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A REVIEW OF DUST EXPLOSION PROTECTION TECHNIQUES

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ABSTRACT

Dust explosions are frequently reported in the process industries that manufacture, store and handle particulate materials. It causes severe damage to lives and properties. The essential conditions for the dust explosion to occur are: the presence of fuel, oxidant, ignition source, combustible dust cloud and confinement. Under these conditions, a dust explosion can take place when the suspended fine dust particles accumulated in air received sufficient energy from the source. Secondary dust explosions, caused by the primary dust explosion, have been found to be extremely disastrous.

Several preventive and protective techniques have been developed to deal with consequences and effects of explosion, e.g. containment, isolation, suppression and venting. The most commonly used protection technique in industrial unit is explosion relief venting, however, it is not always easy to implement it, especially for indoor equipments.

A new advanced dust explosion protection technique, called flameless venting has been developed which has distinct advantage over conventional venting. Flameless venting devices demonstrate a high level of flame extinguishment, dust retention which otherwise may result in blast, and minimization of thermal radiation and noise outside the protective equipment. Another distinct advantage is that it can be easily retrofitted to existing installation, without requiring significant changes to the process.

Keywords: Dust explosion, Protection Techniques, Venting

I INTRODUCTION

1.1 A Brief Overview of the Dust Explosion

Dust is common in process industries that manufacture, store and handle particulate material. More than 70% of dust processed in industries is combustible [1]. Any dust capable of creating a violent explosion when it is suspended in air in ignitable concentrations, regardless of size, shape or chemical composition is called combustible dust [2]. Dust composed of sugar, flour, starch, grain and other organic material, as well as metallic dust (e. g. aluminium, magnesium etc.) are some examples of combustible dust. Grain elevators, size reducers, electrostatic precipitators, settling chambers, mixing and blending operations storage, filter scrubbers, un-loaders etc. are mainly subject to dust explosion.

When the suspended fine dust particles accumulated in the air receive sufficient amount of energy from the source, a dust explosion can occur. During dust explosion, the gaseous products formed are liberated with huge pressure, which results in destruction of plant, property and lives of people. The consequence is akin to a typical gas explosion in terms of the impact on the surrounding environment, industrial assets and monetary value. However, the cause and severity of dust explosion is less familiar compared to the gas explosion among industrialists.

For dust explosion, two vital criteria are: combustible dust cloud and confinement. As dust particles are in a solid phase, therefore, particle size of the dust plays a very important role in combustion. The smaller the particle size, the more fast and explosive burning takes place, till a stage is reached when the particles are too much fine and they join to form nuggets. Moreover, the ignited combustible dust cloud would only cause a flash fire if it is unconfined, but if confined the gases released by combustion of cloud may result in rapid development of pressure and result in explosion. Thus, confinement area is another important condition for dust explosion.

The most devastating dust explosion scenario is the generation of a secondary dust explosion [3] which occurs when the blast wave from a primary explosion entrains dust layers already present in the plant, creating a large dust – air flammable mixture ignited by the first explosion. As the blast wave propagates through the plant, dust fuels the emerging flame, leading to extensive damage owing to the large quantity of dusts involved and the consequent strong pressure wave. Several secondary dust explosions have occurred in the past, the consequences of which have been disastrous.

Despite a much greater awareness of dust explosion hazards, numerous accidents continue to happen throughout the world. Prevention remains an essential part of risk mitigation for dust explosions, in addition, explosion protection techniques such as containment, venting, isolation and suppression, also needs to be implemented to deal with consequences and effects of explosion when they occur.

Explosion relief venting is the most commonly used protection technique in industrial units. In a closed vessel with no venting areas, dust explosion pressures can be very high, placing the unit at risk of severe damage or even complete destruction. Pressure release through a vent opening aims to prevent the build-up of that unacceptably high pressure. While conventional venting is quite efficient and recommended for most of the cases, its implementation is not always easy, especially for indoor equipment.

Recent advancements in venting technique has led to flameless venting. Flameless venting devices are designed to extinguish the flame and prevent the disadvantage of large quantities of dust from the vented vessel into the surroundings. In comparison with conventional venting devices, the most notable benefits of using flameless venting devices are flame extinguishment and dust retention (resulting in blast), thermal radiation, and noise minimization outside the protected equipment. Moreover, it can be easily retrofitted to existing installation without requiring significant changes to the process. Extensive research and development is still being carried out for better understanding of dust explosion dynamics and its protective measures [4].

1.2 Past Accidents and Consequences

Dust explosion is a potential threat to the process industry and many such cases have been frequently reported and analysed. Some of these cases [5,6] are reported here.

<u>Metz, France (1982) [5]</u>

The malt house silo, located on the Moselle River, near Metz (east of France) was designed to transform barley into malt for breweries. On 18th October, 1982, at 2:15 pm, two successive explosions (Fig.1.1) occurred a few seconds apart, the second more powerful than the first. Twelve people were killed in the blast and two others

Fig.1.1 View of the damage caused by the Metz explosion

were injured. Investigations concluded that the initial explosion was generated by the combination of an ignition source introduced during the works, with an explosive atmosphere. The primary event caused dust to spread inside the facility, leading to the second explosion throughout the tower, the upper gallery and spaces between cells.

<u>Blaye, France (1997) [5]</u>

An explosion occurred in a cereal silo located at the Blaye port complex, near Bordeaux (south – west of France) on 20th August, 1997, around 10:15 am, while a dumper truck was unloading corn into a delivery pit. Witnesses reported that the first explosion occurred in the northern handling tower before propagating into the over-cell gallery upto the southern end of this gallery (Fig. 1.2). Eleven people were killed by the explosion and one seriously injured.

Fig.1.2 View of the damage caused by the Blaye explosion

Haysville, United States of America (1998) [5]

DeBruce grain elevator located at Haysville, U. S. A., experienced an explosion on 8th June 1998, at around 9:20 am, killing 7 people and 7 were injured. Witnesses reported several small explosions followed by a large blast. The investigation concluded that the initial explosion occurred when dust was ignited in the east tunnel of the south array of silos and propagated to the overall facility. The most probable ignition source was created when a concentrator roller bearing, which had seized due to no lubrication, caused the roller to lock into a static position as the conveyor belt continued to roll over it, wearing it and leading to a high temperature rise (Fig. 1.3).

Fig.1.3 View of the damage to DeBruce Grain Elevator

Port Wentworth, United States of America (2008) [6]

On 7th February, 2008, at about 7:15 pm, a series of sugar dust explosion took place at the Imperial Sugar manufacturing facility in Port Wentworth, Georgia, United States of America. It resulted in fourteen workers fatalities and thirty six workers were severely injured. A sugar dust explosion occurred in the enclosed steel conveyor belt under the granulated sugar storage silos in the Imperial Sugar manufacturing facility (Fig. 1.4). After a while, a massive secondary dust explosion propagated throughout the entire granulated and powdered sugar packing buildings, bulk sugar loading buildings and parts of the raw sugar refinery. Fireballs erupted from the facility for more than 15 min.

Fig. 1.4 View of the damage to the Imperial Sugar Port Wentworth facility

Fig. 1.5 Fire following aluminium dust explosion at Hayes Lemmerz International

Hayes Lemmerz International, Huntington, Indiana, (2003) [6]

One killed, several injured in an aluminium dust explosion likely originated in a dust collector and spread through ducting, causing a large fireball to emerge from the furnace (Fig.1.5).

II CONDITIONS FOR DUST EXPLOSION

For dust explosion to occur certain conditions are required to be fulfilled, without which no dust explosion will occur. Five essential parameters, which are identified as dust explosion influential parameters [6] are: particle diameter, minimum explosible concentration, minimum ignition energy, minimum ignition temperature and limiting oxygen concentration, whereas the maximum explosion pressure represents the severity of a dust explosion. Five essential elements i.e. fuel, oxidant, ignition source, dispersion and confinement form a dust explosion pentagon (Fig. 2.1).

The dust explosion pentagon represents the conditions required for the dust explosion to occur, i. e.

- The dust which will form cloud must be combustible.
- Presence of oxidant.
- Finer the dust particles, greater will be chance of dust explosion.
- Dust cloud must be confined to be explosive.
- An ignition source to trigger the dust cloud.

When these parameters reach the explosible range, dust explosion occurs.

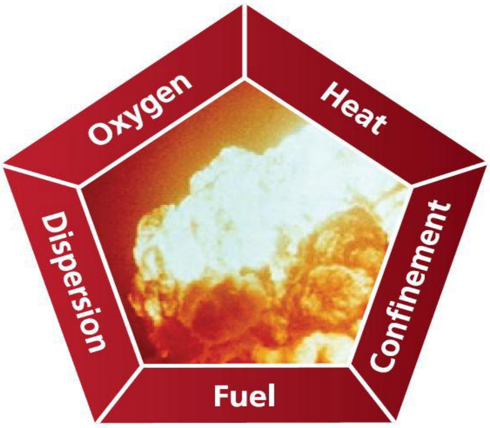

Fig. 2.1 Dust Explosion Pentagon

III PRIMARY AND SECONDARY DUST EXPLOSION

The combustible dust forms cloud in equipments such as mills, mixers, screen, dryers, cyclone separators, hoppers, bucket elevators, silos, aspiration ducts and pneumatic transport system and when this cloud gets ignited it causes increase in pressure and results in destruction. This explosion which occurs in equipments is called primary explosion. Primary dust explosions may occur inside process equipment or similar enclosures. Many common materials which are known to burn can generate a primary dust explosion, such as coal and sawdust. In addition, many organic materials can also be dispersed into a dangerous dust cloud, such as grain, flour, starch, sugar, powdered milk, cocoa, coffee and pollen. Powdered metals (such as aluminium, magnesium and titanium) can form explosive suspensions in air, if finely divided.

Secondary dust explosions occur when a primary explosion takes place in processing equipment or in an area where fugitive dust has accumulated. The blast wave from the primary explosion may dislodge more accumulated dust into the air or damage a primary containment system (such as duct, vessel or dust collector). Small amount of dust layer occupies a very little space but once it is disturbed it will form a dangerous cloud. As a result, the additional dust dispersed into the air, if ignited, may cause one or more secondary explosions. Fig. 3.1 represents a primary dust explosion which leads to a secondary explosion [7]. These can be far more destructive than a primary explosion due to the increased quantity and concentration of dispersed combustible dust. Historically, fatalities from dust explosions have largely been the result of secondary dust explosions.

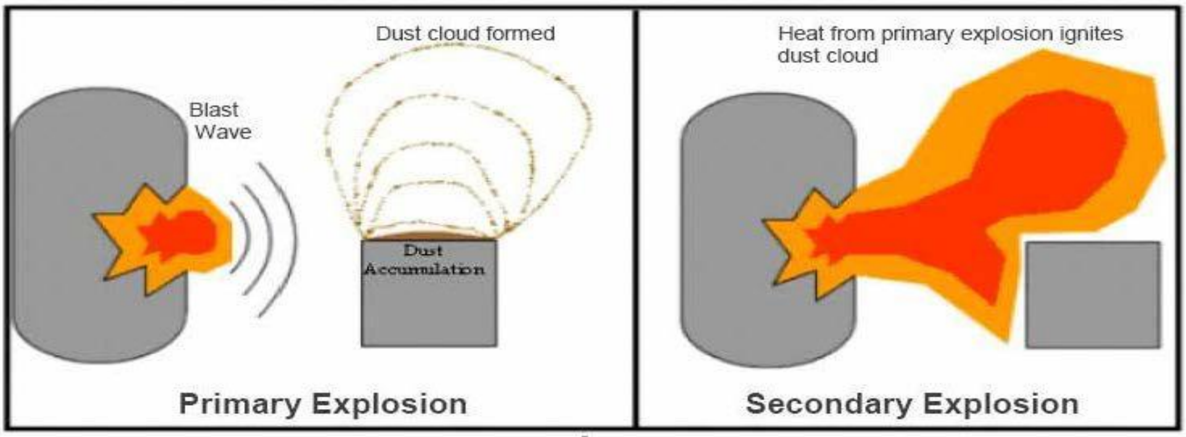

Fig. 3.1 Primary and secondary dust explosion

IV DUST EXPLOSION PROTECTION TECHNIQUES

Despite a much greater awareness of dust explosion hazards, numerous accidents continue to happen throughout the world, resulting in casualties, property losses and business interruptions. Prevention constitutes the first line of defence and remains an essential part of 'risk mitigation' for dust explosions. In addition, explosion protection techniques also need to be implemented to deal with consequences and effects of explosion when they do occur. Some of the dust explosion protection techniques and their advancements [8, 9] are as follows:

4.1 Containment

This method protects against the effects of an explosion, should it occur, by halting it immediately and/or limiting the range of explosion flames and explosion pressures to a sufficient level of safety. With containment the vessel or plant is built to be strong enough to withstand the pressure of a confined explosion. Containment includes overpressure protection which all vessels are required to have, besides overfill and protection from leakage. Plant can be designed to be either explosion pressure/explosion pressure shock resistant.

4.2 Isolation

Isolation plays an important role in minimizing the damage caused by the dust explosion in an equipment of a facility. As process equipment is, most of the time, connected to other parts of a facility by pipes, a dust explosion originating in an enclosure will likely propagate through these pipes and potentially reach other process equipments. By propagating, the flame front will accelerate and stronger pressure effects will be produced. Thus, the resulting explosion in the secondary vessel can be much more violent than the initial event [10]. This emphasizes the need for explosion isolation.

4.3 Suppression

After ignition of a dust cloud, the flame front expands and pressure waves are emitted which cause severe damage. An explosion suppression system consists of pressure sensor, high rate discharge suppressor with appropriate dispersion nozzles and control panel (Fig. 4.3). The pressure sensor detects the pressure increment and sends a signal to the control panel, which in turn initiates the suppressant discharge. Both nitrogen and suppressant agent are rapidly released into the vessel and extinguish the fireball by reducing the temperature of the combustible material below a level necessary to sustain combustion [10].

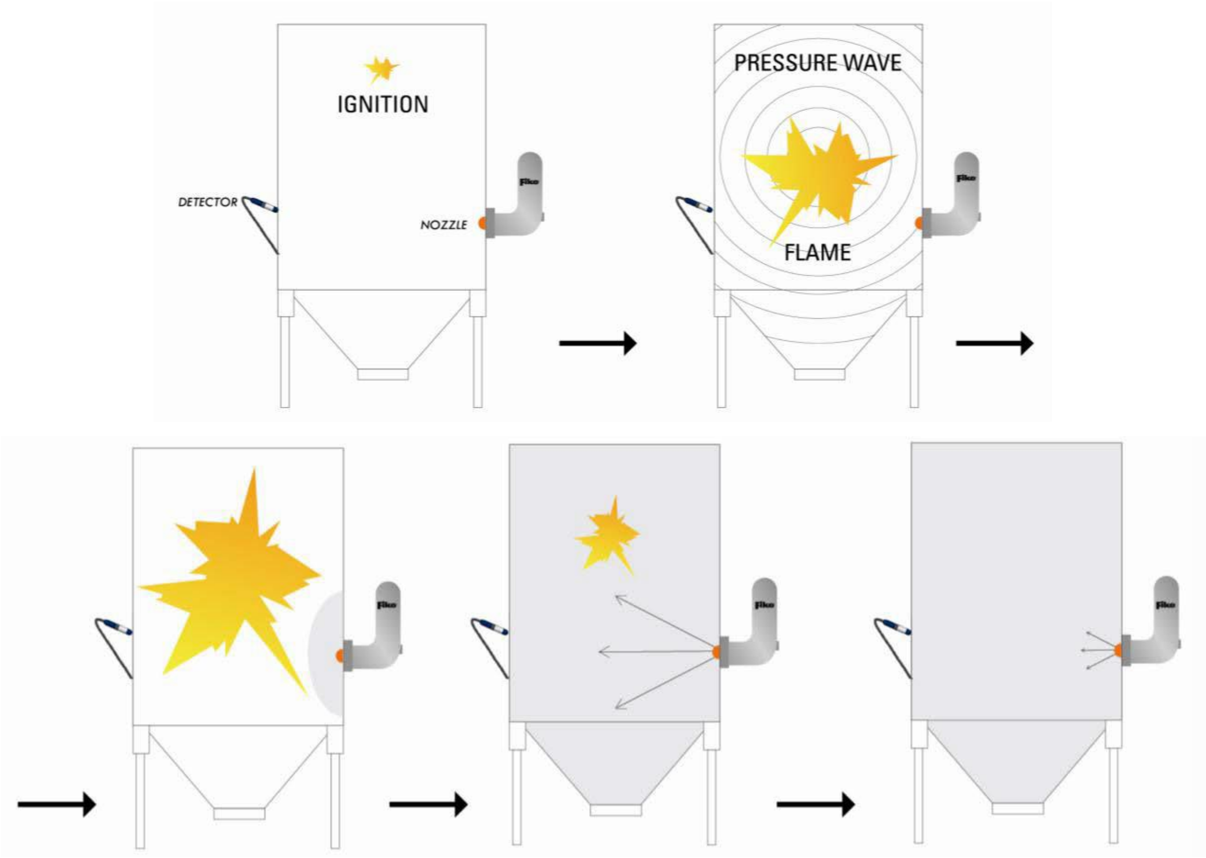

Fig. 4.3 Ignition of a dust cloud, flame expansion, detection of the pressure wave, activation of the suppression container and extinction.

Suppression is an active technique that has several advantages: there is release of pressure, flame or potentially toxic material in the environment, as the explosion is contained within the enclosure. It also reduces the damage to the equipment and mitigates the potential fire hazards which can arise after an explosion.

4.4 Venting

Dust explosion venting is a well-established method of protecting against damaging explosion over-pressures. In the early stages of an explosion, weak panels in the walls of the vessel or explosion venting device open at a low over-pressure. Much of the explosion is then dissipated outside the vessel and the maximum pressure inside the vessel is reduced.

If ignition of combustible dust cloud takes place in the enclosed area then there will be a rapid rise of pressure which damages the plant and building. There must be vent holes, explosion vents are provided for releasing of this excess pressure so that damage of plant will be minimized. The vents that are provided must be able to respond instantaneously. There must be some safety factor between the operation of the vent and the bursting pressure of the plant. The products of dust explosion are discharged by using vent hence keeping the explosion pressure lower than that of design strength and protect the vessel from effects of explosion. Explosion must be vented to the safe place in the open air [11].

Venting is by far the most popular explosion protection technique, which enables pressure developed during an explosion inside a vessel to be safely released in the environment, thus preventing the vessel from bursting. A rupture diaphragm is placed on the vessel and designed to open at a static burst pressure well below the pressure at which the vessel would be destroyed or damaged [10]. While venting allows the control of the pressure developed inside an enclosure, it does not mitigate the hazards of the flame exiting from the vent. It is therefore not recommended to apply conventional venting for enclosure located indoors, because of the secondary dust explosion hazards. In this case, vent ducts can be added to reduce the flame and (also pressure) outside the building. However, adding a vent duct can largely increase the reduced pressure inside the enclosure, making it difficult to apply effectively.

4.5 Flameless Venting

While conventional venting remains the most common and popular method of protection used, its implementation is not always straightforward especially for indoor equipment. A new technology – flameless venting has been developed for protecting indoor equipment from dust explosions. In comparison with conventional venting devices, the most notable benefits of using flameless venting devices are flame extinguishment and dust retention which may result in blast, thermal radiation and noise minimization outside the protected equipment. Another distinct advantage is that it can be easily retrofitted to existing installation, without requiring significant changes to the process. While the flameless venting device is used primarily on indoor equipment, it is also well suited to outdoor equipment that is adjacent to buildings or roads, where a vented explosion’s flame and pressure effects can’t be safely controlled. The flameless venting device can be used in most applications handling non-toxic dry bulk materials.

A flameless venting device is a passive device that typically includes an explosion vent panel and a flame quenching unit that is inside a flanged metal frame (Fig. 4.4(a) & (b)). The frame attaches the element to the process equipment, such as a dust selector. The element is closed at one end and open at the other and it is bolted on to the explosion vent opening on the equipment so that its open end overlaps the opening. The flame quenching element’s frame enclosed layers of particle- retaining, high- temperature stainless steel mesh or carbon steel mesh (Fig 4.4(c)) or ceramic material. The flame quenching element may be cylindrical, rectangular or square to fit the vent opening shape [8].

During the early stages of an explosion inside the process equipment, the explosion vent panel opens. As the explosion expands, flame, burnt and un-burnt dust discharge through the open vent into the flame-quenching element. Most of the dust retained inside the element and the energy (heat) dissipate as it travels through and is absorbed by the steel mesh inside the element. This reduces the burning fuel temperature below the fuel's ignition temperature, extinguishing the flame and preventing flame propagation beyond the device. Only a small amount of dust passes through the flame-quenching element and post-combustion gases from the explosion are safely vented through the device into the external atmosphere around it.

The flameless venting device not only extinguishes the flame and retains dust but completely eliminates the need for explosion vent ducting and minimizes the vent relief area required for indoor explosion venting. Flameless venting devices are designed not only to suit particular storage and process equipment such as silos, bins, hoppers, dryers, mixers, dust collectors, cyclones but also transport equipment such as belt conveyors, screw conveyors, and bucket elevators.

(a) (b) (c)

Fig. 4.6 Picture of Fike FlamQuench II (a) cylindrical & (b) square flameless venting device and (c) layered steel mesh inside flame-quenching element.

Vented explosion tests, performed by Health and Safety Laboratory [12, 13] showed that while an external flame of several meters was observed with a traditional venting device, whereas the flame was completely eliminated by the introduction of a flameless venting device with only smoke, dust and water vapour emitted from the device (Fig. 4.5). While flame is contained, hot gases exit the protected vessel through the flameless venting device. Thus, flameless venting device provides a ready solution for some applications where conventional explosion venting can't provide the required protection, by combining explosion venting and flame-quenching techniques.

Fig. 4.5 Vented explosion test with a flameless venting device.

V CONCLUSION

Dust explosion is a potential threat to the process facilities handling dusts. Dust explosion occurrences are frequently reported in these industries. Industrial professional and researchers have been trying to develop effective measures to assess and mitigate and / or prevent dust explosion. Prevention remains an essential part of risk mitigation for dust explosion; in addition explosion protection techniques also need to be implemented to deal with consequences and effects of explosion.

For many years, the most common and popular method of dust explosion protection has been venting. While conventional venting is quite efficient and recommended for most of the cases, its implementation is not always straightforward, especially for indoor equipment.

A new protection technology has been developed for dust explosions, called flameless venting. In several tests using conventional vent panels and flameless venting devices [12], flameless venting device demonstrated a high level of flame extinguishment. The performance of the device appeared to be sensitive to dust characteristics. The most important advantage of using flameless venting devices are flame extinguishment and dust retention, which could result in a blast. Also, it minimizes the thermal radiation and noise outside the protected equipment. Another distinct advantage is that, without requiring significant changes to the process, it can be easily retrofitted to existing installation.

When considering flameless venting, one has to consider the following [9]:

• The overall efficiency of the flameless venting device shall be determined by testing in order to calculate the required vent relief area.

• Special attention must be paid to dusts that have the potential to block the flame quenching element (Coarse or fibrous dusts).

• Even though flameless venting devices greatly limit overpressures outside the protected equipment, it should be verified whether the building can withstand the pressure effects.

Several research projects are still going-on; working on further improvements in protection techniques. With multiple-range of tests and new technologies available, more advanced dust explosion protection techniques can be expected in future.

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