DUST EXPLOSIONS – A MAJOR INDUSTRIAL HAZARD
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ABSTRACT
Dust explosions are a major hazard in many industrial processes. In operations such as crushing and grinding, conveying, classifying and storage, an explosion may occur in the presence of combustible dusts or powders. A lot of accidental dust explosions take place in industrial plants that have powder-processing equipment. This is because more than 70% of powders processed in industry are combustible. It is essential, therefore, to accumulate much knowledge as possible on the explosion hazards of combustible powders. Some detailed studies were conducted in developed countries. A report of dust explosions in U.S.A. from 1900 – 1956 consists of information details for 75 most serious explosions out of 1125 recorded (Eckhoff R.K.). This covered a wide range of dusts wood, food and feeds, metals, plastics, coal, paper and chemicals. In India, information pertaining dust explosions is almost non-existent solely because in most accidents that occur in India, the broad term ‘Explosion’ is used and recorded which the type of explosion goes unreported. Also, in public perception, explosions are what occur in pressurized vessels containing gases liquids, or by the operation of explosives.

KEY WORDS: Explosion, Dust Explosion, Powder Industry, Dust

DUST EXPLOSION: DEFINITION
A dust explosion is the rapid combustion of a dust cloud. In a confined or nearly confined space, the explosion is characterized by relatively rapid development of pressure with flame propagation and the evolution of large quantities of heat and reaction products. The required oxygen for this combustion is mostly supplied by the combustion air. The condition necessary for a dust explosion is a simultaneous presence of dust cloud of proper concentration in air that will support combustion and a suitable ignition source. The term dust is used if the maximum particle size of the solid mixture is below 500 µm.

An explosion hazard exists when dusts are produced, stored or processed in a plant and these materials are present as a mixture in air. An explosible mixture is present, when combustible dusts are present in such quantities in air that an explosion occurs after an ignition. The industries where the hazard of combustible and explosive dust can be commonly found are:
- Wood processing and storage
- Grain elevators, bins and silos
- Flour and feed mills
- Manufacture and storage of metals such as Al and Mg
- Chemical production
- Plastic production
- Starch or Candy producers
- Spice sugar and cocoa production and storage
- Coal handling or processing area
- Pharmaceutical plants
- Dust collection bins or bags
- Shelves, nooks, crannies, inside of equipment and above false ceilings in all facilities.

1.1 Operations involving dusts:
Operation in which dusts are generated or handled comprise of the following:
1. Size reduction
2. Conveying.
Group (b):
Dusts, which did not, propagated flame in the test apparatus.

2.1 Classification based on ignitability
A measure of the ignitability of a dust layer and intensity of burning of a dust layer is the Combustion Class (CC) (ISSA, 1998). (Tamamini 2002) This classification is based on the behaviour of a defined heap when subjected to a gas flame or hot platinum wire:

1. CC1: No ignition; no self – sustained combustion
2. CC2: Short ignition and quick extinguishing; local combustion of short duration
3. CC3: Local burning or glowing without spreading; local sustained combustion but no propagation
4. CC4: Spreading of a glowing fire; propagation smouldering combustion
5. CC5: Spreading of an open fire; propagating open flame
6. CC6: Explosible burning; explosive combustion.

2.2 Classification based on $K_{st}$ value
The highest value of the maximum rate of pressure rise is used to calculate the $K_{st}$ value of the dust:

$$K_{st} = \frac{(dp/dt)_{max}}{V^{1/3}}$$

The $K_{st}$ value is essentially defined as the maximum rate of pressure rise measured under standard conditions in a 1-m$^3$ vessel, and is used to characterize the explosibility of the dust by reference to four groups (Lunn 1988):

- $0 < K_{st} < 200$ = Group St0: Non-explosible
- $200 < K_{st} < 300$ = Group St1
- $300 < K_{st}$ = Group St2

2.3 Safety codes
A number of safety codes now address the dust/ vapour explosion potential depending on the type of industry or operations. Codes of a general nature are listed as follows:

- NFPA Codes:
  - i.e. NFPA 65, 480, 481
  - Explosion Protection systems
  - i.e. NFPA 68, 69
  - Handling and Conveying of Dusts, Vapour, and Gases,
  - i.e. NFPA 91, 650, 654, 655

- BOCA (Uniform Building Codes):
  - Requirements for Group H
  - Occupancy, Section 307.1
  - VDI (Pressure release of explosions)
  - Verein Deutscher Ingenieure.

3. DUST EXPLOSION PENTAGON
The dust explosion pentagon has put forth five major parameters, which comprises the dust explosion pentagon (Amyotte 1996);

- State of mixed reactants
- A dust explosion is a complex phenomenon involving simultaneous momentum, energy and mass transport in a reactive multi-phase system (Vijayaraghavan, 2004). Particles, when in dust, powder or flake forms from operations such as grinding, finishing and processing may be suspended as a dust cloud in air and consequently may ignite and cause serious damage. If the dust cloud is unconfined the effect is simply one of flash fire. If however, the ignited dust cloud is at least partially confined the heat of combustion may result in rapidly increasing pressure and produce explosion effects such as rupturing of the confining structure (Manju mittal 1999).

4. TRIGGERS OF DUST EXPLOSION
The principle ignition sources for dusts include,

- Flames and direct heat
- Hot work
- Incandescent material
- Hot surfaces
- Electrostatic sparks
- Electrical sparks
- Friction sparks
- Impact sparks
- Self heating
- Static electricity
- Lightning

A brief description of each is presented below:

4.1 Flames and Direct heat
Incident statistics show that a large proportion of dust ignition caused by flames. A flame is a very effective source of ignition for dust suspensions. One source of flames is direct-fired equipment. This source may be eliminated by the use of indirect heating using hot water or steam.

4.2 Hot work
Another principal ignition source for dusts is hot work such as welding and cutting. Again a welding flame is a very effective source of ignition. In this case it is frequently a dust layer may have an ignition temperature in the range 100-200 °C and is readily ignited by hot work. Incidents occur because this hazard is not appreciated and the dust is not cleaned out of the equipment before work is started.
4.3 Incandescent material
Another important contributor to incidents is burning dust, or other incandescent material, is another important ignition source. Considerable efforts are made to prevent ignition by burning dust. Burning dust is an ignition source, which can occur inside dust handling equipment. One consequence of this is that it may travel through the plant. Another is that it may remain undetected. A direct firing system is one potential source of incandescent particles. In direct-fired driers the air inlet is protected by a fine screen to prevent ingress of such incandescent material.

4.4 Hot surfaces
Hot surfaces are another important ignition source. One type of hot surface is equipment with a hot surface such as steam pipe or electric lamp. Another is overheated moving equipment such as distressed bearing. Ignition due to a hot surface is particularly like to occur with dust layers. As already mentioned the surface temperature can cause ignition of a dust layer is frequently no more than 100-200 °C. The ignition temperature of a dust layer decrease as the thickness of the layer increases. It is frequently found in investigations of ignition that a dust layer has ignited at an unexpectedly low temperature. The dust itself may contribute to its own ignition. Dust is a poor conductor of heat and a layer of dust on equipment mat reduce heat loss to atmosphere and thus cause the surface to be hotter than it would be otherwise. Or again dust may enter a bearing and cause it to run hot. Electric lamps give hot surfaces, which may ignite dust suspensions. There are available lamps with special protection for use in dusty atmospheres. Alternatively, areas, which may contain dust suspensions, may be illuminated by lamps, which are separated on the other side of an armoured glass panel. Hot surfaces may also occur as a result of distress in machinery such as pumps and motors. It may be necessary in some cases to monitor features such as bearing temperatures.

4.5 Electrostatic sparks
An electrostatic spark may occur due to a discharge from electrical equipment. Protection against such discharges is based on hazardous area classification and the associated safeguarding of electrical equipment is designed so that incendive capacitive or inductive discharges cannot occur.

4.6 Electrical sparks
Electrical sparks occur in the normal operation of certain equipment such as switches and relays and may occur in electrical equipment generally as a result of malfunction.

4.7 Friction sparks
Another important contributor to incidents is frictional sparks associated with rubbing or grinding. These can occur in plant handling dust in several ways. The dust itself may block the equipment and cause overloading, leading to spark generation. Preventive measures include control of dust flow and machine overload trips. Foreign materials such as tramp iron can cause sparks. Removal of such objects can be effected by magnetic or pneumatic separation, and is especially desirable if the material is to pass through a mill. Failure of equipment can also give rise to sparks.

4.7 Impact sparks
Much concern has centered around the potential of hand tools to create an incendiary impact spark, although there is little evidence from incidents of single impact ignition.

4.8 Self-heating
Self-heating or spontaneous combustion is another significant ignition source. There are wide varieties of reactions, which can give rise to self-heating. They include not only oxidation reactions but reactions with water or wood. For many reactions the reaction rate accelerates with temperature, according to the Arrhenius equation. But there also auto catalytic reactions, which may accelerate due to production of a catalyst or removal of an inhibitor.

4.9 Static electricity
In general terms, the static charge on dust is a function of the work done on them. Hence the charge tends to be a stronger function of the process than of the material. For sieving and pouring the charges are low, but for size reduction they are much higher. It is not easy to screen for situations where static electricity might present a hazard in dust handling. Laboratory tests for this are not well developed. There are certain types of dust handling plant in which static electricity is readily generated. These include mills, conveyor belts and pneumatic conveying systems. The hazard in such equipment should therefore be carefully considered. As with liquids, static charge can accumulate at the center of a large storage hopper. It may then be discharged by an earthed probe. But there is also a hazard unique to dusts that of sliding of highly charged material towards an earthed container wall (Lees 1996).

5. PRIMARY AND SECONDARY EXPLOSIONS

5.1 Primary explosions
The concentrations needed for a dust explosion are rarely seen outside of process vessels, hence most severe dust explosions start within a piece of equipment (such as mills, mixers, screens, dryers, cyclones, hoppers, filters, bucket elevators, silos, aspiration ducts, and pneumatic transit systems.). These are known as primary explosions. It is important to note that one of the main differences between the dust explosion and flammable gas hazard is that gas/vapour explosions rarely happen inside vessels due to a lack of air to support explosions. However with dust it is generally suspended in air in process equipment (unless the vessel are operated in pure nitrogen atmospheres, which can still pose a problem with metal powders), which can allow dust explosion conditions to occur. This can then cause the vessel to rupture if it has insufficient Pressure release devices/venting or if its design pressure is too low.

An important aspect of dust explosion avoidance is the limiting of the possibility of primary explosions,
however more important is to reduce the possibility of a secondary explosion occurring.

5.2 Secondary explosions
These are caused when lying dust is disturbed by the primary explosion and forms a second dust cloud, which then is ignited by the heat released from the primary explosion. The problem is that small amounts of lying dust occupy very little space, but once disturbed can easily form dangerous clouds. A 1mm layer of dust of 500 kg/m$^3$ can give rise to a 5m deep cloud of 100g/m$^3$ dust.

6. FREQUENTLY USED TERMS
A glossary of terms frequently used in the treatment of dust explosions is presented below:

- Activation overpressure: $P_a$, pressure threshold, above the pressure at ignition of the reactants, at which a firing signal is applied to the suppressor (S).
- Blast wave: A shock wave in open air generally followed by strong wind, the combined shock & wind is called blast wave.
- Cubic law: The correlation of the vessel volume with the maximum rate of pressure rise
  \[ K_{\text{max}} = \left( \frac{dp}{dt} \right)_{\text{max}} V^{1/3} \]
- Deflagrations: An explosion in which the reaction front (energy front) moves at a speed less than the speed of the sound in the medium.
- Detonation: An explosion in which the reaction front (energy front) moves at a speed greater than the speed of the sound in the medium.
- Dust: Solid mixture with maximum particle size of 500 micro meter.
- Dust explosion class St: Dusts are classified in accordance with the $K_{\text{max}}$ values.
- Explosion: Propagation of aflame in premixture of combustible gases, suspended duct(s), combustible vapors, mists or mixtures thereof in a gases oxidant such as air in a closed or substantially closed vessel
- Explosion Pentagon: The three elements present in the fire triangle plus two additional elements necessary for two additional elements necessary for explosions–suspension of fuel within the flammable limits and confinement.
- Explosion Severity Test:
  - Per ASTM E 1226-94 using a 20-L spherical chamber.
  - Will determine the dust deflagration index, $K_d$, the maximum pressure output and maximum pressure rise rate of the material.
- Fire Triangle: The three elements necessary for a fire, fuel, heat, (ignition sources), and oxygen.
- Limiting (Minimum) $O_2$ Concentration:
  - Per ASTM proposed standard.
  - Will determine how much inert gas is needed to prevent explosion in case dust concentration is in the explosive range.
- Limiting oxygen concentration (LOC): Maximum oxygen concentration in a mixture of a combustible and air and inert gas, in which an explosion will not occur.
- Maximum explosion Overpressure, $P_{\text{max}}$: The maximum pressure reached during an explosion in a closed vessel through systematically changing the concentration of dust-air mixture.
- Maximum Reduced explosion Overpressure: $P_{\text{red, max}}$: The maximum pressure generated by an explosion of dust air mixture in a vented or suppressed vessel under systematically varied dust concentrations.
- Maximum Explosion Constant, $K_{\text{max}}$: Dust and Test specific characteristic calculated from cubic root law. It is equivalent to the maximum rate of pressure rise in a 1-m$^3$ vessel.
- Minimum Ignition Temperature: The lowest temperature of a hot surface on which the most ignitable mixture of the dust with air is ignited under specified test conditions.
- Minimum rate of Pressure Rise (dp/dt)$_{\text{max}}$: The maximum rate of pressure rise obtained in a closed vessel through systematically changing the concentrations of a dust-air mixture.
- Minimum Explosive Concentration:
  - Per ASTM E 1515-96 using a 20 L Spherical chamber.
  - Will determine the Minimum Concentration of dust – air mixture needed for an explosion.
- Minimum Ignition energy:
  - Per ASTM proposed standard using a 1.2 L cylindrical Hartmann Chamber.
  - Will determine the Minimum (electrostatic spark) energy required to ignite the material in a dust cloud form & measuring energy in the spark gap.
- Minimum Auto Ignition Temperature :(dust cloud form):
  - Per ASTM E 1491-97 standard.
  - Will determine the Minimum Auto Ignition Temperature needed to ignite the material in a dust cloud form and measuring energy in the spark gap.
- Minimum Auto Ignition temperature (dust layer form)
  - Per Bureau of Mines Procedure.
  - Will determine the minimum auto ignition temperature needed to ignite the material in the dust layer form.
- Overpressure: The pressure on an object as a result of an impacting shock wave.
Shock waves: An abrupt pressure wave generated due to sudden release of energy, which move in the medium.

Vent area, $A_v$: area of an opening for explosion venting

7. CONCLUSIONS

From the explanation of the phenomena dust explosion, we can understand the seriousness and severity of the explosion caused due to dust. Also the various sources of dust explosion, we can get clear picture for the route cause of the accident due to various types of dusts. This paper paves a way to have enough knowledge about the dust explosion. Since there is very little awareness and almost no information exists on dust explosions in India. This paper makes it an introductory awareness about dust explosions.

REFERENCES