



the basics of

dust-explosion protection



Dust-Ex

Powders or dust like substances are processed or are byproducts of the production process in many industries.

Whether the dust is useful (e.g. for the production of plastics, pigments or pharmaceuticals) or waste, a large majority of dustlike substances pose the danger of fire or possibly even explosions. Eighty percent of all industrial dusts are combustible, and even a dust layer of 1 mm in a closed room is sufficient to result an explosion when the dust is swirled up and ignited. These facts, combined with the fact that those affected are not sufficiently aware of the danger (in contrast to the hazard of gas explosions) underlines the importance of preventing dust explosions. This brochure is intended to help you analyse the risk of a dust explosion in your facilities and to take the suitable technical and organisational steps to minimise this risk.



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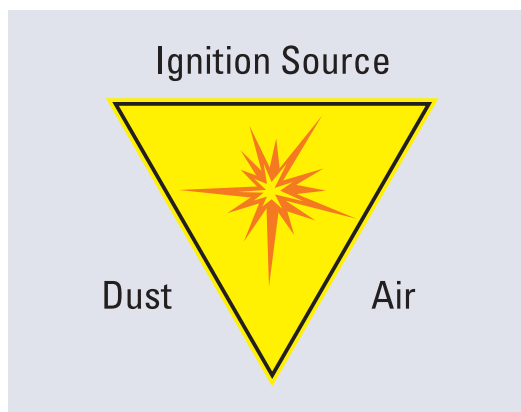
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1. Dust as a Risk Factor

As with flammable liquids and the explosive gas/air mixtures that result from them, certain conditions must be fulfilled to ignite a mixture of dust and air by an effective ignition source and thus trigger an explosion. No explosion can occur if one of the following is not present: combustible dust, air, ignition source.

Dust explosions have a different process of propagation than gas explosions and can in some cases be much more devastating. If a gas/air mixture is ignited, the force of the resulting explosion causes the gas cloud to dissipate rapidly and thus dilutes the gas/air mixture to a concentration lower than that necessary for further combustion. Thus, if no further gas is added, the explosion is over after several milliseconds.

Figure 1: **Explosion Risk Triangle**



With combustible dusts it is different. If, for example, a draft of air swirls up a layer of dust in a small area, the dust, along with oxygen, forms a combustible dust/air mixture. If this mixture is ignited by an ignition source, an explosion is caused. The force of the resulting explosion swirls up more dust, which is in turn ignited. This pro-

cess continues, and under some conditions chain reactions such as these sweep through entire buildings or facilities, destroying them.

As is the case with gases, there are various ignition sources for dusts, such as sparks from electrical or mechanical processes, arcs, open flames, electrostatic discharges, electromagnetic waves and others.

Figure 2 shows the results of statistical studies in North America, which examined the distribution of the ignition sources that caused dust explosions. It shows that mechanically produced sparks were responsible in almost one third of the cases. Add to that the 13% of explosions caused by open fire and welding, and it becomes obvious that many people are not aware of the danger of dust explosions. Figure 3 shows that a wide variety of industries are affected, including branches of the food and wood processing industries, paper and plastics materials production, pharmaceuticals production and others.

The data given above are confirmed by German property insurers, who state that on average there is one dust explosion per day in the Federal Republic of Germany. Approximately one fourth of these are caused by dust from food products or animal feed.

Figure 2: Ignition Sources of Dust Explosions

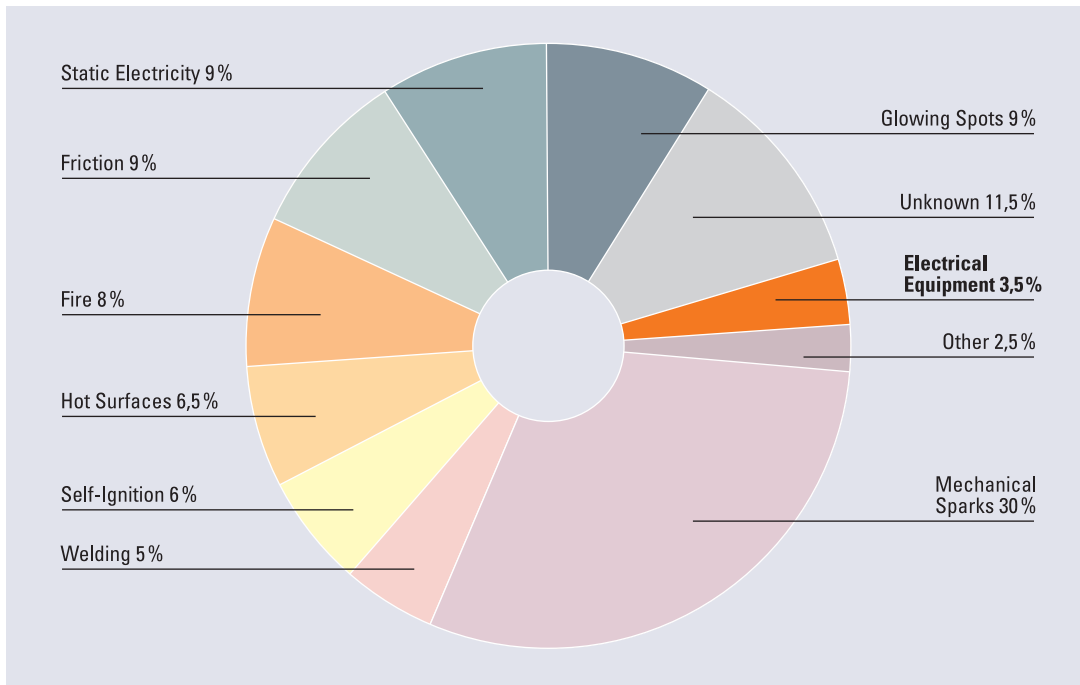
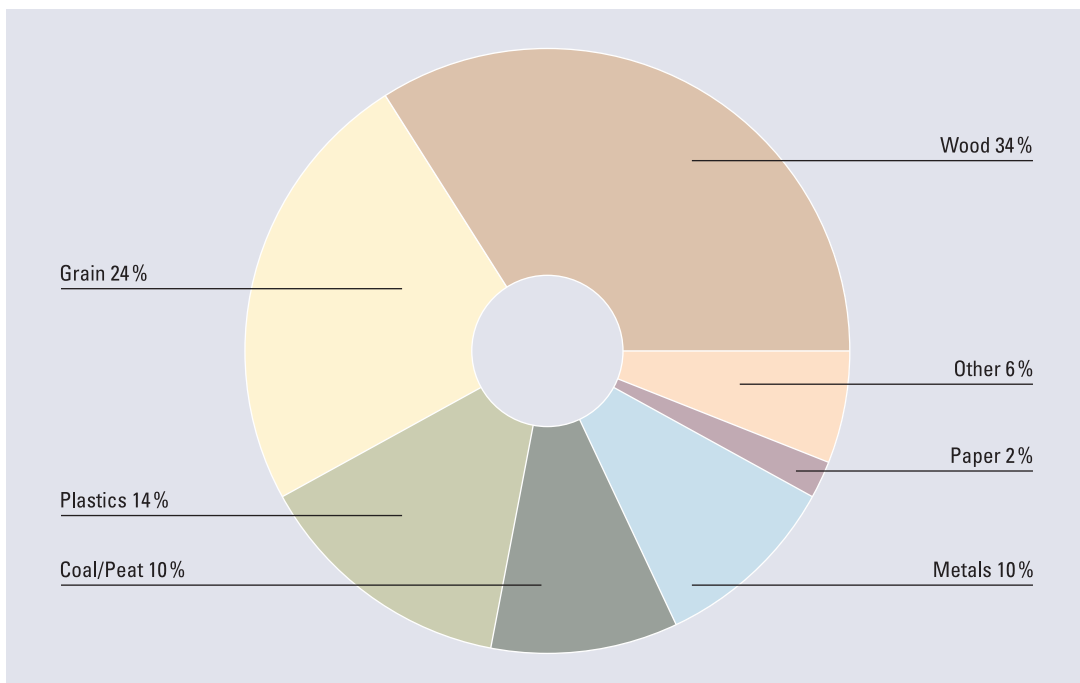


Figure 3: Types of Dusts Involved in Dust Explosions



2. Definitions and Characteristics

What does the word dust really mean?

The European Standard EN 50281-1-1 defines it like this:

Dust consists of small solid particles in the atmosphere which settle due to their own weight, but which remain suspended in air for a time (this includes dust and grit, as defined in ISO 4225).

In Table 2, the important characteristics determining the explosion process of dust are listed. It is necessary to assess your technical procedures in view of potential ignition sources, volume of explosive dust atmosphere, operating temperature, etc. Subsequently, the potential for a dust explosion under the current conditions must be evaluated.

The most important terms in dust explosion protection are listed in Table 1 along with their definitions. In Table 3, the characteristics of some materials from the various product groups are given. These technical safety characteristics have been determined under standard conditions in the laboratory. As a rule, conditions are in practice less likely to lead to an explosion, so that the figures are less alarming.

Be aware that a general term, such as flour dust, can lead to false assessments. Wheat flour has different technical safety characteristics than rye flour, for example.

Table 1: **Definitions in Dust Explosion Protection**

Term	Definition	Remarks
Explosive Dust Atmosphere	Mixture with air, under atmospheric conditions, of flammable substances in form of dust or fibers in which, after ignition, combustion spreads throughout the unconsumed mixture (IEV 426-02-4).	The condition is that the process ends only after one reactant has been entirely consumed.
Atmospheric Conditions	Range of pressure between 0.8 and 1.1 bar Temperature range between -20°C and +60°C	
Hazardous Explosive Atmosphere	Explosive atmosphere in hazardous amount. The presence of a hazardous explosive atmosphere must be assumed if ignition causes an exothermal reaction that endangers people, domestic animals and property.	A thickness of a dust layer less than 1 mm on the floor of a normal room is sufficient to cause a hazardous explosive atmosphere.



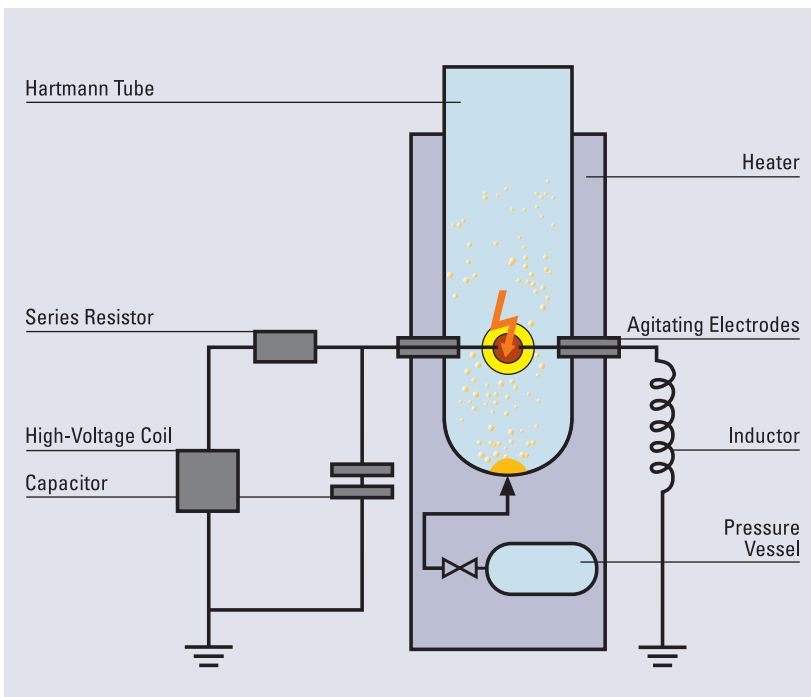
Table 2: Explosion Characteristics

Characteristic	Definition/Description	Remarks
Size of particle	Dust particles larger than 400 µm are not explosive. Dust particles are explosive when they measure less than 400 µm and up to 20 µm	Depending on friction, the transportation and processing of coarse dust result in the formation of fine dust.
Explosion limits	As with gases, dust is explosive within certain concentration limits: lower explosion limit: approx. 20...60 g/m ³ air upper explosion limit: approx. 2...6 kg/m ³ air	These characteristics vary widely throughout the entire range. Extreme dusts can form an explosive mixture in concentrations of less than 15 g/m ³ .
Maximum explosion pressure	In enclosed containers of simple design, combustible dust can reach an explosive pressure between 6 and 10 bar.	In exceptional cases, such as with light metal dusts, explosive pressure of up to 20 bar may develop.
K _{St} -value	This is a classifying value expressing the shattering power of the combustion. Numerically, it is equal to the value for the maximum rate of explosion pressure rise during explosion of a dust/air mixture in a 1 m ³ vessel.	This figure is the basis for calculating pressure relief areas.
Moisture	The moisture of a dust is a significant factor with regard to its ignitions and explosive behaviour. Although no exact limits exist, it is known that a higher moisture content requires a higher ignition energy and impedes the formation of dust swirls.	
Minimum ignition energy E _{min}	Lowest energy which is sufficient to effect ignition of the most easily ignitable explosive dust atmosphere under specified test conditions (EN 13237).	Not every spark is capable of causing ignition. The decisive factor is whether sufficient energy is introduced into the dust/air mixture to initiate a self-sustaining combustion of the entire mixture. A modified Hartmann tube (Figure 5) is used to determine the minimum ignition energy.
Ignition temperature of a dust cloud T _{ic}	The lowest temperature of a hot inner wall of a furnace at which ignition occurs in a dust cloud in air contained therein (EN 50281-2-1).	The shape of the vessel in which the ignition temperature is determined has proved to be especially critical. It may be assumed that ignition on differently shaped surfaces is, in practice, only possible at much higher temperatures. In the case of dust from food products and animal feed, this figure is between 410 and 500 degrees C, depending on type.
Ignition temperature of a dust layer T _{il}	The lowest temperature of a hot surface on which a ignition occurs in a dust layer of specified thickness on a hot surface (EN 50281-2-1).	This temperature describes the ignition behaviour of thin dust layers. If the layer is thicker, or if the ignition source is completely inundated by dust, the thermal insulation provided by the dust layer increases, resulting in quite different, sometimes significantly lower temperatures, which could trigger an exothermal reaction. Experiments have shown that the ignition temperature decreases nearly linearly with an increase in the layer thickness. The ignition temperature of a dust layer is sometimes considerably lower than the ignition temperature of a mixture of the same dust in air. The maximum permissible surface temperature for electrical equipment may be higher, depending on the dust's thermal conductivity. Unnoticed glowing spots can exist unnoticed for long periods in thick layers of dust and can, if the dust is swirled up, become effective ignition sources.

Table 3: Examples of Explosion Characteristics for Dusts

Substance	T_{ic} [°C]	T_{il} [°C]	$\varnothing E_{min}$ [mJ]	min [mJ]
Wood	≥ 410	≥ 200	≥ 100	6
Brown Coal	≥ 380	≥ 225	–	5
Coal	≥ 500	≥ 240	≥ 1000	13
PVC	≥ 530	≥ 340	≥ 5	<1
Aluminium	≥ 560	≥ 270	≥ 5	<1
Sulphur	≥ 240	≥ 250	10	5
Lycopodium	≥ 410	–	–	–

Figure 4: Determining a Dust's Minimum Ignition Energy



Thus it is impossible to provide generally valid characteristics for a particular kind of dust. There are wide variations for identical dusts. Depending on conditions, limit values often cannot be determined exactly; nor then, can the risk of explosion. The minimum ignition energy can also vary to a large extent. In Table 3, the limit values for several products are listed; that is, values that border on the hazardous. In rare cases, the dust/air mixture in question can also be ignited at considerably lower energies.

Note that it is not possible to directly infer the minimum ignition temperature from the minimum ignition energy, and vice versa.

Table 2 includes detailed commentary on the characteristics for dusts.

Functional Description of a Modified Hartmann Tube (Figure 5):

Not every spark is capable of ignition. The deciding factor is whether the energy added to the mixture is sufficient to initiate self-sustaining combustion of the entire mixture. The modified Hartmann tube is used as a qualitative test apparatus for the minimum ignition energy. At the base of the tube is an atomising cone which is employed to swirl a defined quantity of the dust being investigated. A compressed air blast of 7 bar swirls the dust in the glass cylinder and the resulting mixture is then ignited by a spark created between two electrodes.

A test is considered to be positive if the indication instrument shows a deflection of the hinged cover or, if a dust fire occurs (even if the hinged cover is not moved).

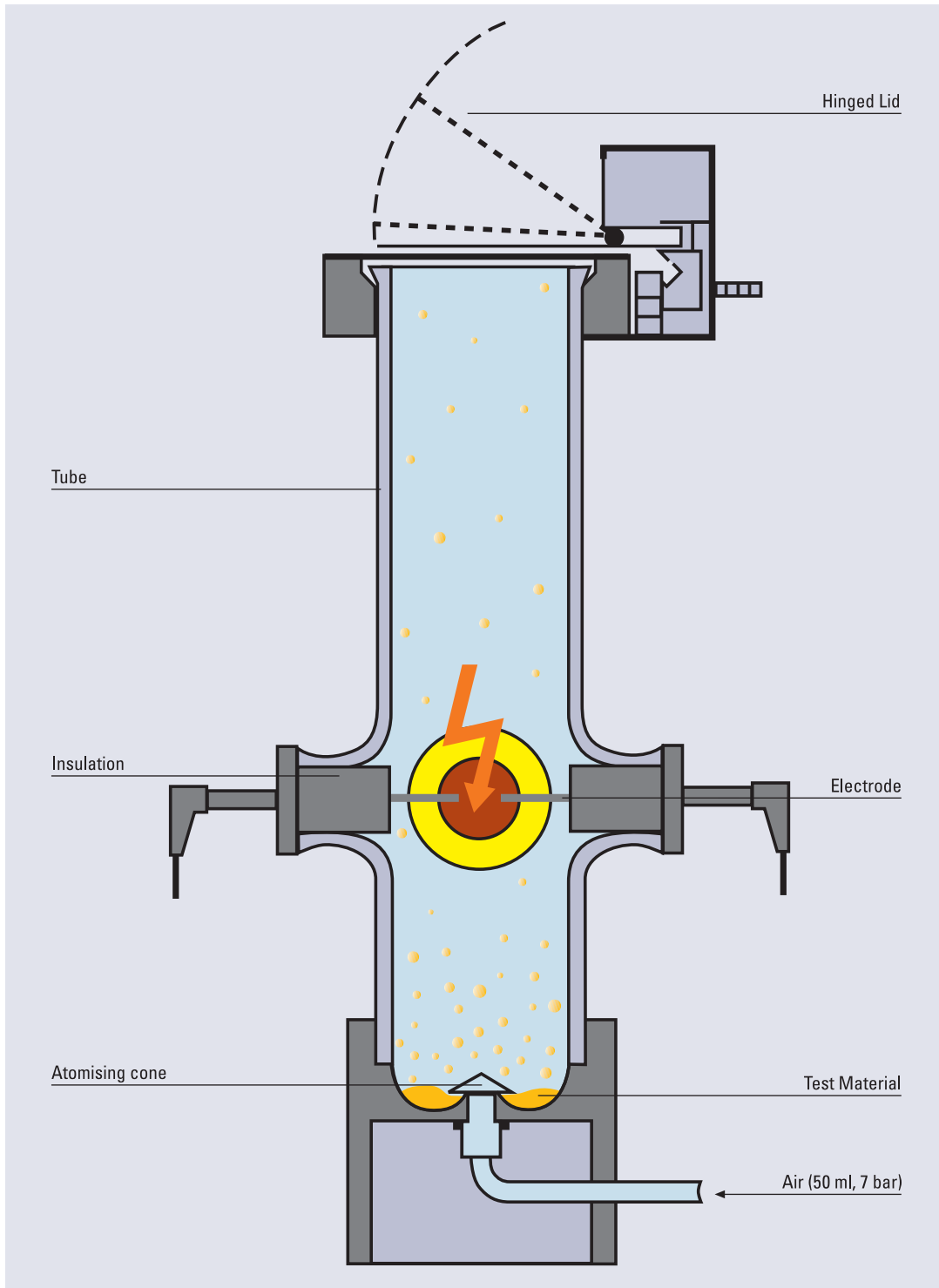
Figure 5: **Modified Hartmann Tube**

Table 4: Dust Explosion Protection Standards

	IEC	EN
General requirements	61241-0	prEN 61241-0
Type of protection "tD"	61241-1 (61241-1-1)	50281-1-1 in future EN 61241-1
Selection and installation	61241-14 (61241-1-2)	50281-1-2 in future EN 61241-14
Inspection and maintenance	61241-17	prEN 61241-17
Testing methods:		
> Min. ignition temperature	61241-20-1 (61241-2-1)	50281-2-1
> Electrical resistivity of a dust layer	61241-20-2 (61241-2-2)	61241-2-2 (50281-2-2)
> Min. ignition energy	61241-20-3 (61241-2-3)	50281-2-3 in future at CEN
> Lower explosion limit	61241-2-4	50281-2-4 in future at CEN
Classification of areas	61241-10 61241-3	50281-3
Protection by pressurization "pD"	61241-2 (61241-4)	
Protection by intrinsic safety "iD"	61241-11	
Protection by encapsulation "mD"	61241-18	

3. Legal Basis and Standards

In the most important industrial countries, regulations and standards covering explosion protection in areas exposed to dust hazard were established early on. In the USA, standards have existed since 1929, in Germany since 1976.

However, it was a comparatively long time before the first international regulations at IEC level appeared – 1993. Work on these commenced in the mid-70's, but the protective techniques used in the different countries were so different that it was very difficult to establish common standards. The IEC 61241:1993 series of standards was still based on the two zone concept.

Before the new European directives for explosion protection (94/9/EC and 1999/92/EC) came into force, explosion protection regulations in Europe existed at the national level, based on the two zone concept.

In Germany the two zones were defined: Zone 10 and Zone 11, in Great Britain: Zone Z and Zone Y. In Germany a special certification of design was not required.

Although the special risk posed by dust explosions has long been known, due to devastating accidents in coal mines, the problem received widespread attention in Germany only after the flour dust explosion that completely destroyed the Rolands Mill in Bremen in 1978.

After this, in Germany a certificate of conformity for electrical equipment to be used in Zone 10 became a legal requirement, based on the VDE standard. VDE 0170/0171, Part 13 developed by following the action of IEC. Based on this standard, BVS (German Testlaboratory and Certification Body) and now EXAM have been certifying electronic devices for use in Zone 10 since 1980, in co-operation with legal authorities and the PTB.

Directive 94/9/EC provided a new regulation for explosion protection in Europe. This directive formulates the requirements to be fulfilled by manufacturers of electrical and non-electrical equipment. The Explosion Protection Regulation of December 1996 (Explosionsschutzverordnung) transfers this directive into German law. In Annex I, Directive 94/9/EC mentions, in the course of an explanation of Equipment Group 2, only the danger presented by an explosive atmosphere consisting of a dust/air mixture, which does not seem to include dust deposits. The special risk presented by these dust deposits as a source of release is only taken into account in the zone classification insofar as other circumstances, such as a swirling up of the dust by air currents, could cause an explosive atmosphere.

The questions of proper use are addressed by Directive 1999/92/EC. The current treatment of dust explosion protection in Directive 1999/92/EC is not very comprehensive and is limited to a simple definition of zones and a reference to deposits of combustible dust.

CENELEC, the European Committee for Electrotechnical Standardization, has developed Standards EN 50281-1-1 and EN 50281-1-2 in parallel with IEC 61241 and based on it. These standards make use of the 3-zone concept as set out in European Directives 94/9/EC and

Table 5: Comparison of "Old" IEC 61241 Standards and "New" Suggestion

Number of Current Standard	Proposed New Number	Subject	Planned Date
IEC 61241-1-1	IEC 61241-0	General requirements	2003
	IEC 61241-1	Protection by enclosures "tD"	2003
IEC 61241-1-2	IEC 61241-14	Selection & installation	2003
IEC 61241-2-1	IEC 61241-20-1	Test methods	2005
IEC 61241-2-2	IEC 61241-20-2	Test methods	2005
IEC 61241-2-3	IEC 61241-20-3	Test methods	2005
IEC 61241-3	IEC 61241-10	Classification of areas	2003
IEC 61241-4	IEC 61241-2	Protection by pressurization "pD"	2005
IEC 61241-5	IEC 61241-11	Protection by intrinsic safety "iD"	2002
–	IEC 61241-18	Protection by encapsulation "mD"	2004
–	IEC 61241-17	Inspection & maintenance	–
–	IEC 61241-19	Repair & overhaul	–

99/92/EC. As part of the consolidation of standards dealing with dust and gas, the goal at the IEC level is to adapt the numbering of the dust standards to the IEC 60079 standard series (Table 5). This plan is laudable, because it would create analogous standards for gas and dust explosion protection.

4. Dust Explosion Protection Measures

4.1 Preventive (Primary) Explosion Protection by Avoiding an Explosive Atmosphere

The complexity of the processes that can lead to a dust explosion means that it is extremely difficult to assess the actual risks in dealing with explosive dust/air mixtures. This makes explosion prevention measures especially important.

These are generally considered to mean avoiding or limiting the amount of a hazardous explosive atmosphere. One possibility is to reduce the concentration of the combustible substance to values below the "lower explosion limit" (see Table 2), such as by mixing it with non-combustible products. Another option is to prevent the release of combustible substances or at least to limit it. Both of these measures can be effectively supported by thorough and regular housekeeping and by implementing suitable construction measures (see p. 15). If release cannot be avoided, the surrounding air with its oxygen can be replaced as a potential reactant by a non-combustible gas such as nitrogen (inertisation).

However, high operational costs mean that this method is limited to a small number of special applications. If these measures cannot be provided at a justifiable cost, there are other effective options of explosion protection available.

4.2 Preventive Explosion Protection by Avoiding Effective Ignition Sources

This measure prevents the hazardous explosive atmosphere from being ignited. This can be achieved by:

- > Analysing potential ignition sources
- > Determining the necessary extent of protective measures
- > Using suitable equipment

For this reason, measures against a possible ignition of a present explosive atmosphere are used. A precondition is that the workflow process in question be assessed in adequate detail for any possible ignition sources.

The nature of the protective measures used and the level of safety required depend on the hazardous zone in question. The probability of the existence of an explosive dust atmosphere and the zone classification of hazardous areas derived from it are important factors for deciding what protective measures are necessary (see Section 5).

4.3 Constructional Explosion Protection

Constructional explosion protection is a method of avoiding the hazardous effects of explosions and/or of limiting the effects of an explosion to a safe level by the use of:

- > **Explosion-resistant design** limits an explosion to the inside of pressure-resistant vessels or pressure-shockresistant vessels – which, however, also means that connected equipment such as tubes/pipes and decoupling measures must meet the same conditions.
Explosion-pressure resistant vessels or apparatus are those that can withstand many times the expected explosion pressure without being permanently deformed.
Explosion-pressure shockresistant vessels or apparatus are constructed so that they can withstand the expected explosion pressure without breaking; however, permanent deformations may be a result. In this case, then, the robustness of the material may be brought closer to its limits.
- > **Explosion relief** (defined pressure relief by means of bursting discs, venting panels or explosion doors, etc.) This measure is intended to prevent the build-up of excessively high explosion pressure in the interior of vessels by the timely release through defined openings. This measure addresses only the effects of the explosion, and can be implemented without additional control mechanisms. As soon as the static response ejection process from the protected apparatus into the surrounding area begins. Apart from the flame and shock wave, this ejection process from the relief apertures associated with the explosion pressure relief also contains burnt and unburnt combustible substances. It must always be checked whether the consequences of the explosion in the location in question can be controlled.
- > **Explosion suppression**
This process is generally used in vessels and production equipment for which an explosion pressure exceeding the explosion pressure resistance of the system in question is predicted. The explosion is suppressed in its initial stages, before a hazardous rise in pressure can take place. To accomplish this, an extinguishing agent is used in the protected area within fractions of a second of the explosion being detected. For the suppression of an explosion (use of extinguishing agent) it is mandatory that the explosion be detected promptly. In the case of explosions that begin slowly, the initial pressure rise is not sufficient for its timely identification. Additional measures such as optical flame detectors or supplementary pressure detectors may be necessary.
- > **Explosion barriers** (prevention of explosion propagation, explosion decoupling).
Isolation as an explosion protection measure allows the explosion to reach full force, but prevents it from propagation into other, unprotected parts of the system. This is accomplished by mechanical barriers which immediately block connecting routes, or by a chemical extinguishing barrier.

Table 6: Zone Definitions

Zone 20	A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously, or for long periods or frequently. NOTE: In general these conditions, when they occur, arise inside containers, pipes and vessels etc.
Zone 21	A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur in normal operation occasionally. NOTE: This zone can include, among others, areas in the immediate vicinity of e.g. powder filling and emptying points and areas where dust layers occur and are likely in normal operation to give rise to an explosive concentration of combustible dust in a mixture with air.
Zone 22	A place in which explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does, will persist for a short period only. NOTE: This zone can include, among others, areas in the vicinity of equipment, protective systems, and components containing dust, from which dust can escape from leaks and from dust deposits (e.g. milling rooms, in which dust escapes from the mills and then settles).

Table 7: Zone Concept and Impacts of Directives 94/9/EC and 1999/92/EC

	Presence of Hazardous Explosive Atmosphere D (Dust)	No Effective Ignition Sources Present	Equip. Category in Accordance with 94/9/EC	Certification Required for Electrical Equipment
Zone 20	Continuously, long-term or frequently	Normal operations and rare equipment malfunction and on the occurrence of two independent faults	Category 1D	yes
Zone 21	Occasionally	Normal operations and frequently occurring equipment malfunctions	Category 2D	yes
Zone 22	Rare and short period	Normal operations	Category 3D	no (manufacture's declaration)

5. Classification of Dust Explosion Hazardous Areas into Zones

The classification into zones has proved its effectiveness in gas atmospheres for years. The definition of zones agreed on throughout Europe in accordance with Directive 99/92/EC applies only to swirled-up dust. Accumulations and deposits of combustible dust must be taken into consideration as well, like all other factors that could lead to the creation of an explosive atmosphere.

Dust deposits are seen merely as a "source of release" for an explosive atmosphere.

Among other sources, EN 50281-3 (Classification of areas where combustible dusts are or may be present) can provide help with the classification.

In Table 6 and Table 7, zone classification and zone definitions are once again given, as well as the connection between the zones and the equipment categories of Directive 94/9/EC.

Classification According to Housekeeping of Working Place

High cleanliness of working area is very important in dust explosion protection, as in contrast to gases a series of releases that are individually under the explosion limit can lead to a hazardous accumulation of dust (see also 4.1, Preventive (Primary) Explosion Protection).

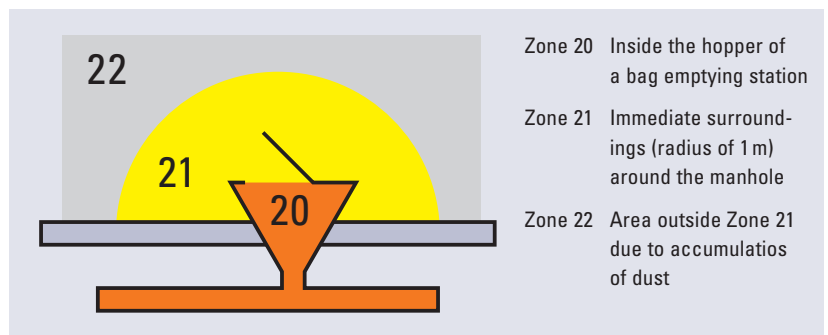
The Directive 99/92/EC and specially the Guide of this Directive, paragraph 3.1.4.1 refer to obligatory cleanliness standards.

In the new version of the Standard "Classification of areas where combustible dusts are or may be present" according to IEC 61241-10 and EN 50281-3, the degree of housekeeping is quantified and included in the classification of the areas (Table 8).

Table 8: Housekeeping and Explosion Hazard

Level of Housekeeping	Thickness of Dust Layer	Duration of Presence of a Dust Layer	Fire or Explosion Risk
good	zero or negligible	not present	none
fair	not negligible	shorter than the length of 1 shift	none
poor	not negligible	longer than the length of 1 shift	fire hazard and Zone 22 if clouds are created

Figure 6: Example of the Classification into Dust Explosion Hazardous Areas According to IEC 61241-10



6. Types of Dust Explosion Protection

The goal of explosion protection is to prevent excessive temperatures and energies in the form of sparks, arcs and so forth in an equipment.

Currently four types of dust ignition protection exist (see Table 9):

6.1 Type of Protection "tD"

In Europe, this is generally regarded to be the most important method for power engineering equipment.

EN 50281-1-1 defines the type of protection for electrical equipment: "Protection by Enclosure." Two degrees of dust protection are defined for dust explosion protection:

1. **Dust-tight:** for the use of equipment in Zone 20, Zone 21 areas and even in Zone 22 areas, in the case of the presence of conductive dust.
2. **Dust-protected:** for the use of equipment in Zone 22 areas, in the case of the presence of non-conductive dust.

The type of protection "tD" requires the limitation of the surface temperature of the enclosure and the limitation of dust ingress into the enclosure (dust-tight and dust-protected enclosures):

> Dust-tight enclosure

An enclosure which prevents the ingress of all observable dust particles (IP 6X).

This means that a safe area is established inside the enclosure. Please note that as combustible dust particles are approx. 20 to 40 µm in size and thus below the gap of flameproof joints required by EN 50018 for flameproof enclosures. Flameproof enclosures are not in themselves dust-tight and must be separately tested and certified according to this condition.

> Dust-protected enclosure

An enclosure which the ingress of dust is not totally prevented, but does not enter to interfere with the safe sufficient quantities to operation of the equipment. Dust shall not accumulate in a position within the enclosure where it is liable to cause an ignition hazard (IP 5X).

The material used for the enclosure is central significant. It must be subjected to specific material tests. Despite the ageing process undergone by the material and the expected mechanical stresses, the enclosure must ensure the required dust protection.

Possible materials are:

- > Metals (such as coated steel, stainless steel, light metal)
- > Glass (for enclosure parts, eg. inspection windows)
- > Moulded plastic

Metals used for this purpose may have to be subjected to an impact test at low temperatures, as some metals (light metals) have less favourable mechanical stress at low temperatures than at higher ones.

In addition, light metal may contain a maximum of 6 % magnesium, as it otherwise tends to form sparks upon impact with materials such as rusty iron. Glass must withstand a thermal shocktest without cracks or without such extensive damage that it breaks during a subsequent impact test.

6.1.1 Enclosures of Moulded Materials

Thermal Endurance

Plastic materials must certainly fulfil the most complex requirements. For electrical equipments of Categories 1D and 2D, the temperature index "TI" must be known, according to EN 50281. This figure allows conclusions about the long-term mechanical performance of moulded materials to be drawn. The temperature index corresponds to the 20,000-h point on the thermal endurance graph without loss of flexing strenght or tenside strenght excluding 50 %. This figure must be 20K higher than the temperature at the hottest point of the enclosure. In addition, the moulded material must be proven to have sufficient thermal resistance for the intended application. Enclosures or parts of enclosures made of moulded materials for electrical equipment from the Categories 1D and 2D must be subjected to thermal endurance tests according to EN 50014 (artificial ageing). The ageing process caused by extreme temperatures must not cause the moulded



material to become brittle which would eliminate the required IP protection.

For electrical equipment of Category 3D, it is sufficient for the material to have a TI at least 10K higher than the temperature at the hottest point of the enclosure. Proof of a continuous operating temperature (COT) which fulfils the same requirement as the TI is also sufficient. No thermal endurance test is carried out in this case.

Table 9: Types of Protection for Use in the Presence of Combustible Dust in the Current Standards

Symbol	Principle	Type of Protection	Current Status at IEC	Future Status at IEC	Status at CLC
tD		IP-enclosure (tightness and temperature limitation)	IEC 61241-1-1	IEC 61241-0 IEC 61241-1	EN 50281-1-1
pD		Pressurization	IEC 61241-4 (2001-03)	IEC 61241-2	
iD		Intrinsic safety	31H/171/CDV	IEC 61241-11	
mD		Encapsulation (moulded compound)	31H/153/CDV	IEC 61241-18	

Table 10: Summary of Requirements for Electrical Equipment

Requirements:	Cat. 1+2 – Zone 20+21	Cat. 3 – Zone 22
No dust infiltration in enclosure	IP6X	IP5X
No dust infiltration at cable entries	IP6X	IP5X
Propagating brush discharges must be avoided	Insulation resistance $\leq 10^9 \Omega$ Breakdown voltage $\leq 4 \text{ kV}$ Thickness of insulation $\geq 8 \text{ mm}$	
Laser radiation (in accordance with EN 50281-1-1)	5 mW/mm ² continually 0.1 mJ/mm ² impulses	
Ultrasonic (in accordance with EN 50281-1-1)	0.1 W/cm ² / 10 MHz continuous 2 mJ/cm ² puls 0.1 W/cm ² average	
External connection for equipotential bonding	as in "e"	as in "n"
Plugs, sockets and connectors	Separation with no voltage applied except up to 10 A, 250 V; here IP6X sufficient for separation; dust must not fall into opening	
Luminaires	Light source with cover, lock or warning label; no low power sodium lamps	
Clearance and creepage distance of connecting parts	IEC 60664	IEC 60664
Certification required	yes	no
Label: CE compliance according to Directive 94/9/EC	CE	CE
Conformity to standards		
Surface temp. in °C, (not temperature class)	T ... °C	T ... °C

Seals

Type of protection "protection by enclosures" depends on the elastomeric seals used. These are evaluated in accordance with Annex B3.3 of EN 50014. This is an ageing test using specially shaped test objects (ISO 48/ISO 1818) which tests the increase in hardness of the material. This figure must not exceed 20 % difference between the initial and the final figure. Materials that have hardened to a greater degree may lose their sealing properties.

Static electricity

An electrostatic discharge is a "very effective" ignition source. When moulded materials is used for enclosures, the outer surface must be prevented from becoming charged. Otherwise, one of the following types of discharge will occur:

> Spark discharge

This type of discharges takes place between grounded and ungrounded components and is able to ignite all gases and vapours, and almost all dust atmospheres.

> Brush discharge

This type of discharge is a special form of the corona discharge. Pipes, elbows, screws, and tools may serve as electrodes at the maximum field strength. This type of discharge represents no risk to most dusts, but caution is advised with regard to gases and vapours.

> Propagating brush discharge



This is a discharge of a chargeable material with a low layer thickness (<8mm) on a substrate with adequate conductive.

An example: Moulded materials in the pipes of pneumatic conveyor systems initially receives a strong electrostatic charge from friction on the inside. This charge produces an influence-charge on the external surface, which is coated with plastic material and covered dust. This double layer of charge may contain large amounts of energy. If one short-circuits both sides of the doubly charged layer, all the stored energy is violently discharged. This causes brightly lit discharge channels to form on the surface of the plastic material. This discharge may contain several joules of energy, so that nearly all gases and vapours and the majority of dusts will be ignited. However, propagating brush discharges are relatively rare in practice.

The following measures can prevent this type of discharge process such as these:

- > Adjusting the surface resistance to $10^9 \Omega$ and grounding the plastic material.
- > Limiting the breakdown voltage of the non-conductive material to 4 kV.
- > Avoiding thicknesses < 8 mm for the non-conductive material.
- > Limiting isolated capacities to < 10 pF.
- > Increasing humidity to > 65 % in order to reduce the insulation resistance of non-conductive materials.

Table 11: Summary of the Requirements for Rotating Electrical Machines, Type of Protection "tD"

Requirements	Cat. 2 – Zone 21	Cat. 3 – Zone 22
Dust tightness of enclosure	IP6X	IP5X
Magnesium content in enclosure material	≤ 6%	≤ 6%
Thermal properties of non-metallic enclosure materials	as in "e"	as in "n"
Insulation resistance of enclosure, fan guards	≤ $10^9 \Omega$	≤ $10^9 \Omega$
Insulation resistance of the fan wheel at all speeds	≤ $10^9 \Omega$	≤ $10^9 \Omega$
External connection for equipotential bonding	as in "e"	as in "n"
Dust tightness of entries	IP6X	IP5X
Degree of protection of the external fan	as in "e"	as in "e"
Protective cover for V1 (air inlet on top)	as in "e"	
Fan and cover construction and mounting	as in "e"	as in "e"/"n"
Clearances in ventilation system	as in "e"	
Magnesium content in the material of the fan	≤ 6%	≤ 6%
Clearance and creepage distances of connecting parts	IEC 60664	IEC 60664
Certification by notified body required	yes	no
CE conformity	CE	CE
Conformity to standards		
Surface temperature in °C (not temperature class)	T ... °C	T ... °C

Mechanical Stability

For equipment from Categories 1D and 2D, mechanical tests are carried out in accordance with EN 50014. The enclosures must withstand an impact energy of 7 joules.

If the enclosure contains light transmitting parts, they are subjected (without basket guard) to a test with 4 joules or (with basket guard) to one with 2 joules.

Tests such as these are to be carried out after thermal shock resistance test at a temperature 10 to 15 K higher than the maximum operating temperature and 5 to 10 K below the lowest operating temperature.

After the mechanical stability test, the degree of protection IP according to Table 10 has to be fulfilled.

In the case of portable electrical equipment, a drop test in accordance with EN 50014 must also be carried out.

Cable Glands

Power supply and instrumentation cables are connected to the explosion-protected electrical equipment. The cable entries must be in accordance with Annex B of EN 50014. This means that the certified "Increased safety" cable glands for hazardous areas may be used. It must be noted, however, that the Ex e cable entries require IP 54, whereas for dust explosion protection, equipments from Categories 1D and 2D require IP 6X and devices from Category 3D IP 5X. In addition, test of increase in hardness is required (see Seals). This verification can be provided by the tests mentioned here or by data sheets from the gasket manufacturer.

6.2 Protection by Pressurization "pD"

This type of protection, based on Pressurized apparatus "p", could become important in the protection of switch cabinets in hazardous areas, for example. Equipment of the type "pD" can only be used in Zone 21 and Zone 22 (not in Zone 20). The purging phase required for gas explosion protection is not permitted for dust explosion protection, as the swirling up of deposited dust could produce a hazardous explosive atmosphere. Section 4.3 of the standard explicitly requires that before the pressurization system is switched on, the interior of the equipment be cleaned and all dust that accumulated there after switching off the external ventilation be removed.

The measures to be taken when the pressurization equipment fails are graduated according to zone and the presence of operational ignition sources (see Table 12).

Table 12: Requirements on Failure of Pressurization

Type of apparatus in the enclosure		
Zone	operational ignition source	no ignition source in normal operation
20	"pD" not applicable	"pD" not applicable
21	Switching off as in 7.5.1.1	Warning as in 7.5.1.2
22	Warning as in 7.5.1.2	Internal pressurization not required

6.3 Intrinsic Safety “iD”

The current draft (CD) largely corresponds to the 4th edition of IEC 60079-11: 1999 for gas explosion protected apparatus with type of protection Intrinsic safety “i”.

The final version should refer for the most part to the directly valid sections of Standard IEC 60079-11 without repeating the text of this standard. This is what is to be expected in practice when the design of “iD” apparatus is derived from existing and already tested intrinsically safe apparatus.

The preliminary translation of the introduction to the future standard IEC 61241-11 mentions the following basic requirements:

- > Electrical circuits must fulfil the requirements of Group IIB from IEC 60079-11, in order to prevent ignitable sparks.
- > Normally, degree of protection IP 6X or encapsulation is required to ensure that clearances and creepage distances are not effected.
- > Power limitation for equipment or their parts that are not protected by an enclosure or encapsulation (e.g. for non-insulated sensors). This is intended to prevent that a dust layer ignites due to a direct transfer of power by conductive dust and to prevent ignition due to heat on the surface of components.

- > Temperature limits on all outer surfaces of apparatus or their parts whose power limits exceed the operational limits required in IEC 61241-11. The surface may consist of an enclosure or an encapsulation.

Work is continuing on the standard for the intrinsic safety “iD” ignition protection type, therefore we refer the reader to current articles in our Ex-Magazine.

6.4 Encapsulation “mD”

The dust type of protection “mD” in accordance with IEC 61241-18 is to be based primarily on type of protection “m” according to IEC 60079-18, which is currently being revised.

Further proceedings on the draft of IEC 61241-18 will therefore be determined by the development of the new IEC 60079-18.

7. Equipment Selection

After assessment of the installation and its possible risk, the user should consider the following criteria when selecting electrical equipment:

- > Determination of the equipment category in accordance with the hazardous zone.
- > Assessment of the properties of existing dust.
- > Maximum permissible surface temperature of the equipment, taking into consideration the type of dust, the ignition temperature of the dust cloud and, if dust deposits cannot be excluded, the ignition temperature of the dust layer.

The selection of the **equipment category** can be carried out as described in Table 13. This defines the design of the enclosure in accordance with the requirements of Clause 4,5 and 6 of EN 50281-1-1. The dust-tightness tested using the procedure described in EN 60529 for Category 1D, must be taken into account.

Table 13: Selection of Dust Explosion Protected Apparatus

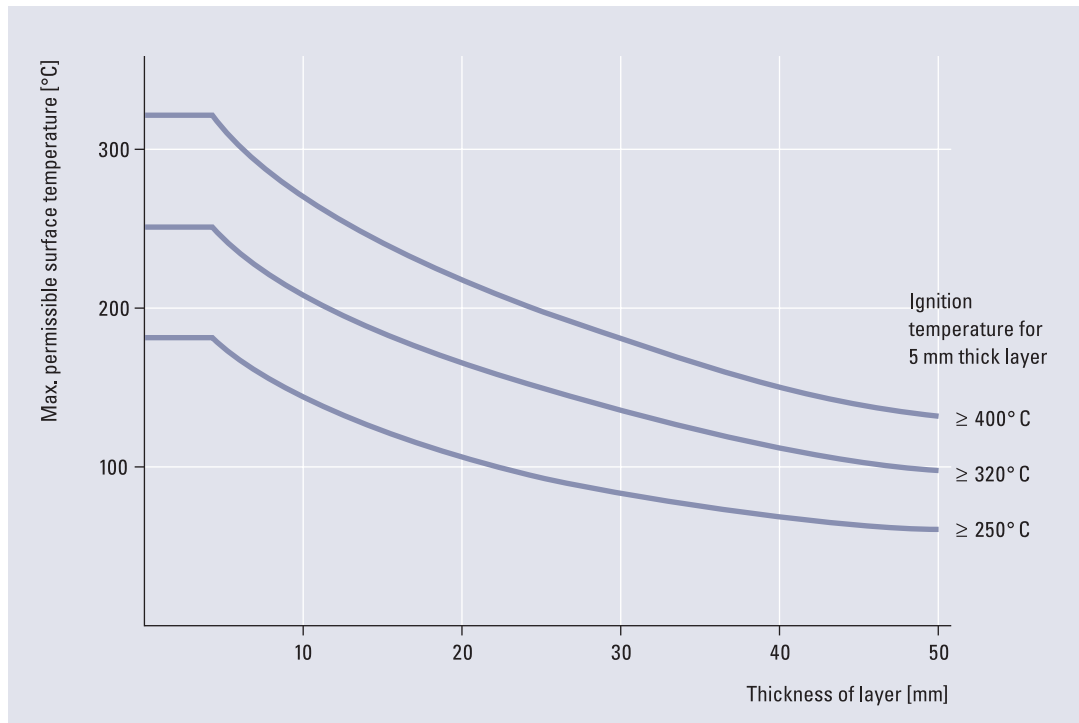
Type of Dust	Zone 20	Zone 21	Zone 22
conductive	Category 1D Temperature limitation when excessive deposits can be present	Category 1D or 2D	Category 1D or 2D
non-conductive	Category 1D Temperature limitation when excessive deposits can be present	Category 1D or 2D	Category 1D, 2D or 3D

The “Essential Health and Safety Requirements” from Directive 94/9/EC deal with the problem of dust deposits in Annex II, Paragraph 1.2.4. In addition to requiring the removal of dust layers, this states that the surface temperature of equipment and equipment parts be well below the ignition temperature of the dust layer. An accumulation of heat must be expected and should be countered with using temperature limitation. Dust accumulations should, if possible, be limited or avoided entirely. For the equipment manufacturer, this means the equipment must be produced in such a way that dust deposits do not arise and/or the equipment is easy to clean.

- > EN 50281-1-2 deals with the selection of electrical equipment and specifies that independent of classification into zones, the possibility of the equipment being covered or completely submerged by dust must be taken into consideration, unless this situation can be avoided.
- > EN 50281 does not currently regulate the question of how dust deposits on electrical equipment influence the safety level. For equipment from Category 3D, there is no requisite consideration of possible faults. This would mean that equipment from Category 3D would be subject to a thermal assessment – in extreme cases when totally submerged in dust – however that common faults need not be taken into consideration.

Zone 21 presents a similar problem. Is the inside of containers in which combustible dust is stored also a part of this zone? The situation is clearer in the case of Zone 20, as due to the definition complete sumerging of the equipment must be taken into account.

Figure 7: Correlation between the Maximum Permissible Surface Temperature and the Thickness of Dust Layers



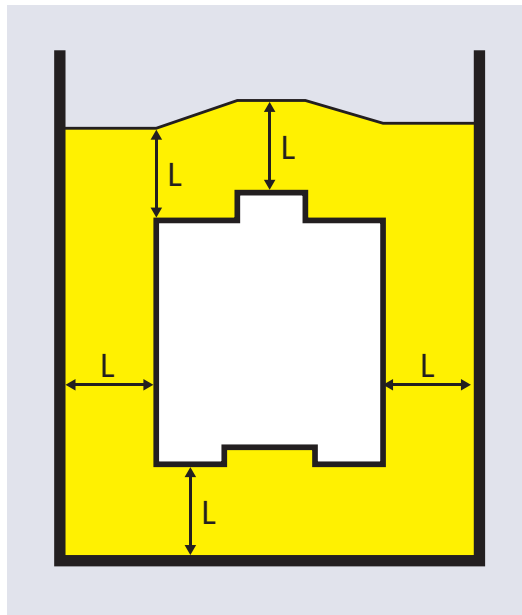
The self-ignition of dust deposits is a critical problem. These processes are often caused by exothermal reactions involving oxygen from the surrounding air. It could be a chemical reaction (oxidation), a physical reaction (adsorption) or a decomposition process (mainly in the case of organic dusts). Self-ignition is determined of the temperature of the surrounding area, of the geometric factors and of the volume of the dust. The reaction heat produced during decomposition of materials can produce carbonisation gas, which in turn can lead to an explosive gas/air mixture.

Not every case of dust ignition necessarily leads to an explosion. Dusts with low rate of pressure rise may first of all be a dust fire. Under certain conditions, an explosion may occur, often in a completely different location than the ignition. The fire can spread from the place of origin to

other areas by way of transportation facilities. During this process, the flames swirl up unburned dust, which in turn takes deposited dust with it. A sudden change in the volume of the dust cloud as it enters a larger room (e.g. a silo) can produce a hazardous explosive atmosphere. The flames cause ignition.

The **ignition temperature of a dust layer** is determined using the method from EN 50281-1-2. The determination of the **maximum surface temperature** that an electrical apparatus can achieve must be done by the manufacturer, with any possible faults taken into consideration. Temperature limitation measures should be used to counter these faults (electrical/thermal fuse). The maximum surface temperature is measured as specified in Clause 10 of EN 50281-1-1.

Figure 8: **Determining the Maximum Surface Temperature T_L Under a Dust Layer of Thickness L in mm**



When determining the maximum permissible surface temperature (in relation to the surrounding dust), two figures should be noted:

1. Maximum permissible surface temperature when a dust cloud is present (calculation in accordance with 6.1 of EN 50281-1-2).
The ignition temperature of the dust cloud must be taken into account.
2. Maximum permissible surface temperature when a dust layer is present. When making the determination, one must take the ignition temperature of a dust layer (which is dependent on the thickness of the dust layer) into account:

- > For dust deposits up to 5 mm thick, the calculation must be made in accordance with 6.2.1 of EN 50281-1-2.
- > For dust deposits > 5 mm – 50 mm, the curves in Figure 7 may be applied.

The reductions in temperature plotted here were determined empirically for dust layers of up to 50 mm on top of electrical equipment. The curves take into account both the reduction, specific to dusts, of the ignition temperature with increasing layer thickness, and also an expected increase of the temperature of the electronic apparatus, due to the reduction of the heat flow. In addition, the curves include the usual safety reduction of 75 K.

Here it must be stated explicitly that this does not take into account an electrical apparatus submerged completely in dust.

- > **Determining a surface temperature for dust deposits > 50 mm:** According to the currently valid requirements in Clause 6.3 of EN 50281-1-1, if dust deposits of excessive thickness are present, the equipment in question must be tested in a laboratory using the relevant dust (see Annex A of the above-mentioned standard).

In the future, manufacturers will have the option, during the type testing, of determining a surface temperature T_L under a deposit of thickness L (orientated toward the thickness of the layer during actual use), which may be stated on labels (Figure 8). Section 5.2 of IEC 61241-0 states: "In addition to the maximum surface temperature T_L required in 5.1, the maximum surface temperature may be stated for a given depth of layer, T_L , of dust surrounding all sides of the apparatus, unless otherwise specified in the documentation, and marked according to 29.2(8)". For the determination of the temperature T_L , 23.4.5.2 requires: "...the electrical apparatus to be tested shall be mounted and surrounded by a layer depth "L" as stated by the manufacturers specification. The measurement for the maximum surface temperature shall be made ...using a dust having a thermal conductivity of no more than $0.003 \text{ kcal/m} \cdot ^\circ\text{C} \cdot \text{h}$." The user must take note of Clause 6.3.3.4 of the installation standard 61241-14: "Where the apparatus is marked T_L for a layer depth the ignition temperature of the combustible dust, at a layer depth L , must be applied in place of $T_{5\text{mm}}$."

The following verification from 1 and 2 must be made by the user!

The maximum permissible surface temperature, in relation to the ignition temperature of a dust cloud T_{ic} and/or the ignition temperature of a dust layer T_{il} of the surrounding dust is determined as follows:

1. Maximum permissible surface temperature in case of dust clouds $T_{\text{max}} = 2/3 T_{ic}$
2. Maximum permissible surface temperature in case of dust layers (5 mm thickness)
 $T_{\text{max}} = T_{il} - 75 \text{ K}$

Example: flour

$$T_{ic} \geq 380^\circ\text{C} \text{ and } T_{il} \geq 300^\circ\text{C}$$

$$T_{\text{max}(1)} = 2/3 \times 380^\circ\text{C} = 253^\circ\text{C}$$

$$T_{\text{max}(2)} = 300^\circ\text{C} - 75 \text{ K} = 225^\circ\text{C}$$

Accordingly, the surface temperature of the electrical equipment in this particular case must not exceed the value of 225°C ; this must be guaranteed by the manufacturer (see "Determination of the Maximum Surface Temperature" above).

Figure 9: Explosion Protected Luminaire 6600 Series for Use in Zone 21 (Category 2D) and Zone 22 (Category 3D).



dust-explosion protection

equipment selection

Radiation-Emitting Equipment

Optical radiation is a peripheral phenomenon in the field of dust explosion protection. The first factor to be considered when determining the limit value is: How high is the power density?

If the power density is $< 0.1 \text{ W/cm}^2$, no further assessment is necessary. Pulse-shaped signals are assessed according to the energy density. In addition, however, the energy density as an average of the pulse-pause ratio must be taken into account. Besides this, an assessment of possible faults is to be carried out in order not to exceed the limit values for equipment from Categories 1D and 2D. The figure for the pulse-pause ratio, which is the basis of the calculation, is particularly important. Radiation in the optical range (especially if it is focussed) may ignite the dust/air mixture. Laser radiation can cause ignition from a great distance, even when it is not focussed.

Limit values to be ensured:

- > Power density 5 mW/m^2 for continuous wave lasers
- > Pulse energy density 0.1 mJ/m^2 for pulsed lasers

In the case of ultrasonic transmitting (e.g. sensors), a large percentage of the energy emitted by the ultrasonic transducer is absorbed by dust. This causes heating of the dust particles, which in extreme cases even reach the ignition temperature. Limit values to be observed:

- > Power density 0.1 W/cm^2
- > Pulse energy density 2 mJ/cm^2

- > Fuses: unopenable when energized, or warning label as for switch gears.
- > Luminaires: lamps containing free metallic sodium (e.g. low-pressure lamps according to EN 60192) are not permitted.

Connecting Components

As in gas explosion protected areas, electrical equipment is connected to the outer power circuit using terminals.

The equipment can also be connected using a cable that is fixed integrated. Apparatus with fixed connected cables are an exception when only one end of the cable is permanently connected. These devices must be labeled with the symbol X.

The user must be given instructions for the unattached end of the cable (e.g. within Zone 21, the free cable end must be plugged into an apparatus of Category 2D).

Operating Instructions and Marking

Table 15 shows the marking for electrical equipment in accordance with EN 50281 and Directive 94/9/EC. Data relevant to explosion protection, such as equipment group, category and maximum surface temperature should be displayed as shown in the following example: II 2 D T 135 °C.

No classification of dusts into temperature classes is planned. Unlike gases, dusts require a margin of safety between surface temperature and ignition temperature of a dust cloud and a dust layer.

Each equipment has a set of operating instructions which must contain the elements shown in Table 14.

Table 14: Contents of Operating Instructions

According to EN 50281-1-1

- > Putting into service
- > Use
- > Assembling and dismantling
- > Maintenance
- > Installation
- > Electrical characteristics
- > Specific conditions

Table 15: Marking of Equipment

EN according to EN 50281-1-1

- > Name and address of manufacturer (trademark)
- > Series and type identification
- > Serial number
- > Electrical characteristics
- > Maximum surface temp.T
- >
- > Equipment Group, in this case II
- > "D" for dust
- > Category
- > Testing laboratory and certification number (year/Id. number.)
- > Year of manufacture
- >

8. Installation and Maintenance

The protective measures described in Section 4 alone are not sufficient to prevent an explosion. Installation carried out according to requirements, punctual, correct and consistent maintenance are all crucial for maintaining safe operations (EN 50281-1-2).

During installation, the manufacturer's operation conditions in the operating instructions must be followed carefully.

8.1 Installation of Cables

Selection of Cables

In general, the common types of cables are permitted, if they are installed into screwed, solid, drawn or steamed welded conduits. Cables whose construction ensure that they are dustproof and suitable for mechanical stress may also be used.

Examples are:

- > Cables with thermoplastic or elastomeric wire insulation, screened or armoured cable and an outer sheath of PVC (poly-vinylchloride), PCP (polychloroprene rubber), or a similar material.
- > Cables with a seamless aluminium sheath with or without armouring.
- > Mineral-insulated cables with metal sheath.

Note: These cables and wires may have to be operated below their rated values to limit the surface temperature from exceeding the required values.

- > When cables are externally provided with protection, or when there is no danger of mechanical damage, cables with thermoplastic or elastomeric insulation and a sheath of PVC, PCP, or a similar material are permitted.

Cabel installation

- > Cables must be placed so that they cannot become electrostatically charged by moving dust (friction effect).
- > Cables runs shall be arranged insofar possible that no large dust deposits can be collected. Sufficient access for cleaning must be possible.
- > If possible, cables shall not pass through areas with potentially explosive dust atmosphere if they are not connected to this area.
- > If dust layers form on cables, preventing free air circulation, a reduction of the current carrying capacity of the cable shall be considered. This applies especially to dusts with a low ignition temperature.
- > If cables pass through walls or other structures, this must be done so as to prevent the passage or collection of combustible dust.
- > For transportable electrical equipment, a suitable cable type must be used. For these purposes, often a suitable connection box must be placed between the moving and fixed cable routing.
- > If metal conduit is used, care should be taken to ensure that there is no possibility of cabel damage at the connecting points, that the connecting points are dustproof, that the impermeability of the connected equipment is not reduced, that the connecting points are included in the potential equalisation.

Cable Glands

The requirements for the entries into dust explosion protected equipment from Categories 1D and 2D are almost identical with those for a gas explosion protected glands, type of protection "Increased safety". Both must be in compliance with Annex B of EN 50014.

The only differences are in the degree of protection and in approval:

- > Dust-Ex: IP 6X, certification for Zone 20 and/or Zone 21
- > EEx e: IP 54, certification for Zone 1 and Zone 2

Cable glands must be assembled and mounted so that they do not compromise the equipment's dust tightness. They can also be permanently connected to the equipment, in which case they are certified together with the equipment.

8.2 Maintenance and Servicing

In addition to the protective measures already taken, an organisational plan must be drawn up for the installation.

- > Cleaning, removal of dust deposits.
- > Inspection and maintenance of equipment and protective systems.
- > Testing of earthing, especially for the parts of the equipment that could become electrostatically charged.

These measures serve firstly to reduce the risk of explosion and secondly to ensure the effectiveness of the constructional protective measures.

"The inspection and maintenance of electrical apparatus for use in combustible dust shall only be carried out by personnel who are familiar with the concept of protection." (EN 50281-1-2:1998, 12.1)

8.3 Documentation

EN 50281-1-2, 10.3:

"Plans of each site shall be maintained to show the following:

- > The classification and extent of the hazardous areas; the information shall include the zoning and maximum layer thickness, if greater than 5 mm.
- > Records of the types and marking details of protected apparatus and sufficient information to enable them to be maintained properly.
- > Types, routes and details of wiring system."

This task is in conformity with the requirement of the Directive 99/92/EC, which obligates the employer to draw up an explosion protection document. The content of the document should indicate:

- > The explosion risk have been determined and assessed.
- > Adequate measures will be taken.
- > Work equipment and warning device are design, operated and maintained with due regard for safety.
- > Provisions to ensure that the equipment is used correctly.

**Some Examples of
Dust Explosion
Protected Products**

ECOLUX 6608
Emergency Luminaire



Optical Beacon 6161
Traffic Light 6091



Control System
Series 8040
Lighting and Heating Panel
Series 8146



Switch- and
Distribution Board
CUBEx



Safety Barriers
INTRINSPAK
EX i Isolators IS pac



Remote I/O System I.S.1
Plugs and Sockets
SolConeX



9. Product Overview

R. STAHL has a fully certified product range for dust hazardous areas in your installation. We take dust explosion protection just as seriously as gas explosion protection. We can offer you a specially adapted solution for almost every application. At a minimum, all dust explosion protection products comply with the regulations of Group 3D; that is, they can be used in Zone 22 (non-conductive dusts).

The following equipment series and systems are certified for both Zone 21 and Zone 22:

- > Luminaire Series 6600 and 6608, Compact Luminaire 6100 and 6108
- > Tank Inspection Light 6122 and Optical Beacon 6161
- > Traffic Light 6091
- > Control System ConSig 8040
- > Position Switches 8060 and 8070
- > Junction and Terminal Boxes Series 8118
- > Control Panel and Terminal Boxes Series 8146 and 8125
- > Ex d Enclosure System CUBEx
- > Safety Barriers INTRINSPAK
- > Isolators Series IS pac
- > Remote I/O System I.S.1
- > SolConeX Plugs and Sockets



Your Safety – Our Reality

If your installation is faced with the risk of a dust explosion, R. STAHL offers the expertise you need.

R. STAHL has decades of experience in the field of electrical explosion protection.

We will be glad to help you solve your safety problems. In addition to a comprehensive range of electrical equipment, we offer you expert advice and training in the dust explosion protection field.

Get in touch with us.

You will find a downloadable list of our dust explosion protection products in PDF form at:

 www.dust-ex.stahl.de



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