Dust Explosion Hazard Assessment and Control

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Introduction

The majority of powders that are used in the processing industries are combustible (also referred to as flammable or explosible). An explosion will occur if the concentration of the combustible dust that is suspended in air is sufficient to propagate flame when ignited by a sufficiently energetic ignition source.

A systematic approach to identifying dust cloud explosion hazards and taking measures to ensure safety against their consequences generally involves:

- Understanding of the explosion characteristics of the dust(s),
- Identification of locations where combustible dust cloud atmospheres could be present,
- Identification of potential ignition sources that could be present under normal and abnormal conditions,
- Proper plant design to eliminate and/or minimize the occurrence of dust explosions and protect people and facilities against their consequences.

Conditions Required for Dust Explosions to Occur

Six conditions must exist simultaneously and in one location for a dust explosion to occur:

1. The dust must be combustible (as far as dust clouds are concerned, the terms “combustible,” “flammable,” and “explosible” all have the same meaning and could be used interchangeably).

   The first stage of a dust explosion hazard assessment is to determine whether the dust will explode when dispersed as a cloud. The combustibility of a dust can be assessed by conducting an “Explosion Classification Test” on a representative sample of the dust. In this laboratory test the observation of flame propagation determines whether or not a suspended dust is capable of ignition and sustaining an explosion.

2. The dust must be airborne.

   A dust deflagration is dependent on intimate contact between the particle surface and the available oxidizer, oxygen in air. This is because most dusts do not contain sufficient oxygen to support combustion. Without suspension and availability of oxygen around each particle a pile of combustible dust will only smolder and burn poorly.

3. The dust concentrations must be within an explosible range.

   If the concentration of a dust cloud is below the "Minimum Explosible Concentration" (MEC) an explosion cannot propagate. This is because when the dust concentration is below the MEC the spacing between the particles will be too great and the energy from a burning particle will not be effectively transferred to the nearby particles. The ease of ignition of a dust cloud and also the resulting explosion violence increase as the dust cloud concentration is increased above the minimum explosible concentration until an optimum concentration is reached causing the highest explosion violence. At higher dust cloud concentrations the explosion violence decreases because there is insufficient oxygen available for the combustion process at the particle surface.

   The "Minimum Explosible Concentration" of dust clouds can be determined by laboratory testing.

4. The dust must have a particle size distribution capable of propagating flame.

   As the dust particles get finer the total surface area that is available for oxidation will increase. Therefore, the sensitivity of a dust cloud to ignition and the resulting explosion violence (severity) increase with a decrease in particle size. It should be noted that in practice very often dust clouds are made up of particles with sizes ranging from fine to coarse. Since the fines become airborne more readily, they play a more prominent role in the initial ignition and explosion propagation.

5. The atmosphere in which the dust cloud is present must be capable of supporting combustion.

   A dust cloud explosion will only occur if there is a sufficient amount of oxidant available. In practice the oxygen in air is the most common oxidant. Some other oxidants include Chlorine, Nitrous Oxide, Nitric Oxide, and Nitrogen Tetraoxide.

   The Limiting Oxidant Concentration can be determined by laboratory testing. An ignition source with sufficient energy to initiate flame propagation must be present

   The ignition sources that have been found to be the cause of the majority of explosions in dust handling/processing plants include (this is not an exhaustive list):

   - Welding and cutting, heating and sparks generated by mechanical failure, sparks generated by mechanical impacts, flames and burning materials, self heating, electrostatic discharges, electrical sparks,

   - The sensitivity of a dust cloud to ignition by different ignition sources can be determined through appropriate laboratory tests.

Laboratory Testing to Assess Explosion Characteristics of Dust Clouds

To assess the risk of a dust explosion to a facility both the “likelihood of an explosion” and “consequences of an explosion” characteristics of the dust(s) that are being handled/processed in the facility must be determined. Two groups of tests are used in this approach:

Laboratory Tests to Determine the “Likelihood of an Explosion”

Explosion Classification Test

The Explosion Classification Test determines whether a dust cloud will explode when exposed to an ignition source. The test results in a material being classified as either combustible or non-combustible.

Dust samples of various quantities are dispersed in either a 1.2-liter Hartmann Tube, a 20-Liter Sphere, or a $1m^3$ Sphere apparatus and attempts are made to ignite the resulting dust cloud by a sufficiently energetic ignition source.

Minimum Explosible Concentration

The Minimum Explosible Concentration (MEC) Test is performed in accordance with the International Standards Organization (ISO) method 618411 or ASTM E1515. MEC test determines the lowest concentration of dust cloud in air that can give rise to flame propagation upon ignition. The test involves dispersing a sample of the dust in a 20-Liter Sphere apparatus and attempting to ignite the resulting dust cloud with an energetic ignition source. Trials are repeated for decreasing sample sizes until the MEC is determined.

Minimum Ignition Temperature

The Minimum Ignition Temperature (MIT) Test is performed in accordance with ASTM E-2021 and the European Standard 61241-2-1. The MIT 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, electrical apparatus, and friction sparks. Dust samples of various sizes are dispersed into a furnace and the minimum furnace temperature capable of igniting the dust cloud at its optimum concentration for ignition is determined.

The MIT value is influenced by the particle size and shape as well as the moisture content of the dust. A decrease in particle size and moisture content of the dust particles results in a lower MIT value.

Minimum Ignition Energy

The Minimum Ignition Energy (MIE) Test is performed in accordance with American Society for Testing and Materials (ASTM) E2019, British Standard 5958, and International Standard: IEC 1241-2-3 using the Modified Hartmann Tube apparatus. The MIE test determines the lowest electrostatic spark energy that is capable of igniting a dust cloud at its optimum concentration for ignition. The test is used primarily to assess the potential susceptibility of dust clouds to electrostatic discharges.

The MIE value is influenced by particle size and moisture content of the dust and by process conditions such as temperature and oxidant content... A decrease in particle size and moisture content of the dust particles results in a lower MIE value. An increase in the temperature of the atmosphere in which the dust cloud is suspended will result in a decrease in MIE.

Limiting Oxidant Concentration

The Limiting Oxidant Concentration (LOC) Test determines the minimum concentration of oxygen (displaced by an inert gas such as nitrogen) capable of supporting combustion. The LOC test is used to study explosion prevention involving the use of inert gases and to set oxygen concentration alarms or interlocks in inerted equipment and vessels.

LOC testing can be performed using the 20-Liter Sphere apparatus. Dust samples of various sizes are dispersed in the vessel and attempts are made to ignite the resulting dust cloud with an energetic ignition source. Trials are repeated for decreasing oxygen concentrations until the LOC is determined.

The LOC of a given dust cloud is dependent on the type of inert gas that is used to replace the oxidant of the atmosphere as well as some process conditions such as temperature.

Laboratory Tests to Determine the "Consequences of an Explosion"

Maximum Explosion Pressure, Maximum Rate of Pressure Rise, and Explosion Severity (K_{st} Value)

Explosion severity testing is performed in accordance with the current American Society for Testing and Materials (ASTM) Method E 1226, National Fire Protection Association (NFPA) Standard 68, German Society of Engineers (VDI) Method 3673, and International Standards Organization (ISO) Method 6184/1.

The Maximum Explosion Pressure and Maximum Rate of Pressure Rise values are determined by using the 20-Liter Sphere apparatus. The dust sample is dispersed within the sphere, ignited by 10,000 Joules chemical igniters, and the pressure of the resulting explosion is measured. The sample size is varied to determine the optimal dust cloud concentration. The maximum explosion pressure and rate of pressure rise are measured and used to calculate the explosion severity (K_{st}) value of the dust cloud. These data can be used for the purpose of designing dust explosion protection measures.

Basis of Safety for Dust Cloud Explosion Hazards

Safety from potential dust cloud explosions could include taking measures to avoid an explosion (explosion prevention) or designing facilities and equipment so that in the event of an explosion personnel and facilities are protected (explosion protection).

Explosion Prevention Measures

The risk of an explosion is removed when one of the following measures is taken:

a. An explosible dust cloud is never allowed to form.

There are two main methods of ventilation for eliminating or controlling the spread of explosible atmospheres (fuel):

Dilution Ventilation

Dilution ventilation provides a flow of fresh air into and out of the building. This normally results in a reduction of the background concentration of the flammable atmosphere in the working area but there is no control of the flammable atmosphere at the source of release. This method is not practical for controlling the concentration of dust cloud atmospheres but is often used to control vapor concentrations.

Local Exhaust Ventilation

Local exhaust ventilation is designed to intercept the flammable atmosphere at the source of release and directs it into a system where air is safely separated from the fuel. A correctly designed local exhaust ventilation system can be very effective in limiting the spread of dust atmospheres beyond the source of release. Local exhaust ventilation is generally less expensive to run than dilution ventilation because less air is used.

A local exhaust ventilation system generally includes dust collection hood, ductwork, filter, and fan.

b. The atmosphere is sufficiently depleted of oxidant (normally the oxygen in air) that it cannot support combustion.

Safety may be based on reducing the Oxidant concentration below a level that will no longer support combustion (LOC), by adding an inert gas. Nitrogen gas is perhaps the most commonly used inert gas because it is readily available in adequate quantity. Other inert gases include carbon dioxide, argon, helium, steam, and flue gas (waste gas from on-site processes).

Once the LOC of the dust has been determined for the inert gas that will be used, the inert gas needs to be introduced into the vessel. Successful inert gas blanketing will only be possible if the entire volume of the vessel is inerted and the inert atmosphere is maintained at all times even when the vessel is opened during the addition of solids and/or liquids to the vessel.

c. All ignition sources capable of igniting the dust cloud are removed.

The ignition sources that have been found to be the cause of the majority of explosions in dust handling/processing plants include welding and cutting, heating and spark generated by mechanical failure, mechanical impacts, flames and burning materials, self-heating, electrostatic discharges, and electrical sparks. This is not an exhaustive list.

Elimination of ignition sources involves:

<u>Control of Heat Sources</u>

A hot surface may directly ignite a dust cloud or first ignite a dust layer that may be settled on it and subsequently ignite a dust cloud. Measures that may be considered for preventing a dust cloud ignition by heat sources include:

– Maintaining an effective housekeeping program to prevent/remove dust accumulations on potential hot surfaces,
– Maintaining the temperature of the processing equipment below the self-heating temperature of the powder,
– Providing regular inspection and maintenance of the processing plant to prevent overheating due to misalignment, loose objects, belt-slip/rubbing, etc.,
– Preventing the overloading of processing plant such as grinders, conveyors. Consider installing overload protection devices on drive motors,
– Preventing "foreign objects" from entering the processing equipment by use of suitable separation devices such as electromagnets or pneumatic separators,
– Isolating/shielding dust layers and clouds from hot surfaces,
– Using of approved electrical equipment (correct temperature rating)

Control of Friction/Impact Sparks

The ability of friction/impact sparks to ignite flammable atmospheres is dependent, amongst other factors, on the composition of the impacting surfaces.

In any work where friction/impact sparks could be expected flammable (gas, vapor, dust clouds) atmospheres should not be present. Additionally, hard surfaces, such as concrete, brick, or rock, should be kept well wetted with water. Alternatively, soft rubber mats may be used to cover the surfaces and act as a cushion for objects that might fall.

Welding, Cutting & Similar Hot work Operations

To avoid fires and explosions measures should be taken to prevent the formation of dust clouds and remove dust deposits from surfaces during welding/brazing/soldering and cutting and other similar operations.

Electrical Equipment and Instruments

Ensuring safety from electrical equipment and wiring systems normally involves conducting an Electrical Area Classification according to article 500 of the National Electrical Code (NEC).

An Electrical Area Classification exercise involves identifying the extent of location(s) in a facility where combustible materials could be present during normal and/or abnormal conditions. The intent of Electrical Area Classification is to ensure that the electrical equipment that is used in those locations will not act as an ignition source.

Electrostatic Discharges

In this section it is assumed that the powder DOES NOT contain any flammable solvent and it is handled and processed in an atmosphere free of flammable gases and vapors.

General Precautions from Electrostatic Ignition Hazards

Bonding and grounding. Spark discharges can be avoided by electrically grounding conductive items such as metal equipment, fiberboard drums, conductive liners, low resistivity powders and personnel.

Use of insulating materials. Where there could be high surface charging processes, non-conductive materials should not be used, unless the breakdown voltage across the material is less than 4 kV. Examples of non-conductive objects include plastic pipes, containers, bags, coatings and liners.

Charge reduction by humidification. High relative humidity can reduce the resistivity of some powders and increase the rate of charge decay from bulked powder in grounded metal containers. However, in most cases this will only be effective if a relative humidity in excess of 65% is maintained.

Charge reduction by ionization. Localized ionization (corona discharges), from sharp, grounded, conducting probes or wires can on occasions be used to reduce the level of electrostatic charge from powder particles entering a vessel. Electrostatic ionization devices are not however without problems, and should only be used after consulting expert advice.

Explosion Protection Measures

If the formation of an explosible atmosphere cannot be prevented and all sources of ignition cannot be reasonably eliminated or excluded, then the possibility of a dust cloud explosion persists. Under such conditions explosion protection measures should be taken to protect personnel and minimize damage to facilities. Explosion Protection measures include:

Explosion Containment

Constructing the equipment to withstand the maximum explosion pressure resulting from a deflagration of the dust present in the equipment under the process (pressure, temperature, etc.) condition will prevent injury to personnel.

Explosion Suppression

Explosion Suppression involves detecting an explosion at an early stage and suppressing it with a suitable suppressant. An explosion suppression system normally includes explosion detector, control unit, suppressor, and a suitable suppressant.

Explosion Relief Venting

Explosion Relief Venting involves relieving the explosion products (pressure and flame) from the plant to a safe location. The principle of explosion relief venting is that a dust explosion in a vessel causes vent(s) of sufficient area to open rapidly and relieve hot gases and burning dust to a safe location.

Explosion Isolation Measures

Dust explosions can propagate through pipes, chutes, conveyors, etc. and cause secondary explosions in other equipment and/or areas of the plant. Therefore, regardless of what type of explosion protection measure is considered, the dust cloud explosion should be prevented from propagating from the location in which it originates from to other locations in the plant. This is referred to as "Explosion Isolation". There are two types of barriers that cold be considered for isolating a dust explosion, Mechanical Barriers and Chemical Barriers.

Containers for Powders

Containers of various sizes, shapes, and materials of construction are often utilized in the manufacturing and processing industries for the transport and storage of flammable powders. Additionally when handling solvent wet or dry powders it is convenient to use an inner liner (loose) in the container. This Focus article is intended to highlight the electrostatic ignition hazards that are associated with the use of some containers.

With a few exceptions, all powders including chips and granules readily become charged during operations/processes such as pouring, sieving, blending, milling, etc. When a highly charged powder is transferred into in a container depending on a number of factors such as "conductivity" of the container, container size, "volume resistivity" of the powder, "electrostatic chargeability" of the powder, particle size, rate of powder transfer to/from the container, etc. the following electrostatic discharges may occur:

- Spark discharges involving electrically ungrounded conductive containers. Spark discharges can potentially ignite flammable gas, vapor and dust cloud atmospheres.
- Cone (Bulking) discharges on the powder surface. Cone discharges can potentially ignite flammable atmospheres with minimum ignition energy less than about 25mJ.
- In the case of an insulating container electrostatic discharges from the powder may lead to polarization across the container wall and to the risk of a Propagating Brush discharge (PBD). PBDs can readily ignite most flammable gas, vapor, and dust cloud atmospheres. PBDs can also cause physiological harm to personnel.
- Insulating containers can be charged externally by rubbing and give rise to Brush discharges. Brush discharges can readily ignite certain flammable atmospheres with minimum ignition energy less than about 4mJ (e.g. solvent vapor atmospheres).

Practical approaches for eliminating/controlling electrostatically initiated flash fires and explosions are briefly discussed below:

<u>Conductive (metal and fiberboard) Containers for Powders</u>

Consideration of the following measures should reduce electrostatic ignition hazards during the use of conductive containers for powders. It should be noted that for electrostatic hazard assessment purposes, containers constructed from uncoated and unpainted fiberboard material are considered to be sufficiently conductive and would dissipate electrostatic charges from their surfaces, if grounded:

- The container and any other conductive object in its vicinity, including the fill pipe and personnel, if present, should be electrically grounded.

➢ In the presence of flammable mixtures of materials with minimum ignition energies greater than 25mJ, grounding of the container and other conductive objects should provide adequate protection.

➢ Where a flammable atmosphere with a minimum ignition energy less than 25mJ is present and “electrostatic chargeability” and “volume resistivity” test results suggest that the quantity of electrostatic charge present is sufficient to cause incendive discharges from the surface of the bulking powder the measures that could be considered to eliminate/control flash fire/explosion hazards include:

- Installation of some form of explosion prevention such as inert gas blanketing or explosion protection such as containment, suppression or relief venting

- Reduction of the quantity of the electrostatic charge on the incoming powder, e.g. by neutralization using ionized air

<u>Insulating (plastic) Containers for Powders</u>

Containers fabricated from materials having volume resistivity > 10^9 ohm.m and/or surface resistivity > 10^{11} ohm/square

➢ If the contents of the container are solvent-wet and can produce a flammable atmosphere, it is generally suggested that insulating containers not be used. Electrically grounded conductive containers should be considered.

➢ For dry powders with minimum ignition energy greater than 25mJ, grounding of conductive equipment should provide adequate protection, if it is established that the rate of electrostatic charge input with the powder is insufficient to give rise to propagating brush discharges.

➢ If a flammable atmosphere with minimum ignition energy less than 25mJ can exist and it is shown that the quantity of charge present is sufficient to cause discharges from the surface of the bulking powder it is suggested that electrically grounded conductive containers are used. Additionally the following protective measures are suggested:

- Installation of inert gas blanketing or explosion protection

- Reduction of electrostatic charge on the incoming powder

➢ If the powder is conductive, it should be in contact with an electrical ground at all times during filling and emptying.

<u>Insulating (plastic) Liners for use in Containers</u>

When handling solvent wet or dry powders in drums, it is often convenient to use an inner liner. However, insulating liners can become electrostatically charged during filling, emptying, or if the liner is removed from the container. When filling the container with a highly charged insulating powder, there is a possibility of a propagating brush discharge from the liner. Additionally, the liner may insulate its contents from ground, even when the outer container is conductive and grounded. **It is therefore suggested that electrically grounded static dissipative or conductive liners be used.**

Insulating liners (liners with surface resistivity > 10^{11} ohm/square) should be used ONLY if they are essential, e.g. for reasons of chemical compatibility between the liner and the product. In that case the ignition risk and the possibility of physiological shock from propagating brush discharges depends on factors such as:

- Thickness of liner
- Resistivity of liner
- Handling procedure
- Electrical properties of the product
- Nature of flammable mixture that may be present

An insulating liner should not be removed from the container, e.g. to shake out any residue, if a flammable vapor/air mixture or a sensitive dust cloud can be present.

References

Please refer to the following references for more detail on the topics that have been discussed in this paper:

1. Bartknecht, Wolfgang. (1989) Dust Explosions Course, Prevention, Protection. Springer-Verlag, Germany.

2. Eckhoff, Rolf K. (1997) Dust Explosion in the Process Industries. *2nd Edition*. Butterworth-Heinemann Linacre House, Jordan Hill, Oxford.

3. NFPA 77 Recommended Practice on Static Electricity.

4. NFPA 68 Guide for Venting of Deflagrations.

5. NFPA 69 Explosion Prevention Systems.

6. NFPA 91 Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids.

7. NFPA 497B Classification of Class II Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas.

8. NFPA 497M Manual for Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified Locations).

9. NFPA 654 Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids.