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Application of dust explosion protection systems

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Abstract

Dust explosions have accounted for numerous deaths, disappearance of companies, and large financial losses, and yet they are one of the least recognized of industrial fire hazards. They can occur within any process where a combustible dust is handled, produced or stored, and can be triggered by any energy source, including static sparks, friction and incandescent material. The management of dust explosion risk includes the implementation of both preventive and protective measures. Whereas preventive measures may reduce explosion risks efficiently, they rarely are sufficient to eliminate explosions completely. Therefore, explosion protection measures often need to be considered as well. This paper presents dust explosion protection methods, including venting, flameless venting, suppression, and isolation, and describes their application limits.

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Keywords: dust ; explosion; hazards; protection

Nomenclature

A_V	vent area (m^2)
K_{St}	deflagration index (bar.m/s)
P_{ACT}	detector activation pressure (bar)
P_{COM}	combustion pressure associated with flame growth (bar)
P_{MAX}	maximum pressure of a deflagration (bar)
P_{N2}	pressure due to injection of nitrogen (bar)
P_{RED}	reduced pressure after deflagration venting (bar)
P_{STAT}	vent nominal static burst pressure (bar)

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T_{ACT}	time for pressure growth to exceed P_{ACT}, or for an optical detector to see a flame (ms)
T_{BAR}	time for an isolation barrier to close (mechanical) or form (chemical) (ms)
T_{ELEC}	electronics response time (ms)
T_{ISO}	total time for the isolation process to take place (ms)
TSP	total suppressed pressure (bar)

1. Introduction

Industrial explosions have been a hazard for as long as man has been processing, storing and transporting materials. Managing explosion hazards involves first characterization of the explosion properties of materials through testing. Once characterized, the hazard can be managed through clear determination of the prevention and protection objectives, followed by selection and implementation of the appropriate protection method(s).

Explosion protection techniques include venting, flameless venting, suppression, and isolation - either separately or in combination. This paper presents these techniques successively, and describes their application limits.

2. Explosion venting

Venting is by far the most popular explosion protection technique, and is extensively described in commonly accepted engineering literature and standards, such as NFPA 68 [1] and EN 14491 [2].Venting 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 (Fig. 1) is placed on the vessel and designed to open at a static burst pressure (P_{STAT}) well below the pressure at which the vessel would be destroyed or damaged (Fig. 2).

Fig. 1. Pictures of FikeSaniV™ and SaniVS™ explosion vents.

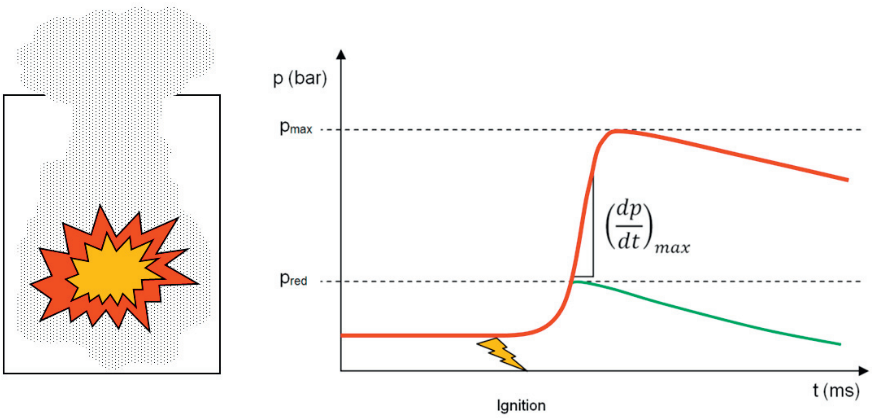

Fig. 2. Venting of a dust explosion (green curve).

The area of the rupture diaphragm (A_V) is calculated to be large enough to allow fast discharge of pressure. Different correlations are used in EN 14491 and NFPA 68, given as example (Equation 1):

$$A_V = 10^{-4} \times \left(1 + 1.54 P_{STAT}^{4/3}\right) K_{St} V^{3/4} \sqrt{\frac{P_{MAX}}{P_{RED}} - 1} \quad (1)$$

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 (Fig. 3).

Fig. 3. Dust explosion venting test at Fike Remote Testing Facility:vent opening (left), and venting with flame release (right).

It is therefore not recommended to apply conventional venting for enclosure located indoors, because of the secondary dust explosion hazards (Fig. 4) [3].

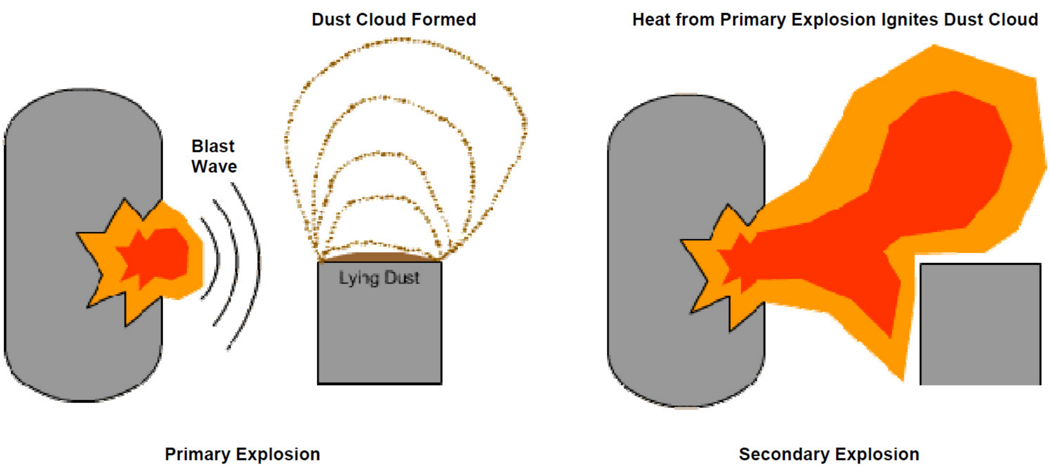

Fig. 4. Secondary dust explosions hazards.

In this case, vent ducts can be added to redirect the flame (and also pressure) outside the building. However, adding a vent duct can largely increase the reduced pressure (P_{RED}) inside the enclosure, making it difficult to apply effectively. Another option presented thereafteris flameless venting.

3. Explosion flameless venting

The principle of a flameless venting device has been described in a previous paper [4]. It typically includes an explosion vent panel and a flame-quenching unit enclosing layers of stainless steel mesh. The flame-quenching unit may be cylindrical, rectangular, or square (Fig. 5).

Fig. 5. Pictures of FikeFlamQuench II[TM](squareand round), and EleQuench[TM]flameless venting devices.

Flameless venting mitigates flame hazards, and also significantly reduces the pressure effects outside the process vessel compared to a conventional venting device, thus reducing the exclusion zones. It offers a compact alternative of vent ducting, with a much better venting efficiency. However, flameless venting does not fit all situations: it may sometimes be preferable to considersuppressiontechnique, especially when there is not enough space to install vents or when the processed material is toxic.

4. Explosion Suppression

An explosion suppression system typically consists of pressure sensor(s), high rate discharge (HRD) suppressor(s) with appropriate dispersion nozzles, and control panel(s). After ignition of a dust cloud, the flame front expands and pressure waves are emitted. 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 (Figure 6).

The maximum pressure reached after ignition of the dustcloud and discharge of suppressant agent into the enclosure is reported as the total suppressed pressure (TSP).The components that make up the total suppressed pressure (Equation 2) in any enclosure are:

- Activation pressure (P_{ACT}) of the detector
- Pressure due to injection of nitrogen (P_{N2}) from the discharge container
- Combustion pressure (P_{COM}) associated with flame growth (after P_{ACT} has been reached):

$$TSP = P_{ACT} + P_{N_2} + P_{COMB} \quad (2)$$

Suppression is an active technique that has several advantages compared to conventional venting: there is no 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 (Fig. 7).

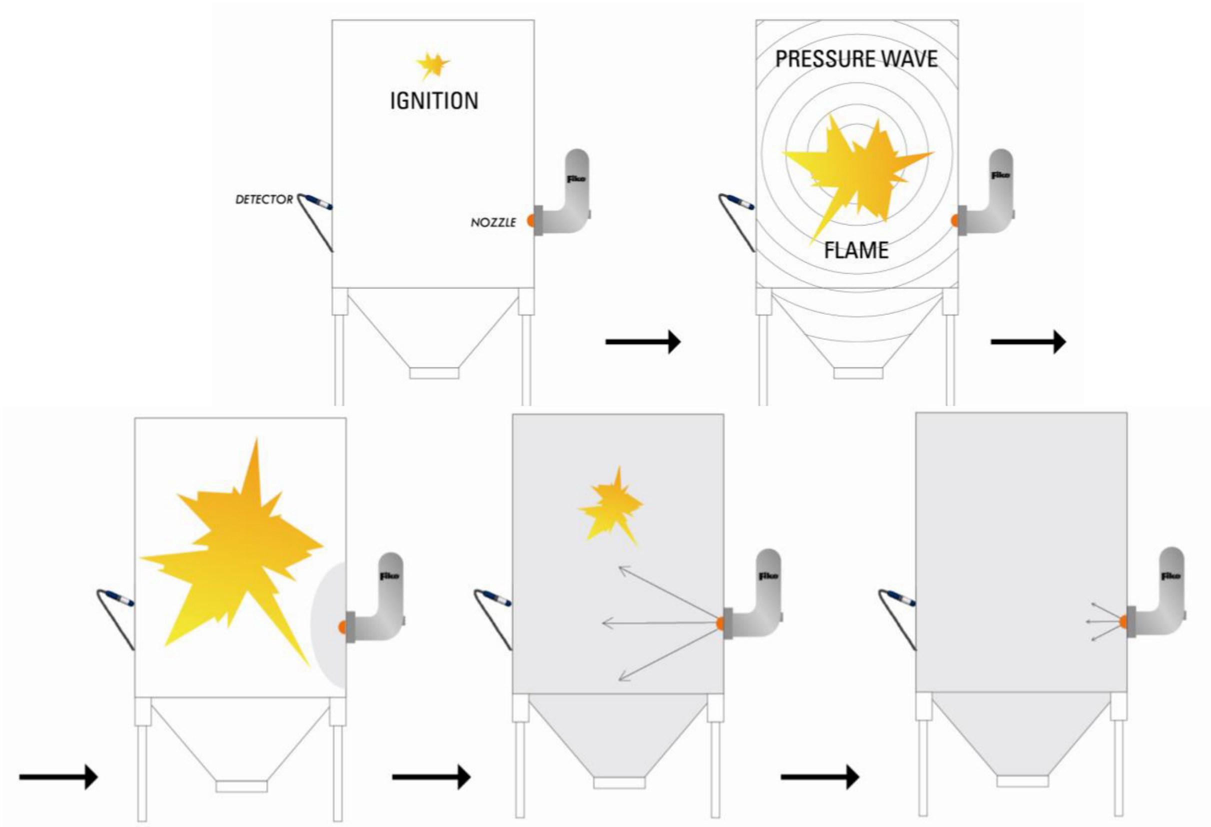

Fig. 6.Ignition of a dust cloud, flame expansion, detection of the pressure wave, activation of the suppression container, and extinction.

Fig. 7. Flames emerging from vent openings after a dust explosion.

On the other hand, suppression systems typically are more expensive than vents. Suppression is also more difficult to achieve in small enclosures (typically < 1 m^3), as pressure rates of rise are usually very high (i.e. the time to reach a certain pressure level is shorter than in a large enclosure).

The table presented below (Table 1) summarizes the different functions of venting, vent ducting, flameless venting, and suppression techniques.

Table 1. Comparison of explosion protection techniques.

Protection System	Venting	Vent Ducting	Flameless venting	Suppression
Control Pressure (In)	X	X	X	X
Control Pressure (Out)			Reduced	X
Control Flame (In)				X
Control Flame (Out)		X	X	X
Avoid Release of Material			Reduced	X
Control Noise			Reduced	X

5. Explosion isolation

Process equipment is,most of the time, connected to other parts of a facility by pipes. A dust explosion originating in an enclosure, even vented, will likely propagate through these pipes and potentially reach other process equipment. By propagating, the flame front will accelerate and stronger pressure effects will be produced. This means that the resulting explosion in the secondary vessel can be much more violent than the initial event. This emphasizes the need to carefully consider explosion isolation.

The objectives of isolation aremultiple:

- to prevent flame propagation to a secondary enclosure
- to prevent pressure piling and flame jet ignition in the secondary enclosure
- to prevent deflagration to detonation transition in pipes (high L/D)

Isolation can be achieved in two different ways; either passive oractive (Table 2). Passive systems are activated by the explosion itself and include diverters, float valves, and flap valves (Fig. 8). In the example of a flap valve, the pressure generated by the explosion will push a gate and close the pipe, thus avoidingpropagation of the flame to the protected area. Passive systems are simpler and typically require less maintenance.Active systems, on the other hand, require tripping by a sensor for activation. Upon triggering, they will close a mechanical valve ahead of the flame front or inject anextinguishing agent in the pipe to stop further flame propagation. Active systems include chemical barriers, gate valves and pinch valves (Fig. 9).

Placement of the device is essential: if an isolation device is placed too far from the ignition, the deflagration can transit into a detonation prior to reaching the device and damage it; if it is placed too close to the ignition, then it may not be entirely closed and able to block the passage of flame when it arrives.The components that make up the total time for isolation (Equation 3) are:

- Time for the pressure growth to exceed the activation pressure of the detector, or for the optical detector to see a flame (T_{ACT})
- Time for the electronics (detector and control panel) to respond (T_{ELEC})
- Time for the mechanical barrier to close, or for the chemical barrier to form (T_{BAR}) :

$$T_{ISO} = T_{ACT} + T_{ELEC} + T_{BAR} \tag{3}$$

The total time for the isolation processshould always be less than the time for the flame to travel to the barrier's location (Equation 4):

$$T_{ISO} < T_{FLAME} \tag{4}$$

Table 2. Comparison of explosion isolation techniques.

IsolationSystem	**Diverter**	**Float Valve**	**Flap Valve**	**Gate Valve**	**Pinch Valve**	**Chemical Barrier**
Control Pressure	X	X	X	X	X	Reduced
Control Flame		X	X	X	X	X
Bi-Directional Barrier	X	X		X	X	X

FikeDiverter

Fike Float Valve
Ventex™

Fike Flap Valve
Valvex™

Fig. 8. Fike passive explosion isolation systems.

Fike Gate Valve
Explosion Isolation Valve (EIV™)

Fike Pinch Valve
Explosion Isolation Pinch Valve (EIPV™)

FikeChemical Barrier
Standard Rate Discharge (SRD™) Device

Fig. 9. Fike active explosion isolation systems.

6. Selection of the Appropriate Explosion Protection Technique

Asimplified chart, provided below (Figure 10),proposes a step by step method to select the appropriate explosion protection technique. The initial stage is to determine whether the handled material is combustible or not. This can be achieved by testing. Then different questions guide the user to the appropriate protection solution between venting, flameless venting and suppression. At the end of the process, the user also needs to consider isolation if the enclosure has connections.

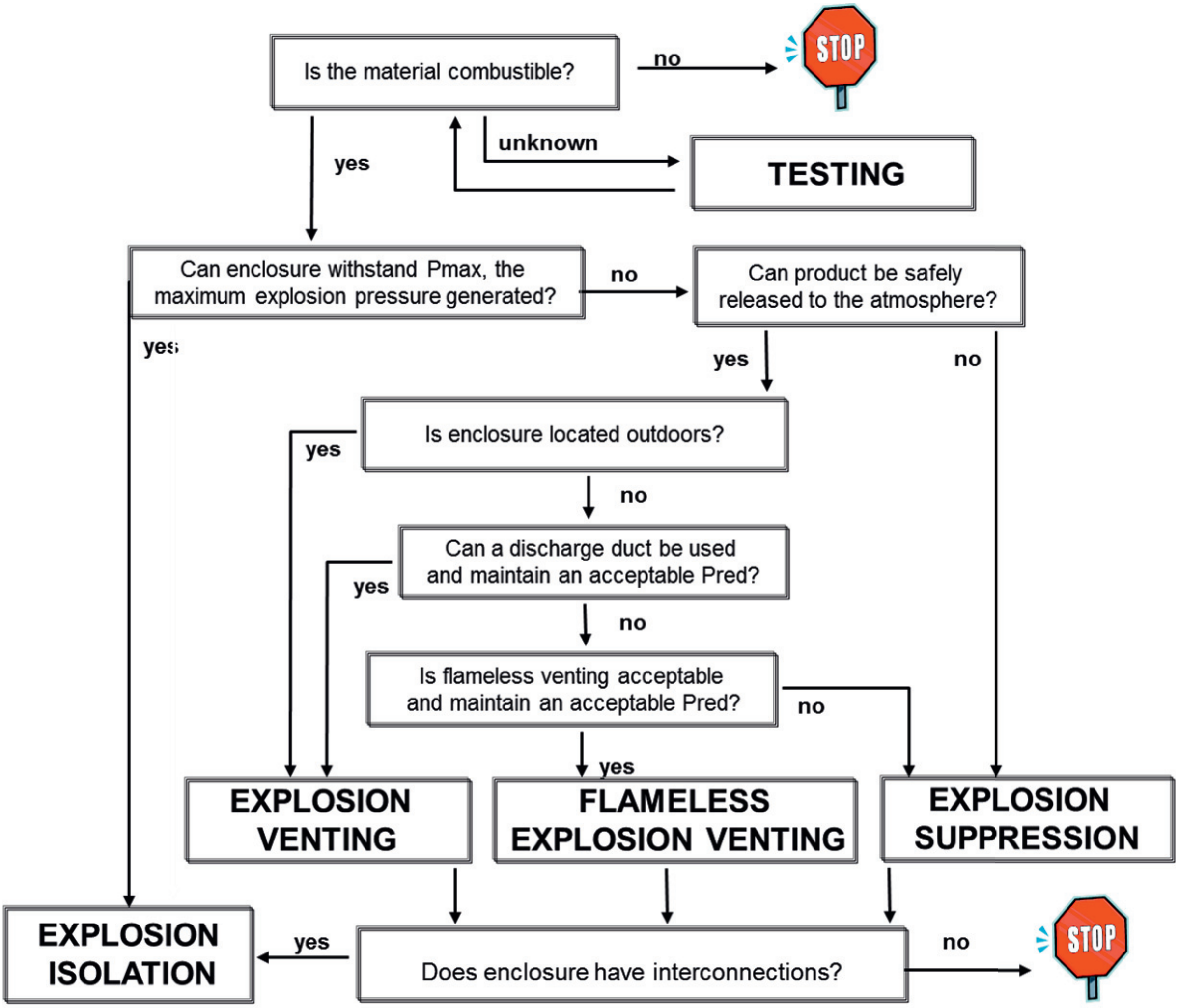

Fig. 10. Explosion protection chart.

7. Conclusions

Explosion protection techniques have been described with their advantages and limitations.

While venting remains the most popular protection method, it is not possible to apply it to indoors equipment due to secondary dust explosion hazards. Other techniques, such as vent ducting, flameless venting and suppression offer good alternatives.

Explosion isolation is often disregarded. However, it is an essential component of an effective explosion protection strategy. Indeed, any dust explosion originating in an enclosure, even vented, can potentially propagate through pipes and reach other process equipment, leading to extensive damage. Passive and active systems have been described and illustrated.

A simplified chart has been proposed, as an example, to find the appropriate solution using several elementary questions. Since industrial processes exhibit specific features, most of the time, it is recommended to work closely with an explosion protection manufacturer who can provide the appropriate recommendations and suitable equipment for the considered application.

References

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