Combustible dust is a major safety concern in many bulk solids manufacturing plants. This article introduces the hazards of handling combustible dust, discusses the relevant standards and guidelines, and explains protection options available to reduce your plant’s risk for a catastrophic dust explosion.

Dust generated during bulk solids manufacturing operations can be separated into two categories: combustible and noncombustible. Under predictable conditions, a noncombustible dust won’t ignite, burn, release flammable gases, or support combustion when subjected to fire or heat. A combustible dust, on the other hand, will pose a fire or deflagration hazard when subjected to fire or heat in the presence of an oxidizing medium (such as air).

A combustible dust will present a hazard regardless of the particle size or shape, but particle size does affect a dust’s hazard level. Generally, as the particle size decreases, the explosion hazard the dust presents increases because finer particles have a larger surface-area-to-mass ratio, which allows more of the dust to ignite quickly. The smaller particles react more quickly with oxygen and require less energy to ignite. This is the same reason small twigs and kindling ignite easier than large logs when starting a campfire.

**Dust explosion mechanics**

A general fire or explosion requires three elements: fuel (such as combustible dust), an oxidant (typically air), and an ignition source. A dust explosion has two additional requirements. First, the dust must be in a state of dispersion in the air or other oxidant. Second, the dust cloud must be confined in an enclosed space at or above the dust’s minimum explosible concentration. These five requirements make up the combustible dust explosion pentagon, as shown in Figure 1.

An initial, or primary, deflagration in a dust collector will cause shockwaves that can reverberate through the building and disturb any accumulated dust. This dust may then become airborne and provide fuel for one or more secondary explosions if the primary deflagration breaks out of the dust collector or if another ignition source is present. Often a secondary explosion is much more destructive than the primary explosion and can potentially level a building in less than a second, as shown in Figure 2.

In a dust collection system, all equipment is connected by ductwork. This ductwork is very efficient at distributing air but can also allow a flame front from a deflagration to travel from one end of the system to the other. A piece of process equipment with an explosive concentration of dust along with an ignition source could trigger a primary explosion that could travel through the ductwork to the dust collector, causing a secondary explosion in the collector. This is also true in the opposite direction; if a deflagration occurs in the dust collector, the resulting flame front could travel through the ductwork back to the process equipment.
Standards and guidelines for handling combustible dust

Over the years, the National Fire Protection Association (NFPA) has created various standards and guidelines related to industrial dust collection, including:

- NFPA 61 Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities
- NFPA 68 Standard on Explosion Protection by Deflagration Venting
- NFPA 69 Standard on Explosion Prevention Systems
- NFPA 70 National Electrical Code (Articles 501, 502, and 503)
- NFPA 91 Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Particulate Solids
- NFPA 484 Standard for Combustible Metals
- NFPA 499 Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
- NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids
- NFPA 655 Standard for Prevention of Sulfur Fires and Explosions

**Figure 2**

**Effects of primary and secondary dust explosions**

(total elapsed time = 325 milliseconds)

- a. Primary deflagration inside dust collector
- b. Shockwaves caused by primary deflagration
- c. Shockwaves reflect off building surfaces
- d. Disturbed dust becomes suspended in air
- e. Primary deflagration breaks out of dust collector
- f. Secondary deflagration ignites
- g. Secondary deflagration propagates through suspended dust cloud
- h. Secondary deflagration bursts from building
- i. Building collapses and burns
• NFPA 664 Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities

On September 7, 2015, the NFPA adopted NFPA 652 Standard on the Fundamentals of Combustible Dust (2016 Edition). NFPA 652 binds all these NFPA standards and guidelines together and is now the overarching standard for the industry.

NFPA 652 contains many new requirements that place more responsibility on the facility owner-operator and the authority having jurisdiction (AHJ). The AHJ is the party responsible for enforcing the standards and for approving equipment, installation, materials, or procedures covered within the standards. Depending on the application’s scope, the AHJ may be a federal, state, or local department or an individual such as a fire marshal. For insurance purposes, however, the AHJ is typically an insurance company inspection department or representative.

Under NFPA 652, the facility owner-operator is responsible for determining whether the materials being processed or generated in the facility are combustible or explosive. If so, a dust hazards analysis (DHA) shall be completed in accordance with the guidelines of NFPA 652, Chapter 7. The purpose of the DHA is to identify hazards within a facility or process and document how the hazards are being controlled. The DHA must be performed by a qualified individual or a team led by a qualified individual, and the DHA results must be documented. The DHA will include a general overview of the entire facility where an explosion hazard exists followed by an evaluation of the materials handled and all processes, buildings, and building compartments where combustible dust is present.

The DHA requirement applies not only to new processes or facility upgrades, but retroactively to existing processes as well. The standard states that “the owner-operator shall schedule and complete DHAs of existing processes and facility compartments within a 3-year period from the effective date of the standard.”

This means that as of September 7, 2018, all facilities that process or generate combustible dust must have a documented DHA on file or risk penalties from the AHJ.

Hazard prevention and protection

OSHA requires that companies dealing with combustible dust put in place all necessary safeguards to collect and handle the dust. This includes ensuring that all electrically powered cleaning devices, such as sweepers or vacuum cleaners, are approved for the dust’s hazard classification, defined in NFPA 70 as follows:

Class I: Gases, vapors, and liquids

Class II: Dusts

- Group E: Metal dusts (conductive and explosive)
- Group F: Carbon dusts (some conductive, all explosive)
- Group G: Flour, starch, grain, combustible plastic, or chemical dusts (explosive)

Division I: Ignitable concentrations of dust are in suspension under normal operating conditions (dust clouds present)

Division II: Ignitable concentrations of dust are not typically in suspension under normal operating conditions (dust layers present)

Class III: Ignitable fibers and flyings

While preventing a dust explosion with absolute certainty is impossible, methods are available to reduce the likelihood of an explosion or limit an explosion’s potential to cause injury or damage. These methods include explosion venting, which is detailed in NFPA 68, and ignition prevention, explosion suppression, and explosion isolation, which are explained in NFPA 69.

Explosion protection methods and devices can generally be categorized as either passive or active. Passive protection methods rely on mechanics and physics in their design and tend to be less expensive than active methods. While some passive protection methods are powered, they don’t require power to operate. Active protection methods tend to allow for greater flexibility in design and application than passive methods, but they do require power to operate. As a result, safeguards and failsafe mechanisms must be incorporated into the system design in case power to the device is lost.

Different protection methods often overlap, and several methods are frequently used in combination to provide a complete explosion protection system. The dust’s explosivity characteristics along with your process and preference will determine what method or combination of methods you should choose. Whatever explosion protection options you use, it’s critical to also establish good housekeeping practices and eliminate dust accumulation on horizontal surfaces to limit the fuel available for an explosion if one should occur.

Explosion venting

An explosion vent is a panel or door on a dust collector or other enclosure that’s designed to burst or open to vent the combustion gases and pressure generated by a dust deflagration, protecting the enclosure’s structural integrity and ensuring the safety of the surrounding area. Expansion vents must be located and oriented to
direct the pressure and flames safely away from workers, equipment, and the building structure.

The three options for orienting and locating dust collectors and vessels with explosion vents are shown in Figure 3. The best option will depend on the local environment around the dust collector and the collector’s proximity to the building exterior. A standard explosion vent is suitable for collectors that are located outdoors (Figure 3a) or indoors near an exterior wall (Figure 3b) and where sufficient space is available for the fireball to vent safely. A flameless or flame-quenching explosion vent (Figure 3c) is more expensive than a standard explosion vent but is a safe option for situations where venting outside the building isn’t practical or desired.

The explosion vent size required for a given dust collection system can be calculated according to NFPA 68 and is a function of both the system design and the dust being collected. Variables associated with determining explosion vent size are shown in Table I.

As the table shows, most of the variables focus on attributes of the dust collection system, but two additional critical variables, $P_{\text{max}}$ and $K_{S_t}$, are determined by the dust’s characteristics. $P_{\text{max}}$ is the maximum pressure (in bar), developed in a contained deflagration at the dust’s optimum concentration. $K_{S_t}$ is the dust’s deflagration index, or the rate of pressure rise (in bar-m/s) during a deflagration. Dusts are placed into hazard classes based on $K_{S_t}$ value, as shown in Table II, with the least explosive dusts classified as St-1, and the most explosive dusts classified as St-3.

NFPA 68 provides a list of some common dusts and their respective $K_{S_t}$ and $P_{\text{max}}$ values. However, these values are intended as reference only. The best way to determine a dust’s explosivity is to have it tested in a lab. The test uses a spherical test chamber outfitted with
pressure sensors and a chemical ignitor. A dust sample is suspended inside the chamber and ignited to produce a deflagration, and the pressure sensors record the resulting pressure increase. The dust is tested in various concentrations, generally starting at 250 g/m³ and increasing in increments of 250 g/m³ until the maximum KSt is found at the optimum concentration.

**Ignition prevention**

A simple and effective way to protect against explosions is to prevent them from occurring in the first place. This primarily involves controlling ignition sources. In a dust collection system, a spark (or flaming ember) presents the greatest ignition risk.

As a spark travels through the dust collection system duct, you might expect the spark to drop out of or be cooled by the surrounding airstream, preventing a fire or deflagration. This is often not the case, however, because the ducts are designed to have a smooth (or laminar) airflow. As the spark travels through the duct, the smooth airflow creates a bubble of hot air around the burning ember that allows the spark to remain buoyant in the cooler airstream, as shown in Figure 4. Both passive and active methods are available for extinguishing sparks in the duct before they reach the dust collector and cause a fire or explosion.

**Passive prevention.** Passive spark extinguishing methods tend to be simple and mechanical in nature. Extinguishing a spark requires disrupting the bubble of hot air around it. This can be accomplished by changing the airflow from laminar to turbulent. A very common approach is to use an inertial separator (also called a drop-out box or spark box) that causes the airstream to strike a wall or plate, creating turbulence and causing the spark to break through the bubble and cool rapidly. Note that, while a cyclone is an inertial separator in that it uses inertia to separate particles from an airstream, a cyclone isn’t very good at extinguishing sparks. The airflow remains fairly laminar inside a cyclone, and it’s very common for sparks to pass through a cyclone without any change.

An alternative to a spark box is an inline spark arrester mounted in the ductwork upstream from the dust collector. A spark arrester divides the smoothly flowing laminar airstream and creates a churning, highly turbulent airflow, as shown in Figure 5. This turbulence allows the spark to separate from the bubble of heated air and cool.

An inline spark arrester will vary in size depending on the airflow through the duct, and the air velocity through the spark arrester can range from 2,500 to 4,500 fpm depending on the application. The device’s pressure drop (resistance to airflow) will also range from 0.5 to 1.0 inches water gauge and should be included when calculating the system’s overall pressure loss.

Both the spark box and the spark arrester are efficient and cost effective but won’t completely eliminate the possibility of a spark reaching the dust collector. As a result, these methods tend to be one part of a total solution that includes other fire and explosion protection methods.

**Active prevention.** Active spark extinguishing systems tend to be more complex than passive methods and work by performing two key operations. First, high-efficiency infrared sensors detect a spark moving through the duct. Second, a fast-acting solenoid valve sprays water into the duct to extinguish the spark. A typical active spark extinguishing system is shown in Figure 6.

As shown in the figure, the infrared sensor detects a spark and sends a signal to a control panel (Figure 6a). The control panel processes the incoming signal and sends an outgoing signal to the solenoid valve, and the solenoid valve opens, spraying water into the duct via an array of nozzles determined by the duct size (Figure 6b).

<table>
<thead>
<tr>
<th>Hazard class</th>
<th>$K_{St}$ (bar·m/s)</th>
<th>$P_{max}$ (bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>St-1</td>
<td>&lt;200</td>
<td>10</td>
</tr>
<tr>
<td>St-2</td>
<td>201-300</td>
<td>10</td>
</tr>
<tr>
<td>St-3</td>
<td>&gt;300</td>
<td>12</td>
</tr>
</tbody>
</table>

### Table II

Combustible dust hazard classes

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**Figure 4**

Spark retaining heat in laminar airflow

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Sensors can be used to detect these pressure waves and trigger a suppressant agent to quench the developing fireball before it reaches a destructive magnitude. A typical suppression system consists of a pressure sensor, a monitoring control panel, a power supply with battery backup, and a suppressant-delivery device, as shown in Figure 7.

The location, quantity, and size of the sensors and suppression devices are determined for each application based on the characteristics of both the dust ($K_{St}$ and $P_{max}$) and the vessel (size and strength). Pressure sensors are available that can sense a pressure increase in less than a millisecond. Once the pressure increase is sensed, the system will have a response time of 300 to 400 milliseconds between sensing the spark and activating the solenoid valve. This means that the distance between the sensor and suppression valve is very critical. For example, if the airstream is moving at 3,000 fpm (50 ft/s), a spark can travel 15 feet in 300 milliseconds and 20 feet in 400 milliseconds.

**Explosion suppression**

At the onset of a dust explosion, pressure waves expand out at the speed of sound ahead of the fireball.

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**Figure 5**

**Inline spark arrester**

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**Figure 6**

**Active spark extinguishing system**

a. Hot sparks detected by sensor

b. Hot sparks extinguished by spray nozzles
increase is detected, a system can deliver the suppressant agent and quench the explosion within several milliseconds. This is very important, as it only takes around 50 milliseconds for the explosion pressure to become destructive.

**Explosion isolation**

Explosion isolation devices prevent a deflagration that starts in the dust collector from traveling upstream through the ductwork and into the workspace. For most applications, this requires the isolation device to be installed on the dust collector inlet. In situations where the filtered dust collector airstream is exhausted back into the building, an isolation device must also be installed on the dust collector outlet.

**Passive isolation.** A *back-blast damper* is essentially a one-way flap valve that remains open during normal operation but is forced shut by pressure waves traveling upstream from the dust collector, preventing a deflagration from spreading through the ductwork. A back-blast damper sometimes comes equipped with a pressure relief panel (explosion vent) on the downstream side of the flap. This panel is designed to burst once the flap shuts to alleviate the deflagration pressure and requires that the damper be installed outdoors in a safe area.

Using a *material choke valve* or *rotary airlock* on the dust collector’s hopper prevents a deflagration from escaping through the collector’s material discharge. A rotary airlock must meet three main requirements to adequately provide explosion isolation. First, the body, rotor, and vanes must be strong enough to withstand the maximum anticipated explosion pressure (\(P_{\text{red}}\)). Second, to prevent flames from escaping, the clearance between the valve body and the tip of the rotating vanes must be less than 0.2 millimeters (0.0079 inches). The vanes must be monitored for wear during normal preventative maintenance activities to ensure that the clearance doesn’t exceed this limit. Finally, each side of the valve (upward rotating and downward rotating) must have two vanes in contact with the housing at all times. To accomplish this, the airlock must have a minimum of eight vanes.

**Active isolation.** Similar to active prevention methods, active isolation methods require sensing devices to detect a deflagration along with controls to activate the protection device. A high-speed abort gate isolates the airflow from the dust collector inlet or outlet and diverts the deflagration pressure and flames into the open atmosphere. The gate is triggered by a control panel that receives an explosion confirmation from a pressure monitor on the dust collector.

Devices are also available that chemically isolate a deflagration. The chemical isolation is triggered in the same way as a high-speed abort gate. Frequently, chemical isolation is part of a complete chemical suppression system, as shown in Figure 8, and the same pressure sensor that triggers the chemical suppression device in the dust collector will also trigger the inlet and outlet chemical isolation devices.

**Reference**

1. All NFPA standards and guidelines discussed in this article are available at www.nfpa.org.

**For further reading**

Find more information on this topic in articles listed under “Dust collection and dust control” and “Explosion protection” in Powder and Bulk Engineering’s comprehensive article index in the December 2016 issue or the Article Archive on PBE’s website, www.powderbulk.com. (All articles listed in the archive are available for free download to registered users.)
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Figure 8

Complete chemical suppression system with chemical isolation