WHITE PAPER

Dust Explosion Hazards in the Food Industry

Nearly all foodstuffs and ingredients including grain, sugar, artificial sweeteners, starch, and powdered flavours will burn with difficulty, as a powder layer, but they can explode violently when ignited in the form of a dust cloud. There are many factors that affect the explosion violence or the sensitivity to ignition of a dust cloud such as particle size, cloud density or moisture content.

The dust cloud density is quite important and it would need to resemble a dense fog before ignition could occur. Although such concentrations are not normally expected to be present within processing buildings, explosible dust clouds are regularly formed inside the material handling/processing equipment, i.e. silos, bin filling/emptying, pneumatic conveying or dust collectors. In addition, dust layers in buildings, if roused for example by a 'primary' explosion inside a vessel, can form combustible concentrations throughout the entire building. These so called 'secondary' dust explosions are often the most devastating.

The particle size of the dust is another important property which influences the explosibility of the dust cloud. The finer the particles, the greater the surface area per unit mass and thus the more explosible a given dust is likely to be. When the cloud is composed of a series of particle sizes, ranging from fine to coarse, the fines play a prominent part in the ignition and the explosion propagation. As dust settles, larger particles drop out of suspension, leaving the finest particles to form the dust cloud. The presence of dusts should be acknowledged in a process stream, regardless of the starting particle size of the material. For example, friable materials (granular sugar) will create very fine dust in transfer operations by means of attrition.

Moisture content will also affect the explosion risk. A dry dust contains less than 10% moisture and the dryer it becomes the higher the ignition sensitivity and explosion violence. Therefore dry dusts, of small particle size will be more easily ignited and produce more violent explosions.

However, it must be noted that moisture contents in the range of 12 – 18%, as found naturally in many agricultural products, are not enough to render the dust non-flammable. Care must also be taken concerning material that has been present in process equipment for a long period of time, e.g. due to poor cleaning programs, and which has now dried out.

Please also be aware that with the introduction of chemicals such as artificial sweeteners, and powdered vitamins into the food industry in recent years, the explosion properties of products may now be totally different, with potential for increased sensitivity to ignition and greater explosion violence.

One of the most catastrophic dust explosions in recent years occurred at a sugar refinery in the USA, in 2008, resulting in 14 fatalities, multiple injuries and major facility destruction. Dust explosions in the food industry are nothing new, and the oldest recorded dust explosion occurred in Mr. Giacomelli's Bakery in Turin on December 14, 1785. As facilities increased in size, equipment became more mechanised and sophisticated, the consequence of incidents also increased, such as the grain elevator explosion in April 1981 that killed 9, injured 30 and caused US$30 million damage. And as the aforementioned sugar refinery explosion shows, devastating dust explosions continue to occur.

Conditions Required for Dust Explosions to Occur

A number of conditions must exist simultaneously for a dust explosion to occur:

> The dust must be combustible (combustible, flammable, and explosible all have the same meaning);

> The dust must be dispersed (forming a dust cloud in air);

> The dust concentration must be within the explosible range (above the Minimum Explosive Concentration, MEC);

> The dust must have a particle size distribution capable of propagating flame;

> The atmosphere in which the dust cloud is present must be capable of supporting combustion e.g. contain enough oxygen;

> Any ignition source must have sufficient energy to initiate combustion.

Most commonly identified ignition sources in dust handling/ processing plants include welding, mechanical sparks, hot bearings, hot surfaces, open flames, burning embers, self-heating, electrostatic discharges, and electrical sparks.

In order to determine the sensitivity of a dust cloud to ignition, appropriate laboratory tests should be performed.

Assessment of Dust Explosion Hazards in your Facility

A systematic approach to dust cloud explosion hazards involves:

> Identifying areas where combustible dust clouds could occur under normal and abnormal conditions;

> Preventing the formation of explosible dust clouds

> Determination of ignition sensitivity and explosion severity characteristics through appropriate laboratory tests on representative dust samples;

> Identifying potential ignition sources that could exist under normal and abnormal conditions;

> Taking measures to eliminate/control ignition sources; and

> Taking measures to protect against the consequences of dust cloud explosions.

Laboratory Testing Assess Explosion Characteristics of Dust Clouds

In order to assess the potential for an explosion and to select the most appropriate Basis of Safety for any operation, the explosion characteristics of the dust(s), handled in the processes, should be determined.

The explosion characteristics normally fall within one of two groups, "likelihood of an explosion (Ignition Sensitivity)" and "consequences of an explosion (Explosion Violence)". Taken together these two groups define the dust explosion risk of a material.

Laboratory Testing to Determine "Ignition Sensitivity"

Combustible Dust and Combustible Flyings Determination (BS EN ISO/IEC 80079-20-2).

This test determines whether a dust cloud will explode when exposed to a sufficiently energetic ignition source. The first part involves using a vertical tube with a constant arc ignition source to see if the dust is capable of supporting combustion and propagating flame. Should the test show no flame propagation, the constant arc is replaced with a hot coil to provide more energy. If this is still negative, a 20-Litre sphere test using a 2 kJ chemical igniter would be used (an acceptable alternative to the 20-Litre sphere, normally in the case of limited material, is the GG vertical furnace).

Processes handling powders which propagate flame during any one of these tests, would make the processes fall under the ATEX[1] or DSEAR[2] regulations. This test answers the question "Can this dust explode?"

Minimum Ignition Energy - MIE (BS EN ISO/IEC 80079-20-2)

The MIE test determines the lowest electric energy that is capable of igniting a dust cloud at its optimum ignitable concentration. The test is used primarily to assess the susceptibility of dust clouds to ignition by electrostatic discharges (sparks).

1. ATEX 153, EU Directive 1999/92/EC
2. DSEAR, Dangerous Substances and Explosive Atmospheres Regulations

Minimum Ignition Temperature of a Dust Cloud – MIT (EN 50281-2-1)

This test determines the lowest temperature capable of igniting a dust dispersed in the form of a cloud. The MIT is an important factor in evaluating the ignition sensitivity of dusts to such ignition sources as heated environments, hot surfaces (electric motors), and friction sparks.

Minimum Ignition Temperature of a Dust Layer – LIT (EN 50281-2-1)

This test determines the lowest temperature capable of igniting a dust layer of standard thickness (5 mm). The LIT is used in evaluating the ignition sensitivity of powders to ignition by hot surfaces (electric motors).

Self-Heating - (JA Abbott (ed.) "Prevention of Fires and Explosions in Dryers", Institute of Chemical Engineers, 1990) / BS EN 15188

Ignition of bulk powders can occur by a process of self-heating when the temperature of the powder is raised to a level at which the heat liberated by the exothermic oxidation or decomposition reaction is sufficient to exceed the heat losses and to produce a "runaway" increase in temperature.

The minimum onset temperature for self-ignition of a powder depends mainly on the nature of the powder, its volume, vessel dimensions and the way it is heated. If these variables are predictable, a reliable assessment of the onset temperature for self-ignition and also the induction time to self-ignition can be made by appropriate small-scale laboratory tests:

- Bulk Powder Test: Simulates bulk powder in IBCs, bags, bottom of dryers, hoppers
- Aerated Powder Test: Simulates fluid bed drying
- Powder Layer Test: Simulates powder deposits on dryer walls/ surfaces and tray drying
- Basket Test: Simulates large-scale storage or transport conditions

Minimum Explosive Concentration - MEC (EN 14034-3)

MEC test determines the lowest concentration of a dust cloud in air that can give rise to flame propagation upon ignition. This test answers the question "What is the minimum concentration of a dust cloud to sustain combustion".

Limiting Oxygen Concentration - LOC (EN 14034-4)

LOC test determines the minimum concentration of oxygen (displaced by an inert gas such as nitrogen or carbon dioxide) capable of supporting combustion. An atmosphere having an oxygen concentration below the LOC is not capable of supporting a dust cloud explosion.

Laboratory Tests to Determine the "Explosion Violence"

Maximum Explosion Pressure (Pmax), Maximum Rate of Pressure Rise, Dust Constant (Kst Value) (EN 14034-1 & 2)

The Maximum Explosion Pressure and Maximum Rate of Pressure Rise values are determined by using a $1m^3$ or more commonly a 20-Litre Sphere test apparatus.

The maximum explosion pressure and maximum rate of pressure rise are measured and the latter is used to calculate the Dust Constant (Kst) value of the dust cloud. These data can be used for the purpose of designing dust explosion protection measures such as explosion relief venting, suppression, and containment.

MIE test in action

Table 1 lists Explosion Characteristics of some dusts that are commonly used in the food industry.

The Basis of Safety for Dust Cloud Explosion Hazards

Safety from dust cloud explosions includes taking measures to avoid an explosion (explosion prevention) or designing facilities and equipment so that in the event of an explosion people and processes are protected (explosion protection). The selection of explosion prevention and/or protection measures is based on:

> Define where flammable atmospheres occur
> The available flammability data
> The nature of the processes and operations
> The level of personnel knowledge regarding the consequences of a dust explosion and adherence to the preventive measures (employee training and culture)
> Environmental effects of a dust explosion
> Business interruption resulting from a dust explosion

Table 1. Explosion Characteristics of Some Dusts in the Food Industry

Product	Explosible?	P_{max} (bar)	K_{st} (bar.m/s)	MIE (mJ)	MIT- Cloud (°C)	MEC (g/m^3)
Corn	Yes	6.5	112	45 - 100	390 - 400	73
Wheat	Yes	7.4	87	50 - 100	370 - 380	67
Oats	Yes	7.2	43	> 500	420 - 430	30
Barley	Yes	6.3	100	50 - 100	360 - 370	73
Soy Beans	Yes	9.2	110	50 - 100	600 - 620	80
Starch (rice)	Yes	10.0	220	> 30	460 - 470	60
Starch (wheat)	Yes	9.1	156	10 - 30	470 - 480	30
Sugar	Yes	9.0	138	< 10	470 - 480	30

Approach to Process Safety Testing

Table 2 specifies the type of data that might be required to assess dust explosion hazards associated with some common unit operations in the food industry and to define a Basis of Safety. Note that this should only be used as a guide and specific data requirements for a particular unit operation may be different.

Table 2. Dust Explosion Test Data Requirements for some Specific Unit Operations

Unit Operation	Explosion Screening[1]	MIE (mJ)	MIT[3] (°C)	LIT[3] (°C)	Explosion Severity – Kst (bar.m/s)	LOC[2] (%)	MEC (g/m^3)	Self-Heating (°C)
Manual Handling / Pouring	X	X						
Sieving / Screening	X	X						
Tumble / Double Cone Blending	X	X	X	X		X		
Ribbon Blending	X	X	X	X				
Milling	X	X	X	X	X	X		X
Jet Milling	X	X			X	X		
Spray, Fluid Bed Drying, Tumble Drying	X	X	X	X	X			X
Tray Drying	X	X						
Pneumatic Conveying	X	X	X	X			X	
Screw Conveying	X	X	X	X				
Transfer to Hopper / Bin / Tote / Container	X	X	X	X	X			
Dust Collector and Exhaust Ventilation	X	X	X	X	X		X	

1. Explosion Screening is only conducted if the combustibility of the powder/dust (as being present in the process/facility) is not yet established. If the material is found to be non-combustible, other tests in the table may not be required.
2. LOC is determined if the Basis of Safety is inert gas blanketing.
3. LIT and MIT are also required for determining the maximum allowable surface temperature for electrical and non-electrical equipment used in hazardous (zoned) areas.

Explosion Prevention and Protection Measures

The risk of an explosion is minimised when one of the following measures is ensured:

> An explosible dust cloud is never allowed to form
> The atmosphere is sufficiently depleted of oxidant that it cannot support combustion
> All ignition sources capable of igniting the dust cloud are removed, or
> People and facilities are protected against the consequences of an explosion by suitable "protection measures".

Avoiding formation of explosive dusts clouds should always be the primary objective. This might be through inherent safety or other means such as good dust extraction, handling techniques, equipment containment and maintenance, and housekeeping.

Note that since ignition sources are difficult to completely prevent, particularly for ignition sensitive materials, a robust basis of safety often requires these measures to be combined e.g. ignition source avoidance combined with explosion protection. Explosion protection on its own does not usually constitute an adequate basis of safety. Other prevention measures must also be used to ensure explosion protection systems have minimum demand on them. Even if protection systems work as intended, you have had an explosion and this is not a good outcome.

Secondary Explosions and Good Housekeeping

A well designed plant is no guarantee of safety, if those who operate it do not understand the hazards involved, and the precautions designed to control them.

A majority of the most serious dust explosions over the years have not been caused by the primary explosion inside the plant, but from a secondary explosion within the building as mentioned earlier. A small initial event causes pressure and shock waves to propagate into the workplace, and dust deposits around the workroom are shaken into a cloud, which subsequently ignites. When this happens in a series of connected rooms, the result can be fatalities and horrific building collapse.

Secondary dust explosions are especially common in industries where traditionally little concern exists for the presence of dust outside the process equipment due to the material not being toxic and not being particularly expensive. Unfortunately, the food industry falls squarely into this category. After all we use sugar and flour at home all the time, how can it be dangerous? Under the right conditions these very familiar materials can be killers.

Housekeeping activities must strive to minimise the presence of dust outside equipment. Of key importance is evaluation of dust release points and exhaust ventilation needs. It is much easier to replace a gasket, refit a manway, or install local dust extract systems, etc., than to spend time cleaning up the dust that has escaped. Other common practices are explosion venting, inside a building. The flame and pressure waves from such a release can cause unimaginable damage to people and plant let alone the increased risk of a secondary explosion occurring.

To avoid these conditions occurring, training and competency are key. In addition, companies should strive to create a suitable culture in the organisation for example that does not tolerate dust layers outside equipment.

Safeguard Reliability

In the EU, legislation is has been in place since June 2003 to reduce the likelihood of dust explosions occurring. The ATEX[1] workplace directive and DSEAR[2], in the UK, are designed to show awareness of dust explosion hazards and to minimise the potential risk to employees. All safeguards intended to prevent dust explosions must be recognized, understood and maintained. Operators should be aware that signs of overheating, excessive vibration, or noise indicating mechanical malfunction or misalignment need prompt attention before a small smouldering clump of dust leads to a serious explosion. Likewise protective safeguards such as explosion relief vents must be appropriately designed and maintained with clear, safe passages of discharge. Maintenance programmes for equipment should be in place and a routine inspection and testing programme should be created for safety critical explosion protections.

References

1. ATEX 153, EU Directive 1999/92/EC
2. DSEAR, Dangerous Substances and Explosive Atmospheres Regulations

DEKRA Process Safety

The breadth and depth of expertise in process safety makes us globally recognised specialists and trusted advisors. We help our clients to understand and evaluate their risks, and work together to develop pragmatic solutions. Our value-adding and practical approach integrates specialist process safety management, engineering and testing. We seek to educate and grow client competence to provide sustainable performance improvement. Partnering with our clients we combine technical expertise with a passion for life preservation, harm reduction and asset protection. As a part of the world's leading expert organisation DEKRA, we are the global partner for a safe world.

Process Safety Management (PSM) Programmes

- Design and creation of relevant PSM programmes
- Support the implementation, monitoring, and sustainability of PSM programmes
- Audit existing PSM programmes, comparing with best practices around the world
- Correct and improve deficient programs

Process Safety Information/Data (Laboratory Testing)

- Flammability/combustibility properties of dusts, gases, vapours, mists, and hybrid atmospheres
- Chemical reaction hazards and chemical process optimisation (reaction and adiabatic calorimetry RC1, ARC, VSP, Dewar)
- Thermal instability (DSC, DTA, and powder specific tests)
- Energetic materials, explosives, propellants, pyrotechnics to DOT, UN, etc. protocols
- Regulatory testing: REACH, UN, CLP, ADR, OSHA, DOT
- Electrostatic testing for powders, liquids, process equipment, liners, shoes, FIBCs

Specialist Consulting (Technical/Engineering)

- Dust, gas, and vapour flash fire and explosion hazards
- Electrostatic hazards, problems, and applications
- Reactive chemical, self-heating, and thermal instability hazards
- Hazardous area classification
- Mechanical equipment ignition risk assessment
- Transport & classification of dangerous goods

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