NEW ENGINEERING GUIDELINE (VDI 2263 PART 7) ON DUST FIRES AND EXPLOSIONS PROTECTION IN SPRAY DRYING AND INTEGRATED EQUIPMENT

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The new engineering guideline was published in 2011 and describes the state of the art in regards to fire and explosion protection measures in spray dryers where, during specified normal use, combustible dust/air mixtures, vapor/air-mixtures or hybrid mixtures occur or maybe formed.

The paper will outline the contents of this new engineering guideline in detail. Special focus will be given to the area of Fire and Explosion risks associated with spray drying operations. The relevant safety characteristics, necessary for a risk assessment, the zoning and consideration of potential ignition sources will be explained in detail. The final part of paper describes equipment specific protective measures to afford protection against fire and explosion hazards.

1. INTRODUCTION

In 1986 the VDI published the first Guideline on Dust Fires and Dust Explosion Hazards. Guideline 2263 Part 1 was the start of several Guidelines within the 2263 series addressing a variety of relevant topics associated with Dust Fire and Dust Explosion Hazards. As of today most of the VDI 2263 guidelines are recognized and acknowledged throughout European and International standards. In 2002 it was decided to continue the VDI 2263 series and to address equipment specific dust fire and explosion hazards combined with practical information and solutions trials for those specific types of equipments. Due to the complexity always two parts were prepared for each equipment specific topic in which the first part summarizes the basics (e.g. description of the installation; risk assessment; protective measures) in general. As a continuation the second part outlines practical information and equipment specific solutions trials for protective measures.

As of today the following types of equipment have been covered within the VDI 2263 series/1-13/:

- *Fluidized Bed Dryer* (*Part 5/5.1*)
- *Dust extracting installations* (*Part 6/6.1*)
- *Spray dryer* (*Part 7/7.1*)
- *Elevators* (*Part 8/8.1*)
- *Dustiness of bulk material* (*Part 9*)

In the following chapters the details of the new VDI 2263 Guideline, Part 7, which was officially made available to the public in July 2010 will be described in detail.

2. DESCRIPTION OF EQUIPMENT

Spray drying is a common process for particle formation and drying. It is a good solution for the continuous production of dry solids in powder or agglomerated particle form from a liquid feedstock. The feedstock can include solutions, emulsions, and suspensions/14/.

During spray drying, a significant heat and mass transfer takes place within a short period of time. The different stages during a spray drying process can be outlined as follows:

- *Atomization of a liquid feedstock into a spray of droplets. The small droplets are created by an atomizer (rotary wheel or a high pressure nozzle).*
- *The droplets are introduced into a hot airstream, which is cooled down due to the evaporation of the water or a chemical solvent from the concentrate.*
- *This now cooler and humid air is discharged from the dryer through a cyclone, bag filter or a combination of the two.*
- *After separation of the now dry particles, the air is discharged into the atmosphere.*
- *The dry particles can be cooled and bagged off after separation from the process air.*

The following two figures are showing a typical set up of spray dryers used in the processing industry:

3. FIRE AND EXPLOSION HAZARDS

Fires and explosions are a great risk to people, the environment and installations. This is mainly due to the sometimes considerable heat and pressure coming into effect and to the combustion products. The temperatures building up inside spray dryers in the event of fires can result in parts of the installation breaking down and, thus, being destroyed. The pressures occurring in the event of explosions can exceed the strength of the installation (unless it is designed to be explosion-resistant) and can, therefore, cause the installation to rupture. Such explosions give rise to additional hazards of flying debris and of flames exiting the Installation, which may injure any personnel in the vicinity. Unless equipment specific safety measures are in place, fires and explosions can spread throughout the installation and to connected installations.

For a fire or an explosion to occur in a spray dryer, the following conditions must be fulfilled:

- *combustible dust* (*either deposited or raised within the explosion limits*),
- *sufficient supply of oxygen and*
- *an effective ignition source*

1	Feed System	6	Drying System (drying chamber)
2	Atomizer System	7	Extract air system with cyclone
3	Supply-air System	8	Downstream fluidized bed as final drying/cooling chamber
4	Supply air for downstream fluidized bed as final drying/cooling system	9	Fines recycling system
5	Drying System (air distributor)	AE	Discharge unit

Figure 1. Spray dryer using a vertical airflow, with cone-bottom drying chamber

The less compact a deposited combustible dust is, the more violent the combustion reaction will occur after ignition. Most dusts will combust fairly slow when deposited. Glowing and smoldering combustion are characteristic. In spray dryers, the airflow will accelerate combustion up to flaming. Raised dust/air mixtures will combust at such an extreme rate that an explosion is most likely to occur.

A fire in a spray dryer can be the immediate consequence of an explosion, although the main causes are other ignition sources. On the other hand, an explosion can also occur during a fire due to fire gases or because of dust being raised.

In contrast with the EU Directives and the pertinent harmonized European standards, this VDI guideline addresses not only the manufacturers but the users as well. The fire and explosion safety of an installation is also determined by risk factors at the installation site and, particularly, by the properties of the product(s) processed in each case. During the planning phase the manufacturer and user must agree on the design of the safety equipment. The user shall then ensure, later on, that *only* such products are processed in the context of specified normal use as per the design of the spray dryer.

A risk assessment of each individual case has to be carried out and should contain the following elements:

Safety characteristics will help to identify the hazards by indicating whether the substances are combustible and how susceptible to ignition they are.

- *Determine whether potentially explosive atmospheres must be expected to form and determine their likelihood of occurrence and expected volume.*
- *Determine the presence of any ignition sources capable of igniting combustible substances or potentially explosive atmospheres, including the likelihood that these ignition sources will be present.*
- *Determine the potential effects of a fire or explosion.*
- *Evaluate the risk.*
- *Consider the measures for reducing the risk.*

The analysis must cover all parts/installation of the spray dryer as well as protective systems and components. The risk assessment shall take into account:

- *spray dryers, the protective systems and the components proper*
- *interaction between the spray dryers, the protective systems and the components as well as the substances handled*
- *the operations taking place in the spray dryers*
- *interactions between the individual processes in the various parts of the spray dryers, the protective systems and components*
- *environment of the spray dryers and potential interactions with neighboring processes*.

3.1 GUIDANCE FOR MANUFACTURER/USERS

It is the obligation of the manufacturer to conduct a risk assessment to identify all hazards associated with their spray dryer. They shall design and construct the spray dryer taking into account the results of their analysis.

The manufacturer shall carry out the risk assessment on the basis of the intended use also to be specified by themselves, i.e. that use for which they declare the spray dryer to be suited. They shall furthermore check whether the entire spray dryer or only individual systems of the installation, such as the drying system, or individual equipment, such as fans, fall within the scope of the EU Directive 94/9/EC/15/. If so, their equipment shall fulfill the basic requirements as well as the supplementary requirements applicable to equipment of the categories 1, 2 or 3, depending on the frequency and likelihood of occurrence of the potentially explosive atmosphere.

1	Feed System	6	Drying System (drying chamber with integrated fluidized bed)
2	Atomizer System	7	Extract air system with bag filter
3	Supply-air System	8	Downstream fluidized bed as final drying/cooling chamber
4	Supply air for final drying/cooling system	9	Fines recycling system
5	Drying System (air distributor)	AE	Discharge unit

Figure 2. Spray dryer using a vertical or rotating airflow, cone-bottom drying chamber with extract-air outlet in ceiling of drying chamber

On the basis of this information, the user shall then conduct their own installation-specific risk assessment taking into account the same elements as mentioned above. They have to document the result in an explosion protection document.

The user of a spray dryers is responsible for determining which areas of the spray dryer involve explosion hazards, taking into account the design data supplied by the manufacturer of the installation, the safety characteristics of the products to be processed and the operating conditions.

The user is also responsible for zoning the environment of the spray dryer. To this end, the manufacturer shall make available data of the potential emissions of the spray dryer. In addition to these potential emissions of the spray dryer, the user shall also consider other emission sources that may lead to the occurrence of potentially explosive atmospheres in the area to be assessed.

3.2 FIRE HAZARDS

Spray dryers processing combustible products as specified in DIN EN 1127-1/16/ must be assumed to create a fire hazard as a matter of principle. The fire hazard depends on the quantity of product and its combustion characteristics. Fires can occur as a consequence of an explosion or, as is the general rule, independently of explosions.

3.3 EXPLOSION HAZARDS

When processing dust-like combustible substances which may form explosive mixtures with air, potentially explosive dust/air mixtures must be expected to occur within the spray dryer as a matter of principle. An additional explosion hazard can result from combustible liquids being sprayed.

When dust exits the installation (e.g., due to leakages in the duct returning dust under overpressure, or during cleaning activities), the environment may be at risk of explosion, too.

The result of the hazard assessment provides information on where potentially explosive atmospheres are to be expected and on the likelihood of occurrence and the expected volume of such potentially explosive atmospheres (zoning).

Zoning is an obligation for all users of spray dryers. This classification shall be recorded in the explosion protection document. Zones must be assessed for the inside and the outside of the installation.

3.4 SAFETY RELEVANT CHARACTERISTICS

Knowledge of the safety characteristics of the product to be dried is a prerequisite to the specification of safe process conditions. The user shall determine these characteristics unless sufficient data are available on which to do this. The sample to be tested must represent the "worst case" in terms of the fine dust content, i.e. the smallest particle size fraction possible during operation.

The following safety characteristics should be known for drying safety:

Assessing combustion characteristics

- *determination of the combustion class at 20°C and at an elevated temperature, usually 100°C*

Assessing thermal stability

- *exothermal-decomposition test in an open cup* (*according to Lütolf*), *including combustibility test of the decomposition gases and measurement of the volume of decomposition gases*
- *test for self-ignition in the airflow* (*according to Grewer*)

The temperature range over which these tests are carried out depends on the selected drying technique, the type of dryer and the user's requested drying conditions.

Assessing explosion hazard

- *minimum ignition temperature of a dust cloud*
- *minimum ignition energy*
- *lower explosion limit*

Additionally, where explosion protection by design is required

- *test of the maximum explosion overpressure*
- *test of the maximum pressure rise over time*

Determination of fire hazard

- *determination of the combustion class at 20°C and at an elevated temperature, usually 100°C*
- *determination of minimum ignition temperature of a 5* mm *dust layer*
- *temperature of exothermic decomposition*

The following table (Table 1) shows ignition sources that may be present in a spray dryer, and the safety characteristics that must be known to determine whether the product can be ignited by these ignition sources or not. Process parameters such as, in particular, temperature and pressure are to be considered in addition to this. Self-ignition is caused by oxidation reactions with oxygen, occurring particularly in dust deposits or on caking.

Testing the potential for the formation of gases from the smoldering of products requires the ignition point to be determined. If such smoldering gases are formed then further determination of the volume and flammability of them is required, i.e. to give appropriate consideration to the formation of hybrid mixtures.

Safety characteristics relevant to avoiding potentially explosive atmospheres are compiled in Table 2.

If the result of the risk analysis shows that residual risk is not tolerable, additional measures for explosion protection must be applied as outlined in Table 3.

3.5 ZONING

Dust explosions are only possible in dust/air mixtures or in dust/air/inert-gas mixtures above the limiting oxygen

Table 1. Safety characteristics relevant to avoiding effective ignition sources

Ignition Sources	Potential causes	Corresponding Characteristics	Principal factors influencing the characteristics
Hot surfaces	Glowing nest, friction of rotating parts	Minimum ignition temperature of a dust cloud, minimum ignition temperature of a dust layer, combustion class	Layer thickness, size and shape of the hot surface, grain size
Flames and hot gases (including hot particles)	Excessive air inlet temperature, direct heating	Minimum ignition temperature of a dust cloud, self-ignition temperature	Solvent content, combustible smoldering gases
Mechanically generated sparks	Disk rupture	Minimum ignition energy, minimum ignition temperature of a dust cloud	Temperature, solvent content, combustible smoldering
Static Electricity	Hazardous electrostatic charges in components isolating products	Minimum ignition energy	gases, humidity, grain size
Exothermal reaction including self-ignition	Excessive air inlet temperature, deposits on surfaces	Minimum ignition temperature of a dust layer, combustion class, decomposition temperature	Temperature, layer thickness, size and shape of dust accumulation, grain size

concentration. Dust whirled up from deposits may give rise to explosive dust/air mixtures, posing serious hazards if effective ignition sources are present. These hazards depend on the frequency and duration of explosive atmosphere. Depending on the likelihood of occurrence and the duration of explosive atmosphere, areas are classified into zones 20, 21 and 22. Appropriate explosion-protection measures shall be selected according to this classification.

In spray dryers, explosive dust/air mixtures can occur in the drying system, the extract-air system, the internal powder handling system, the final-drying/cooling system, the fines recycling system and the additives feed system.

Where combustible liquids are used, explosive gas/air mixtures can also occur in the feed system. Moreover, the possibility of hybrid mixtures occurring in the other systems cannot be excluded in this case. The presence of an explosive dust/air mixture in a spray dryer depends on

- *the volume of product and the volume flow rate of the air in which the product is dried*
- *the volume of product supplied to the installation via the fines recycling system and the additives feed system*
- *the lower explosion limit (LEL) of the dust, taking into account the influence of the air temperature on the LEL*
- *the distribution of the product in the air streams within the spray dryer*
- *the air routing within the drying chamber (diverting the extract air towards the ceiling of the drying chamber increases the dust concentration in the drying chamber)*
- *the shape of the drying chamber (in the conical part of the drying chamber, the dust concentration will increase if the extract air is discharged upstream of the cone*

Zoning of the spray dryer environment must take into account the location of the installation. Provided that the spray dryer operating in negative-pressure mode is sufficiently dust-tight, the area around the installation would not have to be considered at risk of explosion unless other influencing factors at or near the installation site call for the classification into a zone. As a rule, increased hygiene

Table 2. Safety Characteristics relevant to avoid an explosive atmosphere

Preventive measure	Safety characteristics required	Process and installation parameters capable of influencing safety
Limiting the concentration	Lower Explosion Limit	As a rule, the protective measures "limiting the concentration" cannot be realized in dust-carrying parts of a spray dryer
Inerting	Limiting oxygen concentration	Tightness of installation, temperature, solvent vapours, combustible decomposition gases
Reducing the release of combustible substances into the environment of the installation	Lower Explosion Limit	Tightness of installation, positive or negative-pressure mode
Avoiding dust deposits inside and outside the installation	Lower Explosion Limit	Optimisation of air routing, preventive measures such as air brooms, beaters, etc.; tightness of installation, cleaning activities

Table 3. Safety characteristics needed to apply explosion protection by design

Measure for explosion protection by design	Safety characteristics	Important factors influencing the explosion characteristics
Explosion Pressure resistant	Maximum explosion overpressure (P_{max})	Temperature, solvent vapors, combustible smoldering gases, positive or negative pressure, jet ignition, oxygen concentration, humidity
Explosion suppression	K_{st} – value, Maximum explosion overpressure (P_{max}), Minimum Ignition temperature of a dust cloud	
Explosion venting	K_{st} – value and Maximum explosion overpressure (P_{max})	
Explosion decoupling	K_{st} – value, Maximum explosion overpressure (P_{max}), Minimum Ignition temperature of a dust cloud, Maximum experimental safe gap (MESG)	

requirements apply in the food-processing industry. Thanks to the mandatory cleaning management in this case, no hazardous dust deposits are to be expected here.

The following example exclusively deals with hazardous explosive atmospheres consisting of dust/air mixtures. Where combustible solvents are used, a separate assessment will have to be conducted to clarify whether hybrid mixtures can occur in the installation. It shows a spray dryer using a vertical airflow (Figure 3).

3.6 CONSIDERATION OF IGNITION SOURCES

As part of the risk assessment process, all potential ignition sources must be analyzed with regard to the ignition sensitivity of the explosive atmosphere and the likelihood of occurrence.

The analysis should not just cover the normal operation cases but should also take process related deviations into consideration.

The risk assessment should include equipment inherent ignition sources and those which are introduced or acting from outside as well as ignition sources arising from the dust. The following table (Table 4) outlines the different type of ignition sources linked to a spray dryer.

3.7 RISK ASSESSMENT

Operating a spray dryer unit safely can be achieved by measures to avoid either the generation of dangerous explosive atmospheres or ignition sources under all circumstances. Appropriate preventive explosion protective measures must be used to ensure safety under all processing conditions. If appropriate safety measures are not implemented then there is a serious risk of damage/destruction of equipment and potential for injury or fatalities to personnel in the vicinity of the operation. To assess the likelihood and the severity of an explosion/fire a risk assessment has to be done. Based on the likelihood of occurrence determined and the estimation of possible effects of an explosion/fire measures must be defined and applied to reduce the risk to a tolerable level.

The manufacturer/user should plan explosion protection measures as summarized below to reduce the risk of an explosion/fire to a tolerable risk:

- Explosions
  - *Avoidance of explosible atmospheres*
  - *Avoidance of effective ignition sources*
  - *Limiting the effects of explosions through explosion protection by design* (*construction explosion protection measures*)
- Fires
  - *Avoidance of effective ignition sources*
  - *Limiting the effects of fires*

Table 5 will summarize typical examples of measures applicable for a spray dryer.

4. PROTECTIVE MEASURES

4.1 FIRE PROTECTION

It is the users responsibility to specify organizational measures for avoiding fires and for reducing the effect of fire. Such measures have to be documented and summarized

1	Feed System	6	Drying System
2	Atomizer System	7	Bag filter
3	Supply-air System	8	Downstream fluidized bed as final drying/cooling system
4	Supply air for final drying/cooling systems	9	Fines recycling system
5	Extract air system		

Figure 3. Spray dryer using a vertical airflow, with cone-bottom drying chamber

Table 4. Ignitions source categories and associated ignition sources

Ignition Source Category	Ignition sources
Equipment inherent ignition sources	• Hot surfaces • Mechanically generated sparks • Electrical equipment • Static electricity
Ignition sources introduced or acting from the outside	• Flames or hot gases (including hot particle)
Ignition arising from the dust	• Exothermal reactions • Electrostatic discharges

within a written work instruction. In defining fire protective measures it must be ensured that not just the normal operation but also start-up/shut-down phases, maintenance and standstill phases, are included into the decision process.

In the event of a fire the following actions should be carried out:

- *Always shut off the heat supply to the spray dryer*
- *In case of combustible dusts, the fire extinguishing agents shall be applied in such a manner as to prevent dusts from being raises* (*explosion hazard*)
- *Shut off the product feed*
- *Shut-off the supply and extract air-fans*

The prevention of fire is an essential part of preventive fire protection in spray dryers. Experience with damage shows, that due to operational requirements, reliable fire prevention cannot always be ensured. Damage control measures within the spray dryer are therefore required. It is crucial to detect the start of a fire as soon as possible to ensure that within a sufficient time period counter measures are activated to fight the fire. Options for fire detection within spray dryers are:

- *Maximum Temperature detectors*
- *Differential detectors*
- *Temperature measurements*
- *Radiation detectors*
- *Gas monitoring*
- *Smoke-gas density meters*
- *Aspiration fire detectors*

Table 5. Examples of measures for limiting the effects of explosions/fires

Type of measure	Explosions	Fires
Avoidance of explosible atmosphere	Selection of a process that operates safely outside the explosion range (e.g. inerting)	–
Avoidance of ignition sources	• proper earthing of all conductive installation components • proper installation of the electrical equipment • selection of electrical components and equipment approved for the use in the respective hazardous zone • selection of suitable materials • Limiting of the maximum surface temperature • temperature monitoring • maintenance schedules • lightning protection • instruction and training of plant operators	
Explosion protection by design	• explosion resistant design • explosion venting • explosion suppression • explosion decoupling	–
Fire protection system		• automatic fire alarm system • stationary fire-extinguishing system with automatic or manual triggering

Any detection of a fire must result in an alarm in order to allow that fire fighting actions are activated immediately. A fire fighting system includes:

- **separate fire extinguishing systems**
  - *water-spray extinguishing system*
  - *gas extinguishing system*
  - *powder extinguishing system*
  - *foam extinguishing system*
- **integrated fire-extinguishing systems**
  - water supply via the cleaning system of the spray dryer (CIP system)
  - water supply via the product feed system (older installations)

4.2 EXPLOSION PROTECTION

As it has been mentioned earlier a fundamental measure of preventive explosion protection focuses on the avoidance of explosive atmosphere or at least reducing the likelihood that explosive atmosphere will occur. In addition the identification and the reliable elimination of effective ignition sources must be ensured at all time.

Avoidance of ignition sources can be applied normally as the sole protective measure where only explosive dust/air-mixtures with a temperature related minimum ignition energy of 10 mJ or more (measured with additional inductance) occur in spray dryers.

Note: This assumes all other potential ignition sources have been addressed appropriately, i.e. thermal decomposition/smoldering particle, earthing of all conducting items, etc.

Product with a temperature-related minimum ignition energy of less than 10 mJ or in case of hybrid mixtures usually require additional explosion protection by design such as:

- *Explosion pressure resistant design*
- *Explosion venting*
- *Explosion suppression*
- *Explosion decoupling* (*e.g. quick acting gate valve, rotary air lock, extinguishing barrier, . . .*)

5. SUMMARY AND CONCLUSIONS

The new VDI guideline 2263, Part 7.0 describes the state of the art in regards to fire and explosion protection measures in spray dryers where, during specified normal use, combustible dust/air mixtures, vapor/air-mixtures or hybrid mixtures occur or maybe formed. It provides the user with process related details on fire and explosion hazards including basic measures on how to address them. The VDI 2263 guideline 2263, Part 7.1 will provide two examples of a thoroughly risk assessment for two spray dryers from different industrial areas (dairy/pigment drying process) and applied explosion protection measures.

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