Assessment and Protection for Dust Explosion

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Various raw materials are handled in the manufacturing industry such as gas, liquid, solid and powder. The phenomenon of "dust explosion" is a risk unique to the handling of powders. Unlike dangerous goods and flammable gases, the risk of a dust explosion is not well recognized. Therefore, manufacturers should pay more attention to the handling of powders.

This article summarizes the risks, assessment methods, and protection measures for safety operation with proper recognition of industrial dust explosions risks.

1. Summary of Dust Explosion

Dust explosion is a pressure rise due to rapid combustion of powder. When combustibles become powdery, it burn rapidly like flammable gas. The destruction phenomenon caused by radiant heat and gas expansion is "dust explosion".

In typical cases, there are accidents in which dust floating in a dust collector ignites and explodes due to static electricity, and accidents in which a crusher is mixed with foreign materials and sparks are generated to cause an explosion.

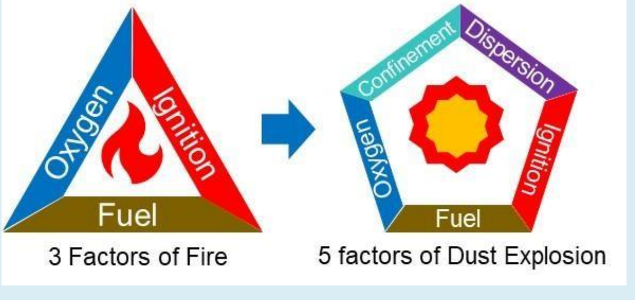

Figure 1 : 5 Elements of Dust Explosion
Source: Created by author

To understand the mechanism of a dust explosion, it is necessary to know the "five elements of a dust explosion" (Figure 1). In fire protection, the "3 elements of combustion", "Fuel", "Oxygen", and "Ignition source" are taken, but in dust explosion protection, the elements of "Dispersion" and "Confinement" are added.

The five elements form the Explosion Pentagon necessary to create and explosion event. Removing any single element will prevent the event from happening.

If this happens in an enclosure, there will be no escape for pressure and the facilities will explode. Therefore, it is necessary to pay attention to the following factors when considering measures against dust explosions.

《Preventive measures》
- Removal of fuel
- Removal of oxygen
- Removal of ignition source
- Suppression of floating

《Damage mitigation measures》
- Measures to prevent pressure rise

In addition to the above, there are other factors that affect the risks of explosion, such as the concentration of dust clouds, particle size and water content, the magnitude of ignition energy, and even if the same substance is used, the risk increases depending on the handling conditions. Table 1 indicates typical prerequisites for dust explosion. It is possible to predict to some extent what kind of powder has an explosion risk from the literature. However, in order to quantitatively evaluate whether it is actually explosive and what measures are necessary, it is essential to evaluate the explosive characteristics via sampling tests.

Factor	Prerequisites for explosion (reference)	Remarks
Combustibility	･Combustible in powder form	Wood, resin, rubber, food, paper, metal etc.
Dispersivity	･Floating powder - particle diameter 500 μm or less	Be careful when dust is generated even with raw materials such as pellets.
LEL Concentration or higher	･Various such as 20-1000g / m3	As a guide, it is dangerous if it accumulates enough to leave footprints.
Oxygen	･Approx.10% or more – 21% in atmosphere in general	Dangerous unless it is in a low oxygen environment due to N2 purging, etc.
Moisture, Humidity	･ Moisture content ≥6% – Reduced dispersivity ･ Moisture content 20-30% - No explosive (depend on particle) ･ Humidity ≥60% - Reduced risk of static electricity	Powder materials are often dried
Ignition Source	･Various such as static electricity, frictional heat, spontaneous combustion, etc.	

Table 1 : Prerequisites for dust explosion

2. Risk assessment of dust explosion

The first step towards dust explosion protection is the evaluation of explosion characteristics. In this evaluation, the parameters for each powder as shown in Table 2 can be used for studying countermeasures and designing. Test evaluation method is defined in JIS Z8817 and JIS Z8818 in Japan and ISO/IEC 80079 internationally. If evaluation is required, the sample powder must be submitted to the evaluation organization.

Measurement values such as Deflagration Index (Kst) and maximum explosion pressure (Pmax) are parameters that indicate the intensity of the explosion. If the powder has a higher value, there is a high potential of explosion risk. Such values can be used to design mechanical protections such as explosion vent, explosion suppression system, explosion isolation valves, and pressure reduction. Kst may be very high for resin dust and aluminum dust.

Minimum ignition energy (MIE) is related to ignitability. For example, spark discharge due to static electricity, which is a typical cause of ignition, has an energy of approx.1,000 mJ, so it can be said that powder with an ignition energy lower than that has a high explosion risk. Figure 2 shows an example of the energy for each type of static electricity discharge and MIE for some gases and powders. If there is a risk of ignition due to static electricity, it is necessary to take preventive measures such as grounding the equipment. When proceeding dust explosion protection, it is important to first check these figures and understand the risks accurately. Please be noted about lower explosion limit (LEL). This parameter is a value that indicates the concentration of powder that can cause an explosion, and is generally expressed in g/m3. In a gas explosion, monitoring the gas concentration and controlling it below LEL is typical measures, but in a dust explosion, the dispersibility is low and the concentration is not constant, so it is difficult to control the concentration and prevent the explosion reliably.

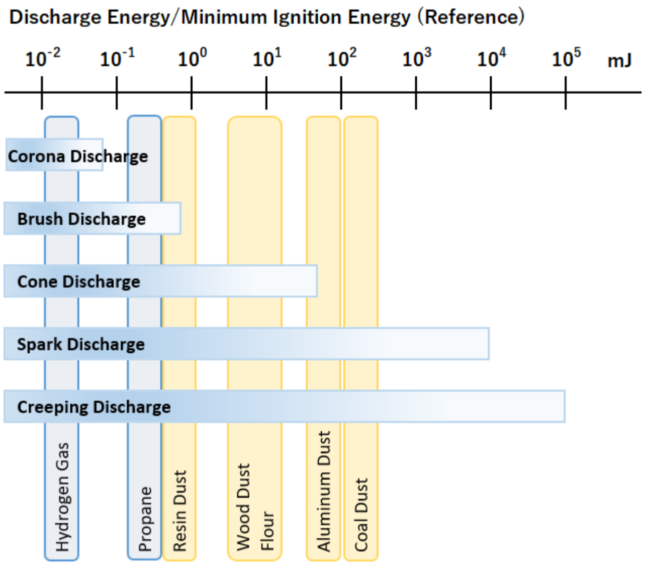

Figure 2 Discharge Energy of Static Electricity
Source: Created by author based on information from JNIOSH (https://www.jniosh.johas.go.jp)

3. Potential Risks in the process

The risk of a dust explosion varies depending on the structure of the process. Figure 3 in the next page shows statistics of ignition sources in past dust explosion cases.

The most common ignition source is "mechanical sparks". This includes sparks from impact forces such as millings.

In second place is “smoldering” (Combustion with a lot of smoke without flames). This is a phenomenon that often occurs with powders with low heat dissipation such as wood powder. As a typical example, small sparks generated from a cutting machine may be buried in the dust sediment in the duct and grow, and the pressure fluctuation may cause the sediment layer to roll up, forming a large amount of spark and burning the dust collector.

"Mechanical heat" is related to heaters and hot air of dryers. "Static electricity" is the fourth most common cause of ignition.

Evaluation item	Explanation	Remarks
Deflagration Index (Kst)	• Value that shows the intensity of the explosion • Essential for designing isolation valves and vents	St1 : 0～200 Ordinary Explosion St2 : 200～300 Violent Explosion St3 :300～ Special Violent Explosion
Maximum Explosion Pressure (Pmax)	• Maximum pressure from a deflagration • Used for explosion-resistant design of vessel	Usually about 8-11 bar g. This is not the case if the explosion translate from deflagration*1 to detonation*2. *Please refer to Page 4.
Minimum Ignition Energy (MIE)	• Required energy to ignite a dust cloud. Lower MIE has high risk of explosion. • Affects evaluation of static electricity ignitability	Lighter gas (butane) : 0.25mJ Resin Dust : 1mJ Flour : 50mJ Coal Dust : 100mJ etc.
Lower Explosion limit (LEL)	• Measure the concentration range where the dust cloud ignites	Approx.20～1,000g/m3

Table 2 : Evaluation Items of Sample Test

Figure 4 shows statistics on the equipment in which the accident occurred. The most accidents have been reported in "Silo facilities". Accidents often occur in silos because equipment such as bucket elevators easily form dust clouds, have large kinetic energy due to mechanical sparks, and are prone to foreign materials. To prevent accidents, it is important to remove foreign materials with a magnetic separator and detect abnormalities such as meandering and slip detectors. In addition, the heat damage of the dust to the heat transfer of the boiler of the transport tanker during transportation may lead to carbonization and smoldering, so it is important to carry out a thorough inspection before acceptance the raw materials.

"Dust collector" has a high risk of explosion due to high-concentration dust cloud inside and has a structure in which static electricity is easily generated by being wiped off by a backwash pulse. If installed indoors, there is a great risk of fire. It is necessary to use anti-static type for the bag filter and to ensure that the entire equipment is grounded. Also, dust accumulation inside duct may increase the risk of fire and explosion, regular inspections and cleaning are important measures. If the explosion vents are installed, please refer to the explanation on the next page.

"Mill" is especially at high risk for high speed rotating type such as hammer mills and pin mills. There is a risk of explosion due to abnormal clearance of rotating parts or intrusion of foreign materials. The mill itself has a strong structure, and even if an explosion occurs, the risk of major damage is low, but the damage may spread due to explosion propagation to adjacent processes. If the inlet/outlet of mill is not isolated by a screw conveyor, rotary valve etc. and is directly connected to the dust collector or hopper, it has high risk of propagating an explosion in the mill.

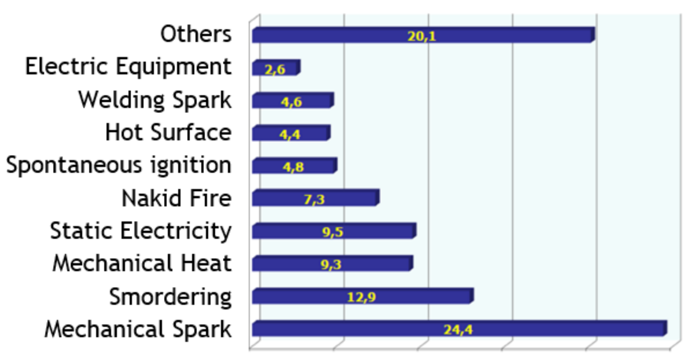

Figure 3 Statistics of Ignition Source
Source: Provided by REMBE GbmH (https://www.rembe.com)

4. Protection Against Dust Explosion

There are preventive measures and damage mitigation measures for preventing dust explosions.

✓ **Preventive Measures**

Preventive measures are important to prevent accidents. It is recommended to check the following points from "Dust Explosion Pentagon".

✓ **Removal of Fuel**

Cleaning is the basis of explosion prevention. Accumulated dust both inside and outside the vessel has a risk of spreading the damage of the explosion accident. There is a high risk in an environment with footprints. When cleaning, use suction instead of air blow. When using a vacuum cleaner, ensure it is explosion-proof.

Please be noted that there are cases where the impact of the explosion caused dust accumulated on the lamps, pipes, and equipment to disperse upwards, causing a secondary explosion outside the vessel.

✓ **Removal of Oxygen**

For highly ignitable powders, it is effective to inert the vessel by nitrogen purging.

✓ **Removal of Ignition Source**

Please make sure to inspect equipment, take measures against static electricity, and take measures against foreign material intrusion. Ignition due to abnormal clearance of rotating machinery and carbonization of contamination on heating equipment is a typical accident case. The basic measures against static electricity are grounding equipment, bonding flanges, removing non-conductors, and making workers and work floors conductive. It must be properly designed and maintained according to the equipment structure.

✓ **Suppression of Floating**

There is a high risk of explosion when manually loading from the hatch. It is effective to remove dust clouds by improving transportation / loading method and installing a dust collection duct.

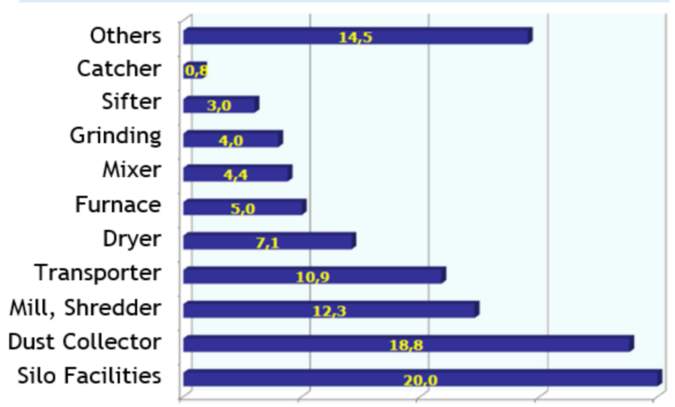

Figure 4 Statistics of Accident Process
Source: Provided by REMBE GbmH (https://www.rembe.com)

✓ **Damage Mitigation Measures**

Unlike a fire, an explosion occurs in a moment from the occurrence to the spread of damage, so special explosion countermeasure equipment is required.

✓ **Explosion Venting**

Relief the explosion inside the vessel to outside through the opening with cover to prevent the equipment from exploding. Appropriate size design is required according to vessel structure (pressure reduction, volume) and characteristics (Kst, Pmax).

In principle, it is prohibited to use it indoors, and it must be installed outdoors. In addition, since it is necessary to pay attention to the installation direction, it should be discussed with contractor.

✓ **Explosion Isolation Valve**

Vents has no function to isolate the explosion propagation to adjacent process and is therefore used in combination with isolation valve. Please note that the valve must be installed at a position about 1 to 5 m away from the vessel. In addition, inspection and cleaning are required for structures that are prone to powder adhesion.

✓ **Explosion Suppression System**

Detects flash or pressure rise, releases fire extinguishing agent and suppresses explosion before exceeding equipment pressure resistance.

Regular inspections are important due to the use of pressure detectors and fast discharge systems. Unlike the explosion vent, dust does not leak out of the equipment, so it is used in equipment for manufacturing chemical substances.

✓ **Pressure Reduction Design**

Since the maximum "deflagration*1" pressure of a dust explosion is up to 1MPa, the equipment may be designed with a pressure resistance of about 2MPa. Equipment costs will increase significantly, but this is a highly reliable measure.

Be aware that if a "detonation*2" occurs, there is a risk of higher pressure.

*1 Deflagration: Phenomenon of combustion at a speed below as an explosion.

*2 Detonation: Phenomenon of powerful explosion with a shock wave exceeds the speed of sound by accelerating when the explosion propagates.

5. [Reference] Explosiveness and Characteristics of Typical Dust

Name/Kst*3 (Reference)	Characteristics
Coal dust Kst : ～100 = St1	The handling amount is large and foreign material is easily mixed. There are many high risk process such as drying and milling, heat generating during storage, and generation of combustible gas.
Wood dust Kst : ～150 = St1	Foreign materials such as nails and stones are easily mixed. Since there are many cutting and crushing processes, there is a great risk of ignition. Since its low heat dissipation, carbonization and smoldering due to heat storage are likely to occur.
Flour, Soi, Grain, Cone Kst : ～200 = St1	The handling amount is large and foreign material is easily mixed. In addition to rotting heat, there are cases of ignition due to heat transfer from boilers during tanker transportation. Bucket elevators are particularly damaging.
Resin dust Kst : ～450 = St3	Petroleum-derived dusts are often extremely ignitable and explosive (MIE=1mJ or less), so special care must be taken when handling them.
Aluminum, Magnesium Kst : 600 = St3	It burns violently with high radiant heat. It may generate hydrogen, so be careful when extinguishing the fire. Due to the violent explosion, the measures that can be selected may be limited.
Ink, Toner Kst : ～400 = St3	Black toner is highly explosive because resin and metal powder may be kneaded with carbon (acetone) black. Damage occurred at manufacturers and recycling plants.
Medicine Kst : ～300 = St2	The oil-based raw material used as the base is explosive. The drug substance has a risk of environmental pollution when leaked. A mixture of flammable vapors and powders poses a particularly severe risk of hybrid explosion.

*3 Kst: A value that indicates the intensity of the explosion.
Up to 200 is called St1, 200-300 is called St2, and when it exceeds 300, it is called St3.

Reference Material
[1] Measures Against Dust Explosion & Fire, Association of Powder Process Industry and Engineering JAPAN
[2] Static Electricity Safety Guidelines 2007, JNIOSH
[3] NFPA652 (2019) : Standard on the Fundamentals of Combustible Dust

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