Loss Prevention Standards

SPRAY DRYING

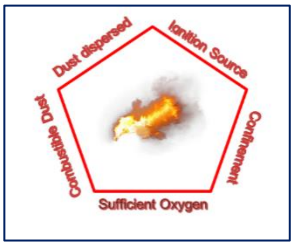
Introduction

The potential for fire and/or explosion when processing powders and dusty materials has been understood for many years. Spray drying processes have historically been the cause of numerous fire/explosion events. Many have caused personal injuries to plant operators and have led to extensive damage to processing plant and surrounding structures. Such events are readily preventable through careful design and operation of the process and plant. This Loss Prevention Standard examines how such events can occur and measures that can be taken to reduce risks.

Understanding the Hazard

Combustible Dusts and Powders

It's important to stress that not all powdered materials are combustible, but many are, and this includes some materials that you may not normally associate as a fire hazard, e.g. certain powdered metals.



Where a powdered material is combustible it can catch fire in the presence of an ignition source and sufficient oxygen, following the rules of the 'Fire Triangle'. Ignition sources can be externally introduced or can in some cases result from self-heating of the substance caused by biochemical reactions within the powder. This is a significant hazard for the dairy industry, for example, caused by the self-heating of milk powders.

For a dusty material to explode, certain additional conditions must be met:

The dust itself has to be combustible, with a certain particle size and distribution and a dust cloud present that is dispersed (typically in air) in such a way that there is sufficient oxygen present to support combustion. The dust cloud must also be confined in some way that will support the propagation of an explosion event. Such an event is a combination of a fast-moving pressure wave and turbulent combustion. Ignition sources can again be externally introduced but can also be caused by the self-heating and combustion of layers of powder that have built-up within the confinement area.

Spray dryers typically spray atomised liquids into a counter-current stream of heated air to create finely dispersed particles of powered product and by the very nature of the way they operate, can provide conditions in which fires and explosions can occur.

To manage the risks, it is first important to fully understand the properties of the powdered materials to then fully comprehend the actual conditions required to cause a fire or explosion. Tests carried out by an accredited testing laboratory can determine the following properties of the materials:

Layer Ignition Temperature (LIT) test determines the lowest temperature at which a layer of dust of specific thickness, usually 5mm, ignites on a heated surface.

Minimum Ignition Energy (MIE) of a combustible substance is the lowest amount energy that is just sufficient to ignite the most sensitive fuel-air mixture at atmospheric pressure and room temperature.

Minimum Ignition Temperature (MIT) is the lowest temperature where a dust has explosible properties in air. It is very important to obtain data at the temperature that the powder will be exposed to in the plant.

Minimum Explosive Concentration (MEC) is the minimum concentration of a combustible dust suspended in air that will support a deflagration, such as explosion or flash fire.

Critical Thicknesses for Self-Ignition

It is important to assess the potential for self-heating to occur. Self-heating typically occurs within layers of powder in which some form of ongoing biochemical processes/degradation occurs. Heat generated by these processes cannot dissipate sufficiently quickly in thicker layers of powder and there will be a critical layer thickness which if exceeded, the powder layer will heat up and eventually exceed the layer ignition temperature and catch fire. The layer thickness at which self-heating takes place will depend on the temperature in which the powder is present. The hotter the temperature (e.g. inside the spray dryer), the harder it is for the layer of powder to lose heat to the surroundings. Moisture and fat content of the powder will also affect the critical layer thickness, meaning that data should be gathered across a range of products manufactured. These principals are illustrated in the test data for milk products below:

Product	Minimum thickness of layer for ignition at 200ºC (mm)	Minimum thickness of layer for ignition at 100ºC (mm)
Skimmed Milk Products	9-17	120-170
Whole Milk Products	10-17	100-170
Buttermilk Products	8-9	100-130
Whey	13	320

Source: Beever (1985)

Not all powders will exhibit these properties, but understanding the properties of the powdered material will help assess the potential for fire/explosion within the spray dryer.

If an explosion risk within the spray dryer is possible, further tests are warranted to determine the characteristics of the explosion so that the spray dryer and associated plant can be designed to minimise the impacts of an explosion, should it occur.

Explosion Severity - Kst & Pmax

Since it is the pressure wave released during the explosion that causes the majority of structural damage, the severity of a dust explosion is determined by both the maximum pressure obtained and the speed at which the pressure wave travels. Accredited laboratories can measure this within specialist test equipment and dusts and powders can be classified based on the severity of the dust explosion. The St or Kst value of the dust is used to describe the severity of the explosion according to the following scale:

Dust Explosion Class	St or Kst Value (bar.m.s^{-1})	Characteristics
0	0	Does not explode
1	<200	Weak to moderate explosion
2	200-300	Strong explosion
3	>300	Very strong explosion

Understanding the maximum pressure obtained within the explosion Pmax will also help understand whether the process plant that could be exposed to the pressure (spray dryer, fluid bed, ducts, etc.), will be able to withstand the maximum pressure or will fail catastrophically under the increase in pressure.

Secondary Dust Explosions

An important characteristic of dust explosions is that the pressure released from a small initial or primary explosion can disturb accumulations of dust in the building, particularly from upper surfaces. Dust and fugitive emissions from the process can collect on surfaces such as rafters, roofs, suspended ceilings, ducts, crevices, dust collectors and other equipment. Disturbing these accumulations can raise a second and potentially much larger dust cloud and the flames from the original explosion can act as the ignition source for this larger cloud; or there maybe another ignition source in the adjacent area. If this second and much larger dust cloud does ignite, a more violent 'secondary dust explosion' results causing significant damage to the building, often putting workers lives in danger.

Sources of Ignition

There are a number of potential ignition sources within spray drying processes. Understanding these will help you design and manage the plant to reduce the risk of an ignition source entering the spray chamber or igniting a secondary dust cloud.

Within the spray drying equipment:

Self-Heating – One of the most common causes of explosion is the self-heating of layers of powder accumulating within the spray drier. Often this has resulted from infrequent or inadequate wash down and cleaning of surfaces within the spray dryer. Layers of powder build-up until the critical layer thickness is reached and the powder begins to self-heat. Early warning of this risk can sometimes be noticed by discolouration and charring of layers of powder within the spray dryer.

Mechanical Friction – Centrifugal disc atomisers rotate at very high speed and failing parts/bearings within them can cause mechanical friction that builds-up sufficient heat to be an ignition source. A hazard can also arise from overheating gearboxes/bearings in mechanical transfer equipment within fluid bed dryers and other process equipment.

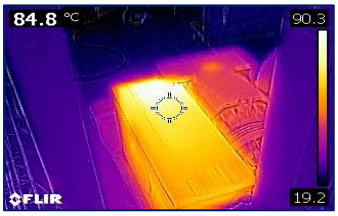
Impact Sparks – Should components fail catastrophically and fall within the spray drying chamber, impact sparks can be an ignition source for an explosion. Component failures most commonly associated with this hazard include centrifugal disc atomisers and extract fans.

Electrostatic Discharge – Electrostatic charge can build-up and accumulate on powder within the spray dryer. Static discharges within the drier will be common and normally they have insufficient energy to ignite the dust cloud. However, they have been implicated in a number of explosion events and it is important that the design of the plant seeks to dissipate static charge from the powder as quickly as possible.

Charred Particles in Inlet Air – The introduction of foreign bodies into the heated airstream can risk charred/charring particles being blown into the spray chamber which can provide the ignition source for an explosion.

Ignition hazards in close proximity to the spray drying equipment can lead to fires involving fugitive emissions of dust and/or be the ignition source for a secondary dust explosion. Examples include:

Nearby Hot Surfaces – Dust can accumulate on nearby hot surfaces and if sufficiently hot, a thick layer of dust can begin to self-heat. Ancillary plant such as pumps, motors, vacuum pumps, heat sealers, hot air inlets and packing machinery can all present a hot surface, even under normal operating conditions. These risks should be assessed and can be easily verified using a thermal imaging camera.

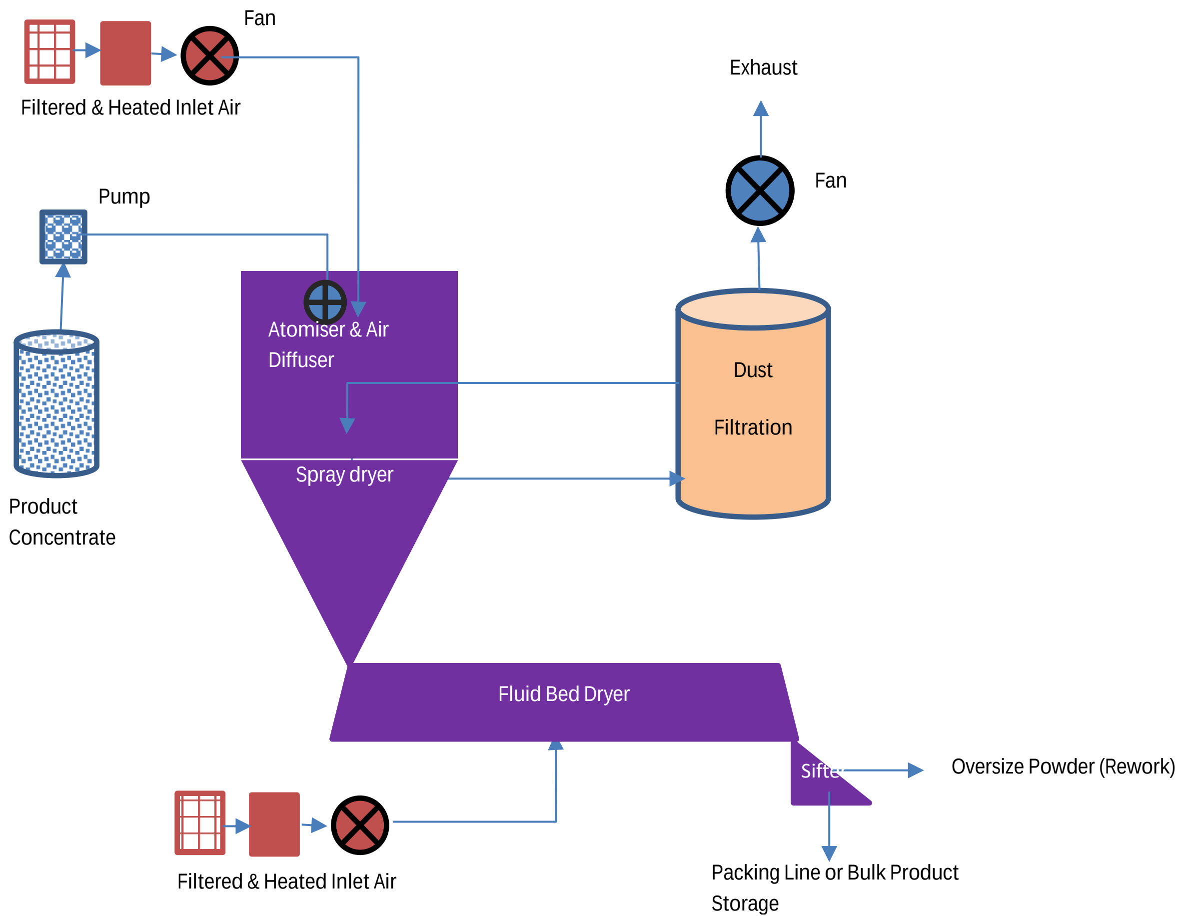


Electrical Sparks - Electrical sparks within motors, switches and contact breakers may be a source of ignition, with sparks containing energy substantially in excess of that required to ignite dusts. Where such equipment is located within areas where explosive concentrations of dusts can arise, this equipment should be suitably protected and marked as suitable for use in these areas. This also applies to portable appliances such as vacuum cleaners which may be used in housekeeping and cleaning activities.

Hot Works – Poorly controlled hot work activities such as cutting, welding and grinding can ignite any combustible dust in the area. These are not always given consideration when such work is planned or when permits to work are issued. Attention should be paid to conduction of heat away from the work source and the potential for ignition elsewhere, or the generation of sparks.

Design of Plant

Not all spray drying plant are the same but typically each plant has:



Air Heating

All air introduced to the spray dryer or fluid bed dryer should be filtered to prevent ingress of particles that can become heated and charred prior to introduction into the process. This should also help prevent product contamination.

Direct heating of inlet air by flame introduces an unnecessary fire hazard and should be avoided if possible. If this method is already employed on your plant, flame/spark arrestors must be installed on the inlet air supply.

Indirectly heated air where filtered air is passed over a heat exchanger supplied by steam or thermal oil is the preferred approach. Spark arrestors on the inlet air supplies in these systems are not always necessary but can provide additional reassurance in case air filters become breached or short circuited.

It is good practice to place air heating plant in a separate fire compartment to the spray dryer itself with at least 1-hour fire separation between them.

Note: There is an associated fire risk from any thermal oil system. This needs to be carefully risk assessed and appropriately managed and protected. There are numerous fires involving this particular hazard.

Atomisers

There are traditionally two different types of atomiser used in spray dryers; centrifugal disc and pressurised jet atomisers. Selection of the atomiser is often determined by the product specification. Both types can present an ignition hazard if incorrectly specified, positioned or maintained.

Centrifugal disc atomisers spin at very high speeds and the stresses placed on the rotating parts and bearings can lead to mechanical friction and failure. As such, continuous vibration monitoring of the disc can provide early warning to plant operators that a problem with the disc is manifesting. This should provide an alarm on the plant control panel when dangerous levels of vibration are detected and procedures for safe shut down of the process should include trained staff responding to the alarm.

Pressurised jet atomisers traditionally have no moving parts, but problems can arise if they are incorrectly selected or positioned within the dryer which can lead to accumulation of powder on the atomiser itself or on the upper surfaces of the dryer. Given the atomiser is positioned within the hottest part of the spray chamber, critical layer thicknesses are likely to be at their lowest value and for some powders, self-heating and ignition on the atomiser itself can occur. Similar problems can arise when the spray trajectories impinge directly on the hottest surfaces. When used the atomisers should be carefully selected and positioned to minimise these risks. It is important that employees are suitably educated and trained with a full understanding of this hazard and the consequence of incorrect siting/adjustment.

Dust Extraction Equipment

Cyclones and/or bag filters are typically used to filter out air extracts from the spray dryer with fines returned to the spray dryer itself. Filtration units should be fitted with explosion relief and preferably be sited external to the process area. If sited internally it is advisable to site them within a separate fire compartment and/or incorporate flame arresting devices into the explosion relief mechanism. This will reduce risks of a secondary dust explosion. The provision of automatic fire detection within these areas is also recommended.

Fans

Fans on both inlet air systems and extraction systems should feature vibration monitoring equipment that will alarm to the control panel. This will give early warning of a catastrophic failure of the fan which could result in impact sparks.

Good design of the fan housing should permit safe access to the impeller for inspection, maintenance and cleaning.

Fines Return

The return of product fines from the dust extraction equipment into the spray dryer should be preferably designed with a downward trajectory within the spray dryer itself. This will minimise risks of blockage and accumulation at the discharge point which can occur if an upwards trajectory is used because of the downward air flow and pressure within the dryer.

Measures to Prevent Build-up of Powder within the Spray Dryer

This is important and the spray dryer should be designed with measures to prevent the build-up of powder deposits within the spray chamber as well as measures to permit the removal of any powder accumulation within.

The shape of the drying chamber is typically conical with the angle of the cone designed to reduce powder build-up. Whilst in theory this should work, powder can often accumulate on vertical surfaces. The picture opposite shows accumulation of powder on an inspection door on a spray dryer. This powder has also discoloured in places suggesting is has begun to overheat.

To reduce risks of accumulation, spray dryers can be fitted with pneumatic air sweep probes, mechanical powder scrapers, vibrating devices or knocking hammers on the chamber walls. Even if fitted there is still a need for regular inspection of the inside of the spray chamber to determine if washdown and cleaning of the spray chamber is required.

This visual check can be made remotely if suitable internal CCTV is fitted to the spray chamber, but often requires a visual check by a trained operator. The provision of automatic remotely activated washdown equipment within the spray dryer itself can facilitate easy cleaning when required, but the design of this equipment requires careful consideration and it should not provide another surface within the dryer itself upon which layers of powder can accumulate. Systems for cleaning should ensure that all internal surfaces can be adequately cleaned. There should also be a means of verifying the efficacy of cleaning via either remote monitoring or by allowing visual inspection via access panels/hatches.

Temperature Control

Continuous monitoring of temperatures within the spray dryer, inlet air and exhaust air is essential. Temperatures should at all times be kept at a safe margin below the layer ignition temperature of the powder. Excessive temperatures can be an indicator of fire and process operators should be alerted to any excessive temperature detected.

Increases of temperature within the spray dryer itself can be caused if there is interruption/impairment to the product feed as the cooling effect on the heated inlet air is removed. As such a temperature control system should feature that will alarm and shut down the product feed, inlet air and sifter whenever excessively high temperatures are detected. A pre-shut down alarm set at a lower temperature can allow operators to investigate process conditions prior to automatic plant shut down as described.

Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) Assessment and Electrical Equipment in Hazardous Areas

Given the risk of explosion, in the UK and many territories, it is a legal requirement to carry out a risk assessment. In the UK this is as described within the DSEAR 2002. This assessment should identify any hazardous areas of the plant where explosive atmospheres may be present, classifying them as either Zone 20, 21 or 22 depending on the frequency upon which an explosive atmosphere may be present. The assessment should be completed by a competent person and any hazardous areas should be clearly identified and signed.

Electrical equipment installed in these areas should be suitably designed and marked as being suitable for use in the appropriate zoned area. Consideration should be given to pumps, motors, control panels, lighting but also items such as hand dryers , insect killers, shrink wrap and heat sealers, which can often be found in food, chemical and pharmaceutical manufacturing environments. Where old equipment includes items manufactured prior to 2002, this may not be marked as being suitable for use in a hazardous area. In such cases, careful evaluation of its suitability should be undertaken and the priority has to be to ensure that this equipment cannot present a source of ignition if exposed to a combustible dust cloud.

Where the dusty product has a low layer ignition temperature, the maximum possible temperature of any external surface of plant/equipment is also a consideration. If dust can accumulate on these surfaces it is prudent to select and install equipment whose external surfaces cannot reach the product's layer ignition temperature. The 'T' Class of equipment which is marked on some equipment can help you determine if the equipment is suitable, see below.

T Class	Maximum Surface Temperature (ºC)
T1	450
T2	300
T3	200
T4	135
T5	100
T6	85

One further consideration is that the equipment should be designed so that dust cannot accumulate within it in such a way that it will cause it to fail. Also, the equipment should be suitable for the method of cleaning/washdown that will be employed. Equipment with an IP rating of IP66 or better will be 'dust tight' and protected against powerful jets of water.

Earthing, Continuity and Lightning Protection

To prevent/minimise the accumulation of electrostatic charge on items of plant and/or the powdered product, all items of plant and all components must be connected to each other and to earth by a low resistance electrical path which permits the dissipation of electrostatic charge. It's important that these systems are inspected and checked regularly as part of planned preventative maintenance programmes. Continuity of earth throughout the entire installation should be confirmed during these checks.

The building in which the spray dryer is installed should feature a lightning protection system which should be installed in accordance with BS EN 62305 and maintained in accordance with BS 7430.

Flexible Hoses

If flexible hoses are used within the plant, it is important to specify conductive hose materials so that earth continuity can be maintained. The use of ATEX rated hoses can provide assurance of the electrical conductivity of the hose materials. Another important feature to consider is the pressure rating of the hoses and it should be ensured that any hose can withstand pressures above those set for pressure relief mechanisms on the plant. This will ensure that the hose will not burst prior to the pressure relief mechanism activating.

Process Siting and Isolation

It is good practice to locate spray drying operations within its own discreet processing area separated from other parts of the building by a 2-hour fire wall or a separation distance of 25m. The building in which the spray dryer is sited should be of fire resisting or non-combustible construction. Ideally the building will not include glazing panels.

An alternative approach is to construct the building to withstand the impacts of an explosion. Access to the process areas should be controlled and restricted to essential personnel only.

Automatic Fire Detection Systems

Early warning of a fire in the plant can provide valuable time for process operators to take appropriate action, be it to evacuate or to initiate a safe plant shut down. As such, the building area should be protected by a suitable automatic fire detection system that meets BS 5839 part 1 – P1 standard. This will almost certainly involve the provision of automatic fire detection around the process plant. The potentially dusty environment makes the use of conventional smoke detectors unsuitable for this purpose and combined heat/carbon monoxide detections or high sensitivity aspirating smoke detection devices can be suitable for such environments.

Developments in systems for the detection of carbon monoxide at very low levels now permit the installation of automatic fire detection systems for the spray dryer itself. The differential analysis of carbon monoxide in the air inlet streams and exhaust air can determine whether carbon monoxide is being generated within the spray dryer, which is likely to be caused by overheating, charring, smouldering or fire. This is specialist equipment that can detect very low concentrations of carbon monoxide but has been shown to be effective in providing early warning of an event that could lead to a fire and/or explosion within the dryer. As such the installation of these systems is highly recommended.

A less effective alternative to providing carbon monoxide detection as described above is to provide spark detection within the plant, including inlet and extract ducts. If a spark is detected a safe shut down of the plant should be initiated. However, the presence of a spark can be an indicator that something is already alight within the plant.

Fire Fighting Systems

The spray dryer, extract ducts, fluid bed dryer, cyclones and bag filters (if fitted) should be protected by a fixed fire protection system. Often these are water deluge systems and any system installed should be designed, installed and commissioned by third party approved contractors who have demonstrated their competence and work in accordance with appropriate certification/listing bodies, e.g. LPS 1204: Requirements for contractors engaged in the design, installation and commissioning of fixed fire systems. Systems should feature both manual and automatic activation. In addition, it is highly recommended that the building areas are protected by a sprinkler system installed to BS EN 12845 or NFPA 13.

Explosion Relief/Containment

Should an explosion occur, the pressure within the spray dryer and associated plant will suddenly increase dramatically and a fireball will develop within the plant itself. It is important to either contain these hazards or safely relieve them to an appropriate location. With knowledge of the Kst & P_{max} value for the dust explosion, an appropriate approach can be determined.

One option is to use pressure rated or pressure shock resistant equipment. However, much more common is the use of explosion relief systems strategically located on the plant that direct both the pressure wave and fireball to a safe location before structural damage to the plant is caused.

A competent engineer should determine the number of explosion relief vents required and their appropriate location, but it is typical for them to be sited on the:

- Spray dryer chamber
- Fluid bed dryer
- Dust filtration equipment (cyclones and bag filters)

The type of explosion relief used, it's sizing and the pressure at which it activates should be determined based on calculations using a recognised method and these calculations cannot normally be completed without knowledge of the Kst and P_{max} value.

The explosion relief mechanism should relieve the pressure wave and fireball to a safe location that will not endanger life or cause property damage. The best options are to relieve the explosion to an external location (e.g. roof) via the shortest and most direct route possible. This is not always possible and the use of a long, convoluted ducted route to direct the explosion to outside can create a further hazard and are more prone to failing in an explosion event. Runs of ducting should be straight and as short as possible. Circular ducts generally have greater strength and are commonly used for this purpose. Explosion relief hatches should be designed so they do not become projectiles and are retained in some way. The direction in which the explosion relief vents is also important. The relieving pressure wave/fireball should not be directed onto:

- Means of escape or areas where pedestrians congregate
- Glazing
- Combustible cored composite insulation panels
- Asbestos containing materials
- Any other critical item of plant
- Air intakes for ventilation systems

While this should be avoided and is not recommended, where explosion relief vents have to relieve internally, they should be fitted with flame arrestors (see picture opposite).

If retrofitted, the impact of these flame arrestors of the ability to relieve the maximum explosion pressure should be re-evaluated. In addition, the impact of any internally relieving pressure wave should be evaluated.

It is essential that any explosion relief system is included within systems for planned preventative maintenance. This should include regular inspections and checks that the relief path has not become obstructed and also that any mechanisms will operate as intended.

Note: If explosion relief vents through a roof then consideration should be given to the potential for snow or ice accumulation in colder periods and water building-up in heavy rain. This will have an impact on the effectiveness of the relief device.

Explosion Suppression and Avoiding Explosion Propagation

Installation of explosion suppression systems, within the spray dryer and ductwork should be given serious consideration. Proprietary systems using dry chemical or high-pressure hot water have been developed for such purposes. In large spray drying chambers, such systems may be difficult to effectively deploy, and protection may have to be limited to ductwork only. This can still be effective in preventing propagation of the explosion through the plant, reducing risks of damage.

Any system installed should be designed, installed and commissioned by third party approved contractors who have demonstrated their competence and work in accordance with LPS 1204: Requirements for contractors engaged in the design, installation and commissioning of fixed fire systems.

If the spray drying plant is physically connected to other downstream processing or storage areas via pneumatic conveying through pipework, the use of rotary valves within these piped connections can arrest the travel of any flame through the pipe. This reduces the risks of fire spreading to the connected process/storage areas.

Management Programmes

Essential for the ongoing safety of the spray drying plant are the operational procedures that are developed to support production activities. These must include:

Safe start-up and shut down procedures – Safe start-up procedures should ensure stable drying conditions have been achieved within the dryer before introducing the product feed. Similarly, during shut down, the plant should be run on water for a period long enough for airborne powder residues to be substantially removed from the dryer. This should prevent powder flowing back into the air disperser and heating section as a result of thermally buoyant air currents. This may not be possible for an emergency shut down of the plant and this hazard should be recognised prior to the plant being re-started.

The correct shut down sequence for the various components in the plant can also be important to reduce risk. The most effective shut down sequence should be assessed prior to initial operation. Where possible the correct sequence should be automated within process control systems.

Maintenance programmes - All process plant and ancillary equipment must be subject to programmes of planned preventative maintenance in accordance with original equipment manufacturers (OEM) recommendations. Regular visual inspection of the condition of equipment and checks for hot surfaces using a thermal imaging camera can also confirm that this equipment remains suitably protected and will not create a hazard.

Cleaning and housekeeping – Frequent cleaning of the building is essential to reduce risks of a secondary dust explosion. The build-up of dusts on horizontal surfaces within the building should not be tolerated. If dust is accumulating this is likely the result of a leak from the process equipment, and this should be investigated and further leakage prevented.

Cleaning schedules should cover the entire building area and include high level areas on a frequent basis. Regular housekeeping inspections/audits are strongly encouraged.

Attention should also be paid to ensuring internal cleaning/washing down of the equipment is effective to remove all deposits and build-up. This will help prevent charring and hot spots.

Hot works – Hot works within process areas should be avoided where possible and if required must be strictly controlled using an appropriate Hot Works Permit (see Aviva LPS on Hot Works). In dusty environments it is important to ensure the work areas and the surrounding areas are cleaned prior to the hot work commencing.

Dealing with blockages – It is important that process conditions are continually monitored by process staff. Blockages can and do occur and if the powder begins to accumulate within the dryer, this can increase risks of fire/explosion. Procedures should be developed to deal with any accumulations that occur, typically deploying the measures described earlier in this document. However, if blockage does occur the dryer should be safely shut down to permit clearance. Procedures for clearing the blockage following shut down should take account of the potential risks from the hot powder and should not unnecessarily disturb or blow the powder onto hot surfaces within and also outside of the dryer/plant.

Operator training programmes – Fundamental to an adequate programme of risk control for spray dryers is the education and training of process operators. All operators should have an understanding of the hazards of spray drying and why the risk control measures are needed. This 'Hazard Education' should be a formal and assessed part of the operator training. As a minimum it is recommended that this training programme includes:

- Hazards of spray drying/combustible dusts
- Safe start-up/shut down procedures
- Plant operation procedures
- Plant fire fighting systems and explosion protection/mitigation
- Plant alarms and alarm management procedures
- Plant emergency procedures
- Plant cleaning procedures
- Essential inspections, maintenance and checks
- Hazard/near-miss reporting
- Management of change procedures

Checklist

A generic Spray Drying Checklist is presented in Appendix 1 which can be tailored to your own organisation.

Further risk management information can be obtained from Aviva Risk Management Solutions

Appendix 1 – Spray Drying Checklist

Location	
Date	
Completed by (name and signature)	

	Spray Drying	Y/N	Comments
1.	Has product testing been completed? • Layer Ignition Temperature? • Minimum Ignition Temperature? • Minimum Ignition Energy? • Minimum Explosive Concentration? • Critical Thickness for Self-Ignition? • Kst? • Pmax?		
2.	Is the process area isolated/compartmentalised? • Spray Drying operations in its own discreet processing area? • Separated from other parts of the building by a 2-hour fire wall or a separation distance of 25m?		
3.	Are air inlets provided? Is there adequate filtration of inlet air?		
4.	Is the inlet air heated? • Is this indirectly heated? • Is direct air heating avoided? • Are there flame/spark arrestors on the inlet air?		
5.	Atomisers: • Is there vibration monitoring on centrifugal disc atomisers? • Are safe trajectories for pressurised jet atomisers defined? ○ Is the plant configured to ensure unsafe trajectories cannot be set?		
6.	Dust Extraction Equipment: • Is this externally sited or in a separate fire compartment? • Is explosion relief adequate and relieving externally to a safe area? • Is automatic fire detection equipment installed? • Is an automatic sprinkler or deluge protection system fitted?		
7.	Fans: • Is there vibration monitoring fitted? • Is there safe access for inspection/cleaning provided?		

	Spray Drying Contd.	Y/N	Comments
8.	Fines Return: Is there a downward trajectory or other measures provided to prevent accumulation of fines on the return line?		
9.	Are there adequate measures to prevent accumulation/build-up of powder anywhere in the process or externally?		
10.	Is temperature control provided? • Are temperatures continuously monitored within the various zones within the plant? • Is there a high temperature alarm? • Is there a very high temperature alarm that is interlocked to the product feed, the inlet air and the sifter?		

11.	Risk assessment (DSEAR) and suitable electrical equipment:
	• Has an appropriate hazardous area risk assessment been completed, e.g. DSEAR?
	  ○ Are there formal zoned drawings?
	  ○ Have all issues raised by this assessment been addressed?
	  ○ Is this assessment revisited with every change to equipment, layout or process?
	  ○ Is this assessment revisited periodically to ensure it is still adequate?
	• Is all electrical equipment suitable for use in hazardous atmospheres?
	• Does all equipment have an appropriate temperature class?
	• Is all equipment suitably IP rated?		

12.	Earthing and lightning protection system:
	• Are all items of plant and all components connected to each other and to earth by a low resistance electrical path?
	• Is the earth continuity checked and confirmed as part of routine plant maintenance?
	  ○ As part of any change?
	  ○ At least annually?
	• Does the building feature a lightning protection system designed and maintained to appropriate standards?
	• Is the lightning protection system inspected and tested on at least an annual basis?		

13.	Flexible Hoses: • Are hoses ATEX rated or appropriately listed for electrically classified areas? • Designed not to burst at pressures below that of explosion relief mechanisms?		

	Spray Drying Contd.	Y/N	Comments

14.	Automatic Fire Detection:
	• Is the building area covered by a suitable automatic fire detection system that meets BS 5839 part 1 – P1, or a local equivalent standard?
	• Does the spray dryer have the following detection provided internally:
	  ○ Carbon monoxide detection?
	  ○ Spark detection?		

15.	Fire Fighting Systems:
	• Are suitably designed fixed fire protection/suppression systems provided in the following areas:
	  ○ Spray dryer?
	  ○ Extract ducts?
	  ○ Fluid bed dryer?
	  ○ Cyclones?
	  ○ Bag filters (if fitted)?
	Are these systems suitably inspected, maintained and tested?		

16.	Explosion Relief/Containment: Has the plant been designed to either contain the pressure of an explosion or safely relieve the pressure to a safe location?		
17.	Explosion Suppression: Has a suitable explosion suppression system been installed within the spray dryer and associated ductwork? Is this system suitably inspected, maintained and tested?		
18.	Explosion Propagation: Are there suitable measures to prevent propagation of an explosion through the process?		
19.	Are there the following procedures established: • Safe start-up? • Steady state? • Safe shut down? • Dealing with blockages? • Dealing with loss of containment/emissions?		
20.	Are adequate programmes of plant maintenance established?		
21.	Are adequate programmes of cleaning in place for all areas of the building and the equipment? • Including high level areas?		
22.	Are there no/few fugitive dust emissions from the process? If discovered are these emissions treated as a high priority maintenance repair task?		

	Spray Drying Contd.	Y/N	Comments
23.	Is hot work managed in accordance with Aviva's Loss Prevention Standard?		
24.	Is there appropriate programmes of operator training? • Is this recorded? • Is this auditable?		
25.	Additional comments:		