



DUST EXPLOSIONS

A comprehensive Guideline to Industrial Explosion Protection including scientific Basics, Case Studies about Incidents, Prevention Methods and constructive Protection Measures

REMBE®'s Booklet of Safety and Security (BOSS)

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This list is an abstract of the most relevant AND reasonable guidelines:

International

EN 1127-1:1997	Safety of Machinery, Fire and Explosions, Part 1: Explosion Prevention and Protection
EN 1050:1996	Safety of machinery - Risk assessment
EN 14034-1:2004	Determination of explosion characteristics of dust clouds - Part 1 and
EN 14034-2:2006	Part 2
EN 13463-1:2001 + Corrigendum:2002	Non-electrical equipment for potentially explosive atmospheres - Part 1: Basic method and requirements
EN 13463-6:2005	Non-electrical equipment for use in potentially explosive atmospheres - Part 6
EN 14373:2005	Explosion suppression systems
EN 14491:2006	Dust explosion venting protective systems
EN 14460:2006	Explosion resistant equipment
EN 14797:2006	Explosion venting devices
EN 15089:2007	Explosion isolation systems
EN 13821:2002	Potentially explosive atmospheres / explosion prevention and protection, determination of minimum ignition energy of dust / air mixtures
EN 50281-2-1:1998	Electrical apparatus for use in the presence of combustible dust, electrostatics code of practice CLC/TR 50404-2003 Tech Report
ISO 6184-4:1985	Explosion protection systems - Part 4: Determination of efficacy of explosion suppression systems
NFPA 68	Standard on explosion protection by deflagration venting, 2007 Edition
NFPA 69	Standard on explosion prevention systems, 2008 Edition

National (just to mention a few):

Germany:	VDI 3673, VDI 2263 and further
South Africa:	SANS (several)
Brazil:	ABNT
Australia:	FPA
etc.	

Introduction

The explosion protection measures described in these examples should not be considered as patent remedies which can be directly used in similar situations. In practice it is necessary to assess the hazard which can arise and to develop a specific explosion prevention and protection concept for each individual case. In the member states of the European Union this hazard assessment and the resulting protection concept must be documented as part of an Explosion Protection Document for each plant.

The purpose of this brochure is to demonstrate to engineers, plant managers, safety officers and others the risks associated with using flammable dusts. Examples of dust explosion incidents which have occurred in practice are used to help people without specialized knowledge in the field of dust explosions to assess whether or not explosion hazards due to dust may exist in their own plant.

The examples have been chosen so that, where possible, all important aspects of dust explosions are illustrated. These include:

- Different types of dust (e. g. plastic, food, sawdust)
- Hybrid mixtures
- The effect of particle size
- Ignition sources (e. g. flames, mechanical sparks, static electricity)
- Different types of plants (e. g. mixers, silos, dryers)
- Protective measures (e. g. limitation of the amount of flammable material, avoidance of ignition sources, explosion suppression).

The different dust explosion protection measures include:

- Explosion prevention (preventing the formation of an explosible dust/air mixture and avoidance of effective ignition sources)
- Explosion protection (measures to prevent the hazardous consequences of an explosion)
- Organizational measures.

The dust explosion examples described in this brochure are based on actual incidents which have occurred in Europe during the last twenty five years. Certain aspects have been simplified either to better show the cause and course of the event or to clearly demonstrate a particular protective measure. In the majority of the examples only one of the possible protective measures which could have been used to prevent a reoccurrence of the incident is described.

Explosion Pentagon

Ignition

**Dispersion of
dust particles**

**Confinement
of dust cloud**



Combustible dust

Oxygen

Energy is the Explosion Pentagons Finger which pulls the Trigger

Potential Ignition Sources which can carry enough Energy to start an Explosion (acc. EN 1127-1):

- Hot surfaces
 - Flames
 - Sparks from electrical equipment
 - Electrical equipment and lights
 - Stray currents from electrical equipment
 - Electrostatic discharge sparks
 - Lightning strikes
 - Electromagnetic fields in frequencies from 9kHz up to 300GHz
 - Electromagnetic radiation in frequencies from 300GHz up to 3×10^6 GHz and of different wavelengths from $1000\mu\text{m}$ up to $0,1 \mu\text{m}$ (optical spectral range)
 - Ionizing Radiation
 - Ultrasonic
 - Adiabatic compression, shock wave, running gases
 - Chemical reaction
- And not to forget: the human factor which turns all potential ignition sources into effective ones.

4 steps to a safer process

#1) Explosion prevention: Avoid the occurrence of an explosion

- **Avoid explosible dust/air mixtures**
 - Replace combustible materials by non-combustible materials
 - Avoid materials with a fine particle size. Note: fines are often produced e. g. by handling a coarse product
 - Limit concentration of combustible material used
 - Use sealed plants to prevent dust releases and deposits inside buildings or outside
 - Use dust extraction systems to control the extent of a dust cloud
 - Implement good Housekeeping (regular cleaning plan) → see also #3
 - Minimize flat surfaces, ledges to prevent dust deposits
 - Use an inert gas blanketing where useful and economic
- **Avoid effective ignition sources**
 - Limit surface temperatures below 2/3 of minimum ignition temperature or 75 K below auto ignition temperature (e.g. broken bearings, friction, etc.)
 - Avoid rubbing, contact of rotating parts (limit rotational speed, choice of materials, separation distance, avoid tramp metal)
 - Use a permit-to-work system to control hot-work (welding, cutting, etc.)
Prohibit smoking and open fire in general
 - Install appropriate electrical and non-electrical equipment
 - Avoid electrostatic charge generation
(choice of materials - earthing measures – effective bonding)
 - Spark detection and extinguishing
 - Consider all other ignition sources (e. g. self-heating, lightning)

**#2) Constructional explosion protection:
Limit the dangerous consequences of an explosion**

- Explosion-resistant design (explosion-pressure-resistant or explosion-pressure shock resistant)
- Explosion venting
- Explosion suppression
- Explosion isolation, decoupling (prevention of explosion propagation)

#3) Organizational measures:

- Comprehensive operator education and training
- Operator instructions, cleaning plans, good housekeeping
- Adequate maintenance
- Permit-to-work system for welding, hot-work and electrical operations (authorized persons only)

#4) Building precautions:

- Isolation of buildings and equipment to prevent transmission of fires and explosion
- Fire zones, clearly marked Hazardous Zones (Ex) / Explosion protection document
- Sealed and tight piping and conveying systems
- Smooth surfaces and easy-to-clean floors, easy access to elevated plant areas

12 Incidents and their analysis



Explosible dust clouds can be easily formed by the dispersion of layers of deposited flammable dust.

Flour packing station in a flour mill

Type of dust

Flour

Description of the plant and process

- The intermediate storage building (1) contained a sample storage room (2) built from wood on the ground floor. On the 3rd floor (3) sacks of flour were temporarily stored.
- A conveying system (4) allowed samples to be transferred from the 3rd floor (3) to the sample room (2).
- An enclosed approx. 45 m long bridge (5) connected the storage building to the main flour storage building (6).
- Packing area (7) with facilities for filling sacks and containers of different sizes inside the main flour storage building (6).

Course of the incident

- Initially a fire started in the sample room (2).
- Fire rapidly spread to the 3rd floor (3) due to the open conveying system (4).
Dust explosion in the 3rd floor (3) of the building.
- Propagation of the explosion through the connecting bridge (5) to the flour packing area (7) in the main flour storage building (6).
- Massive explosion in the packing room (7) destroyed supporting walls and led to the collapse of the flour storage building (6).
- Subsequent explosions occurred in many plant areas, including storage silos, due to flame transmission through connecting conveying systems and dust extraction ducting.

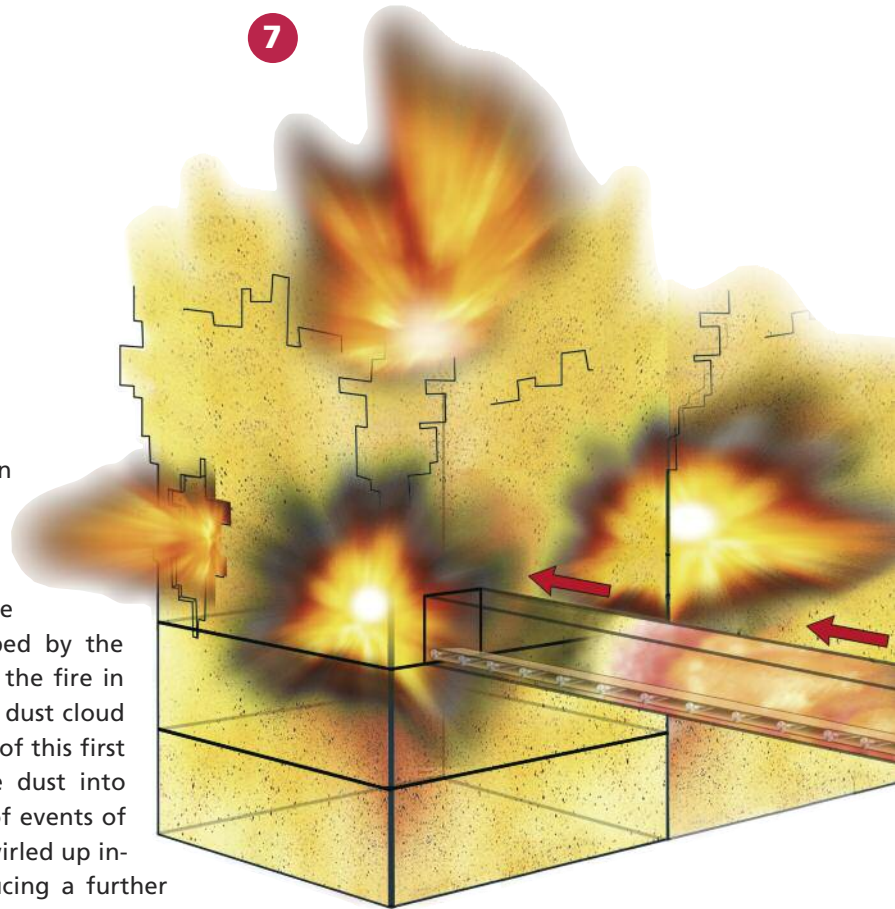
Consequences

- 14 dead, 17 severely injured.
- Building and almost the whole plant totally destroyed.
- 1 year loss of production.
- Cost of material damage more than 100 million Euro.

Causes

The plant design and operating conditions in the storage (1), and bag filling areas (6) resulted in the formation of significant dust layers in the different rooms. The deposits in the 3rd floor of the intermediate storage building (3) were initially disturbed by the draft through the conveying tunnel (4) of the fire in the sample storage room (2). The resulting dust cloud was ignited by the fire. The pressure wave of this first explosion disturbed and swirled up more dust into clouds which then ignited. This sequence of events of an explosion causing dust deposits to be swirled up into a dust cloud which then ignited producing a further explosion pressure wave continued in the form of a chain reaction.

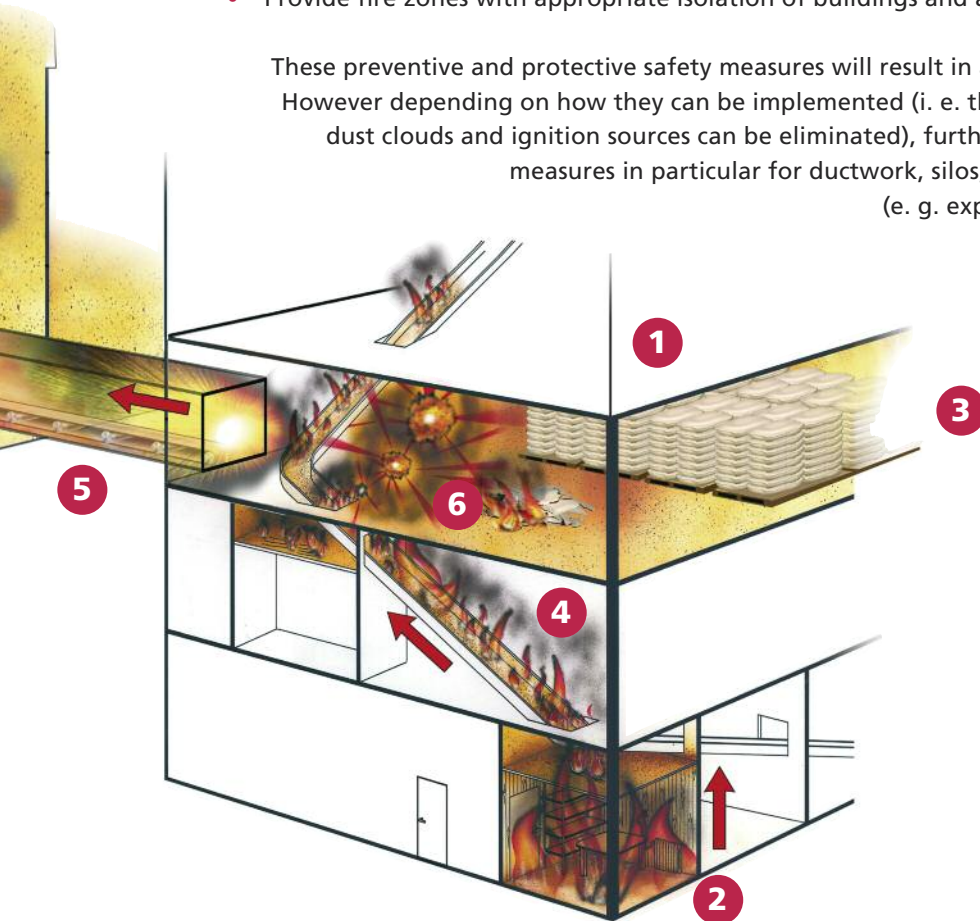
The elongated form of the connecting bridge (5) caused the unburned flour which was swirled up by the explosion pressure wave to be pushed through the bridge in front of the explosion flame. This formed a large explosible dust cloud which filled the whole packing area (7). The following jet flame ignited this cloud and the resulting massive explosion destroyed a major part of the flour storage building (6) and led to further secondary explosions in the adjacent areas.



Measures

- Avoid the formation of dust deposits by using sealed plant and/or dust extraction systems and by reducing the area of surfaces on which deposits could be formed. Remove dust deposits which are unavoidably formed by regular and systematic cleaning procedures (documented cleaning procedures).
- Eliminate ignition sources in areas with a fire or explosion hazard.
- Provide fire zones with appropriate isolation of buildings and areas (fire doors etc.).

These preventive and protective safety measures will result in a high level of explosion protection. However depending on how they can be implemented (i. e. the confidence with which explosible dust clouds and ignition sources can be eliminated), further constructive explosion protection measures in particular for ductwork, silos, cyclones and filters may be needed (e. g. explosion venting, explosion isolation).



Magnesium powder mixing plant (1st incident)

Type of dust

Magnesium

Description of the plant and process

- Preparation of mixtures containing Magnesium used to remove sulphur from molten steel.
- Magnesium powder is filled by gravity from a container (1) through a charge chute (2) into the mixer (3).

Course of the incident

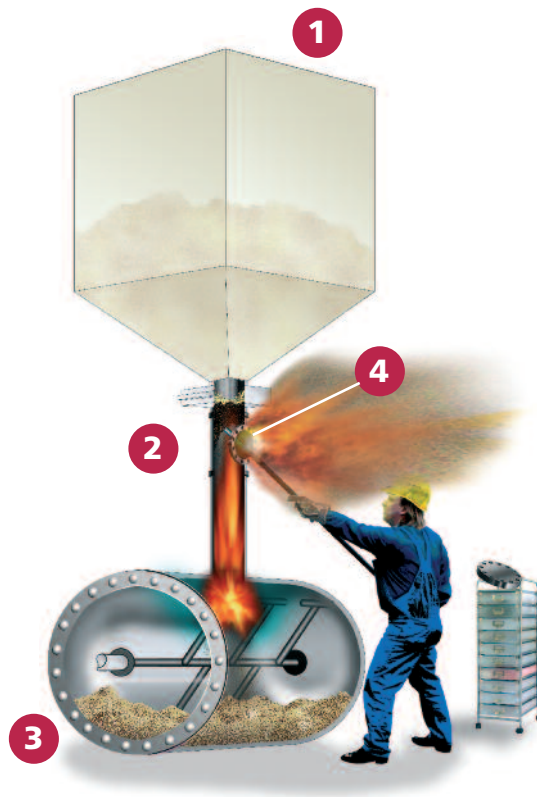
In the course of production it was noticed that contrary to normal experience, the Magnesium powder had stopped flowing into the mixer (3). While the operator tried to clear the blocked charge chute through an inspection hatch (4) with a metal rod, an explosion occurred in the charge chute (2) to the mixer (3).

Consequences

The operator suffered severe burns from the flames which were blasted out of the inspection hatch (4).

Causes

- The plant was not fitted with any explosion protection measure as it was designed to be used with dust free Magnesium granules.
- When the supplier of the Magnesium was changed, it was not noticed that the fine particle content was much greater. In addition to producing a dust explosion hazard, the new material did not flow so easily, causing the blockage in the charge chute (2).
- By hitting the Magnesium in the blocked charge chute with a metal rod, the operator inadvertently generated both a dust cloud and a mechanical friction spark resulting in an explosion.



Measures

- Reverting to the original dust free material would avoid the need for additional safety measures (risk of accumulation of fines must be considered).
- However, in this case it was necessary to continue using the dusty Magnesium and as explosible dust clouds could not be eliminated reliably, additional preventive or protective safety measures are needed. Magnesium powder has a low ignition energy and thus it is not possible to base safety solution by elimination of all ignition sources, constructive explosion protection measures are also needed.
- In this case inert gas blanketing was chosen as the preventive measure.

Magnesium powder mixing plant (2nd incident)

Type of dust

Magnesium

Description of the plant and process

- Preparation of mixtures containing Magnesium used to remove sulphur from molten steel.
- Magnesium powder is filled by gravity from a container (1) through a charge chute (2) into the mixer (3).
- The plant is protected by an inert gas blanketing system (4).

Course of the incident

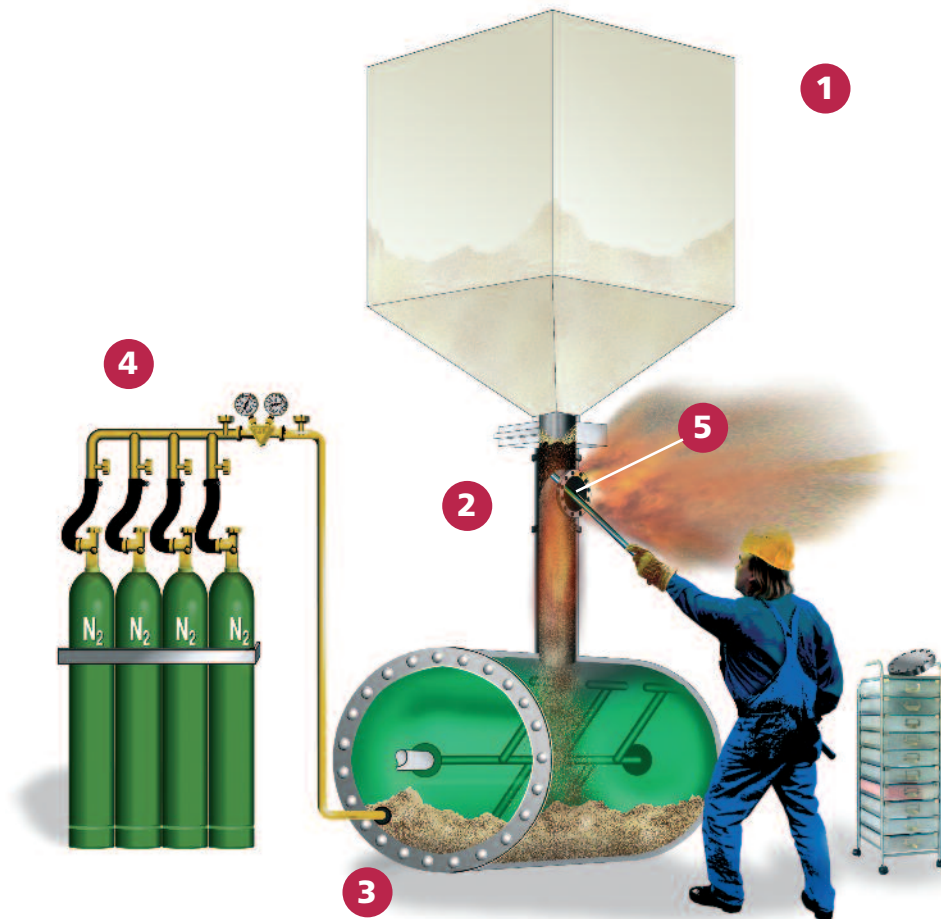
In the course of production it was noticed that the Magnesium powder had again stopped flowing into the mixer (3). While the operator tried to clear the blocked charge chute through an inspection hatch (5) again with a metal rod, an explosion occurred in the charge chute (2) to the mixer (3).

Consequences

The operator suffered severe burns from the flames which were ejected from the inspection hatch (5).

Causes

- The inert gas blanket was poorly designed and ineffective so that air could enter the charge chute (2) and top of the mixer (3) through the inspection hatch (5).
- While trying to clear the blockage with a metal rod instead of the recommended wooden rod a mechanical friction spark was generated at the same time as an explosible dust cloud.



Measures

- The Magnesium charging system should be changed to prevent blockages forming in the charge chute (2) for example by the installation of a vibratory feeder.
- Measures must be provided to clear any blockage that does occur in the charge chute without losing the inert gas blanket, e. g. small inspection hatch, ensure that inert gas supply has a slight overpressure - **Caution: possible asphyxiation hazard.**
- A rod made from non-sparking material (e. g. wood) must be provided to clear any blockages that form.

4

Where the avoidance of ignition sources is used as the only safety measure it must be certain that all possible ignition sources have been considered and eliminated.

Filling a mixer with plastic powder

Type of dust

Plastic powder

Description of the plant and process

- Mixer (1) with powder charging station (2).
- Manual charging of powder from sacks.
- Fan (3) for extraction at the charging point (2).
- The plant is constructed completely from metal and is protected by measures to prevent the occurrence of ignition sources (earthing, limiting the rotational speed of the mixer arm (4) etc.).
- The floor and the workers shoes are conductive.

Course of the incident

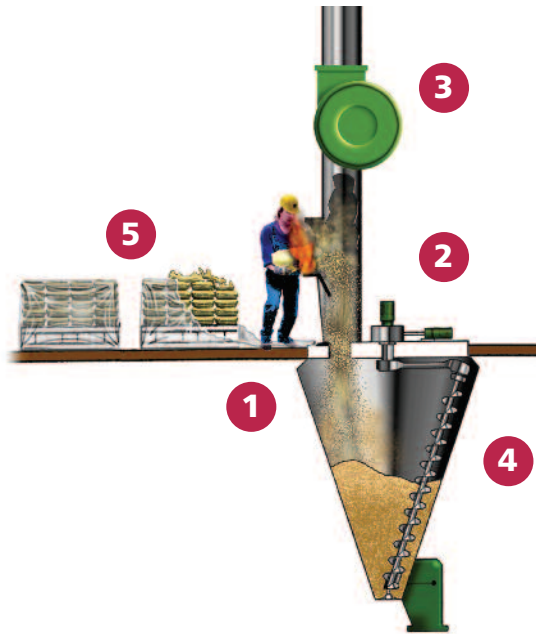
After several sacks had been emptied into the mixer (1), a dust explosion occurred in the charging station (2) while the next sack was being emptied.

Consequences

The worker suffered severe burns to his face and upper body.

Causes

- During the charging operation the worker was standing on the plastic shrink wrapping from the pallet packaging (5) and was therefore isolated from earth.
- The worker had become charged by both charge separation (walking about) and also by induction (emptying the powder out of the sack, shaking the sacks).
- A spark discharge occurred from the worker who was no longer earthed (plastic foil on floor) to the earthed metal plant. This ignited the ignition sensitive dust air mixture (minimum ignition energy MIE < 3 mJ) which was present around the charging point (2).



Measures

- The use of avoidance of ignition sources as a measure to prevent a dust explosion must be rigorously implemented. Not only must all plant items be earthed but also operators (by the use of conductive footwear, conductive floors) in order to prevent spark discharges. In addition it must be ensured that no insulating material interrupts the earthing path.
- The effectiveness of the earthing measures must be ensured by organizational procedures (for example written instructions concerning the wearing of conductive shoes, cleanliness of the floors, removing plastic packaging together with appropriate operator training).
- Where materials with very low minimum ignition energies are handled, the use of avoidance of ignition sources as the sole basis of safety against dust explosions is often not sufficient. In such cases additional measures such as inerting, explosion suppression are needed.

Extraction system of a rubber grinding machine

Type of dust

Rubber dust

Description of the plant and process

Grinding of rubber rollers (1).

Extraction system comprising collection goods, ducting (4), filter (5) and fan (2) to collect the dust from the grinding process.

Course of the incident

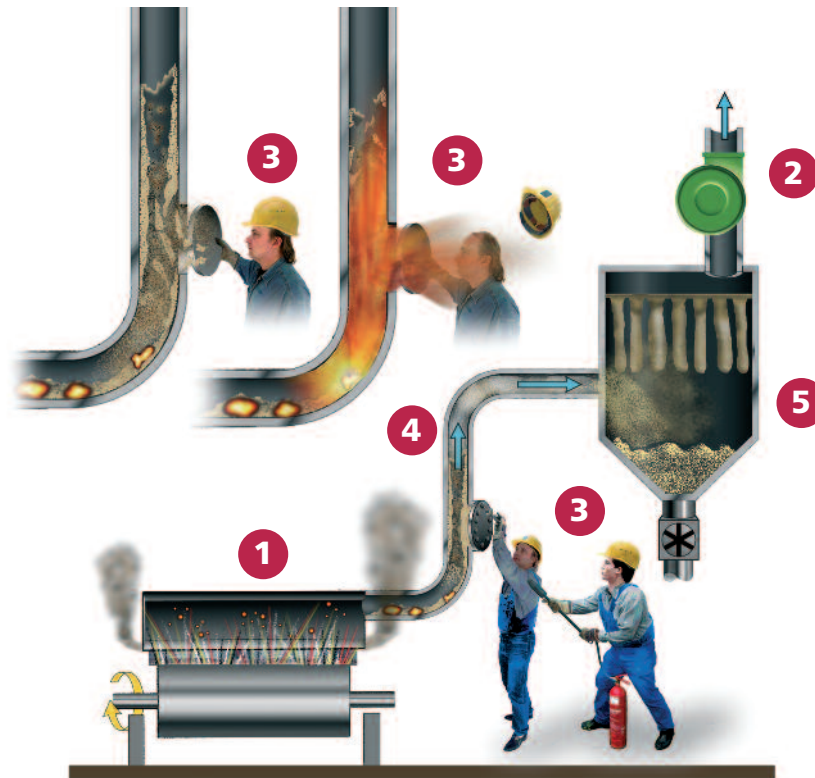
- On observing smoke, the operator opened the inspection hatch (3) in the ducting (4) in order to extinguish the fire.
- An explosion occurred shortly after removing the inspection hatch (3).

Consequences

Two operators suffered serious burns to their faces and upper bodies.

Causes

- Dust deposits were formed in the ducting (4) due to an insufficient air flow and a poor plant layout.
- Sparks from the grinding machine (1) ignited the dust deposits in the ducting (4) and caused them to start smouldering.
- The removal of the inspection hatch disturbed the dust deposits which formed an explosible dust cloud. This was then ignited by the glowing material.



Measures

- Prevent the formation of dust deposits in the ducting (4) by
 - a suitable air flow and design of the ductwork (large radius bends etc.),
 - organizational measures, i. e. regular inspection and cleaning of the ducting (written plan).
- Sparks from the grinding machine cannot be definitely excluded and they could act as an ignition source in the filter (5). This must be avoided for example by a spark detection and extinguishing system.
- The operating instructions must include procedures to be taken in the case of a fire (e. g. stop extraction fan, keep plant closed to prevent ingress of air, use of appropriate fire extinguisher or measures to be taken to inert the plant).

Coal dust extraction system

Type of dust

Coal dust

Description of the plant and process

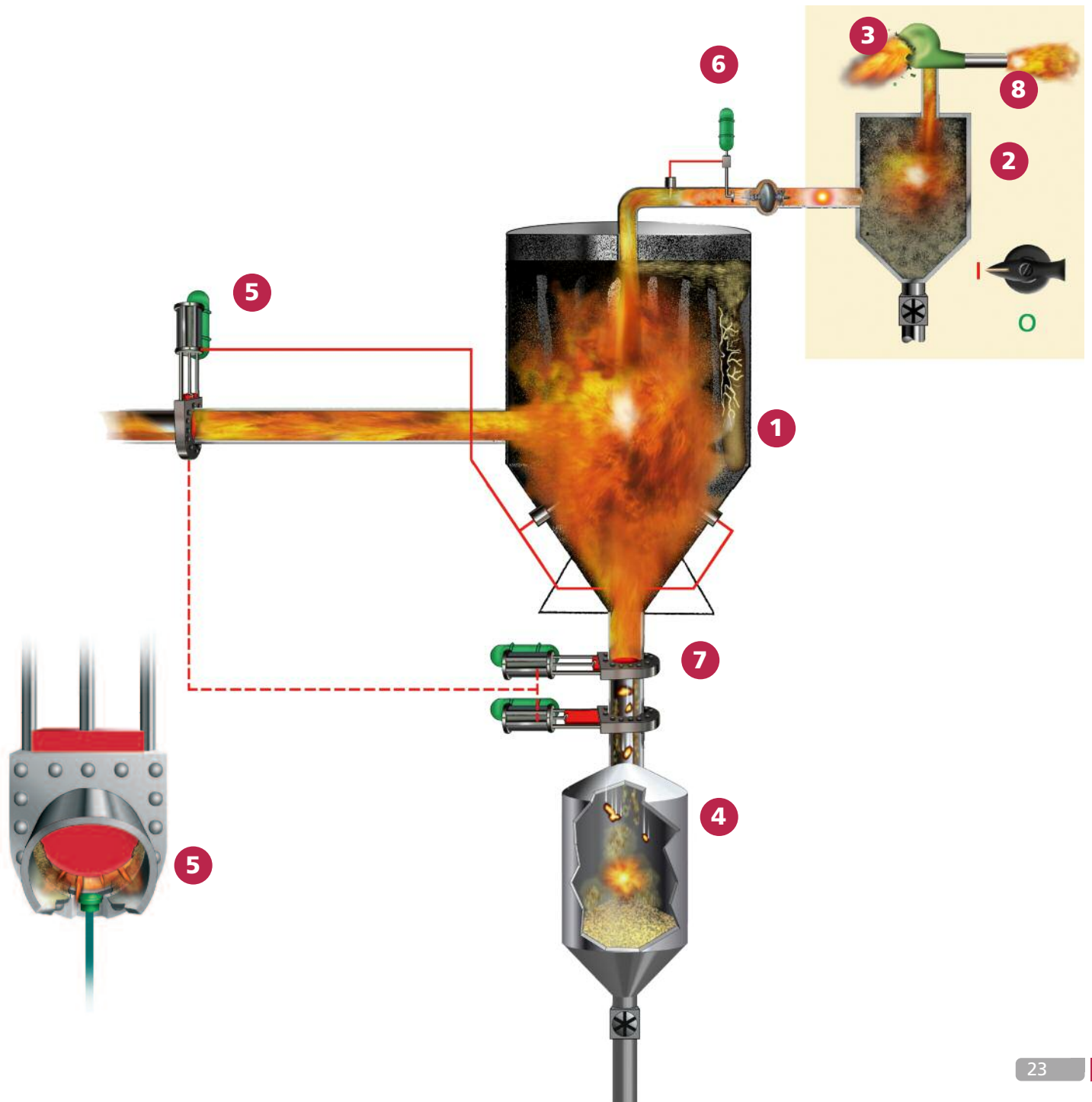
- Centralized dust extraction plant with main filter (1), police filter (2), fan (3) and dust collection vessel (4).
- The main filter (1) is an explosion-pressure-shock resistant construction and can withstand the maximum explosion overpressure.
- The main filter (1) is isolated on the inlet side by a rapid-action gate valve (5), on the clean air outlet to the police filter (2) by a remote actuated rapid-action barrier valve (6), which operates when the explosion starts in the main filter and on the dust outlet of the collection vessel (4) by a double gate valve (7).

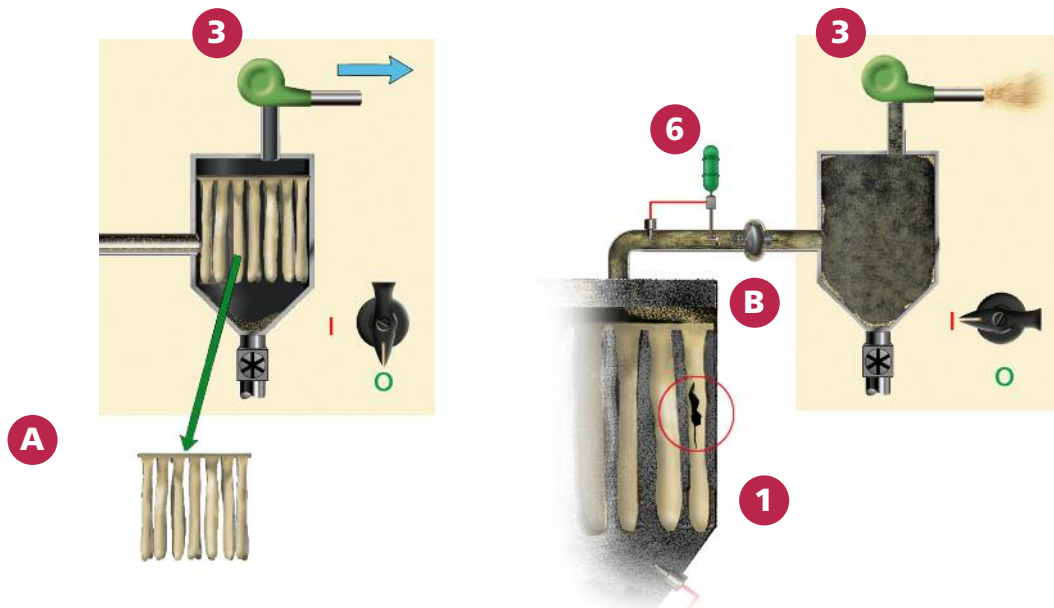
Course of the incident

- Shortly after restarting the extraction plant an explosion occurred in the police filter (2). This was followed by explosions in the main filter (1) and then in the collection vessel (4).

Consequences

- The police filter (2) was completely destroyed. Fires in main filter (1) and in the dust collection vessel (4).
- Burning dust was blown back through the extraction ducting (8) into the working area.



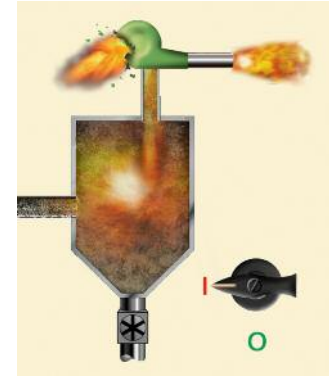
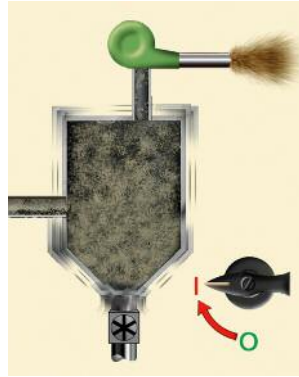
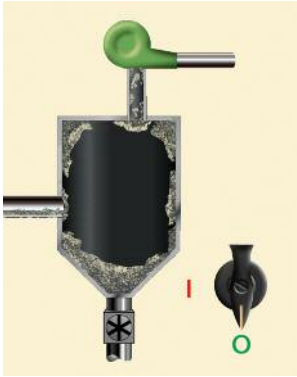


Causes

- During maintenance the filter bags (9) were removed from the police filter (2) for cleaning and were not replaced [A]. The empty filter housing was therefore not able to perform its safety function of preventing dust entering the fan (3). Following unnoticed damage to a filter bag in the main filter (1), dust flowed out of the clean air side [B] and formed dust layers in the empty police filter (2) and the fan (3). When the dust extraction plant was restarted, the dust layers were disturbed and formed an explosible dust cloud in the fan (3) which ignited. The unusually high dust concentration in the fan was probably the reason why the non-explosion proof fan acted as an ignition source.
- The rapid-action barrier valve (6) was installed so that if an explosion occurred in the main filter (1) it would not be transmitted to the police filter (2) and the fan (3). As such it was unable to prevent an explosion in the fan or police filter propagating to the main filter.

The rapid-action gate valve (5) was wrongly installed such that dust could deposit in the guides and this prevented it from completely shutting.

- The double gate valve (7) is activated by the end stop contacts of the rapid-action gate valve (5). As in this case the rapid-action gate valve did not completely close due to dust deposits, the gate valves did not close and burning material passed into the collection vessel (4). This led to a further explosion.



Measures

- Components which have a safety function (e. g. the police filter) should not be changed. This must be ensured by appropriate work instructions and where necessary by technical measures such as locks or special keys for opening.
- Safety components (e. g. the rapid-action gate valve) must be installed in accordance with the manufacturer's instructions and after consideration of the operating conditions.
- Maintenance must include the regular testing of all safety functions (e. g. that the rapid-action gate valve actually closes completely).
- The double gate valve (7) should be activated by its own fire/explosion detector and/or directly by a pressure sensor in the main filter (1).

Explosion vents must be positioned safely.

Welding work on starch silo

Type of dust

Corn starch

Description of the plant and process

- Silo (1) protected by an explosion vent (2). Outlet isolated by an explosion-proof rotary valve (3), inlet by a fast acting valve (4).
- Silo installed inside building.
- Pneumatic filling of silo with starch powder.

Course of the incident

Welding on the silo wall (1) during filling operation resulted in a dust explosion.

Consequences

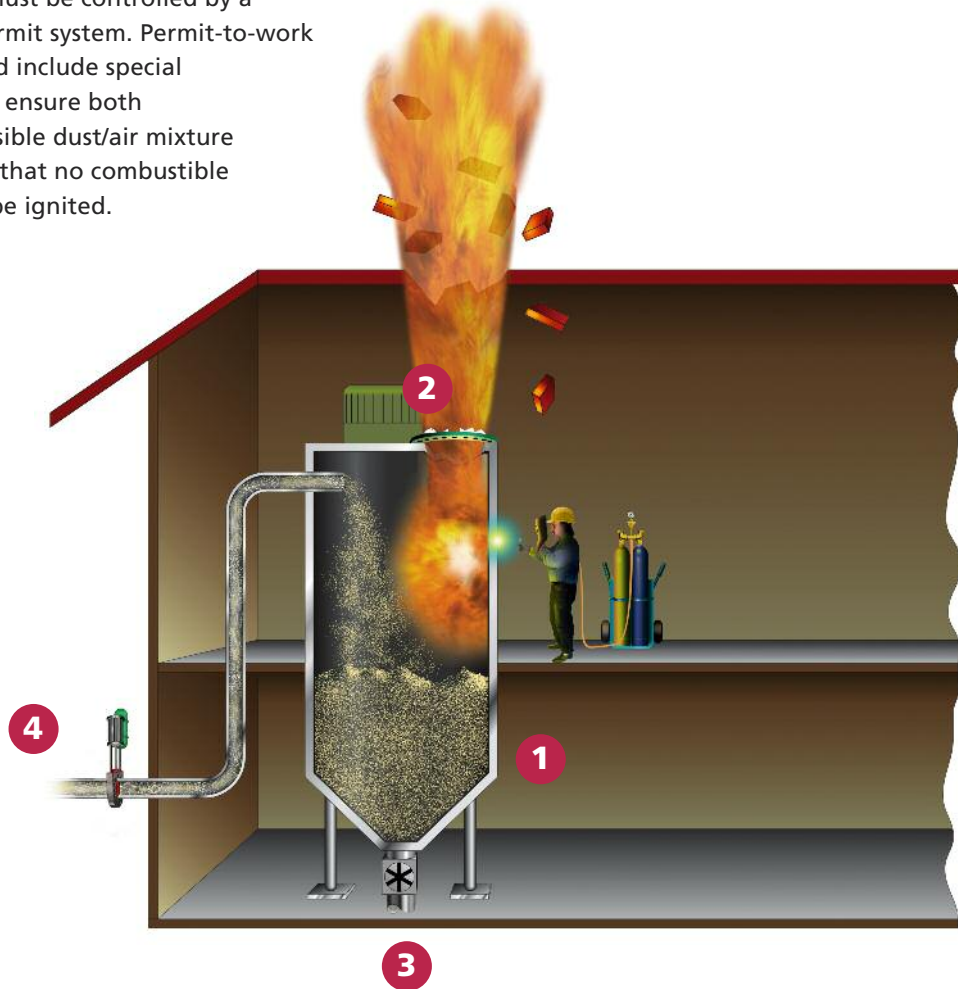
- The venting (2) of the explosion into the production building damaged the roof. The welder was seriously injured by falling debris .
- The silo (1) was not damaged by the explosion as the vents were adequately sized.

Causes

- The welding work ignited the dust cloud which was present as the plant was being operated.
- The pressure wave from the uncontrolled venting of the dust explosion into the room severely damaged the roof.

Measures

- The explosion vents (2) must be ducted to a safe area (ducted to outdoors).
- A much more state-of-the-art solution is Flameless Venting which allows to relief explosion pressure indoors.
- Welding work at operating plants shall be prohibited!
- Welding (and other hot-work e. g. grinding) in areas where there is a possibility of an explosible atmosphere must be controlled by a 'hot-work' permit system. Permit-to-work systems should include special procedures to ensure both that no explosible dust/air mixture can form and that no combustible material can be ignited.



Flash dryer for ABS powder

Type of dust

ABS (Acrylonitrile-Butadiene-Styrene-Copolymer) - used for hardcases and PC housings.

Description of the plant and process

Flash dryer (1) consisting of a drying tube with product inlet (2). Drying air was preheated by a steam heated tube bundle (3). The dried product was separated in a cyclone (4).

As ABS powder has an extremely low minimum ignition energy and self-heating of the powder at the elevated temperatures could occur, a Nitrogen inerting system (5) was also installed.

In order to prevent self-heating of the ABS powder the following procedures were specified in the plant operating instructions to cool the plant on shutdown:

- Switch off the steam inlet to the heating register.
- Maintain the Nitrogen flow until the temperature in the heating register had cooled to 60° C (in normal operation this should take approx. 60 min).
- Switch over from Nitrogen to operation with air.
- Open the inspection hatch (6).
- Remove any deposited dust.

Course of the incident

- The plant had been shut down for cleaning (i. e. steam heating had been switched off). Contrary to the operating instructions the Nitrogen flow had also been immediately switched over to air operation and the inspection hatch (6) opened.
- Dust which had over a long period of time been deposited on the heating register started to selfheat due to the high temperature.
- Due to the air flow this rapidly developed into a fire.
- Two operators who were working on a neighbouring plant noticed the smoke and attempted to put out the fire with a fire extinguisher directed directly at the deposited ABS dust.
- The extinguishing powder, which is released at high pressure, caused the ABS dust deposit to be swirled up into a cloud. This was ignited by the fire at the heating register.
- The resulting dust explosion caused burning material to be pushed out of the inspection hatch in the direction of the operators.

Consequences

- One operator seriously injured and one suffered light injuries.
- Partial destruction of the flash dryer.

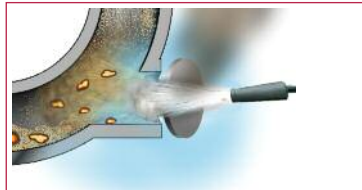
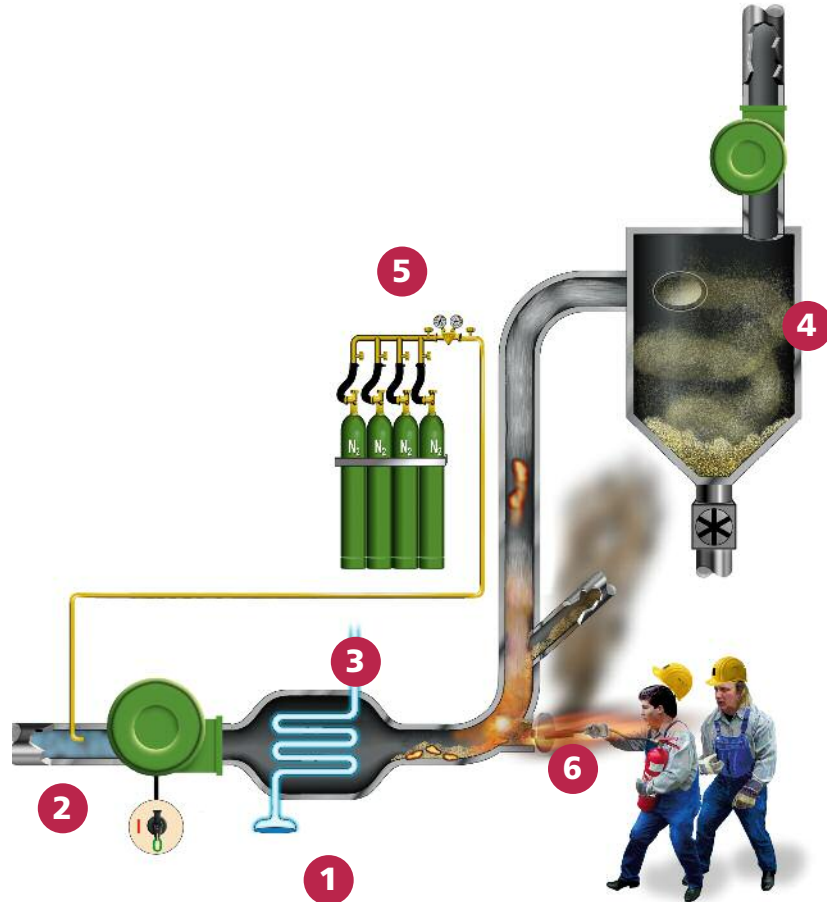
Causes

- Failure to follow the operating instructions for plant shutdown.
- Formation of a dust cloud by pointing a fire extinguisher at the dust deposits.

Measures

The following technical measures were introduced in order to ensure the safe shutdown of the plant

- The switch over from Nitrogen to air operation was changed so that it could only be actuated when the heating register temperature was less than 60°C.
- Similarly the inspection hatch was connected so that it could only be opened at temperatures less than 60°C in the heating register.
- In addition the gas flow was increased and the design of the heating register was changed to minimize the formation of dust deposits.



Wood chip furnace

Type of dust

Sawdust

Description of the plant and process

- Oven for wood chips with an automatic feed system for charging the wood chips from a silo (1) via an explosion-proof rotary valve (2) into the furnace (3).
- Occasionally the furnace has to be manually charged by an operator (4).

Course of the incident

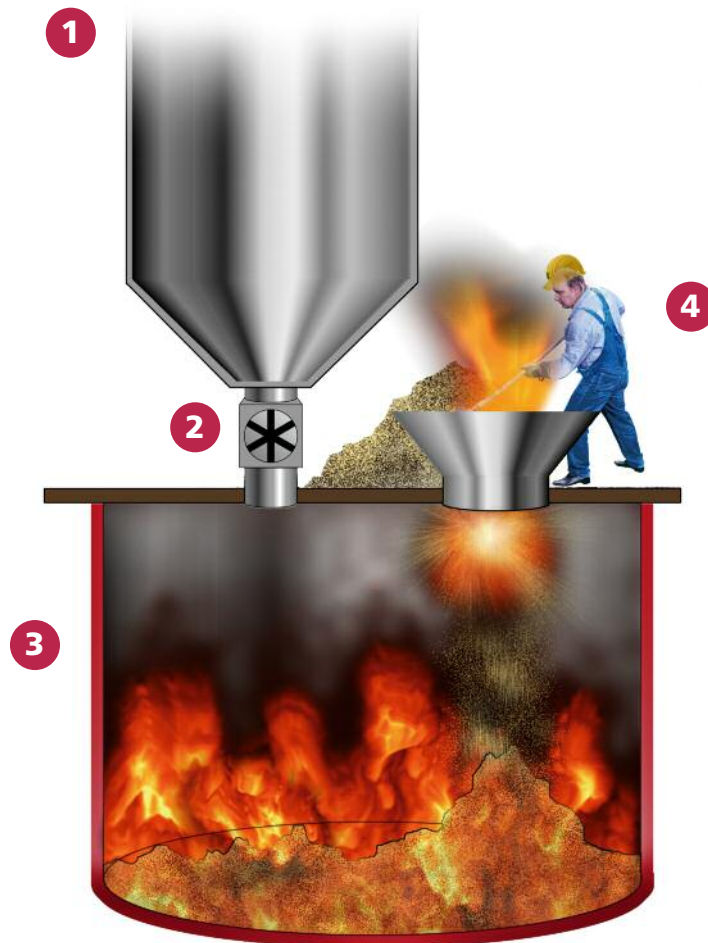
- The fire in the furnace (3) was in the process of being burnt out in order to empty it for cleaning and repair.
- During this, small amounts of waste wood were being incinerated and these were being charged by hand (4).
- An explosion occurred while the waste was being charged. The flame from the explosion shot out of the charge-chute (4).

Consequences

The operator suffered burns to the face and arms.

Causes

- The charging of dusty wood waste into the virtually empty furnace (3) caused a large dust/air cloud to be formed.
- The dust/air cloud was ignited by the still glowing ashes at the bottom of the furnace.
- As there was no isolation system on the manual charge-chute (4) the explosion shot into the room.



Measures

- Explosion isolation measures, for example a rotary air lock, must be used for the manual charging of material with a high dust content.
- Operating instructions, in which potential hazards have been considered, must be prepared for all operations.

Grinding of Aluminium

Type of dust

Aluminium

Description of the plant and process

- Finishing work (grinding, polishing) of cast Aluminium parts (1).
- Central dust extraction plant (2) for all working places (grinding banks).
- Water filled dust separator (3) placed outside the building.
- Extraction fan (4) with partial recirculation of the air (5).
- The recirculated air inlet ducting (6) is mounted along the front of the building underneath the ceiling.

Course of the incident

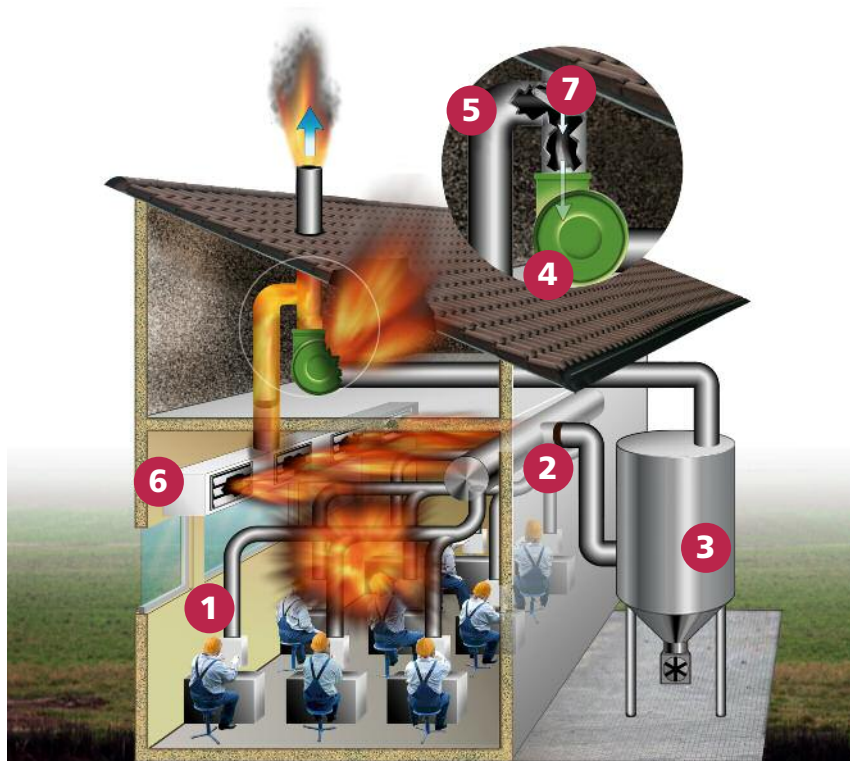
- An initial explosion occurred in the ducting in the vicinity of the fan (4). The ignition source was an air flap (7) which had fallen into the fan generating sparks due to friction.
- The explosion propagated into the recirculation air ducting (6).
- The pressure wave disturbed the large amount of fine dust which had accumulated in the ducting blowing it into the grinding room.
- The dust/air cloud was then ignited by the following flame front.

Consequences

- All eight workers were caught in the fireball which developed. Six died immediately and the other two died in the following days as a result of the severe burns they suffered.
- The grinding building was completely destroyed.

Causes

- The dust extraction system had been poorly maintained for many years (leaks in the ducting, water level in the dust separator (3) not controlled). This led to a large amount of dust being deposited in the ducting downstream of the separator and accumulating in the region of the fan (4) and the recirculation air ducting (6).
- Just before the explosion, an air flap (7) fell into the fan (4) due to a broken shaft. This both disturbed the dust layer causing the formation of a dust cloud and also generated a spark or hot surface due to impact and friction causing ignition of the Aluminium dust cloud.



Measures

Organizational measures are essential in addition to the preventive measures which had been taken.

- Basically a wet dust separator can only function as a preventive measure (i. e. to avoid the formation of dust clouds) if it is properly maintained .
- Additionally, even when correctly operating, small amounts of dust must be expected in the clean air side of such dust separators.
- It is therefore better not to use a recirculating air system - the clean air side must still be kept free of dust by regular inspection and cleaning.
- If, however, it is necessary to install an air recirculation system (e. g. in order to save energy) additional technical measures (avoidance of flat surfaces which could collect dust, police filter) as well as organizational measures (regular cleaning plan) must be implemented to prevent the formation of hazardous dust layers both in the recirculation air ducting and in the working room.

Solvent vapours can sometimes still be released from a product even after it has been dried.

Milling of solvent wet product

Type of dust

Plastic additive

Description of the plant and process

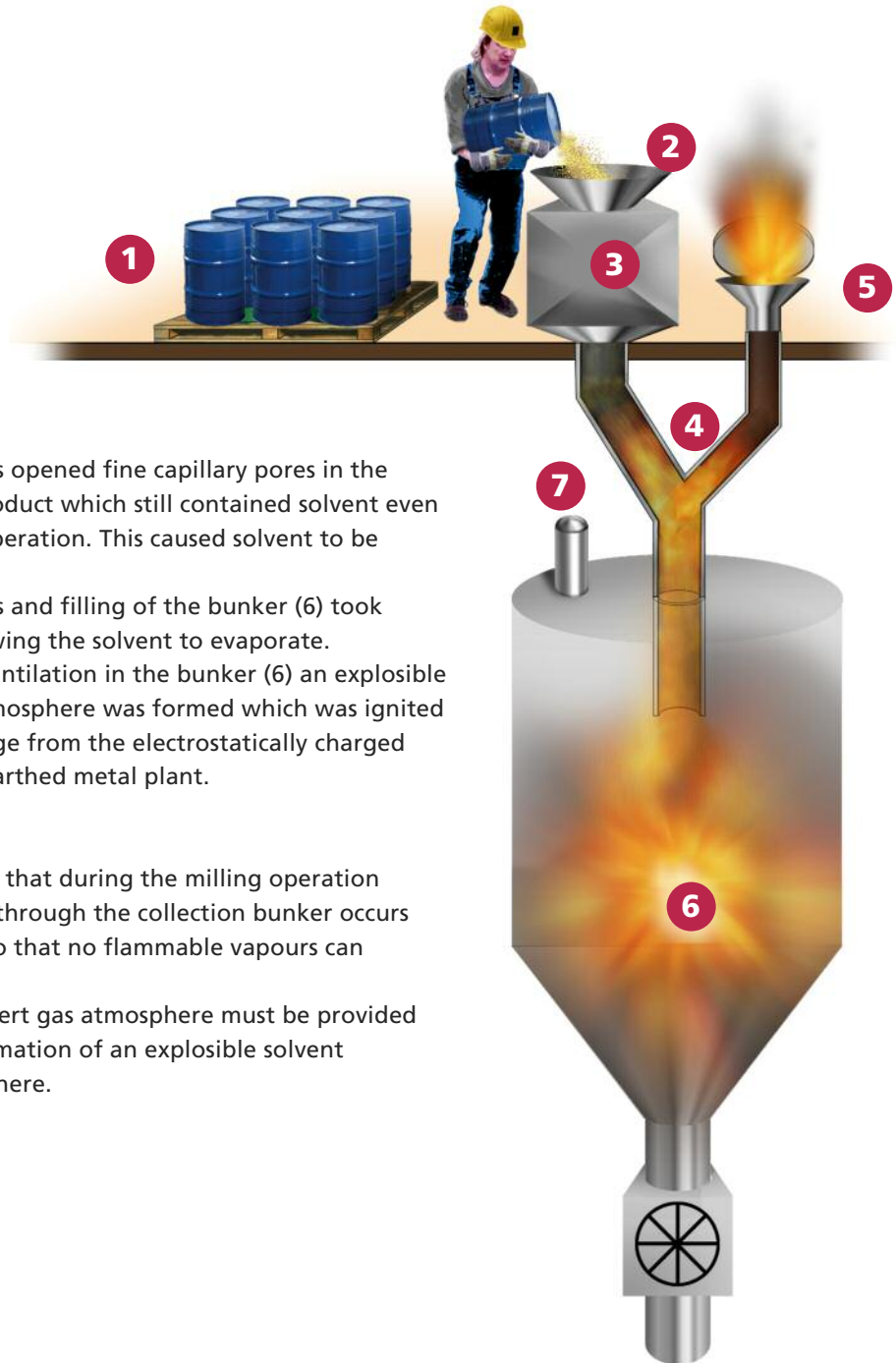
- Before milling, the solvent wet product is dried under vacuum and at elevated temperatures in a paddle dryer before being filled into metal drums (1). The specification for the product was that it should be dried to a solvent content of less than 0.5 wt %.
- A product with such a specification does not generally form an explosible hybrid mixture.
- Per batch, 2 tons of the product were milled in a centrifugal mill with ring sieve and rotor. The product was fed into the mill (3) from the metal drums (1) via a metal funnel (2).
- The outlet from the mill fed into the collection bunker (6) via a V-piece of pipe (4) which allowed material to be filled into the bunker from a second filling point (5). A filter (7) was fitted to the collection bunker to provide pressure equalisation. The plant was constructed from stainless steel and was properly grounded.
- The dried product has a high resistivity.

Course of the incident

Product with a remaining solvent content of just below the limit value of 0.5 wt % was being slowly milled and fed into the collection bunker (6). After several hours when approximately 1 ton of product had been processed, a violent explosion occurred in the collection bunker (6). This propagated through the inlet ductwork (4) back to the second filling point (5) which was not in use.

Consequences

- The worker suffered a severe shock.
- The collection bunker (6) was severely damaged. The filter (7) was blown away by the explosion and pipework (4) from the mill and second filling point (5) was destroyed.



Causes

- The milling process opened fine capillary pores in the plastic additive product which still contained solvent even after the drying operation. This caused solvent to be released.
- The milling process and filling of the bunker (6) took several hours allowing the solvent to evaporate.
- As there was no ventilation in the bunker (6) an explosible solvent vapour atmosphere was formed which was ignited by a brush discharge from the electrostatically charged product and the earthed metal plant.

Measures

- It must be ensured that during the milling operation sufficient air flow through the collection bunker occurs (e. g. with a fan) so that no flammable vapours can accumulate.
- Alternatively an inert gas atmosphere must be provided to prevent the formation of an explosible solvent vapour/air atmosphere.

Emptying Big-Bags (FIBC)

Type of dust

Plastic additive

Description of the plant and process

- The product was supplied in a conductive Big-Bag (FIBC type C).
- The Big-Bag (1) had conductive lifting handles (2) and was also fitted with earthing points (3) on the side.
- The lifting hooks (4) were made of metal and connected with a plastic cable (5) to the crane.
- A filling funnel (6) with sealing system (7) was used to empty the Big-Bag into the silo (8).

Course of the incident

- Dust leaked out of the improperly fitted sealing system (7) during the emptying of the Big-Bag forming a large dust cloud in the filling area.
- In order to solve the problem the operator called two further colleagues for help.
- Shortly afterwards a dust explosion occurred in the vicinity of the filling funnel (6) and also in the Big-Bag (1).

Consequences

Due to the problem with the sealing system (7) and the formation of a large dust cloud three operators were exposed to a much greater hazard than would normally be present.

- The three operators suffered severe burns.
- Following litigation the firm had to pay tens of million Euro in damages to the workers.

Causes

- The Big-Bag was not earthed (9) and became charged due to the emptying operation.
- A spark discharge occurred from the Big-Bag (1) to the earthed metal filling funnel (6) which ignited the dust cloud formed by the leaking seal and also the dust cloud in the Big-Bag (1).

Terms and definitions

Brush / Spark (Static) discharge

A brush discharge is a type of corona discharge that takes place between two electrodes embedded in a non-conducting medium (e.g. air at atmospheric pressure) and is characterized by non-sparking, faintly luciferous furcations composed of ionized particles.

Brush discharges can occur from charged insulating plastics (for example poly-ethene) to a conductor. The maximum energy associated with brush discharges is unlikely to exceed 4 mJ. Such discharges may be incendive but are less likely to cause ignition of a solvent-air mixture than an electrostatic discharge between two conductors.

A spark discharge is another form of electrostatics which occurs between two conductive bodies carrying different potentials.

Terms and definitions

Type of discharge	Effectiveness as ignition source for mixtures with air of:		
	hydrogen, acetylene, etc. MIE \leq 0.025 mJ	solvent vapors MIE > 0.025 mJ	dry, combustible dusts MIE > 1 mJ
Spark	+	+	+
Brush	+	+	(-) ¹⁾
Propagating brush	+	+	+
Corona	(+)	-	-
Cone	+	+	+

¹⁾ Ignition of dusts **highly sensitive** to ignition cannot be completely ruled out.

Terms and definitions

Clean air side

Part of plant after a dust separator which should contain dustfree air.

Dirty air side

Inlet side of a dust separator containing dust laden air.

Double gate valve

An arrangement consisting of two gate valves with a coupled operation such that one of the two valves is always closed. In this way the propagation of an explosion from one vessel into another can be prevented. The valves must be automatically stopped in the event of a fire or explosion to prevent the transmission of burning material.

Explosible dust/air mixture

Mixture of combustible dust and air through which burning completely propagates after being ignited.

Explosion isolation or decoupling

Protection measure which prevents the transmission of an explosion from one part of the plant to another (isolation can be effected with explosion-proof rotary valves, extinguishing barriers, rapid-action gate barrier valves or explosion diverters).

Explosion-proof rotary valve

Special design of rotary valve (number of rotor blades as well as their thickness and gap width) which prevents the propagation of an explosion in the pipe. The rotation of the rotary valve must be automatically stopped in the event of a fire or explosion to prevent the transmission of burning material.

Terms and definitions

Explosion-resistant design

Design of vessels and equipment such that they can withstand the expected explosion pressure without being destroyed. They may be either explosion-pressure-resistant in which case they will withstand the explosion without any deformation or explosionpressure-shock resistant in which case they may be permanently deformed by the explosion but will not rupture.

Explosion venting

Protection measure in which the explosion causes the opening of a vent which has been sized such that the pressure and/or burning material can be released to prevent the pressure rising to above the vessel design pressure.

Flameless Venting

So-called Quenching Devices release the explosion via a rupture disc into a filter system. This filter, preferably stainless mesh, retards the flame and contains dust. Explosion pressure and temperatures are reduced to a negligible level outside the device. These explosion traps allow safe venting of Dust Explosions indoors.

Isolation of buildings

Measure to prevent the propagation of an explosion from one building to another (e.g. by using automatically closing fire doors, gas tight seals, explosion doors etc.).

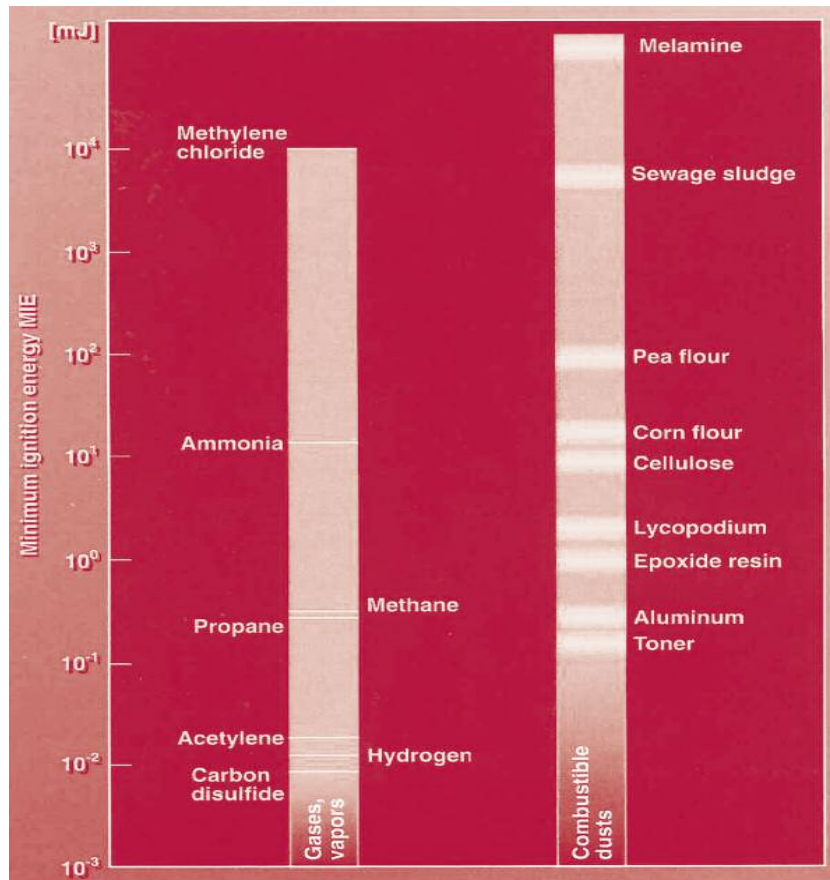
Maintenance

Measures which must be taken to ensure that the plant remains operable and in its design state (e.g. cleaning, oiling and greasing etc.). Maintenance should also include control and evaluation measures to identify any deviations from the intended design of the plant (e.g. Management of Change procedure).

Terms and definitions

Minimum Ignition Energy (MIE):

Lowest spark energy from a capacitive circuit which is sufficient to ignite the most ignitable dust/air mixture under defined test conditions.



Terms and definitions

Police filter

Filter system which is fitted to the clean side of a main filter to prevent the formation of a dust cloud in downstream equipment (e.g. fan) in the event of filter bag breakage or other failure.

Rapid-action barrier valve

A valve which is automatically closed by the pressure wave from an explosion such that the propagation of the explosion in the pipe is prevented. These are often only effective against an explosion coming from one direction.

Rapid-action gate valve

Rapidly closing gate valve which prevents the propagation of an explosion through a pipe. The valve can be actuated by either pressure or a flame sensor. The rapid-action gate valve is also known as a 'slam-shut' valve.

Smouldering agglomerates

Glowing, i. E. flameless oxidising reaction in deposited dusts. Smouldering agglomerates (or nests) can lead to self-heating or can act as an ignition source.

Spark extinguishing system

System which is able to detect sparks and glowing material and to extinguish them by triggering an automatic extinguishing barrier thus preventing their transmission. Most often used: Water (mist) injection.



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