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Section on Prevention in the Chemical Industry
Section on Machine and System Safety

Explosion Safety of Bulk Material Plants
Module: Storage

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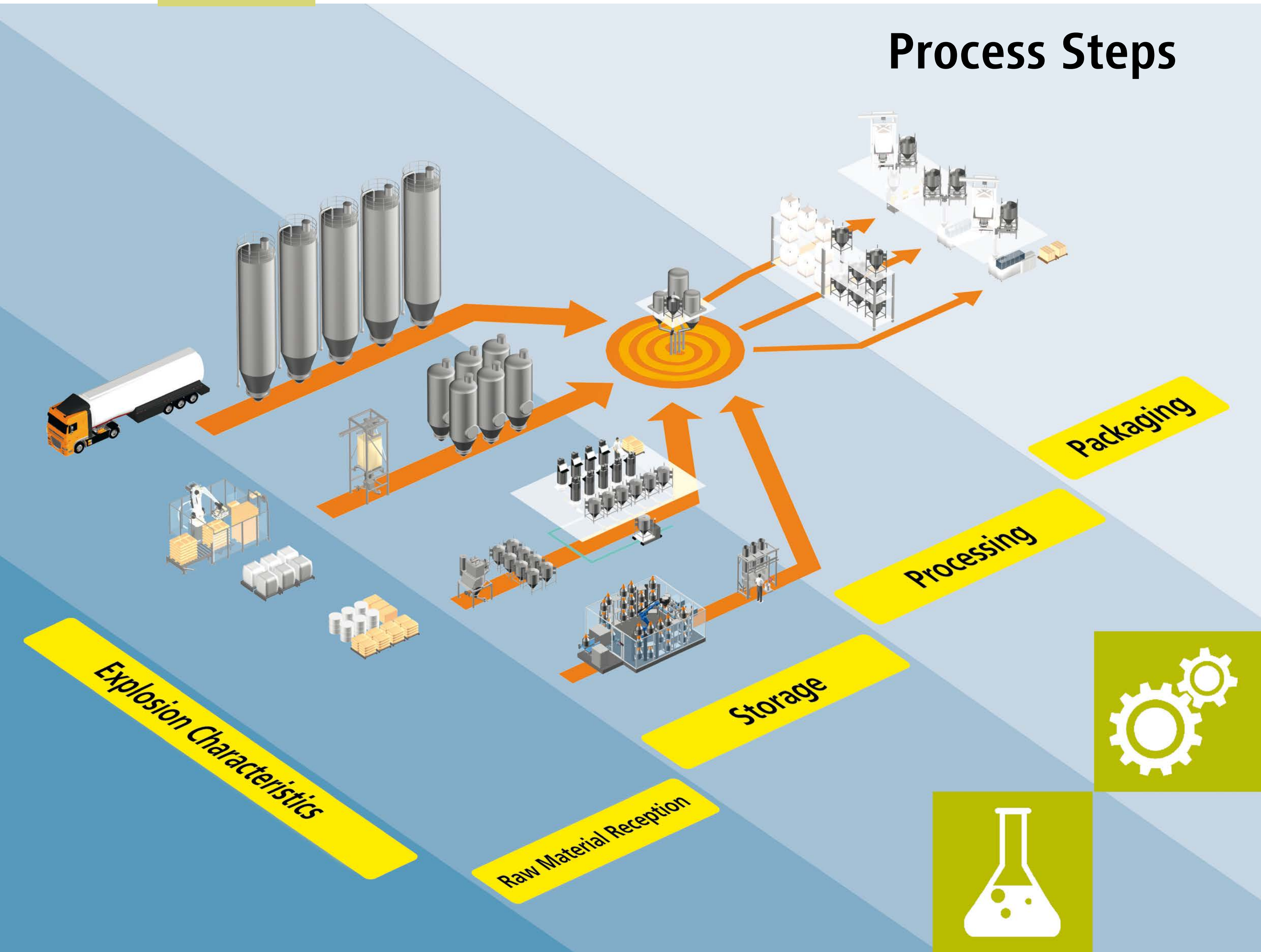

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Explosion Safety of Bulk Material Plants
Module: Storage

Legal regulations refer to both the employer and the entrepreneur. The two terms are not completely identical because entrepreneurs do not necessarily have employees. In the context of the present topic, this does not result in any relevant differences, so that these terms are used synonymously.

To facilitate readability, the forms chosen for personal designations (e.g. employer, entrepreneur) apply to both genders in this brochure.

Content

Foreword

The use of complex systems/equipment requires a suitable risk assessment for each individual explosion risk.

For these ISSA brochures „Modular Structure“, a concept has been developed which makes it easier to divide the explosion risk assessment for a plant into smaller units, so-called „modules“. In addition to a clear layout, this enables a targeted and process-oriented approach. This allows individual assessments of machines from the ISSA example collections „Dust Explosion Protection for Machines and Equipment“ Part 1 and Part 2 and of processes/modules from this series of ISSA brochures to be used and linked together at the end for the overall plant risk assessment.

Individual process steps or machines can be better evaluated. In the end, only the individual interfaces need to be considered in order to obtain the overall concept of the risk assessment.

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President of the Section on
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1 Introduction

In the „storage“ process step, flammable and dust-explosive bulk materials are stored in halls, bunkers and containers. Silos made of metals, concrete, plastic or flexible fabrics are also used. If nothing else is indicated, it is assumed that the bulk material is free of flammable solvents and the environment of the product is free of flammable gases and vapors (see module: Safety-related parameters).

The module consists of:
- Filling of halls, bunkers, containers or silos with bulk materials
- Ventilation through filters
- Storage in halls, bunkers, containers or silos
- Measuring process data (e.g. filling level, temperature)
- Discharge of bulk materials

Figure 1:
Silo plant with outdoor silos (AZO GmbH + Co. KG)

Figure 2:
Storage silo with filling device for silo vehicles (AZO GmbH + Co. KG)

Storage of bulk materials is not always the first process step. Therefore, the product properties (including explosion characteristics) must be taken over from previous steps. Explosion characteristics should be provided by the supplier of the bulk material.

Incoming and quality control, clear identification of the bulk material used and its properties (coarse/fine dust, foreign matter, moisture, smoldering nests) are necessary. Bulk materials can change due to previous process steps (e.g. due to abrasion, temperature increase, etc.) and thus possibly contain more fine dust. The ignition sensitivity to the preceding process step may also change.

2 Process description

2.1 Examples of silo storage

Purpose of silos

Bulk materials produced or processed in a production process are often stocked as raw materials, buffered as intermediate products or stored as finished products.
The bulk material is discharged from the respective storage container and usually fed to the downstream process by means of mechanical conveyors.
Individual devices such as storage containers, discharge and conveying elements must meet the bulk material and process requirements in terms of their properties.

These devices are usually coordinated with each other in terms of process technology.
Often silo cells have large volumes and/or an elongated shape.
Silo cells can be placed outdoors or be parts of building complexes. They can represent a single plant with filling and emptying processes, but they can also be combined in „batteries" and connected to each other by a variety of transport and dust-collecting devices.

Figure 3:
Outdoor silo with process plant (AZO GmbH + Co. KG)

Figure 4:
Separator with pressure venting flap on buffer tank (AZO GmbH + Co. KG)

Figure 5:
Silo filling via cyclone separator with lateral explosion venting (AZO GmbH + Co. KG)

Silos and containers for storage of bulk materials are dust-tight in their typical design. Filter and relief valve exhaust air should be ducted to the outdoors for indoor silos or kept clean and functional using good cleaning practices. Organizational measures, such as good cleaning practices, prevent dust buildup in buildings. This can avoid the designation of a zone for explosive atmospheres in the vicinity of the storage containers (see also 4.5.3 Organizational measures).

2.2 Filling the silos with bulk materials

Bulk materials are fed into the containers/silos e.g. by gravity (from separators) or with conveying elements (see ISSA Brochure Collection of Examples Part 2 Continuous conveyors, Transfers and Receivers).
The introduction of possible ignition sources during filling from the upstream process must be avoided.

Figure 6:
Silo filling via bag filling hopper (AZO GmbH + Co. KG)

Figure 7:
Silo filling from FIBCs, emptying of FIBCs by gravity (AZO GmbH + Co. KG)

Figure 8:
Silo filling via rotary pipe distributor (AZO GmbH + Co. KG)

2.2.1. Transfer points by filling devices

The mechanical feeders in Fig. 9 are characterized by very high product throughputs and low drive powers. However, they require a lot of space and become very complicated in branched production lines.

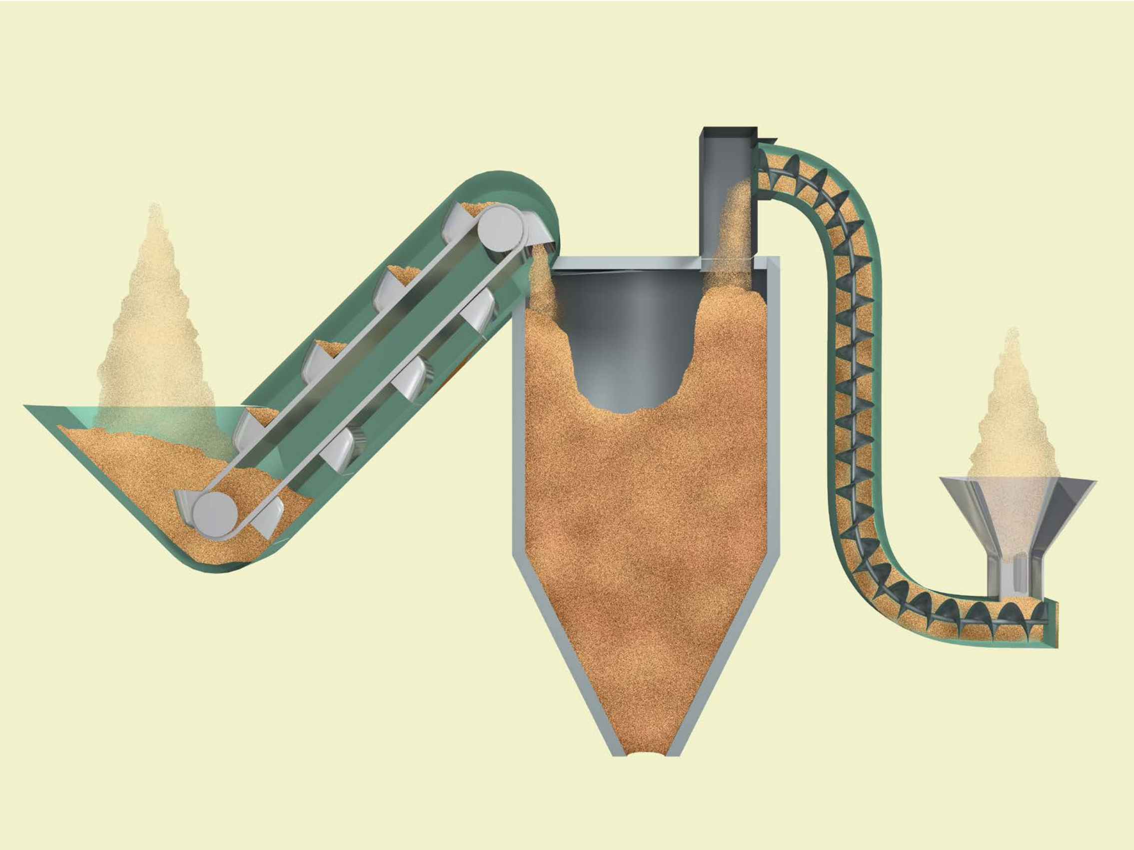


Figure 9:
System diagram to illustrate two filling methods
Left: Product infeed via a mechanical bucket conveyor
Right: Product infeed via a flexible screw

Pneumatic conveyors are the most commonly used feeding equipment. For bulk material production, the arrangements shown in Figs. 10 and 11 can be considered. The conveyor system with a number of two-way diverters as shown in Fig. 10 permits simple line routing in the case of relatively closely spaced silos. Another advantage is that the exhaust air lines of the individual containers can be connected to each other, so that a dust filter only has to be installed on one silo.

1 Suction filter
2 Compressor / blower
3 Spark barrier
4 Non-return valve
5 Pouring funnel
6 Filter for feed hopper
7 Filling opening for the product
8 Fan for suction
9 Discharge airlock
10 Conveying line „Pressure“
11 Pipe diverter
12 Silo
13 Silo vent filter
14 Discharge device
15 Discharge airlock
16 Suction conveying line

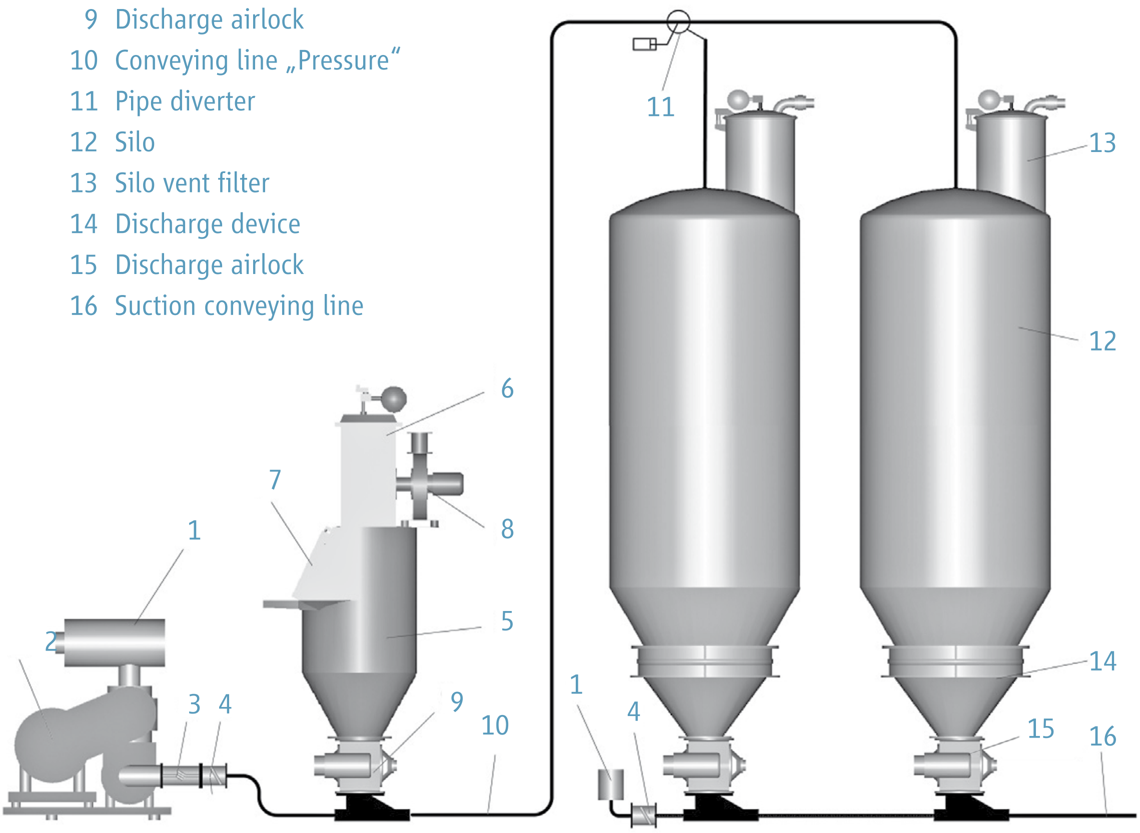


Figure 10:
Example of pneumatic pressure conveying for filling (emptying is done by suction conveying.)
(AZO GmbH + Co. KG)

Pneumatic pressure conveying is always advantageous when several receiving containers are to be filled from one feeding point.
The vacuum conveying system shown in Fig. 11 requires only one suction blower to transport the bulk material from several silos to one discharge point.
Conductive piping should preferably be used. If flexible lines (e.g. hoses made of plastic or rubber) are used, they must comply with the relevant requirements regarding conductivity (in Germany: TRGS 727).

1 Suction filter
2 Non-return valve
3 Pipe diverter
4 Silo
5 Silo vent filter
6 Discharge device
7 Discharge airlock
8 Suction conveying line
9 Filtering separator
10 Filter
11 Clean air line
12 Secondary filter
13 Vacuum pump
14 End flap
15 Mixer

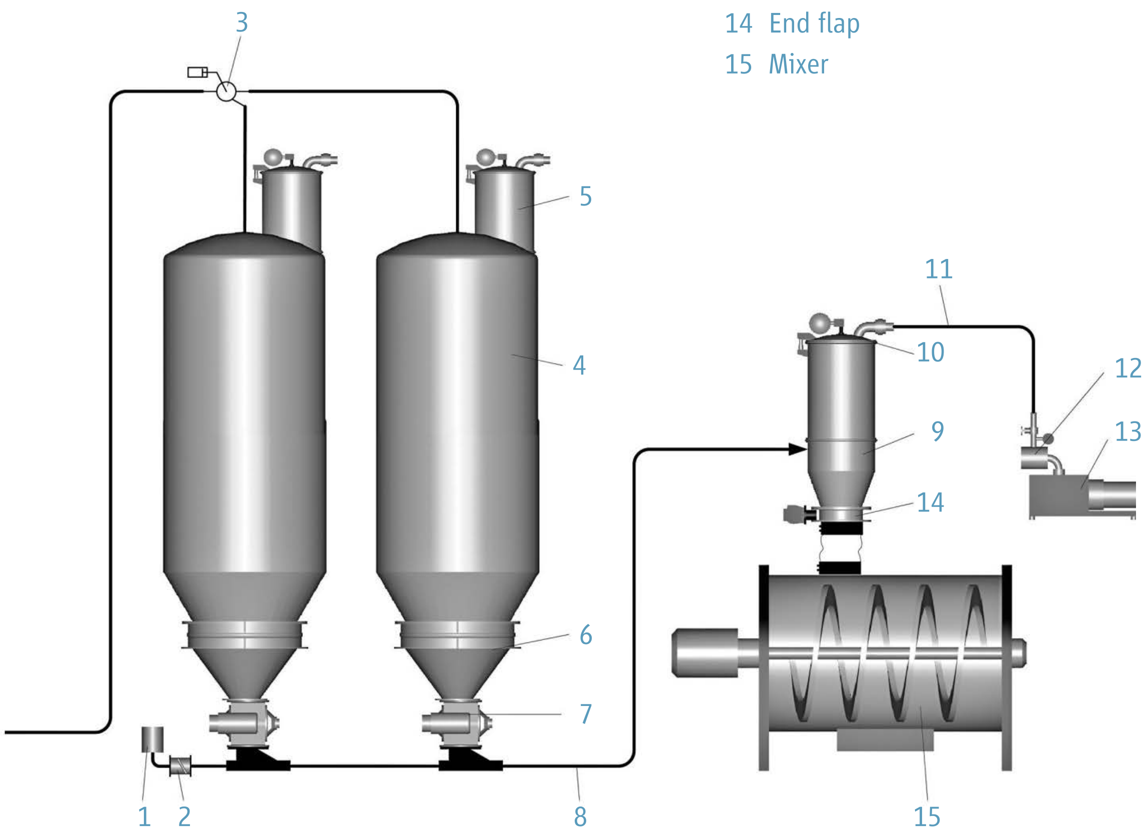


Figure 11:
Example of a pneumatic suction conveying. (AZO GmbH & Co. KG)

The following Figs. 12, 13 and 14 show practical examples in which stationary silos are filled from silo trucks by means of pneumatic pressure conveying.
In pneumatic pressure conveying, silos or containers are usually filled through NW 80 to 100 pipelines either from silo trucks with their own compressors, by stationary blowers or sender vessels. Grounding of the silo vehicle is mandatory.

Figure 13:
Silo vehicle in tipping position for filling the storage silos. (AZO GmbH + Co. KG)

Figure 12:
Silo vehicle connected to filling lines of storage silos. (AZO GmbH + Co. KG)

Figure 14:
Stationary blower with integrated spark barrier and downstream cooler for conditioning the conveying air. (AZO GmbH + Co. KG)

Ventilation and cooling units are necessary to prevent self-ignition (see also Fig. 14).
In the case of round containers, the filling line is in most cases inserted tangentially just below the roof end, which is associated with a rotational material inlet with a „pre-separating" effect.
The disadvantage of this type of filling is that the silo or container wall itself is exposed to direct wear, which can only be countered by installing appropriate wear plates. However, the replacement of these plates is very time-consuming and costly.
It is much more practical to install a so-called injection dome on the silo ceiling, e.g. also in the case of angular containers or multi-chamber silos, which is much easier to handle in terms of maintenance.
Such an injection dome typically has a diameter of about 600–800 mm with a corresponding construction height.
The installation of an injection dome on the silo ceiling has the great advantage of a relatively low air, material and discharge velocity into the container. This also significantly reduces the turbulence in the upper part of the silo and thus the dust loading for an attached filter. In the event of an explosion, these influences significantly reduce the explosion severity.

Figure 15:
Silo ventilation filters designed as purge air filters (A, B: bag filter, C: pocket filter)
(A, B: AZO GmbH + Co. KG, C: WAM GmbH)

During pneumatic filling of silos, the exhaust air filters are very heavily loaded with increasing dust content and decreasing grain size. The dimensioning of the vent filter system depends on:

- the conveying air volume,
- the physical and chemical properties of the product,
- the tank truck volume,
- the so-called final surge and
- the arrangement and length of the filling line.

For silo or storage tank venting, filters with mechanical/motor as well as compressed air cleaning technology can be considered.

2.3 Storage of bulk materials

Individual closed containers and silos as well as open and closed storage halls are used for storing bulk materials. The following figures (Fig. 16) represent an overview of possible storage cells.

Figure 16:
Closed storage containers made of different wall materials
A: Outdoor silos aluminum/stainless steel B: Indoor silos stainless steel C: Indoor silos flexible
(AZO GmbH + Co. KG)

Figure 17:
Flat-floor silos with integrated clearing screws (Prof. Siegfried Radandt)

The clearing screw must not be operated during the filling process. It must be locked for safety reasons. In the event of a fault, hot surfaces may occur due to internal bearings. These represent a potential source of ignition that can subsequently lead to a fire or explosion.
Relocation of bulk materials may be necessary if the bulk materials tend to solidify over time or self-heat, for example. Caking and bridging are prevented by rearrangement, and self-heating is significantly reduced.

Increased dust cloud formation is to be expected during open bulk handling. Explosion-proof charging and discharging equipment must be used for flammable bulk materials.

Figure 18:
Hall with loose storage (Prof. Siegfried Radandt)

Figure 19:
Dust cloud formation during open bulk handling
(Prof. Siegfried Radandt)

2.4 Emptying

2.4.1 Function description

The bulk materials are fed into the silo from above. They completely fill the silo space from the bottom up to the full detector. The full detector prevents overfilling of the silo.
The displaced air and any air introduced by pneumatic conveying is cleaned and escapes through the filter.

Bulk materials have different flow properties, which are indicated by the ff_c value ($ff_c < 1$ non-flowing, up to $ff_c > 10$ free-flowing) and which can be represented in different flow profiles (mass flow or core flow) (see Fig. 22).
The ff_c value is determined by shear tests according to the principle of A. W. Jenike with measurements of the compressive strength σ_c versus the respective hardening stress σ_1 (see Fig. 20).
Based on the results of the shear tests, the required silo geometries (cone angle, outlet diameter, etc.) are determined.

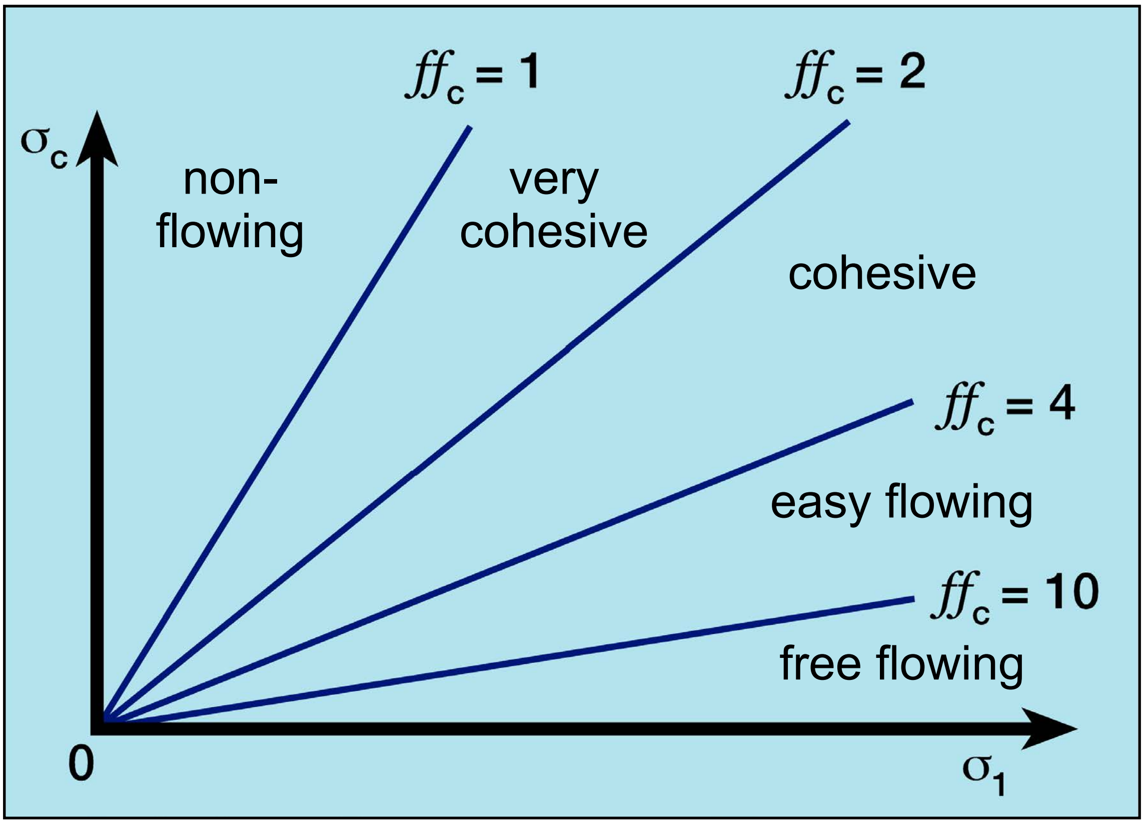


Figure 20:
Areas of different flowability ff_c in σ_c, σ_1 diagram

Bulk material	Bulk density (kg/l)	Flowability factor ff_c
Cornstarch	0,64	10
Cellulose	0,32	3
Malt dust	0,22	6
Powdered sugar	0,60	2
Milk powder	0,56	4
Wood powder	0,23	5
Wheat flour	0,54	3
Granulated sugar	0,85	9
Grain	0,70	11

Figure 21:
Flowability factor ff_c for typical bulk material

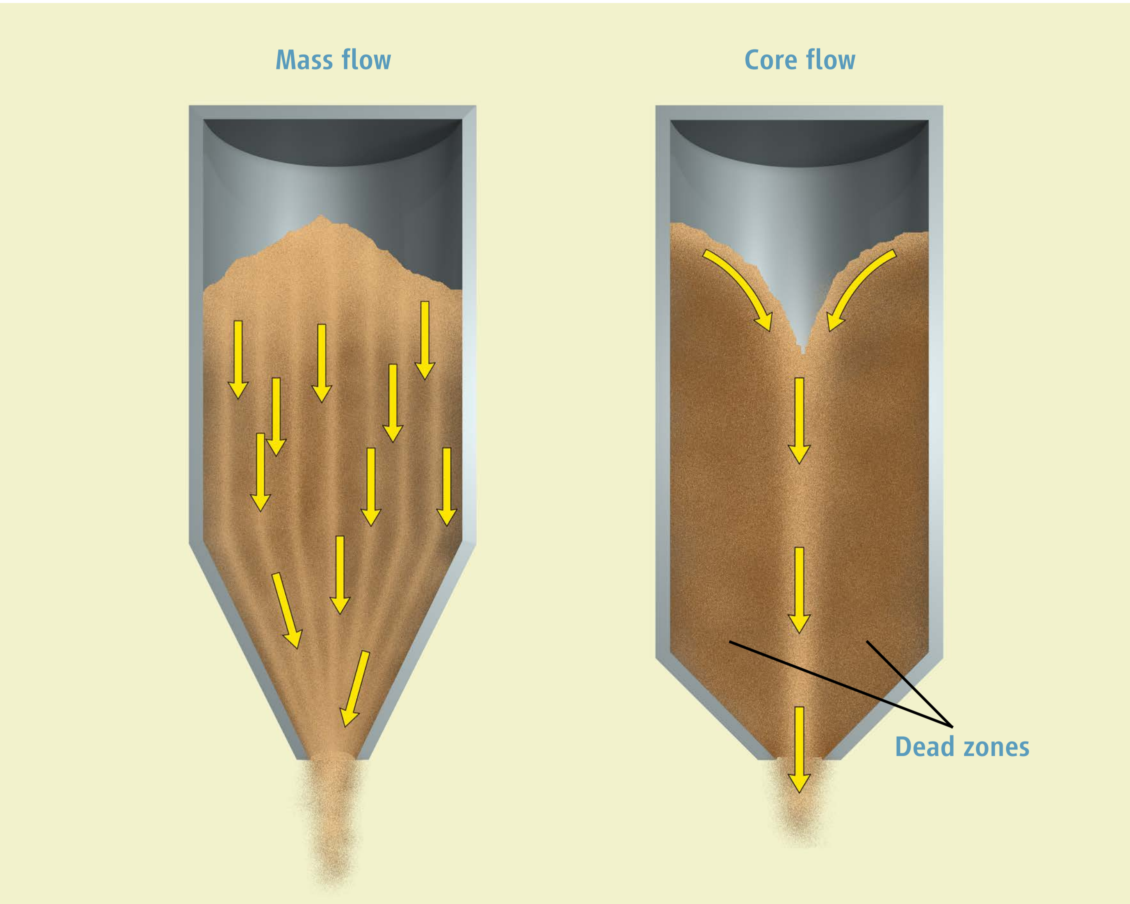


Figure 22:
Flow profiles of bulk materials

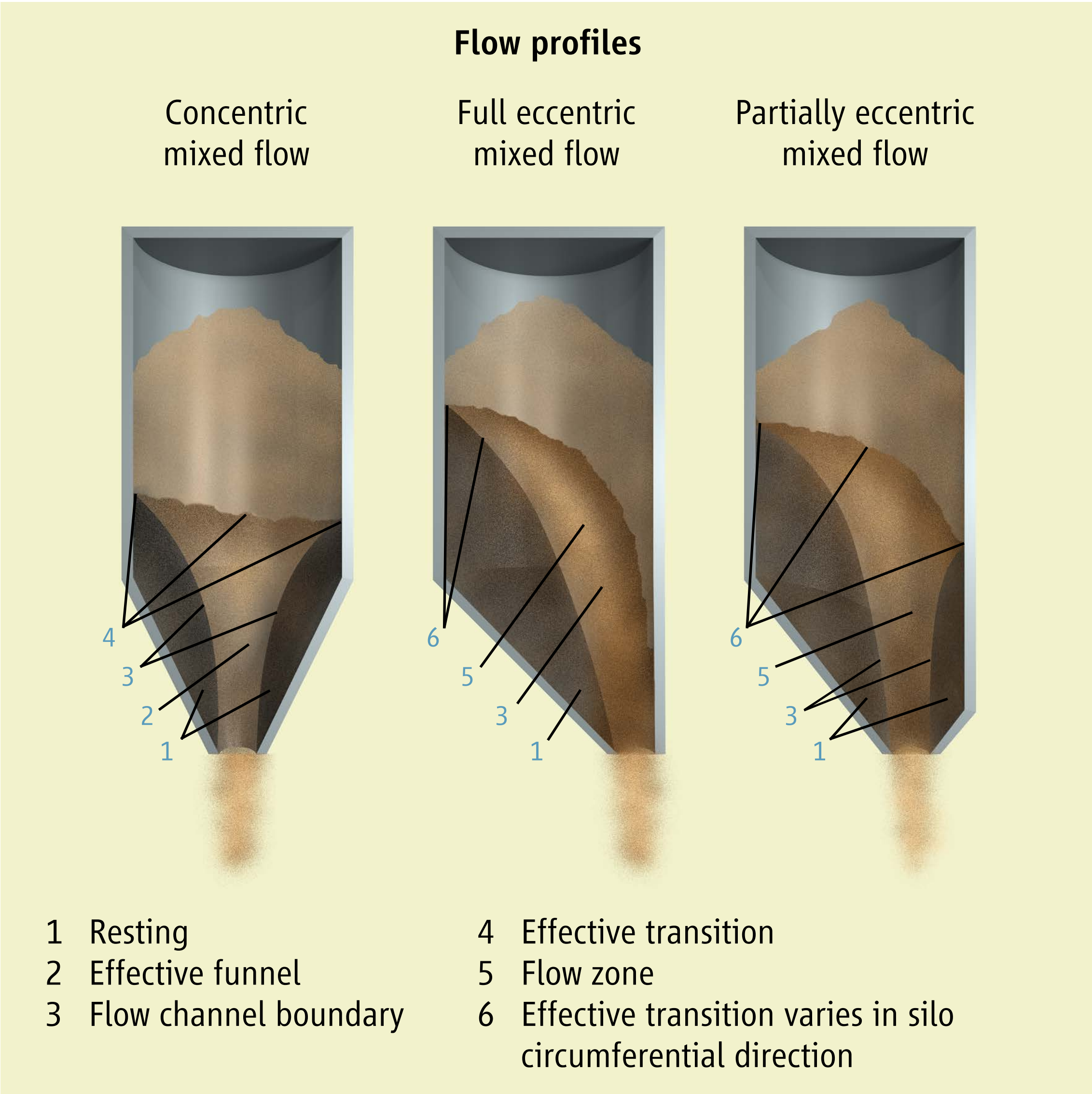


Figure 23:
Flow diagrams of poorly flowing bulk materials

In the case of poorly flowing bulk materials (e.g. cohesive, moisture-containing bulk materials or bulk materials with very different particle size distributions), negative flow situations can occur in the form of bridging or shaft formation (see Fig. 23) during discharge.

In dead zones in particular, there is a risk of heating with subsequent self-ignition in the case of products that have a tendency to self ignite.
In the case of core flow or shaft formation, explosion decoupling by means of the „product plug" measure is not suitable.

2.4.2. Transfer points discharge

Figure 24:
A): Silo emptying via a loading telescope (AZO GmbH + Co. KG)
B): Loading telescope in detail

Emptying and loading equipment
The explosion risks of the emptying and loading equipment shown here is provided in the brochure „Collection of Examples – Dust Explosion Prevention and Protection for Machines and Equipment – Part 2". The measures to avoid explosion risks can also be found in this brochure.
Discharge by gravity, according to Fig. 24, is mainly used for filling silo vehicles.

For filling silo vehicles, the so-called loading telescopes shown in Fig. 24 are used almost exclusively in Europe, so that height differences of the individual silo vehicles of up to approx. 1 m can be compensated.

Screw feeders (see Fig. 25 and Fig. 27) and vibratory feeders (see Fig. 26) are used when a defined flow of bulk material has to be discharged.

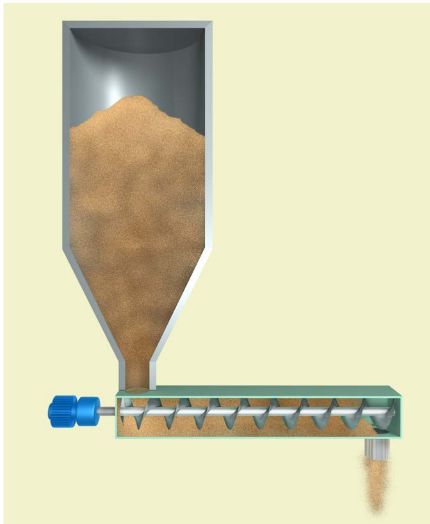


Figure 25:
Screw feeder (left: AZO GmbH + Co. KG)

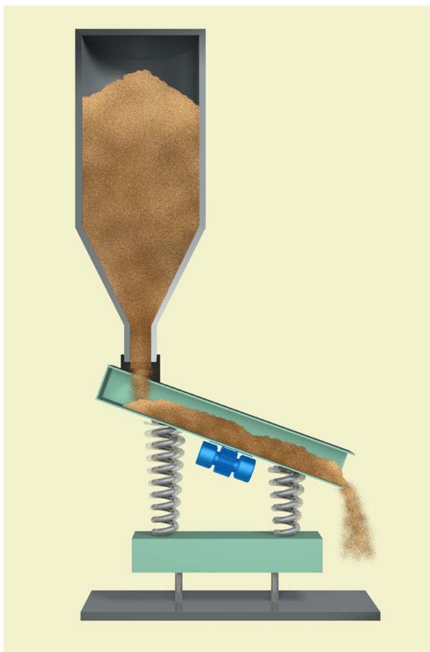


Figure 26:
Silo emptying via a vibrating chute
(left: AZO GmbH + Co. KG)

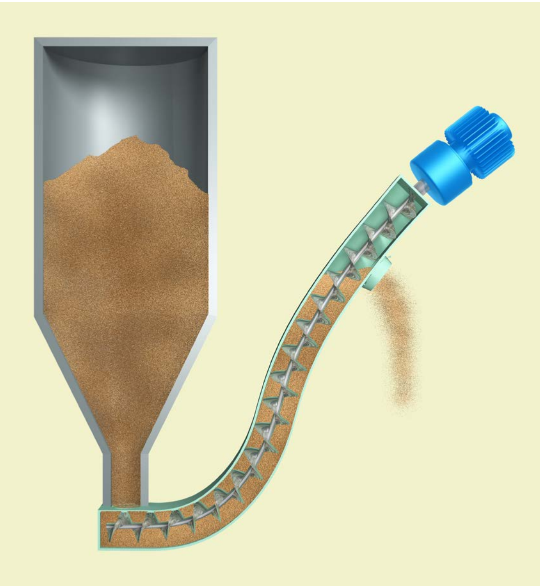
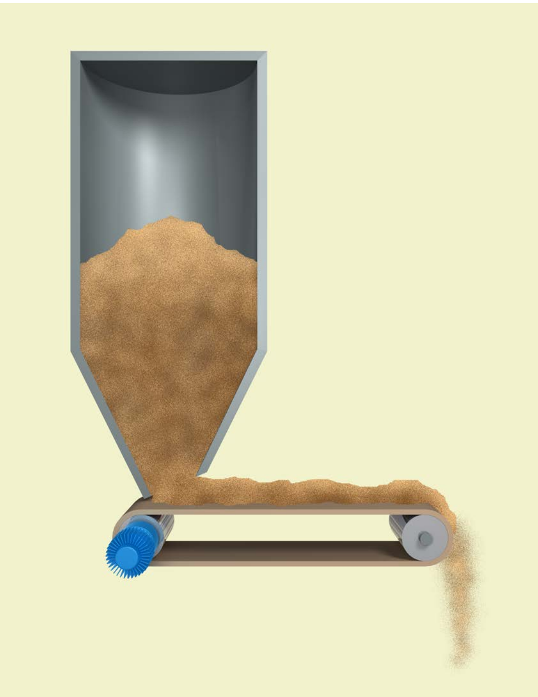


Figure 27:
Silo emptying by means of flexible inclined screw conveyor



The belt conveyors and trough chain conveyors shown in Fig. 28 and Fig. 29 are used when very large product throughputs have to be transported over long distances.

Figure 28:
Belt conveyor for transporting large quantities of product over long distances (AZO GmbH + Co. KG)

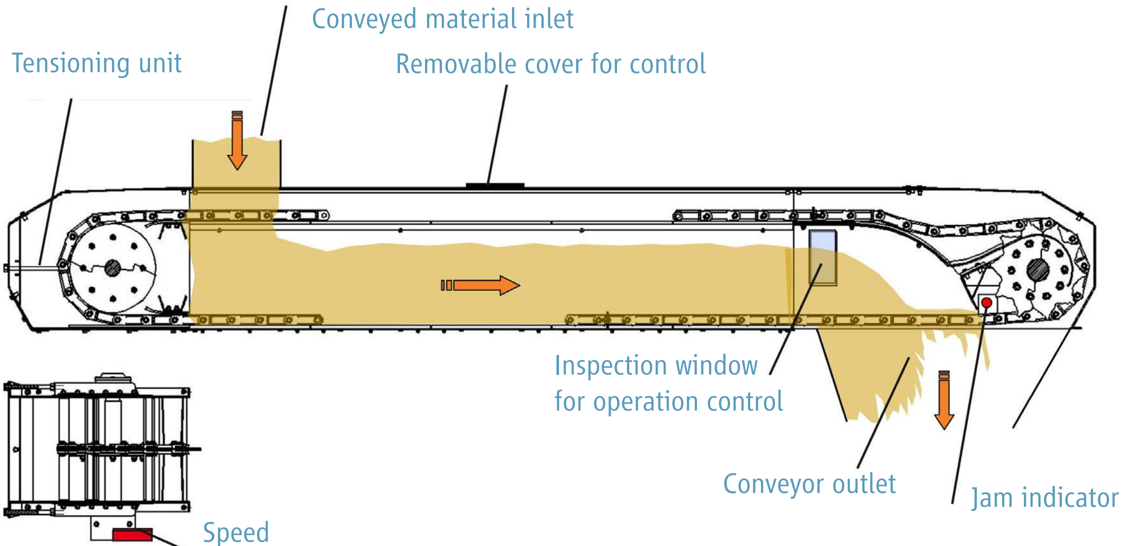
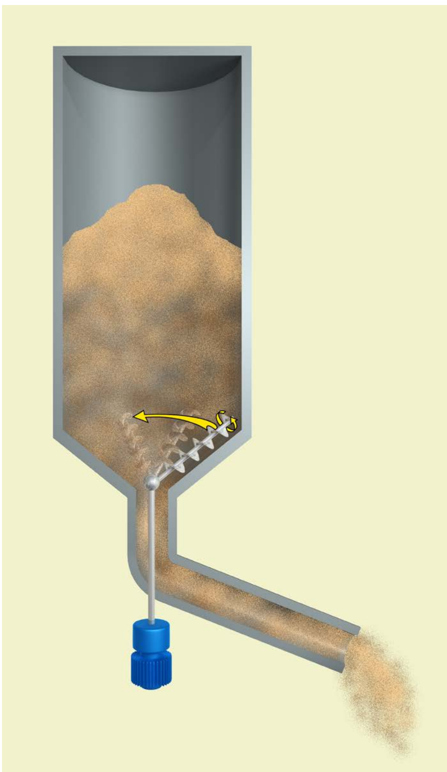


Figure 29:
Diagram of a trough chain conveyor

Sometimes scrapers or clearing screws (see Fig. 30) are used for silo floors with very slight slopes or also for flat-floor silos with large diameters.



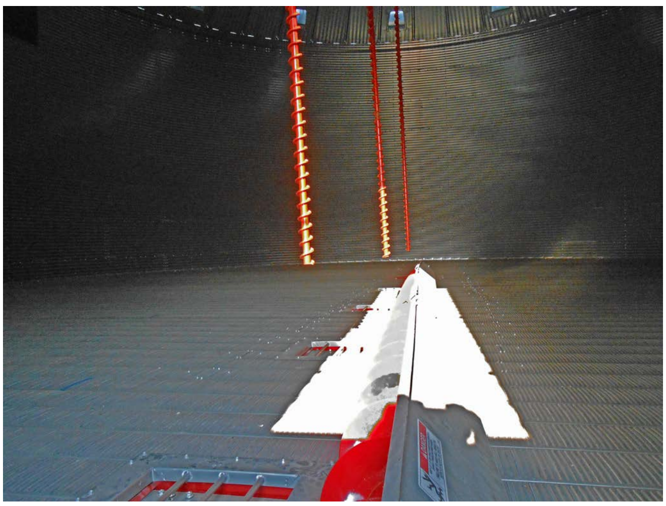


Figure 30:
Clearing screws

To avoid ignition sources, the vertical clearing screws must be switched off during the filling process. The horizontal screw may only run when it is covered with sufficient product.

Probably the most commonly used discharge device is the rotary air lock (see Fig. 31), in which the circulating chambers are filled from the silo by gravity and discharged on the discharge side.

Figure 31:
Silo row with discharge into pneumatic conveying lines by means of rotary air lock (AZO GmbH + Co. KG)

Pneumatic silo emptying equipment
If the containers to be emptied are close together in a row, a common pneumatic emptying line can be laid under all discharge openings and the feeding of the bulk material can be controlled alternately from silo to silo via rotary valves.
If the silos to be emptied are relatively far apart, then the pneumatic conveying system operating in pressure mode is recommended (see Figs. 10 and 11). The disadvantage, however, is that a separate air compressor is required for each conveying line. This disadvantage can be avoided by installing a suction conveying system.
For conveying distances up to approx. 30 m and bulk materials with grain sizes between approx. 20 and 500 µm, flow channels can also be used for emptying the silos.

Discharge aids for non-free-flowing bulk materials
Many bulk materials with particle sizes below approx. 10 µm as well as coarse, fibrous products tend to bridge in silos.
The smallest possible diameter of a silo outlet at which trouble-free discharge without bridging is possible is called the critical diameter. If the silo cone has to be drawn to a smaller diameter, discharge aids are required, the most important of which are summarized in the following figures.
Vibrating floors (see Fig. 32) are very common, but they have the disadvantage that they can additionally compact the bulk material in the silo if the subsequently installed discharge device is not properly dimensioned.
With the vibrating grate, only insignificant vertical forces are transmitted to the fill. Therefore, the compaction is negligible.

Figure 32:
Silo discharge with vibrating floor and rotary air lock (AZO GmbH + Co. KG)

Figure 33:
Ventilation floor (AZO GmbH + Co. KG)

In the pneumatic discharge aids, air (see Fig. 33) is fed continuously into the bulk material through porous plates or intermittently through the discharge cone.
In the case of the „air cannons", a compressed volume of air is suddenly released from small storage tanks into the silo.

Another discharge aid is the discharge screw. Under a silo with precisely calculated slot outlet, it does not allow bridging. Most bulk materials can be discharged perfectly, provided that the bulk material properties have been sufficiently taken into account when determining the angle of inclination of the cone.

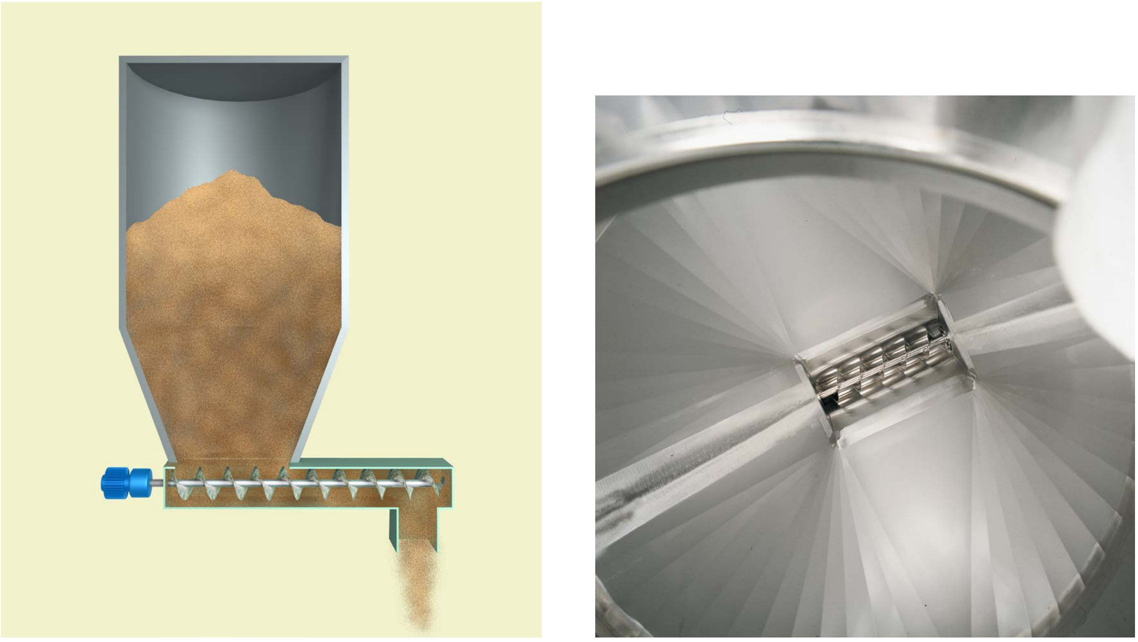


Figure 34:
Silo cone with horizontal clearing screw (right: AZO GmbH + Co. KG)

3 Safety characteristics

As a rule, not all characteristics have to be determined for a specific protection concept or a safe design of silos. However, it requires some experience which characteristics are required and how to apply them correctly.
Safety characteristics of dusts are very dependent on the nature of the dust, such as particle size distribution, particle shape, moisture and composition. Data not explicitly generated from a representative sample of the handled product should be used with caution. This applies in particular to data from safety data sheets or databases, where information on the product is not usually detailed.
In addition to the particle size, which depends among other things on crushing processes and other mechanical stresses, climatic environmental conditions can play a significant role with regard to product moisture.

As product moisture increases, more heat energy must be applied to evaporate the water in the product. This results in a reduction of the combustion rate and, in the event of an explosion, of the pressure rise over time. Of particular importance for practical applications, however, is the associated increase in ignition temperature and minimum ignition energy, which reduces the probability of ignition. Another effect of the higher product moisture is the poorer „swirling ability" of the dust and thus a lower spreading of explosive dust clouds. On the other hand, higher moisture contents in organic dusts can also lead to more critical self-ignition behavior.
The following is an overview of which characteristics are usually required for which protection concepts.

Preventive explosion protection	
Measures	**Required characteristics**
Avoiding combustible dusts	Combustion behavior/burning class, explosiveness, particle size distribution, moisture
Concentration limit	Lower explosion limit, dusting tendency
Inerting	Limiting oxygen concentration, explosive capacity (for solid inerting)
Avoiding ignition sources (depending on the type of dust and the process conditions, not all of the listed characteristics are always required)	Minimum ignition energy, minimum ignition temperature of a dust layer (glow temperature), minimum ignition temperature of a dust cloud (ignition temperature), self-ignition behavior, exothermic decomposition, smoldering point, burning class, bulk material resistance

Design explosion protection	
Measures	**Required characteristics**
Explosion proof construction	Maximum explosion overpressure
Explosion venting	K_{st} value and maximum explosion overpressure
Explosion suppression	K_{st} value and maximum explosion overpressure, minimum ignition temperature of a dust cloud (ignition temperature)
Explosion decoupling	K_{st} value and maximum explosion overpressure, minimum ignition temperature of a dust cloud (ignition temperature)

Further information on the safety characteristics can be found in the module „Safety characteristics of dusts“.

4 Risk analysis

4.1 Explosion risk in silos

Explosions in silo cells can follow different patterns. They depend on the characteristics of the dusts, on the place of ignition, on the distribution of the dust concentration within the cell, on the filling level, on the filling method, on the type of venting devices and on the height/diameter ratio of the silo cells.

The assessment of whether an explosion can be transmitted via conveying equipment or aspiration lines is also important for the selection and design of protective measures. In the case of ignition in the area of the filling openings of the silo cell, flame propagation into the silo interior is very much dependent on the dust/air concentration.

If a silo cell is only partially filled with dust/air mixture – for example, if the dust cloud remains limited to less than 1/4 of the lower silo area – then the pressure and rate of pressure rise in the event of ignition at the silo outlet are significantly lower than if the dust cloud has spread over the entire volume.

Once the filling process has started, not only the dust cloud spreads. In addition, the bulk density increases and the free volume decreases. Inevitably, with a constant pressure venting area, the reduced explosion pressure becomes smaller and smaller.

Two influencing factors play a significant role here, namely the reduction in volume and the change in the height/diameter ratio.

In filling operations in practice, one often has to deal with dust cloud generation mechanisms where the dust cloud concentrations are „inhomogeneously" distributed. This influences the explosion pressure.

Experiments have shown that the explosion sequences are quite clearly influenced by the filling method.

Explosion tests in which the silo was filled via cyclone or rotary air lock through downpipes have shown that there is a significant reduction in explosion severity compared to pneumatic air conveying. During pneumatic filling, the formation of dust clouds can be reduced by tangential conveying line entry, thus also reducing the explosion severity.

When ensiling grain with a low proportion of fine dust, the lower explosion limit is rarely reached. The resulting explosion pressures in the event of an explosion are significantly lower. In some cases, explosion is no longer possible.

The formation mechanisms of dust clouds during filling processes also have consequences for zoning. The dust cloud characteristics depend on the dusting properties of a product and the methods of dust cloud formation (e.g. filling methods). The differences are shown in homogeneities and inhomogeneities, concentration and turbulence of dust clouds.

The dusting properties and sedimentation behavior determine the dust cloud formation and duration of the explosive phase. This has an influence on

- the probability consideration in terms of the zone definition (zoning),
- the selection and assignment of explosion protection measures,
- the explosion sequences (different explosion pressures and rates of pressure rise, dimensioning of the venting surfaces)
- the explosion effects

and is subsequently decisively responsible for the explosion risk.

Explosion hazards

When filling silos, there is a risk of ignition of any dust/air mixture present due to e.g. introduced smoldering nests, discharges of static electricity, mechanical ignition sources or explosion transmissions.

There is also a risk of explosion during emptying, e.g. due to collapse of bulk bridges in connection with smoldering/glowing fires.

In case of corresponding bulk material properties and self-ignition processes, silo cells may be at risk from subsequent fire during prolonged storage. The methods commonly used today to fight fires and possible secondary explosions by inerting require openings or connection nozzles on the silo.

In the event of an emergency, appropriate emergency plans must be drawn up and communicated to the employees by means of instruction (see also Chapter 4.5.3).

Other possible protective measures include:

- Fire and temperature monitoring
- Grounding
- Avoiding ignition-effective bulk cone discharges
- Emergency management
- Inerting option in case of fire with connection at the silo discharge hopper and the downstream trough chain conveyors
- Pressure venting, typically used to protect large silos. Pressure-resistant design or explosion suppression are also possible for smaller silos.
- For particularly ignition-sensitive products, inerting or phlegmatization (reduction of the oxygen content, see also the module „Safety characteristics“) can also be used.

Silo cellars, connecting corridors, stairwells, etc. may also be at risk as adjacent rooms to silo cells. Open belt conveyors provide the corresponding dust supply.

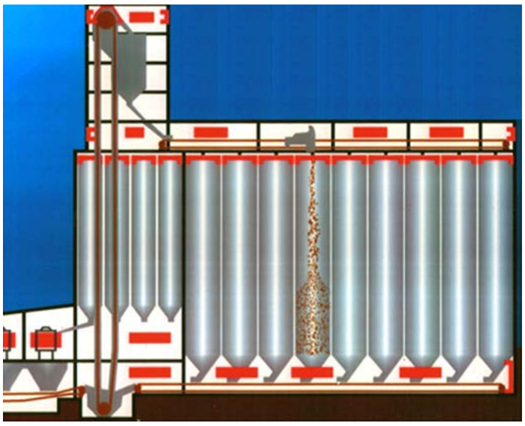


Figure 35:
Venting of silo buildings. The position of the vent openings are marked in red

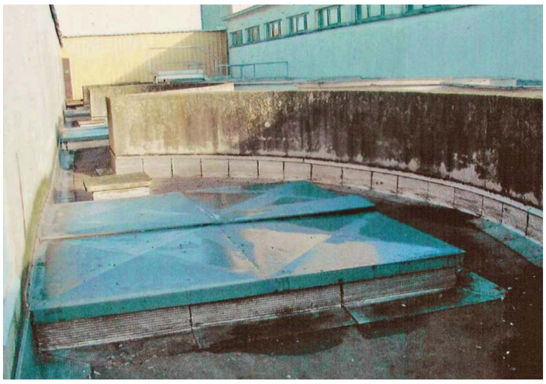


Figure 36:
Silo building made of reinforced concrete without aspiration, explosion venting led to the outside of the silo building (Prof. Siegfried Radandt)

Figure 37:
Silos with machine building and pressure relief areas (Prof. Siegfried Radandt)

Restrictions due to structural specifications
In many cases explosion venting for silos can only be done via the silo ceiling due to the structural specifications. Due to the space required for conveying equipment, top filters, etc., often not even the entire cross-section is available. This results in high minimum explosion strengths for silos, which depend on:

- the type of dust cloud formation (homogeneous/inhomogeneous),
- the response pressure of the pressure venting device,
- the maximum explosion pressure,
- the K_{St} value,
- the available cross-section and above all
- the height / diameter ratio (H/D).

Rooms connected with silos
If silo cells need to have explosion venting in „weather protection rooms" (not service rooms), e.g. silo floors, these weather protection rooms must also have explosion venting. In addition, silo cellars, connecting corridors, stairwells, etc., may be at risk as adjacent rooms to silo cells.

Figure 38:
Emergency exit from a silo cellar, which also serves as pressure venting. (Prof. Siegfried Radandt)

Rooms below the silos

Silo cellar / silo frame:
Since experience has shown that hazardous dust deposits can occasionally be expected despite cleaning, these areas should be defined as Zone 22.

Hazards:
Particularly during maintenance work, ignition of dust swirls is to be expected.

Possible protective measures:
- Organizational measures
- Pressure venting

Figure 39:
Passage with grid floor. (Prof. Siegfried Radandt)

Advantage of grid floor constructions
(see Figure 39)
The grids serve as explosion venting. In addition, dust deposits can be excluded and flame transmission can be prevented.

Vent openings should be located as close as possible to potential ignition sources. Otherwise, they should be evenly distributed over the surface of the room.
The maximum permissible overpressure p_{bem} results from the static load that the weakest part of the structure can withstand without damage. All structural components, such as walls, windows, ceilings, suspended ceilings and roofs, must be included in the structural analysis.
For the assessment of older plants, the current condition of the plant is to be used and not its planning condition. An unobstructed opening must be available for mounting venting areas.
If the necessary venting areas cannot be provided in the plant, the loaded structural elements must be reinforced to withstand increased pressure. The new design pressure is calculated as a function of the existing venting area.

Pressure venting structures for rooms and parts of buildings
The response pressure of venting structures has a static and dynamic component. The static component corresponds to the breaking load under static strain. Geometric parameters, material characteristics and storage conditions influence the amount of breaking load. The dynamic component results from the movement of the pressure venting structures or their parts and depends mainly on the inertial behavior (mass) and the air resistance.
Pressure venting structures can basically be divided into those that can be reused and those that destroy themselves during pressure venting.

According to the principle of the opening of the pressure venting device, pressure venting constructions can further be subdivided into

- hinged constructions
- bursting constructions,
- breakaway and
- drop-off constructions.

Hinged constructions
are almost exclusively vertical pressure venting structures that allow pressure equalization in the event of a sudden increase in pressure in the building, by opening wings or similar components.

Bursting constructions
are pressure venting structures that release an opening in the event of a sudden increase in pressure by destroying opening-closing elements (bursting elements). They can be arranged vertically and horizontally.

Drop-off structures
are horizontal pressure venting structures that are ejected from the pressure venting opening in the event of a sudden increase in pressure.

As a rule, destructible pressure venting designs result in higher response pressures than reusable ones. Higher response pressures and the principle of opening the pressure venting structures are associated with a higher risk to the environment.

Pressure venting structures	**Examples**
Hinged constructions	Pressure venting wing
Bursting constructions	Lightweight constructions with bursting plates and elements e.g.: • Glass • Safety glass • Metal plates • Wooden panels • Plasterboard • Various e.g. glass fiber reinforced plates • Wooden boarding with bituminous roof cladding
Breakaway structures	Tear off elements • Aluminum sheet • Sheet steel (trapezoidal profiles) • Lightweight multilayer elements (e.g. steel-PUR, Al-PUR) • Plastic film • Coated textiles
Drop-off structures	• Freely supported roof elements (prefabricated elements) with joints in the roof cladding, the position of which corresponds to the joints of the roof elements (total mass $m < 120$ kg/m²) • Tile roofing

Rooms above the silos (silo floors):
No zone needs to be defined in silo floors where technically tight equipment is installed, if no hazardous dust deposits can form due to frequent cleaning.

Nevertheless, dust deposits can form around manholes, which can result in a spatially limited zone 22.
The silo floors are at risk when the silos are depressurized and therefore must not be walked on during operation.

Figure 40:
Silo floor with conveyor belt and splinter-free window elements as pressure venting
(Prof. Siegfried Radandt)

Building response to explosion pressure
From experience, dust explosions can be considered approximately as a static load, the effect of which corresponds to the maximum explosion overpressure.
The following table shows typical strengths of building components; when these experimentally determined pressures occur, the structure is damaged under normal conditions.

Remark:
Buildings are usually designed for service, wind and snow loads rather than for explosion resistance; they therefore often have a low pressure resistance. When high pressure resistance is required, reinforced concrete buildings with small reinforced windows are typically used.

Building part	Minimum pressure resistance
Window panes, doors, light partitions and light roofs	0.01 - 0.03 bar
Free-standing brick walls or non-reinforced concrete walls (20 cm thick)	0.17 - 0.25 bar
Industrial buildings in light metal frame construction	0.01 - 0.03 bar
Industrial buildings in heavy metal frame construction	> 0.1 bar

4.2 Zoning

Example of a plant with bulk materials containing explosive fine dust.
Dust-explosive atmospheres are present inside the silos for process-related reasons. These quantities are considered hazardous and thus result in the following zoning classification.

Occurrence of explosive dust/air mixtures inside silos Zone classification based on typical examples		
Plant section	**Zone**	**Remarks**
Exhaust air filter	20	Raw gas space in the immediate vicinity of the filter bags and silo head area with continuous feeding
	21	Raw gas space in filter and silo head area with infrequent filling (e.g. < 2 times per week)

Occurrence of explosive dust/air mixtures inside silos **Zone classification based on typical examples**		
Plant section	**Zone**	**Remarks**
Silo cells, inside	20	At continuous operation (i.e. filling and emptying > 2 times per week) and during vertical pneumatic filling with pure dusty substances or at the silo discharge with air loosening or so-called air cannons for discharge support
	21	In case of infrequent filling and emptying (< 2 times per week) or during vertical pneumatic filling with coarse-grained products or when filling with dusty materials with low dusting tendency via downpipes and the like or during pneumatic tangential filling with dusty materials (with higher dusting tendency) or during pneumatic tangential filling with coarse-grained products or at the silo discharge with air loosening or so-called air cannons for discharge support
	22	For pneumatic tangential filling with coarse-grained products

Occurrence of explosive dust/air mixtures inside silos Zone classification based on typical examples		
Plant section	**Zone**	**Remarks**
Bulk storage halls, silo floors and silo installation rooms	21 22 None	At drop points In the remaining storage area, dust deposits usually occur that can generate explosive atmospheres if stirred up. In the remaining storage area without visible dust deposits
Discharge device e.g. rotary air lock or screw	21 22	In general In case of coarse-grained products

Very fine dusts or even fine fractions of coarse-grained bulk materials tend to stick to silo walls or fittings. They can create irregular swirls by falling, which can lead to more critical zoning depending on frequency.
Dust deposits in the rooms and on system parts (e.g. machine surfaces, pipelines, air conditioning ducts, cable routes, etc.) must be avoided.
The aim is to eliminate dust ingress and swirlable dust deposits in the rooms as far as possible and to reduce the areas operationally contaminated by explosive dust/air mixtures as much as possible.
The following protective measures, which are designed to **prevent dust from escaping from plant components**, serve this purpose in particular:

- Dust-tight design and operation of the plant components
- Operation of the plant with negative pressure
- Exhausting the dust at the point of origin

As well as measures that **prevent dust accumulation and spread in the rooms**. These include, among others:

- Smooth walls
- Beveling of wall projections, beams, roof structures, light fixtures, groove and jointless floors
- Suitable vacuum cleaners; where all dust depositing surfaces are to be taken into account, such as floors, walls, consoles, ledges, beams, supporting structures, machines, pipelines, cables, lights

Dust blowing with compressed air is unsuitable as a cleaning measure, as it tends to aggravate the room dust.

4.3 Assessing ignition sources

The measures mentioned under 4.2 to avoid explosive atmospheres (zoning) are flanked by the prevention of effective ignition sources.
In principle, the 13 ignition sources according to EN 1127-1 must be taken into account for the systems under consideration. In most cases, however, only the ignition sources for dusts listed below are relevant in the process step „Storage".

- Hot surfaces
- Flames and hot gases
- Mechanically generated sparks
- Electrical equipment
- Static electricity
- Ultrasound (e.g. ultrasonic measurement technology)
- Lightning strike
- Smoldering nests and self-ignition

Where and under what conditions they can take effect is listed below.

4.4 Risk assessment

In addition to the measures for preventive explosion protection (avoidance of ignition sources and avoidance of explosive atmospheres), measures of constructive explosion protection may be used; these are then designed by the explosion decoupling and the explosion pressure shock resistant design in connection with explosion venting or as explosion suppression.
To estimate the hazards, the effects of a possible explosion and the probability of occurrence are given in the table below. In addition to the probability of the corresponding ignition source becoming effective, this probability also includes the probability of the occurrence of an explosive atmosphere, i.e. the zone present in each case. If the risk is too high, countermeasures are also listed with the corresponding solutions.

The left column of the table shows the probabilities W of an adverse event occurring without measures having been taken. The following applies:
A frequent
B occasionally
C rare

Ignition source analysis: storage silos for bulk materials; general example			
W	**Adverse event**	**Ignition source**	
C	Fire/explosion in one or several silos	Introduction of smoldering nests	
C	Fire and subsequent explosion in one or several silos	Self-ignition	
B	Explosion in one or several silos	Electrostatic discharge (spark discharge, propagating brush discharge, cone discharge)	
C	Ignition of a dust/air mixture in the upstream process step or in the installation room	Mechanical damage in or at the compressed air generation of the conveying air with simultaneous transmission to the conveying line. Dust concentration > LEL	

Ignition source analysis: storage silos for bulk materials; general example		
	Impact	**Countermeasures**
	In the event of an explosion involving a silo, building statics may be endangered; in the event of a silo fire, there is always a risk of explosion due to smoldering gases or collapsing product bridges	1. Measures to avoid ignition sources, see above. 2. Appropriate design of supplier contracts 3. Inspection of incoming goods 4. Prohibition of open fire, work using fire only with clearance 5. Smoking ban
	In the event of an explosion involving a silo, building statics may be endangered; in the event of a silo fire, there is always a risk of explosion due to smoldering gases or collapsing product bridges	1. Monitoring of upstream processes with temperature load accordingly 2. Preventing water from entering the silos (relocation, proceed according to work instructions)
	Explosion involving silo can endanger building statics	1. Grounding of all plant components 2. No use of insulating coatings with breakdown voltages above 4 kV 3. Seek expert advice when using non-conductive materials (e.g. plastic silos)
	Damage to or destruction of the pipeline, possible explosion transmission into the installation room or into downstream plant components, e.g. into the silo	1. Service and maintenance 2. Specify conditions that LEL is undercut 3. Room cleaning 4. Prohibition of open fire, work using only with clearance, smoking ban

Ignition source analysis: storage silos for bulk materials; general example			
W	**Adverse event**	**Ignition source**	
C	Product ignites on the mixing screw or a mechanical discharge device due to hot surface	Wedged foreign body present in the silo	
B	Ignition of a dust/air mixture in the filter	Electrostatic discharge (spark discharge)	
B	Ignition of a dust/air mixture in the silo by cone discharge Installation room	Electrostatic discharge (cone discharge with insulating product)	

Ignition source analysis: storage silos for bulk materials; general example		
	Impact	**Countermeasures**
	Fire development with explosion hazard in the silo and downstream plant components	1. Low setting of motor protection trip 2. Upstream foreign body separation 3. Bearing temperature monitoring on shaft 4. Use slow-running mixing screws or discharge agitators (U < 1m/s) 5. No internal bearings for agitators or mixing screws
	Damage to or destruction of the filter and possible explosion transmission to the aspirated units or to the installation room	1. Permanently ensured grounding of the filter and all installed parts 2. Pressure relief of the filter 3. Upstream explosion diverter 4. Room cleaning
	In the event of an explosion involving a silo, building statics may be endangered; in the event of a silo fire, there is always a risk of explosion due to smoldering gases or collapsing product bridges Transmission to connected aggregates.	1. Structural protective measures such as pressure venting or explosion suppression in conjunction with pressure-shock-resistant design 2. Explosion decoupling of connected aggregates 3. Installation of grounded electrodes to reduce the energy of cone discharges (multiple rods or ropes) 4. Inerting/phlegmatizing

4.5 Protective measures

4.5.1 Preventive measures

Hot surfaces

Normally, no hot surfaces will occur in storage silos if no rotating built-in parts are present. In mixing silos with rotating built-in parts, hot-running shaft bearings and/or seals cannot be completely ruled out. They must be protected by appropriate monitoring. Sealing rings can be prevented from product penetration into the sealing area or the bearing by sealing air. In addition, bearing temperature monitoring or temperature monitoring of the sealing point may be necessary.
Alternatively, smoldering fires can be detected by fire gas detectors for early fire detection (GSME detectors).

The following potential hazards leading to hot surfaces must be evaluated:

- Introduction of foreign body must be avoided
- Internal shaft bearings must be avoided (if this is not possible, they must be monitored)
- Movable fittings, such as stirring tools or mixing screws, must be operated with low drive power and peripheral speed (usually below 1 m s^{-1}). The upper limit of the circumferential speed must be secured by technical measures.
- Operational hot surfaces, such as heaters, must be avoided

Flames and hot gases

Due to the process, these ignition sources are not relevant during storage itself, but are relevant during direct firing processes, such as flashback of hot gases and flames into the upstream bunkers.

If the following ignition sources

- flare-up of smoldering nests,
- ignition of smoldering gases,
- incoming explosions from adjacent plant components

cannot be prevented, further measures must be taken.
Flames and hot gases (e.g. from welding, cutting and other work producing hot surfaces, smoking) must be excluded as a possible source of ignition by organizational measures.

Mechanically generated sparks

Sparks generated by friction and impact processes are possible ignition sources, but do not directly cause ignition for the majority of dusts. However, they can lead to smoldering nests in the dust bed for dusts with a temperature-dependent burning class ≥ 3.

Electrical equipment

Electrical equipment of appropriate suitability must be used. The device categories 1D, 2D or 3D are necessary for areas with explosive atmospheres of zone 20, 21 or 22.

Static electricity

Preferably, conductive materials (< 10^4 Ωm) must be used and all conductive parts must be reliably and permanently grounded with an earth leakage resistance RE < 10^6 Ω.
If conductive materials (< 10^9 Ωm) are used, they must be in contact with earth.

(For hoses and flexible sleeves, see the ISSA's collection of examples, „Dust Explosion Protection on Machinery and Apparatus," Part 2, Chapter 6.3, „Ignition Sources and Protective Measures")

- Do not use insulating coatings with a breakdown voltage greater than 4 kV in locations of high dust impact velocity (high charge generating process). Strong charge-generating processes there can lead to ignition-effective propating brush discharges.
- For products with low melting point or when filling under elevated temperature: product deposits that form an insulating layer with a breakdown voltage greater than 4 kV due to a sintering or melting process must be avoided.
- Bulk materials are statically charged by mechanical or pneumatic conveying. This can cause brush discharges, which cannot ignite dust clouds in the absence of gases or vapors. Charged bulk material can cause electrically insulated parts to become charged by induction. Therefore, proper grounding of all conductive parts is always required to avoid dangerous spark discharges (see „Static Electricity, Ignition Hazards and Protective Measures", ISSA, Heidelberg 1995, ISBN 92-843-7091-4).
- Starting from the highly charged bulk material, cone discharges can occur inside silos (see „Static Electricity, Ignition Hazards and Protective Measures", ISSA, Heidelberg 1995, ISBN 92-843-7091-4). Whether these become effective for ignition depends on many influencing variables (e.g. silo diameter, particle size distribution and minimum ignition energy). If the bulk resistivity is above 10^{10} Ωm, cone discharges, starting from the bulk material itself, cannot be excluded in a conductive grounded container/silo without insulating internal coatings.

These discharges are difficult to avoid. They can be rendered ignition-inactive by subdividing the silo cells with conductive grounded electrodes (ropes or rods), inerting or phlegmatizing.

Ultrasound

Level measuring devices with ultrasonic waves should only be used if appropriately suitable (device category 1D or 2D depending on the zone definition in the silo).

At extremely high intensities, ultrasound can lead to hot surfaces, which may be evaluated as a source of ignition. In general, however, such high intensities are not present.

Lightning strike

Outdoor silos must be included in the lightning protection measures of the foundation or building.

Smoldering nests and self-ignition

- The introduction of hot foreign bodies and smoldering nests must be avoided.
- Increased humidity and storage temperatures can lead to exothermic biological and chemical reactions.
- Long storage times should be avoided.

When self-heating and self-ignition processes occur, the presence of gases (e.g. CO) is often to be expected. These can be detected and recognized even in small quantities.

In the case of temperature-sensitive bulk materials which have a tendency to self-ignition, the storage silo may have to be insulated to protect the bulk materials from increased heat input.

If the ignition hazards described cannot be excluded with sufficient certainty, additional design explosion protection measures must be applied.

4.5.2. Constructional explosion protection measures

The following options can be considered as explosion protection measures:

- Pressure-resistant or pressure shock resistant design for the maximum explosion overpressure p_{max} (possible for smaller silos)
- Pressure shock resistant design for reduced explosion overpressure p_{red} in conjunction with explosion venting (if necessary also flameless pressure venting)
  Pressure shock resistant design for reduced explosion overpressure pred in combination with explosion suppression (possible for smaller silos)

Conditions relevant to design of protection systems:

Plant configuration:
Container volumes, height-to-diameter ratio, pipeline lengths and diameters, type of conveying equipment, etc.

Process conditions
Dust distributions, volume flows, process temperatures, process pressures, flow velocities and the like.

Ambient conditions
Temperatures, humidity (e.g. condensation)

Product features
(explosion characteristics)
If the transmission of an explosion from one part of the plant to another has to be prevented, decoupling devices are necessary in addition to the above-mentioned design protective measures. They can be divided into passive and active systems.

- The passive systems act automatically without the need for a control unit. Closing takes place due to the pressure wave during the explosion process. Each system requires a minimum pressure to close.
- Known passive systems are the diverter and the explosion protection valve. However, the rotary air lock can also be counted as passive element, although it must be shut down in the event of an explosion. Product receiver in conjunction with conveying elements, such as tubular screws, can also be used for explosion decoupling.
- Active systems require suitable control equipment to trigger them. In the event of an explosion, the external energy required to actuate the active systems is then released via these control devices. A prescribed distance must be maintained between the installation location of the detector and the installation location of the decoupling mechanism, which results from the response time and the explosion behavior.
- The active systems include the rapid action gate valve, the actuated explosion protection valve and the suppression barrier.
- The extinguishing agent barrier can also replace the pressure relief device in conjunction with a suppression system.

Explosion transmission risks
When an explosion is transmitted from one vessel to another vessel, excessive pressure will occur in the secondary vessel. This pressure is particularly pronounced when the downstream vessel is smaller. Explosion decoupling prevents transmission. However, the closing process of the decoupling increases the explosion pressure in the primary vessel. This pressure can be up to 3 times higher than the calculated reduced explosion pressure.

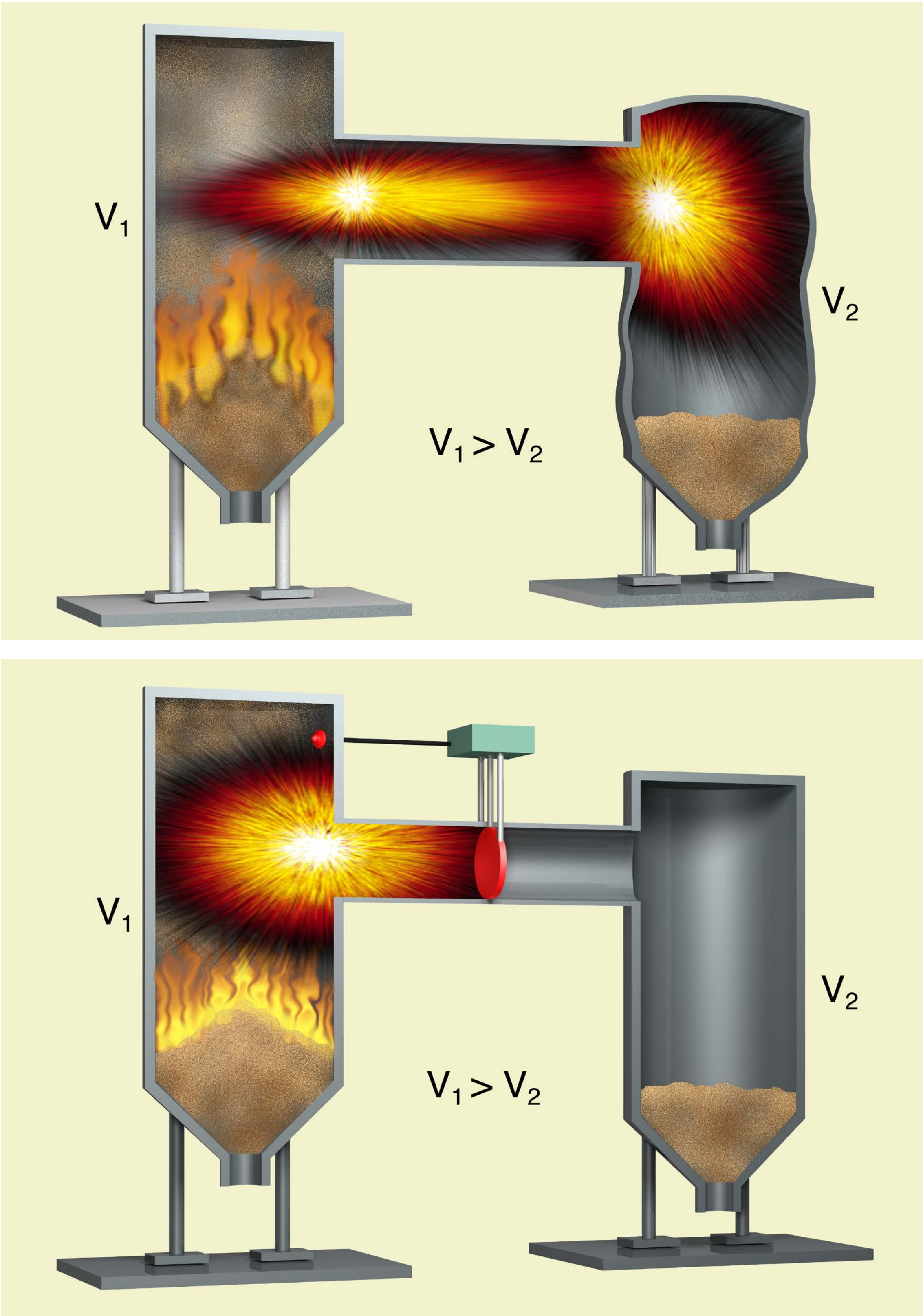


Figure 41:
Explosion transmission through piping and necessary decoupling

Explosion diverters

The spread of dust explosions through connecting pipelines can be prevented in many but not in all cases by installing an explosion diverter. In this way, a dust-conveying line can be routed via an explosion diverter to the downstream separator, e.g. a filter system. The explosion diverter is characterized by a special pipe routing in which a 180° reversal of the conveying direction takes place.

Explosion diverters can practically prevent explosion transmission in both directions. However, experimental studies show that this is not always the case. Thus, the probability of explosion transmission from the outer to the inner pipe is higher than vice versa. Furthermore, explosion transmission is favored if high negative pressures are present on the side facing away from the explosion. Particularly in the case of slow explosions with low pressure build-up, where the pressure relief devices do not open, explosion transmission must be expected.

Rotary air locks

When designed as a protective system, rotary air locks can prevent the spread of explosion flames. There is also largely no abrupt compressive stress on downstream systems. Rotary air locks are suitable for safeguarding product inlet and outlet openings on vessels and apparatus.

Their use at the product transfer points can bring about a decoupling between the upstream and downstream plant areas.

Its adequate resistance to the expected explosion load is of course closely linked to the flame or ignition resistance of a rotary air locks. In order to be able to cover as wide a range as possible of the explosion loads to be expected in practice due to dust explosions, rotary air locks are generally designed for an overpressure of 10 bar. Both properties, but especially that of ignition resistance, must be proven by explosion tests.

Explosion protection valve

Explosion protection valves are primarily suitable for installation in pipelines with low dust loads. Typical applications are found on the clean air side of filter systems, where these valves are used to protect the fans on the clean air side from impermissible high pressure loads in the event of explosions in upstream filters. The valve is closed by the kinetic energy of the pressure wave (passive system). However, flames can pass through in explosions with weak pressure effects.

Rapid action gate valves

Compared to explosion protection valves, rapid action gate valves have the advantage that their closing element is located outside the pipeline cross-section in the open state. The pipeline cross-section thus remains free and can be executed without pockets or dead corners, so that no dust can accumulate. For this reason, rapid action gate valves can be used in pipelines regardless of dust loading. Both flame and pressure detection can be applied.

Suppression barrier

If a flame front is detected, tested valves of extinguishing agent containers open and force extinguishing agent into the pipeline.

This will extinguish the flame. The prescribed distance between the installation location of the detector and the installation location of the extinguishing nozzle must be maintained, which results from the response time and explosion/flame speed. The extinguishing process does not stop the propagating pressure wave. The strength of the piping must be adjusted to the expected explosion pressure. Flame detection must be applied.

Explosion detection

Suitable detection is required to trigger active protection systems. In principle, detection can take place via pressure or flame.
In pressure detection, a distinction can be made between mechanical and electronic detectors.

Mechanical detectors (membranes)

+ Insensitive to dirt
– Vibration sensitivity
  (is avoided, for example, by using two detectors offset by 90°).
– Readjustment required

Electronic detectors

+ Response to static pressure values and rates of pressure rise
+ No danger due to resonance vibration

Flame detection

Especially necessary for weak explosion sequences
+ Short response time < 2ms
– Monitoring visibility

Decoupling through product receiver

In the case of pressure-vented silos, explosion decoupling can be implemented at the product outlet by means of a product receiver.
The product discharge must be protected by two level indicators.
Both detectors are hard-wired together in an AND circuit and connected to the drive of the discharge device (e.g. pneumatically operated flap) so that discharge can only take place when both detectors signal product.
The level indicators must be approved for use in potentially explosive atmospheres. The minimum height of the product dump (H) depends on the bulk density of the stored product (SD) and the diameter of the discharge opening (D) and is calculated as follows:

Bulk density $SD \geq 1\ kg \cdot dm^{-3}$ $\quad H = D$

Bulk density $SD < 1\ kg \cdot dm^{-3}$ $\quad H = \frac{D}{SD}$

Numerical value equation: H [m], *D* [m], *SD* [kg · dm^{-3}]

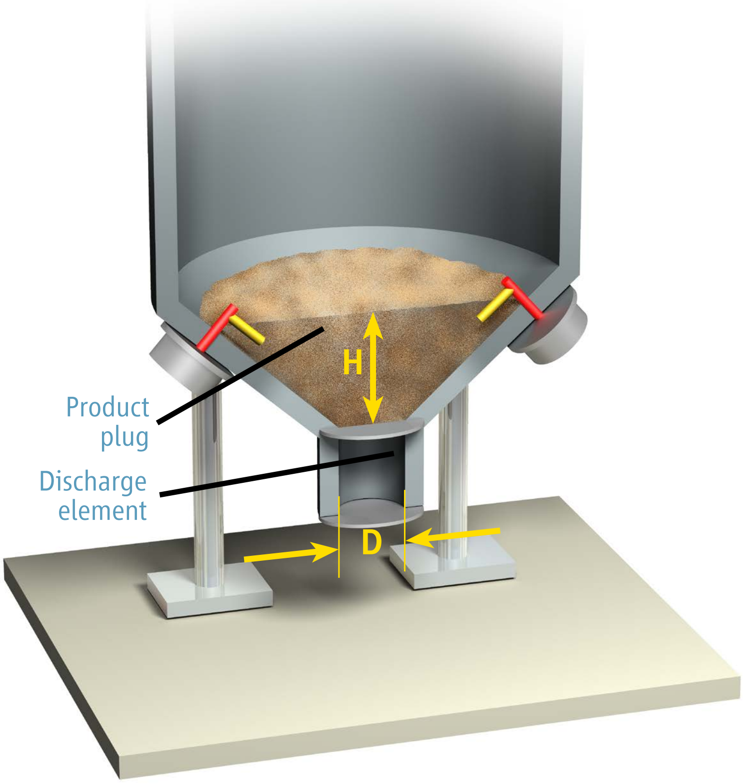


Figure 42:
Explosion decoupling at the product outlet, realized by a product plug

When using the decoupling measure „product receiver", a mass flow is always compulsory for the emptying behavior in the storage silo. Otherwise, cavities or shaft formations may occur within the material column, which does not ensure sufficient coverage with bulk material above the discharge opening (see also chapter 2.4.1 Function description and Figs. 22 and 23). By shear tests (according to A. W. Jenike or Schulze) using the respective raw material can determine whether there is mass flow or possibly only core flow in the silo. Particularly poorly flowing or cohesive products with flow factors $ff_c \leq 4$ only achieve mass flow with a correct silo design and are only then suitable for this explosion decoupling measure.

Decoupling through tubular screw conveyor

Tubular screw conveyors are usually operated with a filling ratio between 30% and 50%. Thus, the upper part of the screw tube is not filled with product. In order to achieve product closure here, individual screw flights are removed shortly before the screw discharge. This achieves a build-up of the product into a product plug. The build-up of the product depends on its flowability.
Decoupling is possible with and without plugs, depending on the product properties.

The main requirements of this type of decoupling are:

- During idling, bulk material plugs remain on the missing screw flights if the flowability factor $ff_c < 5$ (e.g. cellulose, powdered sugar, milk powder, wood flour, wheat flour)

- Without material plug, no flame transmission of dusts whose minimum ignition energy is ≥ 100 mJ; (Minimum ignition energy MIE measured with inductance; reference: wood powder)

- With material plug no flame transmission of dusts whose minimum ignition energy: MIE is ≥ 10 mJ (MIE measured with inductance; reference: cellulose)

- No flame transmission of dusts whose minimum ignition energy is ≥ 5 mJ and $ff_c < 10$ if
  - an „empty run" is technically impossible
  - 2 screw flights have been removed

- Validity scope
  (for all four above mentioned requirements)
  - max. diameter of the tubular screw conveyor: d = 200 mm
  - Minimum distance from product inlet to outlet: lmin = 1.80 m
  - Maximum gap width between screw flights and housing: s = 7 mm
  - Explosion pressure
    p_{red} = 0.2 bar to 2 bar

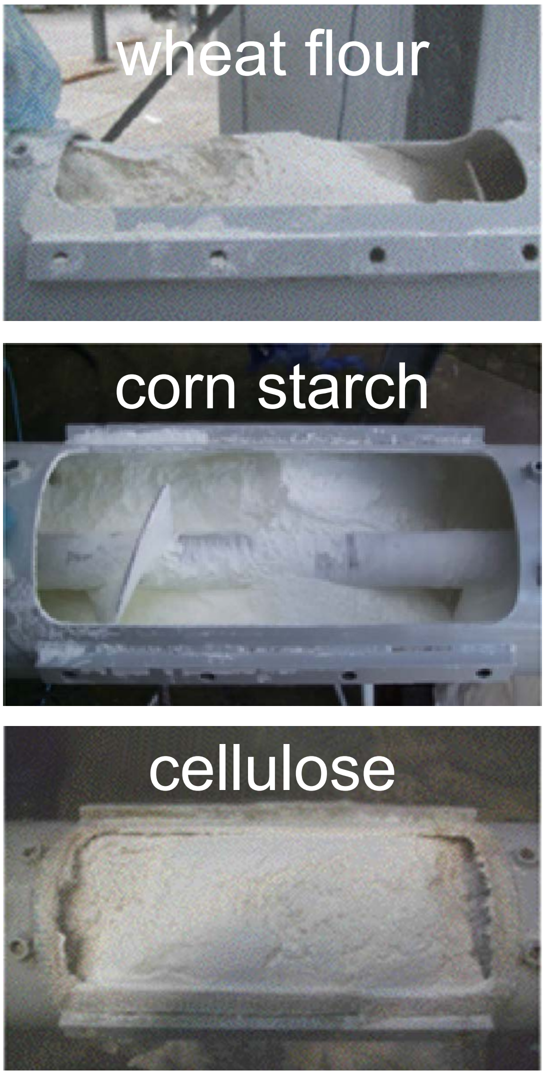


Figure 43:
State of the product plug after the screw has been emptied for the three products wheat flour (partial plug), corn starch (no plug) and cellulose (full plug), (Prof. Siegfried Radandt).

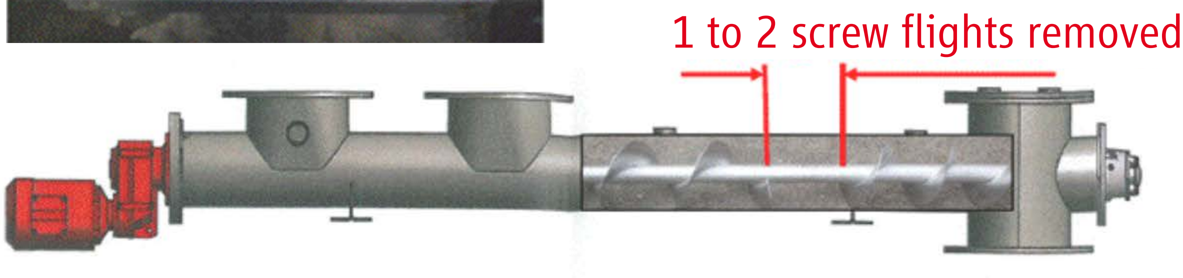


Figure 44:
Use of a tubular screw conveyor for explosion decoupling

Creation of a material plug by removing 1, 1½ or 2 helical mounts. If possible, the plug should remain in place even if no more bulk material is fed when the machine is running empty.

Examples of silos with explosion venting and explosion decoupling

The following figure shows an example of a silo equipped with explosion venting. It is fed pneumatically from a silo vehicle. Important preventive measures are in particular the use of:

- Compressors with integrated spark barrier and downstream cooler that cools the air down to approx. 70 °C as well as
- Conveyor hoses with conductive or dissipative inner wall
- Continuous grounding

Explosion transmission from the silo to the silo vehicle is unlikely. An explosive mixture is required for an explosion in the silo. This can only be created during the filling process. During the filling process, there is a high dust load in the filling line. Experience has shown that backfiring does not occur in pipelines with small diameters when there is a high dust load (blockage effect).

Decoupling device
Rotary air lock
Pressure in the silo filling line approx. 2.0 bar overpressure. Due to the pressure relief and the higher conveying pressure than p_{red}, no flashback of flames against the conveying direction is to be expected.
The following characteristics must be observed: Minimum ignition energy: MIE ≥ 1 mJ K_{St}-value ≤ 300 bar · s^{-1}

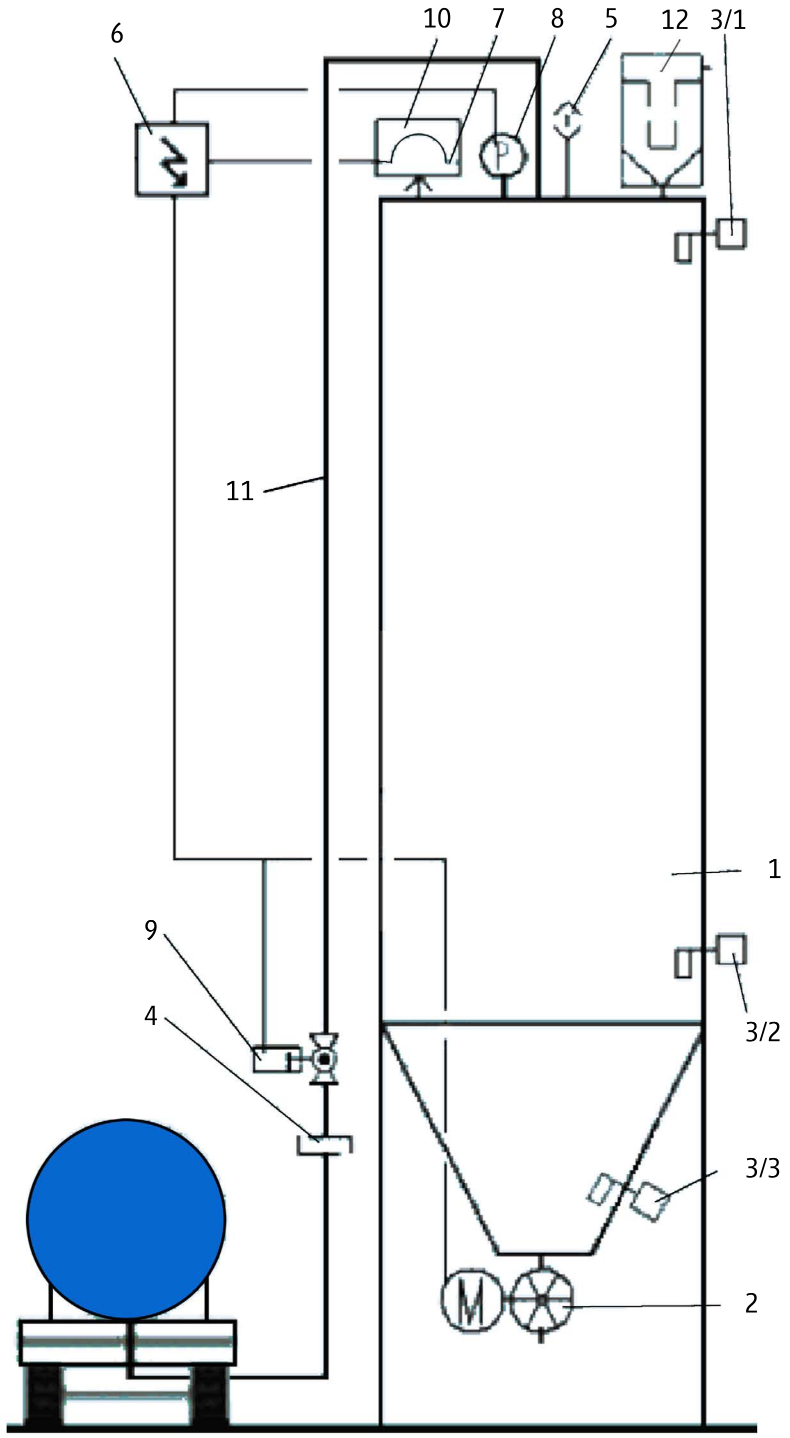


Figure 45:
Requirements for an outdoor silo with explosion venting and decoupling via airlock for discharge. (AZO GmbH + Co. KG)

1	Silo	Pressure shock resistant for p_{red}
2	Rotary air lock	Pressure shock resistant for p_{red} flame arrester (fds)
3	Level indicator	Full, demand, empty detector Pressure shock resistant for p_{red}
4	Coupling	Pressure shock resistant for p_{red}
5	Under-/overpressure relief valve	Response pressure -5/+45 mbar
6	Control system	Hard wiring
7	Switch at pressure relief	
8	Pressure switch	Pressure shock resistant for p_{red}
9	Ball valve	Pressure shock resistant for p_{red}
10	Relief device	Bursting disc
11	Silo filling line	Pressure shock resistant for p_{red}
12	Vent filter	Pressure shock resistant for p_{red} no additional relief for the filter necessary

Switching matrix				
Switch of	**Safety relevant shutdown**		**Functional shutdown**	
	Switch	**Remarks**	**Switch**	**Remarks**
7	Rotary air lock 2	shut down	Vibration floors	shut down if available
7	Filter cleaning	shut down		
7	Aeration nozzles/floor	shut down if available		
7	Level indicator	shut down		
7	Ball valve 9	shut down		
4			Full detector 3/1	is activated
4			Ball valve 9	opens
8			Ball valve 9	Ball valve closes at 45 mbar

Decoupling device
Discharge screw with product cushion
Pressure in the silo filling line approx. 2.0 bar. Due to the pressure relief and the higher conveying pressure than p_{red}, no flashback of flames against the conveying direction is to be expected.
The following characteristics must be observed: Minimum ignition energy: MIE ≥ 1 mJ K_{St}-value ≤ 300 bar · s^{-1}

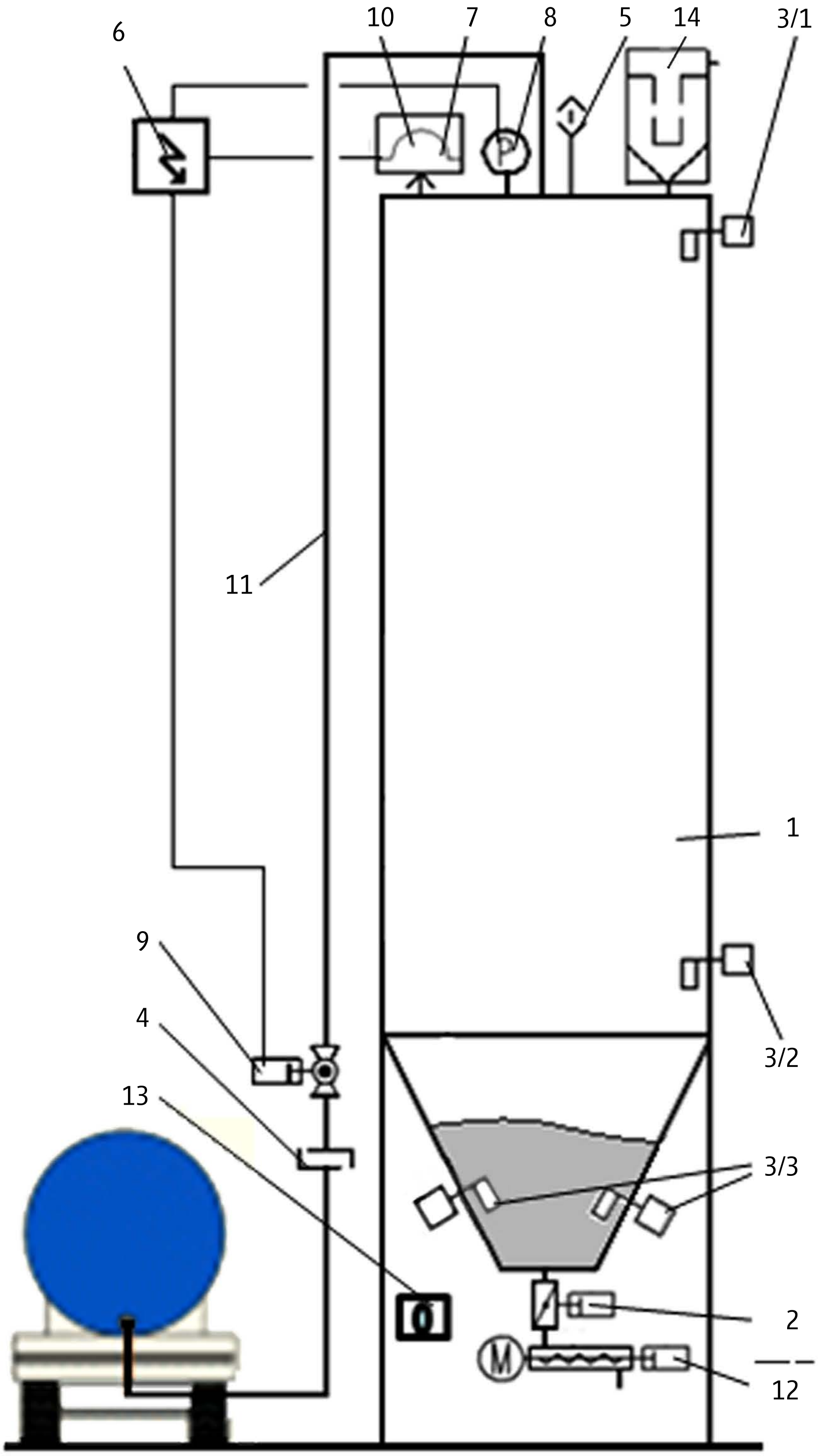


Figure 46:
Requirements for an outdoor silo with explosion venting and decoupling via airlock for discharge. (AZO GmbH + Co. KG)

1	Silo	Pressure shock resistant for p_{red}
2	Shut-off valve pneumatic	Pressure shock resistant for p_{red} and flame arrester
3	Level indicator 2 x detectors 3/3 designed as safety detectors with AND switching	Full, demand, empty detector Pressure shock resistant for p_{red}
4	Coupling	Pressure shock resistant for p_{red}
5	Over-/underpressure valve	Response pressure -5/+45 mbar
6	Control system	Hard wiring
7	Switch at the pressure relief	
8	Pressure switch	Pressure shock resistant for p_{red}
9	Ball valve	Pressure shock resistant for p_{red}
10	Relief device	Bursting disc
11	Silo filling line	Pressure shock resistant for p_{red}
12	Metering screw (e.g.)	
13	Key switch	Pressure shock resistant for p_{red}
14	Vent filter	no additional relief for the filter necessary

Switching matrix				
Switch of	**Safety relevant shutdown**		**Functional shutdown**	
	Switch	**Remarks**	**Switch**	**Remarks**
7	Shut-off valve 2	close	Vibration floors	shut down if available
7	Filter cleaning	shut down		
7	Aeration nozzles/ -floor	shut down if available		
7	Level indicator	shut down		
7	Ball valve 9	shut down		
4			Full detector 3/1	is activated
4			Ball valve 9	opens
8			Ball valve 9	Ball valve clo-ses at 45 mbar
2 x 3/3	Shut-off valve 2	close	Screw 12	Stop after 6 sec
13	Ball valve 9	close		
13	Shut-off valve 2	open 3/3 is bridged		

4.5.3. Organizational measures

- The organizational measures complement the explosion protection concept and are important elements in preventing explosions.
- Before workplaces in potentially explosive atmospheres are used for the first time, the explosion safety of the workplaces, including the intended work equipment and the working environment as well as measures for the protection of third parties, must have been checked and established. All conditions necessary to ensure explosion protection must be maintained. This inspection must be carried out by a qualified person who has special knowledge in the field of explosion protection.
- Areas at risk of explosion must be marked at their entrances.
- The equipment may only be used as intended, with the products intended for the plant.
- Only suitable and appropriately instructed personnel may work on the system.
- Entry of unauthorized persons into potentially explosive atmospheres must be prohibited.
- Bearings and shafts that can generate hot surfaces in the event of a malfunction must be checked regularly.
- All plant components must be operated in an intact and technically perfect condition and must remain operationally safe through careful maintenance.
- Training of employees through written instructions, responsible persons and possibly work release certificates.
- Avoid ignition sources (e.g. by prohibiting smoking, using suitable tools and hand-held equipment).
- Regular and thorough cleaning of all rooms. Even small dust deposits (a few tenths of a millimeter) can lead to an explosive atmosphere when stirred up. It is necessary that especially the operating rooms and equipment placed in them are regularly inspected and kept clean. Dust deposits on floors and surfaces of equipment, cable ducts, pipelines, supports, etc. must be avoided or cleaned as far as possible. Dust deposits caused by malfunctions must be removed immediately. The dust tightness of the plant components must therefore be checked regularly, especially the tightness of the filter elements.
- Marking of escape and rescue routes.
- After maintenance and cleaning work, the correct functionality and grounding of the system parts must be restored and checked (leakage resistance $< 10^6$ Ohm).

4.5.4 Additional fire protection

The measures described in the following sections complement and accompany the explosion protection measures. They are necessary because combustible solids are stored in the silos. The two damaging events of explosions and fires can occur due to combustible solids. Fires are possible as the primary event, followed by an explosion. Explosions are also possible as a primary event, followed by fire. However, fires also occur as individual damaging events (without secondary explosion). The following fire safety measures refer to the safety of people, protection of the environment and things of great value (plant, building).

Structural precautions and measures

It is mandatory to apply national building law. It is not intended to be affected or overridden by these recommendations. In particular, the following aspects are important:

- Access and exit routes as well as working/installation areas (e.g. fire department, inert gas supply) must be kept clear.
- Clearances/separations between silos or silos and buildings must be maintained.
- Silo construction/materials: non-combustible materials are preferable.
- Necessary closable openings closed for driving into the silos (e.g. clearing out burning or incinerated product) must be kept closed.
- Adequate lightning protection equipment must be installed.

Plant precautions and measures

- Early fire detection requires a suitable detection concept (e.g. sensor type, redundant design, robustness, positioning) and an alarm, as a result of which further measures can be triggered (e.g. shutting down the product supply).
- Detection of ignitable particles (e.g. mechanically generated sparks) in the input device, if an introduction from upstream plant areas is to be expected.
- Interfaces on silos must be designed in such a way that they can be sealed gas-tight in the event of fire.
- Connections and necessary risers must be provided through which a) measuring probes can be inserted to investigate the fire and b) extinguishing measures (e.g. inert gas supply) are possible.
- In the event of an incident, the availability of electricity (e.g. emergency power) and extinguishing agents must be ensured.

Organizational precautions and measures

- Precautions and measures for the purpose of fire protection must be checked, maintained (servicing, inspection, repair) and optimized by qualified persons.
- Firefighting measures should be accompanied by a competent person of the company (e.g. a coordinator).
- Employees of the operator must be instructed regularly.
- The operator and the responsible fire department should jointly develop, periodically review, update and practice an object-specific, operational tactical concept.

Preventive precautions and measures

- Fire fighting with extinguishing water in the silo must be avoided (product that tends to swell increases the risk of bridging).
- Firefighting by clearing out: carefully extinguish cleared material (soft spray jet).
- Storage conditions that tend to bridge increase the risk of a secondary explosion; therefore firefighting by means of inert gas (suitability and availability of inert gas, observe occupational safety).
- Firefighting with extinguishing foam (suitability and availability of extinguishing foam).
- When choosing the firefighting concept, the stability of the silo must be taken into account.
- When supplying extinguishing agents, care must be taken to ensure that the silo is not subjected to unacceptable loads due to overpressure.
- Cooling of the silo from the outside.
- When extinguishing, observe constructive explosion protection measures (e.g. protective distances from pressure venting openings, bursting discs, weather protection covers)!

The fire protection precautions and measures selected for a specific facility must be checked for undesirable interactions with the explosion protection precautions and measures taken there.

Example of fighting the fire in a grain silo

The occurrence of fires in silo cells can have various causes. On the one hand, the introduction of ignition sources, e.g. hot foreign bodies or smoldering product cakes (so-called smoldering nests), is possible. Within bulk material, the available atmospheric oxygen is usually only sufficient for the formation of a localized smoldering or glowing fire. This can continue to develop and expand unnoticed inside the bulk material.

On the other hand, fires in bulk material can be caused by self-ignition, due to oxidation processes or microbiological processes. This applies in particular to bulk materials with a high moisture content (> 15.5 %).

Due to poor heat dissipation from the bulk material, the bulk material can heat up to the point of self-ignition.

In the case of products tending to self-ignition, storage times should be kept short. In some cases, it may be necessary to limit the storage time to 2-3 days.

In order to fight a possible fire in the silo, there is the possibility of introducing inert gas in the outlet area via standardized connections (which must be available on the silo) and to provide possibilities for safe bulk material discharge in the lower area of the silos.

In order to be able to clear out fire pockets from the silos, appropriate accessibility must be created in the area of the silo discharge. A discharge device (e.g. a mobile conveyor belt) and a corresponding free area must be available. Due to the process of self-ignition, bulk bridges can form in silo cells as a result of caking of the product on the silo wall.

If part of the bulk material is now discharged through the silo outlet, a cavity is created under the bulk material bridge. If the product bridge is brought down, e.g. by extinguishing work, dust is stirred up which can form an explosive dust cloud. In the case of grain, this dust is usually present in the form of deposits.

An explosive dust cloud can also be created when trying to extinguish a silo fire with water. If the full jet coming from above hits the dust fill, dust can be stirred up as a result.

In bulk fires, pyrolysis can produce flammable smoldering gases when organic bulk materials are exposed to high temperatures, such as those found around smoldering fires. Low temperature carbonization gases consist of a large number of combustible organic compounds. In most cases, they have a higher density than air, so they are heavier and accumulate in fills or on its surface. Mixing with air can result in an explosive atmosphere above the fill. Explosive mixtures of this kind can produce an explosion if ignited by a smoldering fire or other ignition source.

The most reliable and safe way to combat silo fires is by inerting. Suitable inert gases are nitrogen (N2), rare gases or carbon dioxide (CO_2). Additional measures are required to protect the persons involved (due to the risk of suffocation). Inert gas should be introduced into the silo at the silo outlet to reach voids under a possible product bridge.

Adding CO_2 (heavier than air) from above via the access covers is only useful for fine-grained material that cannot be penetrated by the inert gas from below. When CO_2 flows through a fill from below, the fire can be additionally fanned.
To prevent the escape of the inert gas or the supply of oxygen from above, a foam carpet can be placed on the bulk material surface. The open fire is extinguished by prolonged inerting; however, it is usually not possible to completely extinguish the nests of fire with this method.
It is essential to establish a fire watch that can detect rekindled smoldering fires and initiate countermeasures.
In order to extinguish any dangerous residual smoldering nests after extinguishing an existing open fire and thus prevent a renewed flare-up, it must be possible to discharge the silo contents safely while maintaining an inert gas atmosphere. If there is no suitable possibility via the normal outlet, sufficiently dimensioned emergency discharge openings are necessary. The bulk material must be discharged carefully through these emergency discharge openings – without raising dust – preferably via open conveyor belts.
When discharging, check the product for any remaining smoldering pockets to prevent the fire from reigniting outside the silo. As a precaution, the product on the belt can also be sprinkled with a fine spray of water without stirring up dust.
Suitable parking spaces must be provided for the fire department, the inert gas supplier, and any necessary vaporizer.

4.6. Interfaces to other process steps

Interfaces include the equipment for filling and emptying the silos, bunkers, and storage halls, as well as the process connections (e.g., ventilation or heating and cooling line connections). When filling and emptying, the product properties (explosion characteristics and mechanical bulk material properties) of the bulk materials are important. Even in case of granular bulk materials, mechanical or pneumatic conveying processes can generate abrasion in the form of fine dust. For this reason, different product states can be expected, especially in plants with several processing steps (e.g. product reception, cleaning and conveying). Furthermore, drying or cooling processes, for example, may result in different storage temperatures.

Examples of interfaces

- Filling of silo cells via continuous conveyors: pneumatic conveying device via pipeline
- Cyclone or separator (e.g. with rotary air lock)
- Trough chain conveyors, screw conveyors, belt conveyors and elevators

Filling of silo cells via free fall:

- Bulk hopper
- Emptying station for flexible bulk containers
- Emptying station for containers

The following applies to the respective connected device at the interface to storage:

The necessary protective measures must be determined as a result of the ignition hazard assessment. Special attention must be paid to ignition sources that cannot be excluded in the connected device itself.

With respect to the assessment of ignition hazards, see „Collection of Examples - Dust Explosion Prevention and Protection for Machines and Equipment - Part 2, Continuous conveyors, Transfers and Receivers - , ISSA Collection of Examples No. 2057, ISBN 978-92-843-0181-2"

Filling of rooms

- Wheel loader, truck
- Conveyor belt or screw conveyor
- Bulk hopper
- Pneumatic conveying device via pipeline (e.g. wood pellets in storage room)

The statements on filling silo cells with connected continuous conveyors (see chapter 2.2.1) apply here. In addition, ignition sources from mobile equipment such as wheel loaders, trucks (e.g. hot surfaces, hot exhaust gases, mechanical sparks, discharge of static electricity) due to occurring dust clouds must be considered.

Emptying silo cells via continuous conveyors

- Rotary air lock or metering agitator
- Conveyor belt or screw conveyor
- Trough chain conveyor or elevator

Emptying silo cells via gravity

- End flap or flat slide valve
- Metering gate or butterfly valves

Ignition sources can be transmitted from the silo cell to the respective connected device (e.g. smoldering nests, electrostatic charge, foreign bodies, hot or burning product). These possible ignition sources must be considered in the risk assessment and measures must be taken to avoid them and to protect downstream plant components accordingly.

Emptying of rooms

- Wheel loader, truck
- Scraper screw, moving floor
- Conveyor belt

The statements on filling rooms (see above) apply here. In addition, ignition sources from mobile equipment such as wheel loaders (e.g. hot surfaces, hot exhaust gases, mechanical sparks, discharges of static electricity) due to occurring dust clouds must be taken into account.

Process connections

- Aspiration lines
- Ventilation lines
- Drying lines
- Heating and cooling lines
- Gas supply lines
- Sampler
- Sealing air (e.g. for bearing sealing)
- Compressed air (e.g. for filter rinsing)

The process connections with their media (e.g. air, gas, hot liquid) must be included in the risk assessment of the storage cells. Common ignition sources are hot gases, hot surfaces, static electricity discharges, mechanical sparks (e.g. samplers).
The occurrence of explosive atmospheres due to the whirling up of dust, caused by the introduction of air via bearing seals or ventilation equipment, must be taken into account.

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Section on Machine and System Safety

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The ISSA

Creating social security

ISSA, the International Social Security Association is the world's leading umbrella organization for institutions, government agencies and authorities concerned with social security.

In a narrower sense, social security means protection against the consequences of „social risks". In addition to reduction in earning capacity due to occupational accident, occupational disease and occupational disability, this also includes illness, unemployment, assumption of family burdens, ageing and death of employed persons. In a broader sense, social security also includes an active labor market policy, a public education system and a balancing tax policy.

The ISSA was founded in 1927 by 17 European non-governmental organizations as the „International Conference of National Unions of Mutual Benefit Societies and Sickness Insurance Funds". Today, the ISSA has around 350 institutions, government agencies and authorities in more than 150 countries on all continents and is based at the United Nations International Labour Organization (ILO) in Geneva. The substantive work is carried out in 13 specialist committees, including those focusing on occupational accidents and diseases, health benefits and health insurance, employment policy and unemployment insurance, and family benefits and survivors' insurance.

Preventing occupational risks

The „Special Commission on Prevention" plays an important role within the ISSA. It consists of 14 international sections and deals with work-related risks in various sectors such as the chemical industry, mining, electricity and transport industry, but also with cross-cutting issues such as machine and system safety, information and prevention culture. The Special Commission coordinates the joint activities of the International Sections on Risk Prevention and other ISSA prevention activities.

As one of the first sections of the Special Commission, the International Section on Prevention in the Chemical Industry was founded in Frankfurt am Main in June 1970. It is committed to the prevention of occupational accidents and diseases in the chemical and allied industries, particularly in plastics and rubber, paints and coatings, pharmaceuticals and cosmetics, and specialty chemicals and petroleum refining. The chair and secretariat are held by the Berufsgenossenschaft Rohstoffe und chemische Industrie in Heidelberg.

In 1975, the ISSA International Section on Machine and System Safety was founded. Its objective is to increase safety and health protection at work worldwide in the field of machine and system safety. The chair and secretariat are held by the Berufsgenossenschaft Nahrungsmittel und Gastgewerbe in Mannheim.

Chemical industry | Machine and System Safety | Transportation | Construction industry | Information | Mining | Agriculture

Communicating expertise

A particular thematic focus in many branches of industry, e.g. the chemical and food industries, is dealing with explosion risks. Therefore, in 1978, the working groups 'Hazardous Substances' and 'Explosion Protection' were established within the Section on Prevention in the Chemical Industry. In order to exploit synergy effects and increase efficiency, the 'Explosion Protection' working group merged with the corresponding working group of the Section on Machine and System Safety in 2008.

Intensive informal discussions are held in the working groups, brochures and instruction media are developed and workshops are organised to promote the international exchange of experience among experts and to develop targeted-oriented solutions for selected problems.

In this way, the Section on Prevention in the Chemical Industry and the Section on Machine and System Safety aim to contribute to a high level of technology that is comparable among industrialised countries and to pass on their knowledge to industrially less developed countries.

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Section on Prevention in the Chemical Industry
Section on Machine and System Safety

Explosion Safety of Bulk Material Plants

Module: Storage

This ISSA brochure „Storage" is a module of the „Modular Structure" series on explosion safety of bulk materials handling equipment. For these ISSA „Modular Structure" brochures, a concept has been developed that makes it easier to divide the assessment for a plant with regard to explosion risk into smaller units, so-called „modules".

In addition to a clear layout, this enables a targeted and process-oriented approach. This allows individual assessments of machines from the ISSA example collections „Dust Explosion Protection for Machines and Equipment" Part 1 and Part 2 and of processes/modules from this series of ISSA brochures to be used and linked together at the end for the overall plant risk assessment.

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