Rotary Air Lock Devices

2.5.4.1 Install rotary air lock devices (Figure 2.5.4.1-1) as follows:

A. Ensure the angle between adjacent vanes and the shape of the housing allows two vanes per side to be engaged (near the housing wall) at all times.

B. Ensure the vanes (including the tips) are made of metal and have a thickness of at least 1/8 in. (3 mm).

C. Ensure the gap between the tips of the vanes and the housing is between 0.008 in. (0.20 mm) and 0.01 in. (0.25 mm). For aluminum dust, this gap is less than or equal to 0.004 in. (0.10 mm).

D. Interlock the rotary air lock to automatically stop in the event of an explosion, to prevent the passing of burning matter. An interlock is not required if burning matter would not cause a second fire or explosion of any significance.

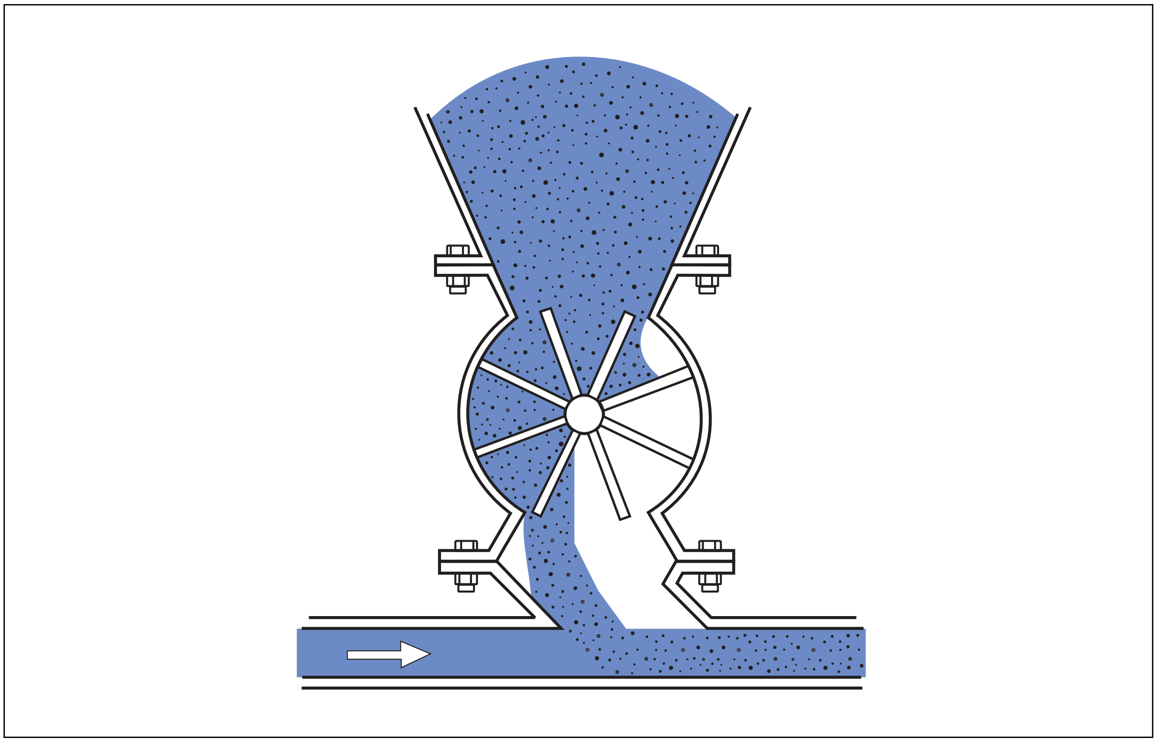


Fig. 2.5.4.1-1. Rotary air lock

2.6 Operations and Maintenance

2.6.1 Develop and implement a program to identify and eliminate fugitive dust sources on a regular and on-going basis. The program should include the frequency of inspections, identify emission points and track any needed repairs or modifications until completion.

2.6.2 Develop and implement an inspection, testing and maintenance (ITM) program for all forms of explosion protection devices. Assign accountability, and keep accurate records of all inspection, testing and maintenance activities.

2.6.2.1 Inspect explosion protection devices per Table 2.6.2.1-1.

Table 2.6.2.1-1. Explosion Protection Device Inspection Frequencies

	*Inspection Frequency*Note 1			
Explosion Protection Devicel	Monthly	Quarterly	Annually	Notes
Explosion vents			x	
Spark detection systems	x			Complete functional testing per manufacturer's guidelines
Spark extinguishing systems	x			Complete functional testing per manufacturer's guidelines
Explosion isolation devices	x			Complete functional testing per manufacturer's guidelines
Metal detection and extraction equipment (ferrous and non-ferrous)		x		
Explosion Suppression Systems	Inspection, testing and maintenance should be per the guidance in Data Sheet 7-17.			
Belts and rotating devices – alignment		x		

Note 1. The inspection frequencies provided are the minimum intervals recommended. Depending on the process being protected, more frequent inspections may be needed to ensure the system will perform properly.

2.6.2.2 When conducting inspections of explosion vents, ensure the condition or mobility of the vents is not impaired. Possible impairments include the following:

A. Corrosion

B. Improper painting of movable parts or rupture membranes

C. Icing

D. Snow accumulation on or in front of vents

E. Obstruction by pipes, wires or other utilities

F. Permanent or temporary equipment located next to the venting device

2.6.3 Remove accumulated dust on rotating equipment bearings and components at least quarterly.

2.6.4 Lubricate bearings and rotating equipment (fans, blowers, size-reduction equipment) in accordance with manufacturer's guidelines. At a minimum, this lubrication should be completed quarterly.

2.6.5 Where suppressant spray systems are present (e.g., oil/water spray systems for bulk grain handling), develop a maintenance and inspection program to ensure the dust suppressant spray system is functioning properly whenever grain is being handled.

2.6.6 Maintain and inspect all interlocks in accordance with the guidance in FM Property Loss Prevention Data Sheet 7-45, *Safety Controls, Alarms and Interlocks (SCAI)*.

2.6.7 Maintain electrically rated equipment classified for use in combustible dust areas per the guidance in FM Property Loss Prevention Data Sheet 5-1, *Electrical Equipment in Hazardous (Classified) Locations*.

2.7 Training

2.7.1 Create a training program for all employees (including operators, emergency response team management, contractors and security personnel) who work in or have access to areas containing or processing combustible dusts. Design and supervise the training program to address the complexity of process operations and the hazard level present at a given facility. At a minimum, include the following in the program:

A. The hazards of the materials in use

B. Common ignition sources for combustible dusts

C. The proper operation and shutdown of the equipment under normal and emergency conditions. Post critical procedures as needed.

D. Proper material handling procedures (i.e., grounding and bonding, electrical ratings, manual handling, etc.)

E. Combustible dust duct system operations and shutdown, including all local and remote shutdowns of the transport media

F. Proper combustible dust transfer procedures

G. Explosion protection equipment related to combustible dusts within the facility and their locations. Items to be addressed include (as appropriate):

- Explosion vents
- Flameless venting devices
- Back-blast dampers
- Abort gates
- Valves (e.g., guillotine and float valves)
- Suppression systems
- Explosion containment
- Inerting systems

- High vacuum systems

H. Methods of combustible dust control, including spark suppression and extinguishing systems, oil/water sprays, and their locations.

I. Acceptable methods, equipment and procedures for dust clean-up and housekeeping. Include trigger points (e.g., 1/16 in. (1.6 mm) accumulation of fugitive dusts) for when cleaning should occur.

J. The location of any fire protection systems for combustible dust fires

K. The location of separator systems (ferrous and non-ferrous)

L. The location, correct type and proper use of fire extinguishers for the hazard present.

2.7.2 Provide training for all new employees, as well as refresher programs for current employees, as needed.

2.8 Human Factor

2.8.1 Develop and implement a process safety program in accordance with FM Property Loss Prevention Data Sheet 7-43, *Process Safety*, that is commensurate with the hazards of combustible dusts.

2.8.1.1 Include the following elements (at a minimum) in a process safety program for combustible dust:

A. Process knowledge on all processes involving combustible dusts. This includes the properties as stated in Section 2.1.2.1.1.

B. A documented process hazards analysis (PHA) for all dust processes

C. A process to manage changes to the process, equipment, formulation, etc. (MOC)

D. A program to manage the integrity of the assets in which combustible dusts are located, transferred, stored, produced and handled

E. A system to investigate incidents involving combustible dusts

2.8.1.2 Where an explosion protection document or similar is required, it should be incorporated into the program used to manage process safety.

2.8.2 Implement a formal dust control program within facilities and areas where combustible dust hazards are present. Review this program annually at a minimum.

2.8.3 Implement a snow/ice cleaning program for all explosion vents where snow/ice can occur. An alternative is heat-tracing per the guidance in this data sheet.

2.9 Contingency Planning

2.9.1 Equipment Contingency Planning

2.9.1.1 When a dust collection system breakdown would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop and maintain a documented, viable dust collection equipment contingency plan per the guidance in FM Property Loss Prevention Data Sheet 9-0, *Asset Integrity*. An explosion that is successfully vented/controlled is considered an unplanned outage.

This guidance includes the process for developing and maintaining a viable equipment contingency plan along with guidance on sparing, rental and redundant equipment mitigation strategies.

2.9.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by a dust collection system breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing.

Routine dust collection equipment spares are spares that are considered to be consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the dust collection systems but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer.

2.9.2.1 For general sparing guidance, see Data Sheet 9-0.

2.10 Ignition Source Control

2.10.1 General

2.10.1.1 Develop and use a hot work program to manage all hot work operations. (See FM Property Loss Prevention Data Sheet 10-3, *Hot Work Management*).

2.10.1.2 Prohibit smoking and open flames.

2.10.1.3 Do not use space heaters that have any exposed surfaces where the temperature is above 340°F (171°C).

2.10.1.4 Provide magnetic separators at the following locations:

A. Upstream of all size-reduction equipment (e.g., grinders, pulverizers, milling or grinding equipment, or other equipment involving mechanical impact with the process material)

B. At car and truck dump hoppers and associated conveyors prior to entering the plant/process

C. At other incoming transition points where materials first enter a plant/process from areas outside of the plant/process

2.10.1.5 Provide separators other than magnetic (e.g., air separators, grates, coarse screens) if nonferrous metal or other objects (e.g., rocks) could enter the product stream and cause an ignition hazard.

2.10.1.6 Within buildings where loading/unloading of railcars or trucks takes place, do not operate railroad locomotives or other vehicles that could ignite a dust cloud while the dust cloud is present.

2.10.1.7 Vehicles such as lift trucks or front-end loaders operating in any facility where combustible dusts are present should be rated per the guidance in FM Property Loss Prevention Data Sheet 7-39, *Material Handling Vehicles*.

2.10.2 Hazardous Area Rated Electrical Equipment

2.10.2.1 In areas/equipment where combustible dust is normally present or may be present upon a process upset, install electrical equipment listed for Class II or III, Division 1 or 2, or Zone 20, 21 or 22 as recommended in an applicable electric code or Data Sheet 5-1.

2.10.3 Static Electricity

2.10.3.1 Provide grounding and bonding for metal components per FM Property Loss Prevention Data Sheet 5-8, *Static Electricity*. Ensure the resistance of the ground connection is less than 1 x 106 ohms.

2.10.3.2 Provide a reliable grounding connection for bag cages (metal wire supports) in bag-type collectors.

2.10.3.3 Provide reliable grounding connections similar to 2.10.3.2 for metal cages in paper-canister units. The use of special “conductive” bag material to dissipate static electric charges is not necessary.

2.10.3.4. Where conveyor or other belts are used in material transport, use belts that are electrically conductive or equipped with static eliminators in accordance with Data Sheet 5-8.

2.10.3.5 When using metal piping and/or ductwork to transfer combustible dusts or powders, they should be properly grounded and bonded.

2.10.3.6 Where plastic piping or ductwork is used for material transfer, provide grounding and bonding for any conductive or metal components used within such piping systems. (e.g., connections to metal piping, metal flanges, etc.)

2.10.3.7 Ground and bond all equipment processing fine combustible powders to prevent static ignition. Consider grounding and bonding for personnel if a static ignition potential exists during manual handling of the powders and/or components.

2.10.3.8 Where piping systems are used to transfer powder, control static accumulation using grounding and bonding to a ground connection with a maximum resistance of 1 megohm.

2.10.3.9 Check annually for continuity of the metal components and security of any bonding connections.

2.10.3.10 Use one or more of the following options to control static, if the material has a minimum ignition energy less than 10 mJ:

A. Operate any equipment that presents an explosion hazard under an inert environment.

B. Operate at a pressure of less than 0.1 bara (1.5 psia).

C. Eliminate the ignitable mixture by operating at no more than 50% of the MEC.

D. Reduce charge generation or accumulation with process changes, such as reducing the flow rate of the transferred material.

E. Provide static eliminators or neutralizers. Ensure they are firmly fixed, well grounded, properly adjusted and kept clean of foreign accumulations.

2.10.4 Processes with High Frequency of Dust Explosions

2.10.4.1 Where a process or system has a high frequency of dust explosions, implement the following:

A. Operate the equipment that is the source of sparks or hot/glowing particles in an inert atmosphere, OR

B. Install a spark-detection system combined with either a spark-extinguishing system or a high-speed abort gate per Section 2.10.4.2.

A process with a high frequency of dust explosions is defined in Section 3.7.

2.10.4.2 When needed, install a high-speed infrared detection system arranged to do the following:

A. Actuate either a spark extinguishing system **AND/OR** a high-speed abort gate in the duct between the process and the collector.

B. Locate the spark-extinguishing system or high-speed abort gate upstream of the first piece of equipment having an equipment explosion hazard.

C. Stop material from being transferred out of the collector (e.g., rotary valves), unless the material can be diverted to a safe location.

Installation of spark control as indicated above does not eliminate the need for explosion hazard mitigation features.

2.10.5 Fans and Blowers

2.10.5.1 Install fans and blowers in negative pressure systems on the discharge side (i.e., clean side) of the dust collector.

2.10.5.1.1 In positive pressure systems, locate the blower upstream of the dust injection point.

2.10.5.2 Where, for design reasons, the fan must be located in the dirty air stream, and the dust/air stream concentration is higher than the 25% of the MEC, install fans and blowers of Type A or B spark-resistant construction per AMCA 99-0401-86, *Classifications for Spark Resistant Construction*.

2.10.5.3 Ordinary fans and blowers can be used in a dust-air stream as follows:

A. In a dust stream of unlimited concentration if the dust has been shown by test to be hard to ignite

B. Upstream of bag and canister collectors in systems handling wood dust if a primary cyclone collector is installed upstream of the fan

C. Where a high-speed abort gate or FM Approved spark-extinguishing system is provided between the fan and any important or valuable downstream equipment

2.10.6. Materials Subject to Spontaneous Heating

2.10.6.1 Prevent accumulations of material(s) subject to spontaneous heating within ductwork by maintaining sufficient transport velocity and by performing frequent cleaning of the ducts.

2.10.6.2 Under normal operation, do not allow moisture to contact these types of material(s). Automatic sprinklers or spark-extinguishing systems are still required where recommended.

2.10.6.3 Clean collectors handling residues subject to spontaneous heating daily or as needed to prevent heating and hazardous accumulations.

2.10.6.4 Do not store excessively wet materials subject to spontaneous heating within bins, silos or other storage vessels for long periods.

2.10.6.5 Where storage of materials subject to spontaneous heating is required, use any/all of the following:

A. Install heat detectors in silos and bins used for long-term storage.

B. Maintain air flow within the vessels to remove heat generated.

C. Turn over the materials storage at frequent intervals to prevent heat generation.

D. Do not store excessively wet materials in silos or bins.

E. Use a first-in/first-out process for stored materials.

2.10.7 Mechanical Drives and Rotating Equipment

2.10.7.1 Avoid using mechanical drives with high rpm or power, as they can cause dust ignition due to heat generated by friction or sparks.

2.10.7.2 Determine the potential for hazardous conditions based on the tangential velocity (v) of the rotating components per Table 2.10.7.2-1.

Table 2.10.7.2-1. Tangential Velocity and Danger for Ignition

Tangential Velocity (v)	*Danger for Ignition*
v < m/s (3.3 ft/s)	There is no danger for ignition.
1 < v < 10 m/s, (3.3 < v < 33 ft/s)	Judge each case separately. Consider the product and material specific characteristics, including MIE and particle size[Note 1]
v > 10 m/s (33 ft/s)	An ignition potential exists

Note 1. Lower values of MIE and particle size indicate materials more susceptible to ignition.

To convert rpm to tangential velocity, use

$$v = \text{rpm} * 2\pi r * \frac{1}{60}$$

Where:

v = length (same units as r) per second
r = length of the rotating part from shaft center to outer tip

2.10.7.3 Where low-velocity, high-power equipment is used, protect against uncontrolled heating using one or more of the following:

A. Shear pins

B. Overload detection and alarm

C. Proper maintenance and cleaning

D. Screens and Separators

Excessive heating in such equipment can be due to excessive residence times of material, accumulations at bearings and foreign objects.

2.10.8 Bucket Elevators and Conveyors

2.10.8.1 Provide belt driven elevators, bucket elevators and conveyors with a mechanical or electromechanical interlock device to shut down the drive motor and sound an alarm if the belt slows downs more than 20%.

2.10.8.2 Provide belt-alignment interlocks to shut down the bucket elevator or conveyor if the belt misaligns.

2.10.8.3 When interlocking conveyors, consider shutting down the equipment preceding the conveyor in addition to the conveyor drive motor.

2.10.8.4 Do not locate or expose bearings within the bucket elevator casing. Locate bearings outside of machinery enclosures, where overheated bearings will be less exposed to dust clouds and more accessible for inspection and service.

2.10.8.5 Use antifriction bearings on all elevator legs.

2.10.8.6 Maintain all bearings per manufacturer's recommendations and keep them free of dust, product and excessive lubrication.

2.10.8.6.1 Within grain occupancies, bearings for conveyor bucket elevator terminal pulleys should be press- or shrink-fitted with tapered adapter sleeves.

2.10.8.6.2 Within grain occupancies, do not use slip-fit bearings secured with set screws.

2.10.8.7 Do not apply oil or other liquid suppressants in bucket elevators, as this could lead to slipping of the rubber belts and potential friction heating.

2.10.8.8 Limit the use of combustible linings (e.g., plastic, rubber, wood) to impact points, wear surfaces and connected hoppers.

2.10.8.9 Install drive belts (e.g., v-belts, timing belts and flat belts) that are electrically conductive at 1 megaohm or less, as well as being fire and oil resistant.

2.10.8.10 Design the drive train with a 1.5 service factor to stall the drive without slipping.

2.10.8.11 Install belts in elevator legs that have a surface resistivity of less than 100 megaohm per square foot (3 x 108 Ohms per square foot) and are fire and oil resistant. (Oil resistance is not needed in flour mills.)

2.10.8.12 For elevator legs whose belt speeds exceed 500 ft/min (2.6 m/sec) provide bearing-temperature monitoring or vibration detection.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Fundamentals of a Dust Explosion

A combustible dust explosion requires five elements to occur. The first three elements (as listed below) in this "Dust Explosion Pentagon" are the same as in the "Fire Triangle", and the first four elements are the same as in the "Flash-Fire Square". These elements are:

1. Fuel
2. Ignition source
3. Oxygen
4. Suspension
5. Confinement

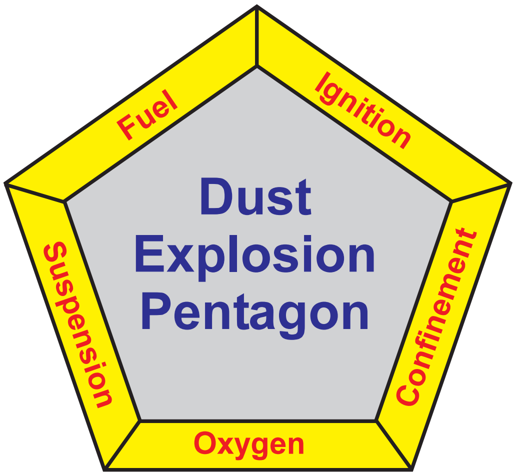


Fig. 3.1-1. Dust explosion pentagon

The following is a brief explanation of each element as it pertains to dust explosions.

3.1.1 Fuel

Fuel must be in dust form. To characterize a dust sample, the “mass median particle size” is typically used to quantify the range of particle sizes that exist. If a fraction of finer material within the sample could become segregated, then the system consists of two distinct particle streams each with its own median particle size. Any stream with a median particle size smaller than 500 microns should be considered explosible until proven otherwise by testing, although a particle size as low as 420 microns has been used in the past as the upper limit of explosibility. Note that a sample with a median particle size above 500 microns could still present an explosion hazard if it is suspended in a dust cloud.

3.1.2 Ignition Source

Dust suspended in a cloud can be ignited by much less energy that the same material in solid form or in a solid pile or layer of dust. Typical ignition energies are less than 30 mJ and are determined via testing.

3.1.3 Oxidizer

In a dust cloud, the oxidizer (usually air) is intimately mixed with the fuel. This condition allows for rapid combustion of a large amount of material and the rapid release of a large amount of energy.

3.1.4 Suspension

Combustible dust needs to be suspended in air before an explosion can occur, because the rate of combustion of a material is proportional to the exposed surface area. In a pile or layer, the exposed surface area is limited. In a cloud, the exposed surface area is significantly greater. This phenomenon of faster combustion with greater surface area availability partly explains why energy is so rapidly released in a dust explosion.

3.1.5 Confinement

A small cloud of dust ignited in a large open area is not truly a dust explosion. This situation may be referred to as a flash fire, fireball or deflagration. If the combustion gases are totally or partially contained in a closed volume, and the volume expansion produced by combustion does not immediately dissipate to an unconfined environment; the pressure produced can lead to an explosion. Even if the vessel is vented, combustion of a dust cloud within the vessel is still considered an explosion.

3.1.6 Properties that Affect Dust Explosibility

The properties most significantly affecting dust explosibility are:

A. Material chemistry (i.e., the dust’s composition)

B. Particle size distribution

C. Moisture content

The dust properties relate only to the material. These properties alone cannot be used for a complete evaluation of the hazards of specific process or conditions. For a complete determination of the explosion, knowledge of the processes and conditions where these materials are present is also required.

Because dust explosibility characteristics are dependent on dust properties (particle size, moisture content and dust chemistry - composition), confirming past data is truly representative of the current materials and conditions is important. Per the guidance in this data sheet, whenever a change in a process or material formulation occurs, retesting of the dust should be completed to verify the effectiveness of any explosion protection. For hard-to-ignite (HTI) dusts where explosion mitigation has not been provided, retesting should occur at least every five (5) years, in accordance with the guidance in this data sheet.

3.1.6.1 Material Chemistry (Dust Composition)

The chemistry of a dust is important. Adequate process knowledge should be present in a facility where a dust is used or generated. Where dust mixtures are produced within the facility, the personnel should possess or be able to access knowledge of all the raw materials that form this mixture and the final mixture itself. (e.g., mixed dusts within a collector or a mixture as part of a process). Such composition information should also be available in a safety data sheet for the material and/or the individual components. Knowing the composition of a material (or mixture) helps to determine any potential fire and/or explosion hazard.

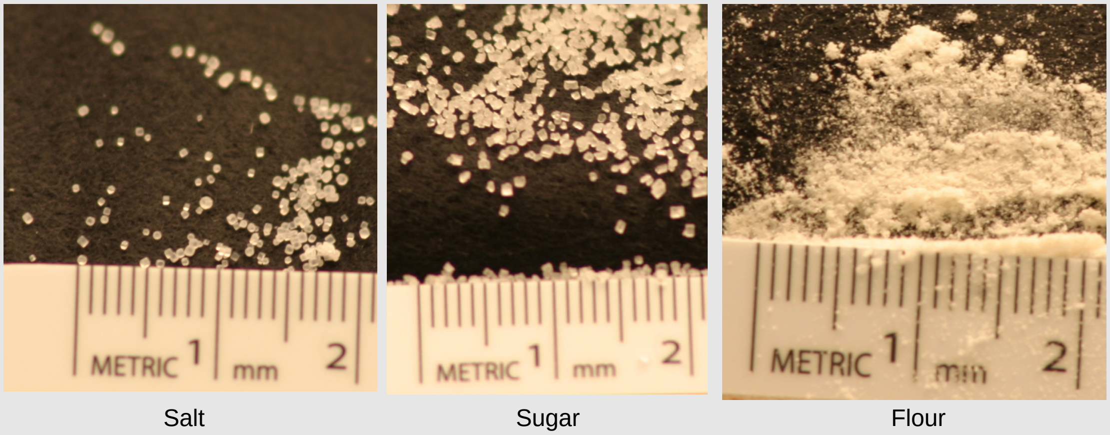
3.1.6.2 Particle Size

Unless an analytical lab is available on site, particle size distribution data will seldom be available at a plant where dust is found. To roughly estimate the median particle size, see Table 3.1.6.2-1 for the following comparisons.

Table 3.1.6.2-1. Particle Size Comparison

Material	*Percentage Smaller than 75 µm*	*Median Particle Size µm*
Granular sugar	0	400
Wheat flour	60	60
Confectioner’s sugar (icing sugar)	92	<45

The three photos below (Figure 3.1.6.2-1) show table salt, granular (table) sugar, and wheat flour, highly magnified. The salt is mostly in the 250-to-500-micron range, and the median is 375 microns. The sugar is also mostly in the 250-to-500-micron range, and the median is 400 microns. Finally, the flour is almost entirely under 125 microns with a median particle size of about 60 microns.



Salt
Sugar
Flour

Fig. 3.1.6.2-1. Particle Size

Particle sizes, if unavailable, can be determined through a sieve analysis of a material.

The median particle size and the percent of material smaller than 75 microns are both very important. The median particle size is the best single representation of the entire sample. The percentage of material smaller than 75 microns is important, since the finer materials in a sample typically have the most significant effect on the explosibility of the sample as a whole.

3.1.6.3 Moisture Content

Moisture content usually has little effect on dust explosibility until it reaches the 10% to 15% range. If moisture content cannot be determined in the field, the sample can be sent for analysis. Dusts with a moisture content greater than 30% are typically considered “wet”.

3.1.7 Fibers, Flyings and Fines

Dusts are traditionally defined as small, finely divided materials that have a particle size less than 500 microns (i.e., can pass through a standard US #35 sieve). Fibers and flyings have a length significantly larger than their diameter and, therefore, may not pass through the #35 sieve. Despite having a dimension greater than 500 microns, if present in suspension in enough quantity, they still present an explosion and/or fire hazard.

3.1.8 DustCalc

DustCalc is FM's proprietary software for verification of explosion vent area and prediction of explosion effects based on the specifics of a given situation. This data sheet does not include any explosion vent sizing equations, nor does it have any dust-testing results to characterize previously tested materials.

DustCalc software is available in all FM offices worldwide but is limited to FM personnel who have been trained in the details of its basis and use. Clients are encouraged to work with those FM personnel trained in DustCalc.

The variables that have an impact on explosion effects are as follows:

- Vessel/room volume (V)
- Dust explosibility constant (K_{st}) and maximum unvented pressure (P_{max})
- Explosion-vent area (A_v)
- Explosion-vent relief pressure (P_{stat})
- Explosion-vent panel mass and orientation
- Explosion-vent duct length (L_d) and area (A_d), if present
- Fraction of vessel volume containing an explosible mixture
- Pre-explosion equipment pressure (P_o)

3.2 Occupancy

3.2.1 Housekeeping

Combustible dust accumulations outside of equipment—known as fugitive dust—present the potential for an explosion. As stated in Section 2.0 of this data sheet, eliminating the source of the fugitive dust release should be the priority, with the subsequent removal of any fugitive dust accumulations where these situations exist. Damage Limiting Construction (DLC) and space separation are options for areas that are subject to uncontrolled releases that cannot be resolved.

As a rule of thumb, in areas that are subject to uncontrolled releases that cannot be resolved (see Section 2.3.1), 1/16 in. (1.6 mm) of dust is a cause for cleanup. This amount is about the thickness of a US quarter (25¢ coin) and assumes wood dust with an approximate bulk density of about 36 lb/ft^3 [580 kg/m^3].

Where dusts of different bulk density are used, the thickness of the equivalent mass of 1/16 in. (1.6 mm) wood dust would be inversely proportional to their bulk densities. For example, for a dust with a bulk density of about 60 lb/ft^3 (950 kg/m^3), a layer of about 1/25 in. (1 mm) thick would be equivalent.

Equivalent thickness = 1.6 mm x (580 kg/m^3 / 950 kg/m^3) = 0.97mm (rounded up approximately 1 mm in thickness.).

For reference, typical bulk density data is given in Table 3.2.1-1.

Table 3.2.1-1. Typical Dust Bulk Density

Material	*lb/ft^3*	*kg/m^3*
Coal, bituminous, smaller than 420 microns	50	800
Flour, wheat	35-40	560-640
Starch	25-50	400-800
Sulphur, powdered	50-60	800-960
Wood flour	16-36	260-580
Source: Perry's Chemical Engineers' Handbook, Eighth Edition (Chemical Engineers Handbook), 2007		

3.3 Protection

3.3.1 Detection

High-speed, infrared detectors are most suitable for detection of burning or smoldering dust particles in a duct transporting dusts at high velocities. Abort gates or extinguishing systems actuated by these detectors can prevent an ignition source from reaching a bag collector or quickly control and extinguish a fire in a collector before the bags are damaged (see FM Property Loss Prevention Data Sheet 5-48, *Automatic Fire Detection*).

Sensors to activate these systems are usually located in the duct as close to the process as possible, unless a fan is located in the duct between the process and the dust collector. Where this situation occurs, sensors should be located between the fan and the dust collector. In manifolded ducts, the sensors are located on the main exhaust duct close to the point of the last duct connection.

3.3.2 Fire Extinguishing systems

Steam, clean agent and carbon dioxide extinguishing systems can be used to supplement sprinkler systems as protection for dust collectors. They are usually designed as total-flooding protection for the dust collector.

Where steam is used, the filter media may require drying. This can be done by drawing ambient air through the collector.

Carbon dioxide and clean agents generally require isolation of the collector from the rest of the process to allow the extinguishment system to maintain effective agent concentrations. Leak points (if present) within the collector may also impact the effectiveness of the suppressant. Dry chemical is not recommended as a fire suppression agent because of its probable lack of effectiveness on vertical surfaces (such as the bags in the upper part of the collector) and the potential for contamination.

An FM Approved, high-speed infrared detector and spark extinguishing system is designed to extinguish potential ignition sources in the duct and prevent propagation into the collector.

Within electrostatic precipitators, the most common forms of protection are automatic sprinkler or water spray. Carbon dioxide and steam suppression are also seen as considered supplementary protection to sprinkler/water-spray systems. Fixed temperature detection is the usual form of system actuation, either in the ductwork or the precipitator.

3.3.3 Wet Collectors

Plastic construction materials are used in wet collectors (including those in the fill/packing material and linings) because of their corrosion resistance. These materials constitute the major fire hazard in wet collectors.

Some dry materials, particularly metal dusts, may ignite spontaneously if allowed to accumulate in the base of the collector (see Data Sheet 7-85).

3.3.4 Clean Versus Dirty Side of Dust Collectors

The distinction between the clean and dirty air sides is not important when considering explosion scenarios. The pressures generated in an explosion frequently rupture the filter media, as the explosion propagates throughout the clean and dirty sides. In addition, the filter media may breach even before an explosion (e.g., a bag break), thus allowing dust to enter the clean side.

The issue of where to locate vents relative to the clean and dirty side is both theoretical and practical. Most testing is based on an enclosure with no internal obstructions that has the vent remote from the ignition. Bags or other obstructions can change the explosion and venting process. Bags generally fail early in the explosion and have a minor effect on the venting process, but the tube sheet dividing the clean and dirty sides can be more of an impediment. The equation (Section 2.4.3.2.3) specifying the minimum amount of explosion venting required on the dirty side is based on providing fully adequate explosion venting for a dirty-side explosion. It assumes the bags do not get damaged and do not allow any gases to vent out through the clean side of the collector.

3.3.5 Cyclone Explosion Venting

Calculations for explosion venting a cyclone (based on typical design proportions) show that the typical gas outlet provides an adequate explosion venting area for dusts with K_{st} values up to 80, based on the following assumptions:

1. The pressure resistance is approximately 0.3 barg (4.4 psig).
2. The gas outlet has a diameter that is one-half the diameter of the cyclone.

Dusts with K_{st} values as low as 80 are typically rather coarse (e.g., sawdust, corn meal), have a very low content of volatile materials (e.g., charcoal), or have very low combustion energy (e.g., iron dust, fiber-reinforced plastic (FRP) with high inert fiber content).

The adequacy of explosion venting cannot be assumed if the cyclone has a duct with L/D greater than 1 extending above the gas outlet. As with any vessel provided with a duct on the explosion vent, explosion pressure calculations will be needed to quantify the effect.

Due to significant backpressure effects produced by bends in vent ducts, any gas outlet provided with a 180° duct (gooseneck) will not likely have adequate explosion venting. If practical, replace the gooseneck with a rainhat over an open gas outlet.

Typical cyclone proportions include a diameter D, cylinder height and cone height - each 2D, and gas outlet diameter of 1/2D.

3.3.6 Inerting (Phlegmatization)

This approach is almost never used; but if used correctly, it could eliminate the explosion hazard.

Combustible and non-combustible dusts must be well mixed to truly create a safe non-explosible product. Typically, non-combustible (inert) dust ranging from 50% to 75% of the total, by weight, is required.

Commonly used non-combustible materials include carbonates, phosphates, salts and rock dust. Determining the required limiting inert powder concentration can be difficult. The final mixture should be tested to determine its inertness and lack of combustibility.

Care must be taken when using phlegmatized dusts to ensure the non-combustible component remains in suspension with the combustible material. Separation of the combustible and non-combustible materials is possible if the material settles (e.g., in bins and silos), or potentially in areas of ductwork where the direction changes.

3.4 Equipment and Processes

3.4.1 Dust Collection Equipment

Wet and dry dust collectors are usually part of a system consisting of hoods, ducts and exhaust fans. Such a system may be used to minimize dust concentrations at processes within the plant, or it may be part of a system to condition air exhausted to the atmosphere to meet air pollution requirements or codes. The collector system may be a part of a process where the material collected is a product or a valuable by-product.

Vacuum cleaning equipment is essentially Air Material Separation (AMS) units (i.e., dust collectors). They can be portable units such as vacuum cleaners, or form part of a central vacuum system used within a plant for the cleaning of building and equipment surfaces. In some central systems, small dust collectors may be present collecting dust within an area of the building. They should be included in any evaluation for dust explosion or fire hazards within the facility.

Bag collectors separate dust from a gas stream by passing the gas stream through a felted or woven-fabric filter medium. The filter media is present as a bag or envelope and is contained within a rectangular or cylindrical steel enclosures that forms the body of the collector.

Canister type filters are an alternative filter medium used in dust collectors. They use a filter media contained within a cartridge (such as a steel cage) through which the air passes. They differ from the traditional bags in several ways:

- The filter media is pleated, increasing the surface area for dust capture when compared to a filter bag of similar size. The filter media can be paper, cellulose, polyester or other materials.

- Maintenance of canisters is easier, and filter changes are faster than with bags.
- Canister filters offer high efficiency and low pressure drop. This makes them best suited for dry dusts and applications handling high quantities of particles less than one micron in size.
- Canister filters have a shorter service life than filter bags and deteriorate faster.
- Canisters are not suited to high temperatures, but some specialized filter media for high temperature applications exist. Filter bags operate well in collectors where elevated temperatures (heat), moisture, heavy dust loading and/or fibrous dusts are seen.

Dust is collected on the filter media (bags or canister media) in a layer. This layer of dust is then removed (cleaned) from the media, collected and removed from the collector itself. Filter cleaning methods can include:

1. Shaker cleaning – This is generally seen in filter bag units rather than canisters. A vibratory action shakes the dust off the bags.
2. Reverse air flow – Incoming air is stopped to allow the cleaning process to occur. Cleaning is accomplished via high pressure air flowing in the reverse direction across the media. If the incoming air cannot be stopped, two compartments within the collector with diverter valves are required.
3. Pulse jet cleaning involves using compressed air that blows the dust off the filter media surface. Incoming air need not be interrupted. This cleaning method is the most common for canister units and is the most aggressive cleaning method. Air pulses are in the range of 0.1-0.15 seconds with a frequency between pulses in the range of 1-30 seconds.

Pulse-jet or reverse-jet collectors can process air with higher dust/air concentrations than can shaker-type units. They are often used when small air volumes are processed or as part of a continuous process.

Bag filter units and canister filter units present the same fire hazard. As such, they should be fitted with automatic sprinkler protection per the guidance in this data sheet.

Use of dust collectors is generally the most economical way to meet local air pollution codes. Air from collectors may be recirculated to the plant as an energy conservation measure.

In dust-collection equipment, detection and/or monitoring systems commonly known as bag-break monitors may be present. Such devices provide advance warning of a filter media failure by monitoring the level of combustible particulates within the equipment. This warning assist with maintenance activities and reduce atmospheric emissions of dust from this equipment.

3.4.1.1 Enclosureless Dust Collectors

Enclosureless collectors discharge the dirty air inside fabric bags where the fugitive dust is collected and the ′clean' air escapes through the fabric bags into the surroundings. This not only increases the possibility of fugitive dust accumulations in the surroundings but limits these systems to irregular or occasional use systems. (See Figure 3.4.1.1-1.)

Enclosureless dust collectors are not meant for use with most dusts collected from process equipment or other aerated dust sources. Fine dust will rapidly blind the filter, reducing the filter performance, and could result in the release of fugitive dust to the surroundings.

Because only the bag normally prevents the release of combustible dust, anything within 10 ft (3 m) could be considered a Class II, Division 2 (Zone 22) area, requiring rated electrical equipment. A better solution is to limit ordinary electrical equipment within the restricted area.

The inside of the bag could be considered a potential dust explosion hazard. However, the bags would fail readily should the contained cloud be ignited; and the result would generally be a flash fire with a limited fireball. No explosion venting is warranted or practical. Similarly, the open construction would allow ceiling sprinklers, where present, to control a fire that could develop.

3.4.1.2 Horizontal Air (Drum) Filters

Horizontal air (drum) filters (see Figure 3.4.1.2-1) are designed to filter particulates from the airstream and return the filtered air to the atmosphere. Particulates are collected on the filter media and removed via suction nozzles. Either the nozzles rotate, and the drum remains stationary; or the nozzles are stationary, and the drum rotates.

Fig. 3.4.1.1-1. Example of an enclosureless collector

Fig. 3.4.1.2-1. Example of an enclosureless drum filter

These filters can be enclosed, or they can be enclosureless. If enclosed, they have the same hazards as a regular dust collector and should be protected as such.

Enclosureless air (drum) filters cannot be fitted with venting due to their construction. The hazard with these units is the same as for enclosureless collectors, and they should be treated and protected as such.

Interlocking these units to shut down in the event of an interruption to the power and/or loss of suction is something that should be considered also.

These devices should not be confused with rotary drum filters seen in some occupancies to remove dust or with rotary drum vacuum filters seen in wet milling operations.

3.4.2 Filter Media

The filter medium used depends on its compatibility with the material collected and on the temperature of the inlet gas stream. The maximum operating temperatures of commonly used filter media are indicated in Table 3.4.2-1. Except for acrylics, temperatures apply both to woven and felted fabric. Filter media can survive temperatures approximately 10% in excess of their maximum operating temperatures for short periods of time. Woven filter media depends on a layer of collected material, which itself acts as a filter. Felted materials depend largely on the change of gas direction as it passes through the maze of fibers.

Tests carried out on filter media in the FM Laboratories indicate the following:

A. Fabrics commonly used as filter media in bag, canister and cartridge collectors (i.e., paper, polyesters, cellulose, polypropylenes and cotton) are combustible.

B. Combustible filter media coated with noncombustible dust can be ignited, and flame spread across the surface will be as rapid as for that of a clean bag of the same material. The weave of the fabric extends above the layer of noncombustible dust, so the fabric acts as if it were “clean.”

C. Some filter media are of low combustibility (i.e., flame retardant or fire resistive). If used in a bag collector processing noncombustible dusts, they should be resistant to the “normal” sources of ignition entering the collector. Media that have been tested and found to be of low combustibility are as follows:

1. Fiberglass fabrics finished with any of the following combinations of materials:
    a. A silicone and graphite finish
    b. A fluorocarbon finish
    c. A combination of the above
2. Teflon, a DuPont registered trademark for fluorocarbon resin

Table 3.4.2-1. Operating Temperature Limits for Commonly Used Filter Media as Woven or Felted Fabric.

Filter Medium	*Operating Temperature Limit*	
Cotton	180°F	(82°C)
Wool (seldom used)	190°F	(88°C)
Polypropylene	200°F	(93°C)
Nylon	200°F	(93°C)
Polyester	275°F	(135°C)
Acrylic (Woven)	275°F	(135°C)
Acrylic (Felt)	250°F	(120°C)
Nomex	400°F	(204°C)
Teflon Polytetrafluoroethylene	425°F	(220°C)
Fiberglass	500°F	(260°C)

3.4.3 “Conductive” Dust Collector Bags

“Conductive” bags typically have fine wire woven or fastened into their cloth. The grid of conductive wires is connected to one or more grounding straps/wires, which must be attached to the dust-collector structure. Because no dependable mechanism exists to migrate charges from the surface of the nonconductive bag material to the nearest grounded wire, measurable (and sometimes substantial) potential energy differences can exist between the bag surface and wires.

The need for any kind of special bag to prevent dust ignition from static has never been established.

3.4.4 Cyclone Collectors (Cyclones)

Cyclone collectors (commonly called “cyclones”) separate dust from a gas stream via centrifugal force. They create a spiral flow within themselves imparting the centrifugal force to the dust particles, causing them to move towards the cyclone internal wall. The gas stream carries the particles to the bottom of the collector, and dust separates from the gas stream when the gas turns upward at the base of the collector. The dust can be deposited into a hopper, dust bin or screw conveyor at the base of the collector. (See Figure 3.5.4-1.)

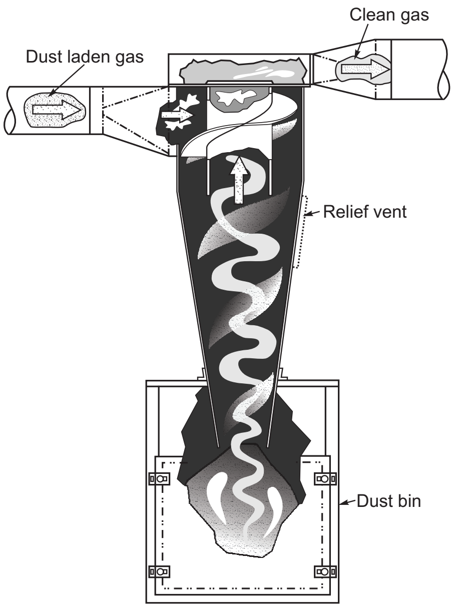


Fig. 3.4.4-1. Particle size

Cyclone collectors are used widely for collection of coarse dusts generated in operations such as woodworking and metal grinding. They may also be used as rough filters to reduce dust loading on bag type dust collectors or electrostatic precipitators.

The cleaned air is exhausted to the atmosphere or to a more efficient collector, such as a dust collector, for further treatment.

High efficiency cyclones consist of a number of small diameter cyclones, usually under 10 in. (250 mm) in diameter, arranged in parallel with a common hopper and common inlet and outlet plenums. Separation forces increase with radial velocity of the particle. Radial velocity in turn increases with decreasing diameter of cyclone tube. High efficiency cyclones may make further air treatment unnecessary.

3.4.5 Electrostatic Precipitators

Electrostatic precipitators collect dusts and hydrocarbon mists from gas streams. They may be used to condition air to meet air pollution codes, or to recover a product or by-product.

They operate by imparting an electrical charge to particles in a gas stream, causing them to adhere to collector plates. Precipitators are not used where explosive concentrations of gases or dusts in air or oxygen are normally present.

The housing, collecting surfaces and electrodes are most commonly of steel construction. However, other material such as fiber-reinforced plastic, wood, aluminum, concrete and ceramic tile have also been used for specialized applications. Large precipitators are usually insulated to prevent condensation and resultant corrosion on internal surfaces.

Wet or dry collection may be used, depending on the material collected, with most electrostatic precipitators using dry collection.

Wet precipitators are sometimes used for oil-coated dusts that would stick to collection surfaces, or for fine submicron-sized particles or corrosive materials.

Precipitators may be single-stage or double-stage units. In a single stage precipitator (Figure 3.4.5-1), charging electrodes and collecting surfaces are located in the same area.

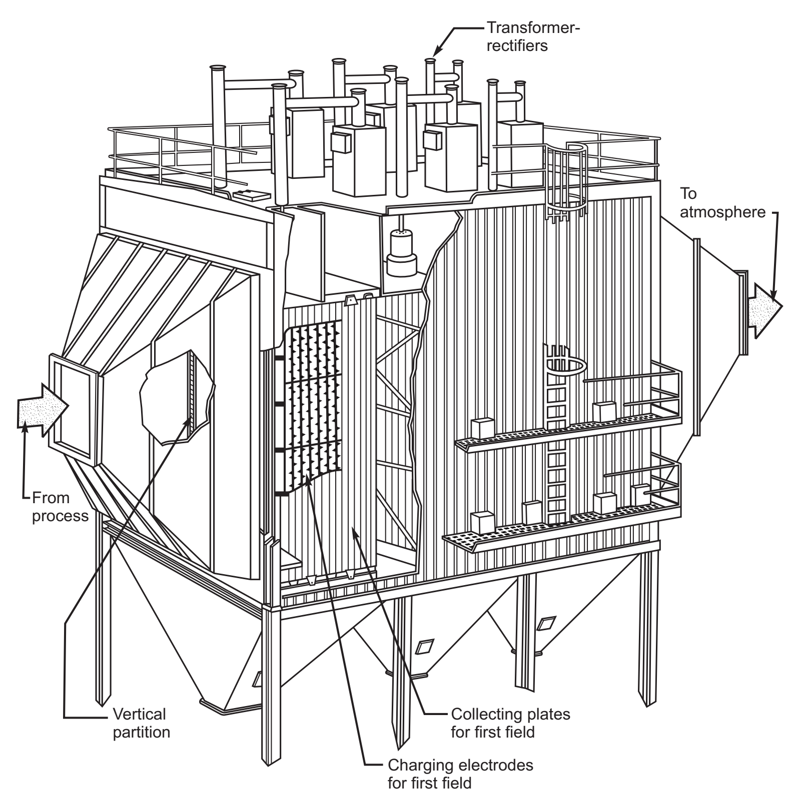


Fig. 3.4.5-1. Single stage electrostatic precipitator. (Unit is separated into two compartments by vertical partition; each compartment has three fields; material collected on plates drops down into hopper below.)

Voltage is supplied to the charging electrodes, increasing from a preset level to a point where the gas between the electrode and the collecting surface ionizes and an electrical discharge (corona discharge) occurs. The voltage is then automatically reduced to a preset level, and the cycle is repeated. Collection efficiency is highest immediately before the corona discharge.

Mechanical rappers or water wash are used to transfer particulate to the hopper below. Collected particulate is removed from the hopper through rotary valves or by screw conveyor.

Large single stage precipitators may have two parallel compartments. Each compartment has from three to five collection fields arranged in series with their own power supply. Rectifier transformers on large units are usually mounted on top of the precipitator. Overall collection efficiencies on modern precipitators may range up to 99.9%.

In double-stage precipitators (Figure 3.4.5-2), charging electrodes are located upstream of the collecting surfaces, with the electrodes arranged parallel to the flow of gas.

Double-stage precipitators may be encountered in metalworking operations and air purification systems for clean rooms. Larger double stage precipitators are frequently used to meet Environmental Protection Agency (EPA) requirements in plastics working, rubber curing, printing, textile-finishing and asphalt-saturating processes.

If solid particulate or a combination of solid particulate and oil mist is collected, a prefilter is generally located upstream of the precipitator. The prefilter may be fiberglass or a series of baffles.

Small double stage precipitators [up to 10,000 cfm (280 m^3/min)] are usually located at ceiling level near the equipment they serve or on mobile carts inside the work area. Cleaned air is usually returned to the work area. Units larger than 10,000 cfm (280 m^3/min) are usually located on the roof or on the ground adjacent

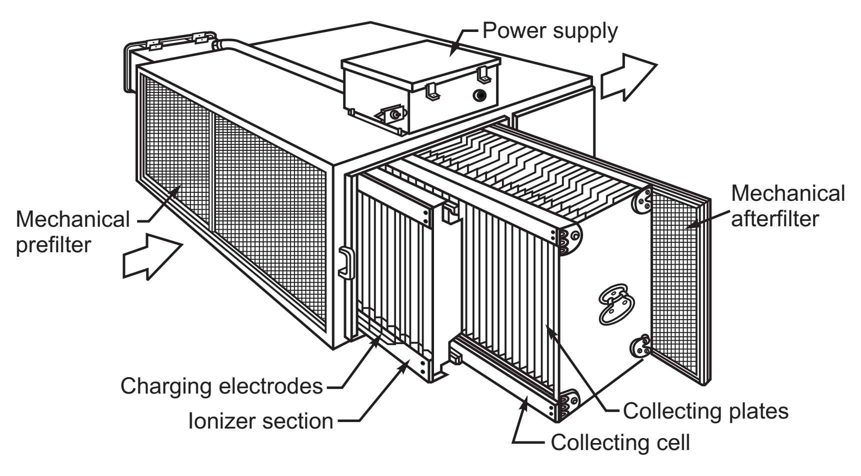


Fig. 3.4.5-2. Double-stage electrostatic precipitator with mechanical filtration

to the building. These units often serve more than one piece of equipment. Ducts usually pass from the equipment directly through the roof. The ducts are manifolded and enter the precipitator. Cleaned air is usually exhausted to the atmosphere.

3.4.6 Grain Processing and Milling Operations

Grain elevator is a term that has several meanings. It can mean:

A. An entire facility complex where grain is stockpiled or stored. This complex (Figure 3.4.6-1) contains storage silos, tanks or other bulk storage buildings, along with a variety of other support functions related to the management of the stored materials.

B. The tower containing the conveyor system to deposit grain into silos (usually a bucket elevator or pneumatic conveying system)

C. Organizations that operate several individual grain elevator facilities

D. The lifting mechanism used to transfer the grain into the storage silos

Grain elevator facilities can be of three basic types: country elevators, regional elevators (inland terminals) or export elevators (port terminals). The flow of grain from country to regional to export elevators is accompanied by a corresponding increase in elevator size and grain throughput capacity.

Reinforced concrete silos, which may be more than 100 ft (30 m) high, with individual capacities in excess of 25,000 bu (880 $m^{3)}$ are common, although grain also may be stored in steel tanks or in bulk storage buildings. Loading and unloading conveyors are present on the top of the storage silos within an enclosure and under the bottom of the storage silos, usually within a tunnel. The conveyors usually run to a headhouse located on top of a multistory workhouse building. The workhouse contains elevating, cleaning, weighing and other grain handling equipment.

Construction within these facilities ranges from the typical concrete construction to metal frame construction or even damage-limiting construction (DLC), depending on the location with the facility.

The DLC acts to limit the extent of explosion damage; and the above ground conveyors provide separation between parts of the facility, together reducing the possibility of an explosion propagating via equipment, tunnels and galleries.

Conveyors can run below or above ground, with above ground becoming more common. Conveyors are used most often to transport grains from the loading/unloading areas to the storage silos. This transport may be done via a single or a separate workhouse depending on the size of the facility. They may also be elevated. Silos and bins may be interconnected by spouts.

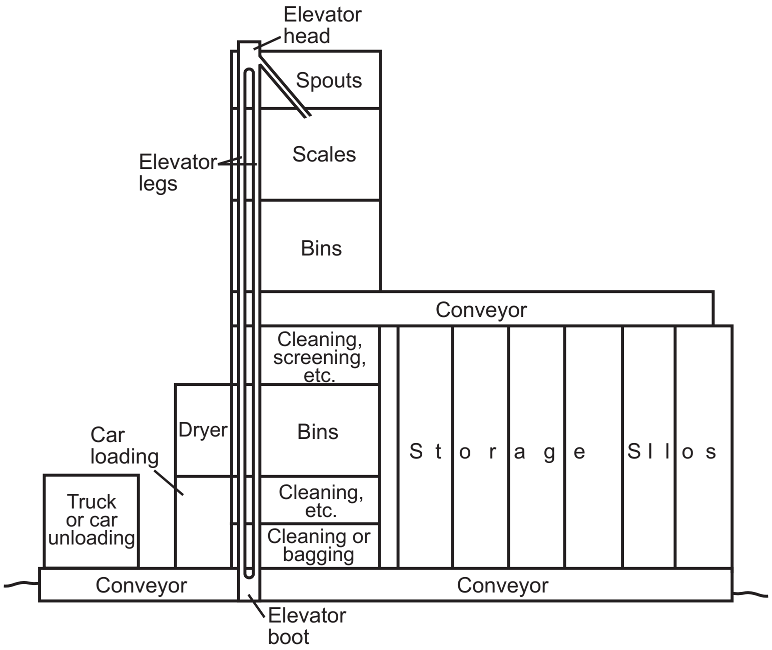


Fig. 3.4.6-1. Typical grain elevator

Weigh scales are present to allow the grain(s) to be weighed at various points within the facility. Grain sampling is performed as the grain passes from the shipping bins to belt conveyors for transfer to ships, barges, rail cars, etc.

Within flour or feed milling operations, various mills, separators and blenders, bagging, bulk storage or bulk loading areas are common. Other processes such as mash tubs or cookers may also be present.

Ignition source control and housekeeping are the traditional methods used to reduce the potential for an explosion within these facilities. Hence explosion venting, if present, is usually inadequate.

3.4.7 Grain Dryers

Drying equipment for grain is usually direct oil-fired or gas-fired. Steam coils to heat the drying air present less of a fire hazard but require a large boiler capacity for a heavy, but infrequent, demand.

Spent grains are commonly dried and bagged as animal feed. Steam-heated rotary dryers are ordinarily used, and the dried material may be further milled and ground prior to shipment. In beer stills and ethanol plants, solids are separated from the liquids prior to drying. Residual solids in the liquid stream are recovered by concentrating in evaporators or centrifuges and then drying in spray towers or drum dryers.

Malting kilns are a special type of grain dryer used in the production of beer, whiskey and several other foods. Kilns vary in size and have perforated metal floors upon which the malt is dried in beds of about 1-2 ft (300 to 600 mm) in depth on perforated metal floors. Malt is introduced to the kiln at 40-50% moisture and progressively dried using heated air. The perforated floors allow the heated air to penetrate the grain beds to facilitate drying. The malt exits the kiln at a moisture level of about 4%.

3.4.8 Conveyor Systems

A number of conveyor systems are used to transport materials that generate dusts. Bucket elevators are perhaps the most common and generally consist of plastic or metal buckets attached to a moving vertical belt, which is driven by an electric motor.

The belt is housed in a metal conveyor enclosure, which is located inside a concrete shaft called an elevator leg. Product is picked up at the bottom (“boot”) of the leg and is transported to the top (“head”) where it is emptied out of the buckets. The buckets then return down the belt to be refilled at the bottom.

Explosive dust and air mixtures can develop within the legs of a bucket elevator, especially in the down leg where residual dust from the upside-down buckets can filter through the entire leg. Common ignition sources include overheated bearings in the head, knee or boot of the conveyor, cutting and welding, tramp metal, or falling buckets. An explosion originating in an elevator leg, especially one located inside a concrete shaft in the workhouse, can rapidly develop extreme pressure and transmit it throughout the entire elevator.

Chain conveyors (Figure 3.4.8-1) can also be used. They consist of paddles or flights in a heavy steel, usually dust-tight, enclosure, installed vertically, horizontally or in an incline position. The flights and material within form a solid mass as they move upward. Dust accumulations with the legs are usually less than that seen in bucket elevators.

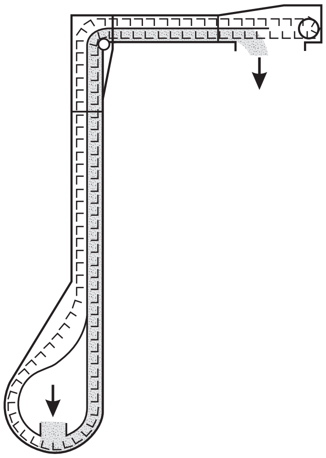


Fig. 3.4.8-1. Chain conveyor

Conventional belt conveyors installed on an incline may also be seen in lieu of vertical elevators. Such an installation requires considerable space but eliminates the need for any elevator legs.

For short conveyor runs, screw conveyors are common. These conveyors can provide a choked feed, especially if flights are omitted. One hazard with screw conveyors is that material particles can be caught between the auger and the enclosure and be partially ground, creating dust. Hence, ensuring that the duct around the screw conveyor be completely dust tight is important.

Pneumatic conveying may be used for light materials including dusts. Pneumatic conveying is generally used to transport materials between processes as well as for dust collection. Interconnected pneumatic ducts may provide a means of carrying burning material throughout a facility. Design of the ducts should prevent dust from escaping into the external environment as it is transported.

Additional dust is generated each time the grain is transferred, but it is usually returned to the grain stream. Larger quantities of dust must be handled in regional and export elevahead3tors as opposed to country elevators or other grain handling facilities such as those at solvent extraction plants, distilleries, etc. In addition, certain grains (i.e., corn, milo) produce more dust than others (i.e., wheat).

3.4.9 Connecting Ducts

Dusts are transferred in ducts either as part of a fugitive-dust-control system or to move the product from one part of the process to another. Fugitive-dust transfer is almost always at much less than the Minimum Explosible Concentration (MEC), while process transfer may be at much greater concentrations than the MEC. Process transfer might be referred to as dense phase transfer.

Knowing the transfer conditions is key to understanding the hazard. This includes knowing the amount processed/collected over some period of time or measured by sampling or monitoring the actual flow in the duct.

The hazard in the duct can be affected by the actual transfer rates or by dust that settles out and accumulates from insufficient flow velocity in the duct. Preventing this settling from occurring is important; it can be controlled by maintaining sufficient airflow, typically on the order of 3,500 – 4,000 ft/min (18-20 m/sec). Dust that has accumulated can be re-entrained by the pressure wave from an explosion and create localized combustible concentrations that can move and become ignited by the trailing flame front. After considerable propagation, this turbulent jet flame becomes a very strong ignition source (see Appendix A) that can destroy even properly protected equipment.

A small amount of deposited dust can propagate an explosion. For a circular duct of diameter ”D” with a dust layer of thickness “h” settled on 1/4 of its inner circumference (i.e., at the bottom), the concentration of dust dispersed homogeneously throughout the cross section of the duct would be $C = \rho_{bulk}\ h/D$.

As an example, a dust with a bulk density of 31 lb/ft^3 (500 kg/m^3), a thickness of only 1/125 in. (0.2 mm) and a duct of 8 in. (0.2 m) diameter, could generate a dust concentration of 500 g/m^3. This concentration is well above the MEC of virtually any dust; and therefore, can propagate an explosion.

The settled dust is most likely not homogenously dispersed throughout the duct, but research by the US Bureau of Mines has shown that explosions can propagate through ducts even at dust concentrations as low as half the MEC. Propagation only requires a continuous path of mixture that is above the MEC. This condition can be satisfied even when not enough dust exists to fill the entire volume of the duct with a mixture above the MEC. Even very small amounts of dust can be sufficient to create a propagating explosion. Thus, the air velocity through the duct should be sufficient to prevent any settling of the transferred dust.

Explosion venting in duct work is not provided to save the duct (which is usually of low value and easily replaced) but to reduce the violence of a potential explosion propagating down its length. Venting would not stop the explosion propagation but would reduce the intensity of the ignition source to exposed, connected equipment. Designing the duct to fail at low pressure rather than installing explosion vents could be an acceptable alternative approach where no equipment exposure exists.

Explosion isolation systems may be needed for connecting ducts where the consequence of an unprotected event in equipment or flash-back to a building is unacceptable. For example, a large panel sander might have six dust pickup points, three on the top and three on the bottom, all joining into a common duct. Each pickup pipe would not need an isolation device. Explosion isolation would best be provided on the main duct after it leaves the building to prevent an explosion in the dust collector from propagating back towards the sander.

3.4.10 Silos

Silos can also present a dust explosion hazard, even when they are used with granular material having a very small portion of fines. As the coarse material continually transfers into the silo, it will fall to the bottom, but the finest, most explosible material will remain in suspension. If transfer operations continue long enough, the airborne combustible dust concentration will exceed the MEC and create an explosion hazard.

When a dust collector is mounted directly onto a silo (i.e., with a short connecting pipe of sufficiently large diameter), any explosion originating within the dust collector will create a silo explosion as if the explosion had originated there. So, the dust collector can be considered part of the silo. Explosion venting provided on the silo and dust collector assembly and sized based on the sum of both volumes is adequate, regardless of whether an explosion originates in the silo or the attached dust collector.

When the dust collector is separated from the silo via a small or elongated pipe, the silo and dust collector no longer act as a single volume during an explosion. If an explosion originates in a dust collector that has no explosion venting of its own, the jet flame will propagate down the connecting pipe, igniting any combustible dust cloud within the silo. This situation would cause a much more violent explosion than if the silo explosion was ignited by a conventional (weaker) ignition source.

Air cannons used to break up bridging material can disperse fines in the bulk material into the silo headspace. Even if the percentage of fines is very small (e.g., 1-2%), repeated air blasts will concentrate the fines at the top of the bed. Repeated air-cannon operation creates more fines at the top of the bed and a higher concentration of dust in the head space at every air cannon firing. Only an ignition source is needed for a potentially severe dust explosion.

Additionally, certain combustible materials such as coal, grain and wood are susceptible to spontaneous heating; and introducing air over an extended period of time can increase the probability of such spontaneous heating. Air introduced to glowing combustion could fan it into flames or ignite a dust explosion.

Alternative solutions to air cannons include using vibratory wands inserted temporarily or permanently into the bottom portion of the silo or using acoustic horns and lances.

3.4.11 Bucket Elevators

Bucket elevators come in two varieties, single or double casing (single and twin leg).

In a single casing, buckets move upward and downward in the same casing (enclosure) with a common head (top) and boot (bottom).

A double casing bucket elevator has a separate casing for the upward and downward moving buckets but shares a common head and boot.

Even though bulk combustible material may have a very small percentage of fines mixed in with material too coarse to constitute a dust explosion hazard, handling that bulk material will likely create an explosion hazard in a bucket elevator enclosure. Because of the high degree of turbulence within the bucket elevator enclosure, any fines will be easily picked up into suspension. As fines are continuously added to the air space in the elevator with very little fall out, the concentration can exceed the MEC and create a dust explosion hazard.

3.4.12 Size-Reduction Equipment (Grinders, Pulverizers, Hammer Mills, etc.)

Size-reduction equipment presents the inherent hazard of mechanical impact in the presence of combustible dusts. The mechanical impact can create frictional and impact heating. Sparks may occur if unintended metal enters the machine. The result can either be glowing particles leaving the equipment to become an ignition source in downstream equipment or actual ignition of the dust cloud in the equipment. These machines are most frequently of substantial construction and able to withstand an internal explosion without damage.

Explosion venting is usually not needed; but explosion propagation to other parts of the installation should be considered, and explosion isolation techniques may be needed.

Where present, these explosion isolation devices should be maintained regularly to ensure adequate lubrication is provided, proper clearances are maintained, and dust and debris do not accumulate and become ignited or impair proper operation.

3.4.13 Condensation Inside Equipment and Insulation on Vents

Condensation can form on the inside walls of dust-handling equipment located outdoors or in equipment vents that vent outside during cold weather. This situation can introduce moisture into the dust stream, creating problems that may include particle agglomeration, formation of off-spec product or spontaneous heating in certain materials. Insulation can prevent this condensation from occurring, but it must not affect the performance of explosion vents. Prefabricated, rupture-type explosion vents are available that have a foam-insulated core to prevent condensation on the inside of the vent. Additional insulation should not be applied as it could impede operation of the vent. Under no circumstances should caulking be applied to the explosion vent to prevent condensation, as this can prevent the vent from opening as designed.

3.5 Protection

3.5.1 Electrostatic Precipitators

Heat from a fire or process over-temperatures can warp collecting plates, unless they have been specially braced or installed with stiffeners. Warped collecting plates have a reduced efficiency.

In larger units with four or five fields in series, fires may burn undetected for long periods of time, because downstream fields collect smoke particulate and exhaust clean air. Instrumentation is important for early detection of fire.

Loss frequency in precipitators is highest in those units collecting oil/hydrocarbon mists from high-speed metal grinding and textile center frame operations, where oil-coated dust or lint that builds up between the plates and electrodes is ignited. Spontaneous ignition of deposits in ducts or in the precipitator can also occur. Build-up of deposits is likely to occur if solid particulate is located in the inlet gas stream or if duct velocities are low.

Precipitators serving cement kilns, black liquor recovery boilers and pulverized coal-fired boilers have a high frequency of loss, despite handling non-combustible materials.

The most common forms of protection for electrostatic precipitators are automatic sprinkler or water spray. Carbon dioxide and steam suppression are also used as supplementary protection to sprinkler/water spray systems. Fixed temperature detection is the usual form of actuation for these systems, either in the ductwork or the precipitator.

3.5.2 Spark Extinguishing Versus Explosion Suppression

A spark-extinguishing system, also known as a spark-suppression system, detects and extinguishes sparks or glowing embers upstream of dust-collection equipment to prevent these ignition sources from traveling to the dust collector(s).

Using an infrared sensor for detection, particles passing by at elevated temperatures trigger water spray located downstream from the detector, to extinguish the particle.

Spark-extinguishing systems are very effective in reducing the frequency of combustible dust explosions. They are not designed to suppress an explosion or reduce the severity of one. They are systems designed to control ignition sources only. They may also be connected to a high-speed abort gate to remove any embers or sparks that were not extinguished. This arrangement is especially common in woodworking industries.

Limitations of these systems include the following:

- Failure to extinguish particles if they are too large
- Failure to extinguish tramp metal ignition sources within ductwork
- Failure to detect and/or extinguish particles or ignition sources created downstream of the detection/extinguishing system
- As the severity of a resultant explosion is not affected, explosion protection or mitigation still need to be provided.
- Changes in the air/gas stream velocity can impact their performance.

Explosion venting, explosion-blocking systems or explosion-suppression systems differ from spark detection and extinguishing systems in that they control the effects/products of an explosion after it has occurred. Venting directs the explosion to a safe location, explosion-blocking systems isolate systems from each other, and explosion-suppression systems detect the early phases of an explosion and prevent pressure from rising to a level at which equipment may be damaged or destroyed.

3.5.3 Foreign Material Separators, Magnetic or Other

Using separators upstream of all equipment that mechanically impacts with the process material, prevents metal and other foreign objects from entering the equipment. Without the separators, tramp metal or other material entering the equipment can create impact or friction sparks capable of igniting a dust cloud.

3.6 Ignition Source Control

The following equipment and processes are considered to have a high frequency of dust explosions:

A. Woodworking industry: rotary dryers, flash dryers, sanding equipment, particleboard milling equipment (See Data Sheet 7-10 for additional fire and explosion protection requirements related to this industry.)

B. Any mechanical milling equipment with connected equipment such as a downstream cyclone (Exceptions: coal pulverizers and human food-product milling are not considered to have a high frequency of explosions for the purposes of this data sheet.)

C. Processes that routinely produce sparks or glowing embers (e.g., due to grinding or friction) that can enter a dust collection system

D. Any process or system that has experienced two or more explosions within a 10-year period

3.6.1 Minimum Ignition Energy (MIE)

The Minimum Ignition Energy (MIE) a measure of the lowest amount of energy a suspended dust cloud requires to initiate an explosion. Combustible dust MIE's range from 1 mJ and 1000 mJ. It is rare to find a dust with an MIE value of less than 10 mJ and dusts with an MIE of 3 mJ or less require special handling. A dust with an MIE of 25 mJ or less could potentially ignite from a static discharge. Typical combustible dusts have an MIE of greater than 25 mJ. MIE testing is normally pursued only when there are reasons to suspect a dust might be particularly susceptible to ignition from static. Any test result reporting an MIE of 10 mJ or less should be interpreted as proving static ignitability.

Incendive electrostatic charges can develop when insulative powders are transferred into silos or bins, or where insulating linings (e.g., plastic) cover metal surfaces (lined metal ductwork). Charges on the surface of an insulative powder pile can create brush discharges that are usually limited to 20 mJ or less and not likely to ignite typical combustible dusts. Charges developed on lined surfaces can result in propagating brush discharges that can release sufficient energy (hundreds of mJ) to ignite combustible dusts. If these conditions exist, an evaluation should be performed by an expert in electrostatics. Metal powders such as aluminum typically have low MIEs (as low as 0.1 mJ), making them easily ignitable. Also, metal powders in general have high K_{st}, making adequate explosion venting difficult to provide.

3.7 Additive Manufacturing (3D Printing)

Additive manufacturing (AM), more commonly known as 3D printing, is growing in importance in the manufacture of intricate parts. Components are being produced for diverse services from toys to aerospace.

Figures 3.7-1, 3.7-2 and 3.7-3 show schematic representations of the main technology categories and their characteristics. The 3D printing referred to in Figure 3.7-3 is more representative of personal-scale printers than the industrial-scale types.

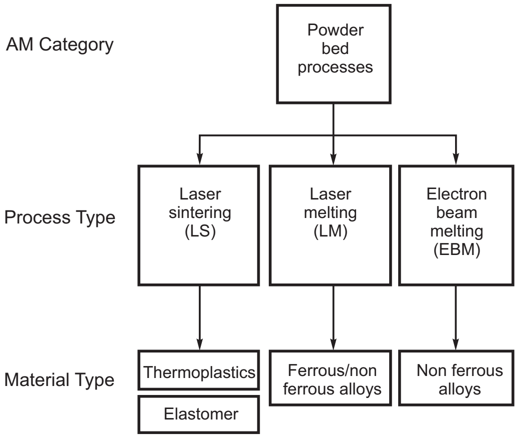


Fig. 3.7-1. Powder bed processes

Powder bed fusion is generally the most common method used with metal powders. It involves using digital design data to construct a component by depositing a layer of material 20 to 100 microns thick (0.0008 to 0.004 in. [0.02 to 0.1 mm]), fusing the component pattern into the layer and repeating the sequence until the "build," (the part being created) is complete. With metal powders, the fusing is done with a laser or electron beam; while polymers/plastics may be fused with a laser or a binding liquid sprayed onto the powder layer.

Figure 3.7-4 is a schematic representing the selective laser sintering (SLS) fusion bed technology that produces the actual product. The powder layer is distributed by a spreader bar located just above the surface of the build platform or the prior layer.

Material deposition processes use powders or extrusion methods to build the design layer-by-layer. One technique uses selective dispersion of a powder through an aerosol jet, followed by fusing with heat or an electron beam (material jetting). These processes use small individual "shots" of material and typically do not create clouds of dust in the equipment.

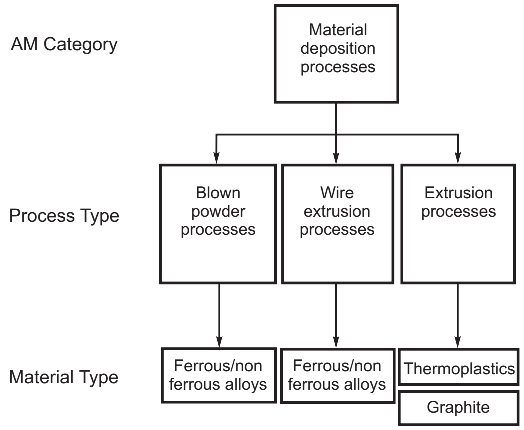


Fig. 3.7-2. Material deposition processes

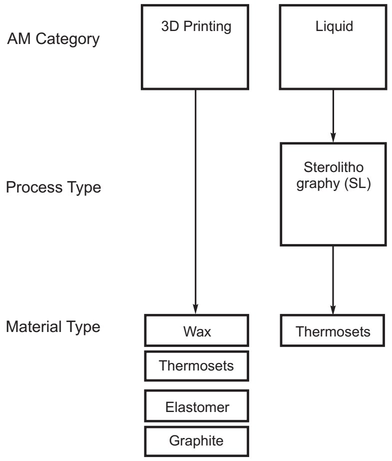


Fig. 3.7-3. 3D printing and liquid processes

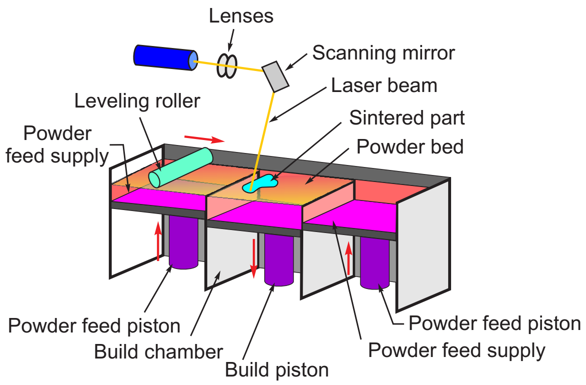


Fig. 3.7-4. SLS design concept (Chemical Engineering Progress, May 2014)

For liquid plastic resins used in a pool, the shaping mechanism fuses the polymer into the form needed (stereolithography) with light beams (laser, UV). One method uses high flash point liquid resins (over 212°F, 100°C) and moderate flash point cleaning fluids (185°F, 85°C).

The build material can be fine powdered metal, plastic, ceramic or glass. Commonly used metal alloy powders include cobalt-chromium, aluminum-titanium, magnesium, stainless steel (iron and chromium plus other, lesser metal additives) and Inconel (nickel and chromium with iron and other metals as lesser additives). Material explosibility (K_{st}) varies with the particular metal or alloy. Dust should generally be considered combustible until proven otherwise by testing.

Figure 3.7-5 shows examples of typical industrial printers. The ProX 300 and the Concept M2 have a build envelope (chamber for the printing part) of about 10 x 10 x 12 in. (250 x 250 x 300 mm). The industrial-scale printer can cost US$0.5 million or more per machine.

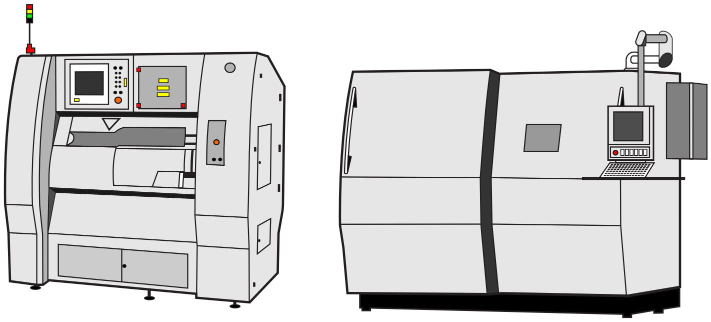


Fig. 3.7-5. Industrial-scale 3D systems: ProX300 and Concept M2 Laser printers (Source: manufacturers' brochures)

3.7.1 Potential Hazards

The primary property hazards involve combustible dust handled in fine powder form (often 30-150 microns [0.001- 0.006 in.] or less) and ignitable liquid used by some systems. Only hazards associated with powder operations are addressed here with a focus on metal powders.

The metal-based processes run under low oxygen atmospheres (less than 1% oxygen) for product-quality purposes. Therefore, they do not present an explosion hazard while in the build chamber or the inert atmosphere recirculation system. Any cartridge or panel filters present will consist completely or primarily of combustible construction. Most filters are used for two or three build cycles and then replaced. Some systems identify the fumes from the laser process as a “highly flammable metal condensate”. These require special handling and precautions to prevent spontaneous smoldering events in the filters as they are removed and exposed to air. In many cases, localized intense flash fires have resulted when these filters have been removed for cleaning. Such events appear to be exacerbated by disturbance of the condensate on the filters during the cleaning operation.

Depending on the size of the machines, the process powders required can vary from small amounts of material in the smaller machines, up to several hundred pounds/kilograms in the largest. The process powders are handled in heavy fiberboard containers or plastic bottles of no more than about 2 gal (7.6 L) in size. Static accumulation when transferring these powders is possible; and manufacturers typically recommend bonding and grounding of personnel, the containers and the machines during these operations. On the material handling side, given the current scale at which these systems are used, controlling ignition sources by grounding, bonding, etc. is more practical than inerting the operation.

Production-scale equipment will likely require additional material-handling methods and will need to be evaluated based on the properties of the powders involved, as previously indicated.

The cleanup process for the build chamber would typically use portable vacuums, which need to be rated for hazardous operations involving combustible metal or plastic dusts.

The completed parts are removed from the low oxygen atmosphere. Excess powder is either shaken off, blown off using air or removed via vacuum by the operator and recycled back to the machine for future use. The parts are then sent to other finishing operations. Some plastics are cleaned using high-pressure water jets in a glove box enclosure. Where air blowdown is used it could create a small, local, dust flash fire hazard; or an associated dust collection system could present a dust explosion hazard.

3.7.2 Protection for 3D Printers

As noted previously, the machines handling combustible metal powders operate under inert atmospheres and present no dust explosion hazard. Machines using other combustible powders would need to be evaluated to understand how the process is operated and if significant clouds of combustible dust could be created.

Machine enclosures completely contain the combustible powders. Therefore, no hazardous location electrical equipment is needed within the surrounding area.

Due to the combustible loading of these additive manufacturing machines, sprinkler protection designed for the surrounding occupancy should be adequate for controlling a fire that involves a printing unit.

Where the combustible loading in the surrounding area will result in a fire that is larger and/or more intense than that involving the machine alone (such as in cases where combustible construction or storage of the powders is present), the sprinkler protection should be designed to mitigate the impact of a fire involving these materials.

Certain metals will evolve hydrogen gas when in contact with water. If the metal is already burning, the addition of water will not create an explosible atmosphere; because the evolved hydrogen will be readily consumed in the burning fire.

If a burning metal powder forms a metal pool (i.e., a melt) and water gets underneath it, the potential exists for a steam explosion.

3.7.3 Storage of Metal Powders in Containers

Conductive materials, such as metals, allow electrons to flow freely due to their low electrical resistance. This allows electrical charges (e.g., static) to be easily grounded, or for the equalization of charge when connected to other conductive materials (bonding).

Static-dissipative containers are typically made of plastic, which has a high electrical resistivity, and some other material (usually carbon) to allow the charge to dissipate. Typically, the flow of a charge to ground from a static-dissipative container is slower than that seen with a conductive container.

The drawback to these plastic containers is that, in a fire, the high heat release rates from the burning containers can overwhelm sprinkler protection, particularly in storage situations.

This situation is made more severe if combustible metal powders are stored within static-dissipative (plastic) containers. At the time of writing of this document (2024), no known protection scheme for static-dissipative (plastic) containers storing combustible metal powders are available. However, a research project is underway to examine protection schemes that may apply for these situations.

Until this project is completed, metal containers remain the preferred method for the storage of combustible metal powders.

4.0 REFERENCES

4.1 FM

Data Sheet 1-28, *Wind Design*
Data Sheet 1-44, *Damage-Limiting Construction*
Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 4-4N, *Standpipe and Hose Systems*
Data Sheet 5-1, *Electrical Equipment in Hazardous Locations*
Data Sheet 5-8, *Static Electricity*
Data Sheet 5-48, *Automatic Fire Detection*
Data Sheet 6-9, *Industrial Ovens and Dryers*
Data Sheet 7-10, *Wood Processing and Woodworking Facilities*
Data Sheet 7-14, *Fire Protection for Chemical Plants*
Data Sheet 7-17, *Explosion Protection Systems*

Data Sheet 7-39, *Material Handling Vehicles*
Data Sheet 7-43, *Process Safety*
Data Sheet 7-45, *Safety Controls, Alarms, and Interlocks (SCAI)*
Data Sheet 7-59, *Inerting and Purging Vessels and Equipment*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-85, *Combustible and Reactive Metals*
Data Sheet 7-111A, *Fuel-Grade Ethanol*
Data Sheet 7-111B, *Carbon Black*
Data Sheet 8-27, *Storage of Wood Chips*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-3, *Hot Work Management*

4.2 Other

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APPENDIX A GLOSSARY OF TERMS

A_v: Explosion venting area

Air material separator (AMS): A broad term for a device designed to separate powders from the air in which it is transported. Most commonly, this would be a cyclone or dust collector.

Back-blast damper: Essentially a check valve that is effective in stopping explosion propagation in the opposite direction of normal flow.

Bag collectors: Air material separators (dust collectors) that separate dust from a gas stream by passing the stream through a felted or woven-fabric filter medium.

Bakery: A place where baked goods are made (baked) and/or sold. Baked goods can include, but are not limited to, breads, cakes, cookies, biscuits (sweet or savory), doughnuts, bagels, pastries and pies. Typically, these goods are produced using flour. However, such products can also be gluten-free.

Bara: bar, absolute (unit of pressure).

Barg: bar, gauge (unit of pressure)

Bins: Short squat metal storage vessels. See also “Silos”.

Bonding: Electrical connection between two electrically-conductive objects that minimizes any difference in electrical potential between them.

Canister collectors: Air material separators (dust collectors) that use a filter media contained in a cartridge (such as a steel cage). The media is pleated to increase the surface area for dust capture.

Damage-limiting construction (DLC): Construction designed to minimize the damage from a deflagration (explosion) in equipment or building. This can be pressure resistive, pressure relieving, or some combination of the two. Most commonly this would be vent panels on enclosures (buildings or equipment) releasing at a pressure below the strength of the enclosure.

Design strength: Pressure to which a vessel can be exposed without any risk of damage (because a safety factor has been applied to the yield strength).

Discharge, brush: An electrostatic discharge between an insulating (non-conductive) surface that has accumulated a charge and a conductive surface.

Distributor, turnhead: See definition for “**Turnhead distributor**”.

Double dump valve: An arrangement of two gate or butterfly valves in series. Only one is open at a time. This valve is often used where material discharged from one vessel is gravity fed to another vessel (i.e., not pneumatically conveyed) such as a dust collector discharging into a hopper below it or a material blender or grinder discharging into a pneumatic conveying system.

Dust: Small solid particles capable of being suspended in air by pouring, blowing, grinding, etc. For the purposes of this data sheet, it refers only to combustible dusts.

Dust, combustible: Any organic material (agricultural, plastic, chemical, coal, etc), unoxidized metal particles, or other oxidizable materials (e.g., zinc stearate) should be considered combustible.Tests involving the application of a spark, match flame, Bunsen or Meker burner flame to small layers or piles of material may help in identifying such materials, but can result in false negatives.

Dust, explosible: Established by ASTM E1226, Standard Test Method for the Explosibility of Dust Clouds, or international equivalent (e.g., EN 14034-1, *Determination of Explosion Characteristics of Dust Clouds - Part 1: Determination EN of the Maximum Explosion Pressure* P_{max} *of Dust Clouds*, and EN 14034-2, *Determination of Explosion Characteristics of Dust Clouds - Part 2: Determination of the Maximum Rate of Explosion Pressure Rise* $[dP/dt]_{max}$*) of Dust Clouds*). A dust that does not ignite and burn in layer or pile testing could be determined to be explosible in an E1226-type test.

In the past, particles larger than 500 microns were specified as unlikely to present a dust explosion hazard. Mixtures consisting of a range of sizes could present a dust explosion hazard even where a large portion of the dust exceeds the 500 micron limit. Where there is a doubt, testing is the most appropriate way to determine the explosibility of such a mixture.

Dust, fines: See definition for “**Fines**”.

Dust, fugitive: See definition for “**Fugitive dust**”.

Dust, hard-to-ignite: A dust that has been confirmed by FM test protocol to require a strong ignition source to cause a combustible dust cloud to ignite.

Dust, inert: A dust that will not ignite or combust in the presence of oxygen when exposed to an ignition source.

Dust, reactive: A dust that will ignite and/or combust in the presence of oxygen when exposed to an ignition source.

Electrostatic precipitators: Equipment that collects dusts and hydrocarbon mists from gas streams by using an electrostatic charge. They may be used to condition air to meet air pollution codes or recover a product or by-product.

Enclosureless Dust Collector: A device designed and used to remove dust from the transport air where the filter media is not enclosed or in a container.

Explosion isolation: System or single device that prevents the propagation of explosion effects from one volume to an adjacent volume.

Explosion mitigation: Methods used to reduce damage from the explosion after the explosion has started.

Explosion prevention: Methods used to prevent an explosion by controlling either the air, fuel, ignition source, or a combination of these.

Explosion-resistant design: Any vessel with a design pressure of 6 barg (87 psig) or more that would not be deformed by a dust explosion that occurs at an initial (pre-explosion) pressure of less than 0.1 barg (1.5 psig).

Fines: Particles less than 75 microns in size.

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

Fugitive dust: Dust that has escaped from process equipment, ductwork or dust collection systems.

Gallery, conveyor: A structure (usually composed of steel trusses) that surround and house a conveyor belt.

Grain elevator: A facility used to store grain. An alternate use for a grain elevator, specific to the grain industry, is a tower containing a vertical bucket elevator or other pneumatic conveyor which transfers grain from a lower level to a storage silo.

Grounding: Electrical connection between a conductive object and the ground that minimizes the difference in the electrical potential between the object and ground.

Hard-to-ignite (HTI) dust: This is a sub-category of combustible dusts that have been tested using the appropriate FM testing protocol. Hard-to-ignite dusts require a larger ignition source compared to other combustible dusts. Hard-to-ignite dusts are still combustible dusts that can explode, with all the potential consequences. This definition of hard-to-ignite is not related to definitions found in other codes and standards.

Ignitable Liquid: Any liquid or liquid mixture that is capable of fueling a fire, including flammable liquids, combustible liquids, inflammable liquids, or any other reference to a liquid that will burn. An ignitable liquid must have a fire point.

Inert: See definition for **Dust, inert**.

K_{st}: The dust explosibility constant, defined as the maximum rate of pressure rise of a dust explosion in a 1 cubic meter vessel. The units are bar meter per second (bar m/s). The test method used to obtain this constant is standardized worldwide. This value (K_{st}) is used in all modern dust explosion vent sizing to characterize the reactivity (i.e., explosibility) of a particular dust. Only metric units are used for this constant.

MEC: Minimum explosible concentration, the lowest concentration of dust that can support a self-propagating explosion. (The terms LEL [lower explosible limit] or LFL [lower flammable limit] mean the same, but are not often used in the context of dust explosions.)

Media type collector: A device (enclosure) that separates dry, solid material from air by passing the air through a dry filtering medium. Examples are enclosures with bag-type filters, cartridge-type filters (normally a pleated filter arranged in a cylindrical shape, similar to automobile air filters), rotary drum filters, and panel filters. (See Data Sheet 1-45, *Air Conditioning and Ventilating Systems*, and Data Sheet 7-73, *Dust Collectors and Collection Systems*, for information on filter types.)

MIE (minimum ignition energy): The minimum amount of thermal energy released at a point in a combustible mixture to cause indefinite flame propagation under specified test conditions. The lowest value of MIE, known as LMIE, is found at a certain optimum mixture. It is this value that is usually reported as the MIE.

Overpressure: This is the pressure above normal atmospheric pressure that is caused by a shock wave from an explosion.

Packing material: Filler material inside a wet collector used to increase the surface area of contact between the gaseous stream carrying the dust and the liquid stream within the collector unit. Such material can be metal, ceramic or even plastic.

Phlegmatization: The process of mixing inert dusts with combustible dusts to reduce or eliminate the explosion hazard.

$P_{blast, max}$: The localized pressure as a result of the fireball and pressure from a vented explosion.

P_{max}: The maximum pressure developed in the 20-liter sphere when testing dust for explosibility characteristics by ASTM E1226 method. It is factor used to help size explosion vents.

P_{red}: Highest explosion pressure in a vessel protected with explosion vents; usual units are barg or psig.

P_{stat}: Explosion vent relief pressure; usual units are barg or psig.

Psia: Pounds per square inch, absolute (unit of pressure).

Psig: Pounds per square inch, gauge (unit of pressure).

Reactive: See definition for “**Dust, reactive**”.

Scrubber: A scrubber is a device used to remove particulates and/or gases from an industrial exhaust stream.

Shock-resistant design: Any vessel having 3 barg (43 psig) design pressure or more when designed in accordance with ASME Boiler and Pressure Vessel Code, Section VIII, or yield strength of 6 barg (87 psig) or more according to other codes. With this design, the vessel may deform but not rupture in the event of a dust explosion that occurs at an initial (pre-explosion) pressure of less than 0.1 barg (1.5 psig).

Silos: Large, tall structures of concrete used for storage of grains. See also “**Bins**”.

Strong ignition source: A strong ignition can provide more than approximately 100 Joules of energy.

A. Examples of a strong ignition source include open flame, welding arc, gas or dust explosion, and electric arc/short.

B. Conversely, examples that would not be considered a strong ignition source include frictional sparks, mechanical impact sparks, static sparks, cigarettes, hot surfaces, overheated electrical components.

Strong vessel: A vessel that can withstand explosion pressures in excess of 0.2 barg (3 psig) without being damaged or destroyed. This includes most process vessels constructed or used in Europe.

Textile tenter frame: Found in the textile industries, this is a machine that allows the uniform distribution of heat to a fabric, while preventing the fabric from shrinking as a result of the applied heat.

Tobacco manufacturing: Facilities where tobacco products are made, mixed, manufactured, fabricated, assembled, processed, labelled, repacked, relabeled or imported. Such products include cigarettes, cigars, snuff, chewing tobacco and pipe tobacco. Electronic cigarettes, “vapes” and other electronic nicotine delivery devices are classified under tobacco manufacturing.

Tube sheet: The mounting plate for cartridge-type filters or bag-type filter tubes and cages.

Turnhead distributor: Also known as “Swivel switches” these are devices used to distribute products from a single inlet to multiple outlets (typically storage silos or bins). This distribution can either be done via gravity or pneumatically. They are most commonly found in grain handling and grain storage occupancies.

Ultimate strength: Pressure at which an enclosure will be torn open (i.e., ruptured).

Weak vessel or enclosure: A structure that cannot withstand explosion pressures in excess of 0.2 barg (3 psig) without being damaged or destroyed. This includes most rooms, buildings, and many North American process vessels.

Wet scrubbers: Wet scrubbers use a liquid medium as the principal method of separating particulates from an air stream.

Yield strength: Pressure at which an enclosure will be deformed without rupturing.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

October 2024. This document has been completely revised and consolidates several existing documents into one. Significant changes include the following:

A. Changed title to *Combustible Dusts* (from *Fire and Prevention and Mitigation of Combustible Dust Explosion and Fire*).

B. Incorporated guidance from FM Data Sheet 7-73, *Dust Collectors and Collection Systems*. Data sheet 7-73 has been made obsolete.

C. Incorporated guidance from FM Data Sheet 7-75, *Grain Storage and Milling*. Data Sheet 7-75 has been made obsolete.

D. Added new guidance for the evaluation of combustible dust properties. This knowledge allows for better hazard evaluation and development of risk mitigation strategies.

E. Updated the guidance for determining room/building and equipment explosion hazards.

F. Provided new guidance for the testing of non-combustible dusts and dust mixtures.

G. Updated the guidance for the evaluation and treatment of fugitive dust accumulations within buildings and rooms.

H. Updated the guidance for enclosureless dust collectors to align with current FM Research guidance on explosion potentials with these devices.

I. Provided new guidance for the hazards associated with horizontal drum filters (a subset of enclosureless dust collectors).

J. Revised spray dryer fire protection guidance to reference FM Data Sheet 6-9, *Industrial Ovens and Dryers*.

K. Relocated guidance for equipment isolation to Appendix E.

July 2020. Interim revision. The following significant changes were made:

A. Updated guidance to ensure consistency with recent changes to Data Sheet 7-73, *Dust Collectors and Collection Systems*.

B. Added guidance on compressed air blow-down (previously contained in Data Sheet 7-73).

C. Updated guidance on hard-to-ignite dusts.

D. Reorganized the document to ensure consistency with other data sheets.

April 2017. Interim Revision. Recommendation 2.7.2.3 on protection of bucket elevators was modified for clarity.

January 2017. Interim Revision. The following changes were made:

A. Added new material on additive manufacturing (3D printing).

B. Expanded explosion venting design criteria and added fire protection criteria for bucket elevators.

C. Added new material on enclosureless dust collectors.

D. Expanded information on the proper application of flameless venting devices (quench tubes, quench pipes).

E. Made editorial changes.

October 2014. Interim revision. The defnition of an explosible dust was modified to align with industry practice by removing the specific particle size limit.

January 2014. Minor editorial changes were made.

April 2013. Minor editorial changes were made.

January 2012. Terminology related to ignitable liquids has been revised to provide increased clarity and consistency with regard to FM's loss prevention recommendations for ignitable liquid hazards.

March 2009. Minor editorial changes were made for this revision.

January 2009. Correction to the equation in Section 2.4.2.2.1 was made.

May 2008. Reformatted the document for clarity and ease of use, especially the recommendations.

Added more construction and location guidance on preferred locations for dust hazard occupancies.

Emphasized explosion-hazard elimination and mitigation features.

Added chokes as an isolation method.

Refined the criteria on fans and blowers located in fugitive dust – air streams where they can become an ignition source in an atmosphere that may exceed the MEC.

Simplified the criteria for protection of vessels of unknown strength.

Resolved inconsistencies with other data sheets, especially Data Sheet 7-73, *Dust Collectors.*

Simplified the Support for Recommendations section.

May 2006. Minor editorial changes were done for this revision.

New section 3.2.3.9.1, Typical Vent Panel Mass (inertia) was added.

May 2005. Added recommendations to implement a management of change program.

January 2005. Minor editorial changes

May 2004. Minor editorial changes

May 2003. Minor editorial changes

January 2001. The document was reorganized to provide a consistent format.

August 1995. Major revisions implementing K_{st} based vent sizing technology and abandoning the prior method of vent area to protected volume method.

This data sheet includes many new recommendations which were not in the 1976 edition but many locations will require less protection than the previous version required. The following exceptions have been made to the general explosion protection requirements:

- Explosion venting is not needed for cyclones handling dusts with a K_{st} less than 80 (weakly explosible) and having an open gas outlet on top whose diameter equals or exceeds 45% of the cyclone diameter.
- Systems operating at a pressure below 0.1 bara (1.5 psia) require no protection.
- Spray dryers require a reduced amount of explosion venting compared to other equipment with the same volume. Note: the explosion venting area for spray dryers and for other equipment is now calculated using the FM Research DustCalc software.

APPENDIX C EXPLOSION VENTING

C.1 Explosion Venting for Buildings

C.1.1 Arrange pressure relieving walls to vent to a safe location. Do not expose important buildings, equipment or utilities.

C.1.2 Consider wind-loads when setting the relief pressure (P_{stat}) of the pressure-relieving wall to prevent unnecessary venting of the wall during a high wind event.

C.1.3 Do not use the roof to provide explosion pressure relief except as noted below:

A. If the walls cannot provide the needed explosion relief area, conduct an engineering study to confirm if the roof can be used to provide the portion of the explosion venting area needed.

B. Where explosion venting/pressure relief should be provided on the roof:

1. Position the explosion vents at a minimum 60° angle, either on a roof pitched at that angle or as a projection above the roof line (see Figure C.1.3-A).
2. For vents projected above the roof line, the effective vent relief area to be used in vent sizing calculations is the smallest cross-sectional area through which the combustion gases would flow.

C. In areas subject to snow and ice, prevent the buildup of snow and ice on the explosion vent as follows:

1. Provide heat tracing along the perimeter and across the surface area of the explosion vent.
2. The heat tracing can be left on permanently, or a system can be used that automatically turns on heat tracing whenever the outside temperature drops to 32°F (0°C) or lower.
3. The wiring for the heat trace cabling incorporates enough slack to allow the explosion vent to deploy as intended.
4. An acceptable alternative to heat tracing is explosion venting panels without insulation. These panels allow building heat to melt away snow or ice. Expect condensation under the explosion vent, and take measures to ensure condensation does not cause problems.

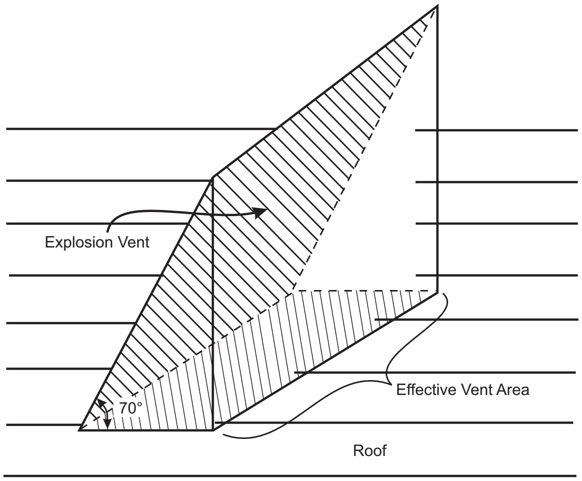

Fig. C.1.3-A. Schematic of rooftop explosion vents that project above the roof line

C.1.4 Where explosion venting devices swing out of the way rather than rupture, use gravity or mechanical devices to ensure they cannot reclose.

C.1.5 To prevent uncontrolled release of explosion vent panels where they could become projectile hazards, take the following steps:

A. Provide tethering cables to limit the vent movement.

B. Attach tethering cables to no more than two corners, making sure the tethered corners are adjacent.

C. To prevent the tethered panels from swinging back into the vent opening after the explosion, make connections at the side or bottom of the panel rather than the top. If tethers are used, set the minimum tether length per the guidance in Section 3.1.9.

D. Where the tether length is less than that specified above, consider the explosion vent a hinged panel when calculating the vent area and vented explosion pressure (P_{red}). This will account for the hindrance to the venting process created by the short tethers.

E. Tethers located at all four corners can be considered tolerable if the cable length exceeds the minimum length specified in item D. Any less, and the vent area is restricted to the annular space determined by the cable length and the dimensions of the panel.

C.1.6 Construct explosion vents of material as light in weight (mass per unit area) as possible to minimize the vent area required.

C.1.7 Avoid any windows and/or other penetrations (doors, cable runs etc.) in pressure-resistant walls. Where necessary, these penetrations should be designed to withstand the same pressure as the wall and should be sealed dust-tight using non-combustible materials.

C.1.8 Design ductwork that penetrates pressure resistant walls to prevent buckling at the juncture with the wall.

C.2 Explosion Venting for Equipment

C.2.1 General

C.2.1.1 Locate equipment with identified explosion hazards outside of buildings.

C.2.1.2 Where equipment with identified explosion hazards is inside, locate equipment along an outside wall to permit venting to an outside location.

C.2.1.3 Do not use damage-limiting construction to control an explosion involving combustible metal dusts.

C.2.1.4 Install vent ducts that redirect the flame, combustion products and pressure produced by a deflagration in a piece of equipment to a safe area in accordance with the following:

A. Route the vent to a safe outdoor area.

B. Do not locate objects in the path of explosion vents.

C. Use straight sections of duct only.

D. Limit the length-to-diameter ratio (L/D) of the duct to 1. For non-circular ducts, the equivalent diameter (D_{eff}) can be calculated as follows:

$$D_{eff} = \sqrt{\frac{4A_d}{\pi}}$$

where A_d is the cross-sectional area of the duct (m^2 or ft^2)

E. Ensure the vent duct is at least as strong as the P_{red} design of the vessel.

F. Permit no closures on the discharge end of the duct that obstruct the free venting of the discharged combustion products or pressure.

G. When the above conditions cannot be met, quantify the effect on the vent area using FM DustCalc software.

C.2.1.5 Where explosion vents can reclose, and no other openings could draw in air, provide vacuum breakers. Reclosure can potentially create vacuum conditions that can cause the vessel to implode.

C.2.1.5.1 When using tethers to prevent an explosion vent from becoming a projectile, set the minimum tether length to prevent reclosing of the vent using the following equation:

$$l \geq \frac{(a \times b)}{2 \times (a+b)}$$

Where:

l = Length of tethering cables
a, b = Side dimensions of explosion vent

C.2.1.6 Where venting devices are heavier than light-weight membranes, calculate the effect on the vent area using FM DustCalc software.

C.2.1.7 Explosion vents that are rupture membranes (e.g., prefabricated rupture disks, aluminum foil, etc.) have virtually no inertia and require no adjustment to the required explosion vent area.

C.2.1.8 Where a wire mesh screen or other obstruction should be provided between an explosion vent and the free atmosphere, adjust the effective area of the explosion vent for the reduction in venting efficiency as follows:

A. If the screen or obstruction is less than 15% of the explosion vent area, no adjustment is required.

B. A screen or obstruction that is between 15% and 40% of the explosion vent area will reduce the actual vent area. Calculate the effective explosion venting area using:

$$A_{v,eff} = A_{v,actual} \text{ X } \frac{115\text{-}\%\ blockage}{100}$$

C. Where the screen or obstruction exceeds 40% of the explosion vent area, blockage is excessive. Replace the screen or obstruction with something that creates a smaller blockage.

D. Where explosion barriers have been installed, evaluate their effect on surrounding equipment and processes using any calculations and as-built drawings of the barriers. At a minimum, that information should include the size, explosion reduction factor due to distance, efficiency and angle.

C.2.1.9 Provide a distance of at least two explosion vent diameters between an explosion vent outlet (face of explosion vent or vent duct) and any large, fixed, flat obstruction (e.g., a wall). Where a non-circular explosion vent is provided, use the largest dimension of the vent instead of the diameter.

C.2.1.10 Where a weather protection cover (“rain hat”) is provided over the end of an explosion vent duct, estimate the effect on the venting efficiency as follows:

A. If a distance of at least one explosion vent diameter is provided between the end of the duct and the weather cover, efficiency will not be affected.

B. If the distance is between 1/4 and 1 explosion vent diameter, consider the weather cover as a 90° bend in the vented flow when calculating the effect of the vent duct.

C. A distance of less than 1/4 explosion vent diameter away from the vent duct is unacceptable unless the cover is designed to fly off in the event of an explosion.

For non-circular ducts, use the hydraulic diameter for these calculations.

C.2.1.11 For explosion vent outlets having cross sections other than circular, use the hydraulic diameter as calculated below.

$$\text{Hydraulic Diameter} = \frac{4A}{p}$$

Where:

A = Cross-sectional area of vent
p = Perimeter of the cross-section

C.2.1.12 Do not provide explosion venting if the dust or its combustion products

A. Are poisonous

B. Are radioactive

C. Are corrosive to nearby equipment or structures

D. Should not be released from an otherwise closed system for any other reason

Alternatives to venting should be used instead.

C.2.1.13 Where a vessel requiring explosion venting contains significant obstructions to the free flow of gases, the installation of one large vent may be impeded by these obstructions. Use of multiple smaller explosion vents distributed at different places around the vessel can mitigate these obstruction effects. Where this is done, the total venting area provided by the multiple smaller vents should meet or exceed the vent area as specified by DustCalc. (See Section C-3.6 for support information.)

C.2.2 Vessels Operating at Greater Than 0.1 Bar(g)

C.2.2.1 When calculating the required explosion venting area for a vessel with a dust explosion hazard operating at pressures exceeding 1.5 psig (0.1 barg), apply the following guidance:

A. Set the vent-relief pressure, P_{stat} above the maximum operating pressure by at least 1.5 psig (0.1 barg)

B. Obtain vent sizing criteria from experts familiar with high initial pressure venting.

Such vessels require careful analysis. FM DustCalc software can handle initial pressure up to 58 psig (4 barg) for full-volume explosions.

C.2.3 Recoil Forces

C.2.3.1 Recoil forces from the venting of an explosion can dislodge even large vessels that are not properly anchored. Implement one of the following to control recoil forces:

A. Provide equal-sized vents at opposite sides of the vessel.

B. Calculate the magnitude and duration of the dynamic recoil force (or an equivalent static force) from a vent, and provide anchorage to resist those forces.

C.3 Support Information

C.3.1 Strength of Vessels

An explosion vent design based on P_{red} values that allow for vessel deformation will prevent catastrophic vessel failure and allow the forces and products of an explosion to move safely through the explosion vent. However, this could make the vessel unfit for future use.

If data on vessel strength is unavailable, and the assumed values 3 to 4.4 psig (0.2 to 0.3 barg) of P_{red} are used for explosion vent sizing, then the vessels will likely not be deformed in the event of an explosion, if they are of typical design. However, the possibility of deformation does exist. The innumerable variations in equipment design can make a vessel weaker than other seemingly comparable vessels. In most cases, the assumed values will be sufficiently conservative to prevent vessel rupture. Estimating the pressure that a generic type of vessel can withstand involves uncertainties. Obtaining actual design information for any vessel whose protection is being evaluated or planned is always best.

Determining the ability of a vessel to withstand an explosion event using design variations, yield, and ultimate strength as a basis has been eliminated from this document.

In cases where design strength is unknown, collection of such information can be difficult. As much information as possible should be collected to allow further analysis that can identify any potential deficiencies. This analysis may require a design engineer to determine the strength of the vessel in question.

C.3.2 Effects of Explosion Vent Mass (Inertia)

A heavy explosion vent relief panel takes longer to move out of the way than a similarly sized lightweight panel and can produce higher pressures inside the vented enclosure. Because the delay is a continuous function of the panel’s weight, its effect needs to be evaluated whenever a panel’s inertia is greater than zero.

Rupture membranes, which are typically very thin sheets of metal or plastic film, are zero-inertia devices. However, the effect of any other type of vent panel cannot be neglected and should be calculated.

DustCalc provides data from numerous organizations worldwide within a theoretical framework to effectively predict the inertia effects of explosion vent mass.

The following are examples of venting panel materials or wall construction and their mass:

- Single-layer metal panels: 2 lb/ft^2 (10 kg/m^2)
- Insulated metal sandwich panels: 3 to 4 lb/ft^2 (15 to 20 kg/m^2)
- FM Approved Explovent: 2.5 lb/ft^2 (12 kg/m^2)
- FM Approved Kalwall panel: (2.5 lb/ft^2 (12 kg/m^2)

Note: The following materials have an additional dimension of thickness in inches (cm):

- Gypsum board: 4 lb/ft^2/in. (8 kg/m^2/cm)
- Steel: 40 lb/ft^2/in. (77 kg/m^2/cm)
- Aluminum: 14 lb/ft^2/in. (27 kg/m^2/cm)
- Glass: 15 lb/ft^2/in. (29 kg/m^2/cm)
- Concrete: 12 lb/ft^2/in. (23 kg/m^2/cm)

C.3.3 Effect of Explosion Vent Ducts

The effect of the vent duct must be anticipated in the sizing of explosion vents. Placing a duct at the discharge of an explosion vent can significantly affect the pressure inside the enclosure. Depending on the length and diameter of the vent duct, the value of P_{red} can be increased by as much as an order of magnitude (10 times), which is usually enough to completely destroy the protected vessel.

Because P_{red} sharply rises as vent duct length increases, vessels with a low strength generally cannot be protected by venting through ducts if the L/D of the vent duct exceeds a value of one to two unless the vent size is proportionately increased.

Although an explosion vent duct having a cross-section smaller than the explosion vent will increase the value of P_{red} (i.e., create a worse situation), using an explosion vent duct with a cross section larger than the explosion vent area will not lower the P_{red}.

FM's DustCalc software readily calculates the effects caused by vent ducts.

C.3.4 Reclosing Explosion Vents

After the combustion of dust inside a room or vessel has ended and gases are no longer being produced to generate pressure, explosion vents that can reclose by gravity will do so. The very hot combustion gases trapped within the room or vessel begin to cool; and, unless fresh air moves into the enclosure fast enough (e.g., via an appropriately sized vacuum breaker), a vacuum will be created. This vacuum can result in vessel damage or equipment implosion. In rooms or buildings, vacuum damage is less severe but is still possible.

C.3.5 Fixed Obstructions Near the Face of Explosion Vents

A fixed obstruction located too close to an equipment explosion vent opening creates significant resistance to the free outflow of combustion products from the vented equipment, mainly due to dust burning after being ejected from the protected equipment. The combustion occurs in the semiconfined area between the vessel and the obstruction. This creates significant backpressure effects on the equipment explosion. The knowledge regarding this phenomenon is limited, and the effects are impossible to quantify. Providing any guidance on safe distances to non-flat obstructions is also not possible due to the complex effects of different geometries producing partial confinement. The only safe course of action is to locate and orient explosion vents so they do not point to nearby surfaces.

C.3.6 Distribution of Explosion Vents

To provide well-distributed explosion venting on a protected vessel that has significant obstructions within it, the following should be considered:

A. If an explosion vent is obstructed, gases will not flow out as quickly compared to an explosion vent with a completely unobstructed volume. This can cause the vented explosion pressure P_{red} to rise above the expected level.

B. If the gases heading toward the explosion vent pass over any significant obstructions, turbulence will increase substantially within the vessel. Because the rate of pressure rise of an explosion increases with turbulence, the obstacles can worsen the explosion.

C. Vents distributed throughout an entire enclosure will help ensure the gases vented during the explosion take the shortest path out of the enclosure.

APPENDIX D FM APPROVED FLAMLESS VENTING DEVICES

D.1 Supporting Information

A flameless explosion venting device (FEVD) is similar to a flame arrester fitted onto a rupture disk explosion vent (see Figure D.1-1). They are also known as “flameless explosion vent”, “flame arresting and particulate retention device”, “quench tube” or “quench pipe”. The flame arresting component does reduce the effective vent area compared to an open vent.

FEVDs are a form of explosion protection and can be used in lieu of traditional explosion vent panels or other protection systems as applicable.

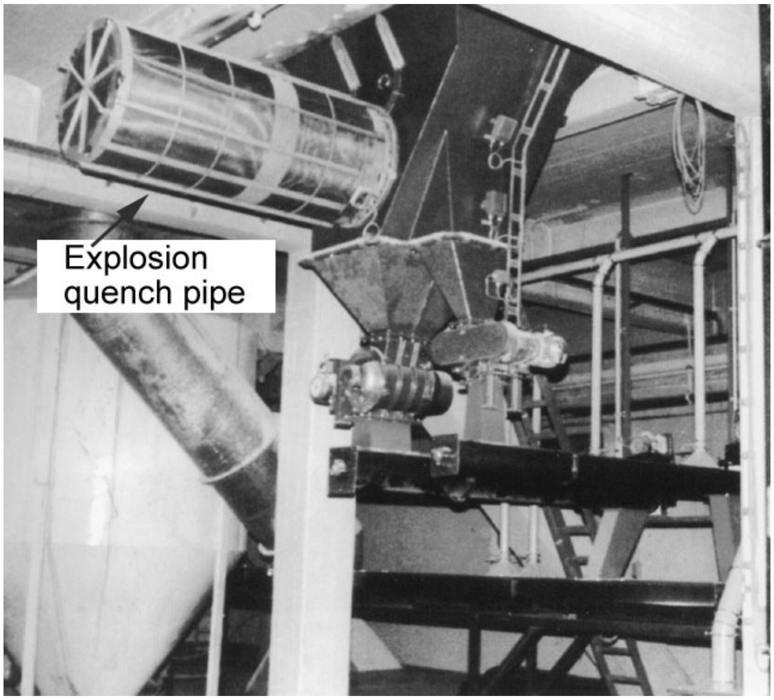

Fig. D.1-1. FM Approved flameless venting device (Photo courtesy of Rembe GmbH)

When using flameless venting devices, consider the following factors:

A. Dust K_{st} and P_{max}: These determine the vent area for the protected vessel.

B. Type of dust: Non-melting, melting or fibrous dusts can affect the efficiency factor of the flameless venting device.

C. Metal dusts: Currently no devices are FM Approved for use with metal dusts.

D. Efficiency factor (h_{total}): This is the numerical fraction (0.99 or less) that represents the effective value of the vent area after accounting for the impact of the device’s flame arresting components. In Approval Guide listings it is mainly represented by the “Effective Vent Area.” In the European (EN) standards the efficiency factor is reported as "Efficiency (E_f)." Their methodology for calculating the efficiency is different from that used in FM Approvals' testing.

E. Maximum protected volume (MPV): The maximum protected volume (MPV) is limited by the dust loading on the device, $m_{st,max}$, and the dust loading per nominal vent area (lb/in.^{2} [g/cm^2]). This loading is directly related to the nominal dust concentration used in Approval testing (lb/ft^3 [g/m^3]).

For actual applications, the design loading is based on the C_{st} of the dust used in the vent sizing design. The C_{st} is the concentration, determined by testing where K_{st} and P_{max} occur. In practice, the MPV may need to be adjusted if the C_{st} is different from the dust loading used for testing. The adjustment factor is:

$$V_{max2} = V_{max1} \text{ x } (C_{st1}/C_{st2})$$

Where:

V_{max1} = MPV listed
V_{max2} = Volume corrected for C_{st}
C_{st1} = Concentration used in the Approvals testing.
C_{st2} = Concentration of the design dust determined by testing

In choosing the proper flameless explosion venting device (FEVD), calculate the required vent area for the application, and then use the "Effective Vent Area" in the *Approval Guide* listing to select the device that would provide at least the required vent area. Doing so may require one or more devices. Some manufacturers limit the number of flameless venting devices that may be installed on the equipment to be protected. Where this limitation cannot be avoided, other protection measures may need to be used.

The selected flameless venting device(s) should not exceed the MPV. Where multiple devices are used to provide the required venting, the MPV of each device should be added to determine the total MPV. For example, if two devices each having an MPV of 110 ft^3 (3.1 m^3) are used, the vessel volume to be protected would be limited to 220 ft^3 (6.2 m^3).

As the explosion is vented through the flameless venting device, any burned or unburned dust is retained, combustion gases are cooled and no flame exits the quench pipe. In addition, the nearfield blast (pressure) effects outside the vent are greatly reduced. Thus, an explosion can be safely vented indoors through the device without the fear of igniting nearby combustibles or creating damaging pressure in the room. However, the exit gases are hot (approximately 212°F [100°]).

The listing of all FM Approved devices includes their vent efficiency, which is the factor by which the effective vent area of the device is reduced. This is different than the pressure effect calculation above.

As flameless explosion protection devices are a form of explosion venting, they can be used anywhere a traditional explosion vent can be used, subject to the specific limitations of the flameless explosion venting device.

APPENDIX E EXPLOSION ISOLATION

E.1 General

Explosion propagation between connected equipment can allow an explosion to progress through an interconnected system. Additionally, it can create "pressure piling" (see Section E.3 for additional information). The result is a large explosion pressure that can rupture connected equipment, increasing property damage and/or business interruption.

Two types of isolation devices are commonly used.

1. Mechanical isolation: This includes rotary air locks, rapid action valves, flame front/explosion diverters, high speed abort gates, double-dump valves and back-blast dampers.
2. Chemical isolation/chemical blocking systems. These systems create a chemical curtain that interferes with the explosion flame front.

For equipment designed to contain an explosion, any mechanical isolation devices on both the upstream and downstream sides of the equipment should be the same strength as the equipment they are protecting. This will prevent the device from failing and becoming a potential weak point.

On equipment fitted with explosion venting, the mechanical isolation equipment should be designed to resist the reduced design pressure (P_{red}).

When using chemical isolation systems (chemical blocking systems), consider the following factors:

A. The duct volume the system is designed to protect (may include the largest duct volume from any documented tests)

B. Actual volume to be protected by the blocking system

C. Duct strength and P_{red}

D. Worst case explosion P_{red}

E. SRD (standard-rate discharge) device layout

F. Fuel type (the material within the duct that requires protection)

G. Detection type and detection time of the blocking (isolation) system

H. Delivery rate of the suppressant

I. Delivery time of the suppressant into the volume to be protected

J. Type and quantity of suppressant used

K. System drawings of the proposed/installed system

L. The recognized code or standard (or national equivalent) to which the system is designed

M. If the vessels are not certified to a recognized code, provide documentation, signed by a PE (or national equivalent), indicating the design methods, design criteria and any safety factors used.

E.2 Specific Isolation Equipment Recommendations

E.2.1 Rapid-Action Valves

E.2.1.1 When installing rapid-action valves (float-type), do the following:

A. Locate the valve at least 16 ft (5 m) but no more than 41 ft (12.5 m) from the equipment where the explosion initiates.

B. Ensure the value of P_{stat} (the vent opening pressure) for explosion vented equipment upstream or downstream of the float-type valve exceeds the differential pressure required to shut the valve, typically about 1.5 psig (0.1 barg).

C. Where the value of P_{stat} is below the required differential pressure, arrange an alternate closing mechanism by installing an optical detection system at the explosion source to trigger the high-speed release of compressed gas near the float valve and force it to close.

D. Do not locate a float-type valve in an air stream that has a significant loading of abrasive dust that would prematurely wear down the surfaces of the moving float.

An example of this type of valve is the Ventex ESI (Figure E.2.1-1).

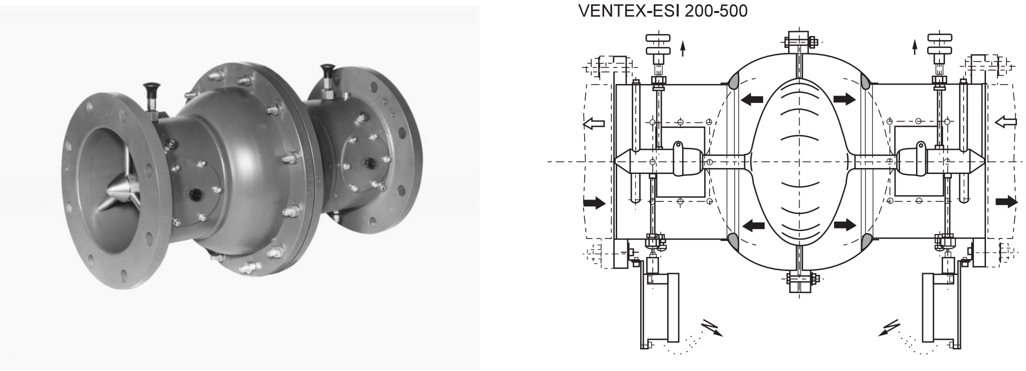

Fig. E.2.1-1. Rapid action float valve (Ventix ESI ®)

E.2.2 Explosion and Flame-Front Diverters

Do not install flame-front diverters or explosion diverters (Figures E.2.2-1 and E.2.2-2) upstream of an air-moving device, because an explosion originating upstream of the diverter can propagate past the diverter.

Do not use explosion diverters in air streams that have a significant loading of abrasive dust that would eventually erode through the pressure-relieving diverter cover.

Do not use explosion diverters for hybrid mixtures, if the flammable vapor exceeds the LEL.

Fig. E.2.2-1. Explosion diverter

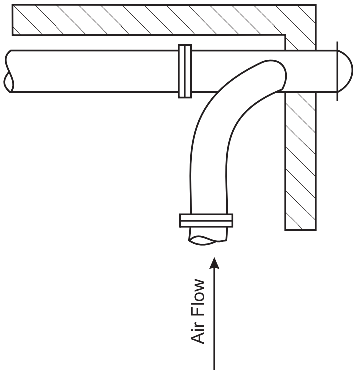

Fig. E.2.2-2. Indoor installation of explosion diverter

E.2.3 High-Speed Abort Gates

When installing high-speed abort gates (Figure E.2.3-1), do the following:

A. Actuate the high-speed abort gate by either pressure detection or infrared explosion detection in the upstream vessel where the explosion is expected.

B. Ensure the abort-gate reset is manual. Do not use automatic reset.

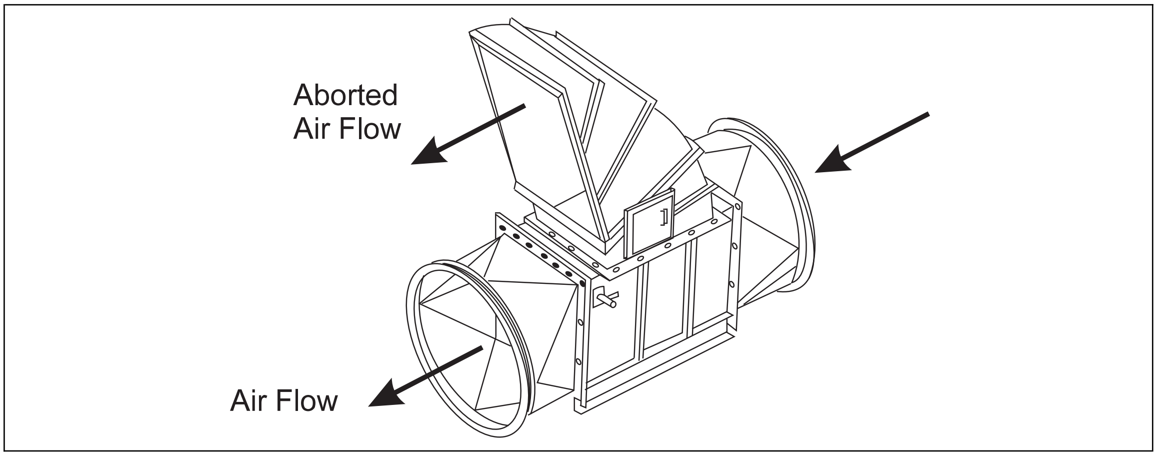

Fig. E.2.3-1. High-speed abort gate

E.2.4 Double Dump Valves

Where a double-dump valve is used as a form of isolation, provide an interlock to ensure both valves do not open simultaneously.

E.2.5 Back Blast Dampers

Where a back-blast damper is used to provide isolation, ensure the device is provided with an explosion vent downstream from the normal system flow.

E.2.6 Chokes

Chokes allow the accumulation of material through which an explosion cannot propagate.

When using chokes as a method to control explosion propagation, the following guidance applies:

A. Rotary air locks are acceptable to act as chokes if they meet all the criteria in Section 2.5.4.

B. Rotary air locks that do not meet all the criteria in Section 2.5.4 can serve as chokes if the height of powder above the air lock is equivalent to the diameter of the discharge opening and this powder height is always present.

E.3 Supporting Information

E.3.1 General

When an explosion occurs within a vessel protected by pressure containment, the pressure and the generated flame propagate along any open connected ductwork into adjacent enclosures. If the adjacent enclosure (e.g., vessel) also has a pressure-resisting design, “pressure piling” can occur. Pressure piling increases the pressure within the second vessel before the explosion flame front arrives, as the pressure disturbance travels faster than the flame front. Thus, when a dust explosion is ignited within the second vessel, the initial pressure will be well above the normal (ambient) pressure. This increase can render the pressure-resistance design of the second enclosure ineffective.

For a given fuel-to-air ratio, the final, unvented pressure of an explosion is directly proportional to the initial pressure. For example, if the first explosion pre-pressurizes the second vessel to 44 psi (3 bar) absolute, then the final pressure of the explosion in the second vessel would increase by a factor of three. For a dust with a P_{max} value of 131 psi (9 bara), the final unvented pressure in this example would be 392 psi (27 bara), well above the strength of even the sturdiest vessel designed for dust explosion pressure containment. Thus, where explosion containment is used as a protection method, providing explosion isolation is important to prevent pre-pressurizing a vessel from another explosion.

When an explosion occurs within one vessel protected by explosion containment that is connected to a second vessel protected with explosion venting, the turbulence created by the pressure front and the strong ignition source from the flame front results in a more rapid explosion in the second vessel. This connection is often unaccounted for in the vent design, causing the failure of the second vessel.

These effects occur to a lesser extent if the connected vessels are both protected with explosion venting.

Thus, where explosion venting is used as a protection method, providing explosion isolation is important to separate the vented vessel from any connected vessels protected by explosion containment.

When using active devices for explosion isolation, adequate separation between the point of detection (i.e., the installed sensor) and the isolation device is important to allow the active device time to react.

If installed too close together, the protection offered by the isolation device can be ineffective; as it will not open in time to divert the flame front. Consult with the manufacturer of the isolation device to provide the appropriate separation for that device and its associated sensor.

E.3.2 Conveying Systems as Explosion Isolation

Dense phase pneumatic conveying systems operate at comparatively low transport velocities (200 to 1,000 fpm [1 to 5 m/s]) with a high solids loading rate and high pressure (up to 125 psig [8.6 barg]). Because of the high dust loading (well above the MEC), they are unlikely to propagate the flame front from an explosion.

Dilute phase pneumatic conveying systems operate at high velocity (3,000 to 8,000 fpm [25 to 40 m/s]), with a low solids loading rate and low pressure (less than 15 psig [1 barg]).

E.3.3 Rapid-Action Float Valves

These devices actuate either on a differential pressure caused by the approaching flame front or the gas velocity in the duct. Thus, the vent relief pressure (P_{stat}) of the equipment experiencing the explosion must be high enough to ensure the valve will shut. Where a lower P_{stat} is needed to protect the equipment, an additional explosion sensor and “helper” gas (an additional gas injection into the valve) are both needed to actuate the valve. Valves may be either uni- or bi-directional (i.e., they will actuate from a pressure event coming from one direction only or from either direction). Once closed, they lock in that position and need to be manually reset.

Minimum and maximum installation distances are commonly specified to ensure the device closes properly and no transition to detonation has occurred. These distances are determined by testing but are approximately valid for a broad range of operating conditions. If hybrid mixtures are involved, both distances will be reduced; and the exact figure depends on the valve/pipe size. Manufacturer’s data supersedes this general guidance.

APPENDIX F EXPLOSION SUPPRESSION

F.1 Where explosion suppression is the chosen explosion hazard mitigation method, FM Approved explosion suppression systems should be installed in accordance with Data Sheet 7-17.

F.2 For explosion suppression systems protecting metals dusts, ensure the activation time of the detection system and the speed of the suppressant delivery are evaluated.

F.3 Do not accept any system designs that assume a partial volume explosion as the exposure.

F.4 Install FM Approved equipment in accordance with its listed limits of application.

F.5 Where explosion suppression is used as the protection method of choice, arrange explosion suppression systems as follows, to cover the full volume of the equipment:

A. At all elevator legs

B. At the head and boot pulley enclosures of indoor vertical bucket elevators

C. Throughout all interconnected, enclosed equipment for the vertical bucket elevator. This equipment includes conveyors, garners and scale hoppers, unless the equipment is arranged for choked feeds using star valves, screw conveyors with flights removed, or drag conveyors.

D. Throughout all indoor dust handling equipment, including cyclones, bag collectors and associated ducting for dust-laden air that cannot be adequately and directly vented to the outdoors.

E. Throughout all dust and product handling systems on the discharge end of equipment that has a history of explosions.