Explosion Risks in Silo Filling and Discharge

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Introduction

Many bulk solids are flammable and, when dispersed as a dust cloud in air, can cause a dust explosion. Because silos are very large volumes, the consequences of a dust explosion in a silo can be devastating. When silos are interconnected, either directly or via the solids handling equipment, the explosion can propagate from one silo to the next and the consequences are even more severe.

Another feature commonly encountered in bulk handling of solids is the presence of dust outside the equipment. Even moderate amounts of dusts in the plant can, when raised to a dust cloud, create a flammable atmosphere. The force to raise the dust can be provided by the blast of a minor explosion in some equipment. The following, so-called secondary, dust explosion in the plant is often responsible for the collapse of whole buildings.

This paper will briefly review when and how dust explosions can occur in silos and what preventive and protective measures are available to control the risks.

The risks of an explosion of the gases given off by the material, either as volatile content or as the products of decomposition of the material, are not considered here.

Which Solids Are Flammable?

Dust explosions only occur with flammable dusts. Many bulk solids are flammable and are recognised as such. Typical examples are fuels such as coal. However, many other products such as grain, starch, milk powder, sugar, resins and polymers are equally flammable. Provided the particles are small enough, the majority of solids will be able to cause a dust explosion. In testing it is found that approximately 70% of all dusts tested are classified as "flammable". This is even true for dusts that can hardly (or even not at all) be ignited as a dust layer.

For a dust explosion, one needs "dust". In this context, particles smaller than about 0.5 mm diameter are classified as dust. The smaller the particle size, the larger the surface area and the faster the explosion will be. Unfortunately, bulk solids usually contain at least a fraction of fines, either because of the way it was produced or because of the handling of the material.

What is a Dust Explosion?

A dust explosion resembles a gas explosion in many respects. The difference is that the fuel is not a flammable gas but a fine flammable dust. In both cases the fuel burns very rapidly, the speed being caused by the fact that the fuel and air are mixed prior to ignition. Because the fuel and air are mixed, the explosion will consume the whole mixture once it has been ignited.

The burning of the fuel causes a large volume of hot combustion products. In an open space, this will lead to an expanding fireball. The maximum size of the fireball will be about 8 to 10 times the size of the initial dust cloud. In a closed vessel, however, the expansion is not possible and the pressure will rise to about 8 - 10 times the initial pressure. The time to reach that pressure depends on the type of dust, the dust concentration, the turbulence conditions in the cloud and the volume of the vessel. Typically, a dust explosion will take a few hundred milliseconds. This time, albeit short, provides the basis for some protective measures. The fact that the time is so short means that there is little room for correction of any mistakes.

A situation that must be considered separately is an explosion propagating in a long duct. In this case the expansion of the combustion products causes a flow in the dust which increases the level of turbulence. Since turbulence enhances the combustion rate, the explosion will accelerate continuously until a different type of explosion propagation is reached: a detonation. A detonation typically runs at 2 km/s (much faster than the speed of sound in the unburned mixture), has a peak pressure of about 20 bar and is more devastating and more difficult to control than a normal dust explosion. Luckily, detonations in dust-air mixtures are relatively rare (they are more common in pipelines containing a flammable gas mixture). The initial process of flame acceleration, however, is certainly very relevant because this may cause a much stronger explosion in any vessel connected to the duct.

Dust Explosion Characteristics

A range of standard tests have been developed over the years in order to determine relevant characteristics of dusts. Using standard tests has the advantage that dusts can be compared and that the data can be used when applying guidelines for preventive and protective measures.

Because the dust explosion characteristics depend strongly on the particle size, shape, moisture content and contaminants, published data can only be used with great care. Besides, it is not always clear which standard has been used for the tests. This limits the applicability of the data even further as most data have been determined some time ago or in another geographical area. Consequently, in order to obtain the necessary data, tests are often necessary.

The explosion severity can be characterised by the maximum explosion pressure generated in a closed vessel and the maximum rate at which the pressure increases in the explosion. In order to find the maximum values, a range of dust concentrations must be tested. It is common practice to consider only the maximum values. Even if it is likely that the dust concentration will not be at the optimum value, it is virtually impossible to be sure of this because deposited dust inside the equipment can always be re-suspended in the incident.

Because the rate of pressure rise is volume dependent, it is common to convert that value into a volume independent parameter, KSt. Using the KSt value, dusts can be divided into so-called dust explosion classes: St 1 (includes most bulk materials), St 2 (includes many "man-made" products) and St 3 (typically metals like aluminium).

The explosion sensitivity of a dust can be different for different types of ignition source. Therefore different parameters must be determined to determine the sensitivity. The most common ones are the Minimum Ignition Energy (MIE) for spark ignition of a dust cloud, the Minimum Ignition Temperature (MIT) of a dust cloud (comparable to the auto ignition temperature for gases and vapours) and the Layer Ignition Temperature (LIT) for ignition of a thin dust layer by hot surfaces. The ignition of thick deposits or bulk material by high temperatures is subject to separate tests, where the exact conditions, especially air availability, must be tailored to represent the plant conditions as well as possible.

There are more characteristics that can be determined, like the Limiting Oxygen Concentration or the Minimum Explosible Concentration, but the need for these data must be judged case by case.

Preventing Dust Explosions in Silos

For a dust explosion to occur, a flammable dust-air mixture is needed. Most silos are filled with air, so the only way to prevent the flammable mixture is to avoid the dust. Depending on the type of material, a large amount of fine dust can be present at any time. Even granular material will contain some fines in most cases. During pneumatic transfer, the fines may well remain suspended long after the granules have fallen down, so that the dust concentration in the head space can be much higher than expected on the basis of the average dust content of the product.

Even if this does not happen, flammable concentrations may occur occasionally. For example, at the end of a charge, all collected fines may be fed into the silo in a short period of time. Alternatively, dust sticking to the silo walls can be dislodged by a disturbance. A collapsing bridge may create flow conditions totally different from that occurring in normal operation.

So, unless the oxygen is removed from the silo (i.e. the silo is inerted using an inert gas instead of air), a flammable dust cloud will be present in most silos at some point in the operation.

The other requirement for a dust explosion is the presence of an ignition source. Some thirteen different types of ignition source have been identified. The most common ignition sources for dust explosions are:

- flames (fire)
- welding and cutting
- self heating, self ignition
- electrical equipment
- mechanical friction and mechanical sparks
- static electricity
- hot surfaces.

Flames (including smoking), welding and cutting are potential ignition sources that must be controlled by company procedures. In some cases they can ignite a dust explosion in a silo directly, e.g. when welding on the outside of dust handling equipment. In other cases they occur indirectly because sparks or burning material enters the silo either with the product or through openings.

Self heating and self ignition are treacherous because they do not need any input from outside. If the material in the silo is likely to self heat in some conditions of storage temperature, moisture content and storage time, there is no way to stop it. The only prevention is to recognise the hazard and avoid the conditions altogether. Examples are reduced storage time, use of smaller silos (more heat losses) etc..

Electrical equipment, when suitably selected and installed according to the appropriate British Standards, should not pose any risks. The number of ignitions by electrical equipment is consequently not very high. Unsuitable equipment or wrong use of equipment, however, still leads to incidents. Examples are the use of hand-held lamps in silos, where they can be either damaged by impact against the wall or they can be buried in the product with overheating as a consequence.

Mechanical sparks are often identified as the ignition source in a dust explosion. Further analysis of the data shows that in many cases the power of the mechanical sparks would not have been sufficient to ignite the dust, but the friction that generated the sparks will also generate a very hot surface that is definitely capable of igniting the dust cloud. In many silos there should be no source of frictional heating or sparking. But again, often the ignition source is introduced into the silo with the product.

Static electricity occurs whenever materials are rubbed together and then separated. This means that in most solids handling a lot of static electricity is generated. When all material is conducting and earthed, however, the static charge will not be apparent. When the product is non-conducting it will become charged even in metal plant. Similarly, even conducting product will become charged if it flows through non-conducting piping.

When the charge can accumulate and then discharge, a static ignition hazard arises. There are several forms of electrostatic discharge, ranging from a "spark" from a charged conductor to "cone discharges" on the surface of bulked material in the silo.

Depending on the type of bulk handling, the product handled and the conditions in the silo, electrostatic ignition sources can be very important. In some cases the hazards are so intrinsic to the process, that it is impossible to prevent them and either inerting or protective measures are necessary.

Hot surfaces can arise in many ways and it is clear that they must be controlled in all places where either a dust cloud can be in contact with it or where a dust deposit can occur.

Ignition sources must always be prevented, even if the silo is protected, because the frequency of explosions must be kept as low as possible. In some cases, an additional measure can be used to reduce the frequency of ignitions: spark detection and extinguishing. Where mechanical sparks or hot particles are generated in one place (plant machinery), but the most likely location for the explosion is elsewhere (silo), it is sometimes possible to extinguish the sparks before they enter the silo. It must be noted, however, that such a system is not designed to stop an explosion, just one or more sparks.

Explosion Protection

If it is identified that an explosion could occur in a silo, and that it is not possible to prevent this to an acceptable level, explosion protection measures are needed to control the effects of an explosion.

When considering silos, it must be recognised that the volume tends to be large. This means that any explosion will have severe consequences. This may influence the hazard assessment: if the consequences are just not acceptable, protection is necessary even if the probability is small.

To protect plant against dust explosions, there are several options. The detailed design of protection methods is very much specialist work. Even where national or international standards are available, experience shows that the application is rarely straightforward.

The options for explosion protection are:

- explosion containment
- explosion venting
- explosion suppression

In all cases, it is necessary to prevent propagation of the explosion from one plant item to the next ("isolation"), not only to minimise the damage, but also to prevent pressure piling and flame jet ignition effects.

Containment means building the plant explosion resistant, i.e. so strong that it will resist the internal pressure of the explosion. For most equipment this means a strength of around 10 bar. Obviously, this is rarely an option for large silos, but for smaller hoppers it may well be feasible. Because the full explosion pressure is contained, the maximum force is generated for propagation to connected equipment, so isolation is of the utmost importance.

Two options have been developed over the years: explosion pressure resistant and explosion pressure shock resistant. The latter makes better use of the strength of the construction. This is deemed acceptable because an explosion is a one-off event of short duration. Obviously, the probability that some deformation of the equipment occurs is increased.

Explosion venting is sometimes called the "natural" explosion protection. This is because without any protection, the equipment would fail and the explosion would be vented. To apply explosion venting in a controlled manner, however, is not as simple as this analogy suggests. It is imperative that a vent opening of sufficient size is available at the right time. Because of the short duration of the explosion, there is no time to lift heavy covers. In many explosions where "vent covers" were designed in the wrong manner, the explosion pressure increased so fast that the vessel ruptured before the vent was opened!

For large silos the necessary vent area is large and there may be problems to accommodate the vent on the silo roof, especially if the roof is not free of obstructions. Many silos are elongated and this must be taken into account in the design of the vent area: in the extreme a silo can resemble a duct and what that means for the explosion process inside has been explained before.

Venting is in reality nothing more than displacing the explosion to another location: when the vent opens, both unburned and burned dust is expelled from the vent and this creates a huge flame jet or fireball outside the vent opening. The size of this flame is often underestimated and the safe area is either too small or lacking altogether. Also the pressure is vented from the vessel and that can cause some damage to the surroundings.

Explosion suppression relies on the detection of the incipient explosion and the injection of a suitable suppressant. This effectively extinguishes the explosion and so limits the pressure rise to a value that the silo can withstand. Suppression systems must be designed to work effectively in the time available and the design is therefore dependent on the hardware of the particular supplier. Especially on large volumes like silos, the investment can be considerable. Suppression of large silos is therefore very much limited to those cases where venting is not permissible (e.g. for environmental reasons) and inerting (as a preventive measure) or containment are not feasible.

Explosion isolation is, as mentioned before, needed to prevent propagation of an explosion from one vessel to the next. There are a range of measures available that can be implemented. The best, in terms of value for money, are those that do not need additional investment. The first of this kind is to simply avoid any connections between vessels that are not absolutely necessary. The second is the use of an explosion proof rotary valve instead of a standard one. Such rotary valves are stronger than normal and have smaller gaps (which stop the flame).

Other options are the use of special valves to stop the explosion in a duct, diverters (a local venting arrangement on a duct) and advance inerting barriers. Each option has its advantages and disadvantages.

Concluding Remarks

The analysis of dust explosion hazards in a plant needs to take into account the actual plant conditions and all relevant environmental factors. Seemingly similar plants can thus have a totally different level of hazard and consequently the measures needed to minimise the risk can be different. Likewise, the selection of the most appropriate protective measure can give different results. As there is no preventive or protective measure that is ideal in all respects (product quality, investment, operating cost, environmental impact, etc.) it is important not to exclude any option too soon.

In general, if the potential dust explosion hazard is recognised before a plant is built, it is possible to improve the design to obtain a better level of safety without additional investment. Besides, any investment that is still needed will be lower than if the explosion prevention and protection are only considered once the plant is built.

Biography

Pieter Zeeuwen has almost 20 years experience in gas and dust explosion prevention and protection, acting as an independent consultant to both industry and authorities. He has worked for almost 11 years for the Dutch research organisation TNO as head of the Gas and Dust Explosion section. After that, he joined a Belgian consultancy firm before joining Chilworth Technology in 1995. Throughout his career, Mr Zeeuwen has participated in national and international working groups drafting codes of practice and standards. He regularly publishes and lectures on the subject.

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