

Dust Explosion Primer

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Dust Explosion Primer

Dust explosions have been documented as early as the late 18th century, when an Italian count reported his analysis of an explosion in a baker's flour warehouse.¹ Although the understanding of dust explosions has greatly improved since then, CSB found in its investigations that many workers and managers are not aware of the potential for dusts to explode. Further, these individuals often do not understand the nature of dust explosions. This document provides an overview of the fundamentals of dust explosions and combustible dusts.

1.0 Basics

Combustible materials are materials that are capable of burning in air. Most organic materials and many metals—and even some nonmetallic inorganic materials, if finely divided and dispersed in suitable concentrations—will burn or explode if they contact a sufficient ignition source.² Not all small particles burn, however. For example, salt and baking soda, no matter how finely powdered, will not burn because they contain no combustible material. Coffee creamer, on the other hand, will burn because it contains fat (i.e. organic material).

Combustible dusts are, either manufactured products, or they can be generated when solid combustible materials are handled or processed due to gradual reductions in the particle sizes and/or segregation of the particles. NFPA 654 (2006) defines combustible dusts as a combustible particulate solid that presents a fire or deflagration hazard when suspended in air or some other

¹ Eckoff (2003)

oxidizing medium over a range of concentrations, regardless of particle size or shape. Awareness of combustible dust hazards is important to ensure employee safety, to ensure proper facility design, and to develop adequate operations and maintenance procedures.

While many factors influence the likelihood, and severity of dust explosions, there are some basic facts about dust explosions that are worth highlighting:

- Typically, for dust explosions to occur, all of the following conditions must be present:
 - Combustible dust is suspended or lofted in air;
 - The dust is ignited; and
 - The dust is confined such that damaging pressures can accumulate
- The finer the dust particle and the more easily the dust oxidizes, the greater the explosion potential.
- Accumulated dust can become explosive if lofted into a cloud and ignited. Dust layers can ignite and will smolder, but if disturbed, they may transition to a dust explosion.
- Dust explosions result in pressures many times higher than the typical building walls can withstand.³
- The explosive dispersion of most dusts appears as a nearly opaque cloud and, for many materials, is much denser than the amount considered “breathable.”

² Ignitability and Explosibility of Dusts, Table A.1, Appendix A.2 (Eckhoff, 2003).

³ Crowl (2003) Damage to houses and other unreinforced structures can occur at pressures below 1 psig.

- Dust clouds, when ignited, can produce deflagrations, which are flame fronts that move at speeds below the speed of sound.⁴ Although not technically explosions, these deflagrations are commonly referred to as dust explosions.⁵

1.1 The Dust Explosion Pentagon

Fuel, ignition, oxygen, suspension, and confinement form the five sides of the dust explosion pentagon (Figure 1.) Like all other fires, a dust fire occurs when fuel (the combustible dust) is exposed to heat (an ignition source) in the presence of oxygen (air). Removing any one of these elements of the fire triangle eliminates the possibility of a fire. A dust explosion requires the simultaneous presence of two additional elements—dust dispersion and confinement.⁶

Suspended dust burns more rapidly, and confinement allows for pressure buildup. Removing either the suspension or the confinement elements prevents an explosion, though a fire may still occur, because the elements of the fire triangle (fuel, oxygen and ignition) exist.

⁴ In contrast, a detonation flame front moves at speeds greater than the speed of sound. Although subsonic, deflagrations can generate overpressures that can injure people and damage structures.

⁵ For purposes of this report, “dust explosion” includes deflagrations.

⁶ Confinement keeps dust particles in proximity after suspension—allowing sufficiently rapid heat transfer to continue propagation. Without confinement, a propagating explosion is not possible, though a large and very dangerous fireball may occur.

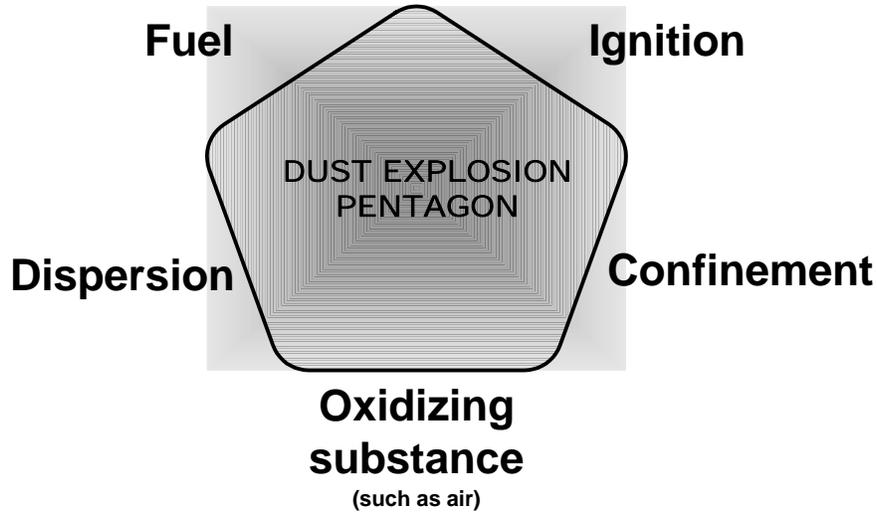


Figure 1. Dust explosion pentagon.

1.2 Secondary Dust Explosions

Many dust explosions occur when a small primary event—not necessarily a dust explosion—lifts dust deposits from floors, walls, overhead beams, or equipment. As illustrated in Figure 2, the suspended dust is then ignited, causing a secondary dust explosion. The blast wave from the secondary explosion causes the suspension of accumulated dust in other areas. In turn, this suspension may generate additional dust explosions. Depending on the extent of the dust deposits, a weak primary explosion may cause very powerful secondary dust explosions.

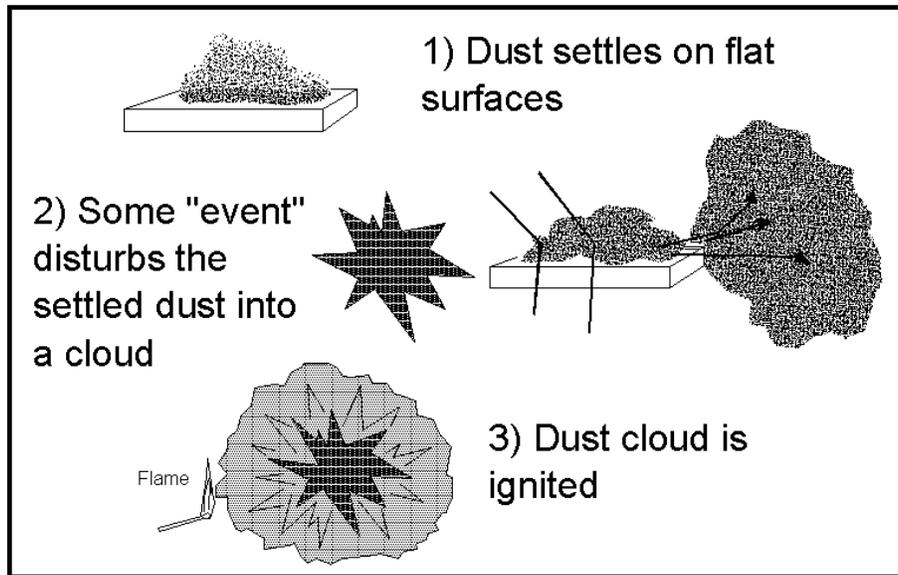


Figure 2. Mechanism for a secondary dust explosion.

1.3 Dust Explosion Characteristics

The relative explosibility of a given combustible dust is typically expressed using the deflagration index, K_{St} ⁷ and depends on several factors (these are discussed later in this appendix.) This index is determined experimentally by measuring how fast pressure rises following the ignition of dust of a known concentration in a container of a specific volume (20 liters). The higher the K_{St} , the more severe a dust explosion can be. NFPA 68 (2002) defines three “dust hazard classes”, used to indicate relative explosiveness. Class St-1 dusts have a K_{St} at or below 200 bar-m/sec, St-2 dust K_{St} values range from 201 to 300 and St-3 dusts have a K_{St} above 300 bar-m/sec. The following table shows the K_{St} values and hazard classes for some commonly known combustible dusts.

Table 1. K_{St} values for common combustible dusts.

Dust	K_{St} , bar-m/sec	ST-class
Aluminum	400-1100	3
Aspirin	217	2
Copier toner	134-196	1
Rubber	138	1
Wheat flour	87	1
Yellow food dye	288	2

Source: Eckhoff (2003).

1.4 Properties of Explosible Dusts

For any combustible solid, the severity and likelihood of an explosion can be quantified based on measurements of various physical properties. Some of these properties are discussed below.

⁷ $K_{St} = (dP/dt)_{max} \times V^{1/3}$, where $(dP/dt)_{max}$ is the maximum measured rate of pressure rise and V is the container volume. The units of K_{St} are bar-m/sec.

1.4.1 Particle Size

Particle size (specific surface area.⁸) primarily influences the ease of ignition and the severity of combustible dust explosions. Finely divided particles have a large surface area, which allows them to react rapidly with oxygen when dispersed in air and ignited. Greater surface area correlates with a faster reaction, and more vigorous explosion.



Figure 3. Burning increases with increasing surface area.

As depicted in the figure above, (Eckhoff, 2003):

- A large piece of wood burns slowly, releasing heat over a long period.
- When cut into smaller pieces, ignition is easier and the pieces of wood burn faster because the total contact surface area between the wood and air has increased.
- When the wood pieces are further cut, ground into sawdust, suspended in air as a confined dust cloud, and ignited, the dust burns very rapidly and may explode.

⁸ Specific surface area is the total surface area per unit volume or unit mass of dust.

Many of the common dusts involved in dust explosions have a particle size of 10 to 50 microns⁹ in diameter, similar to talcum (baby) powder. The table below lists the particle sizes for some commonly known materials.

Table 2
Particle Size of Common Materials¹⁰

Common Materials	Size (microns)
Talcum powder, fine silt, red blood cells, cocoa	5 to 10
Pollen, milled flour, coarse silt, fine human hair	44 to 74
Table Salt, coarse human hair	105 to 149
Coarse Sand	297 to 1000

Particle size influences dust explosion severity and sensitivity to ignition. Most combustible dusts ignite at lower energy and produce a greater rate of pressure rise (another indicator of explosion severity) at smaller particle sizes. Generally, the maximum explosion pressure and rate of pressure rise for any given type of dust will *increase* as the particle size *decreases*, and the minimum energy required to ignite a dust cloud decreases with particle size.

1.4.2 Dust Chemistry and Moisture

Dust explosions are, first and foremost, combustion-oxidation reactions. The composition (i.e. chemistry) of a material determines properties such as the rate of reaction and the amount of heat

⁹ One micron equals 0.000039 inches

¹⁰ Source: http://www.wateruse.com/micron_equivalents.htm

released in the reaction and governs the rate at which materials combust. Some dust particles (for instance, polyethylene) must be melted and evaporated to vapor form before they burn. This evaporation process also affects the burning rate. The faster the particle combustion rate, the faster the flame front will move across a dust cloud. Faster flame speeds yield greater pressure. Therefore, the sensitivity to ignition, the flame speed, and the explosion severity are all affected by the composition of the material.

The amount of oxygen available to the dust in the dispersed cloud also affects the combustion rate. Therefore, substituting an inert gas (such as nitrogen) for some of the air in dust-containing equipment can reduce the risk and severity of a dust explosion. Inerting is only practical within process equipment and storage vessels; the normal working environment provides adequate air for most combustible dust explosions.

Moisture content, by acting as a heat sink to slow evaporation and combustion, also has a measurable effect on dust burning rate and explosion severity.. Moisture in the atmosphere also reduces the amount of static electricity available for ignition, and makes the dust more difficult to ignite.¹¹

1.4.3 Measured Dust Properties

Measuring key properties for a dust at the particular process conditions (temperature, particle size, moisture content, etc.) is the first step in evaluating the hazards of a combustible dust, and to addressing those hazards. The most commonly measured properties are listed in the table that follows. The American Society for Testing Materials (ASTM) publishes the standard methods for measuring most of these properties.

¹¹ Eckhoff (2003)

Table 3. Measured properties of combustible dusts¹².

Property	Definition	ASTM Test Method	Application
K_{St}	Dust deflagration index	ASTM E 1226	Provides a measure of the relative explosion severity compared to other dusts.
P_{max}	Maximum explosion overpressure generated in the test chamber	ASTM E 1226	Used to design enclosures and predict the severity of the consequence.
$(dp/dt)_{max}$	Maximum rate of pressure rise	ASTM E 1226	Predicts the violence of an explosion. Used to calculate K_{St} .
MIE	Minimum ignition energy	ASTM E 2019	Predicts the ease and likelihood of ignition of a dispersed dust cloud.
MEC	Minimum explosible concentration	ASTM E 1515	Measures the minimum amount of dust, dispersed in air, required to propagate an explosion. Analogous to the lower flammability limit (LFL) for gas/air mixtures.
LOC	Limiting oxygen concentration	ASTM standard under development	Determines the least amount of oxygen required for explosion propagation through the cloud.
ESC	Electrostatic Charging Tendency	No ASTM standard	Predicts the likelihood of the material to develop and discharge sufficient static electricity to ignite a dispersed dust cloud.

¹² Dastidar, et al. (2005)

2.0 Preventing and Mitigating Dust Explosions

The dust explosion pentagon is the basis for preventing and mitigating (reducing the consequences of) dust explosions. Eliminating the fuel, the ignition source or oxygen for combustion will prevent an explosion. The focus of the NFPA standards is on reducing the likelihood of an explosion by controlling fuel, oxygen and/or ignition source.

When it is not possible prevent dust explosions, it is still possible to limit the amount of damage and injury they cause. The other two sides of the pentagon, confinement and dispersion, provide keys to mitigating the hazard. Dust explosion prevention and mitigation are discussed below.

2.1 Methods of Dust Explosion Prevention

The practical focus of dust explosion prevention is to control or minimize the three legs of the explosion pentagon that came from the fire triangle: fuel, oxygen and ignition.

2.1.1 Fuel

One of the requirements for a dust explosion is an accumulation of combustible dust. If the fuel is contained within a piece of process equipment or a dust collector, a primary explosion can result. If the dust accumulation is on floors, beams, ceiling tiles or other areas outside of equipment, secondary explosions can occur. As previously discussed primary explosions are often followed by secondary explosions of accumulated dust.

Housekeeping and maintenance play a critical role in minimizing uncontrolled dust accumulations. It is essential to maintain pipes, ducts and equipment to keep dust from escaping into the work environment. Housekeeping includes cleaning dust filters to reduce the amount of fuel accumulated in the dust collector, and to keep the dust collector working at peak

performance. Diligent, regular housekeeping to remove dust accumulations safely,¹³ is vital to prevent secondary explosions.

Another way to control fuel is to mix an inert material, like rock dust, into the dust. This can prevent an explosible concentration inside dust collection equipment. Coal mining uses a similar method to prevent coal dust explosions.

2.1.2 Oxygen

Most dust-carrying or dust-producing operations occur in an air environment. There is more than enough oxygen in the workspace to feed a dust explosion. Contained equipment can sometimes be inerted with nitrogen or other gases, however, to eliminate the oxygen from the dusty space. Inerting is difficult, however, and is not often the primary means of protection employed.

According to Ebadat,¹⁴ inerting is only practical in a closed-loop system. Where several non-inerted systems (such as conveyors, hoppers and dryers) are inter-connected, inerting is infeasible.

2.1.3 Ignition

Eliminating all sources of ignition is nearly impossible; therefore, the goal is to control them. Process safety expert Trevor Kletz stated “Possible sources of ignition are so numerous that we can never be certain that we have eliminated them completely, even though we try to remove all known sources.”¹⁵

¹³ Safe dust cleaning includes using dust-approved vacuums, not using compressed air to blow (and disperse) the dust, and careful sweeping. See NFPA 654 for guidance.

¹⁴ Ebadat (2003)

¹⁵ Kletz 1994

The following is a partial list of possible ignition sources for dust explosions¹⁶. NFPA 654 provides guidance on controlling ignition.¹⁷ The means for controlling them is unique to each type of ignition source.

- Static charge caused by moving particles
- Electrical system faults
- Open flames or sparks (including furnaces, hot work, smoking materials)
- Hot surfaces
- Improperly sealed electrical components

2.1.4 Methods for Dust Explosion Mitigation

Mitigating dust explosions usually requires an engineered solution. Venting and suppression are common approaches to reducing the effects of dust explosions. Another approach is isolation. These are discussed briefly below¹⁸.

2.1.5 Explosion Venting

Dust explosion vents are analogous to safety valves on reactors. These vents are usually a weak panel designed to rupture if pressure builds inside the protected equipment. This allows the pressure to vent in a more desired direction, rather than exploding the equipment. In some situations, the vented gases are ducted to a location away from employees, but this creates

¹⁶ CSB found in the West and Hayes investigations that determining the exact cause of ignition after an explosion is especially difficult. In many cases, potential sources are listed, then eliminated by evidence or ranked in order of likelihood.

¹⁷ NFPA (2005). Also see Babrauskas (2003).

¹⁸ For detailed guidance on venting, suppression and isolation, consult NFPA 68. Also see Barton (1986).

additional complications.¹⁹ Buildings can be constructed so that if an explosion does occur, the force is directed outside rather than inside where there are employees.

2.1.6 Explosion Suppression

Engineered systems to suppress an explosion in process are used successfully in some applications. These include a pressure or temperature sensor to detect the earliest stage of the dust explosion, and some form of chemical suppression or inerting to cool or extinguish the moving flame front.²⁰

2.1.7 Explosion Isolation

Conceptually, if a dust explosion can be detected early and the piping or duct connecting the protected equipment (usually a dust collector) is long enough, a fast-acting isolation valve can be installed to close and prevent the explosion from traveling to other equipment. However, some dusts (like aluminum) burn so quickly that the flame front might pass by the isolation valve before it ever got the signal to close, let alone completely closed.²¹ There are commercial dust explosion isolation systems available, and more work is being done to improve these systems.²²

¹⁹ Ural. Vent ducts, especially those with long pipes or changes in direction, can impose a backpressure on the vented chamber. Ducted vents may need to be much larger to compensate for the backpressure.

²⁰ Goings (2002) and NFPA 69

²¹ Snoeys (2004)

²² CSB (2005) Hayes Lemmerz investigation. CSB recommended research on explosion isolation and suppression systems for aluminum dust.

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