Measures for the Prevention of Sugar Dust Explosions

with supplements for pulp and pellet dust

Set of measures and decisions (11/2003)

Translation, without liability, by Ulrike Münz, Braunschweig.
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Measures for the Prevention of Sugar Dust Explosions

1 Background

The present set of measures and decisions was prepared by a working group set up by the trade association ‘sugar’. The members of the working group include representatives of the sugar industry, suppliers of dust arrester systems, as well as experts representing, for instance, the trade association’s institute for industrial safety (BIA). In drawing up the present document, due consideration was given to the experience gained with previous cases of sugar dust explosions both at home and abroad, as well as the latest results of research into dust explosion phenomena, the requirements made on preventive measures in response to government and trade association regulations, as well as accepted rules and regulations of explosion protection.

This list of decision models and possible measures is to assist planners, manufacturers and users of sugar producing machinery and equipment in assessing potential dust explosion hazards and in defining suitable explosion protection measures.

Although the document primarily concentrates on the explosion hazard produced by sugar dust, such factors as pulp and pellet dust are considered as another possible source of explosions in sugar factories and are included in an appendix of the present document. The statutory provisions and the general procedures, however, equally apply to any kind of dust, which is why the general chapters by analogy also relate to pulp and pellet dust.

The document does not claim to offer a shortcut to solving problems that may occur in practice. It rather aims to propose a systematic approach in assessing potential hazards as well as possibilities in developing protection concepts. Wherever sufficient details are available for acceptable generalization, these will be considered.
2 Fundamental considerations

In the sugar industry, dust explosion protection is a vital prerequisite of the safe operation of sugar producing plants. If such explosions occur, they often have serious consequences not only for the machinery but also, either directly or indirectly, for the staff concerned. Great store hence has to be set by the factor of preventive industrial safety. The truism, according to which requirements not adequately attended to during the planning phase will need a much greater input of financial and human resources when addressed at a later stage, equally applies to explosion protection. The provisions of the German law relating to the principles of industrial safety account for this basic understanding.

In Germany, explosion protection is basically governed by two regulations.

The explosion protection regulations (ExSchV), which were put into force on 12 December 1996, relate to the placing on the market of equipment and protective systems for hazardous areas (requirements of quality and condition). The legal basis for the explosion protection regulations is set forth in the equipment safety act (GSG). /27/

The regulations on the safety of operation (BetrSichV) of 27 September 2002 regulate, among other things, the provision and the operation of equipment and protective systems intended for use in hazardous areas (operating regulations). /28/

Additional regulations (technical rules and regulations, regulations set forth by trade associations, principles and information) serve to put the requirements made into more concrete terms.
3 Conditions favouring dust explosions

Dust explosions may be the result of the following situations:

- flammable (exothermally oxidizable) dust of sufficient fineness
- sufficient oxygen supply (generally available in the form of atmospheric oxygen)
- dust concentration in the air within the explosion limits
- active source of ignition

All the above conditions have to prevail at the same place and time.

Then and only then will a dust explosion take place.

The effects of such dust explosions primarily depend on

- the dust parameters
- the propagation and turbulence of the dust cloud
- the technical standard of the plant or equipment, and
- the given ambient situation: e.g. dimensions, relief areas, connection with other rooms.
4 Definition of zones in sugar factories

Areas in which hazardous explosive atmospheres have to be expected to occur are referred to as “hazardous areas”. Depending on the likelihood of the occurrence of potentially explosive atmospheres, these are classified into different zones. The regulations on the safety of operation (BetrSichV) /28/ use the following definitions:

Zone 20

"Area in which a hazardous explosive atmosphere in the form of a cloud of flammable air-borne dust is present either constantly, over prolonged times or frequently."

Zone 21

"Area in which under normal operation a hazardous explosive atmosphere in the form of a cloud of flammable air-borne dust can occasionally form."

Zone 22

"Area in which under normal operation a hazardous explosive atmosphere in the form of a cloud of flammable air-borne dust is normally not expected and if so only for a short period."

For purposes of this classification, normal operation is considered to be the condition in which the plant or equipment is used within its design parameters.

Above and beyond that, the particular problems of deposited dust have to be accounted for in all three zones.

- On the one hand, deposited dust is a constant source for the formation of dust clouds.

- Dust having settled on energy converting operators may, because of its insulating properties, in addition, produce a number of effects (e.g. higher operator temperature) which, when compared to the “dust-free situation”, may give rise to active sources of ignition.

- A third aspect, which in connection with many other flammable dusts may increase the risk potential in a special way, i.e. the potential of forming pockets of smouldering material, is of minor significance for sugar dust, which is due to its low melting point.

The formation of sugar dust is a production-inherent effect when crystallized sugar is ground to powdered sugar in powder mills, but sugar dust may also form in an uncontrolled manner, e.g. as a result of abraded particles produced when handling sugar. As long as just minor percentages (<= 3%) of dust are uniformly distributed in the bulk of coarse crystallized sugar, there is a relatively low risk of potentially explosive atmospheres.
Measures for the Prevention of Sugar Dust Explosions

Dust is primarily released as a result of separation and sizing processes when handling and moving the sugar

- at conveyor transfer points,
- in silo and hopper intake and outlet ends, and
- in elevators.

Experience shows that hazardous explosive atmospheres have to be expected to occur

- as a result of the production process used
  
  **constantly, over prolonged periods** or **frequently** (zone 20)
  
  - in dust arrester filters at the nonfiltered-gas end,
  - in powder mills in the grinding gear,
  - in powder bins,

- **occasionally** (zone 21)
  
  - in screening machines,
  - in elevators,
  - in grade bins for fine sugar (< 250 µm),
  - in powder and dust screw conveyors operating at high speeds (v > 1 m/s),

- **normally not** or, if so, for a **short period** (zone 22)
  
  - in crystallized sugar silos,
  - in grade bins with coarse sugar (> 250 µm),
  - in slowly rotating powder and dust screw conveyors (v < 1 m/s),
  - in sugar dryers (crystallized sugar),
  - in fluidized-bed dryers (crystallized sugar),
  - in dust arrester piping,
  - in areas with dust deposits
    e.g. in the vicinity of open belt systems (silo cellar)
    or in the vicinity of screening machines.
5 Selection of equipment and protective systems

A fundamental requirement of effective explosion protection is the use of suitable equipment and protective systems. The explosion protection regulations (ExSchV) (11th ordinance for the equipment safety act, GSGV) hence cover a very wide field of applications. /27/

**Equipment** means machines, apparatus, fixed or mobile devices, control components and instrumentation thereof and detection or preventive systems, which, separately or jointly, are intended for the generation, transfer, storage, measurement, control and conversion of energy for the processing of material, and which are capable of causing an explosion through their own potential sources of ignition.

**Protective systems** means all devices except for components of equipment as defined above, which are intended to halt incipient explosions immediately and/or to limit the effective range of an explosion, and which are placed on the market for use as autonomous systems.

**Components** means any item essential to the safe functioning of equipment and protective systems, but with no autonomous function.

The explosion protection regulations define the formal and technological conditions that have to be met when placing the equipment, protective systems and components on the market (cf. Fig. 1). In this context the placing on the market is the first-time provision, either against payment or free of charge, of a product on the internal market which is intended to be marketed and/or used in the national or European market.

If the basic safety and health requirements specified in Attachment II of Directive 94/9/EC for the design and construction of a product are complied with, a product may be assumed to be safe. /29/

*Note:*

The above statements start from the premise that the equipment, protective systems and components are used as specified.
Fig. 1: Formal and technological conditions

In compliance with the explosion protection regulations, the equipment and protective systems intended for use in explosive dust atmospheres in the sugar industry are classified as group II equipment. Subject to the conditions of use (proper use), the equipment and protective systems are divided into three categories.

**Category 1:**

This category covers equipment designed in such a way that it can be operated in compliance with the parameters specified by the manufacturer and that a very high level of safety is safeguarded. Equipment falling under this category is intended for use in areas in which a potentially explosive atmosphere is present either constantly, over prolonged periods or frequently (for dust this is equivalent to zone 20).

Equipment in this category must ensure the requisite level of protection even in the event of rare incidents relating to equipment. It is characterized by means of protection such that in the event of failure of one means of protection, at least an independent second means provides the requisite level of protection, or that the requisite level of protection is assured in the event of two faults occurring independently of each other.
Category 2:

This category covers equipment designed in such a way that it can be operated in compliance with the parameters specified by the manufacturer and that a high level of safety is safeguarded. Equipment falling under this category is intended for use in areas in which a potentially explosive atmosphere can occasionally form (for dust this is equivalent to zone 21).

The means of protection relating to equipment in this category ensure the requisite level of protection, even in the event of frequent disturbances or equipment faults which normally have to be taken into account.

Category 3:

This category covers equipment designed in such a way that it can be operated in compliance with the parameters specified by the manufacturer and that a normal level of safety is safeguarded. Equipment falling under this category is intended for use in areas in which a potentially explosive atmosphere is unlikely to occur or, if so, only infrequently and for short periods of time (for dust this is equivalent to zone 22).

Equipment in this category ensures the requisite level of protection during normal operation.

Conformity assessment procedures:

Depending on the category, the explosion protection directive requires the manufacturer to use different kinds of conformity assessment procedures. These are the following modules defined in Annexes III to IX of Directive 94/9/EC 

- EC Type Examination (Annex III)
- Production Quality Assurance (Annex IV)
- Product Verification (Annex V)
- Conformity to Type (Annex VI)
- Product Quality Assurance (Annex VII)
- Internal Control of Production (Annex VIII)
- EC Unit Verification (Annex IX)
Equipment and protective systems falling under equipment group II are subject to the following requirements of conformity assessment (cf. Fig. 2).

<table>
<thead>
<tr>
<th>Equipment group</th>
<th>Category</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>1</td>
<td>Module III “EC Type Examination” in conjunction with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Module IV “Production Quality Assurance” or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Module V “Product Verification”</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>For internal combustion engines or electrical equipment:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Module III “EC Type Examination” in conjunction with</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Module VI “Conformity to Type” or</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Module VII “Product Quality Assurance”</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>For any other equipment:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Module VIII “Internal Control of Production” in conjunction with:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Filing of documents by notified body</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Module VIII “Internal Control of Production”</td>
</tr>
</tbody>
</table>

Fig. 2: Equipment groups/categories in the conformity assessment procedure

Note:
Manufacturers may alternatively always use the process of unit verification in compliance with Annex IX.
The relationship between categories and zones follows from the following table:

<table>
<thead>
<tr>
<th>Category</th>
<th>Protection level</th>
<th>Sufficient safety in case of...</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – High likelihood of an Ex atmosphere</td>
<td>Highest</td>
<td>2 means of protection</td>
<td>Zone 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 faults</td>
<td></td>
</tr>
<tr>
<td>2 – Occasional Ex atmosphere</td>
<td>Elevated</td>
<td>disturbance or equipment fault</td>
<td>Zone 21</td>
</tr>
<tr>
<td></td>
<td></td>
<td>normally to be considered</td>
<td></td>
</tr>
<tr>
<td>3 – Low likelihood of an Ex atmosphere</td>
<td>Normal</td>
<td>trouble-free operation</td>
<td>Zone 22</td>
</tr>
</tbody>
</table>

**Fig. 3: Relationship between categories and zones**
6 Protection measures designed to prevent dust explosions

In respect of protection measures taken to prevent dust explosions, a distinction is drawn between preventive and structural measures.

Preventive protection measures aim at preventing the occurrence of explosions by removing at least one of the conditions likely to trigger an explosion.

Structural protection measures are to reduce the effects of an explosion to a level that can be regarded to be safe.

<table>
<thead>
<tr>
<th>Protection measure</th>
<th>Characteristic features to be observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevention of flammable dusts</td>
<td>Flammability, explosion potential</td>
</tr>
<tr>
<td>Concentration limitation</td>
<td>Explosion limits</td>
</tr>
<tr>
<td>Inertisation</td>
<td>Limiting oxygen concentration</td>
</tr>
<tr>
<td>Avoidance of ignition sources</td>
<td>Smoulder temperature, ignition temperature, exothermal decomposition, auto-ignition behaviour, smoulder point, minimum ignition energy, impact sensitivity, electrostatic behaviour</td>
</tr>
<tr>
<td>Explosion-resistant design</td>
<td>Maximum explosion overpressure</td>
</tr>
<tr>
<td>Explosion pressure relief</td>
<td>$K_{St}$ value and maximum explosion overpressure</td>
</tr>
<tr>
<td>Explosion suppression</td>
<td>$K_{St}$ value and maximum explosion overpressure</td>
</tr>
</tbody>
</table>

Fig. 4: Relationship between characteristic features and protective measures

Great significance is attached to the measures “concentration limitation and inertisation”, as these prevent explosive dust/air mixtures from being formed at all or at least reduce the likelihood of their formation.

A first step should always be to check whether flammable materials can be replaced, or whether the occurrence of explosive dust/air mixtures can be prevented by limiting the dust concentration or by means of inertisation (primary explosion protection).

Hazard situations can often be mitigated considerably when these measures are combined in an appropriate way. This effect can be produced by both technical and organisational measures.

Depending on the material properties that have to be dealt with (see Fig. 4), and depending also on the situation produced by the machinery installed and the process used, a second thought should be given to whether it will as a next measure suffice to avoid active ignition sources or whether the possible effects of an explosion have to be reduced to a safe level by means of structural explosion protection measures.
6.1 Avoiding potentially explosive atmospheres

6.1.1 Concentration limitation
Efforts made to avoid potentially explosive atmospheres should always be seen as a first means of preventive explosion protection. When limiting the dust concentration it is not only the dust produced inside the machinery as a result of the production process that has to be considered. Dust settling in production areas represents another important hazard potential, which may have even graver consequences for production floor staff. When deposited dust is raised, virtually any dust concentration may be produced in the air.

A dust layer of 1 mm on the floor may suffice for a room of normal height to be completely filled with a potentially explosive atmosphere. In industrial practice there are normally all sorts of additional surfaces on which dust may deposit, e.g. the top of machinery, T-girders, cable trays, piping, etc.

*Note:* If dust has settled, a first explosion event (even this is just a so-called deflagration) may raise this dust and ignite it again. This process may repeat in a chain reaction and thus trigger severe secondary explosions that may extend to other production areas (room explosions) with devastating consequences. In production plants, equipment, silos, hoppers or bins, settled dust and dust encrustations have to be considered as a potential hazard, in addition to dust raised as a result of normal operation. Settled dust and dust encrustations may be raised by vibrations or currents of air and may thus temporarily produce hazardous explosive atmospheres.

Measures that help avoid or limit the formation of hazardous explosive atmospheres include the following:

- Rate control, in conjunction with adequate ventilation, allows dust concentrations produced in equipment under conditions of normal operation to be controlled to a certain extent.
- Gentle handling (belt conveyors, etc.) helps avoid dust from being formed.
- Reduced dropping heights (use of telescopic downpipes, etc.) help avoid dust from being released.
- Limited use of surfaces on which dust may settle within dust-carrying equipment.
- Optimised design of points of entry, piping optimised for perfect flow conditions, and sufficient flow velocities prevent dust from settling in dust separating facilities.
- Dust-tight construction to prevent dust from exiting into production rooms.
- Dust separating measures (extraction from objects) to prevent dust from exiting into production rooms.
- Limited use of surfaces in production rooms on which dust may settle (possible measures may include the subsequent provision of inclined planes, smooth coats of paint, etc.).
- Regular cleaning, preferably under vacuum, as part of a cleaning schedule to remove dust wherever deposits cannot be avoided.
6.1.2 Inertisation
Inert gas introduced into a tight, dust-carrying apparatus allows the oxygen content to be reduced to such an extent that explosions are rendered impossible. Due care has to be taken that the limiting oxygen concentration remains below the inert-gas and dust-specific level.

Note:
This protective measure is practically without relevance in the sugar industry. (exception: carbon dust silos)

6.2 Avoidance of ignition sources
Another means of preventive explosion protection is the avoidance of active ignition sources. However, when used as an isolated measure, exact and detailed information has to be available on the properties of the products handled, as well as the plant systems and processes used. (cf. Fig. 10)

The 13 types of ignition sources are listed in both the explosion protection regulations /4/ and DIN EN 1127-1 /13/, where details of the ignition mechanisms involved and the means available for avoiding such sources of ignition are provided. (cf. Fig. 9)

In the sugar industry this concerns in particular:

- surfaces that are hot in normal operation,
- mechanically produced sparks and hot surfaces (friction and sliding processes),
- naked flames and hot gases,
- electrostatic discharge, and
- electrical operators (electricity).

6.2.1 Hot surfaces in normal operation
Hot surfaces that are in contact with potentially explosive atmospheres may trigger an ignition process. But not only the hot surface itself may come to act as a source of ignition. A layer of dust or a flammable solid may be ignited when in contact with the hot surface and may thus itself become a source of ignition in the presence of a potentially explosive atmosphere.

The ignition potential of a hot surface is determined by the kind and concentration of the substance in question when mixed with air. The ignition potential always increases with increasing temperature and surface of the heated body.

The temperature that may trigger an ignition process also depends on the size and the shape of the heated body, the temperature gradient near the wall, and possibly also the material of the wall.

In addition to surfaces that can be easily identified as hot bodies (e.g. radiators, drying cabinets, heating coils), there are also mechanical and metal cutting processes that may produce dangerously high temperatures.
Equipment, protective systems and components converting mechanical energy into heat, may similarly produce hot spots. This includes all kinds of frictional clutches and mechanically operating brakes of vehicles and centrifugals. All rotating parts in bearings, shaft ducts, stuffing boxes, etc., also have to be regarded as potential sources of ignition if insufficiently lubricated. Parts moved in tight enclosures may produce friction if foreign bodies have entered or if axes are displaced, so that high surface temperatures are produced within relatively short periods of time (e.g. in elevators).

If hazards are identified as a result of hot surfaces, the equipment, protective systems and components have to meet the following requirements depending on the category in which they are classified:

**Category 1:**

The temperatures of all surfaces that may be in contact with dust clouds must not exceed 2/3 of the minimum ignition temperature in °C of such dust clouds. This also applies to rare cases of malfunction. The temperatures of surfaces on which dust may settle must, in addition, be lower by a safety margin than the minimum ignition temperature of the thickest possible layer that may form from the dust concerned, and this condition must also be met for rare cases of malfunction. If the thickness of the dust layer is not know, considerations have to start from the thickest foreseeable layer.

**Category 2:**

The temperatures of all surfaces that may be in contact with dust clouds must not exceed 2/3 of the minimum ignition temperature in °C of such dust clouds. This also applies to rare cases of malfunction. The temperatures of surfaces on which dust may settle must, in addition, be lower by a safety margin than the minimum ignition temperature. This condition must also be met for cases of malfunction.

**Category 3:**

In normal operation, the temperature of all surfaces that may be in contact with dust clouds must not exceed 2/3 of the minimum ignition temperature in °C of the dust cloud. The temperature of surfaces on which dust may settle must, in addition, be lower by a safety margin than the ignition temperature of that layer.

**Note:**

*For sugar, a maximum admissible surface temperature of 235 °C is regarded to be adequate. However, this only applies to surfaces without or only minor dust deposits (< 5 mm).*

*The reservation that under special conditions the above specified temperature limits may be exceeded, if it can be demonstrated that an ignition is not expected to occur, applies to the equipment, protective systems and components of all categories.*

**6.2.2 Mechanically produced sparks and hot surfaces**

Sliding movement, friction and impact are processes that may separate particles from solid materials, which, as a result of the energy used in separating these particles, reach elevated temperatures. If these particles consist of oxidizable substances, e.g. iron or steel, they may undergo an oxidation process in which they reach even higher temperatures. These particles (sparks) may under certain conditions ignite a hazardous explosive atmosphere.
Measures for the Prevention of Sugar Dust Explosions

Whenever foreign matter, such as stones and metal, enter equipment, protective systems and components, this must be regarded to be a possible source of sparks.

Friction, even if it involves similar ferrous metals or certain ceramic materials, may be the cause of local heating and the formation of sparks similar to those produced by slipping or sliding. Under certain conditions, this, too, may ignite potentially explosive atmospheres.

Impact processes involving rust and light metals (e.g. aluminium or magnesium) and their alloys may trigger a thermite reaction which may then ignite potentially explosive atmospheres.

Impact or friction between titanium or zirconium and sufficiently hard materials may also produce ignitable sparks. This is even the case in the absence of rust.

If hazards are identified as a result of mechanically produced sparks, the equipment, protective systems and components have to meet the following requirements, depending on the category in which they are classified:

**Category 1:**

Equipment, protective systems and components, which even in rare cases of malfunction may favour sparks as a result of ignitable friction, impact or sliding movement, must not be used. In particular, friction between aluminium or magnesium (except for alloys containing less than 10% Al, and paints and coating materials of a mass concentration of less than 25% Al) and iron or steel (except for stainless steel, if the presence of rust particles can be excluded) must be positively prevented. Impact and friction between titanium or zirconium and any hard material must be prevented.

**Category 2:**

The requirements specified for category 1 above should be complied with. The production of sparks must be prevented under normal operation and in case of malfunctions.

**Category 3:**

Measures taken to prevent ignitable friction sparks, impact sparks or sliding movement sparks expected to occur in normal operation are considered to be adequate protection.

**Note:**

*Close analysis of occurrences in industry and the results of studies into this matter have shown that at low circumferential velocities (velocity < 1 m/s) there is no risk of mechanically produced sparks igniting potentially explosive atmospheres.*

If relative velocities of one plant element with respect to another are limited to $v < 1$ m/s, and if the drive powers are limited to $P < 4$ kW, dangerous friction and sliding movement, as well as any mechanically produced sparks or hot surfaces that may result from such processes can be avoided.

If higher conveyance speeds or higher drive powers have to be used, elevators have, for instance, to be provided with watchdog devices monitoring off-track running and slip. If points can be clearly identified at which friction and sliding movement may occur, these hazard spots can be eliminated by combining materials that do not show such behaviour (e.g. friction or sliding partners made from thermoplastic materials that will soften before any critical temperatures are reached).
Internal bearings have to be avoided. Where this is not possible, these bearings should be flushed as required or be provided with temperature monitoring devices.

<table>
<thead>
<tr>
<th>Tools not producing more than individual sparks as a maximum, e.g. screw drivers</th>
<th>Tools that may produce a ray of sparks, e.g. abrasive wheels</th>
<th>All spark producing tools, e.g. screw drivers, abrasive wheels</th>
</tr>
</thead>
<tbody>
<tr>
<td>accepted in zone 22</td>
<td>accepted in zone 21</td>
<td>not accepted in zones 22 and 21, unless:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• work area is shielded to separate it from the zone;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• dust deposits have been removed or are kept moist (work permit);</td>
</tr>
<tr>
<td></td>
<td></td>
<td>not accepted in zone 20</td>
</tr>
</tbody>
</table>

Fig. 5: Tools used in hazardous areas

6.2.3 Naked flames and hot gases

Flames occur in connection with combustion reactions at temperatures of 1000 °C plus. Both the flames themselves and the hot reaction products (hot gases, or, in connection with dust flames and/or smoky flames, also blazing hot solid particles) or other very hot gases may ignite potentially explosive atmospheres. Flames, including those of very small dimensions, count among the most active sources of ignition.

Should there be a potentially explosive atmosphere both inside and outside an item of equipment, protective system or component, or in adjacent plant sections, an ignition occurring in one of the sections may produce flames spreading through openings (e.g. ventilation piping) into other sections. Special protection measures are required to prevent flame propagation.

Spatters produced when welding or cutting are sparks with a very large surface, which also represent highly active sources of ignition.

If hazards are identified as a result of flames and/or hot gases, the equipment, protective systems and components have to meet the following requirements, depending on the category in which they are classified:

All categories:

Naked flames are not accepted, unless under conditions as defined below:

Category 1:

Not accepted are, in addition to naked flames, the fumes produced by flames or other hot gases, unless special protection measures are taken. These may include temperature limitation or the separation of ignitable particles.

Categories 2 and 3:

Facilities with flames are accepted only if the flames are safely enclosed, and if the temperatures specified for the outside faces of the plant sections are not exceeded. Equipment,
Measures for the Prevention of Sugar Dust Explosions

protective systems and components involving enclosed flames (e.g. special heating systems) shall, in addition, safeguard that the enclosure offers adequate resistance against the effect of flames and that flame propagation into the hazardous area is prevented.

Organisational measures that have to be taken to avoid active ignition sources include a ban on smoking, fires and naked light in explosive dust atmospheres. Gas-cutting, welding and grinding operations are subject to a written permit in which the superior concerned specifies the measures that have to be taken (working and ambient conditions, tools used). /2/

Uncontrolled spatters may fly off and cover fairly long distances (10 meters or more). The same is true of rays of sparks produced by abrasive wheels. Wide areas of work places for this kind of work, therefore, have to be freed from dust. Wall and floor openings may have to be covered in addition.

Note:
A fire picket has to be provided if such work is performed in hazardous areas. /2/

6.2.4 Electrostatic discharge
There are different forms of electrostatic discharge that go along with different levels of ignitability.

All categories:

As a primary measure, all electrically conductive plant sections should be earthed electrostatically. The earth leakage resistance should be $< 10^6 \Omega$. It is also advisable to conductively interconnect all neighbouring conductive parts.

The electrostatic discharge processes with the highest ignition potential have to be expected to occur in practice whenever electrically conductive plant elements are installed in an isolated manner favouring a considerable build-up of an electrostatic charge (spark discharge). Examples that should be mentioned here are pipe sections in conveyor or dust separation systems isolated by sealing or coating, supporting baskets in filters that are not earthed, or elevator buckets mounted on non-conductive belts.

Another form of discharge, in addition to such spark discharge, which may prove to be an active source of ignition, is propagating brush discharge.

Propagating brush discharge is favoured by the following conditions:

- if a chargeable thin-layered substance (d $< 8$ mm) backed by a material of sufficient conductance charges up.

- a minimal surface charge density of $Q < 2.5 \times 10^{-4}$ C/m$^2$

These conditions are met if silos are made from metal or concrete, their inside walls are provided with an insulating coat, and the sugar is blown into the silo tangentially.

Propagating brush discharge has been found to occur inside jet mills, cyclones and tubular conveyors provided with a non-conductive lining. It will be produced only if the non-conductive lining has no pores. The insulating effect of normal product encrustations does not suffice to trigger this kind of discharge.
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Propagating brush discharge can be avoided if only conductive materials are used. Non-conductive lining or coating in conductive plant elements (silos) have to be avoided, in particular, at points at which there is a high likelihood of electrostatic charging.

Coating, which in the electrostatic meaning of the word, offers a sufficient amount of pores (disruptive charge voltage < 4 kV) does not favour any hazardous charging.

If hazards are identified as a result of static electricity, the equipment, protective systems and components have to meet the following requirements, depending on the category in which they are classified: /18, 8/

**Category 1:**
Explosive discharge has to be positively excluded also for rare cases of malfunction or failure.

**Category 2:**
Explosive discharge must not occur when the plant elements are operated as specified, including maintenance and cleaning operations, and in case of malfunctions or failures which normally have to be taken into account.

**Category 3:**
Measures in addition to the earthing of conductive elements are normally not required.

*Note:*
According to the current state of the art, explosive sugar dust/air mixtures do not have to be expected to be ignited as a result of propagating brush discharge. For reasons of potential dust explosions it is, therefore, not necessary to provide conductive filter media.

### 6.2.5 Electrical operators (electricity)
In connection with electrical operators, electric sparks and hot surfaces may act as sources of ignition. Electric sparks may, for instance, be produced

- when opening and closing electric circuits;
- as a result of loose contacts;
- by transient currents.

*Note:*
Safety extra-low voltage (e.g. less than 50 V) only offers protection against electric shock, but it can in no way be regarded to be an explosion protection measure. Even very low voltages may produce enough energy for a potentially explosive atmosphere to be ignited.

**All categories:**
Electrical systems must be conceived, installed and maintained in compliance with the effective European Standards.
When electric operators, such as motors, switches or connectors are used, different requirements apply, which are subject to local conditions, the zone, and the material properties: /27/

In zone 20, only operators approved for this purpose may be used (e.g. liquid level indicators):

The conditions for use in zone 22 are met, if the conditions that previously applied to zone 11 are complied with. They are set forth in DIN VDE 0165. Major requirements are the degree of protection IP 54 (for motors with squirrel-cage rotor, degree of protection IP 44 suffices, which does, however, not apply to the terminal box), as well as the surface temperature which must not exceed 2/3 of the ignition temperature or a value which is by 75 °C below the smoulder temperature. For sugar this means a maximum permissible surface temperature of 235 °C. This temperature limit equally applies to other hot surfaces.

Installed light fixtures may, in addition, have to be protected against mechanical impact.

Connectors have to be arranged such that the opening receiving the plug points downwards (maximum deviation from the perpendicular: 30°). If the plug is not inserted, a captive cover shall make sure that the opening is closed such that the required degree of protection is maintained.

6.3 Structural explosion protection
Wherever measures of preventive explosion protection do not offer adequate safety against dust explosions, structural measures have to be taken.

This concerns above all zone-20 sections and plants in which there is a high likelihood of potentially explosive dust/air mixtures under conditions of normal operation.

With this type of explosion protection measures, the effects of dust explosions are to be limited such that the plants concerned are explosion-resistant for the explosion pressure expected to occur. The explosion pressure expected may be either the maximum explosion pressure ($p_{\text{max}}$) or, for instance in conjunction with explosion pressure relief or explosion suppression devices, a reduced explosion pressure ($p_{\text{red}}$).

Structural explosion protection may include the following measures:

- explosion-resistant design,

possibly in conjunction with,

- explosion pressure relief or explosion suppression.

A fundamental prerequisite in this connection is that the transmission of explosions to other plant sections or operating areas are prevented by

- explosion isolation.

6.3.1 Explosion-resistant design
With explosion-resistant design a distinction is drawn between explosion-pressure resistance and explosion pressure shock resistance. The design commonly used is that for explosion pressure shock resistance. /21/
Explosion pressure resistance

Tanks, equipment or pipelines are explosion pressure resistant if they are designed for the expected explosion overpressure and if they sustain this pressure without deformations after repeated exposure.

Note: 
*Explosion pressure resistant tanks, equipment or pipelines are designed and built on the basis of the relevant pressure vessel regulations.*

Explosion pressure shock resistance

Explosion pressure shock resistant tanks, equipment or pipelines must be designed such that they are capable of sustaining the expected explosion overpressure without cracking. Permanent deformation is, however, acceptable. The regulations in VDI 2263, sheet 3, contain details of calculation, design and testing. /21/

The maximum explosion overpressure for sugar dust is 9 bar. (cf. Fig. 11.1) A typical value of the explosion overpressure reduced as a result of the protection measure "explosion pressure venting" is \( p_{\text{red}} = 0.4 \) bar.

![Fig. 6: Possible designs of explosion-resistant equipment using the example of ductile materials. /21/](image)

6.3.2 Explosion pressure relief

Explosion pressure relief means that tanks or equipment provide a relief section (rated break point) that allows them to open in a safe direction should an explosion occur. This prevents any inadmissible pressure build-up, and the equipment may be designed for a reduced explosion overpressure \( (p_{\text{red}}) \).

If the characteristics of the dust as well as the tank dimensions are known, the size of the required relief section can be established on that basis. /23/

Pressure relief devices include rupture disks, explosion doors or flameless explosion venting, for instance by means of fire barrier, Q-tube, dust-retaining quenching device.
Explosion pressure relief systems have to be designed such that the relief process does itself not represent a risk. The same applies if vents are used.

If relief openings are taken to the outside by means of vents, the reduced explosion pressure will increase substantially as a function of the length of the vent pipe. /23/

Explosion pressure relief is a very simple but highly effective means of structural explosion protection, which should be included in plant design and planning at a very early stage.

6.3.3 Explosion suppression
Explosion suppression means that an incipient explosion is detected by sensors, so that rapid injection of a quenching medium ($t \leq 5\text{ms}$) can prevent it from developing fully. In that case the equipment has to be designed to offer explosion resistance for the thus reduced explosion overpressure ($p_{\text{red}}$). Sodium bicarbonate has proved to be a suitable quenching means for dust explosions in many different areas.

Since explosion suppression keeps the explosion inside the equipment concerned, this measure offers the advantage of being independent of a specific location. An added benefit is that it is much more easily retrofitted in existing systems than any other structural explosion protection measure. /22/

6.3.4 Explosion isolation
Structural explosion protection should normally be accompanied by measures that allow the plant sections concerned to be isolated such that an explosion spread is positively prevented. This can be done by providing

- rotary feed valves,
- quick-closing gates or doors,
- quenching-medium barriers,
- quick-closing valves, or
- explosion pressure vents.

**Rotary feed valves** prevent the flame front as well as the shock wave from propagating. If an explosion has occurred, the feed valve must shut-down automatically to make sure that no burning or glowing material is discharged.

When **quick-closing gates or doors** are used, an incipient explosion is detected by sensors, and a tripping mechanism makes sure that the gate or door is closed within milliseconds. The pipeline is thus sealed off hermetically, and neither flames nor pressure can pass the isolating device.

With **quenching-medium barriers**, sensors detect an explosion or a flame front, and the spreading flame is quenched by the injected quenching medium. This kind of barrier has no influence on the explosion pressure, which is why the pipeline and other equipment downstream of the barrier have to be designed for the expected explosion pressure.

**Quick-closing valves (explosion protection valves)** seal off the pipe cross section automatically and hermetically as soon as a defined flow velocity (explosion shock wave) is ex
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The flow velocity required to close the cross section may also be generated actively by means of a sensor-controlled auxiliary flow.

**Note:**
The operability/effectiveness of any rotary feed valves, quick-closing gates, doors, or valves used has to be demonstrated by adequate means.

**Explosion pressure vents** are the most common means of explosion isolation in the sugar industry. In this case, the spread of the explosion is prevented because the pressure is relieved at points of flow redirection. This does not always safely prevent an explosion from spreading, but the spread of the flame front is disturbed in such a way that the explosion will be slow to start in downstream pipe sections. Explosion pressure vents can be regarded to be an adequate means of isolation, if they are used to prevent explosions from spreading from the filter of a dust arrester system to surrounding sections. This presupposes, however, that hazardous explosive atmospheres are not expected to occur in the dust arrester piping under conditions of normal operation. The piping, in addition, must be free from any dust deposits, a requirement that can be met by designing the pipe system for perfect flow conditions and adequate flow velocities (> 18 m/s).

**Note:**
The dust concentration in dust arrester piping normally remains by far below the bottom-end explosion limit, provided the system is operated as specified by the manufacturer. One requirement is that the minimum flow velocity (> 18 m/s) is monitored and maintained.

### 6.3.5 Examples of structural explosion protection

The following structural explosion protection solutions are available for the individual plant sections:

#### 6.3.5.1 Piping

- The required pressure shock resistance is safeguarded if welded pipes made from material S235JR G1 or G2 (previously UST 37/2 or RST 37/2) as specified in DIN EN 125 are used with the following minimum wall thickness:

<table>
<thead>
<tr>
<th>Pressure shock resistance (bar)</th>
<th>Minimum wall thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>&lt;825</td>
</tr>
<tr>
<td>9</td>
<td>&lt;700</td>
</tr>
<tr>
<td>10</td>
<td>&lt;650</td>
</tr>
</tbody>
</table>

**Fig 7:** Relationship between pressure shock resistance, wall thickness and pipe diameter

- At least at pipe bends, flanges have to be tack welded.
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- Y-pipes at branch points shall not have any end faces.

*Note:*

Pressure shock resistance must also be safeguarded for internal elements (e.g. cleaning and inspection openings).

6.3.5.2 **Filters (for dust separation in conveyor systems)**

1. Filters to be pressure shock resistant for a reduced explosion overpressure of, say, 0.4 bar /21/
2. Flameproof rotary feed valve as a means of isolation at the product discharge end
3. Pressure relief vent as a means of isolation at the unfiltered-air intake end
4. Explosion pressure relief is immediately to the outside / or via “Q-tube” /23/  

*Note:*

Filters used for dust separation in conveyor systems have to meet the above requirements, because open intake points and modifications concerning the dust arrester system prevent the protection concept “exclusion of ignition sources” from being guaranteed consistently.

6.3.5.3 **Filters (for dust separation in conveyor systems) - alternative –**

1. Filters to be pressure shock resistant for a reduced explosion overpressure of, say, 0.4 bar /21/
2. Flameproof rotary feed valve as a means of isolation at the product discharge end
3. Automatic flame barrier as a means of isolation at the non-filtered air intake end
4. Filter compartment provided with explosion suppression device. /22/  

*Note:*

Filters used for dust separation in conveyor systems have to meet the above requirements, because open intake points and modifications concerning the dust arrester system prevent the protection concept “exclusion of ignition sources” from being guaranteed consistently.

6.3.5.4 **Filters (for silo conditioning)**

1. Filters to be pressure shock resistant for a reduced explosion overpressure of, say, 0.4 bar /21/
2. Flameproof rotary feed valve as a means of isolation at the product discharge end
3. Pressure relief vent as a means of isolation at the non-filtered air intake end  

*Note:*

The requirements made on a filter for silo conditioning (bulk storage silo for crystallized sugar) can remain below those for dust arresters in conveyor systems, because the air is circulated in a closed system, and there is no risk of uncontrolled entry of ignition sources. Measurements have also shown that even hazardous explosive atmospheres hardly ever
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occur in silos or the silo conditioning piping as a result of a sudden breaking away of dust deposits (zone 22).

6.3.5.5 Floor vacuum cleaning system

- Filter housing to be pressure-resistant for the maximum explosion overpressure
- Permanent nonfiltered-gas pipes to be pressure-resistant for the maximum explosion overpressure
- Quick-closing valve in the nonfiltered-gas manifold upstream of the filter housing intake
- Filtered-air pipe to be explosion-resistant for the maximum explosion overpressure
- Isolation device in the filtered-air pipe, e.g. in the form a Ventex valve.

Note:

Because of the large number of points of connection in a building, stringent requirements have to be made on the technical standard of a floor vacuum system used for building and plant cleaning. Since the system provides for flexible use by the staff, the protection concept “exclusion of ignition sources” cannot be guaranteed. Active sources of ignition may enter the system at any point and time.

6.3.5.6 Powder mill

- Mill housing to be pressure-resistant for the maximum explosion overpressure.
- Mill room to be pressure shock resistant for the reduced explosion overpressure of, say, 0.4 bar.
- Points of access must be kept closed when starting and stopping the mill.

Note:

In the milling compartment of the mill housing there is always the risk of an active source of ignition forming (e.g. should one of the pins in a pin mill break). However, the upper explosion limit can be expected to be exceeded in the milling compartment when in operation. Hazardous explosive atmospheres will be produced only when starting and stopping the mill.

6.3.6 Examples for avoiding ignition sources

When using operators, or when operating equipment within hazardous areas, measures have to be taken to ensure that sources of ignition are avoided whenever the generation of hazardous explosive atmospheres cannot be excluded safely.

In areas in which there is a risk of dust explosion, the following has to be avoided:

- in zone 22 – any sources of ignition that occur either permanently or frequently (e.g. during normal operator operation), to prevent ignition of dust clouds or dust layers,
- in zone 21 – in addition to the sources of ignition specified for zone 22, any source of ignition that occurs infrequently (e.g. as a result of operator malfunction), to prevent ignition of deposited and raised dust,
- in zone 20 – in addition to the sources of ignition specified for zone 21, even any source of
ignition that occurs very rarely (e.g. as a result of operator malfunction), to prevent ignition of deposited and raised dust.

Note:
If the likelihood of a source of ignition to become active cannot be anticipated, the source of ignition shall be regarded to be permanently active.

6.3.6.1 Pneumatic handling
Pneumatic conveyors normally operate within totally enclosed systems. This is why measures taken to avoid the formation of ignition sources can be limited to sources that may occur inside such systems. Only inside pneumatic conveyor systems do potentially explosive atmospheres have to be expected to occur.

6.3.6.1.1 Fluid lift
Hazardous explosive atmosphere: Possible in transmitting tank, piping, receiving tank

Measures:
- Electrostatic grounding of all electrically conductive plant sections. The earth leakage resistance should be $< 10^6 \Omega$.

- It is also advisable to conductively interconnect all neighbouring conductive parts. (cf. 6.2.4)

6.3.6.1.2 Dense-phase conveying
Hazardous explosive atmosphere: Possible in transmitting tank and receiving tank

Measures:
- See 6.3.6.1.1 and 6.2.4

6.3.6.1.3 Plug flow
Hazardous explosive atmosphere: Possible in transmitting tank and receiving tank

Measures:
- See 6.3.6.1.1 and 6.2.4

6.3.6.2 Mechanical handling
When crystalline sugar is handled in mechanical systems, additional dust is produced when sugar crystals are destroyed.

6.3.6.2.1 Elevators
Hazardous explosive atmosphere: In elevators, hazardous explosive atmospheres have to be expected to be produced when any excess sugar trickles down from the buckets. Be
cause of the air movement, the dust particles thus released may remain suspended in the air longer than is normally expected.
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Measures:

- Off-track running to be monitored
- Speed to be monitored
- Slip to be monitored (normally in conjunction with speed monitoring)
- Bucket elevator made from material showing a low sparking behaviour.

Note:

Watchdog devices provided to monitor off-track running have to make sure that neither the buckets nor the belt can hit against the housing. Sliding movement does normally not represent an active source of ignition. A major risk is produced when a bucket comes off or when the entire belt tears. Any falling system elements may in such situations produce impact sparks. Limiting values for the acceptable minimum clearance to be left from the elevator housing are not available. Any adjustments have to be made on the basis of the technical and organisational conditions at site.

6.3.6.2.2 Screw conveyors

Hazardous potentially explosive atmosphere: In screw conveyors for crystallized sugar (not for powdered sugar or dust), additional dust may be produced and deposit when sugar crystals are destroyed. This dust may drop to the ground from time to time and then briefly produce a potentially explosive atmosphere.

Measures:

- Speed to be limited
- Outside bearings

6.3.6.2.3 Belt conveyors

Hazardous potentially explosive atmosphere: Only at belt conveyor transfer points can a locally confined potentially explosive atmosphere be produced if the non-sized sugar drops from considerable heights.

Measures:

- All electrically conductive plant sections to be earthed; the earth leakage resistance should be $< 10^6 \, \Omega$.
- It is also advisable to conductively interconnect all neighbouring conductive parts. (cf. 6.2.4)
Planning, safety concept

The regulations on the safety of operation (BetrSichV) require that production plant planning has to include a hazard analysis to establish the risks represented by hazardous explosive atmospheres. If the formation of hazardous explosive atmospheres cannot safely be excluded (Note: employer's accountability!) the employer/planner shall establish:

1. the likelihood of the occurrence and the duration of hazardous explosive atmospheres,
2. the likelihood of the occurrence and the activation of sources of ignition, including electrostatic discharge, and
3. the extent of the effects explosions are expected to produce.

The following procedure is recommended:

- Establish whether and, if so, where potentially explosive atmospheres are produced or may be produced either during normal operation or in the event of malfunctions.
- Assess the volume of potentially explosive atmospheres that are/may be produced.
- After the options available for preventive explosion protection have been utilised, the hazardous areas have to be classified under the relevant zones. Experience shows that in the sugar industry this normally concerns the following areas:
  - Powder mills/milling systems
  - Conditioning systems
  - Conveyors/elevators
  - Dryers
  - Dust arresters/separators/filters
  - Silos/hoppers
  - Points of entry and piping (dust separation/aspiration)
  - Screening machines
  - Rooms in which the above equipment is installed, if dust deposits cannot be excluded
- Check whether and, if so, where active sources of ignition may occur either during normal operation or in the event of malfunctions.
- Check measures that may have to be taken to prevent active sources of ignition from being produced (e.g. by using suitable electrical operators, by limiting conveying or circumferential velocities, by means of devices monitoring speed/off-track running).
- Assess the remaining explosion risk.
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- Select suitable additional explosion protection measures, e.g.:
  - Means limiting the effect of an explosion
  - Structural measures

Note:
The findings of the risk assessment as well as the technical and organisational measures taken shall be documented in the explosion protection document as laid down in the regulations on the safety of operation (BetrSichV). /28/
8 Structural measures

- Fire isolation has to be safeguarded by dividing the building into a number of fire compartments.

- Careful surface finish is an indispensable prerequisite for the prevention of dust deposits. A primary means to this effect is the exclusion of surfaces favouring such deposits. If such surfaces cannot be avoided, they have to be designed so as to facilitate removal of any deposited dust.

- A central vacuum cleaning facility with a multitude of local points of connection in the hazardous areas will provide for rational and thorough removal of dust deposits, including work platforms that are not easily accessible (e.g. access by means of a ladder). Mobile vacuum cleaning systems can often not be taken to these points for dust removal. Important! Mobile vacuum cleaners have to be suited for potentially explosive dust. Compliance with St class 1 must be demonstrated.

- Pressure relief is required for rooms (e.g. powder mill room) if other structural protection measures cannot be used, and if protection of life is safeguarded in other ways, e.g. by defining such rooms as a prohibited areas without work place and by masonry of adequate strength. /23/

- Lightning protection as set forth in DIN V ENV 61024-1/VDE 0185 have to be provided. /31/.

- In special cases, buildings may also have to be isolated by providing connecting conveyor systems with adequate means of isolation.
9 Organisational measures

9.1 Identification
Hazardous areas have to be identified as set forth in the accident prevention regulations “Sicherheits- und Gesundheitsschutzkennzeichnung am Arbeitsplatz” (BGV A 8). Hazardous areas also have to be provided with a permanent notice showing clearly that there must be no unauthorised access to these areas. /28, 30/

9.2 Cleaning and maintenance
Since the requirement that process rooms have to be free from dust is given high priority, cleaning schedules have to be prepared in which the kind, extent, and intervals of the necessary cleaning measures are listed with name of responsible persons (see Fig. 8).

Methods using vacuum should be preferred for removing dust deposits (central vacuum cleaning system, mobile industrial vacuum cleaners). Industrial vacuum cleaners must be suited for dry, flammable dusts classified under dust explosion class St 1.

<table>
<thead>
<tr>
<th>Kind of cleaning measures</th>
<th>Extent</th>
<th>Intervals</th>
<th>Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweeping</td>
<td>Feed end</td>
<td>Daily</td>
<td>Ms K.</td>
</tr>
<tr>
<td>Vacuum cleaning</td>
<td>Silo floor</td>
<td>At the end of shifts</td>
<td>Mr S.</td>
</tr>
<tr>
<td>Wiping</td>
<td>Mill room*)</td>
<td>As required, but not less than weekly</td>
<td>Mr W.</td>
</tr>
</tbody>
</table>

*) Plant must not be in operation

Fig. 8: Example of a cleaning schedule

In addition to maintenance required to safeguard smooth operation, in particular such maintenance measures have to be considered, which concern

- the operability of protective systems (e.g. devices preventing off-track running, slip monitoring devices, or explosion suppression systems),
- the tightness of dust-carrying systems,
- the effectiveness of dust arresting facilities, and
- the absence of friction for moving plant elements.

For these maintenance measures, a schedule similar to the cleaning schedule shall be set up.
9.3 Repair and inspection

Work permits are required for all work involving flames, such as welding and flame cutting (cf. chapter 9.5). Electrical systems shall be inspected by an expert for such systems or under the supervision of such an expert to check them for proper assembly, installation and operation. Such inspections have to be made before electrical systems are put into operation and at regular intervals (not less than every three years). /28/

9.4 Operation manual, staff instructions

An operation manual shall be prepared which describes how flammable substances and substances that are potentially explosive when mixed with air have to be handled (e.g. sugar dust).

The staff shall be instructed on

- the general conditions favouring explosions,
- the general conduct in hazardous areas,
- the general ban on smoking in hazardous areas,
- the ban on using naked flames or performing work involving flames, unless a permit has been issued (see chapter 9.5), and
- areas to which there is no unauthorised access.

Such instructions shall be provided in the form of initial and repeat instructions.

Note:

*Detailed instructions shall also be provided for external staff. /28/*

9.5 Job release

In hazardous areas, work may be performed only as instructed in writing by the employer. For hazardous work, such as welding, flame-cutting, grinding, a job release system shall be applied.

This kind of work must not be started unless the superior concerned has issued a work permit for the staff put in charge of these jobs, and unless the necessary protection measures have been taken. /28/

9.6 Employer's documentation requirements

All measures taken must be recorded in an explosion protection document, which must be updated regularly. The document has to be prepared before any construction work commences, i.e. at the planning stage, and it shall be revised whenever work equipment or work procedures are modified, expanded or reorganised. The document must, in particular, show

1. that the explosion hazards have been established and subjected to an appraisal,
2. that adequate measures are taken to make sure that explosion protection objectives are met,
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3. what areas have been subdivided into zones in compliance with annex 3 of the regulations on the safety of operation (BetrSichV), and

4. to what areas the minimum requirements set forth in annex 4 of the regulations on the safety of operation (BetrSichV) apply.

Note

Previous hazard assessments, documents, or equivalent report made or prepared at an earlier stage on the basis of other legal requirements, may be updated as required and may also be used. Such documents include, but are not limited to: expert opinions, approval documents, plant schedules, registers of hazardous substances, cleaning schedules, reports on routine inspection tours, staff instruction documents, contingency plans, etc..

The explosion protection document must cover all details of explosion protection concerning the plant and must not be limited to dust explosion protection.
# 10 Annex (general)

## 10.1 Terminology used, characteristics (for flammable dust)

### Flammability

The flammability of dust is defined by the burning number.

<table>
<thead>
<tr>
<th>Type of reaction</th>
<th>Burning number</th>
<th>Type of dust (example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No spread of fire</td>
<td>No ignition</td>
<td>BZ 1 Common salt</td>
</tr>
<tr>
<td></td>
<td>Temporary ignition and rapid extinction</td>
<td>BZ 2 Sugar dust, tartaric acid, casein</td>
</tr>
<tr>
<td></td>
<td>Local burning or smouldering without propagating</td>
<td>BZ 3 Lactose, dextrin</td>
</tr>
<tr>
<td>Spread of fire</td>
<td>Spread of a smouldering fire</td>
<td>BZ 4 Tobacco, lignite, peat</td>
</tr>
<tr>
<td></td>
<td>Spread of an open fire</td>
<td>BZ 5 Sulphur, timber cellulose</td>
</tr>
<tr>
<td></td>
<td>Violent, deflagration-like combustion</td>
<td>BZ 6 Black powder</td>
</tr>
</tbody>
</table>

### Explosion

Rapid combustion accompanied by a distinct increase in pressure.

### Explosion limits

Lower explosion limit (LEL) and upper explosion limit (UEL) are the limiting concentrations of dust in air, between which the dust/air mixture may explode as a result of an externally supplied ignition.

### Potentially explosive atmosphere

A potentially explosive atmosphere is a mixture of air and flammable dusts under atmospheric conditions, in which, after ignition has occurred, combustion spreads to the entire unburned mixture.

### Explosion-resistant design

Plant sections, such as tanks, equipment, and piping, are designed such that they will withstand an inside explosion without cracking.

### Explosion pressure resistant design

Plant sections, such as tanks, equipment, and piping, withstand the expected explosion pressure without permanent deformation.
Design and manufacture are based on the design and construction regulations for pressure vessels (Bauvorschriften für Druckbehälter). The design pressure is rated for the expected explosion pressure.

Explosion pressure shock resistant design

Plant sections, such as tanks, equipment, and piping, are designed such that they will withstand the pressure shock resulting from an inside explosion, which is equivalent to the expected explosion pressure. Permanent deformation is accepted under these conditions.

For design and manufacture, the regulations issued by “Arbeitsgemeinschaft Druckbehälter” (AD code of practice) are used by analogy, but, assuming a high degree of plasticity for the materials used, the material strength may be utilised to a greater extent than is accepted for pressure vessels.

Hazardous area

A hazardous area is an area in which a hazardous explosive atmosphere may occur. Areas in which the potentially explosive atmosphere is not expected to occur at a rate at which special protection measures would have to be taken, are not considered to be hazardous areas.

Hazardous explosive atmosphere

A hazardous explosive atmosphere is a potentially explosive atmosphere which occurs at such a rate (dangerous rate) that special protection measures have to be taken in order to maintain safe and healthy conditions.

Smoulder temperature

Describes the minimum ignition temperature of a dust layer 5 mm thick.

KSt value

Dust- and test-specific constant calculated on the basis of the cubic law. It is numerically equivalent to the maximum rate of pressure rise in a volume of 1 cubic metre at test conditions as defined in VDI directive 2263-1. The KSt value depends, in particular, on the particle size distribution and the surface structure of the dust.

Cubic law

Volume dependence of the maximum rate of pressure rise

\[(dp/dt)_{\text{max}} \cdot V^{1/3} = \text{konst.} = K_{\text{St}}\]

In view of the relationship between volume V and the maximum rate of pressure rise \((dp/dt)_{\text{max}}\), it does not suffice to specify details for the maximum rate of pressure rise, if volumetric data are not specified at the same time.

Maximum explosion pressure

Maximum pressure produced if a potentially explosive atmosphere explodes at an optimal concentration in a closed tank.
Measures for the Prevention of Sugar Dust Explosions

Maximum rate of pressure rise

Maximum value of the rate of pressure rise produced in a closed tank at optimal concentration when dust explodes (also see “cubic law”)

Median value

Value of mean particle size: 50 wt % of the dust are coarser and 50 wt % are finer than the median value.

Minimum ignition energy

Lowest value of the electric energy stored in a capacitor, which, when varying the parameters of the discharge circuit, will at the point of discharge just suffice to ignite the most readily ignitable dust/air mixture at atmospheric pressure and room temperature.

Minimum ignition temperature of a dust layer

Lowest temperature of an exposed, hot surface, at which a dust layer of defined thickness on that surface ignites (at 5 mm layer thickness identical with the smoulder temperature).

Minimum ignition temperature of a dust cloud (ignition temperature)

Lowest temperature of a hot surface on which the most readily ignitable mixture of the respective dust in air will just ignite.

Normal operation

Condition at which equipment, protective systems and components meet the intended function within their design parameters. The release of small amounts of combustible substances may be part of normal operation. Malfunctions requiring the systems to be repaired or taken out of service cannot be deemed to be part of normal operation. /13/

Limiting oxygen concentration

Experimentally determined oxygen concentration in a dust/air/inert gas mixture, at which, irrespective of the dust concentration, an explosion is just not possible any more. /13/

Auto-ignition of a bulk volume of dust

Ignition of dust caused by situations in which the heat production rate of the oxidation or decomposition reaction of the dust is greater than the rate of heat lost to the environment. /13/

Dust

Solids fines of random shape, structure and density below a particle size of approx. 500 µm.
Measures for the Prevention of Sugar Dust Explosions

**Dust explosion classes**

Classes used for the classification of dusts on the basis of their $K_{St}$ values.

<table>
<thead>
<tr>
<th>Dust explosion class</th>
<th>$K_{St}$ in bar \cdot m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>St 1</td>
<td>$0 &lt; K_{St} \leq 200$</td>
</tr>
<tr>
<td>St 2</td>
<td>$200 &lt; K_{St} \leq 300$</td>
</tr>
<tr>
<td>St 3</td>
<td>$K_{st} \geq 300$</td>
</tr>
</tbody>
</table>

**Dust/air mixture**

Dust suspended in air. Characteristic value is the dust concentration.
### 10.2 Explosion events (major sources of ignition)

<table>
<thead>
<tr>
<th>Category</th>
<th>Source of Ignition</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview</td>
<td>Mechanical sources of ignition</td>
<td>32.7</td>
</tr>
<tr>
<td>Timber</td>
<td>Mechanical sources of ignition</td>
<td>35.9</td>
</tr>
<tr>
<td>Paper</td>
<td>Mechanical sources of ignition</td>
<td>50</td>
</tr>
<tr>
<td>Carbon</td>
<td>Pocket of smouldering material</td>
<td>25.4</td>
</tr>
<tr>
<td>Food and feedstuffs</td>
<td>Mechanical sources of ignition</td>
<td>35</td>
</tr>
<tr>
<td>Plastics</td>
<td>Mechanical sources of ignition</td>
<td>29.2</td>
</tr>
<tr>
<td></td>
<td>Electrostatic discharge</td>
<td>30.8</td>
</tr>
<tr>
<td>Metals</td>
<td>Mechanical sources of ignition</td>
<td>49.4</td>
</tr>
<tr>
<td>Others</td>
<td>Mechanical sources of ignition</td>
<td>23.7</td>
</tr>
<tr>
<td></td>
<td>Electrostatic discharge</td>
<td>23.7</td>
</tr>
</tbody>
</table>

Fig. 9: Distribution of ignition sources established (BIA report 11/97)

**Note:**

It is evident from the graph that at a percentage of 35 %, mechanical sources of ignition stand for the most important explosion potential in the food and feedstuffs industry, and thus also in the sugar industry. This factor has hence to be given particular attention.
10.3 Explosion events (equipment affected)

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silos/bins/hoppers</td>
<td>19.4%</td>
</tr>
<tr>
<td>Timber</td>
<td>34.7%</td>
</tr>
<tr>
<td>Paper</td>
<td>25.0%</td>
</tr>
<tr>
<td>Carbon</td>
<td>22.2%</td>
</tr>
<tr>
<td>Food and feedstuffs</td>
<td>26.9%</td>
</tr>
<tr>
<td>Plastics</td>
<td>15.4%</td>
</tr>
<tr>
<td>Metals</td>
<td>44.1%</td>
</tr>
<tr>
<td>Others</td>
<td>18.6%</td>
</tr>
</tbody>
</table>

Fig. 10: Plant areas concerned, based on dust groups (BIA report 11/97)

Note:
It is evident from the graph, that at a percentage of 26.9 %, conveyors/elevators stand for the most important explosion potential in the food and feedstuffs industry, and thus also in the sugar industry. This type of equipment hence has to be given particular attention.
10.4 Explosion isolation in pipelines

Fig. 11: Quenching medium barrier (automatic flame barrier)
10.5 Pressure development in connection with explosion suppression

![Diagram showing pressure development](image)

Fig. 12: Pressure development when using means of explosion suppression

**Legend**

1. The explosive mixture ignites at $p = 0$ bar, $t = 0$ ms
2. Pressure sensors detect an incipient explosion at $p = 0.10$ bar, $t \approx 35$ ms
3. Suppression by quenching medium addition starts at $p = 0.16$ bar, $t \approx 40$ ms
4. The explosion has been suppressed at $p_{\text{red}} = 0.40$ bar (reduced explosion pressure), $t \approx 60$ ms
5. The flame reaction has been suppressed
10.6 Quick-closing valve for explosion isolation

Fig. 13: Quick-closing valve
10.7 Rotary feed valve for explosion isolation

![Schematic of a rotary feed valve](image)

*Fig. 14: Schematic of a rotary feed valve*
10.8 Pressure relief vent for explosion isolation

Fig. 15: Schematic of a pressure relief vent in a manifold
### 11 Annex (sugar dust)

#### 11.1 Ignition and explosion characteristics of sugar dust

Sugar dust is one of the flammable (exothermally oxidisable) dusts, and, when available as a sufficiently fine dust in a mixture with air, it is also potentially explosive.

The risk for a dust/air mixture to explode is described by ignition and explosion characteristics, which are determined by the fineness (median value) of the dust as one factor. It should be noted, however, that deviations (both higher and lower values) may occur under certain conditions (see, for instance, the overview for sugar dusts shown in the BIA report 12/97/12/). To the present day, not all factors are known that may be of relevance for sugar, in addition to the particle size (e.g. water bound in the crystal, fine structure of particle surface as a function of the production process).

The tables below use a number of sugar dusts as examples to illustrate the fundamental relationships.

<table>
<thead>
<tr>
<th>Median value (µm)</th>
<th>Minimum ignition energy (mJ) (with inductivity)</th>
<th>Minimum ignition energy (mJ) (w/o inductivity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>MIE &lt; 5</td>
<td>5 &lt; MIE &lt; 10</td>
</tr>
<tr>
<td>30</td>
<td>MIE &lt; 10</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>30 &lt; MIE &lt; 100</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>MIE &gt; 1000</td>
<td>MIE &gt; 10</td>
</tr>
<tr>
<td>275</td>
<td>$10^5 &lt; MIE &lt; 10^6$</td>
<td></td>
</tr>
<tr>
<td>300</td>
<td>MIE &lt; $10^6$</td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 16: Fundamental relationship between minimum ignition energy and sugar dust for different particle size distributions*
Measures for the Prevention of Sugar Dust Explosions

<table>
<thead>
<tr>
<th>MW (µm)</th>
<th>LEL (g/m³)</th>
<th>p_max (bar)</th>
<th>K_St (bar m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>60</td>
<td>9.1</td>
<td>140</td>
</tr>
<tr>
<td>80</td>
<td>60</td>
<td>8.3</td>
<td>135</td>
</tr>
<tr>
<td>300</td>
<td>500</td>
<td>4.0</td>
<td>12</td>
</tr>
<tr>
<td>380</td>
<td>no explosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>790</td>
<td>no explosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1250</td>
<td>no explosion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 17: Fundamental relationship between lower explosion limit (LEL), maximum explosion pressure (p_max), K_St value and sugar dust for different particle size distributions

If no concrete characteristics are available for the assessment of the explosion hazard involved with a specific sugar dust that has to be handled, the values shown in Fig. 18 shall be used. Experience shows that these values are on the "safe side" for normal operating conditions (so-called atmospheric conditions).

Dust explosion class: St 1
Max. explosion overpressure p_max: 9 bar
K_St value: 140 bar m/s
Lower explosion limit (LEL): 30 g/m³
Minimum ignition temp. of the dust cloud (ignition temp.): 350 °C (BAM furnace)
Minimum ignition temp. of the 5-mm dust layer (smoulder temperature): 420 °C
Flammability: BZ 2
Minimum ignition temperature: < 5 mJ (with inductivity)
: > 5 mJ/<10 mJ (w/o inductivity)
Melting point: 169 °C
Limiting oxygen concentration: 9 % by volume

Because of its low melting point, sugar dust does not tend to produce pockets of smouldering material.

Fig. 18: Most critical burning and explosion characteristics of sugar dust

Note:
The above figures are average values that may have to be confirmed for actual conditions by measurements. For the terminology used, reference is made to annex 10.1.
11.2 Conventional zone classification for sugar dust
This type of zone classification has in the past proven to be both useful and adequate for safety considerations for different types of industrial plants and sectors.

<table>
<thead>
<tr>
<th>Zone classification for equipment and plant sections in the sugar industry exposed to an explosion risk as a result of sugar dust</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
</tr>
<tr>
<td><strong>with crystallized sugar</strong></td>
<td></td>
</tr>
<tr>
<td>Inside of silos</td>
<td>22</td>
</tr>
<tr>
<td>Screening machine (inside)</td>
<td>21</td>
</tr>
<tr>
<td>Filter (only non-filtered gas end inside the filter)</td>
<td></td>
</tr>
<tr>
<td>a) General: regular cleaning</td>
<td>20</td>
</tr>
<tr>
<td>b) Concentration extracted &lt; LEL, occasional cleaning</td>
<td>21</td>
</tr>
<tr>
<td>Inside of dust arrester piping</td>
<td>22</td>
</tr>
<tr>
<td>Elevator (inside)</td>
<td>21</td>
</tr>
<tr>
<td>Drying drum (inside)</td>
<td>22</td>
</tr>
<tr>
<td>Fluidized-bed dryer (inside)</td>
<td>22</td>
</tr>
<tr>
<td>Sized-crystal bin (inside)</td>
<td></td>
</tr>
<tr>
<td>a) Crystal size coarse &gt; 250 µm</td>
<td>22</td>
</tr>
<tr>
<td>b) Crystal size fine &lt; 250 µm</td>
<td>21</td>
</tr>
<tr>
<td>Pneumatic conveyor system (pinging, transmitting and receiving tank) using</td>
<td></td>
</tr>
<tr>
<td>a) Dense-phase conveying</td>
<td>21</td>
</tr>
<tr>
<td>b) Dilute-phase conveying</td>
<td>20</td>
</tr>
<tr>
<td>c) Plug flow conveying</td>
<td>-</td>
</tr>
<tr>
<td><strong>with powdered sugar</strong></td>
<td></td>
</tr>
<tr>
<td>Powder conditioner (with addition of air)</td>
<td>20</td>
</tr>
<tr>
<td>Powder mill (only inside of mill, milling compartment)</td>
<td>20</td>
</tr>
<tr>
<td>Powder bin (inside only)</td>
<td>20</td>
</tr>
<tr>
<td>Powder screw conveyor / dust screw conveyor with</td>
<td></td>
</tr>
<tr>
<td>a) Circumferential speed slow (v &lt; 1 m/s)</td>
<td>22</td>
</tr>
<tr>
<td>b) Circumferential speed fast (v &gt; 1 m/s)</td>
<td>21</td>
</tr>
</tbody>
</table>
## Plant sections

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>with dust-tight equipment without dust deposits</td>
<td>-</td>
</tr>
<tr>
<td>with non-dust-tight equipment and dust deposits</td>
<td>22</td>
</tr>
<tr>
<td>Exception: deposits reaching hazardous amounts are safely prevented at any time by adequate cleaning schedules!</td>
<td>-</td>
</tr>
</tbody>
</table>

### Note

Classification into zones other than those shown above is conceivable to a certain extent. However, in such a case an extensive risk assessment has to be made to demonstrate in detail on the basis of what assumptions and boundary conditions another way of classification is preferred. These details must be included in the explosion prevention documentation.
12  Annex (pulp and pellet dust)

12.1  Burning and explosion characteristics for pulp and pellet dust

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dust explosion class</td>
<td>St 1</td>
</tr>
<tr>
<td>Max. explosion overpressure $p_{\text{max}}$</td>
<td>8.6 bar</td>
</tr>
<tr>
<td>$K_{\text{St}}$ value</td>
<td>91 bar m/s</td>
</tr>
<tr>
<td>Lower explosion limit (LEL)</td>
<td>125 g/m$^3$</td>
</tr>
<tr>
<td>Ignition temperature</td>
<td>420 °C</td>
</tr>
<tr>
<td>Smoulder temperature</td>
<td>270 °C</td>
</tr>
<tr>
<td>Flammability</td>
<td>BZ 4</td>
</tr>
<tr>
<td>Minimum ignition temperature (350 µm)</td>
<td>&gt; $10^3$ mJ</td>
</tr>
<tr>
<td>Limiting oxygen concentration</td>
<td>9 % by volume</td>
</tr>
</tbody>
</table>

*Note:*
*The above figures are average values that may have to be confirmed for actual conditions by measurements. For the terminology used, reference is made to annex 10.1.*
12.2 Conventional zone classification for pulp and pellet dust

This type of zone classification has in the past proven to be both useful and adequate for safety considerations for different types of industrial plants and sectors.

<table>
<thead>
<tr>
<th>Zone classification for equipment and plant sections in the sugar industry exposed to an explosion risk as a result of pulp and pellet dust</th>
<th>Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
</tr>
<tr>
<td>Fluidized-bed/steam dryer (inside)</td>
<td>-</td>
</tr>
<tr>
<td>Pulp drying drum (discharge section inside the drum)</td>
<td>22</td>
</tr>
<tr>
<td>Cyclone (inside) downstream of pellet drying drum</td>
<td>22</td>
</tr>
<tr>
<td>Bucket elevator for dried pulp (inside)</td>
<td>21</td>
</tr>
<tr>
<td>Distributor screw conveyor for dried pulp (inside, upstream of pulp hopper)</td>
<td>22</td>
</tr>
<tr>
<td>Dried-pulp hopper (inside, upstream of feeder screw)</td>
<td>22</td>
</tr>
<tr>
<td>Feeder screw (inside, upstream of press, no molasses added upstream of press)</td>
<td>22</td>
</tr>
<tr>
<td>Feeder screw (inside, upstream of press, molasses added upstream of press)</td>
<td>-</td>
</tr>
<tr>
<td>Pellet press (pelleting compartment only)</td>
<td>-</td>
</tr>
<tr>
<td>Gravity screen/pipe (downstream of pellet press, upstream of pellet cooler)</td>
<td>22</td>
</tr>
<tr>
<td>Conveyor belt (at discharge end), e.g. flexible wall belt conveyor</td>
<td>22</td>
</tr>
<tr>
<td>Pellet cooler (inside only)</td>
<td>22</td>
</tr>
<tr>
<td>Fan (downstream of pellet cooler, upstream of cyclone)</td>
<td>22</td>
</tr>
<tr>
<td>Cyclone (inside; to remove dust from pellet cooler)</td>
<td>22</td>
</tr>
<tr>
<td>Bucket elevator for pellets (inside the trunks)</td>
<td>21</td>
</tr>
<tr>
<td>Screw conveyor or flexible wall belt conveyor for pellets (for post-handling)</td>
<td>22</td>
</tr>
<tr>
<td>Storehouse (bulk storage; pellets dropped from storehouse ceiling)</td>
<td>22</td>
</tr>
<tr>
<td>Silo/hopper interior (when pellets are dropped from silo/hopper ceiling)</td>
<td>22</td>
</tr>
<tr>
<td>Pellet loading station (see plant sections)</td>
<td>22/-</td>
</tr>
</tbody>
</table>

Filters for dust removal in conveying paths (only non-filtered gas end of interior))

- **a)** General: regular cleaning | 20 |
- **b)** Exceptions: concentration extracted < LEL and occasional cleaning | 21 |
- Inside of dust arrester piping (concentration extracted < LEL) | 22 |

Pellet dust screw conveyor (inside)

- **a)** Circumferential speed slow (v < 1 m/s) | 22 |
- **b)** Circumferential speed fast (v > 1 m/s) | 21 |
Measures for the Prevention of Sugar Dust Explosions

<table>
<thead>
<tr>
<th>Plant sections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>with dust-tight equipment without dust deposits</td>
<td>-</td>
</tr>
<tr>
<td>with non-dust-tight equipment and dust deposits</td>
<td>22</td>
</tr>
<tr>
<td>Exception: deposits reaching hazardous amounts are safely prevented at any time by adequate cleaning schedules!</td>
<td>-</td>
</tr>
</tbody>
</table>

**Note**

Classification into zones other than those shown above is conceivable to a certain extent. However, in such a case an extensive risk assessment has to be made to demonstrate in detail on the basis of what assumptions and boundary conditions another way of classification is preferred. These details must be included in the explosion prevention documentation.
13 References

13.1 Regulations and tables

[1] BGV A 1 (VBG 1)
Allgemeine Vorschriften
(General regulations)

[2] BGV D 1 (VBG 15)
Schweißen, Schneiden und verwandte Arbeitsverfahren
(Welding, flame cutting and similar techniques)

[3] BGV C 12 (VBG 112)
Silos

[4] BGR 104 (ZH 1/10)
Regeln für Sicherheit und Gesundheitsschutz bei der Arbeit
- Explosionsschutz-Regeln
(Regeln für die Vermeidung der Gefahren durch explosionsfähige Atmosphäre mit Beispielsammlung)
(Regulations for the prevention of hazards as a result of explosive atmospheres, with examples)

Richtlinie zur Vermeidung der Gefahren von Staubbränden und Staubexplosionen beim Schleifen, Bürsten und Polieren von Aluminium und seinen Legierungen
(Regulations on the prevention of hazards as a result of dust fires and dust explosions when grinding, brushing, polishing aluminium and its alloys)

[6] BGR 121 (ZH 1/140)
Regeln für Sicherheit und Gesundheitsschutz an Arbeitsplätzen mit Arbeitssplatzlüftung
(Regulations for industrial safety and health at ventilated work places)

[7] ZH 1/180
Sicherheitsregeln für Anforderungen an ortsfeste Sauerstoffwarneinrichtungen für den Explosionsschutz
(Safety regulations for requirements on stationary oxygen signalling devices used for explosion protection)

[8] BGR 132 (ZH 1/200)
Richtlinien für die Vermeidung von Zündgefahren infolge elektrostatischer Aufladungen (Richtlinien “Statische Elektrizität”)
(Regulations for the prevention of ignition hazards as a result of electrostatic charging)

[9] BGR 133 (ZH 1/201)
Regeln für die Ausrüstung von Arbeitsstätten mit Feuerlöschern
(Regulations for the provision of fire extinguishers at work places)

[10] Dispensed with
Measures for the Prevention of Sugar Dust Explosions

Sicherheitsregeln für den Explosionsschutz bei der Konstruktion und Er-richtung von Wirbelschichtsprühgranulatoren, Wirbelschichttrocknern, Wir-belschichtcoatinganlagen
(Safety regulations for explosion protection in the design and installation of fluidized-bed spray granulators, fluidized-bed dryers, fluidized-bed coating systems)

Brenn- und Explosionskenngrößen von Stäuben
Berufsgenossenschaftliches Institut für Arbeitssicherheit Dezember 1997
(Burning and explosion characteristics in dusts)

[13] DIN EN 1127-1
Explosionsfähige Atmosphären
Explosionsschutz
Teil 1: Grundlagen und Methodik
German version EN 1127-1:1997
(Explosive atmospheres, explosion protection Part 1: Fundamental principles and methods)

[14] DIN EN 60079 Teil 19/ VDI 0165 Teil 201 Entwurf
German version IEC 31J(CO)7
Errichten elektrischer Anlagen in explosionsgefährdeten Bereichen Reparatur und Überholung von Betriebsmitteln für den Einsatz in explo-sionsgefährdeten Bereichen Februar 1993
(Installation of electrical equipment in hazardous areas Repair and maintenance of operators intended for use in hazardous areas)

[15] DIN VDE 0165
Errichten elektrischer Anlagen in explosionsgefährdeten Bereichen Februar 1991
(Installation of electrical equipment in hazardous areas)

[16] DIN VDE 0170/0171 Teil 13
Elektrische Betriebsmittel für explosionsgefährdete Bereiche Anforderungen für Betriebsmittel der Zone 10 November 1986
(Electrical operators for hazardous areas Requirements for zone-10 operators)

[17] DIN VDE 0170/0171 Teil 1
Elektrische Betriebsmittel für explosionsgefährdete Bereiche Allgemeine Bestimmungen 1998
(Electrical operators for hazardous areas General conditions)

[18] VDI 2263
Staubbrände und Staubexplosionen Gefahren - Beurteilung - Schutzmaßnahmen Mai 1992
(Dust fires and dust explosions Hazards – Assessment – Protection measures)
Measures for the Prevention of Sugar Dust Explosions

[19] VDI 2263 Blatt 1
Staubbrände und Staubexplosionen
Gefahren - Beurteilung - Schutzmaßnahmen
Untersuchungsmethoden zur Ermittlung von sicherheitstechnischen
Kenngrößen von Stäuben
Mai 1990
(Dust fires and dust explosions
Hazards – Assessment – Protection measures
Analysing methods for determining safety-specific characteristics of dusts)

[20] VDI 2263 Blatt 2
Staubbrände und Staubexplosionen
Gefahren - Beurteilung - Schutzmaßnahmen
Inertisierung
Mai 1992
(Dust fires and dust explosions
Inertisation)

[21] VDI 2263 Blatt 3
Staubbrände und Staubexplosionen
Gefahren - Beurteilung - Schutzmaßnahmen
Explosionsdruckstoßfeste Behälter und Apparate
Berechnung - Bau - Prüfung
Mai 1990
(Dust fires and dust explosions
Hazards – Assessment – Protection measures
Explosion pressure shock resistant tanks and equipment
Design – Construction – Testing)

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