FREQUENCY AND CAUSES OF GRAIN DUST EXPLOSIONS

Grain dust explosions at elevators are in reality a series of explosions. The first explosion referred to as the "primary explosion" is usually small with pressures less than 2 pounds per square inch, (psi). It propagates a pressure wave and fire front. The pressure wave moves away from the location of the primary explosion at a speed of about 1000 feet per second (fps) while the fire front follows at about 10 fps. The movement of the pressure wave results in secondary concentrations that are subsequently ignited by the relatively slow moving fire front. Secondary explosions can result in rupture pressures in excess of 100 psi.

Four ingredients are required for a grain dust explosion:

- oxygen,
- ignition source,
- fuel, and
- containment.

All four ingredients must be present for an explosion to occur. An explosion can be prevented by eliminating any one of the four ingredients. An oxygen-free environment in grain elevators is obviously impractical. OSHA and the FDA have established numerous regulations and guidelines to eliminate the ignition sources. The fuel for a dust explosion is the grain dust in suspension in the air at or above the minimum explosive concentration (MEC). Most experts use 50 grams per cubic meter (g/m^3) as the MEC for grain dust. If the dust concentration at a grain transfer point is less than the MEC an explosion will not occur even if all other ingredients are present. A concentration of 50 g/m^3 is so high that a person standing in this concentration would not be able to see their fingers one foot away. The engineering strategies for reducing the probability of dust explosions include pneumatic dust control, liquid additives, enclosed conveyers, direct spouting and other equipment and techniques that reduce and/or eliminate dust emissions. These strategies are directed at reducing the concentration of grain dust suspended in air at grain transfer points and thereby eliminating one of the required ingredients for an explosion -- fuel.

The effectiveness of using dust control systems, or oil or water additive systems, in preventing grain dust explosions, is dependent upon reducing the concentration of grain dust entrained in air at grain transfer points to levels below 50 g/m^3. Properly designed pneumatic dust control systems can capture a portion of the dust entrained in air at the grain transfer point, diluting the concentration to less than the MEC. Oil additive systems consist of an application of a food grade quality oil to the grain surface that results in fine dust particles "sticking" to the surface of the grain kernel thereby not being entrained in air at the transfer point. Hence, the concentration of grain dust at the transfer point will be less than the MEC. The use of water for dust suppression consists of using a fine mist spray at the grain transfer point. Lai et al [1979, 1982] reported that water sprays at 0.3% by weight were effective in suppressing 60-75% of corn dust emissions at grain transfer points [Lai et. al., 1982]. One or more of these dust removal and dust suppression strategies have been implemented by most grain elevators.

The fourth ingredient for an explosion (containment) is essential for an explosion to occur for the obvious reason that the rapid build up of pressure results in a rupture of the containment vessel (explosion). Without containment, an explosion will not develop and ignition of a dust cloud results in a fire only. However, containment is also required for the attainment of the very high concentrations of grain dust needed for an MEC to occur. Fifty g/m^3 is such a high concentration, it will not occur without containment. Some industry personnel have indicated that other elevator design changes can reduce MEC or reduce major damage if a primary explosion occurs. Explosion venting is a design concept used with elevator legs to vent the pressure and fire front of the primary explosion outside the elevator, thereby reducing the probability of the more devastating secondary explosions. Locating elevator legs external to the main elevator has a similar objective [U. S. House of Representatives, 1993].

Strehlow [1982] found two major sources of dust explosions: (1) the bucket elevator, considered to be the most dangerous piece of equipment in the elevator; and (2) smoldering dust. Strehlow concluded that poor housekeeping practices that allowed accumulation of dust provided the fuel for an explosion. A heat-generated fire or a spark provided the ignition source for an explosion. [Strehlow, 1982]

In summary, prevention of grain dust explosions is associated with eliminating one or more of the ingredients, other than oxygen, associated with dust explosions. Removal of ignition sources eliminates "ignition". Pneumatic dust control and dust suppression using oil or water additives reduces the concentration of grain dust suspended in air at a grain transfer point. This approach addresses the fuel for a grain dust explosion which is a concentration of grain dust at or above the MEC. Concentrations of dust below the MEC do not explode. Hence "fuel" is eliminated. Safety measures have been adopted to minimize damage given that a primary explosion occurs. These include fire and explosion suppression (Fenwall) systems. If a primary explosion were to occur in the leg, the faster moving pressure wave activates fire suppression systems to quench the slower moving fire from the primary explosion, prior to ignition of secondary explosions. Explosion venting is used to vent the products of combustion from the primary ignition prior to ignition of secondary explosions. The engineering concept associated with explosion venting is that a release of the pressure valve prior to formation of secondary MEC's will prevent secondary explosions. Housekeeping addresses the potential fuel for a secondary explosion given that a primary explosion occurs. If the layered dust associated with housekeeping were eliminated, a secondary explosion would not occur.

However, no one strategy is adequate by itself. Sound safety management should include a total system approach in which dust control is only one element. Prevention of dust explosions requires careful layout and design of plants and equipment, including: moderating speed of equipment; enclosure and negative pressurization of equipment; utilizing controlled venting; and minimizing grain breakage and dust separation by avoiding long free-fall drops, sharp angles, and steep inclines in the grain-handling process. Design and layout should be supplemented with aspiration and air-cleaning equipment at critical points in the process. Proper preventive maintenance and housekeeping practices and the installation of heat-sensing, shaft speed monitors, and motion detection equipment in the operation is also recognized as essential by the industry.

Cargill illustrated the diversity of approaches in their testimony at the congressional hearings. "We do not have pneumatic dust control in every one of our grain elevators. We do not use a mineral oil addition in every one of our grain elevators. We use a combination of housekeeping practices, maintenance practices, and design practices, and we supplement it with aspiration where it is needed or with pneumatic dust control where it is needed and in some cases, we use mineral oil." [Botos, 1993].

The number of dust explosions in the United States is small relative to the number of grain handling structures in the market channel. However, many of these explosions are of such a severe nature that percentages and probabilities are of little consolation given the loss of life and property damage in historically documented explosions such as those in Westwego and Galveston in 1977. "Fortunately, since 1977, the number and magnitude of dust explosions has significantly declined due to a greater safety awareness and better engineering. Smoke and heat detectors, improved bearings and buckets, fire and explosion suppression systems, improved cleaning techniques, and better dust control methods have contributed to a safer work environment".[Galliart, 1993].

There is no particular geographical pattern to the explosions, nor has there been any success in predicting them. Many elevators, where conditions leave the facility highly susceptible to a spark and explosion, have never experienced problems. Other elevators with relatively good records of cleanliness have been involved in very serious conflagrations. It is therefore difficult to identify any one strategy that will guarantee elimination or reduction in the probability of an explosion occurring at any particular location.

A comparison of the number of grain dust explosions per year since 1960 supports the theory that there has been a decrease in the frequency of explosions since the highs of the 1980's (Figure 1). The unusually large number of explosions in 1980 (many of which were not associated with grain dust) distorts any trend using annual averages that include that year. With the exception of 1980, grain dust explosions and total explosions in grain handling facilities are highly correlated (Figure 1). It is difficult to identify causality in the annual pattern. It has been hypothesized that the number of explosions was highest in those years when export volume was highest. [Parnell,1981]. In the five year period from 1980 to 1984 export volume and the number of explosions reached an all time high. Five year averages show an increase in number of explosions from 1960-64 through 1980-84 and a decline for the next two periods. Export volume for all grains shows a similar pattern (Table 2).

Annual data fail to support the theory that the number of explosions is a function of export volume. The simple correlation coefficient between volume of grain exports and the number of grain elevator dust explosions from 1960 to 1994 was 0.45. The relationship shown in Figure 2 illustrates the low correlation. Not all of the explosions occurred at export elevators. There are obvious exceptions to the weak pattern that exists. The number of explosions during the high export periods of 1979-81 and 1988-89 ranged from 14 to 62 (Table 3).

The limited amount of data on the number and causes of grain dust fires and explosions, makes it unlikely that any control method would be highly correlated with a change in the number or the probability of an explosion occurring. During the eight year period following the FGIS' approval of water as a dust suppressant the average number of explosions per year was 7.25. The 5-year averages for the three decades from 1960 through 1974 were 7.0, 7.4, 8.6.The next three decades were nearly double in the number of explosions the previous three decades -- not an adequate basis for assigning causality. In addition, during this same time period there were many changes in technologies, practices, and regulations that had direct and indirect effects on the ingredients required to generate dust explosions. Although the FGIS safety manager reported that "there's been no explosion where water was used" [Milling and Baking News, 1993], this is not conclusive evidence that water application will eliminate explosions, since thousands of elevators not using water for dust control also have had no explosions in their history.