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HDI-Gerling Risk Engineering Services

Risk Engineering Guideline

Fire protection and
fire-fighting in silo
and bin installations

international



Proper planning and the right measures in case of fire allow controlling silo fires.

Silo fires are special fires and require special measures from operating companies, fire brigades and specialist consultants.



1 General

Insufficient preventative fire protection and ignorance of special circumstances to be observed in case of fire make fires in silos and closed bin installations the origin of major material loss and personal injury again and again. Conventional extinguishing agents and methods are hardly suitable for reliable silo fire fighting and for avoiding dust explosions. The dust explosion hazard is particularly high when attempting to clear the material out of a silo loaded with hot spots or glowing nests. The difficult access, the building height, the dust explosion hazard of the combustible bulk material, the required special fire-fighting agents and the enormous amount of time needed make silo fires special cases of fire-fighting. Such fires can be controlled only when suitable preparation, coordinated fire-fighting and patience are provided.

2 Risk situation and examples of losses

2.1 Risk situation

Silos, closed bins and similar large-scale containers serve as storage for loose bulk material. The container sizes are quite different and may reach up to several thousand cubic metres. Silos can be made of steel, concrete, plastics (GRP), wood or textile materials. Loose bulk material can be present in the following conditions:

- as dust (e. g. fibre dust, plastic powder)
- as grains (e. g. cereals, plastic pellets)
- as lumps (e. g. coal, potatoes)
- as mush (e. g. mud)
- as machined pieces (e. g. wooden chips)
- as shredded pieces (e. g. plastic waste)

Ignition sources frequently include self-ignitions or introduced sparks and glowing nests. Organic bulk materials (e. g. food and fodder) may tend to self-ignite when stored



too long or in conditions that are too moist or too hot.

Solid bulk material may ignite itself when:

- the storage temperature is sufficient for igniting the existing bulk volume or vice versa, i. e. when the bulk volume is large enough for being ignited at the prevailing storage temperature,
- the storage duration at the prevailing temperature is longer than the induction time,
- the discharge of combustion gases and feed of oxygen into the reaction zone is possible.

Fires can spread through operational transport routes (pipes, conveyor lines), thermal radiation and flying sparks. Smouldering and pyrolysis gases may be generated, even outside of the container, which can create an explosive atmosphere. Flash fire may escape through openings. Opening the container and evacuating the bulk material involves a ladder ignition/explosion hazard. Dust explosions may occur even outside of the silo due to dust deposits. The statics of the container and of the building may be affected by heating-up of load-bearing components and it may be overloaded by fire water and fail. When in contact with water, materials may become swollen and cause the container to burst.

2.2 Examples of losses

2.2.1 Fresh tankage silo

A 30 t fresh tankage silo catches fire, presumably due to biologically induced self-ignition. When no fire-fighting success is achieved after actuating the existing manual CO₂ fire protection system several times, it is decided two hours later to call the fire brigade. The fire brigade calls in a nitrogen tanker. Before the tanker arrives, silo discharge is started. A short time later, a "whooshing noise" is suddenly perceived from inside the silo. Flames of several metres length come out of the upper silo manhole, destroying the silo and the conveyors and setting the surrounding storage hall on fire. It must be assumed that fresh air entering during the discharge process (product level dropping) has started the flash fire. The fire can only be extinguished one hour later, after calling in more fire-fighters. The loss suffered is more than one million Euros.

2.2.2 Coal silo

Slight smoke development is perceived on a 3,000 t reinforced concrete hard coal silo on the site of a power station. The temperature and carbon monoxide sensors provided inside the silo respond by signalling a smouldering fire. The fixed foam-type fire protection system on the silo head is activated and also the fire brigade is called in and smoke is reduced. Assuming that the fire has been extinguished, discharging the silo starts some hours later under supervision of the fire brigade. In the morning of the second day, a powerful explosion suddenly occurs while discharging the silo, very likely intensified by ingress of fresh air, making the 250 t concrete silo roof collapse and destroying the conveyors on the silo head. The silo was not equipped with an explosion pressure relief arrangement. Provision of this safety feature, although obvious, is often missing from coal silos. The fire brigade now orders the silo to be opened with a wrecking ball. This work takes another six days. The silo suffers total loss and the surrounding plants are damaged. The power station has to be shut down temporarily. The loss suffered is just under € 10 million.

2.2.3 Wood chips silo

Smoke is seen escaping through the top hatch of a wood chips silo. The fire brigade opens the top hatch from its turntable ladder and detects heavy smoke generation, but no flames. Now the silo bottom hatch is opened in order to discharge the silo content and extinguish any possible fire pockets. The fire brigade discharges the wood chips out of the silo using shovels, with the chips getting darker and soon totally black. Suddenly a flash fire comes out of the bottom hatch and injures a fire-fighter. Presumably dust whirled up combined with the high temperatures and ingress of oxygen upon opening caused this sudden combustion. The fire brigade is on the site for more than twelve hours in total before the silo is finally discharged and completely extinguished.



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2.2.4 Cereals silo

An explosion occurs while fighting a fire on a cereals silo, making the concrete roof of the eleven-storey silo collapse, killing two fire-fighters. Another six fire-fighters are seriously injured. The operator is sentenced to several years of prison for lack of preventative fire protection.

3 Terms

Operating instructions

The operating instructions (in the sense of Safety Information) are instructions issued by the employer to the employees. They define the behaviour on the site regarding workplace and work and aim at avoiding accidents and health hazards. In addition, the operating instructions serve as a basis for training.

A distinction is made between operating instructions describing how to handle hazardous substances and operating instructions describing how to operate machinery and plants. Only hazardous and/or safety-relevant work processes are dealt with. To this end, the operating instructions contain the necessary information provided in the user manual (for technical products) or the safety data sheets (for hazardous substances) issued by the producer, importer or supplier.

Explosion pressure relief

Pressure relief devices are intended to discharge the excess pressure in a well-designed way in the event of an explosion in order not to endanger the stability of a silo or a bin. The required pressure relief surfaces and container stability values can be calculated from the specifications in EN 14491 "Dust explosion venting protective systems". In explosion, when the pressure relief system responds, persons must not be endangered by ejected or falling parts and by possible effects of pressure and flames.

Inert gas

Low-reactivity gases (participating in few chemical reactions only) are referred to as inert gases. However, it

depends on the specific case whether a given gas is referred to as inert gas for a given application. Examples of inert gases are nitrogen and all noble gases, i. e. argon and helium.

Inert gases in the sense of fire and explosion protection can basically be all non-combustible and non-oxidizing gases not reacting with the substance and/or the dust, e. g. nitrogen, carbon dioxide and argon.

Inertness

To create inertness means filling a volume with an inert gas (in the sense of fire and explosion protection) in order to displace oxygen so that combustion/explosion inside this volume is no longer possible.

Spray water system

Spray water systems serve for feeding fire water to the fire in a very well-designed way. This can be achieved by a dry pipe fire protection system with signalling to the fire brigade or by pipes that are permanently connected to the water supply and activated either automatically or manually in case of fire.

Safety parameters

Safety parameters is a collective term for substance properties of combustible dust according to VDI 2263 sheet 1 "Dust fires and dust explosions, hazards, assessment, protective measures – Dust fires and explosion protection in dust extracting installations; Examples".

4 Operator obligations

The role of silo operators and similar facilities includes among others, the analysis and documentation of possible fire and explosion hazards and taking the necessary safety measures. This is done using a risk analysis that the operator must carry out prior to putting the facility into operation for the first time. The essential element is to consider all operating conditions, starting with construction, putting into operation, operation, maintenance and cleaning up to



dismounting and disposal. As far as explosion hazards are concerned, the Operational Safety Decree applies in particular. An explosion protection document applying to the facility must be prepared. Operating instructions must show the employees the correct and safe operation of silo and bin facilities and the proper behaviour in case of danger.

Rating of the fire and explosion risk must consider that organic material dust may always be combustible and/or enable a dust explosion. More details in specific cases can be obtained from the safety data sheets, databases for safety parameters, safety literature and laboratory tests. Dust may be generated even from lumpy or shredded material, following abrasion inside the silo, in the surroundings and in the conveyor systems, possibly causing a dangerous dust explosion. When changing to storage of another material, a new fire and explosion hazard analysis must be carried out.

The operator obligations also comprise having fire protection systems and electric installations including the lightning protection systems, Operational Safety Decree/explosive atmospheres, Technical Inspection Rules, Insurer's Inspection Regulations etc. inspected and maintained at regular intervals.

5 Protective measures

A series of tried-and-tested preventative and fire protection measures can be taken that can prevent a silo fire or minimise its consequences:

5.1 Avoiding fire loads and ignition sources

Throwing the product into the silo may stir up dust, especially during filling. If an ignition source is present, a dust explosion may result.

Additional fire loads from dust deposits near the silo must be kept to a minimum by regular cleaning. Ignition sources inside the silo and around the silo must absolutely be avoided.

5.1.1 Avoiding introduction

A cell occupation and control schedule can avoid mixtures and critical conditions can be identified and traced. This can reduce the risk of self-ignition inside the silo, e. g. due to introduction of moisture. The moisture content of stored materials tending to self-ignition in connection with moisture should be examined before storing. Silo ventilation can serve for keeping the moisture content of the stored material low.

The formation of hot or burning material, glowing nests and sparks and/or spark-generating parts must be avoided efficiently as early as in the conveyor systems to the silo. Safety monitoring of conveyors (off-track monitors, slip control, speed measurement and temperature control) as well as metal separators serve this purpose.

Transportation of hot or burning substances (e. g. glowing nests) by conveyors to the silo must be effectively prevented. To this end, infrared sensors (hot spot sensors) or spark detectors can be employed. However, these make sense only if after detecting a hot or burning substance, this substance is either reliably discharged automatically or extinguished or the conveyor system is shut down immediately. Spark extinguishing systems have proved their worth for extinguishing substances in conveyors. The decisive aspect here is that the bulk density within the conveyor system is not too high, covering up glowing nests and sparks, and that the stored material is not too sensitive to water. Soiling of spark sensors can be removed e. g. by compressed-air cleaning of the optical units. These reasons among others necessitate that design and installation are by a VdS-approved spark extinguishing systems company in accordance with VdS guideline 2106 "Spark detection, spark separation and spark extinguishing systems, planning and installations".

5.1.2 Ignition sources on and in the silo

When an explosive atmosphere is specified inside the silo (so-called explosion zones, see Operations Guideline 1999/92/EC), electric and non-electric devices and systems in Europe must meet the requirements of ATEX Product Guideline 94/9/EC (explosion-protected equipment).



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Similar laws and regulations govern the purchasing requirements outside of Europe, such as NFPA 499. These must be regularly checked by a capable person according to the Operational Safety Decree every three years at the latest.

Electric installations (e. g. lights) should not be installed inside the silo if possible. All electric equipment (including lighting fixtures) in explosive atmospheres must be suitable for use in explosive atmospheres and arranged so that they cannot be covered up with material. See also EN IEC 60079 "Explosive atmospheres". Conductive silo cells must be earthed or connected to equipotential bonding to counteract static electricity (see VDE standards). Static electricity may also occur in filling and conveying operations and when pouring substances into another container. Such processes require equipotential bonding measures as well, especially including the vehicles connected with operational facilities, such as lorries and railway wagons. See also NFPA 77 and Cenelec CLC/TR 50404.

High silo buildings should be equipped with a lightning protection system according to EN 12779. This system must be completed in accordance with NFPA 780/IEC 62305.

5.2 Permanent Inerting

In case of bulk material with a heavy self-ignition tendency such as some hard coal grades or coal dust, operation of the silo and bin facilities in a permanent inert gas atmosphere is recommended. A constant feed of inert gas (usually nitrogen) keeps the silo atmosphere permanently below a critical oxygen concentration which is between 2 and 12 % by vol., depending on the bulk material. This avoids a fire from the start, but inert gas escaping during silo filling and draining processes must be permanently replaced. This may cause considerable costs.

5.3 Design measures for explosion protection

This comprises all measures involving well-aimed discharge of excess pressure which avoid damage to the silo body and the (pneumatic) conveyors in case of a dust explosion. Dust explosions can create an excess pressure level of up to 8 bars. Pressure relief must be to the outside and without any hazards. If this is not possible, technical measures must be taken that enable safe control of the excess pressure (e. g. quenching unit). The examples listed below describe some possible measures that must be defined in a protection concept and matched to one another.

The most frequently applied measure is to provide explosion pressure relief areas on the silo head, e. g. by installing rupture discs, rupture flaps or breaking films which relieve the pressure either to the top or laterally. The silo containers must be designed to withstand the reduced explosion pressure resulting from the pressure relief. The size of the necessary pressure relief areas is calculated among others as a function of the dust explosion hazard of the substance (KSt value) and of container shape and size. Precise calculations can be found in EN 14491.

Mechanically closed conveyors such as elevators can also be protected by pressure relief units such as rupture discs and pressure relief flaps. In that case, the conveyors must be designed to withstand the reduced explosion pressure.



Picture 1: Examples of rupture discs

Pneumatic conveyors may be protected by so-called explosion diverters. In such a unit, the conveying direction of the material to be transported is redirected at an acute angle so that the main excess pressure direction can be relieved through a rupture disc arranged in the direction of transport.

All conveying systems must withstand the reduced explosion excess pressure when pressure relief units are provided.

To prevent transmission of dust explosions to other silo cells or conveyor systems, the individual units must be isolated from one another from an explosion protection point of view. To achieve this, rotary valves or explosion diverters are usually installed. Special explosion protection valves and quick-acting gate valves for pneumatic conveyors which close within fractions of a second are also available. In such a configuration, the conveyor systems must withstand the full or the reduced (if pressure relief is provided) explosion pressure. In addition, explosion suppression systems can be installed that suppress a starting explosion by spraying in an extinguishing agent (extinguishing powder, water) very quickly. When used for isolation purposes, these systems are referred to as extinguishing agent barriers. Even conveyor systems equipped with extinguishing agent barriers or explosion suppression systems must be designed to withstand a reduced explosion excess pressure.

5.4 Structural fire protection

Silos and bins must be stable and sufficiently strong according to the general technical rules. Dimensioning must take explosion protection measures into account (arrangement, size, static response pressure and load relief capability of pressure relief units and container strength for reduced explosion pressure).



Picture 2: Prepared sealing for clearing-out of silo

Silo and bin facilities should be built from non-combustible building materials in order to avoid additional fire loads. Solid silo facilities made of brickwork or reinforced concrete offer the benefit that they resist a fire well and offer good stability. Silos made of metal, plastic (GRP) or textile materials, however, will quickly lose their stability in case of fire and may collapse. The statics may quickly fail in particular when filling fire water into such silos. Moreover, the electric conductivity should be ensured for silos made of plastics (protection against sparks due to electrostatic charges).

Silo and bin facilities should be separated with a fire rating inside buildings and with respect to other buildings and plant components. When setting up silos and bins outdoors, a minimum distance from buildings and plants of 5 m and of 10 m in case of combustible silos should be respected, especially if the silo body is not solid and there is a high danger of collapse. When setting up silos and bins inside buildings, the walls and ceilings of the building should be fire-resistant (REI 90/ATSM 3-hours). As for the rest DIN EN 12779 must be met.

Essential inertness of the silo in case of fire necessitates that all openings can be made as gas-tight as possible (even temporarily) so that the inert gas cannot escape quickly.

As far as the subsequent clearing-out of the silo is concerned, access hatches at different silo body elevations (inside diameter 0.60 m min.) and additional emergency clearing openings at the silo base have proved their worth; from there the stored material can be transported to a safe area and extinguished if necessary.

Special requirements on the condition of silos and bins and their surroundings may apply to the storage of special bulk materials due to provisions imposed by authorities or employer's liability associations. See also chapter 8.

5.5 Fixed fire protection

These measures are to serve for detecting and/or fighting a fire.

5.5.1 Silo monitoring

In addition to the usual technical monitoring equipment such as level indicators and overfilling protections, silos and bins should also be monitored for internal fire. The simplest measure frequently involves permanently installed temperature sensors or measuring lances provided at different elevations of the bulk material. However, their disadvantage is that they react quite slowly or do not detect the fire at all, and that experience tells us that before they respond, smoke can already be seen escaping from the silo.

Smoke detectors detecting typical smouldering gases (e. g. carbon monoxide CO and methane CH₄) very early are better suited for this purpose. Depending on the material stored, a high carbon monoxide concentration is frequently found inside a silo (holding e. g. coal or wood pellets) plus air humidity and fine dust so that smoke detectors detecting CO exclusively can be used only with restrictions. Oxygen sensors may also serve for fire monitoring.

Conventional smoke sensors are less suited inside the silo as they soil quickly. They can be installed in spaces above the silo tops if required, and possibly as smoke intake systems as far as the amount of dust produced is low. Special filters and dust separators for smoke intake systems have been developed for use especially inside silos so that now smoke monitoring is possible, depending on the material stored. In open bin facilities, stationary thermal image cameras are often suitable for early fire detection.

At any rate, the automatic monitoring concepts must be adapted specifically to the local conditions. Engineering design by a specialist is required because incorrect selection of equipment and wrong locations of fire alarms may

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result in system trouble, false alarms or failure to respond/general failure. Universal monitoring systems that can be used for silos without restrictions are not available so far.

5.5.2 Fixed fire protection systems

5.5.2.1 Inerting in case of fire

The most favourable option for fire-fighting and safe clearing-out in case of fire is inerting of the silo or bin. In this process, an inert gas (nitrogen in most cases) is fed into the silo or the bin so that the air and consequently oxygen is displaced from the silo and the oxygen content drops below 4-6 % by vol. At this oxygen concentration, fire spread in the usually stored materials is no longer possible. Dust explosions of organic materials (food and fodder, wood, coal and plastics) are no longer possible as early as below 8 % by vol. (oxygen limit concentration). The oxygen limit concentrations depend on the material and are between 3 % by vol. (magnesium) and 14 % by vol. (hard coal), see table 1. In case of fire, you should subtract at least 1 % by vol. from the values in the table as a safety margin.

Nitrogen as an inert gas offers the advantage that it is a little more lightweight than air and non-toxic (but it displaces oxygen!). It is true that carbon dioxide has slightly

better fire-fighting properties, but is toxic in higher concentrations and above all is heavier than air, thus accumulating in lower-level rooms. This may become dangerous for fire-fighters in an inert silo if the inert gas feed point is below ground level or carbon dioxide escapes from other silo leaks and accumulates beneath the silo. In addition, it may react to produce explosive carbon monoxide at very high temperatures.

To achieve well-designed and rapid inertness of a silo or bin, requires fitting permanently installed gas pipes to the silo top and closing gas feed and measuring sensor connections (gas, pressure, \varnothing approx. 15 cm). A C-pipe connection (DIN 14302) as a nozzle or annular channel is useful for gas feeding and the pipe should be installed so that it cannot be clogged by the bulk material. The inert gas connections should be provided at the top and the bottom. Suitable sealing fixtures shall be provided for the silo top and bottom area.

At least three closing 1/2" openings should be provided for measuring sensors; these should be located at the silo bottom (between the discharge and the inert gas feed), at half the silo elevation and at the silo top. In addition a ventilation opening should be provided at the silo top in order to discharge displaced air.



Picture 3: Examples of explosion-proof smoke detectors



Picture 4: Smoke detector in a practical application

5.5.2.2 Spray water systems

The installation of stationary spray water systems inside silos and bins is recommended for bulk materials that can well be extinguished with water, e. g. wood chips and dust as well as paper chips and dust. Design and installation must comply with NFPA 15 (VdS 2109en "Water Spray systems, planning and installations"). The water applied should be at least 7.5 mm/min (l/m² x min). Activation may be either manual or automatic, e. g. by an activation pipe-work (frequently seen in bins) or by automatic fire alarms. The fire protection systems of smaller silos may also be

installed as dry, semi-fixed systems supplied by fire water from hose reels or by the fire brigade in case of fire. Filter systems using textile components in suction systems should also be fitted with manual, automatic or semi-stationary spray water systems. Electric fire water booster pumps must be relied upon in the event of a fire and should therefore be connected to an emergency power supply.

5.5.2.3 Gas protection systems

Gas protection systems are suitable for silos and bins only with reservations. The working principle relies on inertness.

Example:

Silo dimensions:	height: 40 m, diameter: 8 m
Silo cross-section area:	4 m x 4 m x (3.14) = 50 m ²
Total silo volume:	50 m ² x 40 m = 2,000 m ³ (organic material)
Filling level:	24 m (= 60 %), i. e. 800 m ³ of empty top space, 1,200 m ³ of bulk material
Inert gas quantity in top space:	800 m ³ x 1.5 m ³ of nitrogen/m ³ = 1,200 m ³ of nitrogen
Inert gas quantity of bulk material:	1,200 m ³ x 0.5 (1.0) m ³ of nitrogen/m ³ = 600 (1,200) m ³ of nitrogen
Feed rate in top space:	1,200 m ³ /4 hours = 300 m ³ /h
Feed rate in bulk material:	600 (1,200) m ³ /4 hours = 150 (300) m ³ /h

Plus more inert gas for maintaining the concentration (leaks, depending on the silo in question).

Substance	Limit oxygen concentration with nitrogen inertness in % by vol.
Aluminium	5
Brown coal	12
Cellulose	9
Wood	10
Magnesium pre-alloy	3
Maize starch	9
Polyacrylnitrile	10
Polyethylene (PE)	10
Carbon black	12
Hard coal	14

Table 1: Limit oxygen concentrations of various dusts



Picture 5: Inert gas delivery by tank lorry with a mobile evaporator

However, the technical effort required is quite considerable because the entire extinguishing gas quantity needed must be stored. As compared with conventional gas protection systems, the flooding periods are much longer (roughly one to two hours). The goal of keeping the extinguishing and/or inerting gas inside the silo during many hours or days cannot be achieved by using gas protection systems alone. A continuous inert gas feed for an extended period of time is required because silos are usually not 100 % gas-tight and the extinguishing and/or inert gas will slowly escape.

5.6 Fire water supply

Sufficient water supply is necessary for initial measures, for cooling building parts, for feeding existing fire protection systems and for extinguishing cleared-out glowing nests. The fire water supply should be at least 192 m³/h (= 3,200 l/min) for two hours duration. When fixed fire protection systems are involved, an independent fire water supply must be sized in accordance with the design and kept available.

For manual fire-fighting at the silo top, a (dry) riser which can be fed from a safe area in the ground floor should be available in the silo building for the fire brigade. This riser can also be used for inerting (upward gas transport). This pipe must be equipped with C- and/or B-couplers according to DIN 14 302 and should have a diameter of at least DN 65 (or even larger, depending on the situation). All pipes must be earthed for protection against electrostatic charges (connection to equipotential bonding).

5.7 Fire protection organisation

According to the Operational Safety Decree, an explosion protection document must be prepared and updated for stored materials that are susceptible to dust explosions. All inspections required by the Operational Safety Decree must be carried out at regular intervals.

Operating instructions should be prepared for work near silos and bins (entry permit, cleaning schedule etc.). No hot work is allowed near silo facilities and inside the silo, or increased safety measures must be taken, with the silos being completely empty and cleaned (free of dust). See also the Technical Safety Information on the subject-matter of "Hot work". Smoking is not allowed. This ban must be clearly communicated by means of signs.

A sufficient number of employees must be instructed in how to act in case of a silo fire and in the handling of the safety equipment in the silo and bin facilities. Practical fire extinguisher training using a training unit is also strongly recommended.

An alarm plan should indicate who must be informed in case of fire, e. g. company management, fire brigade, inert gas supplier, technical advisor, employer's liability association, trade supervision, fire insurer (fire protection dept). The inert gas suppliers must be contacted in order to find out which suitable gases and quantities as well as necessary equipment (evaporator) can be supplied within which time.

The practical fire-fighting measures must be discussed in advance with the fire brigade in charge and regular exercises must be performed!

Fire brigade plans providing the necessary information and design documents of the silo and bin facilities as well as the present Technical Safety Information should be handy on site for the fire brigade and for technical advisors/experts.

5.8 Maintenance

Regular maintenance of filters, moving parts including bearings and hinges and the existing safety equipment of the silo and bin facilities according to the manufacturer's specifications is urgently required.

6 Measures in case of fire

After notifying the offices in charge (fire brigade, technical advisor), in case of fire all conveyors should be shut down and to prepare for inerting and all silo openings closed as gas-tightly as possible, if necessary using wet bags, panels, adhesive tape or similar things. This avoids further oxygen ingress. In this process, it must be ensured that no persons are endangered by smoke and if required, respiratory equipment must be worn (fire brigade). In addition, further adjoining silos not affected by the fire should be emptied if possible in order to avoid fire spread.

6.1 Inertness

The inert gas quantity required must be calculated and made available. The process to achieve inertness should only be started when enough inert gas is available and further supply is ensured.

Moreover, continuous gas measurements are required, among others:

- oxygen in order to prove sufficient inertness,
- CO: determination of fire intensity and fire-fighting success.
- the measured values (course) must be assessed on site by an expert.

6.1.1 Required inert gas quantities

As practical experience has shown, achieving an inert empty silo top space requires 1 m³ of carbon dioxide (gaseous) or 1.5 m³ of nitrogen (gaseous) per m³ of empty top space. This reduces the oxygen concentration to less than 8.0 % by vol. so that there is no more dust explosion hazard for organic substances in the top space. A four-hour period is aimed at for feeding in the corresponding inert gas quantity.

Feed rates of 0.5 to 1.0 m³ of inert gas (gaseous) per m³ of bulk material reduce the oxygen content to < 2 % by vol. This is necessary for extinguishing the smoldering fire within the bulk material and must be maintained during an extended period (usually 48 hours). Here as well, an inert gas feeding period of four hours is aimed for. The precondition in each case is that the silo is relatively gas-tight and/or can be sealed (temporarily); otherwise the

inert gas quantities needed may be substantially larger. In addition, the actual silo filling level should be checked, regardless of automatic level indicators which may occasionally be defective or imprecise.

6.1.2 Storage and purchasing of inert gas

Inert gas can be ordered as an emergency supply from major gas suppliers. However, several hours may pass until the gas delivery arrives at the silo in question. This is un-critical in most cases because a smouldering fire inside the silo spreads only very slowly and there often is no other promising fire-fighting method available anyway (depending on the material stored). All persons involved must be prudent and above all patient!

Both cylinder bundles (gaseous inert gas) and tank lorries (liquid inert gas) can be delivered. One road tanker with 20,000 kg of liquid nitrogen on a semi-trailer yields around 17,100 m³ of gaseous nitrogen. A drawback of tanker deliveries is that the inert gas can be withdrawn from the tank in gaseous condition only during the first roughly three hours (and the residual pressure must not drop below 0.5 bar). After that, evaporation from the liquid to the gas phase is needed which can be realized only with a separate and suitably dimen-



Incomplete fire-fighting and early clearing-out of a silo often results in dust explosions – with fatal consequences!

sioned evaporator unit. Nitrogen cylinder bundles, however, can be used continuously until completely empty (this does not apply to CO₂ cylinders!).

In an optimum configuration, inert gas can also be stored in the operations, e. g. in cylinder bundles or liquefied gas tanks (with evaporators). In this way the process of achieving inertness in a silo or a bin can be started early in case of fire and continued by gas delivered later. The gas quantity to be stocked depends on the silo size. It should be sufficient for creating inertness for four hours. In the example above and when supposing an unfavourable filling degree of only 10 % of the silo volume, there would be 1,800 m³ of empty top volume so that 1,800 m³ x 1.5 m³ of nitrogen/m³ = 2,700 m³ of nitrogen would be required (equalling around 3,160 kg).

6.1.3 Task of inert gas and fire extinguishing

As a basic rule, the top space should be made inert first. This serves as a protection against possible dust explosions in the empty top volume, which has priority for the time being. However, feeding in inert gas from the top alone (opposed to the thermal lift) usually cannot penetrate the bulk material in the silo and therefore not completely extinguish the smoldering fire, which, in turn, is a precondition for clearing out the silo without hazards. In

Guideline values for silo inertness/overview		Remarks
Oxygen concentration against dust explosion (Limit oxygen concentration)	< 8.0 % by vol. for organic material on average	Applies to clearing-out of the silo; in this process, measure the oxygen at the silo bottom and top.
Oxygen concentration (O ₂) against fire spread	4-6 % by vol. O ₂ max.	Measure the oxygen at the silo top Maintain this concentration for at least 48 h.
Oxygen concentration (O ₂) for extinguishing	< 2 % by vol. O ₂	Measure the oxygen at the silo top Maintain this concentration for at least 48 h!
Inert gas feed quantity in top space for oxygen concentration < 8 % by vol.	1.0-1.5 m ³ per m ³ of empty silo volume	N ₂ : 1.5 m ³ /m ³ of empty volume CO ₂ : 1.0 m ³ /m ³ of empty volume
Inert gas feed quantity in bulk material for oxygen concentration < 2 % by vol.	0.5-1.0 m ³ per m ³ of bulk material volume	Regardless of inert gas!
Tank lorry load (liquefied nitrogen) (liquefied carbon dioxide)	approx. 20,000 kg (liquefied) = approx. 17,100 m ³ N ₂ gas = approx. 10,820 m ³ CO ₂ gas	An evaporator is required!
Max. internal silo excess pressure	See manufacturer's specifications	Depending on design; to be measured near the inert gas feed point.
Measuring of fire intensity (smoldering fire)	Measure the carbon monoxide (CO) concentration at the silo top	Decreases from >> 1.000 ppm to <100 ppm, possibly to 0 in case of successful inertness.

Table 2: Practical guideline values for silo inertness

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the second step, inert gas is therefore also fed in at the silo bottom at the same time, e. g. using a prepared connection, a lance or an outside ring line with openings protruding into the silo. The oxygen concentration must be permanently measured in the silo top and bottom area. Gas feeding at the bottom must be slow and at low pressure so that the gas penetrates the bulk material evenly and no major channels form inside the bulk material. The oxygen displaced from the bulk material ends up in the previously inert top space. Depending on the oxygen concentration in the silo top, gas feeding from the top can be reduced slowly and finally shut down altogether. However,

should the oxygen concentration in the top space rise above e. g. 8 % by vol. again (in case of organic material), inert gas must again be fed in from the top. Prior to filling the filling lines with the inert gas, these lines must be vented and/or flushed with the inert gas so that no additional oxygen is blown into the silo. The inerting process must be monitored by measurements. The parameters below must be measured on the silo top:

- oxygen concentration
- carbon monoxide concentration
- temperature inside the silo if required
- carbon dioxide concentration if required



Picture 6: Tank trailer and mobile evaporator



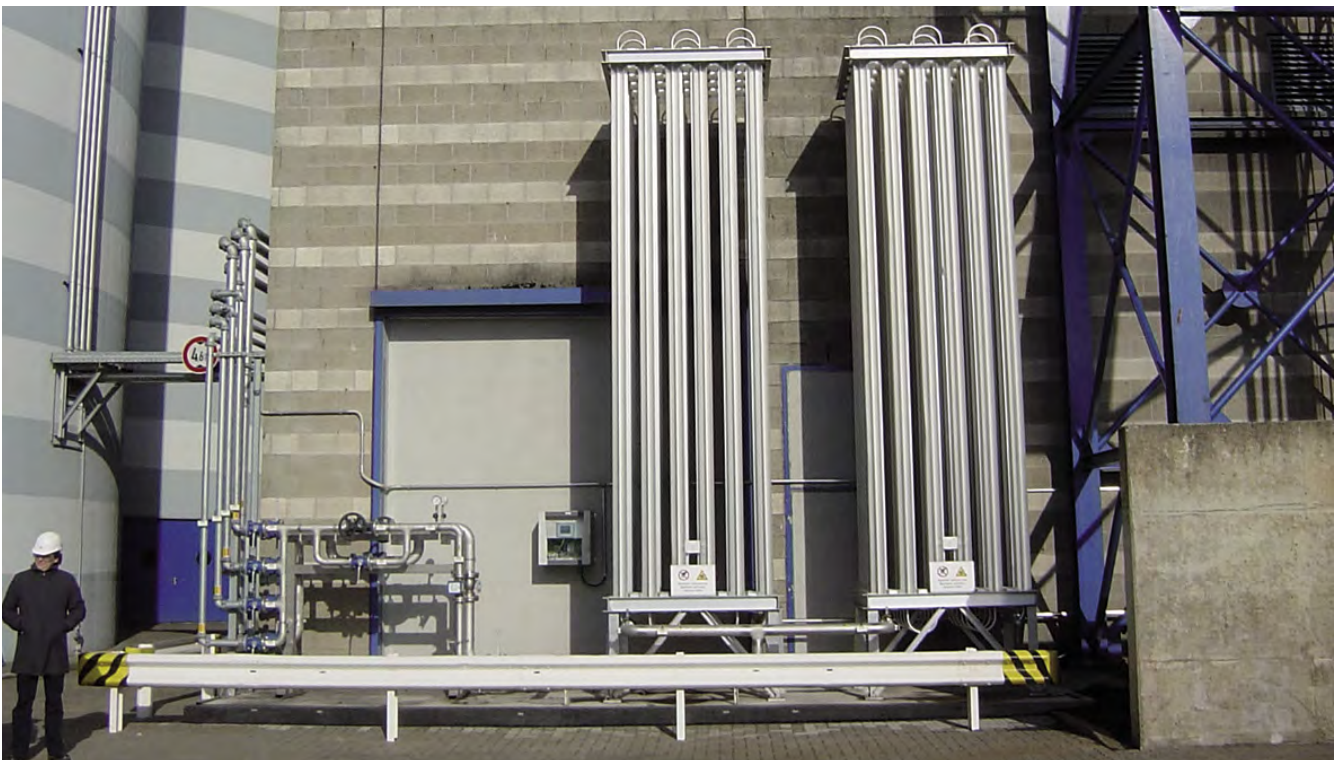
Pictures 8a+b: Inert gas delivery

The pressure inside the silo must be monitored at the silo bottom near the inert gas feeding point. If the necessary connections and openings are not provided on the silo, these must be made available temporarily, if necessary by drilling holes into the silo (only in the bulk material area and while using water for drill cooling). In this process, explosion protection must be observed. Igniting sparks and hot surfaces must absolutely be avoided. The filling and extinguishing process may take from several hours to some days. The CO concentration is used to determine if the fire has been extinguished. A permanent CO concentration of < 30 ppm after finishing the

inerting process (no more inert gas feeding) indicates successful fire-fighting.

6.2 Use of water/foam

Fire water with wetting agent, medium- and high-expansion foam or extinguishing gel can be applied for cooling and/or covering up the bulk material under inert gas protection. The use of fire water and foam inside the silo is usually impossible if the substances in question are prone to becoming swollen or if the bulk material will not impregnate well with water, forms lumps or if the silo is made of metal, plastics or textile materials and will not



Picture 7: Stationary evaporator next to a silo



Picture 9: Inert gas connection to stationary evaporator



Picture 10: Inert gas feeding through pre-installed pipes

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tolerate increased weight due to water (danger of collapse). The use of fire water without additives (full jet/spray jet) inside the silo should be avoided. When using water near the silo, ensure that no dust is stirred up (use a spray jet) and that the water will not flow into silo cells. Silo cooling from the outside using water is usually possible and makes sense.

6.3 Clearing-out of silo

Clearing out of the silo may be started only after the fire is completely extinguished. The CO concentration is used to determine if the fire has been extinguished. A permanent CO concentration of < 30 ppm after finishing the inerting process (no more inert gas feeding) indicates successful fire-fighting. If the fire cannot be extinguished, the silo must be cleared out under an inert atmosphere both inside the silo and in the associated conveying systems. The decision about when to start clearing out must be made by an expert in cooperation with the fire brigade.

Failure to observe this procedure involves the danger of another fire or a dust explosion while clearing out the silo!

A smoldering fire may create so-called bridges inside the silo which may collapse while clearing out the silo and stir up dust. A dust explosion may follow if there is no more inert atmosphere.

Before starting clearing-out, the absence of dust must be ascertained in the spaces connected with the silo and if required, these must be cleaned. Raising dust must absolutely be avoided in this process.

While discharging the bulk material, suitable measures must be taken to avoid the formation of hazardous dust/air mixtures even outside the silo, e. g. by applying a water curtain.

7 References

Local standards should be complied with.

Internationally recognised standards:

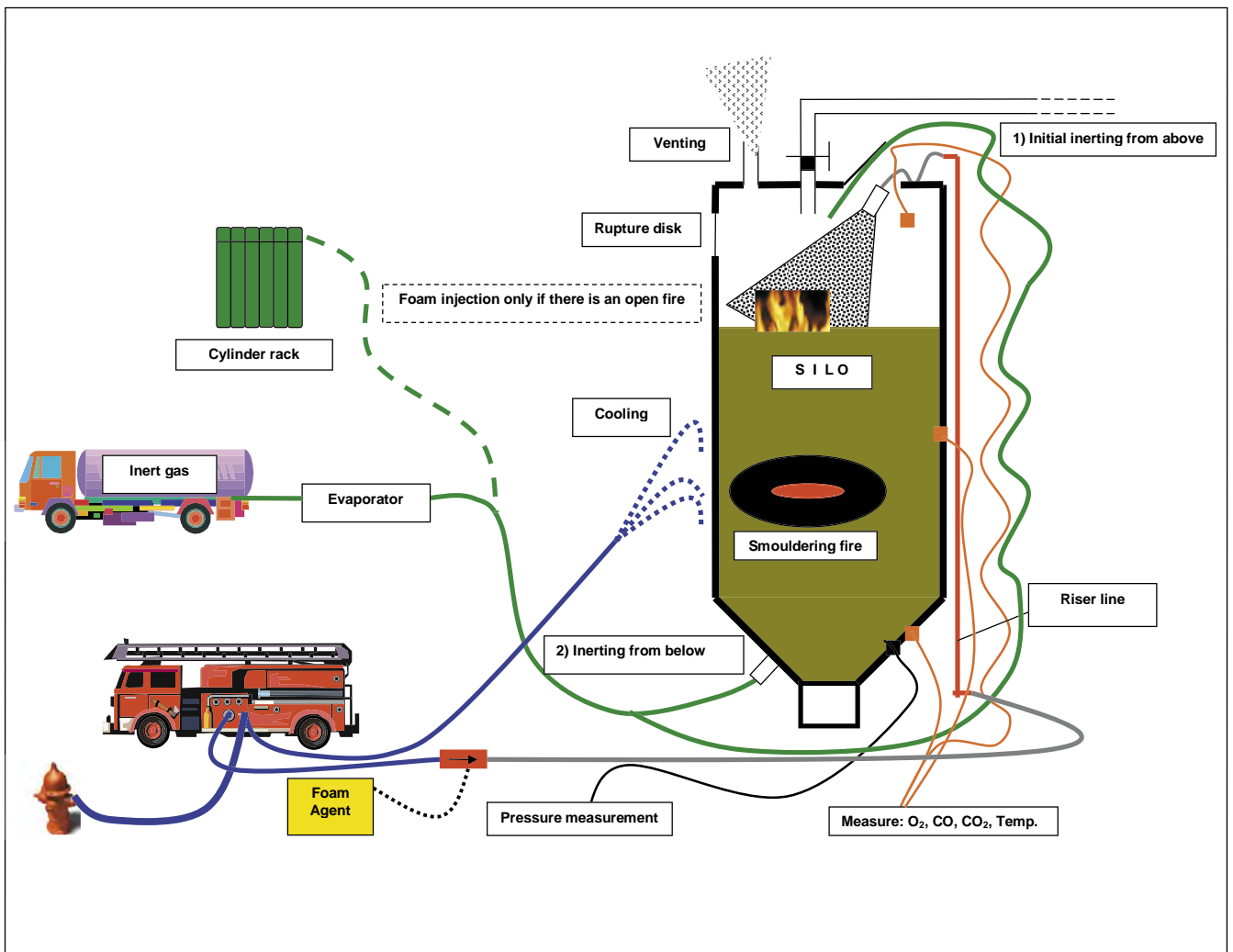
VdS 2106 en	Spark detection, spark separation and spark extinguishing systems, planning and installations
NFPA 15/Vds 2109 en	Water spray systems, planning and installations
EN 14491	Dust explosion venting protective systems
EN IEC 60079	Explosive atmospheres – Part 0: Equipment – General requirements
NFPA 68	Standard of explosion protection by deflagration venting
NFPA 77	Recommended Practice on Static Electricity
NFPA 654	Standard for the prevention of fire and dust explosions from the manufacturing, processing, and handling of combustible particulate solids
EN 62305/NFPA 780/IEC 62305	Lightning protection systems
VDI 2263	Dust fires and dust explosions, hazards, assessment, protective measures – Dust fires and explosion protection in dust extracting installations; Examples
EN 12779	Safety of woodworking machines – Chip and dust extraction systems with fixed installation – Safety related performances and safety requirements
Operations Guideline 1999/92/EC	
ATEX Product Guideline 94/9/EC	
CLC/TR 50404	
NFPA 499	Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas

Some useful background literature:

- Murphy, Dennis J. and Arble, William C. (2000)**, 'Extinguishing Fires in Silos and Hay Mows', NRAES (Natural Resource, Agriculture, and Engineering Servicers)
- NFPA (1998)**, 'Fire Investigation Summary – Grain Elevator Explosion', Haysville, Kansas
- NiCe (2008)**, 'Guidelines for storing and handling of solid biofuels', NT ENVIR 010, Nordic Innovation Centre
- NIOSH (2002)**, FACE-85-49: 'Three Fire Fighters Killed Fighting Silo Fire in Ohio'
- NIOSH (1986)**, 'Preventing Fatalities Due to Fires and Explosions in Oxygen-Limiting Silos', (NIOSH), 4
- Persson, Henry and Blom, Joel (2008)**, 'Research helps the fighting of a silo fire again', BrandPosten, (38), 30-31
- Persson, Henry and Blomqvist, Per (2009)**, 'Silo Fires and Silo Fire Fighting', Bioenergy 2009, 4th International Bioenergy Conference (Finland: FINBIO).



Annex 8: Outline in principle of silo fire fighting (overview)



About HDI Risk Consulting GmbH

HDI Risk Consulting GmbH supports mid-size companies, industrial companies and corporations in loss prevention and in establishing risk management systems. HDI Risk Consulting GmbH offers customers access to about 180 engineers and experts from a wide range of different disciplines. The goal is to support companies in managing risks and working out individual, risk-based concepts for insurance cover. HDI Risk Consulting GmbH operates across the world in the segments of Fire, Motor, Engineering Insurance and Marine with particular focus on the identification and assessment of risks and the development of appropriate, individual protection concepts. HDI Risk Consulting GmbH is a wholly owned subsidiary of HDI-Gerling Industrie Versicherung AG.

HDI Risk Consulting GmbH
HDI-Platz 1 - D-30659 Hannover
Phone: 49-511-645-3219
Fax: 49-511-645-4542
Internet: www.hdi-gerling.de

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