COMBUSTIBLE DUST EXPLOSIONS

Most people would not think that dust made up of ordinary materials such as food could explode, but under certain circumstances it can. On 7 February 2008, a violent explosion occurred in a silo where refined sugar was stored at the Imperial Sugar Company Plant on the Savannah River at Port Wentworth, Georgia, killing 12 people and injuring many others. This dust explosion was not a solitary incident as many industrial dust explosion accidents have occurred in the past. In this newsletter we will examine the five essential circumstances that must come together before a dust explosion can occur. But first, let us examine some real-world accidents.

Imperial Sugar Co. 7 February 2008 Explosion

Google Earth image of general location before blast, plant entrance at location A, Savannah River at right

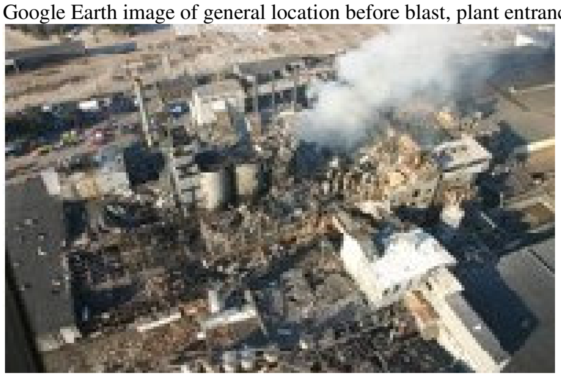


Photo after blast, from Chemical Safety Board website

The sugar refinery plant is known in Port Wentworth, Georgia, as the Dixie Crystals plant. In 1997, Imperial Sugar Co. acquired Savannah Foods & Industries Inc., which makes Dixie Crystals and where the explosion and fire occurred. The refinery accounts for about 9% of the total U.S. capacity, or 58% of Imperial Sugar Company's capacity. There were about 100 workers in the plant at the time of the accident.

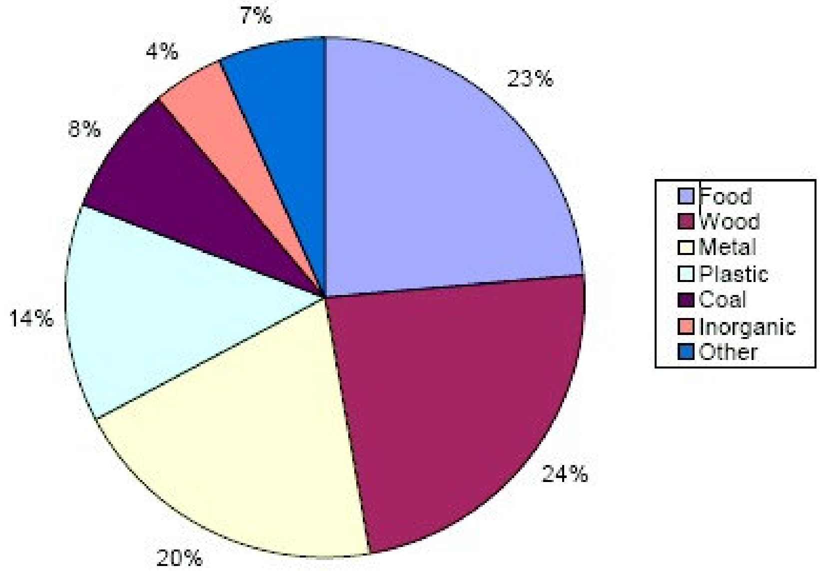
See Savannah Morning News at http://savannahnow.com/node/444690 for additional photos.

At about 7 PM on 7 February 2008, in what was described by the CEO of Imperial Sugar as "a sugar dust explosion" occurred in a silo where refined sugar was being stored before repackaging. The CEO was at the plant at the time of the explosion. A fire quickly took place causing a partial collapse of the nearby four-story building. The Savannah Fire Department and others from the surrounding area responded at about 7:30 PM. Nine people were killed by the explosion or resulting fire, 62 people were reported injured and subsequently treated including 22 people who were hospitalized. As of February 19, 16 people remained hospitalized in critical or serious condition from burn injury. It took fire crews a week to extinguish the fire. Some of the dead were not located in the rubble for several days, and some of the burn victims later died raising the total dead to 12 (which may increase). The U.S. Chemical Safety Board (CSB), the government agency charged with investigating the cause of chemical accidents, arrived at the site on 8 February. The CSB confirmed that finely-divided sugar dust was involved in the explosion, but at the writing of this newsletter the CBS has not issued a statement as to the ignition source.

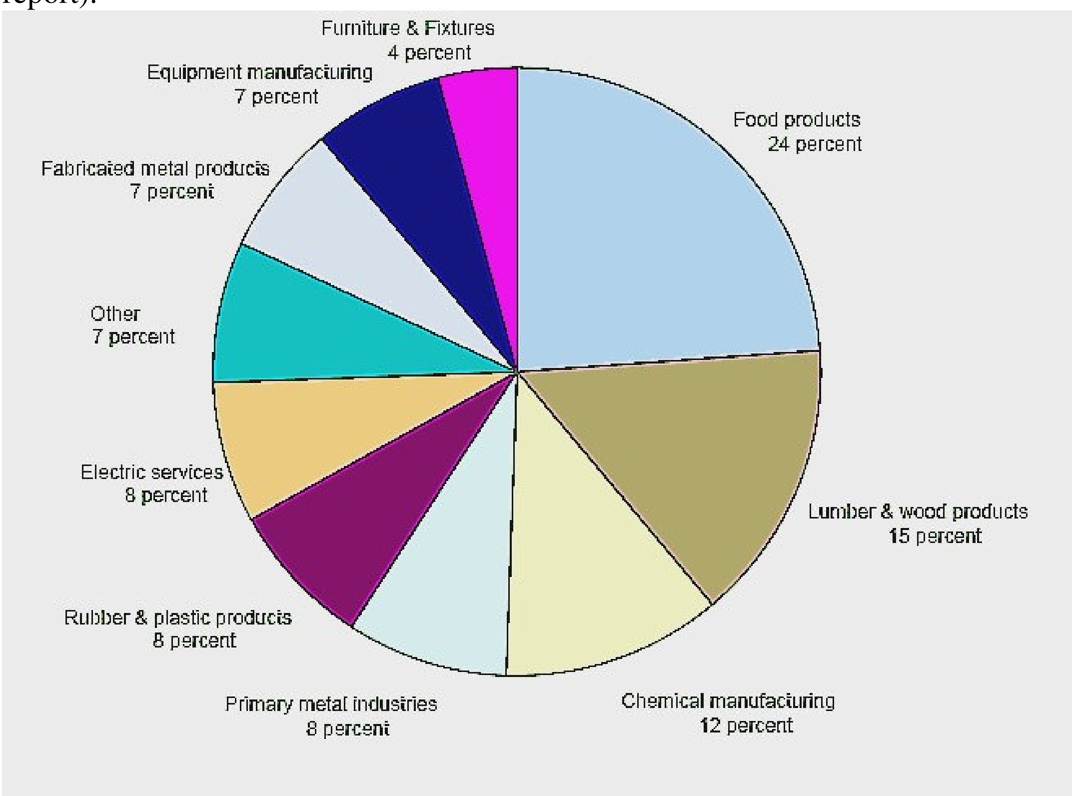
U.S. Chemical Safety and Hazard Investigative Report on Combustible Dust Explosions

The U.S Chemical Safety Board issued a 108-page investigative report dated November 2006 (report no. 2006-H-1) titled Combustible Dust Hazards Study. The entire report is available at http://www.chemsafety.gov/index.cfm?folder=completed_investigations&page=info&INV_ID=53. (or go to the CSB home page and link to "completed investigations").

The report researched the history of 281 major combustible dust explosions and fires in the United States from 1980 and 2005. The 281 incidents resulted in 119 worker deaths, 718 injuries, and destroyed many industrial facilities. Excluded from the study were (1) grain handling facilities, (2) coal mines, (3) transportation incidents, and (4) non-manufacturing facilities. Grain handling facilities were excluded from the study because these facilities are already under the OSHA Grain Handling Facilities Standard. One of the reasons why the study was done was to determine whether OSHA needed to beef up standards to protect workers against dust explosions in other industries (the answer was yes). The percentage breakdown for the 281 incidents by dust material is listed below:



The percentage breakdown for the incidents by industry is listed below (from CSB report):

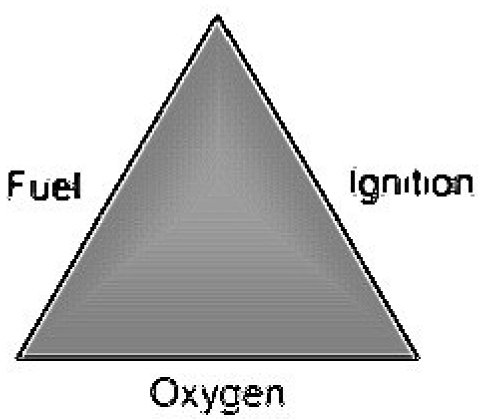


The CSB investigation also reviewed the Material Safety Data Sheets (MSDSs) of 140 known combustible dusts as to how effectively they communicated the explosion potential. Although 59 percent of the MSDSs included some language referring to the explosive nature of the dust, most of the information was not specific, and only seven of the 140 MSDSs referenced the applicable National Fire Protection Association (NFPA) standard for managing dust hazards. Partly because of lack of information, employees in these facilities and to some extent even management were unaware in many situations that the materials could explode violently under certain conditions. Sometimes the MSDSs used vaguely worded instructions such as "Avoid dusty conditions" as opposed to "This material in its finely divided form presents an explosion hazard". Newer MSDSs were generally better at communicating hazards than those 20 or 30 years old.

The CSB investigation found many dust explosion incidents resulted from accumulated dust being disturbed by some incident that resulted in the dust becoming airborne. The first incident may be a minor explosion or other disturbance in some ductwork or process equipment that lifted the dust into the air. The disturbance caused dust on the floor and other locations to become airborne causing secondary explosions. The CSB found that although MSDSs often contained a dust warning hazard saying dusty conditions should be avoided, none explicitly stated that dust accumulations should be avoided to prevent secondary dust explosions.

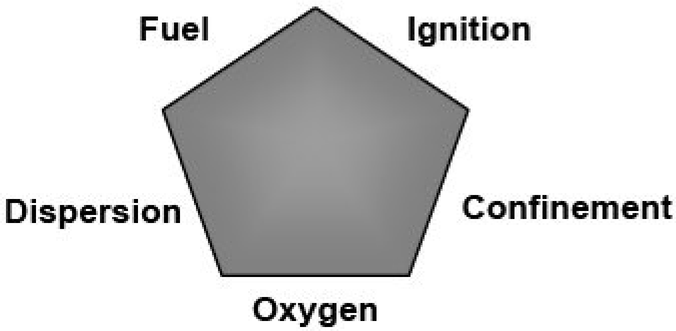
Fires and Dust Explosions

Firemen and First Responders are familiar with the classic fire triangle.



For a fire to occur, all three elements (a fuel, oxygen, and an ignition source) must be present. The oxygen can come from the air, which is composed of 21% oxygen. In a few situations, the oxygen can come from a chemical which is in contact with the fuel, for example nitrates and ethers. The ignition source could be static electricity, lightning, a lighted cigarette, another fire, sparks from equipment, etc. The fuel is anything that can burn and could include metal fines. This fire triangle is applicable to dust fires.

A dust explosion requires the simultaneous presence of two additional factors, dust suspension and confinement. If any of the five elements depicted below are removed, a dust explosion will not occur, although a fire can still occur with oxygen, an ignition source, and the combustible dust serving as a fuel.



The combustible dust is the fuel. The dispersion is any event that causes settled dust to become airborne. The confinement could be the process equipment, ductwork, a storage vessel, or silo. The ignition source could be static electricity or anything that causes a spark. The suspended dust if ignited burns rapidly, and confinement allows for rapid buildup of pressure resulting in an explosion.

Often an initial dust explosion might occur in some process equipment or ductwork causing dust which has accumulated on floors or other areas to become lofted resulting in secondary explosions. The initiating event for a secondary explosion is not necessarily another dust explosion but could be some other event that cause the accumulated dust to become airborne.

The CSB report examined incidents at two facilities involving dust explosions that spread through pipes and vents, from one piece of equipment to another and to other areas of the facility as the explosions caused the settled dust to become airborne. The pressure increased as the explosion moved from one location to the next increasing the damage. It is this disturbance of previously accumulated dust which causes the greatest damage and is not communicated very well in industry.

Physical Properties of Combustible Dusts

The NFPA defines a combustible dust as any finely divided solid material that is 420 microns (0.42 millimeters) or smaller in diameter and that presents a fire or explosion hazard when dispersed and ignited in air. Materials 420 microns and smaller pass through a U.S. No 40 Standard Sieve, and is about the size of fairly coarse sand. The dust also must be combustible. Some dusts, such as quartz sand or table salt no matter how finely ground will not burn because they are not combustible. Many metal powders will burn and could form explosive mixtures if suspended in air.

There are several physical properties that can be measured to determine the explosiveness of dusts. Particle size is a major factor, the smaller the particle size the larger the surface area relative to weight, which allows the particles to rapidly react with oxygen in the air.

Table 1 Measured Properties of Combustible Dusts

Property	ASTM Test Method	Description
MEC (Minimum explosive	ASTM E 1515	Analogous to lower flammability

concentration)		limit in vapor cloud explosions; measures the minimum amount of dust dispersed in air required to spread an explosion
K_{st} (Dust deflageration index)	ASTM E 1226	Measures the relative explosive severity compared with 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 (related to K_{st})
MIE (Minimum Ignition Energy)	ASTM E 2019	Predicts the ease and likelihood of ignition of a dispersed dust cloud
AIT (Auto Ignition Temperature)	ASTM E1491-97	Minimum AIT of dust clouds

National Fire Protection Association (NFPA) Standards

The CSB and regulatory agencies recognize that the voluntary NFPA standards provide effective technical guidance to prevent industrial dust explosions. Portions of the voluntary standards have been codified into many state fire systems in the United States, but have not been adopted by other states and local jurisdictions. Enforcement is often lacking, and many state inspectors do not have adequate training to recognize the potential for dust explosions according to the CSB report. OSHA has issued Grain Facility Standards 20 years ago for addressing the risk of dust explosions in the grain industry, but has not set up dust standards for other industries. However since the recent Imperial Sugar accident, several U.S. Senators (Enzi, Isakson, Chambliss, Kennedy, and Murray) are working with OSHA and CSB as they investigate this accident, to affect change in the interest of worker safety.

Table 2. List of Voluntary NFPA Standards Relating to Industrial Dust

NFPA 654	Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids-2006
NFPA 484	Standard for Combustible Metals -2006
NFPA 61	Standard for the Prevention of Fires and Dust Explosions in Agriculture and Food Processing Industries - 2008
NFPA 68	Guidelines for Deflagration Venting - 2007
NFPA 69	Standard on Explosive Prevention Systems -2008
NFPA 70	The National Electric Code - 2008
NFPA 499	Recommended Practice for the Classification of Combustible Dusts and Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas - 2004
NFPA 655	Standards for the Prevention of Sulfur Fires and Explosions - 2007
NFPA 654	Standards for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities - 2007

The NFPA Standards are updated about every five years; the latest edition is listed. They can be purchased by typing in the name of the standard, e.g. "NFPA 654", in a computer search engine such as Google, which provides a link to a site where the document may be ordered.

AristaTek in researching websites on the subject of industrial dust explosions noted that there was considerable motivation by parties to prompt industry to make work places as safe as possible. The motivation came from several fronts:

- Death and injuries to workers, and loss to their families, as noted in the news media
- Listings of economic loss in terms of bankrupted and out-of-business facilities which were destroyed by dust explosions; loss in stock value for Imperial Sugar
- Lawyer firms encouraging injured workers to file claims
- Even the CSB reports are not bashful as to laying blame. For example, the CSB report 2006-H-1 reviewing dust explosions cited earlier contained actual examples including pictures of destroyed facilities with captions such as "Figure 14. Mr. XXXX did not follow NFPA 484 guidance on locating and maintaining the dust collector, which exploded on October 29, 3003" [AristaTek withheld the name XXXX in this Newsletter]. That organization also had plenty of blame for OSHA for failure to codify standards.