ESCIS
Expert Commission
for Safety in the Swiss Chemical Industry

Series
Safety

Milling of Combustible Solids

Safety Evaluation of the Feed Material, Protective Measures with Mills

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Translation of 3rd, revised German edition

PREFACE TO THE THIRD EDITION

The assurance of state of the art safety and environmental protection in a chemical processing plant is based to a large extent on the predictive identification and assessment of hazards and the use of appropriate measures to reduce the risk. Systematic risk analysis has proved to be the most important tool to tackle these tasks and problems. Its basic methodology is described in ESCIS booklet No. 4 "Introduction to risk analysis".
Risk analysis must embrace all possible critical areas of an undertaking: Chemicals and other work materials, chemical reactions and physical processes, various energy inputs, plant items/instruments/technical aids, personnel and organizational factors.
The present ESCIS booklet treats the hazards associated with the milling of dry, combustible substances in mechanically acting, size-reducing machines and the in part empirically derived measures suitable to reduce the risk. The contents are based on the findings and experience gained in operational practice in the exchange of experience between the Basle chemical companies.
This 3rd edition is an extensive revision of the 2nd edition of 1987, particularly with regard to the division of the mill feedstock into different safety classes. For testing of the substances for their handling safety in milling, mastery of the problems associated with electrostatic charging and the implementation of technical protective measures, reference is made to the relevant, recently revised ESCIS booklets and other special literature.

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Expert Commission for Safety in the Swiss Chemical Industry, ESCIS

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Milling of combustible solids

Safety evaluation of the feed material, protective measures in mills

1. Introduction, objectives

The purpose of this ESCIS booklet is to discuss the hazard factors associated with the milling of combustible solids, to facilitate their acquisition by safety oriented testing and evaluation of the properties of the feedstock, and finally to summarize briefly the most important potential protective measures afforded by state of the art technology and furnish criteria which serve as bases for decision in regard to their application. It is obvious that these protective measures can not always be implemented fully, especially in older installations. The present document is intended to prompt the location and technical reorganization of critical sites or stimulate consideration of alternative measures which, if circumstances permit, can also be entirely of an organizational nature.

In the design of new plants, the establishment of at least the basic requirements (plant item strength, available space) for the technical protective measures is advisable; this allows their implementation at a later date should the need arise.

2. Hazard situation

Dust is formed during the milling of combustible solids, primarily within the mill and the associated equipment such as receiver, filter, and transport and extraction systems, but frequently also in the production room if plant items are defective. The occupational hygiene problems always associated with dust formation are not treated in this booklet.

Dust dispersed in air can be exploded by suitable ignition sources. It is not unusual for dust explosions to result in damage more extensive than that caused by the explosions of flammable gas/air mixtures.

In dust deposits, smoldering fires can be initiated by ignition sources, e.g. hot surfaces. In mechanical milling, the products are subjected to impact. Explosions or detonations can thus be induced with impact sensitive materials.

In milling, the feedstock is subjected to thermal stress. This can initiate exothermic deflagrations[1]) or decomposition reactions, which subsequently result in fires or explosions (see section 3.2.3).

If the feedstock contains a flammable liquid – for example residual solvent – so-called hybrid mixtures (dust/vapor/air mixtures) can be formed during milling.

Hybrid mixtures are easier to ignite and can explode more violently than pure dust/air mixtures.

As primary ignition sources within the mill itself – in addition to possible ignition of the product by thermal or impact stress – prime consideration must be given to sparks or hot surfaces arising from tramp material or mechanical damage. The ignition of combustible dust/air mixtures can also be initiated by discharges of static electricity. The various forms of electrostatic discharge and their incendivity are described in ESCIS booklet 2 "Static Electricity". In milling operations with possible dust generation or dust deposition in the workroom, the ignition sources which must be taken into account are basically the same as those occurring in work with flammable liquids: naked flame, spark-generating apparatus, electrical systems and equipment, hot surfaces, smoking, etc.

3. Evaluation of feedstock properties relevant to safety during milling, division into safety classes

(Test methods, see ESCIS booklet 1 "Sicherheitstests für Chemikalien")

3.1 Safety class concept, introduction and application range

To facilitate a pragmatic assessment of the situation, the products to be milled are divided into 3 ***safety classes for milling (SCM)*** on the basis of their properties relevant to milling. The safety class concept is used to identify those products which can lead to an incident during milling under normal operating conditions or in the event of malfunctions (e.g. tramp material in the feedstock, mechanical defect, overstressing of the mill). Directions regarding measures to be implemented to avoid incidents can be formulated for every safety class.

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[1]) The expression "Deflagration" has different interpretations. It is used in this booklet as follows: Deflagration = decomposition reactions locally initiated by external ignition which, in contrast to combustion, are propagated automatically even in the absence of atmospheric oxygen at a propagation rate which does not exceed the speed of sound.

The safety class concept is valid for mechanically acting mills, crushers, screens, etc., which must be considered as potential ignition sources, e.g. when the feedstock contains tramp material or rotating parts are defective.

Experience has shown that no ignition due to mechanically generated sparks is expected with circumferential speeds up to 1 m/s even in the case of damage or a malfunction, whereas in the range above 10 m/s, ignitions must be anticipated. In the grey area between these limits, an assessment by explosion protection experts is advisable.

3.2 Material properties relevant to safe milling

3.2.1 Ignition and explosion behavior of the airborne dust

On contact with an effective ignition source, combustible solid in the form of airborne dusts can explode with lesser or greater vehemence within a certain concentration range. Of prime importance for safety during milling are the minimum ignition energy and the minimum ignition temperature of such dusts. In the milling of dusts with a ***minimum ignition energy greater than 1J and a minimum ignition temperature (BAM) above 500°C,*** experience has shown that dust explosions are not expected. With lower values, however, dust explosions must be anticipated. In such cases, the dust explosion class of the feedstock must be known in order to design the constructional protective measures. In special cases, it may also be necessary to determine the K_{St} value and the maximum explosion overpressure to allow correct sizing of the required technical safety devices. (See [1], [4].)

3.2.2 Burning behavior of the deposited dust

The feedstock can often experience a large rise in temperature during milling and under certain circumstances it can even ignite. The burning behavior is thus an important characteristic for the safety evaluation in milling operations. In the testing of the burning behavior under clearly defined conditions, six burning classes are distinguished with class rating [CR] 1 representing the lowest hazard level (not flammable, reference substance salt) and CR 6 representing the highest hazard level (reference substance black powder). In the cases of dusts with CR 1 or 2, no dust fire is expected during milling. To take into account the possible heating of the feedstock during milling, the burning behavior is tested at both room temperature and 100°C.

3.2.3 Thermal stability (self-ignition, decomposition)

The thermal stability of the feedstock must also be evaluated owing to the temperature rise occurring during milling. In addition to the temperature range of a decomposition, its severity (temperature rise/energy content) must also be included in the evaluation. The decomposition is tested in a fresh air stream (Grewer) or, if this is not possible owing to the melting point being too low, by another thermal screening method (e.g. in an open vessel [Lütolf], Radex, TDP; see ESCIS booklet 1). The following cases are distinguished:

- If the results of the testing for thermal decomposition under defined test conditions are negative up to 220°C, experience has shown that no problems are expected during milling in regard to thermal decomposition.
- If significant decomposition is observed in the range 90°C to 220°C, it is expected that a decomposition or its consequences (fire, dust explosion) can be kept under control during milling by appropriate protective measures.
- If decomposition occurs below 90°C, the substance is thermally so unstable that it should either not be milled at all or at the outside only after considerably more exhaustive testing of the risk situation with consideration of the factors specific to the installation.
- A special case of thermal decomposition is represented by deflagration. This is a locally initiated thermal decomposition which is also propagated in the absence of (atmospheric) oxygen with a corresponding rise in temperature and the release of considerable amounts of deçomposition gases. Products which deflagrate violently under defined test conditions must usually not be milled dry. Deflagration is tested in a special apparatus at 100°C. Once a deflagration has started, it can be stopped only by rapid cooling usually with vast quantities of water. However, rapid introduction of water into the apparatus or vessels downstream from the mill can be difficult.

3.2.4 Content of flammable liquids

Products which contain a flammable liquid, e.g. solvent can form hybrid mixtures during milling which are more readily ignitable and explode with greater severity than pure dust/air mixtures. This increase in hazard can be significant even when the concentration of the flammable liquid in the airborne dust has reached only around 20% of the lower explosibility limit. This situation can also occur with liquids with a high flash point. With substances containing less than about 0.5 wt% flammable liquids, this is not expected (these limits are, however, very rough estimates). Dusts with a relatively high solvent content require extensive investigation of the ignition and explosion behavior as well as of other properties if they are to be milled. Particular note should be made of the increase in the dust explosion class in the presence of solvent vapors.

3.2.5 Impact sensitivity

As the feedstock is subjected to impact stress during mechanical milling, it is necessary to test the impact sensitivity. Testing is performed with a drop hammer. Substances which detonate in the drop hammer test under specified conditions may have explosive character and should not be milled mechanically in the dry state.

3.3 Classification of products, definition of the safety classes

The products are divided into safety classes on the basis of test results.

CRITERIA	SAFETY CLASS SCM 0	SCM 1	SCM 2
Ignition behavior			
– Minimum ignition energy	above 1 J	up to 1 J	–
– Minimum ignition temperature (BAM)	above 500 °C	up to 500 °C	–
Burning behavior			
– Burning class at 100 °C	up to 2	3 to 5	6
Thermal stability			
– Self-ignition Exothermicity in a fresh air stream (Grewer) or	above 220 °C	90–220 °C	below 90 °C *)
– Exothermicity in an open vessel (Lütolf)	above 220 °C	90–220 °C	below 90 °C *)
– Deflagration at 100 °C	neg.	neg.	pos. *)
Flammable liquids	none	up to 0. 5 wt%	above 0. 5wt% *)
Impact test (detonation)	neg.	neg.	pos.

*) Exceptions, see 4. 4

Definition of the safety classes

SCM 0: A product is classed as *SCM 0* if the corresponding conditions are *fulfilled in all criteria.*

SCM 1: A product is classed as *SCM 1* if it can not be assigned to SCM 0 in at least one criterion and meets none of the conditions for SCM 2.

SCM 2: A product is classed as *SCM 2* when the conditions of this class are *reached* in *at least one* criterion.

Application of the safety classes in milling operations

SCM 0: Experience has shown that these products can be milled in installations without special constructional explosion protection measures as none of the product properties important for safe milling reaches the hazard threshold. (The preventive protective measure "Avoidance of effective ignition sources" must always be used.)

SCM 1: For the milling of SCM 1 products, extensive technical explosion protection measures are usually necessary, if need be combined with permanently installed extinguishing systems.

SCM 2: The handling safety of SCM 2 products is generally so problematic that mechanical milling (dry) and milling in air or jet mills is not admissible. Possible exceptions are described in 4.4.

4. Recommendations for technical protective measures

4.1 General measures

In addition to the protective measures for safety characterized in the following sections, in milling operations with combustible solids the following elementary measures must always be implemented:

Effective ignition sources must be avoided, e.g. by

- separation of tramp material from the feedstock by use of magnetic or inductive metal separators, screens or safety precrushers
- grounding (or equipotential bonding) of all conductive plant items
- regular checks of bearings (hot running) and other rotating parts (friction, caking).

The *electrical installations in the work room* must be protected against dust in accordance with the locally applicable standards and regulations and, if applicable (in the processing of products containing solvent), also satisfy the demands for explosion protection in flammable atmospheres.

Dust deposits on the floor, ledges, equipment parts, lighting fixtures, pipes, etc. must be removed at regular intervals. Otherwise, there is a danger that the pressure shock of an explosion occurring inside the installation will disperse the dust deposits in the room, which in turn supply the fuel for a secondary explosion with possibly devastating effects (indoor explosion[2]).

In every milling operation, based on the local conditions and particularly the level of sophistication of the mill equipment, *decisions* are necessary regarding

- assignment of the products to certain mills
- necessity of additional measures such as
  - monitoring of the power consumption of the mill
  - monitoring of the mill temperature
  - milling in small, controlled batches
  - restriction of the throughput of the mill.

4.2 Measures for the milling of SCM 0 products

SCM 0 products may be milled in mills without any special technical protective measures as the hazard threshold is not reached with any of the product properties important for safe milling.

2) Even a dust layer of only 0. 5mm on a surface of 1 m^2 can generate an explosible dust cloud of 5 m^3.

4.3 Measures for the milling of SCM 1 products

4.3.1 Overview

In the milling of SCM 1 products, dust fires or dust explosions and their secondary phenomena are always possible so that extensive technical protective measures are usually necessary. These include measures

- against dust explosions:
  - inerting (see 5.1)
  - explosion-resistant construction (i.e. explosion pressure resistant or explosion pressure shock resistant for the maximum explosion overpressure, see 5.2.)
  - explosion venting (see 5.3)
  - explosion suppression (see 5.4)

in combination with the necessary isolation measures

- against dust fires
  - flooding with water; with very easily ignitable products (e.g. minimum ignition energy below 10 mJ) a combination with inerting is advisable. A dust explosion frequently also results in a dust fire. It is thus also advisable to plan a water deluge installation for mills protected by explosion venting (see 5.6).
- against fire/decomposition of the freshly milled product:
  - quarantine storage (see 5.7).

4.3.2 Selection of the measures

The measures are selected on the basis of the conditions specific to the operation such as:

- Size of the mill
- Flow of the feed material
- Frequency of operation
- Surroundings of the mill
- Material properties (toxicity, surrounding hazards, etc.)
- Holdup, that is the amount of feed material within the mill installation
- Connections to containers, mixers, silos, conveyors, charging and discharging equipment, etc.

In established plants not protected against dust explosions, additional criteria can be of decisive importance for a cost/benefit analysis with respect to possible provision of technical protective measures. Such criteria include:

- Age, condition and expected operating life of the mill
- Strength and shape of individual plant items
- Available space
- Endangerment of adjacent objects

As a matter of principle, when new mills are constructed it is advisable to safeguard them with one of the above-mentioned protective measures if no guarantee exists that only SCM 0 products will be processed during the lifetime of the plant. In borderline cases, consideration should be given to the establishment of at least the basic requirements for the provision of explosion protection devices at a later date. This particularly concerns the strength of the equipment and pipelines as well as the space available for the installation of vents, vent ducts, metal separators and explosion barriers such as rotary valves and rapid action slide valves.

4.3.3 Scope of the measures

The explosion protection must cover all parts of the plant which could contain explosible mixtures and/or which would be exposed to the pressure shock resulting from an explosion within the plant. It must be ensured that an explosion can not be propagated into unprotected areas via pipelines, discharge devices, charge ports, etc. (see 5.5). If an incident occurs, the installation must be shut down automatically.

If dusts with a minimum ignition energy below 10 mJ (measured with an inductance in the discharge circuit) are milled, electrostatic discharges in the dust filter must also be incorporated in the considerations if the grounding of all conductive parts in the filter can not be definitively assured. Experience has shown that this can not be guaranteed with filter supports with filter cloth between the support and the fastening mounts, even when conductive filter cloth is used. Special grounding connections between filter supports and filter housing have not proved reliable as the support/mount connections are usually poorly accessible and virtually impossible to check. Exceptions to this rule are possible under certain circumstances

- when the filter has a small volume, a certain pressure shock resistance and the dust-laden gas volume is small compared with the total volume;
- when the filter supports are perfectly grounded automatically by metallic surface contact through the nature of their mechanical fastening;
- when the filter is installed at a location where no person can be injured (e.g. on the roof) in the event of an explosion and product discharge on explosion can be tolerated. The admissibility of such exceptions must be assessed by specialists for each individual case.

Spark detectors can be installed in product supply lines which detect hot particles that could cause an ignition. As the ignition of dust-air mixtures by electrically and mechanically generated sparks is favored by excessive temperatures, it is advisable to monitor the power consumption of the mill and/or plan a temperature measurement.

For small mills of the type used frequently in pharmaceutical production, for example, it is often possible to simplify the protective measures described above or even dispense with them entirely. Such decisions should, however, be left to safety experts.

4.4 Measures for the milling of SCM 2 products

The safe handling of SCM 2 products is generally so problematic that mechanical milling (dry) and milling in

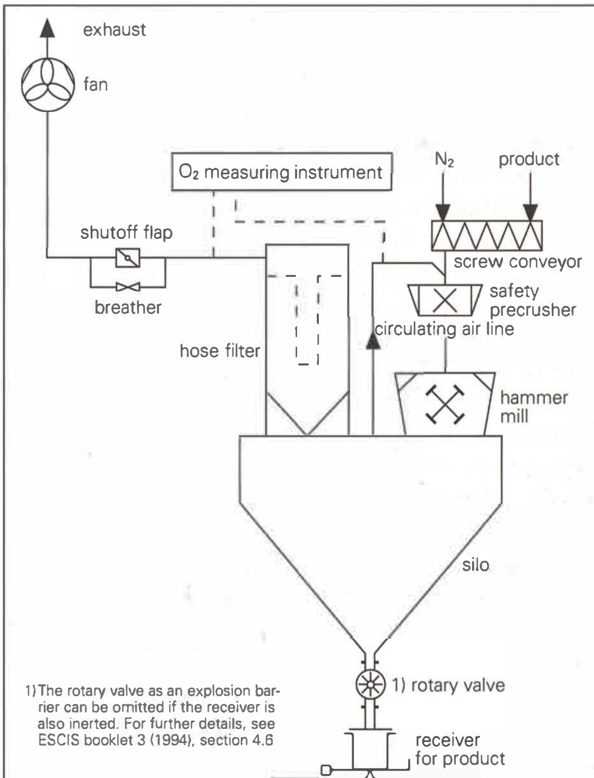
air and jet mills is not admissible. A special risk assessment is indispensable when it is intended to mill an SCM 2 product in the dry state.
Notes:
- Products which are classed as SCM 2 ***exclusively*** on the basis of their content of flammable liquids of above 0.5 wt% can be milled as SCM 1 products by inerting with max. 10 vol% oxygen.
- Products which are classed as SCM 2 ***exclusively*** on the basis of their low self-ignition temperature can be milled as SCM 1 products by inerting with max. 1 vol% oxygen.
- Products which are classed as SCM 2 products ***exclusively*** on the basis of a positive deflagration test can be checked to determine whether the deflagration risk can possibly be combated by automatic flooding with water (see 3.2.3) or by cryogenic milling ("very low temperature", e.g. with liquid nitrogen or solid carbon dioxide) so that they can be milled like SCM 1 products. In such cases quarantine after milling may be required.

5. Characterization of the most important protective measures

5.1 Inerting

(see also ESCIS booklet No. 3)

The entire milling system is operated under a closed inert gas circuit (Figure 1). The maximum permissible oxygen concentration in the entire system must not exceed a specified value, in general 10-12 vol% with organic dusts and 8-10 vol% with hybrid mixtures. In isolated cases a higher residual oxygen concentration may be admissible for a certain product after special testing. The oxygen concentration must be continuously measured and recorded at suitable points. The temperature dependence of this limiting oxygen concentration – it decreases with increasing temperature – must be noted. When a selected limit value is exceeded, the necessary safety measures must be initiated automatically, for example interruption of the product feed, increased inert gas supply, alarm, shutdown of the milling system. Continuity and dependability of the oxygen monitoring must be ensured by suitable measures (e.g. self-monitoring systems, maintenance service).
Smaller installations, e.g. in pilot plants can also be operated without continuous oxygen measurement and recording with a simplified inerting system in which the inert gas is not recycled but continuously supplied in a controlled manner. In such cases, oxygen measurement must first be used to determine the inert gas flow rate and the prepurge time needed to ensure operation of the mill below the maximum permissible oxygen concentration. The oxygen content must be checked from time to time, and particularly after any modification to the installation.



1) The rotary valve as an explosion barrier can be omitted if the receiver is also inerted. For further details, see ESCIS booklet 3 (1994), section 4.6

Figure 1: Inerting

When the type of protection "Inerting" is used, it should be noted that this is ineffective when a product can burn in the absence of a supply of atmospheric oxygen (deflagration) or when the decomposition temperature of the product is reached during processing. For such cases, it may be necessary to implement more extensive measures. Explosion specialists must be consulted.
The operating instructions for inerted installations must contain the instructions necessary to prevent accidents due to asphyxiation (e.g. when entering the equipment or during special checks as well as at product discharge points). Sufficient oxygen content of the air must be ensured in the vicinity of inerted milling systems.
Industrial nitrogen or flue gas is usually used as the inert gas.
Cold milling, e.g. with liquid nitrogen or solid carbon dioxide can also bring additional benefits: Reduction of the hazards due to baked-on deposits and their consequences, as well as simultaneous cooling and inerting. However, addition of liquid nitrogen or solid carbon dioxide alone without control of the residual oxygen content does not constitute adequate inerting.
If periodic filter cleaning is effected with gas, inert gas must be used.
If the recycled gas has to be cooled, the gas cooler must be located after the filter to avoid contamination.

5.2 Explosion-resistant construction

Here explosions are anticipated and hence installations with this type of protection must be designed to a certain *explosion resistance.* They are designated *explosion pressure resistant* when the pressure resistance of the construction corresponds to the maximum explosion overpressure. *Explosion pressure shock resistant* vessels also withstand the expected maximum explosion overpressure without rupturing, but suffer permanent deformation if an incident occurs. Guidelines also exist today [8] for the construction and calculation of *pressure shock resistant* vessels. Whether the pressure used as a basis for the sizing is the maximum or a reduced explosion overpressure depends on whether one of the explosion protection measures explosion venting or explosion suppression has also been used.

The explosion-resistant construction generally requires explosion barriers of the type described in section 5.5.

5.3 Explosion venting

In this type of protection, part of the pressure resulting from an explosion is vented by relief devices directly or via vent ducts to the open air provided this does not represent a hazard; the residual pressure must be withstood by the equipment without rupture or leakage. Venting into a workroom is not permissible, nor must toxic prod-ucts be allowed to escape into the environment (Fig-ure 2). While explosion venting normally constitutes the simplest technical protective measure with regard to maintenance, when it is used the toxicity and environmentally harmful effect of the products as well as the possible flame jet at the end of the vent duct must be taken into consideration. For details, including sizing of the vent area, see [5].

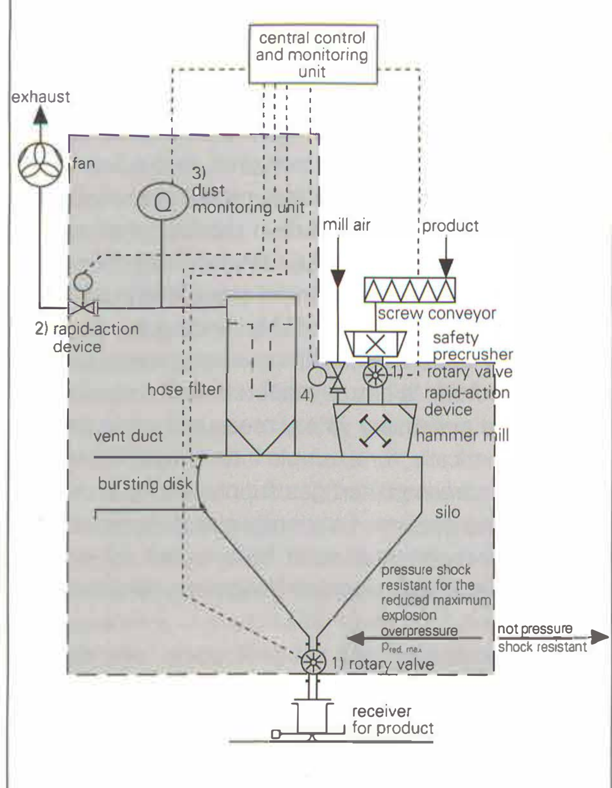
The installation must have a pressure shock resistant design for an overpressure to be determined in each individual case (calculation principles, see [4], [5] and [8]). This applies to all parts which could contain explosible mixtures or which would be subject to stress as a result of the pressure shock of an explosion, i.e. to the entire area to be protected. It must be ensured that the venting device is indeed the weakest part of the system. Proof of the required device strength must be provided by the suppliers. Particular attention must be paid to the strength of door latches and the construction of sight glasses. The *size* of the *area required for effective venting* depends on a number of factors such as the explosion behavior of the products to be processed (as a rule, for new equipment it is advisable to design the vent area for dust explosion class St 2), volume and strength of the equipment, static activation pressure of the vent device and length of the vent duct. The vent area can be subdivided into several smaller areas if need be.

If combustible dust and flammable vapors can be present at one and the same time (hybrid mixture), explosion specialists must be consulted.

Vent ducts must be straight, as short as possible and as a rule no longer than 6 m. The ducts must have at least the same cross section as the vent opening and at least the same strength as the apparatus itself. Each vent opening must have its own duct leading to the open air, a combination of several vent ducts is not admissible. Consideration must be given to the reaction forces generated in the venting process.

In the area of the vent opening or the outlet of a vent duct, the possible effects of flame jets, hot combustion gases and unburned product (danger of secondary explosions) must be taken into account in each case; injuries to people and damage to neighbouring buildings or installations must be prevented. The propagation of an explosion into unprotected plant areas (e.g. blower, filter) must be prevented by special explosion barriers which are activated automatically if an explosion occurs (see Section 5.5).

The pressure arising in an explosion as a result of the increase in volume (combustion gases) is vented by the venting device (bursting disk or explosion door) directly or via vent ducts. Bursting disks and explosion doors are commercially available. These relief devices provide a tight seal in normal operation. Their activation pressure is normally 0.1 bar gauge. The material strength must be taken into consideration when selecting these components. Functioning (opening) of these parts must not be inhibited by any internal fittings. Suitable design measures are necessary to prevent



1) The rotary valve as an explosion barrier can be omitted if the feed including feed container or the receiver vessel and the connection are incorporated in the protection plan and have the appropriate pressure shock resistance.
2) The rapid action device can be omitted if the filter acts as a flame barrier.
3) The dust monitoring unit is recommended for monitoring a filter breakthrough.
4) The rapid action device can be omitted when the air supply is pressure shock resistant and a possible escape of flame at the aspiration site results in no hazard, e.g. aspiration from a vent duct.

Figure 2: Explosion venting

these devices flying off when an explosion occurs; for details, see [5]. The response of the venting device must automatically cause immediate shutdown of the installation. Explosion doors can have a lower venting capability than a bursting disk of the same cross-section owing to the mass inertia of the movable cover and its arrangement (horizontal/vertical). This must be taken into account in sizing.

5.4 Explosion suppression

With this type of protection, an incipient explosion is detected by pressure sensors and suppressed at a very early stage by injection of a suitable suppressant before the pressure within the unit can reach a dangerous level (Figure 3).

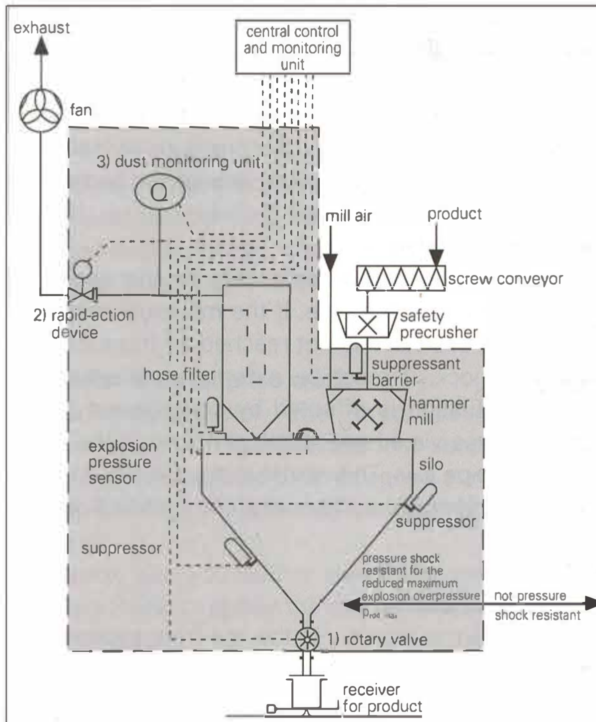
With an activation overpressure of the suppression device of 0.1 bar, the explosion overpressure is reduced to a maximum value of not more than 1 bar. Explosion suppression can also be used against explosions of flammable substances with toxic properties, irrespective of the location of the installation. However, explosion suppression constitutes a protective measure with relatively high demands, above all in regard to the maintenance needed to ensure operational efficiency.

In general, it is advisable to design the explosion suppression device for St 2 dusts. The suitability of the suppressant for the planned application must be proven.

Explosions of St 3 dusts and of hybrid mixtures of all dust explosion classes can be suppressed only to a limited extent. Consultation with explosion protection experts is necessary in such cases. The mill must be designed for the expected overpressure of generally 0.5 to 1 bar in the event of a suppressed explosion. If this requirement can not be fulfilled – for example with old equipment – the sizing of the suppression device must be modified accordingly. The propagation of an explosion into unprotected parts of the plant (e.g. blower, filter) must be prevented, if necessary by special explosion barriers which are activated automatically by an explosion (see section 5.5).

Explosion suppression systems comprise the explosion pressure sensors, the central control and monitoring unit with power supply, the suppressors[3]) and suppressor nozzles. These components are commercially available as complete systems. The explosion pressure sensors normally detect both the rate of pressure rise and the overpressure. The electronic part is supplied as a self-monitoring unit including power supply.

The suppressors contain a powder suppressant, preferably based on ammonium phosphate, under a nitrogen propellant pressure of 60 bar (3" and 5" systems) or 120 bar ($^{3}/_{4}$" system). The suppressant is injected via special nozzles into the vessel under protection by rapid action valves which are opened by the response of a detonator activated electrically when an explosion occurs. If use of a normal nozzle is not possible, e.g.



1) The rotary valve as an explosion barrier can be omitted if the receiver and the connection are pressure shock resistant.
2) The rapid action device can be omitted if the filter acts as a flame barrier.
3) The dust monitoring unit is recommended for monitoring a filter breakthrough.

Figure 3: Explosion suppression

owing to contamination, specially developed telescopic hemispherical nozzles can be installed. This nozzle is located outside the object it protects and separated from it by a thin diaphragm. When the system is activated, the nozzles are projected into the area under protection by the propellant pressure. For details, see [4], [6] and [11].

The response of a suppression system must automatically initiate immediate shutdown of the installation.

5.5 Explosion barriers

The propagation of an explosion from the protected area of an installation protected by explosion venting, explosion suppression or explosion-resistant construction into unprotected plant items must be prevented. The breakthrough of an explosion, the transmission of a pressure shock or the transport of smoldering particles, which in turn can initiate a secondary explosion, must be excluded. Suitable explosion barriers must therefore be installed in the connecting lines and discharge openings. These barriers are activated by the incipient explosions directly, via pressure or optical sensors, or by the response of other safety devices. Barriers which are not self-closing are closed by compressed air from permanently installed pressure vessels. Their rapid trip valves are opened by the sensors mentioned above via the central control and monitoring unit.

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3) HRD suppressors (HRD = High Rate Discharge).

The following barriers can be installed.

Rapid action slide valves and flaps

These are closed by compressed air acting on a piston which closes the slide or flap. To keep the compressed air line as short as possible, the pressure vessel must be installed in the immediate vicinity of the barrier.

Rapid action valve

This barrier is closed automatically by the explosion pressure arising in the pipe. If the minimum response pressure of this valve is not reached by the explosion pressure shock, it must be externally actuated. The external actuation is effected by compressed gas in the valve area via a hemispherical nozzle in the direction of the pipe axis. This nozzle is supplied by a vessel filled with nitrogen or from the compressed air network.

Suppressant barrier

A suppressant is blown into the line from suppressors via special nozzles. The valves of these suppressors are usually activated by optical sensors. Only the flame is extinguished, the pressure wave can be propagated unhindered.

Rotary valve (motor with short run-on)

The rotary valve is installed at discharge openings and, if necessary, also at feed openings. In the event of an explosion, the valve and the product feed (e.g. screw conveyor) are shut off. The valve must have at least 8 chambers. For details, see [4]. Explosion barriers must be tested and approved by a recognized authority.

5.6 Water deluge installations

The water deluge installation mentioned in several of the previous sections is used to extinguish a dust fire, cool overheated product effectively (e.g. on decomposition in an installation) or protect downstream equipment such as textile filters against overheating.

The deluge installation should allow intensive spraying of the walls and top part of the milling vessel as well as any product collected in the conical part and filter. Whether this should be initiated manually or automatically should be decided for each individual case on the basis of the operating conditions. The deluge installation is usually connected to the work's fire-fighting water supply. Adequate drainage of the water must be ensured. It must be decided for each individual case whether the water can be drained into the water treatment plant or whether separate catchment possibilities must be provided. Where water can accumulate in equipment parts, the resulting weight loads must be taken into consideration.

5.7 Quarantine storage following milling

Products which

- have a burning class number greater than 2 at 100°C
  and
- show an exothermicity in the range up to 300°C in the test for self-ignition hazard following Grewer
  and
- self-heat in the Grewer test to over 350°C

must be stored after milling at a monitored location for at least 12 hours before further processing. During this time any smoldering fire initiated during milling can be reliably detected.

If freshly milled product in containers of more than 200 L content is to be stored ***in a warehouse,*** intermediate storage in quarantine is necessary

- when the above-mentioned criteria are met (danger of smoldering fire)
  or
- when there is a danger of heat accumulation. For assessment of the heat accumulation hazard, see ESCIS booklet No. 8 "Thermal Process Safety".

Requirements for quarantine store:

- The storage arrangement must be such that
  - each container is accessible for control purposes and to allow an incident to be combated
  - any incident can be restricted to one or a few containers by early detection
- Early detection of an incident must be ensured, e.g. through
  - technical monitoring (automatic detectors)
  - checks by employees who can act effectively
- In the case of an incident (smoldering fire, heat accumulation), appropriate defensive measures must be ready, e.g.
  - water deluge installation
  - extinguishing agent locations with spray jet pipe
  - equipment and devices to handle the storage containers, extinguish and empty them if need be
  - retention of extinguishing water and environmentally compatible disposal.

6. Selection of safety components

All safety components in use (e.g. sensors, electronics, suppressor nozzles, suppressants, rapid action slide valves, rapid action valves, bursting disks, rupture foils, flaps, rotary valves) must have been approved by a recognized testing agency.

7. Maintenance of the safety devices

To assure the operational reliability of the explosion protection measures, a regular monitoring and maintenance service is necessary. The required activities and the time intervals depend on the technical specifications and the operational circumstances. In general, after startup of the installation inspection should be carried out at relatively short intervals; experience to date has shown that these intervals can be extended if need be. It is advisable to conclude a service and maintenance contract with the suppliers.

The following controls and maintenance work must be performed on safety devices for explosions:

Explosion venting equipment

- Check that the bursting disks are in perfect condition
- Test the freedom of movement of the explosion doors and covers
- Test the holding devices of bursting disks or covers
- Check that the interiors of the vent ducts are free from obstruction
- Test the alarm contact for shutdown.

Explosion suppression equipment

- General visual inspection of the suppressors, hose connections and mountings
- Monitor the content level of the suppressors or compressed gas bottles by weighing
- Measure the propellant pressure of the suppressors
- Test the telescopic nozzles for free movement and the protective diaphragms for intactness
- Electrical check of the detonator actuators
- Electrical check of the central control and monitoring unit and the activation circuits
- Test the battery charge.

Explosion barriers in pipelines

- Suppressant barriers, see explosion suppression
- Rapid action devices: check freedom of movement of the fittings, otherwise as for explosion suppression.

Particular maintenance work

- Frequently, possibly after every cleaning of the installation: setting of the response sensitivity of the pressure sensors to their designed alarm pressure (applies only to mechanical explosion pressure sensors)
- Approx. every 2 months: check emergency battery
- Every 3 years: replace the detonator actuators of the suppressors
- Every 5 years: pressure vessel check of suppressant or compressed gas bottles by the manufacturer.

8. References

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Expert Commission for Safety in the Swiss Chemical Industry (ESCIS)

Tasks and Aims

ESCIS promotes safety in the chemical industry. It is composed of individuals with responsibilities for safety in chemical industrial concerns, in SUVA (Swiss national accident insurance fund), the Swiss federal labor inspectorate and other professional organizations, as well as people at research and educational institutions in a position to further the interests of safety and in particular safety training; all are members **ad personam.**

ESCIS endeavors to recognize current safety problems and fundamental safety aspects of particular importance at an early stage and initiate and promote their treatment by specialists or working parties. The aim involves the minimization of risks by suitable measures and the continuous extension and improvement of the methods and instrumentation used to identify risks.

In collaboration with the responsible authorities and institutions, ESCIS strives for meaningful interpretations and practical solutions within the framework of statutes and official regulations. It is at the service of such bodies in the preparation of guidelines and the establishment of legal bases.

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