Explosion Protection

For the Chemical and Pharmaceutical Industry

White Paper
Dust Explosions in the Chemical and Pharmaceutical Industry

When we think of the historical explosions in the Chemical and Pharmaceutical industries we think of Union Carbide Pesticides in Bhopal, Bunsfield, & Flexborough in the UK, T2 Laboratories Inc. Florida, Pepcon in Henderson & DuPont plant in Tonawanda USA. Corden Pharmachem Ltd Little Island was fined €300,000 following a chemical explosion that happened in a process reactor at its Co Cork plant that killed one of its employees and seriously injured another. All of these were explosion events, but they were not caused by dust explosions.

What is most amazing is how little those in the chemical process industry understand about the risks posed by dusts. While most people understood that certain dusts are an explosion risk — for example, coal dust, grain dust and fertilizer dust — very few understood the broad range of powders and dusts that actually pose a fire and/or explosion danger in the industrial plants. This fact was recently brought home by the explosion at Imperial Sugar. We all know that it takes three components to make a fire: a fuel the fire will feed on, a source of oxygen to sustain the fire and an ignition source, such as a spark, flame or heat.

Fire is a chemical process — an oxidation reaction — we can more easily understand how a seemingly non-hazardous material can become a great fire or explosion risk. In fact, most materials can oxidize. A prime example is iron that rusts, or chemically reacts, to form iron oxide. When we place a bar of steel where it is exposed to air, the surface will slowly rust. This process typically takes days, weeks or longer. However, if we grind that iron bar up into very fine particles, there is significantly more surface area that becomes exposed and this surface will react with the available oxygen at a much more rapid rate.

<table>
<thead>
<tr>
<th>Sample Examples only:</th>
<th>Iron Powder</th>
<th>Iron Powder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median Value [μm]</td>
<td>32</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Lower Ex-Limit [g/m3]</td>
<td>500</td>
<td>125</td>
</tr>
<tr>
<td>Max.Ex-Overpressure [bar]</td>
<td>5.1</td>
<td>6,1</td>
</tr>
<tr>
<td>KSt Value [bar m/s]</td>
<td>41</td>
<td>111</td>
</tr>
<tr>
<td>Ignition Temperature G-G- [°C]</td>
<td>520</td>
<td>310</td>
</tr>
<tr>
<td>Glowing Temperature [°C]</td>
<td>450</td>
<td>300</td>
</tr>
</tbody>
</table>

The finer the particles are, the quicker the reaction will proceed. This reaction also releases heat, so if the reaction proceeds at a rapid rate, it will generate heat at a quicker rate, and this heat will cause the gas around the particles to expand. This rapid heat generation and oxidation of the fine particulate creates a flame front. If that flame front moves at less than the speed of sound it generally is considered to be a deflagration. When a deflagration occurs in an enclosed space, an increase in pressure results when the expansion of the internal gases caused by the heat generated, is restricted by the enclosure walls. This creates an explosion, where the expanding pressure wave can cause damage to the enclosure.
If the flame and pressure wave moves faster than the speed of sound, the “explosion” is classified as a detonation. Detonations generally are associated with high explosives and, in general, cannot be controlled with pressure relief vents of any type.

This same mechanism will occur with any material that can oxidize with the release of heat (called an exothermic reaction). Therefore, most organic chemicals, plastics, foods, metals, carbon compounds, pharmaceuticals and chemical intermediates can present a risk when they are in the form of very fine powders. The finer the powder, the greater the risk. In contrast, materials that require the addition of heat to oxidize (endothermic reactions) will not spontaneously ignite or explode.

**Incidents:**

CTA Acoustics USA, Dust Explosion and Fire.

On February 20, 2003, an explosion and fire damaged the CTA Acoustics manufacturing plant in Corbin, Kentucky, fatally injuring seven workers. The facility produced fibreglass insulation for the automotive industry. CSB investigators have found that the explosion was fuelled by resin dust accumulated in a production area, likely ignited by flames from a malfunctioning oven. The resin involved was a phenolic binder used in producing fibre glass mats.
Key Findings:

1. Combustible phenolic resin dust fuelled the fire and explosions.

2. Line 405 was operated with the oven doors open due to a malfunction of temperature control equipment. Combustible material in the oven likely caught on fire, and the flames then ignited a combustible dust cloud outside the oven.

3. Lack of effective firewalls and blast-resistant physical barriers allowed the fire and explosions to spread to nonproduction areas of the facility.

4. Borden Chemical did not explicitly communicate the explosive hazard of phenolic resins to CTA.

5. Borden Chemical did not communicate to CTA the safety lessons from the 1999 John Foundry dust explosions that involved a similar Borden phenolic resin.

6. CTA management was aware of the explosive potential of combustible dust, but did not implement effective measures to prevent explosions or communicate the explosion hazard to the general work force.

7. Inefficient bag house operations and improper production line cleaning activities dispersed combustible dust and deposited it on elevated flat surfaces, where it accumulated.

8. Lack of housekeeping on elevated flat surfaces allowed combustible dust to build up to unsafe levels.

9. The Kentucky Office of Occupational Safety and Health conducted comprehensive inspections of the facility in previous years but did not issue citations regarding combustible dust hazards.

10. The Kentucky State Fire Marshal’s office had not inspected the facility since it was constructed in 1972.

11. Despite frequent inspections, none of CTA’s insurers identified phenolic resin dust as an explosion hazard after 1995.
**Warwick International LTD UK fined £12,000 after factory explosion**

The UK Health and Safety Executive has warned the chemical industry to maintain their plant and ensure safe systems of work are in place after a North Wales company was prosecuted following an explosion and fire at their factory.

The incident, which occurred on 24 April 2006 at the Warwick International Group Ltd operation in Mostyn, Flintshire, caused extensive damage to the plant, although no-one was killed or injured. Warwick International Group Ltd pleaded guilty at a previous hearing to a charge under section 2(1) of the Health and Safety at Work etc. Act 1974, and were fined £12,000 and ordered to pay £22,500 costs when they appeared for sentencing at Mold Magistrates Court.

An investigation by HSE showed the initial dust explosion occurred within the granulation plant at the factory, and spread to connected parts of the plant. The resulting fire spread rapidly throughout the building, taking fire-fighters several hours to bring it under control.

The investigation showed that risk assessments had not been updated, and measures to prevent or mitigate an explosion in the granulation plant had also not been taken, putting employees at risk.

After the hearing, HSE investigating inspector Jo-Anne Michael said: "This incident was entirely foreseeable and avoidable, and it is extremely lucky that no-one was hurt as a result".

"While the company took action quickly following the incident, our investigation showed that this was a continuing breach and they could, and should, have taken measures several years before to prevent this happening."
West Pharmaceutical Plant

The explosion was an industrial disaster that occurred on January 29, 2003 at the West Pharmaceutical Plant in Kinston, North Carolina, United States. Six people were killed and thirty-six people were injured when a large explosion ripped through the facility. Two fire fighters were injured in the subsequent blaze. The facility's purpose was to manufacture syringe plungers, to manufacture intravenous components and rubber compounding.

In October 2002 an inspector found a total of 22 "serious violations" at the plant, but said that these were routine findings for numerous industrial premises in North Carolina. West Pharmaceutical Services was fined $10,000 as a result.

The plant was ripped apart by a violent explosion. Witnesses reported hearing "a sound like rolling thunder", as what was later determined to be a chain reaction of explosions rapidly propagated. The shock wave broke windows at distances of up to 1,000 feet (330 m) away, and propelled debris as far as two miles (3 km) away, some of which started additional fires in wooded areas at this distance. The blast could be felt 25 miles (40 km) away. A large fire raged for two days at the site of the plant. Damage to the plant was estimated to be in the region of $150 million. One half of the 150,000 square-foot (13,935 m²) plant was completely destroyed.

Within twenty-four hours of the explosion, the Chemical Safety and Hazard Investigation Board, who conducted the investigation, had determined from eyewitness interviews that the explosion originated in an area known as the Automated Compounding System. This was a synthetic rubber-processing system. It was the site for mixing, rolling, coating, and drying of a type of rubber called polyisoprene. The process adds oils and fillers to the material, as well as creating significant quantities of dust. Therefore, the working theory from an early point was the rubber dust explosion theory.

One particular machine was identified. It coated strips of rubber by dipping them in "ACumist", a finely powdered grade of combustible polyethylene. This machine had operated for 24 hours a day, five or six days a week, since 1987. The space around the machine, including a suspended ceiling three feet (0.9 m) above the machine, were regularly cleaned by the factory's maintenance personnel. They were unaware that ventilation systems within the room pulled the dust up into the ceiling, where an accumulation 6.3 to 12 mm thick had gathered. Several weeks prior to the accident, some maintenance personnel did notice a thick layer of dust coating surfaces above the suspended ceiling. They failed to realize the imminent danger posed.
The investigation determined that the explosion occurred when something disturbed the dust, creating a cloud, which ignited. The investigation was unable to determine what disturbed the dust or what ignited it, due to the extremity of the damage at the plant. However, it is known that the machine suffered multiple internal fires, including one that was powerful enough to blow off the mixer door. Four other theories were developed regarding possible causes: a batch of rubber that overheated and ignited; an electrical blast or light fixture that ignited accumulated dust; a spark caused by a possible electrical fault; or ignition of dust in a cooling air duct feeding an electric motor.

It was determined that West had in their possession Material Safety Data Sheets (MSDSs) supplied by the powder manufacturer that warned of the danger of such explosions, but did not refer to them. Instead, they relied on the MSDS supplied by Crystal Inc. PMC, who supplied West with a polyethylene-water slurry. However, this neglected to mention the hazard posed by dust as it was not thought to be hazardous once the slurry had dried.

The final report into the disaster was highly critical of West, saying that the four "root causes" of the disaster were West's inadequate engineering assessment for "combustible powders", inadequate consultation with fire safety standards, lack of appropriate review of MSDSs, and inadequate communication of dust hazards to workers." It also criticized West for not investigating a minor incident in which dust ignited during welding, by which West could have realized the imminent danger posed by the dust.

An explosion ripped through the New Cumberland A.L. Solutions titanium plant in West Virginia on December 9, 2010, fatally injuring three workers. The workers were processing titanium powder, which is highly flammable, at the time of the explosion.

Two workers were killed and two others injured as a result of a fire and explosion that occurred at the Carbide Industries facility located in Louisville, KY. The facility produces calcium carbide products.

On July 22, 2010, an explosion and fire killed two workers at the Horsehead Holding Company zinc recycling facility located in Monaca, PA. The facility recycles and purifies zinc through a high temperature distillation process and is located approximately 35 miles north of Pittsburgh.
Process Plant

Dust explosions, which originate in one piece of equipment, propagate to other equipment, and finally emerge from the equipment to produce a massive deflagration in a process building.

Dust explosions occur in process equipment when there is a particulate concentration between the Minimum Explosible Concentration (MEC) typically 30g/m³ and the Upper Explosive Concentration typically >1000g/m³ (both of which depend on the oxidant present), and then an ignition source develops Minimum Ignition Energy (MIE) typically >1mJ or Minimum Ignition Temperature (MIT) typically > 300°C or reaches the combustible cloud. The types of process equipment that routinely have combustible dust concentrations in at least a portion of the equipment volume include blenders, dryers, dust collectors, and grinders/pulverisers. Table 1 lists the number and percent of dust explosions that have been reported to occur in these and other equipment in surveys.

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<tbody>
<tr>
<td></td>
<td># Incidents</td>
<td>%</td>
<td># Incidents</td>
</tr>
<tr>
<td>Dust Collectors</td>
<td>156</td>
<td>42</td>
<td>55</td>
</tr>
<tr>
<td>Grinders/Pulverizers</td>
<td>35</td>
<td>9</td>
<td>51</td>
</tr>
<tr>
<td>Silos/Bunkers</td>
<td>27</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Conveying System*</td>
<td>32</td>
<td>9</td>
<td>33</td>
</tr>
<tr>
<td>Dryer/Oven</td>
<td>22</td>
<td>6</td>
<td>43</td>
</tr>
<tr>
<td>Mixers/Blenders</td>
<td>&gt; 12</td>
<td>&gt; 3</td>
<td>7</td>
</tr>
<tr>
<td>Other or Unknown</td>
<td>84</td>
<td>23</td>
<td>95</td>
</tr>
<tr>
<td>Total</td>
<td>372</td>
<td>100</td>
<td>303</td>
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*Conveying systems include conveyors, ducts, and elevators.
I Googled “plant explosion” when writing this paper and found an explosion in a Silicon factory.

“Hebei, China – According to Xinhua News, an explosion happened in a silicon (not to be confused with silicone) factory in Pingshan county, Hebei province. The accident killed 6 workers suffering from high temperature asphyxia; 2 died at scene and 4 died later in the hospital. The cause of the explosion remained unclear and is under investigation.

Now we do not know the facts in this incident but we do know about the potential dangers with Silicon dust. We look up the Gestis database for silicon. Although the data indicates that it can explode, its MIE and MIT are relatively high. Therefore although this factory had an explosion it may not have started with a silicon explosion.

<table>
<thead>
<tr>
<th>Detailed information on: Silicon (2485)</th>
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<tbody>
<tr>
<td>characteristic</td>
<td></td>
</tr>
<tr>
<td>Particle size &lt;71 μm [% by weight]</td>
<td>99</td>
</tr>
<tr>
<td>Particle size &lt;32 μm [% by weight]</td>
<td>98</td>
</tr>
<tr>
<td>Particle size &lt;20 μm [% by weight]</td>
<td>97</td>
</tr>
<tr>
<td>Median Value [μm]</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Lower Ex-Limit [g/m³]</td>
<td>125</td>
</tr>
<tr>
<td>Max.Ex-Overpressure [bar]</td>
<td>10,2</td>
</tr>
<tr>
<td>Kε Value [bar m/s]</td>
<td>126</td>
</tr>
<tr>
<td>Explosibility</td>
<td>St 1</td>
</tr>
<tr>
<td>Minimum Ignition Energy [mJ]</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Ignition Temperature G-G [°C]</td>
<td>n.i.b.850</td>
</tr>
<tr>
<td>Glowing Temperature [°C]</td>
<td>n.g.u.450</td>
</tr>
<tr>
<td>Combustibility BZ</td>
<td>3</td>
</tr>
</tbody>
</table>

The fineness and moisture content indicated in the first column refer to the state of the dust sample as delivered. The "delivered" state may also be identical to the tested state.

The listed combustion and explosion characteristics always apply only to the dust with the conditions described in the same column.

The data of GESTIS-DUST-EX are compiled and updated carefully. Nevertheless, any liability is excluded.

Further investigation about Silicon raised this report:

"Reactor explosion injures two"

Portland Fire crews responded to a suspected reactor explosion at the Wacker Siltronics plant in Northwest Portland on Thursday night last....
Equipment:

**Dust Collectors**

Three possible reasons for the high occurrence of dust collector explosions are:

1) They are almost omnipresent in particulate handling facilities
2) They inherently concentrate the smaller particles which are easier to ignite than the mostly larger particles in other equipment
3) Dust collectors are often structurally weaker than other process equipment and therefore more prone to explosion damage.

Data from the German compilation of dust explosions GESTIS indicate that the most frequent ignition sources have been mechanical sparks (41%), smouldering nests (11%), electrostatic discharges (10%), and mechanical heating via friction (7%).

**Incidents**

A tantalum dust collector explosion, for which an electrostatic discharge was attributed in the collector. The small, corral shaped tantalum particles have a high resistivity, and become electrostatically charged by rubbing against the collector wall. Apparently an electrostatic discharge from the charged particles triggered the explosion in the 5-m high, 1.5-m diameter bag type collector.

An explosion in a Filter used to collect a pharmaceutical product from a hammer mill/flash drying operation illustrates how frictional heating in upstream equipment can produce a smouldering nest ignition source for a dust collector explosion. The impact hammer mill had been operating for...
approximately 10 minutes when the operator heard unusual grinding sounds coming from inside the mill.

He immediately shut down the mill just as an explosion occurred within the dust collector, located inside the building on the second floor. The pressure wave caused the explosion vent (a hinged panel) of the dust collector to open, and the explosion products and unburned powder were directed outside the building via a vent duct. However, a screen had been securely fastened at the end of the duct to prevent birds from entering, and as the vent panel swung upward and outward, it struck the screen and opened no further.

It is estimated that the screen prevented the explosion vent panel from opening to no more than 50 percent of the vent area. With the vent partially obstructed, the access door to the dust collector failed under pressure and released a dust cloud into the building, which ignited. The flame front went through the vent duct and followed the dust cloud through the access door, resulting in a fireball at both locations.
Weather Protection options

Vent duct angled downward slightly with additional mesh - NOT tested, heavy metal vent duct cover!

On the first floor, a fireball was seen exiting the vicinity of the rotary valve outlet at the bottom of the dust collector, which feeds a sifter. There was no secondary explosion on the first or second floors. However, windows were blown out at both floors. The ensuing fire in the dust collector engulfed the wool filter bags (which were burned up) and the remaining powder in the collector hopper, but the fire was quickly extinguished by the automatic sprinkler system inside the dust collector.

A subsequent investigation of the incident revealed that a carbon steel bolt from the inside of the feeder (which feeds wet powder to the hammer mill/flash dryer) had become loose and fell into the hammer mill. The bolt became trapped inside the 3600 rpm mill, where it became heated to above the autoignition temperature of the powder. The hot metal ignited some of the powder in the mill, which was pneumatically conveyed into the dust collector. In the collector, a dust cloud created by the blow ring (pulse jet), was ignited by the hot powder conveyed in from the hammer mill. An inspection of the feeder revealed that six 3/8-inch carbon steel bolts were missing.

Blenders

The blending of particulates of two or more different compositions inherently involves the kind of inter-particulate friction and particulate-wall friction that causes electrostatic charge generation. If the particulate resistivity is sufficiently high, the electrostatic charge can continue to accumulate with correspondingly increasing voltage differences. Furthermore, if the blender wall is not well grounded, charge and associated high voltages can accumulate on the blender wall. If the particulate Minimum Ignition Energy (MIE) is sufficiently low, and if the eventual electrostatic discharge occurs in a location where combustible concentrations exist, the result is a dust explosion. This has occurred in a plastic manufacturing plant in a blender used to mix the primary polymer with various additives. The primary polymer had a resistivity of 2 x 10^16 ohm-cm, a MIE of about 7 mJ, and a MEC of 20 g/m3. The latter two values are lower than those of most organic powders. However, even with significantly larger MEC values, concentrations above the MEC should be anticipated toward the top of the blender during normal operation and throughout most of the blender volume during batch loading and unloading.

- An aluminium dust explosion, in a screw blender/mixer in 1973. A rubber lined steel tube surrounded the centre screw of the mixer. The explosion was probably ignited by a propagating brush discharge due to electrostatic charge generation on the rubber lining within the grounded steel tube. The aluminium flakes had a specific surface area of 7.5 m2/g, and Minimum Ignition Energy of only 1 mJ. Even though there was an attempt to nitrogen-inert the mixer, the volume within the steel tube was not inerted, and oxygen concentrations were also sufficiently high to support combustion. Thus, the explosion was initiated at the 3.3 m long enclosed screw, and then propagated as a flame jet into the 5.2 m3 mixer.
Dryer Explosion Scenarios

Overheating of particulate by a hot surface is by far the most likely ignition source in dryers. In some cases, the particulate accumulates on the hot surface and forms a smoldering nest, while in other cases the hot surface temperature is sufficiently high to directly ignite the suspended dust cloud. Although particulates near the dryer inlet may be too wet to be readily ignited, particulates exiting the dryer are both dry and often suspended in concentrations above the MEC.

- A fire and explosion in a batch rotating vacuum dryer used for drying a pharmaceutical powder. An operator had tested dryer samples on a number of occasions without any problems. After the last sampling, he closed the manhole cover, put the dryer under vacuum, and started rotation of the dryer. A few minutes later an explosion and flash fire occurred, which self-extinguished. No one was injured. Investigations revealed that after the last sampling, the dryer manhole cover had not been securely fastened. This allowed the vacuum within the dryer to draw air into the rotating dryer and create a flammable atmosphere. The ignition source was probably an electrostatic discharge (the Teflon coating on the internal lining of the dryer could have built up a charge). No nitrogen inerting had been used. After the incident, the following two precautions were instituted to prevent similar accidents from occurring in the future: 1) Nitrogen purging is carried out before charging or sampling of the dryer. 2) If the absolute pressure rises to about 4 psi, the rotation is stopped, an alarm sounds, and a nitrogen purge starts automatically.
Grinder/Pulverizer Scenarios

Grinders, pulverisers, and other size reduction equipment inherently dissipate large energy inputs required to break up the particles. This energy dissipation inevitably causes heating of the particles and metal surfaces. Particles accumulating in the grinder can easily overheat, smoulder, and ignite a dust explosion during grinder loading or unloading.

- Frictional heating of the housing of a grinder being used to produce 50 μm (300-mesh) silicon powder caused one explosion. Tramp metal was the apparent ignition source in another explosion that occurred in a hammer mill being used for an intermediate stage powder with a low MIE and Autoignition Temperature (AIT).

- The figure above shows evidence of the frictional or impact heating of hammers in a hammer mill used to produce powdered sugar. The heating of sugar and metal in that vicinity of the mill ignited a sugar dust explosion that burned the hammer mill operator who was responding to the sound of severe vibration due to tramp metal or a broken hammer in the mill.

Other Process Equipment to be aware of are: bag openers, extruders, screw conveyors, feeders and rotary valves, sampling systems, classifiers, silos and hoppers, size enlargement equipment, solids charging systems, and weighing systems. Also, transport equipment, rail cars and hopper truck loading and unloading stations.

Protection Options

Venting

A big explosion at Evonik Industries, in the Ruhr area of Germany last March 2012:

“A huge explosion rocked a chemical industrial park in Marl, western Germany, leaving one or two workers injured and three missing…."

The Ruhr Area is home to one of Europe’s largest and most densely populated integrated production sites, the Marl Chemical Park. On the site’s 6.5 square kilometres (2.5 square miles), some thirty different companies manufacture over four thousand different products. Seventy percent of the approximately 10,000 employees in the chemical park work for the Industrial Chemicals, Coatings & Additives, Consumer Specialties, Health & Nutrition, and Performance Polymers Business Units of Evonik Industries.

The publicity from such events, even though the consequences were deemed to be harmless, still gives the venting of Chemical and Pharmaceutical combustion products bad publicity.
Explosion Protection For The Chemical and Pharmaceutical Industry

Venting options:

- Rectangular
- Round
- Flameless Venting

ATEX regulations are supported by European Norms. Still in draft, form prEN 14491 states:

Explosion venting is a protective measure for enclosures by which unacceptably high internal explosion overpressures are prevented. Weak areas in the walls of the enclosure open at an early stage of the explosion, burning and/or un-burnt material and combustion products are released and the overpressure inside the enclosure is reduced. Information required for calculation of the vent area includes the explosion resistance of the enclosure, the explosion characteristics of the dust, the shape and size of the enclosure, the static activation overpressure and other characteristics of the vent closure, and the condition of the dust cloud inside the enclosure.

Explosion venting shall not be performed if unacceptable amounts of materials that are classified as poisonous, corrosive, irritant, carcinogenic, teratogenic or mutagenic can be released. Either the dust or the combustion products can present a hazard to the immediate environment. If there is no alternative to explosion venting an endangered area shall be specified.

NOTE 1 There is no direct guidance for estimating an endangered area for toxic or other harmful emissions, but the safe discharge area for external flames will be at least 8 to 10 times greater than the protected volume, gives some indication of the area required in direct line from the vent. Harmful emissions will be dispersed by air movements, however, and an extensive area in lateral directions can be required.
Venting although traditionally the preferred cheaper option in most industries is not the popular choice in the Chemical and pharmaceutical industry.

Even though calculated for individual autonomous vessels, the venting will not be correct if you connect both of these vessels into an interconnected system without explosion isolation.

**Interconnected vessels:**

Vent areas determined by the standard Equations are too small if a dust explosion propagates from one vessel into another through a pipe. Increased turbulence, pressure piling and broad flame jet ignition may result in increased explosion violence, especially with duct length > 6 m. This results in an elevated maximum reduced explosion overpressure. Measures for explosion isolation in the connecting pipe are therefore needed in most situations. The same applies for other protection systems like suppression and containment.

**Definition under ATEX:**

Explosion isolation is a technique which prevents an explosion pressure wave and a flame or only a flame from propagating via connecting pipes or ducts into other parts of apparatus or plant areas. Complete isolation is understood in this sense, that on operation the isolation device(s) or system(s) are able to prevent the propagation of the flame as well as pressure effects, while in the partial isolation systems, only the flame propagation is isolated. This distinction is important for practical application, because the necessity does not exist in all cases, to achieve a complete isolation of flame and pressure, but in some cases it is sufficient to achieve only flame isolation.
Explosion protection products are normally broken into 2 types:

- **Passive isolation type**

Passive isolation systems do not require the addition of detection and control and indicating equipment to function.

Explosion Isolation protection

<table>
<thead>
<tr>
<th>Flame Arrester</th>
<th>Barrier Valve</th>
<th>Flame Diverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary Airlock</td>
<td>Product plug</td>
<td>Choked screw</td>
</tr>
</tbody>
</table>

Process Equipment like Rotary Airlocks can also be certified as Explosion Isolation if their quench gap is maintained but other pieces of equipment although not certified as Explosion Isolation may through smart engineering, by default perform as passive barriers under specific conditions.

If you keep the correct density of **product plug** above the rotary valve then there can be no flame break through.

<table>
<thead>
<tr>
<th>Bulk density BD ≥ 1 kg/ℓ</th>
<th>H = D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density BD &lt; 1 kg/ℓ</td>
<td>H = D / BD</td>
</tr>
</tbody>
</table>

- H = the height of the product pile in m
- D = the outlet diameter in m
- BD = the bulk density of the product in kg/m³

A round screw conveyor can be kept plugged by inclining the angle of installation or if it’s a trough screw you can install a baffle plate to prevent flame break through above the screw.
Active isolation type

Active isolation systems require detection and control and indicating equipment to function. Detection systems are systems usually based on optical or pressure sensors.

Slamshut valve system

The explosion is detected by pressure rise and if the control panel is armed it will fire the Slamshut valve or the powder extinguishers into the pipe preventing the mitigation of the explosion flame front. The Slamshut valve isolates flame, pressure and spark, but the Chemical powder barrier only isolates flame and spark, it cannot isolate pressure.
Containment:

Explosion resistant:

Property of vessels, and products designed to be either explosion-pressure-resistant or explosion-pressure-shock resistant. As indicated earlier due to the type of products used in the chemical and pharmaceutical industry explosion protection by containments is very common.

There are many ideas about pressure resistance. Generally most process equipment like concrete silos and special buildings only have a reduced pressure resistance of 0.2barg so they are normally vented. Most filters, elevators and conveyors whether they are square or round in construction have a typical pressure resistance of 0.3 to 0.5barg. Special equipment like mills and PSR silos are designed specifically from 1 to 3 barg depending on their application. Then there is a bigger step of the traditional containment range; typically 6 to 10 barg for Explosion-pressure-resistant and Explosion-pressure-shock-resistant

Components of the system can be either explosion-pressure-resistant or explosion-pressure shock-resistant:

Explosion-pressure-resistant: property of vessels, and products designed to withstand the expected explosion pressure without becoming permanently deformed

Explosion-pressure-shock-resistant: property of vessels, and products designed to withstand the expected explosion pressure without rupturing, but allowing permanent deformation

Explosion-pressure-resistant products are considered to be explosion-pressure-shock resistant for a 50 % higher gauge pressure.
NOTE 1 If the inside of the product is divided into sections (e.g. tanks connected by a pipeline or containing baffles or surge plates), during an explosion in one of the sections the pressure in the other sections of the product will be increased. As a result, an explosion in these sections will occur at an elevated initial pressure. Further pressure peaks occur which are higher than the value expected under atmospheric conditions. In the case of such arrangements, appropriate measures should be taken, either explosion de-coupling techniques or explosion resistant design derived from representative explosion trials.

The Rule about interconnected vessels still applies, plus the explosion isolation system must be compatible with a containment design.

**Inerting:**

Inerting is a measure to prevent explosions. By feeding inert gas into a system which is to be protected against an explosion, the oxygen content is reduced below a certain concentration until no explosion can occur. The addition of sufficient inert gas to make any mixture non-flammable when mixed with air (absolute inerting) is only required in rare occasions.

Inerting may also be used to influence the ignition and explosion characteristics of an explosive atmosphere. The guidance given on inerting is also applicable to prevent an explosion in case of a fire. Inerting which is sufficient to prevent an explosion is not a protective measure to prevent fires, self-ignition, exothermic reactions or a deflagration of dust layers and deposits.
Important Terms:

Limiting Oxygen Concentration (LOC):

Experimentally determined oxygen concentration which will not allow an explosion in a fuel/air/inert gas mixture

NOTE It is a characteristic which is specific for a given fuel/inert gas combination. The determination should be in accordance with pr EN 14756 for gases and vapours and EN 14034-4 for dusts respectively.

Maximum Allowable Oxygen Concentration (MAOC):

Concentration which should not be exceeded in the system which has to be protected, even with anticipated upsets or operating errors

NOTE It is set using a safety margin below the limiting oxygen concentration. This safety margin should consider variations in process conditions which might deviate from the experimental conditions.

Inert gases:

Inerting may be achieved by using a non-flammable gas which will neither react with a given fuel nor with oxygen. This has to be considered carefully. For example light metal dusts will react with steam or carbon dioxide, and in some cases even with nitrogen.

The most commonly used inert gases are:

a) Nitrogen: may either be received from a commercial supplier with an appropriate purity or may be generated from ambient air at technical quality by on-site facilities.

b) Carbon dioxide: may be received from a commercial supplier at an appropriate purity.

c) Steam: with pressures over 3 barg might be used as an inert gas, as its oxygen content is usually negligible. Condensation has to be taken into account and might lead to a pressure drop which supports air ingress into the plant or create a vacuum. When using steam for fire fighting in dust plants the condensation can be an advantage as the dust becomes wet, preventing dust dispersion and extinguishing smoulders into the plant or create a vacuum. However, there can be a risk of increased mass, chemical reaction due to the water, or microbial activity.

d) Flue gases: from combustion can be used if the oxygen concentration can be controlled sufficiently. Fluctuations in oxygen concentration have to be taken into account, and appropriate measures to minimise fluctuations have to be taken (e.g. gas buffer storage). Flue gases shall be assumed to be similar to nitrogen when defining the limiting oxygen concentration.

e) Noble gases: Argon or other noble gas may be received from a commercial supplier at an appropriate purity. Their use will be limited due to economic reasons to applications where no other inert gas can be identified. Helium may be advantageous as an inerting medium where hydrogen is used, as the molecular size of helium approaches that of the hydrogen, so leaks may be more readily detected.
Methods of Inerting

a) **Pressure swing inerting:** This method pressurizes the system with inert gas and vents down to atmospheric pressure. The cycle is repeated until the required oxygen concentration is reached. It is only suitable for a system which can be pressurised.

b) **Vacuum swing inerting:** This is similar to pressure swing inerting, but evacuates the system and releases the vacuum with inert gas. This method is suitable where a system can withstand vacuum but not pressure, such as glass vessels.

c) **Flow through inerting:** This method feeds inert gas at one point and simultaneously vents gas at another point remote from the feed point. This method is suitable for a system that cannot withstand either internal or external pressure. Also, in a long thin vessel or pipeline, pressure or vacuum swing inerting may be ineffective due to poor mixing if the gas is fed and removed from the same end, so the flow through method would be applicable.

d) **Displacement inerting:** This method relies on a large density difference between the inert gas and the air being removed. It is usually only suitable for specialised situations where there is a large density difference and mixing is likely to be poor.
Explosion Protection for the Chemical and Pharmaceutical Industry

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