GRAIN INDUSTRY'S APPROACH TO DUST EXPLOSIONS

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Introduction

It has been over 30 years since the series of devastating explosions in late 1977 and early 1978 in the Gulf area that created sensational stories by the media, government regulatory focus on the grain industry and industry reaction. These events caused us to re-look at what we know about explosions and how they can be prevented. In the intervening years we have learned a lot and have seen many changes to facility and equipment design and operations. The industry undertook a series of research projects totaling over 41 projects to give us new information about dust explosions and their prevention or control. Over 3 million dollars was spent on the research plus a lot of industry time and effort. The first recorded grain dust related explosion happened in 1785 in Turin Italy. History shows us that these events can run in cycles where intensive efforts are applied to their elimination followed by a great reduction in their occurrence. Everyone relaxes their guard and the problem reappears often times alarming the industry and the public that the problem is back. This illustrates that we must remember the past least it is repeated.

Figure 1 - Westwego, LA Explosion 12/77

Figure 2 - Houston, TX Explosion 2/76

The devastating sugar explosion that happened last year in Georgia is a sobering reminder of the importance of preventing fires and explosions in industries where combustible dusts is handled prompts us to revisit the ABC's of dust explosions. The number of explosion events, injuries and fatalities has continued to decline in the grain industry since the 1980's with dust explosion incidents averaging slightly over 12 per year. This is a great improvement over an extended prior of years showing a downward trend. Data also shows that the grain industry has been doing a good job regarding prevention and control of dust explosions. The major Kansas explosion in 1998 was out of the norm for recent trends. The graph (**Figure 3**) below shows the average number of dust explosions and related fatalities and injuries by five year periods. **Figure 4** contains the explosion incidents and related fatalities and injuries for each year from 1976-2005 for grain handling facilities. **Table 1** below shows the explosion incidents by facility type and commodity handled with grain elevators (65.5%) and corn (49.5%) being the most predominant. 355 explosions were analyzed where sufficient data was available from 27 years of the last 40 years. Thus this data gives us a good indication of explosion factors and causes that we must deal with.

An early effort by the industry to address explosions was to examine grain handling facility design with a conference held in 1979 by NGFA to compile best design ideas to minimize the effects of an explosion. An outgrowth of that effort can be viewed when looking at facilities built in the last 30 years. Most new facilities put more hazardous equipment outside the facility or in separated structures. Most new grain handling legs are now installed completely outside of the facility. Head house structures have been changed such that they no longer are tall concrete structures full of legs, hammermills, grain dryers and dust filters. Current designs place much of this equipment outside or have it protected by explosion venting to the outside, suppression, or hazard monitoring systems. Open headhouse designs have been used to eliminate containment and critical operating areas placed in remote or separated structures to help minimize explosion propagation. Dust control systems are in greater use and used more effectively. Free standing bucket elevators with steel tank storage is a very common design today rather than the enclosed concrete and wood headhouse structures of the past. Mills are often still concrete but many of the raw grain legs are placed outside and all major equipment have appropriate hazardous monitoring systems with centralize PLC controls systems receiving signals of potential hazards so they can be promptly address. The facility design and much of the grain handling equipment has been changed to avoid problems of the past and to give greater reliability.

Figure 3- Average Number of Dust Explosions , Fatalities and Injuries 1976-2005

Source: References 1 and 2

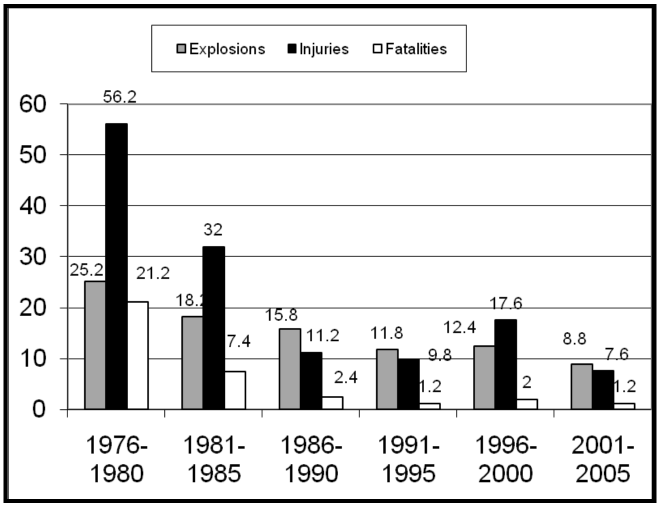


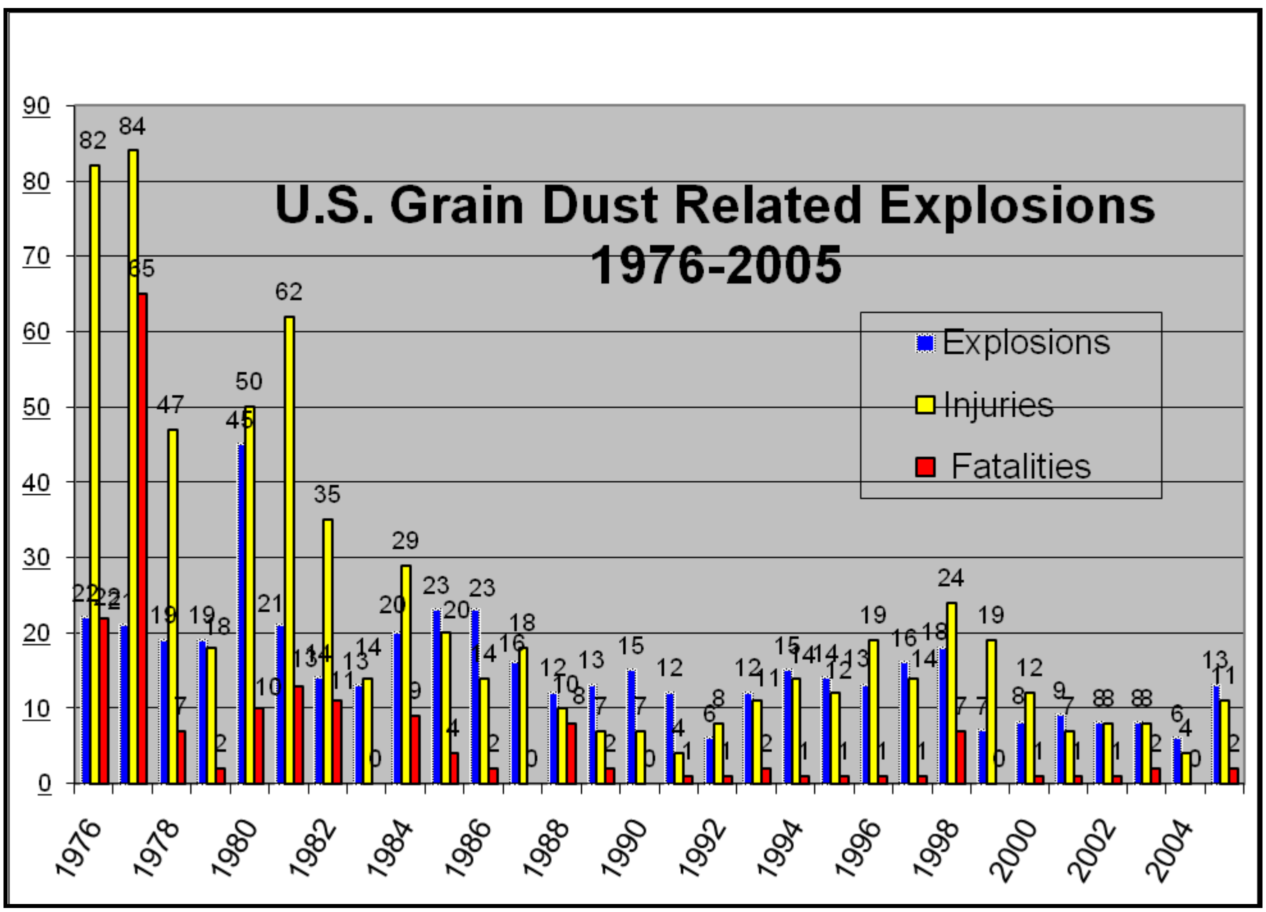
Table I Explosion Factors by Facility Type And commodity Handled

Source: References 1 and 2

Type of Facility Involved in Explosions		Commodity Handled at Time of Explosion	
Facility	Percent	Commodity	Percent
Grain elevators	65.5	Corn	49.5
Feed Mills	15.3	Sorghum	7.3
Corn Processors	6.2	Wheat	7.3
Flour mills	3.1	Soybeans	5.2
Rice mills	2.8	Rice	4.7
Others	7.1	Corn starch	3.6
		Barley	2.6
		Others	19.8
Total	100.0		100.0

Figure 4 - Number Of Explosions, Fatalities And Injuries For Each Of The Last 30 Years

Source: References 1 and 2



Past explosion information also tells us two other important facts that helps us understand how to deal with explosions. The most frequent locations of primary dust explosions indicates that bucket elevators , storage bins, hammermills, dust collectors and enclosed equipment are the areas where explosions often initiate. Most probable ignition sources that have been identified in past explosions. Welding and cutting operations, fires, overheated bearings, and electrical failures are among the most frequent explosion ignition sources. Industry research has shown that bearing failure and mechanical failures are a major factor in dust explosions.

Table 2 - Probable Location Of Primary Dust Explosions For A 27 Year Period
Source: References 1 and 2

Probable Location of Primary Explosion (1958-1978) and (1984-85, 1988-89, 1991, 1992-95)

LOCATION	NO. OF FACILITIES	PERCENT OF FACILITIES
Unknown	146	41.2
Bucket elevator	105	29.6
Storage bins or tanks	19	5.4
Hammer mills, roller mills or other grinding	18	5.1
Dust collector	14	3.9
Other areas inside elevator	12	3.3
Other areas inside equipment	11	3.0
Headhouse	9	2.5
Adjacent or attached feed mill	8	2.2
Grain drier	3	.8
Inside electrical equipment	2	.6
Outside and adjacent to facility	2	.6
Pellet collector	2	.6
Tunnel	2	.6
Other	2	.6
Sample size	**355**	**100.0**

Table 3. - Probable Ignition Sources Of Dust Explosions For A 27 Year Period
Source: References 1 and 2

Probable Ignition Sources (1958-1978) and (1984-85, 1988-89, 1991, 1992-1995)

Source	No. of Facilities	Percent of Facilities
Unknown	154	43.4
Welding	51	14.4
Fire other than welding or cutting	22	6.1
Overheated bearings	17	4.7
Miscellaneous	15	4.3
Friction from choked leg & rubbing pulley.	14	3.9
Tramp metal	13	3.6
Friction sparks	13	3.6
Other spark	12	3.3
Electrical failure	12	3.3
Unidentified foreign objects	10	3.0
Lightning	7	2.0
Faulty motors	5	1.5
Extension cords in legs	4	1.2
Static electricity	4	1.2
Smoking Material	2	.5
Sample size	**355**	**100.0**

Understanding Dust Explosions

The elements of an explosion are well known and represent the fire triangle of a fuel, ignition source and oxygen with the event occurring in an enclosed area or volume to allow pressures to build due to rapid increases in gas temperatures during the combustion process, often called a deflagration. **Figure 5** below shows the elements of a dust explosion and factors affecting them in our industry. Controlling any one element will theoretically eliminate the explosion. Explosions are complex and generally moving events as the pressure wave travels at the speed of sound with the flame front traveling behind at speeds that vary from a few meters to 100 meters per second. The pressure wave from a primary, initial explosion, usually from inside of equipment or enclosures, disturbs dust accumulations putting them into suspension. If the dust concentration exceeds the lower explosive limit in the space a more devastating secondary explosion can occur. The industry has primarily relied upon the elimination or control of dust (the fuel) and potential ignition sources. However each element of an explosion needs to be considered and the operational practices implemented to minimize their impact on explosions. In addition to physical controls, establish good work procedures such as clearing of legs. Use of welding permits will do much to address explosions as well.

Figure 5 - Dust Explosion Elements

FUEL

- Grain dust
- Powdered food product
- Explosive dust clouds resemble a very dense fog
- Dust layers can be thrown in suspension causing more intense secondary explosions and ignite at temperatures 1/2 those of clouds

IGNITION SOURCE

- Must exceed minimum ignition energy and temperature
  over $400^{o}C$ dust cloud
  over $200^{o}C$ dust layer
- Typical Sources
- open flames (lighters, matches, fires, burning cigarettes)
- electrical sparks and failures
- hot surfaces
- overheated bearings
- slipping bucket elevator belts or v-belts
- improper welding and cutting
- grinding or equipment sparks
- foreign objects

OXYGEN

- Air is everywhere
- Supression can interfere with the explosion reaction (Halon, CO^2 chemical powder, H^2O)
- Normally not practical to eliminate

CONTAINMENT/ENCLOSURES

- Eliminate containment
- open structures
- explosion venting
- outside location of critical equipment (legs, filter, etc.)
- separation of buildings
- Build to withstand explosion

The precise circumstance under which an explosion of a grain dust will occur is a complex combination of dust particle size, concentration in the air (gram/cubic meter), the energy of the ignition source, and less easily determined factors such as the moisture content of the dust (or percent relative humidity of the air) and the actual composition of the dust. Dust from each agricultural commodity has its own explosion characteristics. While researchers have not agreed precisely on the limits of the various characteristics of a particular dust, their conclusions are generally within an acceptably narrow range. Studies of explosibility of agricultural dust show that lower explosion limit for dust concentrations needed for an explosion range from 25 to 500 g/m^3. Grain dust generally varies from 25 g/m^3 to 55 g/m^3 (see **Table 4**). Suspended dust concentrations of this type represent a severely dense cloud through which a 100 watt light bulb cannot be seen at a distance of approximately 3 meters or your hand cannot be seen at arm's length. Such dust concentrations make breathing extremely difficult. Some of the highest dust concentrations occur inside bucket elevators, grain bins, scale garners and other enclosures. Maximum explosive pressures can exceed 100 psi with the maximum rate of rise of pressure approaching up to 8500 psi per second which is an indication of the intensity and speed of a grain dust explosion. When the rate of rise of pressure is higher, explosions are more severe.

Table 4 - Dust Explosibility Properties
Source: Reference 5

Material	Lower Explosive Limit g/m^3	Minimum Ignition Energy (Joules)	Minimum Ignition Temperature°C		Maximum Explosive Pressure psi	Maximum Rate of Pressurize psi/sec
			Cloud	Layer		
Coffee	to	.16	410	240	44	500
Corn	45	.04	400	250	95	6,000
Corncobs	30	.04	400	190	110	5,000
Grain (Mixed)	55	.03	430	230	115	5,500
Soy	35	.05	520	190	99	6,500
Sugar	35	.03	350	220	91	5,000
Wheat	55	.06	480	220	103	3,600
Wheat Starch	25	.02	380	210	105	8,500
Flour	50	.05	380	360	95	3,700
Coal.	55	.06	610	---	83	2,300

The fuel

Dust particles emanating from various emission points within a grain elevator are of varying composition and of a wide range of sizes. It is generally agreed by researchers that particle sizes below 100 microns constitute the greatest hazards. A considerable portion of the dust within the elevator environment is smaller than 100 microns. Larger particles tend to settle out rapidly.

While it seems improbable that such a dense cloud would exist within the ambient space of an elevator structure where personnel are present, such concentrations have been measured within the confines of bucket elevators and may also occur in conveyor housings, bins being loaded, silos, dust collecting systems, and connecting spout work. The mechanism of an explosion depends upon the immediate heat release of a burning particle to ignite and support the burning of adjacent particles.[8] As this rapid spread of flame proceeds from particle to particle, pressure waves and thermal expansion of the air can create an intense shock sufficiently strong to rupture the typical reinforced concrete structure (see **Figure 6**). In studies performed by the U.S. Bureau of Mines,[5] the maximum pressures for corn dust are greater than 100 psig (690 kPa). Concrete structures found in elevators can usually withstand no more than 25 psig (172 kPa). Most grain handling equipment enclosures fail at pressures less than 6 psi.

Figure 6 - Inland Concrete Head House Damaged From An Explosion

Suspended dust is not the only fuel with which to be concerned. Dust accumulation on floors, walls, rafters, and equipment may become suspended if disturbed by vibration, fires, or small explosions. If this accumulated dust is suspended in sufficient concentration, the resulting explosive dust concentration can become ignited and progress into an explosion. This re-suspended dust can encompass large volumes and propagate explosions through an entire elevator. This illustrates the importance of keeping overhead surfaces and ledges clean of excessive dust accumulations. Research conducted for the National Grain and Feed association showed that as little as $1/100^{th}$ of an inch of dust could fuel a flame front. If the explosion moves to areas where greater amounts of dust exist then a secondary explosion could occur.

Equally important to sweeping and housekeeping practices is the need for proper inspection and repair of dust control equipment. The following should be considered regarding controlling the fuel, dust or bulk powders at grain and combustible dust handling facilities of any type.

A. Housekeeping - eliminate dust in open areas on floors and walls using brooms, vacuums, and manual labor where needed. Housekeeping should be conducted concurrent with operations or as soon as resources permit.
B. You should have a written housekeeping plan with periodic inspection of the facility for excessive dust levels with emphasis on priority areas within 35 feet of a leg. Both the floors and overheads should be cleaned.
C. Utilize and maintain dust systems-fabric filter and cyclones. Check pressure drops on system monitors to ensure they are working correctly. If too high, change fabric-filter socks. Repair broken bags as soon as possible.
D. Eliminate handling equipment leaks and the causes of dust accumulations. If temporary patches or sealing is done they should be scheduled for permanent repairs.
E. Utilize enclosures to keep dust in where you can and aspirate the equipment to prevent dust from escaping. Shrouded or covered belt conveyors is an example of how to help contain and control dust.
F. Oil suppression system can be effective in helping control dust. They are used by many in the industry but care is needed to ensure you do not coat everything with oil and create a fire concern.
G. If blow down is allowed then you need good controls in place to ensure no ignition sources are in the area such as hot or overheated equipment and no open sparks of any kind. Consider using a permit system with the affected area shut down.
H. Consider using wash down if weather and construction allow the use of water.
I. Pressurize work areas such as headhouses and tunnels to help keep dust inside equipment. This requires sealing up of areas to maintain a positive pressure. This has been an effective tool for smaller elevators or in the design of new facilities.
J. Where dust is returned to the grain try to do it down stream of the collection point or in a manner it doesn't create airborne dust.

Ignition sources

Another important element of a grain dust explosion to try to control is ignition of the suspended dust cloud by a source of energy of sufficient intensity and duration. One ignition source that has been identified in a large percentage of known instances is improper use of welding and cutting equipment. Other identified ignition sources include fires, heat caused by the frictional energy of mechanical equipment such as bucket elevators, bearings and belt drives. Heat or arcing caused by the failure of or the use of improper electrical equipment, such as lighting, motors, and wiring, has also been identified as an ignition source. Miscellaneous ignition sources include open flames from matches or smoking, space heaters, lightning, and internal combustion engines on vehicles, slipping V-belt drives, and improper operation of grain dryers, hammermills and bucket elevators. The importance of an effective preventive maintenance program cannot be over stated. Periodic inspections, lubrication, and adjustment of equipment can be a major tool to prevent explosions. Implementation of various safety monitoring devices, such as temperature of bearings or rubbing conditions, speed monitoring to detect stalling of bucket elevators, various proximity and touch switches that can detect misalignment of equipment, plug switches that detect overloading of equipment and bins (which can cause equipment malfunctions), vibration detectors can signal when equipment goes out of balance (hammermills and grinders), are in common use at many facilities today. The use of speed monitoring equipment to detect legs stalling from overloading or grain flow plugging and temperature monitoring of bucket elevator bearings have been the most beneficial to avoiding explosions.

Torches and electric arcs used for hot work represent one of the most intense energy sources used at grain facilities. These sources can quickly ignite dust and construction materials. Welding and cutting is also a concern in the grain industry because many elevators do not have full-time maintenance personnel. This results in unsupervised contractors performing welding operations within the grain elevators. These contractors may be unfamiliar with the fire and explosion potential of grain dust and need to be monitored by elevator management. A formalized hot work welding and cutting work permit is most often established to help control hot work operations.

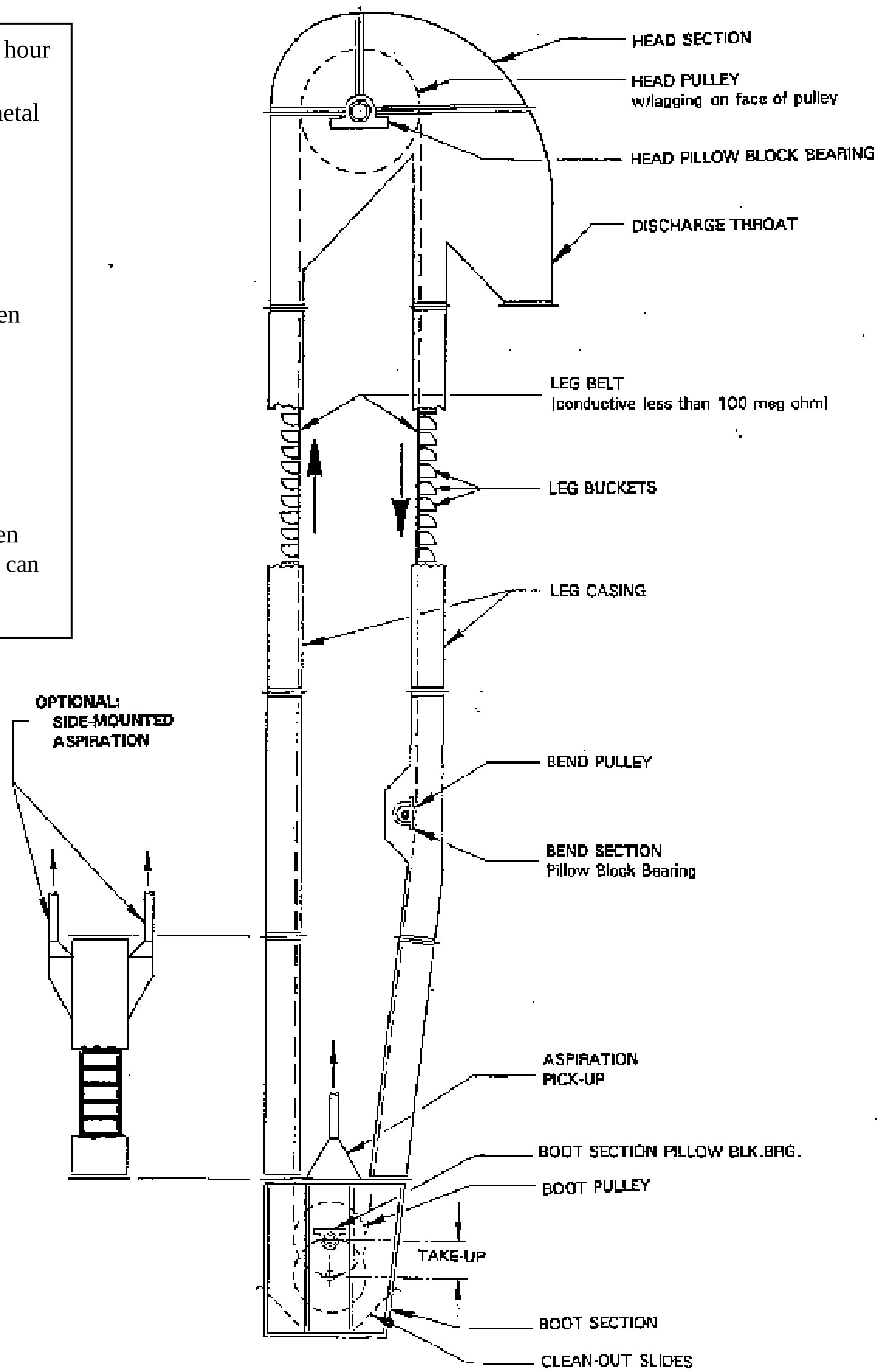
The energy inherent in electrical systems is extremely high, but can be minimized as an ignition source by adherence to the provisions of NFPA 70, *National Electrical Code*®, for the appropriate hazardous area classification. For areas that have an exposure to higher levels of airborne and layer dust, electrical equipment is normally rated as explosion proof for Class II, Group G, Division I areas. Other areas can be rated for electrical equipment that is suitable for class II, Group G, Division II (dust tight). Many in the industry choose to utilize electrical that has a dual rating for Class II, Group G, Division I and II areas to avoid the problem of the wrong equipment getting in an area. The importance of proper electrical equipment applies to both fixed and portable equipment. This consideration is important for portable electrical devices, lighting, low-voltage control circuitry, extension droplights, and communications equipment.

Bucket Elevators

In as much as the majority of known locations of explosions in grain elevators stems from the bucket elevator (see **Figure 7** below), it would follow that this single piece of operational equipment presents the most serious ignition hazard

Figure 7 - Bucket Elevator

1. Capacity can be a few hundred bushels per hour to 60,000 bushels per hour.
2. Belts can have multiple rows of buckets (metal or plastic, which is preferred) across them.
3. Take up can be gravity or screw style.
4. Capacity is belt speed X bucket capacity.
5. Head pulley is normally lagged.
6. Legs can be in excess of 200 feet tall.
7. Legs interconnect the entire headhouse when placed inside.
8. Slow motion devices are used to detect overload for belt slippage.
9. Bearing & alignment rub blocks with thermocouple establishes temperature monitoring.
10. Casings & head sections can be vented when leg is outside. Head sections of inside legs can often be vented to the outside.



to the grain handler. This conveyance produces ignition energy in a number of ways. Overloading or stalling of the belt generates intense frictional heat on the rotating drive pulley and belt. This has been known to cause ignition or melting of the belting to the point of failure, allowing the severed and flaming pieces to drop within its housing. Failure of belt splices could lead to the same results if not done properly or maintained. Most in the industry now use plastic buckets on legs rather than metal buckets used in the past. Some past explosions have occurred when the belt has dropped from splice failure and spark ignition of dust inside the leg.

Misalignment of belts can cause the leg casing to become hot enough to ignite combustible materials, such as dust or lubricants. A misaligned belt itself probably does not get hot enough to ignite while it is moving, since it has the chance to cool as it moves, but may ignite after the equipment is turned off and the belt is stationary next to the hot casing, bearing or roller.

Another potential ignition source associated with bucket elevators is that of overheating bearings. Some older conveyor designs have tail or head pulley bearings located inside of the casings. If these bearings overheat, they can provide sufficient heat for ignition of static or suspended dust. Today most legs with inside bearings have been changed to have outside located pillow block roller bearings. Babbited bearings have been eliminated from use by most in the grain industry. Even bearings located outside of casings can ignite layered dust which in turn can be drawn into the leg casing by the dust collection aspiration or the "air pumping" action of the leg itself.[6] Most grain elevators use a hazard monitoring system to identify overheating bearings or equipment misalignment using temperature monitoring systems or touch sensors or proximity devices.

Extraneous foreign material, such as scrap metal, tools, wood, stones, or pieces of concrete, are also a concern within a bucket elevator. They may or may not produce sparks with sufficient energy to ignite dust, but certainly can result in plugged spouts, damage to the belting, or deformation of the elevating cups. When large foreign objects get in the legs the chances of belts stalling or continuous frictional rubbing is increased. The use of grating to reduce foreign objects from entering the grain receiving pit and subsequent handling equipment is common at most facilities. Most grates are set at 2.5 inches apart with varying lengths of the opening. The grate size can be adjusted for the commodity; for example, a smaller opening can be used for wheat than can be used for receiving soybeans in southern locations or for receiving corncobs. Many processors, millers and grain export facilities rely upon magnets on the grain stream to capture tramp metal.

Nonconductive belting moving over the pulleys in bucket elevators can create significant static electricity on the buckets. Research indicates that sufficient energy to initiate a dust explosion is generally not released from this static discharge, but prudent practice is to reduce this static accumulation by using electrostatic conductive belting and good grounding practices.[7] OSHA calls for all newly installed leg belting to have a surface resistivity less than 300 megohms.[9] Rubber belting has typical resistivity of 1 megohm and PVC belts are typically 15 megohms in resistivity.

Oxygen

The oxygen concentration required for a dust explosion is that found in the atmosphere. Using inert gases in equipment to reduce the oxygen concentration enough to prevent explosions has been suggested, but has limited application due to the large size and volume of grain handling equipment. Electrical equipment, such as enclosures and possibly smaller process equipment are more likely candidates for inerting.

Confinement:

As with all dust explosions (except detonations), the pressures generated after ignition of a grain dust explosion increase until the fuel or oxygen is consumed or until the explosion is vented. If there is no confinement (i.e., unlimited venting), explosion pressures are minimal, and the incident should more properly be called flash fire. On the other hand, as confinement increases, the explosion pressures can build up to experimentally observed levels over 100 psig (690 kPa). Grain elevator structures and equipment cannot withstand pressures anywhere near these levels, so considerable damage will occur, unless these pressures can be vented. Due to structural considerations, most existing grain elevators would be nearly impossible to retrofit with adequate venting, but newly designed elevators are adaptable to increased venting and the resulting reduction in explosion confinement. Explosion venting must be done to the outside of the facility to avoid secondary explosions or endanger personnel. Although the levels of recommended venting is not always possible, some venting is better than no venting when feasible to help eliminate pressure development during an explosion.

An alternative to explosion venting is explosion suppression during which a chemical is injected into equipment during the early stages of explosion development to stop the process. The chemical can interfere with the combustion reaction or inert the environment (CO_2) or cool the process with a water spray. Suppression system can be specifically engineered for a piece of fixed equipment.

The construction of structures and equipment that can totally contain an explosion is generally not practical with the exception of hammermills which can often withstand the explosive pressures. However the transmission of pressures and flames to connecting equipment can present explosion problems.

The only other means of dealing with confinement is to provide separation between buildings and structures to help minimize the propagation of an explosion. NFPA 61 recommends that a separation of 100 feet be provided between personnel intensive areas and concrete elevator head houses and silos. Some exceptions are allowed based on the location of bucket elevators (outside), type of construction (damage limiting) or property size. The concept of separation can be taken into account for major modifications or new facilities but is often impractical for existing facilities.

Consider the following items to address confinement:

A. Use explosion venting to help relieve the explosion and minimize propagation. Often provided on outside dust collection systems. Outside legs or inside legs that can be vented directly to the outside by short straight duct work less than 10 feet. Vent panels should relieve at ½ to 1 psi . Explosion relief fasteners or specially designed panels can be used. See NFPA 61 and 68 for guidance on venting.
B. Do not vent equipment to the inside of facility.
C. It is possible to vent some structural areas with walls that relieve to the outside but it takes expertise to design the systems. Galleries can have louvers or explosion relief walls or panels to help deal with an explosion. However, don't forget to keep all bin inlets except the one being filled closed when not needed as these can serve as a paths to secondary explosions in bins during an explosion propagation event. The bins can then explode like roman candles going off. And it is so simple to keep the bin lids closed particularly for non-automated trippers.
D. Bin venting has been tried but generally can not be relied upon because of possible turbulent explosions and the length to diameter ratio not permitting proper venting except under special conditions.
E. Explosion suppression systems are available and can be used where practical on some equipment such as critical inside legs, dust systems or grinding operations.
F. When adding new legs consider placing them outside and venting them.
G. Provide separation between portions of the plant where possible using enclosed equipment such as screw or drag conveyors or shrouded belt conveyors to connect them.

Emergency Action Plan and a Safety program are needed

Every facility should have a safety program and an established emergency action plan that outlines what is to be done in the event of a fire or explosion. A method is needed to notify everyone at the facility that there is an emergency when they might be at risk. Generally a central alarm system, page system or horn can be used to signal the need for evacuation. Have a procedure to call the fire department as soon as needed. It is best to error on the side of calling them. For very small facilities word of mouth might work as long as someone has the responsibility to carry out notification of those at the facility. Establish a safe assembly area for the emergency and a system to account for everyone at the facility. Establish safe means of exiting all work areas. And give assignments to workers to carry out needed duties. Train all workers coming to your facilities in the hazards of dust explosion and proper action.

Conclusion

Many techniques have been developed to identify and control explosion risks including safety monitoring equipment, improved handling equipment and dust control systems, implementation of good safety and operations practices, good housekeeping practices and having an effective preventive maintenance program**.** Dust explosions are devastating and life threatening. You should always be aware of the risks. No one can predict precise effects of the explosion or all the circumstances surrounding them. You need to arm yourself with as much knowledge about them as you can and constantly look for the potential risks so they can be eliminated. You don't want to have to deal with all the problems and suffering that can result. Remember the factorss of dust explosions to have a safer and prosperous career.

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