DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Agriculture and Natural Resources

FSA1092

Preventing Grain Dust Explosions

Sammy Sadaka,
Ph.D., P.E.
Associate Professor -
Extension Engineer

Kingsly Ambrose, Ph.D.
Associate Professor -
Purdue University

John W. Magugu, Ph.D.
Professional Assistant -
University of Arkansas

Introduction

Combustible dust explosion hazards are prevalent in various industries including, but not limited to, agriculture grain, food, chemicals, fertilizer, tobacco and pesticides. The total number of reported agricultural dust explosion incidents in the United States reached 84 cases between 2009 and 2018 (Fig. 1), resulting in 16 fatalities and 96 injuries cases, respectively (Fig. 2). There were 12 dust explosion incidents in 2018 alone, the highest rate in a decade. Dust explosions in grain elevators corresponded to 51 percent of all U.S. agricultural dust explosion incidents, with many of these occuring in grain milling facilities. This fact sheet presents an overview on how to help prevent dust explosions in both industrial mill facilities and producer-owned facilities.

Grain Dust

Figure 1. Total U.S. Agricultural Dust Explosions

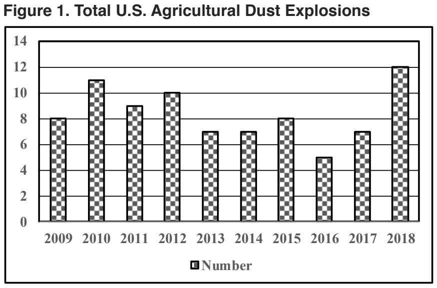
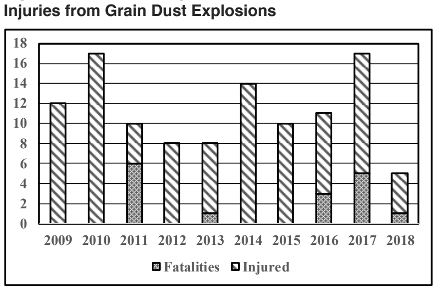


Figure 2. Number of Reported Fatalities and Injuries from Grain Dust Explosions



The National Safety Council defines dust as solid particles derived from crushing, grinding, rapid impact and detonation of organic or inorganic materials such as rocks, metal, wood or grain. Dust originates from operations of dry and powdery material such as conveying, trimming of excess material, solids crushing and screening, sanding, tank and bin feeding and storing of granular materials, among others.

Figure 3. Westwego Grain Dust Explosion in Louisiana, December 1977 (Courtesy of Gambit)

Grain dust is a highly combustible material, and has more combustible power than coal dust. The generation and accumulation of the combustible dust in grain facilities create explosion risks and possess an immediate danger to human lives and grain facilities (Fig. 3). Alongside vapor cloud explosions, dust explosions pose the most hazard within the process industry, especially within grain elevators, bins, silos, flour bins and feed mills. The particle size of dust generated during grain handling and processing are very small (< 500 µm), posing flagration and explosion risks.

Arkansas Is Our Campus

Visit our web site at:
https://www.uaex.uada.edu

Grain Dust Explosion Elements

The critical requirements of a fire are fuel, oxidizer and ignition. These three elements are part of the five elements required for a dust explosion to occur (Fig. 4):

1. **Fuel** – Tiny particles of dry grain dust from wheat, milo, oats, barley, flour, corn starch and other particles are highly combustible. The National Fire Protection Association (NFPA) standard mentions that dust particles of less than 500 μm size can lead to a fire and explosion.

2. **Oxygen** – Enough air supply with normal oxygen levels is always present in grain handling and processing facilities. Oxygen concentration, usually close to 21 percent, will increase the burning efficiency of the fuel.

3. **Ignition source** – Overheated bearings within elevator leg boots, heads or conveyors; elevator leg belts rubbing against leg sidewall casings; electrical shorts, electrical arcs from a non-explosion proof electrical devices; static electricity; phosphine pellets or tablets exploding in a wet aeration duct; cigarette lighters or lit cigarettes; cutting torches or weldings; metal sparks from grinders; metal to metal sparks; dropped tools and lightning are some of the potential ignition sources located in the grain elevator or feed mill facility.

4. **Dispersion of dust** – Grain dust must be suspended in the air to create an explosion. Layers of dust in a confined space can ignite and lead to a minor explosion. This minor explosion may unsettle the dust and create a secondary explosion of greater magnitude. The air turbulence of the dust cloud within a grain dust matrix will increase the chances of an explosion.

5. **Confinement** – A vertical elevator leg casing or housing; an enclosed drag conveyor; basement tunnel; dust bin; aeration duct; downspout; bin deck gallery or silo are some examples of confined spaces within a grain handling facility. Within confined enclosures like buildings, rooms, vessels or process equipment, an explosion may result in a pressure rise that can damage the facilities.

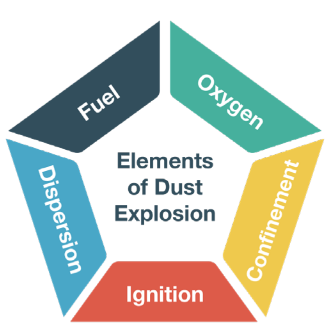


Figure 4. The Essential Elements for Grain Dust Explosion

Most elements required for a grain dust explosion are present in a grain handling facility. Some — primarily oxygen, grain dust and confined spaces — are difficult to control. Apart from the usual fire triangle of fuel (the dust), oxygen and heat, dispersion of dust particles in sufficient quantities and concentrations can cause rapid combustion (deflagration). The presence of flammable gases, such as methane and its heterogeneous mixtures within the dust mixture, increases the propensity of these gases to explode.

If one of the elements of the dust explosion pentagon — fuel, oxygen, heat, dispersion or confinement — is missing, the possibility of an explosion decreases. Eliminating ignition sources and controlling dust through improved material handling and housecleaning remain the most effective techniques for preventing grain dust explosions.

Development and Occurrence of Grain Dust Explosions

Combustible grain dust is composed of fine particles that pose an explosion hazard when suspended in the air under certain conditions. Several dust explosion incidents have resulted from employers' or employees' lack of awareness. It remains critical to determine if the facility has dust hazards and, if so, to take immediate action.

In most cases, dust explosions often occur at grain transfer points – in bucket elevators or enclosed conveyors (Fig. 5), where small dust particles separate from kernels due to tumbling, agitation and impacts, as fast-flowing grain hit the bucket elevator cups or change direction in drag or belt conveyors. Reducing the dust generation in these conveyors through appropriate design substantially reduces this risk.

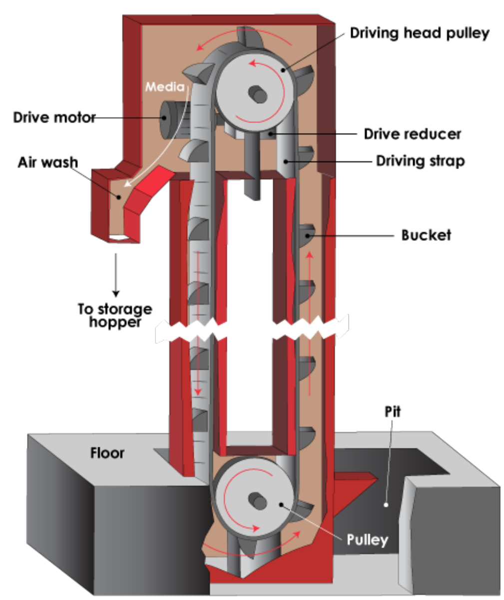


Figure 5. A schematic drawing of a Bucket Elevator System

Mechanical or electrical devices can become a potential ignition source. The ignition sources are usually either sparks or a hot surface. In some cases, ignition of the dust cloud occurs directly; in other cases, fire or an open flame may take place first, acting as the ignition source for the dust cloud. Energy requirements for igniting the dust clouds are quite small, and most ignition sources that occur during grain handling are capable of supplying sufficient amounts of this energy.

For illustration, an initial explosion in the processing equipment or in an area where fugitive dust has accumulated may eject additional accumulated dust into the air. This dust, if ignited, may cause a secondary explosion, which is more likely fatal and destructive.

Explanation of Grain Dust Terminologies

Flame propagation within the dust cloud matrix is mainly a function of the nature of dust, dust particle size and the byproducts formed. The following terminologies must be understood:

1. **Minimum Explosion Concentration (MEC) of Dust** – Dust concentrations within certain limits of 0.050-0.100 kg/m^3 (lowest concentration) and 2.0-3.0 kg/m^3 (highest concentration) are enough for a dust explosion to occur, provided an ignition source is present. Fine dust particles tend to combust faster than larger dust particles.

2. **Minimum Depths of Dust for Explosion (MED)** – The minimum explosion depth (MED) varies between 0.001 in and 0.021 in, depending on the depth of the enclosed space, as shown in Table 1. On the other hand, the maximum explosion depth (OED) for dust varies between 0.01 in and 0.20 in.

Table 1. Relationships between the height of the enclosed space and the minimum and optimum grain dust explosion depths.

Height of enclosed space (ft)	Minimum depth of dust for the explosion (MED)	The optimum depth of dust for the explosion (OED)
1	0.001 to 0.002 in	0.010 to 0.020 in
2	0.002 to 0.004 in	0.020 to 0.040 in
4	0.004 to 0.008 in	0.040 to 0.080 in
7	0.007 to 0.015 in	0.070 to 0.150 in
10	0.010 to 0.021 in	0.100 to 0.210 in

3. **Minimum Ignition Temperature (MIT) for Dust Cloud or a Layer** – If an ignitable dust mixture is heated, it will catch fire depending on the minimum ignition temperature. The minimum ignition temperature of a cloud is less than 400°C, while the minimum ignition temperature of a grain layer of about 5 mm is less than 300°C. For example, the ranges of ignition temperatures for some common grains including wheat flour, corn starch and rye dust are 410-430°C, 410-450°C and 410-500°C, respectively.

4. **Minimum Ignition Energy (MIE) of Dust** – The Minimum Ignition Energy of a dust cloud is less than 15 MJ.

5. **Maximum Explosion Pressure and Rate of Pressure Rise** – The maximum explosion pressure and the rate of pressure rise depend on the dust type, dust particle size and dust cloud concentration. Decreasing the particle size increases the explosion pressure, and to a more significant degree, increases the rate of pressure rise. For most organic dust, the explosion pressure and rate of pressure rise tend to plateau at a particle size of 10 to 40 microns.

Preventing Grain Dust Explosions

For a grain dust explosion to occur, all the elements in the dust explosion pentagon must be present (Fig. 4). Thus, if a single factor is removed, a dust explosion can be prevented. The following approaches can reduce the formation of dust explosion pentagon:

1. **Modify the process to reduce dust handling effectively** – Minimize hazardous materials, the substitute less hazardous materials, and moderate hazardous materials handling methods.
2. **Prevent suspension of combustible dust** – Work with smaller piles of dust, remove dust and thorough clean dust “hot spots” within facilities.
3. **Remove the ignition sources entirely or at least minimize their presence** – Eliminate ignition sources traceable to workers’ actions, including smoking, open flames, open light bulbs, welding, cutting, and grinding through training and enforcement.
4. **Provide appropriate equipment maintenance** – Read the equipment operator’s manuals, become familiar with them and follow the instructions for regular equipment maintenance. Workers should review these manuals regularly, and always refer to the manufacturer’s operating manual for specific operational and safety information. Workers should maintain signage and guards.

Industrial Design Suggestions to Avoid Dust Explosion

Most grain dust primary explosions start in elevator legs. Stored grain often contains 2 to 10 lbs. of grain dust per ton. Current standards suggest installing bucket elevators outside the facility to prevent the transmission of a primary explosion to the rest of the facility. Additional concepts to minimize explosion risks include:

1. Eliminate tunnels by using open galleries and

catwalks above ground, stacked by modern bucket elevators at the end of every horizontal silo.

2. Install bucket elevators at the end of every tunnel to eliminate connections between tunnels and to avoid the propagation of an explosion.
3. Fit all mechanical handling equipment with hazard monitors, speed sensors, belt slip monitors, plug switches, belt misalignment sensors and maximum belt tension sensors, with an emergency stop.
4. Replace cyclones with low-pressure baghouse filters to reduced dust spread (fugitive dust).
5. Design elevator towers to be open and made of steel. Elevator pits should be open also.
6. Include dust-suppression systems in the ship loading tubes with telescopic hoses, thereby minimizing the dust emission during loading of a vessel.
7. Design large aspiration systems with filters (baghouses) to collect the dust emitted during operations in various sections of the facility.
8. Reduce belt speed and increase capacity, with wide belts to reduce dust generation.

Best Industry Practices for Preventing Dust Explosions

The associated hazards of grain dust explosions apply to more than 250,000 workers at 24,000 grain elevators and mills that are under constant threats of fires and dust explosions. It is essential to provide some guidance on the best industry practices for preventing grain dust explosions.

1. **OSHA Standard**

A good starting place for good industry practices to prevent dust explosions is the OSHA standard 14. The Occupational Safety and Health Administration (OSHA) supplied its Grain Handling Standard – *"Title 29 Code of Federal Regulations* (CFR), Part 1910.272" in 1987 to help producers avoid fires and explosions. The General Duty Clause, (Section 5(a)(1)) states that employers must keep workplaces free from known hazards that might cause death or serious physical harm.

2. **Good Housekeeping**

- To help eliminate dust explosion dangers, employers should develop and implement a written housekeeping program.
- The program must contain commands for reducing dust accumulations on ledges, floors, equipment and other exposed surfaces. It should identify "priority" areas in grain elevators that are known to be potential sources of ignition.
- The housekeeping program should highlight procedures for removing grain and dust spills from work areas
- The use of compressed air to remove dust is allowed if machinery that poses a source of ignition is not operational, and alternative potential ignition sources are removed or controlled.
- Grain dust depth should never exceed 1/8th inch.
- Keep conveyor covered/closed when not in use.
- Open the windows in head houses and galleries when the weather allows.
- Once the dust is out, keep it out. Avoid blending it back to the grain if possible.

3. **Preventive Maintenance**

- Preventive maintenance can help prevent an occurrence of an ignition source.
- Keep all mechanical and electrical equipment in good working condition.
- Inspect the mechanical and safety control equipment associated with dryers and grain stream processing annually.
- Maintain and lubricate equipment according to the manufacturers' recommendations.
- Repair or replace equipment that breaks down or operates below standards immediately.
- Enforce "lock out, tag out" procedures to prevent the inadvertent application of energy or motion to equipment being repaired or serviced.
- Educate all workers who operate, repair, and service the equipment with the employer's "lock out, tag out" procedures.

4. **Hot work**

- Shut down the facility and clear all dust within the vicinity.
- Check the hidden spots near the location where the hot work will be done and remove any flammable materials.
- Use fire retardant tarps as needed.
- Move flammable items and materials at least 35 feet away.
- Make sure that the person performing the hot work is qualified.
- Inspect the equipment after hot work to check for any smoldering fire.
- Have at least one extra person standing by as a fire watch.
- Conduct follow-up inspections after the hot work.
- Enforce a strict "no smoking" policy.
- Place hot work signs to alert employees, con-

tractors and truck drivers.

5. **Bucket Elevator Legs**
   - Belts purchased after March 30, 1988, should be conductive and have surface electrical resistance less than 300 megohms.
   - For inspection, maintenance and cleaning purposes, bucket elevators must have openings to the head pulley and boot sections.
   - Bearings must be mounted externally to leg casings. If the bearings are mounted partially or entirely internal to a leg casing, the employer must provide temperature, vibration or additional monitoring platforms.
   - Elevator legs must be fitted with motion-detection devices that stop the leg when belt speed is decreased by 20 percent or more of its operating speed.
   - Belt alignment-monitoring devices - with alarms to alert employees when the belt is not tracking correctly - are required.
   - Should the employer equip bucket elevators with fire and explosion suppression system for protecting leg and boot sections or with pneumatic dust control systems, if so, then bearing monitors, detection devices, belt alignment devices need to be installed. Keep dust concentrations inside the leg casing at least 25 percent below explosive limits during handling operations.
6. **Emergency Action Plan**
   - Notify all affected employees immediately.
   - Sound an alarm.
   - Shut down all nearby equipment if it is safe to do so.
   - Call 911 as needed.
   - Extinguish any fire, if it is safe to do so.
   - Evacuate the workplace immediately if there is a chance of explosion or the rapid spread of fire, or if it is unsafe to take action.
   - Do not blast a pile of dust with an extinguisher. The pressure will suspend the dust.
7. **Training and Education**
   - Provide training to all workers, supervisors and contractors on general safety precautions regarding the grain facility, recognition, and prevention of hazards related to mechanical devices, dust accumulations and common ignition sources like smoking and engulfment.
   - Provide training on specific procedures and safety practices applicable to job tasks such as clearing choked legs, performing housekeeping, hot work, preventive maintenance and lockout/tag out.
   - Plan and conduct safety drills with first responders.

Dust Explosion Damage Control

Damage control refers to remedial measures that can be taken to reduce damage by explosions. The remedial measures include explosion containment, isolation, suppression and venting.

1. **Explosion Containment** – These techniques use systems and equipment to contain an explosion internally by absorbing the pressures generated by dust explosions.
2. **Explosion Isolation** – These techniques involve processes that prevent dust explosions from spreading, often by using shut-off valves.
3. **Explosion Suppression** – These techniques involve the establishment of systems that activate immediately when explosions begin to occur, suppressing the explosion quickly by adding suitable inert material. The following are desirable characteristics:
   - The system should respond immediately if an explosion occurs.
   - The system should inject inert material in enough quantities quickly to suppress the flames.
4. **Explosion Venting** – Venting can effectively reduce the destruction from a dust explosion in the absence of toxic gases. The process involves letting off the unburnt fuel, fire, and the explosion pressure quickly through the weakest spot in the building. This prevents the explosion from affecting other sections of the facility.

Grain Dust Control and Prevention Procedures Summary

1. Educate employees about the dangers of dust explosions.
2. Ensure the housekeeping and sanitation program are meticulous. If you see any dust, remove it.
3. Use the bearing lubrication program according to the manufacturer's specifications.
4. Fit bearing temperature sensors on leg boot, head, and knee pulley shafts, on boot bearings, flat drag head and belt conveyor drive and idler bearings.
5. Fit belt rub sensors inside bucket elevator leg casings to detect belt misalignment and to prevent friction heating.
6. Keep a periodic (weekly or bi-weekly) bearing temperature-tracking program: record periodic bearing temperature readings and compare with previous readings. A significant bearing temperature rise (10°F to 20°F in a week or

two) may signify bearing failure and the need to replace the bearing.

7. Replace steel cups with plastic ones in elevator legs.
8. Use the anti-static belting material in legs and horizontal belt conveyors.
9. Install quick-opening cleanout doors on leg boot side panels for grain and dust cleanout.
10. Install ventilation systems in tunnels and galleries with open conveyors or dust aspiration systems at grain transfer points, and truck dump pits where dust accumulation is a significant concern.
11. Install dust aspiration or suction ventilation systems inside enclosed legs and conveyors to keep suspended dust below MED levels.
12. Replace filter bags and clean out dust collectors at periods specified by the manufacturer.
13. Clean out the dust cyclone collector holding bins at scheduled intervals.
14. Install dump pit baffles on truck dump pits to provide a significant reduction in airborne dust during grain receiving.
15. Incorporate explosion relief panels and dust explosion protection devices in elevator design.
16. Install explosion-proof electrical outlets and equipment.
17. Establish effective "damage control" remedial measures for every facility to reduce damage, casualties and fatalities should a dust explosion occur.

References

Abbasi, T., & Abbasi, S. A. (2007). Dust explosions–Cases, causes, consequences, and control. *Journal of hazardous materials, 140(1-2)*, 7-44.

Ambrose, K. (2019). Agricultural Dust Explosions in 2018. Available online at https://engineering.purdue.edu/FFP/research/dust-explosions/Dust_Explosions_2018.pdf

Cheremisinoff, N. P. (2014). *Dust Explosion and Fire Prevention Handbook: A Guide to Good Industry Practices.* John Wiley & Sons.

Eckhoff, R. K. (2003). *Dust explosions in the process industries: identification, assessment and control of dust hazards.* Elsevier.

Grain Handling U.S. (1996). Department of Labor, Occupational Safety and Health Administration, OSHA 3103, (Revised).

Jones, C. (2011). Preventing Grain Dust Explosions.BAE-1737 http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-2604/CR-1737web.pdf

Parnell, C. (1998). Personal Conversation and E-mail. *Texas A&M University, College Station, TX.*

Price, D. J., Brown, H. H., Brown, H. R., & Roethe, H. E. (1922). *Dust Explosions: Theory and Nature Of, Phenomena, Causes and Methods of Prevention.* National fire protection association.

Schoeff, R. W. (2006). *Agricultural dust explosions in 2005.* Dept. of Grain Science, Kansas State University. KS, March 20, 2006, 5 pp.

SAMMY SADAKA Ph.D., P.E., is an associate professor - Extension engineer with the Department of Biological and Agricultural Engineering located in Little Rock. **KINGSLY AMBROSE**, Ph.D., is an associate professor with the Department of Agricultural and Biological Engineering - Purdue University located in West Lafayette, IN. **JOHN MAGUGU**, Ph.D., is a professional assistant in Biological and Agricultural Engineering at the Rice Research and Extenstion Center in Stuttgart.

FSA1092-PD-7-2019N