

Managing Dust Explosion Hazards

VAHID EBADAT
CHILWORTH TECHNOLOGY, INC.

Companies that handle powders or other particulate solids need to be aware of the potential for fire and explosions, and follow industry best practices, codes and standards to manage the risk.

Following last year's catastrophic dust explosion at the Imperial Sugar Refinery in Georgia, the U.S. Chemical Safety and Hazard Investigation Board (CSB) pointed to its 2006 study (*1*), which indicated that 281 dust fires and explosions had occurred in the U.S. between 1980 and 2005, killing and injuring 119 and 718 workers, respectively. Since that study was released, news reports have covered approximately 80 additional dust fires and explosions. Furthermore, the CSB cited widespread failure to follow good engineering practices at facilities where these accidents took place.

Effective management of dust explosion risks requires first an understanding of the dust's explosion characteristics. Locations where combustible atmospheres and potential ignition sources could be present during both normal and abnormal operating conditions need to be identified. And the facilities must be properly designed and maintained to minimize catastrophic risks to the people who work there, as well as those living nearby. This article outlines engineering best practices aimed at managing the risks associated with dust explosions.

Required conditions for explosion

Several conditions must exist simultaneously for a dust explosion to occur:

- the dust must be combustible
- the dust must be airborne (suspended)
- the dust concentration must be within the explosible range
- the dust must have a particle size distribution capable of propagating a flame

- the atmosphere of the dust cloud must be able to support combustion
- an ignition source with sufficient energy to initiate flame propagation must be present.

Avoiding this combination of conditions is key to preventing dust explosions.

Laboratory testing

The first step in managing dust explosion risks is laboratory testing to assess powder characteristics relevant to the likelihood of an ignition and consequences of an explosion (explosion severity).

Explosion likelihood tests

The *Explosion Classification Test* (outlined in U.S. Bureau of Mines Report of Investigations 5624, Laboratory Equipment and Test Procedure for Evaluating Explosibility of Dusts) determines whether a dust cloud will explode when exposed to a sufficiently large ignition source. Based on the test results, a material is classified as either explosible or nonexplosible.

Minimum Explosible Concentration (MEC), determined by ASTM E1515, Standard Test Method for Minimum Explosible Concentration of Combustible Dusts, is the lowest concentration of dust in air that can propagate flames when ignited.

Limiting Oxidant Concentration (LOC) is measured by European Norm (EN) 14034-4, Determination of the Limiting Oxygen Concentration of Dust Clouds, which determines the minimum concentration of oxygen (as displaced by an inert gas, such as nitrogen) that is capable of

supporting combustion. An atmosphere having an oxygen concentration below the LOC is incapable of supporting combustion, and therefore cannot support a dust explosion.

Minimum Ignition Temperature (MIT) is assessed by two different methods. The lowest temperature at which a dust cloud can be ignited is determined by ASTM E 1491, Standard Test Method for Minimum Autoignition Temperature of Dust Clouds. The lowest temperature at which a dust layer of standard thickness (5.0–12.7 mm) can be ignited is determined by ASTM E 2021, Standard Test Method for Hot Surface Ignition Temperature of Dust Layers. The results of the minimum ignition temperature tests can be used to evaluate the dust’s sensitivity to ignition by hot environments and process equipment surfaces, hot surfaces caused by overheating of bearings and other mechanical parts due to mechanical failure, frictional sparks, and exposure to temperatures beyond the maximum temperature rating of electrical equipment.

Minimum Ignition Energy (MIE) is evaluated by ASTM E 2019, Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air, which determines the lowest electrostatic spark energy that is capable of igniting a dust cloud at its optimum ignitable concentration. This primarily assesses the susceptibility of dust clouds to ignition by electrostatic discharges from ungrounded metal struc-

tures, people, insulating (plastic) objects, and the surface of the bulk powder during transfer to vessels.

Electrostatic Volume Resistivity and Electrostatic Chargeability can be assessed based on the general provisions of ASTM D 257, Standard Test Methods for DC Resistance or Conductance of Insulating Materials (which is currently undergoing revision to address powders). Based on volume resistivity, powders are classified as low, moderately, or highly insulating. Insulating powders have a propensity to retain static charge and can produce hazardous electrostatic discharges when exposed to grounded facilities, equipment, or personnel. Electrostatic chargeability is a measure of powder particles’ tendency to become charged during handling, processing, and transfer conditions. This test provides data that can be used to develop appropriate materials-handling guidelines from an electrostatic hazards point of view.

Explosion severity tests

The *Maximum Explosion Pressure* (P_{max}), *Maximum Rate of Pressure Rise* ($(dp/dT)_{max}$), and *Deflagration Index* (K_{st}) are evaluated using ASTM E 1226, Standard Test Method for Pressure and Rate of Pressure Rise of Combustible Dusts. P_{max} and $(dp/dT)_{max}$ are used to calculate K_{st} for the dust cloud. These data are then used to design explosion-protection measures, such as explosion relief venting, suppression, containment, and isolation.

Management deficiencies

The CSB has identified three areas that often receive inadequate management attention (1).

Existing codes and standards, although comprehensive, are inconsistently applied and therefore are ineffective. Codes and standards incorporate the most up-to-date experience and information in the form of best industry practices.

As this issue goes to press, the U.S. Occupational Safety and Health Administration (OSHA) is preparing to issue an Advanced Notice of Proposed Rulemaking on combustible dust hazards. Until such regulations are promulgated, companies must comply with OSHA’s “General Duty Clause,” which requires employers to provide a safe place to work. This involves following the best industry practices specified in pertinent dust codes and standards. Most of these codes and standards (Table 1) are cited in the dust explosion hazard-management section of the International Fire Code and are requirements of that code.

Material Safety Data Sheets (MSDSs) do not adequately convey combustible powder properties. The existing OSHA Hazard Communication Standard (HCS) and the American National Standards Institute consensus standard for MSDS format and preparation (ANSI Z400.1) do not

Table 1. Best industry practices for dust explosion management are based on National Fire Protection Association (NFPA) Standards.

NFPA 61	Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Products Facilities, 2008 Edition
NFPA 68	Guide for Venting of Deflagrations, 2007 Edition
NFPA 69	Standard on Explosion Prevention Systems, 2008 Edition
NFPA 77	Recommended Practice on Static Electricity, 2007 Edition
NFPA 484	Standard for Combustible Metals, Metal Powders, and Metal Dusts, 2006 Edition
NFPA 499	Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, 2008 Edition
NFPA 654	Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids, 2006 Edition
NFPA 655	Standard for Prevention of Sulfur Fires and Explosions, 2007 Edition
NFPA 664	Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities, 2007 Edition

specifically require MSDSs to include quantitative data on combustible dust properties and fire/explosion hazards. As a result, when an MSDS does provide explosivity information, it is often in the form of qualitative statements, such as “Powder may form explosive dust/air mixtures.”

Qualitative statements give no hint as to the conditions required to create an explosion hazard, or the relative violence of the resulting deflagration (*i.e.*, propagation of a combustion zone). Good information on the hazardous properties of materials is critical to an adequate process hazards analysis. Therefore, all pertinent fire and explosion, electrostatic, and thermal instability information should be included in the MSDS to allow adequate understanding and control of the hazards associated with combustible dusts.

Awareness and training are needed to ensure that operating personnel and others responsible for safety and fire prevention oversight are knowledgeable on the subject of dust explosion hazards and can apply existing codes and standards to prevent dust explosions. A common thread in many of the most serious incidents has been substandard housekeeping practices resulting in the ignition of secondary explosions that caused massive damage.

Prevention and protection

Safety initiatives aimed at preventing dust cloud explosions typically involve implementing measures to avoid an explosion (explosion prevention), as well as designing facilities and equipment so that in the event of an explosion people and facilities are protected (explosion protection). Selection of explosion prevention and/or protection measures is usually based on:

- the availability of information on the sensitivity of the powder(s) to ignition and the resulting explosion severity
- the nature of the processes and operations
- the level of personnel knowledge of the consequences of a potential dust explosion and adherence to the appropriate preventive measures
- the potential environmental effects of a dust explosion
- the potential for business interruptions resulting from a dust explosion.

Limit the availability of fuel

An explosible atmosphere such as a dust cloud serves as fuel for a fire or explosion. Proper ventilation can prevent the formation and/or spread (beyond the source of release) of an explosible atmosphere.

Dilution ventilation provides a flow of fresh air into and out of a building. This method is not effective at controlling the concentration of dust cloud atmospheres, but it is often used to reduce the background concentration of a flammable vapor atmosphere in the work area.

Local exhaust ventilation (LEV) is designed to intercept the fuel at the source of release, dilute the atmosphere, and direct it into a system where the material is recovered or destroyed. Correctly designed LEV systems are very effective at limiting the spread of dust cloud atmospheres beyond the source of release.

Limit the availability of oxidant

If the local atmosphere is sufficiently depleted of oxidant — normally the oxygen in air — it will be unable to support combustion.

Adding an inert gas can reduce the oxidant concentration below the level needed to support combustion. Nitrogen is the most commonly used inert gas; other inert gases include carbon dioxide, argon, helium, steam, and fluegas from onsite processes.

Oxidant can also be removed by working under vacuum conditions.

The limiting oxidant concentration (LOC) for combustion depends on the type of dust and inert gas used. Once the dust's LOC has been determined for the inert gas that will be used, the gas is introduced into the vessel. Successful inert-gas blanketing is possible only if the entire volume of the vessel becomes inert and the inert atmosphere is maintained at all times — even when the vessel is opened to the atmosphere during the addition of solids and/or liquids.

Eliminate heat sources

The elimination of ignition sources requires the control of heat sources, such as:

- external surfaces of hot process equipment, such as heaters, dryers, steam pipes, and electrical equipment
- mechanical failure of equipment, such as bearings, blowers, conveyors, mills, mixers, and unprotected light bulbs
- hot work, such as welding, burning and cutting.

A hot surface may directly ignite a dust cloud, or it may first ignite a dust layer that has settled on it that subsequently ignites a dust cloud. Such burning layers can also propagate fire throughout the area.

Measures that may be considered for preventing a dust cloud ignition by heat sources include:

- In processes that involve heating (*e.g.*, drying), maintain the temperature below the solid's self-heating temperature.
- Prevent the overloading of processing equipment (*e.g.*, grinders, feeders, conveyors, blenders, etc.), because internal buildup will reduce heat loss from the material and increase the operating temperature above normal. Consider the installation of thermocouples and/or overload protection devices on drive motors.

Article continues on next page

Safety

- Isolate or shield hot surfaces.
- Prevent the accumulation of dust on hot surfaces, and promptly remove any that does build up.
- Use approved electrical equipment.

Prevent friction/impact sparks

The ability of friction/impact sparks to ignite flammable atmospheres depends (among other factors) on the composition of the impacting surfaces. Frictional sparks could be expected when:

- items constructed from light alloys (such as aluminum) strike a rusty steel surface
- a rusty steel surface that has been coated with a layer of aluminum-containing paint is struck by a hard object
- surfaces containing flint, rock, or grit are struck with a hard object
- operators use, drop, or otherwise strike metal equipment with metal tools or objects.

In work environments where friction/impact sparks might be expected, consider the following measures:

- Prevent overheating due to misalignment, loose objects, belt-slip/rubbing, etc., by regular inspection and maintenance of equipment.
- Prevent foreign material that may present an ignition hazard from entering the system. Consider using screens, electromagnets, pneumatic separators, etc., especially at milling and grinding feed locations.
- Do not return floor sweepings to any machine.
- Minimize the likelihood of impact sparks through proper tool selection, wrist straps to prevent operators from dropping tools, and operator awareness (training).
- Control hot-work operations through a hot-work permit system in accordance with NFPA 51B, Standard for Fire Prevention During Welding, Cutting and Other Hot Work.
- Remove any dust deposits promptly.

Finally, a gas/vapor detector should be installed to ensure that flammable vapors are not present, as they pose additional hazards.

Electrical equipment and instruments

Incorrectly specified electrical equipment can create an ignition source by causing electrical sparks or hot surfaces. Therefore, electrical equipment must be suitable for the environment in which it is to be used. In order to select the appropriate equipment, it is necessary to define hazardous (classified) locations where ignitable atmospheres could occur.

Article 500 of the National Electrical Code (NFPA 70) specifies area classifications and the type and design of equipment and wiring methods that are permitted to be used in classified areas. Its intent is to prevent electrical equipment from providing a means of ignition for an ignitable

atmosphere. Additional guidance on the extent of classified areas for dust/air atmospheres is provided in NFPA 499, Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas.

Control of electrostatic hazards

General precautions for controlling electrostatic ignition sources (2) include:

- *bonding and grounding.* Spark discharges can be avoided by electrically grounding conductive items such as metal equipment, fiberboard drums, conductive/static dissipative plastic liners and containers, low-resistivity powders, and people.

- *restricting the use of insulating materials.* Where processes could create high surface charges, nonconductive materials should not be used, unless the breakdown voltage across the material is less than 4 kV. Examples of nonconductive objects include plastic pipes, flexible connectors, containers, bags, coatings, and liners.

- *charge reduction by humidification.* High relative humidity can reduce the resistivity of some powders and insulating objects and increase the rate of charge decay to ground. However, in most cases this will only be effective if a relative humidity in excess of 65% is maintained (at ambient temperature).

- *charge reduction by ionization.* Localized ionization (corona discharges) from sharp, grounded, conducting probes or wires can sometimes reduce the level of electrostatic charge from powder particles entering a vessel. Electrostatic ionization devices are not, however, without problems, and should only be used after consulting with an expert.

Explosion protection measures

If the formation of an explosible atmosphere cannot be prevented and all sources of ignition cannot be reasonably eliminated or excluded, then the possibility of a dust cloud explosion persists. Under such conditions, measures should be taken to protect people and minimize damage to facilities. Explosion protection measures should be considered *in addition to* taking all reasonable steps to reduce the possibility of forming or spreading a dust cloud and to eliminate potential ignition sources.

Explosion containment. Equipment should be able to withstand the maximum explosion pressure resulting from the deflagration of the dust/air mixture present in the equipment

Explosion suppression. Explosion suppression relies on early detection of an explosion and the rapid injection of a flame suppressant before damaging pressures are attained. A typical explosion pressure at the moment of detection is 0.035 to 0.1 barg. Suppressant extinguishes the flame within

a fraction of a second. An explosion suppression system normally includes an explosion detector, control unit, suppressor, and suppressant. Activation reduces the system pressure to a “safe” level well below that of the unsuppressed explosion (preventing enclosure rupture) and extinguishes the flame.

Explosion relief venting. The principle behind explosion relief venting is that a dust explosion in a vessel causes a vent (or multiple vents) of sufficient area to open rapidly and discharge the combustion products (flame, hot gases) to a safe location, thereby preventing overpressurization of the vented enclosure. In other words, the vessel fails in a planned and predictable way, such that people and facilities are protected from the effects of the dust explosion.

Explosion relief venting has the advantage of being relatively inexpensive compared to other explosion protection options, and in many cases is simple to install. However, relief venting is limited in that it is not suitable for toxic materials, some of which will be released to the atmosphere in the event of an explosion. Also, the venting of combustion products inside a building is usually unacceptable.

Explosion isolation measures

Regardless of the explosion protection measures considered, any dust cloud explosion should be prevented from propagating from the location where it originates to other locations in the plant. This is referred to as explosion isolation.

Dust explosions can propagate through ducts, pipes, chutes, conveyors, etc. The first step in isolating an explosion is to avoid unnecessary connections. If this is not possible, barriers should be created in the path of the explosion.

Mechanical barriers. Explosion propagation may be prevented by the presence of some type of physical barrier. Mechanical barriers may include rotary valves that have a sufficient number of blades to form a barrier, screw feeders that are modified to continuously contain a plug of material, and fast-acting shutoff valves.

Chemical barriers. The flame front or pressure wave is detected and a suitable suppressant is injected to extinguish the flame. Although chemical barriers extinguish the flame, they cannot prevent the explosion pressure from propagating. Downstream process equipment should therefore be able to withstand the resulting “suppressed” pressure.

Closing thoughts

The safe management of potential dust cloud explosions could include taking measures to avoid an explosion (explosion prevention) or designing facilities and equipment so that in the event of an explosion people and facilities are protected (explosion protection). Selection of explosion prevention and/or protection measures is usually based on:

- the availability of information on the powder’s sensitivity to ignition and the resulting explosion severity
- the nature of the processes and operations
- the level of personnel’s knowledge and appreciation regarding the consequences of a potential dust explosion and adherence to preventive measures
- the environmental effects of a dust explosion
- the business interruptions resulting from a dust explosion
- the corporation’s safety culture and its commitment to protecting personnel and property.

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FURTHER READING

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VAHID EBADAT, PHD, is the CEO of Chilworth Technology, Inc. (250 Plainsboro Rd., Building 7, Plainsboro, NJ 08536; Phone: (609) 799-4449; Fax: (609) 799-5559; E-mail: vebadat@chilworth.com; Website: www.chilworth.com). He has worked extensively as a process and operational hazards consultant for the chemical, pharmaceutical and food industries, and is a regular speaker at training courses on gas and vapor flammability, dust explosions, and controlling electrostatic hazards. He is a member of several standards committees, including NFPA 77 Recommended Practice on Static Electricity, NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids, and ASTM E 27 Hazard Potential of Chemicals. He received a BS and PhD in electrical engineering from Southampton Univ.