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# Mitigating Dust Explosion Risks in Solid Powder Processing

## A Quadro Engineering White Paper

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## Introduction

Dust explosions are a risk in many processing environments but they pose a special risk when the product being processed is a fine, solid powder. Many materials, such as organic solids (sugar, wood, grain, etc.) and some metals (such as aluminum and magnesium), while being merely ***combustible*** to various degrees in large sizes, become ***explosive*** when sized very finely and dispersed in dense enough concentrations. Combustible substances with an average particle size smaller than 420 micron are generally considered to be explosive (1).

A 2006 investigation by the U.S. Chemical Safety and Hazard Investigation Board identified 281 combustible dust incidents between 1980 and 2005 that resulted in at least 119 fatalities and 718 injuries in the United States. These incidents included seven "catastrophic dust explosions" in the decade preceding publication of the investigation report, which involved multiple fatalities and "significant community economic impact" (1). Dust explosion incidents continued to occur after this report was published. A particularly notable recent incident was the explosion at the Imperial Sugar Refinery in Port Wentworth, Georgia in February, 2008, which killed 14 people and injured 36 (2).

The apparent lack of reduction in the number and severity of dust explosion incidents over the years has propelled industrial regulations around the world to grow more stringent with respect to dust explosion safety. Manufacturers are currently facing the challenges of complying with these new regulations. This paper will explain the basic mechanics of combustion and explosion, outline the different dust explosion properties that are commonly measured, and present different methods of minimizing dust explosion hazards that are compliant with the new regulations and that are relevant to companies working with solid powders.

## Combustion and Dust Explosion Basics

For any combustion to occur, the three elements in the "fire triangle" must be present. There must be a ***fuel***, ***oxygen***, and an ***ignition source*** (3).

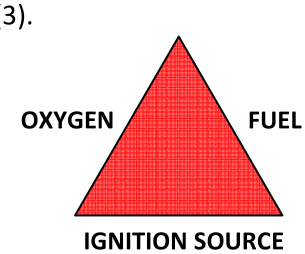


***Figure 1: Fire Triangle***

If combustion of a powder occurs in an open atmosphere, the result is a ***flash fire***, not a dust explosion. Flash fires can be less damaging since they have room to expand and the resultant pressure shockwave is easily dispersed without damaging the machine or plant structures. The more dangerous ***dust explosion*** occurs when two additional elements are added to the fire triangle: ***Dispersion*** and ***Confinement***, resulting in the dust explosion pentagon (3).

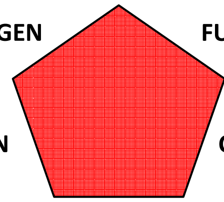


***Figure 2: Dust Explosion Pentagon***

When powder is ***dispersed*** in air, maximum material surface area is exposed. Since most materials will burn through a process known as deflagration (burning of the layer exposed to air, followed by the next layer, etc.) the dispersed powder burns much faster than if the dust is settled in a stable layer.

When the other four elements of the pentagon are present in a confined space, the danger is exacerbated in two ways. Firstly, confinement permits the dispersed material to achieve a high enough concentration to explode. Secondly, if there is no proper venting or strength in the confining material, an explosion will cause catastrophic damage to the equipment which poses a great risk to nearby personnel.

Small particle size plays a strong supporting role in increasing the dust explosion danger. The smaller the particle size, the more surface area is exposed to oxygen which increases the rate of deflagration. Smaller particle sizes also allow for easier dispersion as the particles are able to remain suspended in the air for longer periods of time.

## Dust Explosions in Solid Powder Processing Equipment

The potential for dust explosion needs to be accounted for in any industrial operation. Processes that handle dry, solid powders such as particle size reduction, pneumatic conveying, and fluid bed drying (FBD's) pose a special explosion risk due to the high potential of all five dust explosion pentagon elements being present.

In a powder processing environment, fuel is provided by the material being processed. As the particle size is reduced, the material becomes more volatile. Air flow inside the equipment provides for the dispersion of the material. Oxygen is present in the surrounding atmosphere. Confinement occurs in the machine's action chamber. And finally, ignition sources can come from the heat of the machine operation or by friction, and sparks can occur due to nearby electrical sources or static discharges (which can be caused by external sources or particle-to-particle attrition within the product).

## Testing Powders and Environment

The level of dust explosion protection required for equipment will depend on the powder properties. The parameters that are tested for generally measure the propensity of the material to explode, how damaging that explosion would be, and what level of protection would be required to prevent an explosion. They include the following:

***Table 1: Properties of Combustible Dusts (1)***

| Property | Definition | Explanation/Use |
|---|---|---|
| $P_{max}$ | Maximum Explosion Pressure | Indicates severity of the explosion. Used to design explosion-proof equipment. |
| $(dp/dt)_{max}$ | Maximum Rate of Pressure Rise | Indicates speed of explosion. |
| $K_{St}$ | Dust Deflagration Index | Calculated using $P_{max}$ and $(dp/dt)_{max}$. Measures explosion severity relative to other substances. |
| MIE | Minimum Ignition Energy | Measures minimum amount of energy required in a spark to ignite the dispersed powder. |
| MIT-C | Minimum Ignition Temperature-Cloud | Determines the minimum surface temperature required to ignite the powder while dispersed in the air. |
| MIT-L | Minimum Ignition Temperature-Layer | Determines the minimum surface temperature required to ignite the powder while settled in a layer. |
| MEC | Minimum Explosible Concentration | Predicts minimum concentration of dispersed powder that will explode. |
| LOC | Limiting Oxygen Concentration | Measures minimum oxygen level required to ignite dust cloud. Provides required level of inertion. |
| ECT | Electrostatic Charging Tendency | Indicates propensity of material to build up and discharge static electricity spark containing energy ≥ MIE. |

The following points regarding material properties should be noted:

- Powders with low MIE and MIT-C are particularly dangerous.
- Certain powders that may not explode can still pose a fire hazard.

## Dust Explosion Protection

Once the explosive properties of the product are known, processing equipment can be configured to mitigate the risk. Options include the following:

***Containment***

Once the $P_{max}$ value is determined, a pressure vessel can be designed accordingly around the danger area to contain the force of such an explosion. This option is usually chosen when nitrogen inerting cannot be used.


***Figure 3: Explosion Pressure Shock-Resistant (PSR) Quadro® Comil®***

***Venting***
If possible to integrate safely into the facility, equipment can be designed to vent explosion gases to a safe zone (typically to outdoors) instead of attempting to contain them.  This option results in less bulky equipment but usually requires ancillary ducting to connect equipment to safe areas.  Venting is again implemented when nitrogen inerting cannot be used, or as a back-up safety measure.

***Nitrogen Inerting***
A very effective method of avoiding dust explosions in the first place is to limit the presence of one of the elements of the fire triangle, making even basic combustion close to impossible.  Since fuel cannot be removed as it is the product being processed, and ignition sources are often unpredictable, oxygen becomes the fire triangle element that is easiest to control.

In this process, which is also known as ***nitrogen purging***, nitrogen gas is introduced into the danger zone to displace atmospheric oxygen and reduce its concentration from the usual 21% found in the atmosphere, to well below the material's LOC (usually below 5% in an inerted zone).  At this low concentration, there is not enough oxygen in the air to permit combustion.  Oxygen sensors can be installed into the system to monitor oxygen levels during the process and adjust nitrogen flow accordingly, providing a closed loop system.

***Figure 4:  Quadro® Comil® With Nitrogen Purge System***

***Ignition Source Control***

As previously mentioned, ignition sources are difficult to predict and control. Studies have shown that 27% of incidents involving dust explosions had an "unknown" ignition source. This is the reason protection against sources of ignition is often part of a more elaborate dust explosion prevention system that would include containment, venting, or nitrogen purging.

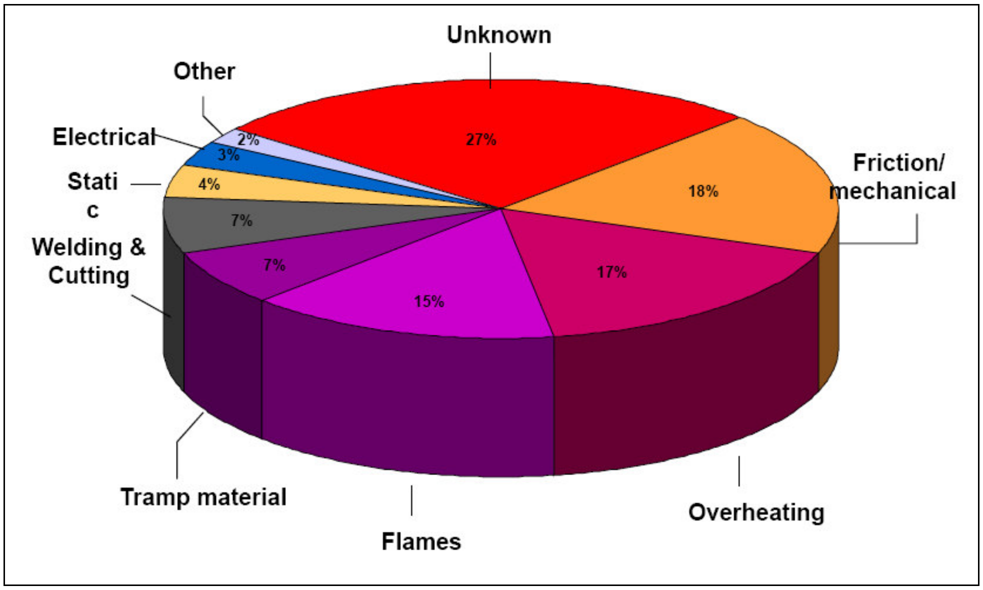


***Figure 5: Types of Ignition Sources Involved In Incidents*** (4)

In an effort to limit sources of ignition, equipment is routinely earthed (connected to ground) and bonded (having all metal components of a machine connected to each other) to help prevent electrostatic discharges. The equipment can also be set with up an ***Earth Monitoring System*** to ensure that the earth connection is always present and to warn if the connection is broken. The use of intrinsically safe wiring can help prevent electronic sources of ignition.

***Figure 6: Quadro Vac® Pneumatic Conveying System equipped with an Earth Monitoring System***

***Process Monitoring***

Other process parameters such as ambient temperature, product temperature, amperage, and equipment speed can be monitored in order to ensure that product parameters do not approach or exceed dangerous values.

## Selecting Explosion-Proof Equipment

Some regions of the world require equipment to have an explosion-proof rating in order to be deployed in explosion hazardous environments or to process potentially explosive products. In the European Union, such equipment must meet the ATEX 94/9/EC directive. Within the ATEX directive, for example, there are various equipment categories dependent on the level of protection that is required and each equipment category is associated with a hazardous area zone. Process equipment manufacturers must ensure their equipment is certified for operation in the hazardous area zone specified by the purchaser. This has been a requirement in EU countries since 2003 and similar regulations are increasingly being put in place in North America.

Selecting equipment to provide dust explosion protection is a vital process. Equipment should be purchased from reputable manufacturers who have experience in mitigating dust explosion risks and who can provide appropriate explosion-proof certification, such as ATEX, for their equipment.

## Conclusion

In solid powder processing, dust explosion risks must be mitigated in order to protect against workplace injuries, needless loss of life, and damage to facilities and equipment. The properties of the materials being processed must first be understood and measured accurately, and then appropriate counter-measures can be implemented into the process. Users must ensure that appropriate, certified equipment is selected in order to provide proper protection for employees and to comply with local laws and regulations.

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***About Quadro Engineering Corp.***

*Quadro engineers, manufactures and markets an innovative line of size reduction mills, mixers, emulsifiers, powder dispersion units, shear pumps, high shear wet mills, security screeners and vacuum conveyors for the Food, Pharmaceutical, Cosmetic/Personal Care and Fine Chemical industries. Services include custom equipment engineering, free process testing in Quadro's R&D Test Center, a complete Parts & Service Program, and a Rental Program featuring a wide range of Quadro's equipment. Quadro is always ready to meet the needs of its customers in more than 80 countries around the world.*

*Quadro equipment can be custom designed to meet any process environment including appropriate options to provide explosion-proofing. Quadro has vast experience in providing systems with containment, nitrogen purging, earthing & bonding, and monitoring. All Quadro solids processing equipment can be provided with ATEX certification. For more information regarding Quadro products, visit www.quadro.com.*

## References


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