TESTIMONY BEFORE CONGRESS

July 29, 2008; 10:00 AM; Room SD-430, Dirksen Senate Office Building

"TECHNICAL ASPECTS OF DUST EXPLOSIONS AND FLASH-FIRES"

Richard W. Prugh
Sr. Process Safety Specialist
Chilworth Technology, Inc.

Introduction

Thank you for the opportunity to present some of the technical details that are involved in dust explosions and in methods for preventing such incidents, with some discussion of existing hazard-control rules and regulations.

As stated in the "Background" to the National Emphasis Program of the Occupational Safety and Health Administration:

"Dust deflagration, and other fire and explosion hazards in industries are covered by several OSHA standards and the general duty clause. A chemical dust deflagration occurs when the right concentration of finely divided chemical dust suspended in air is exposed to a sufficient source of ignition to cause ignition (combustion) of the dust. If the deflagration is in a confined area, an explosion potential exists. These materials can also cause other fires. Combustible dust is often either organic or metal dust that is finely ground into very small particles. The actual quantity of dust that may accumulate in an affected area may vary, depending upon air movement, particle size, or any number of other factors." [Reference 1]

Recent incidents have indicated that the hazards of combustible materials in dust form either:
(1) have not been recognized by the persons that have a responsibility to protect employees, or
(2) adequate precautions – in the form of engineering or administrative controls – to minimize the hazards have not been taken. Aside from exposures to toxic dusts, the most serious of worker exposures to dusts involves explosion and flash-fire of clouds of combustible dust.

The most-basic premise in the control of dust-explosion hazards is that all materials that are combustible can explode, under "the right" set of conditions. Thus, it is essential that managers study processes that generate dust, to determine the properties of the materials involved, identify the conditions that could lead to dust explosions, and then take action to prevent such incidents.

The Right Concentration

Like flammable gases and vapors, there is a lower limit to dust-cloud concentrations that can result in propagating combustion, if a strong ignition source is present. The lower limit is termed the Minimum Explosible Concentration [MEC], as distinguished from the Lower Explosive Limit [LEL] for gases and vapors. Whereas LELs usually are expressed in terms of volume percent, the MECs are expressed in terms of grams per cubic meter of air.

Mixtures of combustible dust and air at and above the Minimum Explosible Concentration are very dense. The "rule of thumb" for such mixtures is that the thumb cannot be seen at the end of an outstretched arm. Concentrations above the Minimum Explosible Concentration occur in some items of process equipment, such as mills and grinders, mixers and blenders, and screeners and sifters, and in dust collectors when the collected dusts are shaken or blown-back from the filters.

However, it is very unlikely that such high concentrations would occur in rooms or buildings. Typically, such mixers occur only when accumulations of dust are disturbed or dispersed; as examples, by mechanical shock, a blast of air, dumping bags of powder, and vigorous sweeping. Dense dust clouds also can occur when accumulations of dust at high elevations in rooms or buildings are disturbed by a “primary” explosion, and ignition of the dense dust cloud can result in a damaging “secondary” explosion.

High-elevation accumulations of dust can result from use of compressed air for cleaning equipment and surfaces. This type of cleaning results in “classification” of the dust, such that the larger particles descend to the floor and the very small particles may remain in suspension. Air currents can then loft the small particles to upper elevations, where they may settle onto horizontal surfaces, such as roof supports, ductwork, tall equipment, process piping, and cable trays.

Unlike flammable gases and vapors, which have rather sharp Upper Explosive Limits, most dusts do not have an upper limit for explosible concentrations. Flammable gases and vapors at very high concentrations in air form a mixture that is “too rich” to allow propagating combustion. That is, the heat capacity of the “extra” gas or vapor absorbs the heat of combustion, and flame does not propagate. For high concentrations of combustible dust in air, however, the burning dust can consume most of the available oxygen in the mixture, but combustion may not completely stop. Thus, venting of an explosion from a ruptured process vessel or from a dust collector can result in a very large fireball, with the size of the fireball being several times the volume of the original container.

There is an “ideal” concentration for each mixture of combustible dust and air, and ignition of this concentration yields the maximum explosion pressure, the fastest burning rate, and – typically – this mixture is easiest to ignite. For some dusts, this concentration can be calculated and is termed the “stoichiometric” concentration. For example, the stoichiometric concentration for sugar/sucrose is about 245 grams per cubic meter; this corresponds to at least twenty million dust particles in every cubic foot of air and would be a very dense dust cloud.

Prevention of dust clouds is attained by good design of equipment – to provide containment of powders and dusts – and good housekeeping – including prompt and careful removal of spilled powders and dusts.

A Sufficient Source of Ignition

If the energy of an ignition source is not sufficient, propagating combustion cannot occur. For many combustible dusts, the Minimum Ignition Energy is very low, such that the electrostatic energy on the human body can cause propagating combustion. It is more typical, however, that somewhat greater energies are required, such as the energy in an electrical arc, a flame, a hot surface, or the electrostatic energy on ungrounded equipment.

Preventing ignition of possible dust clouds is attained by grounding and bonding of equipment, to prevent accumulation of electrostatic charges; installing electrical equipment that will prevent intrusion of dusts, with compliance to the National Electrical Code; ensuring absence of flames and high-energy arcs, with a “hot work” permit system; prohibiting smoking in potentially dusty areas; insulating or otherwise protecting hot surfaces; and good preventive-maintenance and mechanical-integrity programs, to prevent friction and impact-caused ignition sources.

Confinement of Combustion

If the combustion of a mixture of dust and air is confined, the resulting hot combustion gases can generate very high pressures. Typically, the pressures resulting from dust/air explosions are near 100 pounds per square inch. Such pressures can rupture equipment, destroy walls and ceilings of rooms, severely damage walls and roofs of buildings, and threaten personnel.

Preventing confined combustion of dust/air mixtures can be accomplished by installing explosion vents on equipment that could contain explosible mixtures. The size of the required explosion vent depends primarily on the volume of the equipment – or room, or building – and the ability of the equipment – or room or building – to withstand internal pressure, and the speed of the combustion reaction.

Preventing Explosive Combustion of Dust/Air Mixtures

There are several methods for preventing damaging dust explosions, in addition to the explosion-venting described above.

In one method, the oxidant (the oxygen in air) can be removed from processing equipment through the use of an inert gas (such as nitrogen or carbon dioxide) to purge the air from the equipment. For many dusts, reducing the oxygen concentration by about one-half prevents propagating combustion. However, the oxygen concentration must be reduced much further for some metal dusts (such as aluminum and magnesium).

Another method utilizes an inert powder or mist to quench or suppress the combustion, such that the combustion pressure is limited to a few percent of the unsuppressed explosion pressure. Discharge of the suppressant can be triggered by flame detectors or the small pressure increase that signals the beginning of combustion.

A third method involves constructing the process equipment to withstand the maximum pressure that could be developed by a dust/air explosion; thus, "containing" the explosion. This method is used infrequently, due to the cost of constructing equipment to withstand the high pressures attained by dust/air explosions.

A fourth method involves "combustible concentration reduction", by preventing the formation of large high-concentration dust clouds. This is accomplished by providing local exhaust ventilation at equipment openings where dust is generated or released, with the objective of reducing the concentration below one-quarter of the MEC. For flammable gases and vapors, floor-level exhaust ventilation and general area ventilation (with wall and roof fans) are very effective in diluting flammable vapors and preventing the formation of large explosible clouds; however, dilution ventilation is not very effective for dusts, since particles can settle on surfaces that are outside the areas that are swept by the entering and exiting air stream.

Unfortunately, this fourth method – preventing the formation of small-particle dust clouds having high concentrations – cannot be used reliably within process equipment because of the variability of powder-handling processes. For example, attrition and grinding of coarse powders during handling, mixing or blending, and conveying usually results in formation of more-hazardous small-particle dusts.

However, use of this fourth method – combustible concentration reduction – is important in preventing secondary explosions within rooms and buildings. Frequent inspections of areas where combustible dust can accumulate, and frequent removal of accumulated dust – thus, "good housekeeping" – can minimize the secondary-explosion hazard.

Unconfined Combustion

When combustion of a small dense dust cloud occurs in an unconfined space, the result can be a flash-fire, often without pressure effects. Although persons outside the flash-fire might not be seriously affected, persons inside the flash-fire are at risk of serious injury, particularly if they are wearing combustible clothing. Thus, persons who handle dusty and combustible powders – or are otherwise exposed to flash-fire hazards – should be wearing flame-resistant clothing.

Suggestions for Prescriptive and/or Performance-Based Legislation

There are several existing "models" for control of combustible-dust hazards, ranging from the "simple and non-specific" General Duty Clause, to the "all-inclusive" recent legislation of the State of Georgia.

1. General Duty Clause   Section 5(a)(1) of the Occupational Safety and Health Act of 1970

"Each employer shall furnish to each of his employees employment and a place of employment which is free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."

The General Duty Clause is often used by OSHA when there is no specific standard that applies to a recognized hazard in the workplace. OSHA may also use the General Duty Clause when a standard exists, but it is clear that the hazards involved warrant additional precautions beyond what the current safety standards require [Reference 2].

Other OSHA standards that can be referenced as a "general duty" in citations are 29 CFR 1910.22:

"(a) Housekeeping. All places of employment, passageways, storerooms, and service rooms shall be kept clean and orderly and in a sanitary condition."

and 29 CFR 1910.176:

"(c) Housekeeping. Storage areas shall be kept free from accumulation of materials that constitute hazards from tripping, fire, explosion, or pest harborage."

and 29 CFR 1910.307:

"(a) Scope. This section covers the requirements for electric equipment and wiring in locations which are classified depending on the properties of the flammable vapors, liquids or gases, or combustible dusts or fibers which may be present therein and the likelihood that a flammable or combustible concentration of quantity is present. Hazardous (classified) locations may be found in occupancies such as, but not limited to, the following: . . . . agricultural or other facilities where excessive combustible dusts may be present, . . . "

These "general duty" requirements provide very limited guidance to owners/operators who generate or handle combustible dusts. For example, the housekeeping standards do not address the need for preventing and removing accumulations of dusts on elevated surfaces, and the electrical standard does not address other types of ignition sources, such as hot surfaces and static electricity – outside or inside equipment – and open flames or welding sparks.

<u>2. OSHA Process Safety Management Standard</u>   29 CFR 1910.119

"Purpose. This section contains requirements for preventing or minimizing the consequences of catastrophic releases of toxic, reactive, flammable, or explosive chemicals. These releases may result in toxic, fire or explosion hazards."

"Application. (1) This section applies to the following: . . . . "

Combustible dusts are not included in the scope of this section, but at least six of the listed chemicals are solids at room temperature and could form explosible dusts. This standard provides good guidance concerning fourteen aspects of process safety, and all could be applied to control of combustible-dust hazards.

<u>3. OSHA Grain Handling Facilities Standard</u>   29 CFR 1910.272

"Scope. This section contains requirements for the control of grain dust fires and explosions, and certain other safety hazards associated with grain handling facilities."

"Application. Paragraphs (a) through (n) of this section apply to grain elevators, feed mills, flour mills, rice mills, dust palletizing plants, dry corn mills, soybean flaking operations, and the dry grinding operations of soycake."

This standard is limited to control of hazards in grain operations, but could be modified to serve as guidance for control of combustible-dust hazards, generally.

<u>4. NFPA 654, "Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids"</u>

"Scope. This standard shall apply to all phases of the manufacturing, processing, blending, pneumatic conveying, repackaging, and handling of combustible particulate solids or hybrid mixtures, regardless of concentration or particle size, where the materials present a fire or explosion hazard." [This standard excludes – but references – the following similar standards: NFPA 61 (Food Processing Facilities); NFPA 484 (Combustible Metals); NFPA 655 (Sulfur); and NFPA 664 (Woodworking Facilities).]

These standards contain both prescriptive and performance-based recommendations concerning the typical operations and equipment in dust-generating and dust-handling processes. Alternative approaches to hazard control are offered in "performance-based design options" of NFPA 654 and NFPA 664.

5. Factory Mutual Engineering Corp., Property Loss Prevention Data Sheets 7-76, "Prevention and Mitigation of Combustible Dust Explosions and Fires" (2000).

"Scope. This data sheet provides preventive measures to reduce the frequency of combustible dust explosions, and protection features to minimize damage from a combustible dust explosion."

This document references NFPA publications but provides much more prescriptive and quantitative guidance concerning dust-explosion prevention and mitigation.

6. Georgia Rules and Regulations of the Safety Fire Commissioner Chapter 120-3-24-0.8

"Promulgation and Purpose: A primary purpose of these rules and regulations is to establish the state minimum fire safety standards and requirements for the prevention of loss of life and property from fire and explosions in facilities that have operations involving the manufacturing, processing, and/or handling combustible particulate solids including manufacturing processes that create combustible dust."

This document lists 76 NFPA Codes and Standards, but (perhaps inadvertently) omits NFPA 499, "Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas". New subsections have been added to several of the referenced Codes and Standards to change a recommended practice to "Facilities . . . shall comply with this standard as a mandatory requirement."

Thus, at the present time, there exist several legislated and guidance documents that could serve as models for Federal rules for dust-hazard controls. The attached document illustrates how the Grain-Dust standard could be modified for combustible dusts in general. However, it is likely that further modifications would be needed to cover the wide range of dusts that are encountered in U. S. industries, which include coal, pharmaceuticals, plastics, basic chemicals, explosives, and many other combustible materials, in addition to foodstuffs and grains.

Key Points in the Prevention of Combustible-Dust Explosions

A. The Problem

1. A very high percentage of dusts are combustible, including solid hydrocarbons (such as polyethylene and polystyrene), carbohydrates (such as sugar and grains), and many metals (such as magnesium and aluminum); exceptions are materials such as dirt and clay dust, sand, limestone and other carbonates, and most oxides.

2. Every combustible material will create an explosion with the right conditions: particle size [fuel], dispersion in air, concentration in air [oxidant], ignition energy, and confinement [thus, the "dust-explosion pentagon"].

3. Existing today are: the technology and knowledge; codes, standards, and guidelines; and engineering expertise that are needed to prevent and mitigate combustible-dust explosions.

4. Limited generic data are available concerning the properties of combustible dusts; data for the specific powders and dusts that are involved in the processes of owners/operators usually need to be developed, primarily through testing.

5. At present, there apparently is very-modest enforcement of the consensus codes and standards that apply to combustible dusts, although all 50 states "administer" the International Building Code [http://www.iccsafe.org/images/pmg/map-IBC.jpg]. The IBC includes the requirements of the predecessor Uniform Building Code, the BOCA Building Code, and the Southern Building Code. As such, there are extensive requirements for explosion prevention and mitigation for combustible dusts. Similarly, 25 states have adopted the International Fire Code [IFC], and municipalities in an additional 16 states have adopted parts or all of the IFC [http://www.iccsafe.org/images/pmg/map-IFC.jpg], although there is limited specific guidance for control of dust-explosion hazards in the IFC.

6. The National Fire Protection Association has published compilations of several of the Fire Codes, in NFPA 1 [Uniform Fire Code] and NFPA 5000 [Building Construction and Safety Code]. Relatively few states and municipalities have formally adopted these more-recent Codes.

B. The Solution

1. Companies that produce, process, or handle dusts and powders need to generate data concerning the explosibility properties of their materials.

2. The data that are obtained by these companies should be formally communicated within their organizations and to their customers via media such as Material Safety Data Sheets.

3. Using the explosion-hazards data, owners/operators should assess the hazards that are associated with processes that are operating in their plant.

4. Based on the dust-explosion hazards assessments, owners/operators should implement preventive and explosion-mitigating measures that will protect personnel and property.

5. An objective of the proposed Federal legislation should be to require owners/operators to adopt and abide by the above guidance toward solution of the existing dust-explosion "problem".

Summary

Combustible powders and dusts present significant hazards, but the risk of injury and/or property loss can be controlled by "recognized and generally-accepted good engineering practices", as expressed in existing Codes and Standards. The owners/operators of facilities that generate or handle such materials should be expected to recognize dust-explosion and flash-fire hazards in their operations and minimize the risk of such incidents, for protection of their employees. Several models of prescriptive and performance-based methods for control of combustible-dust hazards are available and are in use in many industries; these models could serve as the basis for appropriate Federal legislation.

References

1. U. S. Department of Labor, Occupational Safety and Health Administration, "Combustible Dust National Emphasis Program" [reissued], CPL 03-00-008 (March 11, 2008).

2. J. J. Keller & Associates, Inc., "OSHA Compliance Manual", page OSHA-25 (June 2006).