EPRA - European Phenolic Resins Association

Dust Explosion Guidelines

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1 INTRODUCTION

Wherever combustible solids are handled, dust fires and explosions hazards may exist. Phenolic resins are among the materials that pose a dust explosion hazard under appropriate conditions.

Dust explosions can lead to loss of life, injuries, property damage, environmental damage as well as consequential damage such as business interruption losses.

Dust explosions involve most commonly “dust”, i.e. fine material. This can be the product being handled or it can be produced as the result of the processing. However, in many cases fine dust is present in material that is otherwise too coarse to pose a dust explosion hazard, either as part of the product or generated by attrition during handling or transport. Therefore, while replacing a fine material by a granular one (such as pellets or flakes) will reduce the dust explosion hazards, this may not be sufficient to eliminate the hazards. Similarly, a user of a granular material may process it to a particle size that introduces dust explosion hazards.

Many dust explosions that occur in process plant are relatively small, leading to limited damage. However, under the right circumstances, even small explosions can escalate into major incidents. This is most commonly the case when secondary dust explosions happen. The typical scenario is that a small “primary” explosion raises a dust cloud, often from dust deposited over time on plant surfaces, and ignites the resulting dust cloud. This “secondary” explosion takes place in the workplace where often people are present, placing them in immediate danger. Secondary dust explosions can form a chain reaction that can run through a facility as long as fuel is present, leading to widespread devastation.

Dust explosions do not only occur in the plant where the phenolic resins are manufactured. Dust explosion hazards exist wherever fine dust is raised into a cloud with flammable concentrations, whether during production or at the end user of the material.

These Dust Explosion Guidelines aim to provide information on:

- Background to dust explosions;
- Brief overview of some reported incidents and key issues found in their investigation;
- Key data required for assessing dust explosion hazards;
- Safety measures for some specific unit operations.

2 BACKGROUND TO DUST EXPLOSIONS

2.1 Fire triangle and explosion pentagon

For a fire or explosion to occur, three elements must be present at the same time and place:

- A fuel (i.e. a flammable gas, vapour or dust),
- An oxidant,
- An ignition source.

These elements are often depicted in the so-called "fire triangle". In order to have an explosion, two more requirements must be fulfilled:

- The fuel and oxidant must be mixed in the right proportions,
- The mixture must be confined.

The extended fire triangle can be depicted as the "explosion pentagon".

Dust explosions are in many respects very similar to gas or vapour explosions. A special case is the “hybrid explosion”, when both a flammable dust and a gas/vapour are present. These guidelines will concentrate on dust explosions.

2.2 Fuel

Most dusts, if sufficiently fine and dry, will be capable of forming flammable dust clouds in air. The flammability of dusts, and hence the dust explosion risk, depends strongly on the particle size and moisture content.

Particle size

Particle size has a profound effect on reaction rate due to the surface area available for reaction: a reduction to 1/8th of the original particle size results in an 800 per cent increase in surface area. Experimental evidence suggests that particulate matter in excess of 500 µm is unlikely to contribute to flame propagation due to thermal inertia (heat sink) effects.

Just mentioning particle size is a simplification of the actual situation. Particle shape and surface structure are also important parameters that must be considered together with the particle size distribution. The influence of these parameters can explain why sometimes a powder with a larger (median) particle size shows a higher explosion severity and/or a higher ignition sensitivity than a finer dust. However, no simple correlations exist to allow for all these parameters.

Special problems with dusts can arise if fine dispersible powder is formed by natural attrition. When segregation occurs the fines (< 75 µm) remain in suspension and present a dust explosion risk, for considerable periods. Therefore the characteristics of dusts should be measured on material which is representative of plant conditions (i.e. the finest material handled within the specific process stream).

Moisture content

Moisture in dust reduces both ignition sensitivity and explosion violence; firstly by minimising dispersibility of the dust to form a cloud and secondly by absorbing heat during combustion.

Worst case conditions must be considered when identifying specific hazards in plant. This is usually the driest material handled under both normal and abnormal conditions.

It must not be assumed that sufficient water/moisture is present either within the dust itself or within the environment/atmosphere to render conditions non-flammable without confirmation (i.e. testing). High moisture contents can also lead to thermal instability in some materials and this needs to be considered when high moisture contents are possible.

2.3 Fuel concentration

Fuel air mixtures must lie within certain concentrations (i.e. within the flammable range) to give rise to an explosion risk. Wherever possible therefore, plant should be so designed to operate outside this range.

Lower flammability limits (also called Minimum Explosible Concentration for dusts) will vary with the type of fuel but a value of 15 - 50 $g.m^{-3}$ often applies.

The upper explosion limit can sometimes be used as a safety feature for gases and vapours. This is not recommended for dusts since specific values are difficult to determine due to non-uniformity and process atmospheres will pass through the flammable region as the dust loading/concentration changes (e.g. during start-up and shut-down periods). Dusts will rarely form a homogeneous suspension. In industrial situations therefore, control of dust atmosphere concentrations outside the flammable range is difficult to guarantee.

2.4 Oxidants

The oxidant in an explosion or fire is usually oxygen in the surrounding air. Whilst oxygen concentrations above 21 %v/v tend to enhance combustion, levels below 21 %v/v cause a decrease in ignition sensitivity and ultimately non-flammable conditions at the LOC (Limiting Oxygen Concentration) value, usually in the range 9 - 15 % by volume.

2.5 Ignition sources

The presence of a flammable atmosphere does not solely constitute a hazard. An ignition source that is sufficiently energetic to induce the combustion reaction is also required.

There are many potential sources of ignition, but it has proven possible to describe them in 13 different types of ignitions sources. Table 1 is based on information in European

Standard EN 1127-1 [1][1]. For dust explosions numbers 1 – 4, 6 and 13 are the most commonly identified ignition sources.

Table 1 Ignition sources according to EN 1127-1

Ignition source
1 - Hot surfaces
2 - Flames and hot gases (including hot particles)
3 - Mechanically generated sparks
4 - Electrical apparatus
5 - Stray electrical currents, cathodic corrosion protection
6 - Static electricity
7 - Lightning
8 - Radio frequency (RF) electromagnetic waves from 10^4 Hz to 3 x 10^{12} Hz
9 - Electromagnetic waves from 3 x 10^{11} Hz to 3 x 10^{15} Hz
10 - Ionising radiation
11 - Ultrasonics
12 - Adiabatic compression and shock waves
13 - Chemical reactions, including self-ignition of dusts

Potential sources of ignition should be formally assessed as part of the hazard assessment of process operations for both new plant design and modifications to existing equipment.

The incendivity of a potential ignition source depends on the spatial and temporal distribution of energy (i.e. size, location, temperature and exposure period).

2.6 Flash fires

A flash fire can be regarded as an unconfined explosion. These can occur external to plant and are localised in nature.

The effects of flash fires can be equally destructive as an explosion due to the secondary fire risk and potential for disturbance of powder layers leading to secondary explosions.

In addition to the plant/structural damage, the radiant energy from flash fires can cause severe burns to plant operatives in the vicinity. It is vital therefore to control the extent of airborne fuel at all opportunities. This is particularly relevant to dust emission points that involve loading or discharge operations i.e. where plant personnel are present.

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[1] References (indicated by numbers in square brackets) are listed in Section 6.

2.7 Explosion effects

Explosion pressures up to 9 bar g or even more are generated in explosions. Generally relatively weak plant is used and this will be insufficient in strength to prevent rupture in the event of an internal explosion.

Overpressures in weak plant give rise to serious secondary hazards such as fireball emission inside buildings, entrainment and re-ignition of powder (secondary dust explosions), secondary fires from deposits of burning material, noise/vibration/shock-waves, smoke and fume, missiles and other debris.

It is important to assess explosion effects in terms of their impact on neighbouring structures etc. Adequate explosion prevention, protection and isolation are essential to avoid catastrophic damage and "domino" effects. Especially "pressure piling" must be prevented since the explosion pressure is proportional to the initial pressure (although usually quoted as an overpressure, the explosion pressure is really a multiple of the initial pressure).

The speed of an explosion is often more important than the maximum pressure attained. The maximum rate of pressure rise is usually given as a measure of that speed. Because the rate of pressure rise is volume dependent, often a volume-independent constant, the K_{st} value, is used.

3 INCIDENTS

3.1 Statistics

There are no comprehensive statistics on dust explosions in industry, either nationally or internationally. One of the best sources of data available is based on reporting of incidents in Germany [2], which is estimated to cover only about 10% of the incidents that occurred over the reporting period (late 1960's to about 1995). Most of the about 600 incidents are included based on reports from the "Berufsgenossenschaften" (compulsory accident insurance bodies in Germany), as well as factory inspectors, which means that the data set will be biased towards incidents with personal injuries.

It is not reported how many of the incidents involved the various types of products, to avoid drawing unjustified conclusions regarding the relative hazard of different product types. However, it is estimated that about 13 – 15% are "plastics", which includes phenolic resins and similar products.

Within the "plastics" group, the equipment types most often involved in dust explosions are mixing installations (15.4%), grinding installations (13.8%), dust extraction and separation installations (13.8%), dryers (10.8%) and conveying installations (9.2%). The same types of installations tend to be involved in dust explosions in other industries, in so far as they are used there.

The most common ignition sources identified for "plastics" are electrostatic discharges (30.8%) and mechanical sparks and frictional heating (29.2%). Compared to other products, electrostatic discharges feature quite frequently for plastics, which is understandable considering the highly insulating nature of most products in this group.

3.2 Brief incident descriptions

The database yielding the above statistics contains some brief incident descriptions [3] that can give an insight into possible explosion scenarios.

- Doors that were coated in phenolic resin were being sanded in a workshop at the same time as tools were being sharpened. The sanding dust was wiped off using a cloth. Shaking the dust off the cloth created a small dust cloud that was ignited by mechanical sparks from the tool sharpening operation. The small explosion was followed by a violent secondary explosion from dust that was disturbed from beams and other surfaces. The secondary explosion engulfed the whole workshop and injured two people, causing large property damage.

- To prevent phenolic resin dust coating a grinder, nylon brushes were mounted that were pressed onto the grinder using spring forces. These brushes filled with dust that hardened over time, leading to frictional heating and the formation of smouldering (glowing) product. Sparks were transported by the pneumatic conveying system into a mixer where a dust cloud was ignited, leading to limited material damage.

- Three incidents occurred in a screw mixer in phenolic resin manufacture, ignited by electrostatic discharges. No injuries were reported, but each time there was property damage.

- In phenolic resin manufacture, material caked between the shaft and housing of a mixer. Frictional heating caused a smouldering (glowing) fire in the mixer. When a valve was operated below a mill, resin dust dropped into the mixer and was ignited. The resulting dust explosion vented through a hatch that was not secured into the workplace where an employee was injured.

- In a mixer for phenol-formaldehyde resin a fire started. Instead of extinguishing the fire, additional fine material was added with a scoop. A small explosion resulted, propagated into the dust extraction system where dust deposits were raised and ignited. That resulted in a severe explosion that the ducts as well as the cyclone downstream ruptured. This caused vibrations that shook dust off a large duct in a sieve room, leading to a typical secondary room explosion. Seven people were killed and two were injured.

- Phenol-formaldehyde resin was processed with fillers (here wood dust), dyes and other additives in small quantities. In a pre-mixer as well as the dust collector a severe dust explosion occurred, causing five fatalities and 17 injuries, as well as heavy damage to the building and other property. Iron parts were found in the mill, so it was assumed that frictional or impact sparks in the mill caused the ignition source for a primary explosion that in turn caused some secondary explosions.

3.3 Description of a significant explosion

A significant dust explosion at a phenolic resin user occurred in 2003 in the United States. Because of the consequences, seven workers were killed and 37 were injured, this incident was investigated extensively and the report that was subsequently published [4] contains many detailed observations and lessons.

The plant involved in the incident manufactured acoustic and thermal insulating materials using fibreglass and phenolic resin. The fibreglass was chopped, mixed and spread to create a web onto which phenolic resin was deposited. Air-suction dispersed the resin throughout the fibreglass to create a resin impregnated fibreglass mat. This mat was then cured in a direct-fired oven after thin plastic sheeting was applied to both sides of the mat.

The plant had a history of poor dust extraction and poor housekeeping. Several operating conditions would lead to the release of significant amounts of dust into the building. Improvements to the ventilation system were planned but not yet realised at the time of the explosion. To clean equipment, compressed air was used as well as other methods that lead to dispersion of dust, allowing it to settle on horizontal surfaces. During cleaning, fans would be used to blow the dust away from the operators, increasing the dispersion of the dust and allowing dust to settle on overhead surfaces. Twice a year the whole plant was shut down for cleaning; the last time before the incident was several months previously.

On the day of the incident, a routine cleaning of the production line was carried out while the oven remained in operation. It was discovered that a dust extraction duct was clogged by dust, and a compressed air lance was used to clear the blockage. As soon as the extraction was switched on again, an explosion occurred in the extraction system and the oven. Because the temperature control for the oven was defective, the temperature was controlled manually by opening and closing access doors on the oven. A fireball emerged from an oven access door. The pressure wave dispersed dust from elevated surfaces such as overhead roof joists, which was ignited by the fireball. This secondary dust explosion caused further fires and secondary dust explosions at other production lines.

As a result of the explosions, roof and wall panels were displaced or blown over. Fire walls were damaged, allowing the fires to propagate to non-production areas. Nearby homes and a primary school were evacuated and a section of an interstate highway was closed. As a consequence of this incident, the plant was effectively destroyed.

3.4 Key findings

The key issues identified during the investigation of the incident described in Section 3.3 are similar to those found in other investigations:

Hazard awareness
Although at least some managers were aware of the dust explosion potential of the phenolic resin handled, the company did not communicate this information to the employees.
Management did not consult appropriate standards and did not implement measures to prevent dust explosions in the facility.

Work practices
Maintenance procedures did not prevent the release of fine dust into the workplace. Housekeeping was inadequate to remove the dust and keep dust deposits to acceptable levels, especially on high level surfaces.
In addition, the tools and techniques used to remove dust, including metal tools, brooms, compressed air and fans, dispersed the dust in potentially explosive dust clouds and caused it to settle on elevated flat surfaces throughout the facility.

Inadequate investigation of incidents
In the above case, fires occurred in the oven several times a year, but these were not adequately investigated to identify (and remedy) root causes. Fires in equipment can be potential ignition sources for dust explosions, but they can also be “near misses”, i.e. incidents that under slightly different circumstances could have developed into a dust explosion.

Building design
The original building and subsequent modifications did not effectively address dust explosion hazards. Examples are the failure to avoid flat surfaces where dust can accumulate and failure to provide measures to prevent the spread of explosions.

Hazard communication
It was also identified that the supplier of the phenolic resin had not explicitly communicated that the dust posed a dust explosion hazard, although the MSDS noted that phenolic resin was a combustible dust.

4 ASSESSING DUST EXPLOSION HAZARDS

4.1 General

To ensure that a process is carried out safely, all potential hazards need to be assessed and measures must be implemented to control those hazards. In these guidelines only dust explosion hazards are considered, but in practice the hazard assessment is not limited to one hazard. While carrying out a hazard assessment is always good practice and is often legally required under general safety legislation, it is also explicitly required under ATEX (Directive 1999/92/EC) as will be discussed in Section 4.2.

In order to establish whether dust explosion hazards are present in a plant or operation, it is necessary to know whether the materials handled are “flammable”. A dust is flammable when it is possible to create an explosion using the finest and driest material that could possibly be present. It must be noted that some combustible materials in a solid form, or as a pile of dust, will not burn easily or even at all, but could still give a dust explosion when fine dust is dispersed in air and ignited.

The majority of solid materials that have ever been subjected to testing turned out to be flammable, and phenolic resin and many of the other materials handled in conjunction with phenolic resins are among those dusts.

Once it has been established that a flammable solid is involved, it must be assessed whether that material could be in the form of a fine dust and whether that dust could be raised into a dust of sufficient density, or create a flammable or explosive atmosphere. It is important to consider normal operating conditions as well as abnormal occurrences, including start, stop and malfunction conditions.

Once it is determined that an explosive atmosphere could be present, all that is needed for an explosion or a flash fire is a suitable ignition source. Clearly, some materials will require a smaller ignition source than others, but in most cases a suitable ignition source would be expected at some time.

The likelihood of a dust explosion and the possible consequences must be considered when deciding on a suitable “Basis of Safety” for the operation. The “Basis of Safety” of an operation describes how the safety of the plant and personnel has been safeguarded. Bases of Safety can be divided in “preventive” (preventing the occurrence of an explosive atmosphere; or prevention of ignition sources) and “protective” (provision of protective measures: explosion containment, explosion pressure relief venting or explosion suppression). Even when protective measures provide the ultimate Basis of Safety, preventive measures must be implemented to reduce the frequency of incidents.

The above description of hazard assessment uses only qualitative information, and in fact this is often suitable for the first step. However, to design measures for specific plant, quantitative data are often required. These will be introduced in Section 4.3.

4.2 ATEX

In Europe, the “ATEX Directives” have been implemented in the national legislation of all EU Member States to cover “explosive atmospheres”[2], which are explosive mixtures in air under normal atmospheric conditions, whether formed with a flammable gas, vapour, dust or mist. One ATEX Directive, Directive 94/9/EC [5], is aimed at the manufacturers of equipment[3] intended to be used in potentially explosive atmospheres. As such it is of limited importance to end users of equipment, except for the fact that under certain circumstances they need to use equipment that complies with that Directive (see below).

The other ATEX Directive (1999/92/EC) [6] is concerned with safety in the workplace and is therefore directly relevant for manufacturers and users of phenolic resins and similar products within the European Union.

The ATEX Directive requires in Article 3 that to protect the safety of workers, the following measures are taken:

“… the employer shall take technical and/or organisational measures appropriate to the nature of the operation, in order of priority and in accordance with the following basic principles:

- *the prevention of the formation of explosive atmospheres,*

or where the nature of the activity does not allow that,

- *the avoidance of the ignition of explosive atmospheres, and*
- *the mitigation of the detrimental effects of an explosion so as to ensure the health and safety of workers.*

These measures shall where necessary be combined and/or supplemented with measures against the propagation of explosions and shall be reviewed regularly and, in any event, whenever significant changes occur.”

Article 4 of the ATEX Directive stipulates that the measures must be based on a risk assessment:

“1. … the employer shall assess the specific risks arising from explosive atmospheres, taking account of at least of:

- *the likelihood that explosive atmospheres will occur and their persistence,*
- *the likelihood that ignition sources, including electrostatic discharges, will be present and become active and become active and effective,*
- *the installations, substances used, processes, and their possible interactions,*
- *the scale of the anticipated effects.*

Explosion effects shall be assessed overall.

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[2] “ATEX” stands for “atmosphères explosives”, French for explosive atmospheres.

[3] Directive 94/9/EC concerns both equipment and protective systems that are intended to be used in potentially explosive atmospheres. “Equipment” as defined in the Directive is limited to equipment that has its own potential source of ignition and excludes therefore many items that would commonly be described as equipment.

2. Places which are or can be connected via openings to places in which explosive atmospheres may occur shall be taken into account in assessing explosion risks."

The ATEX Directive requires that the results of the risk assessment are documented in a so-called Explosion Protection Document.

The approach taken in the ATEX Directive (base measures on a risk assessment, prevention is first line of defence, document the risk assessment) is common to a number of similar "safety in the workplace" Directives. In fact, when an explosive mixture falls outside the definitions of ATEX, for example because the temperature is well above ambient, other Directives[4] demand the same approach to be taken to ensuring safety in the workplace, even if some specific requirements do not apply.

One of the specific requirements in the ATEX Directive that apply wherever potentially explosive atmospheres can occur, is that the area must be classified into hazardous and non-hazardous areas. Non-hazardous in this case does not necessarily mean that no explosion hazard exists, but that the extent of any explosive atmosphere is such that it does not require special measures to protect the workers. Hazardous areas are then classified in terms of "Zones" on the basis of the frequency and duration of the occurrence of an explosive atmosphere, as follows:

- ***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.
- ***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.
- ***Zone 22***
  A place in which an 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 occur, will persist for a short period only.

Notes:
1. Layers, deposits and heaps of combustible dust must be considered as any other source which can form an explosive atmosphere.
2. 'Normal operation' means the situation when installations are used within their design parameters.

The definitions of Zone 20, 21 and 22 mirror the definitions for Zone 0, 1 and 2 for flammable gases and vapours.

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[4] For example the "Chemical Agents Directive" or CAD [7].

Once the hazardous areas have been assigned, any “equipment” that is to be used in the various zones must generally[5] be “ATEX compliant” (comply with Directive 94/9/EC), as follows

- *in zone 0 or zone 20, category 1 equipment,*
- *in zone 1 or zone 21, category 1 or 2 equipment,*
- *in zone 2 or zone 22, category 1, 2 or 3 equipment.*

In addition all equipment must be suitable for the specific fuel, for example have the correct temperature rating.

As there is insufficient room in these guidelines to include a comprehensive explanation of all ATEX requirements, reference is made to National Legislation for the legal requirements in the jurisdiction of the reader. The European Commission has published a non-binding Guide of Good Practice for implementing Directive 1999/92/EC [8]. This is a general and fairly basic guide.

Many European Standards have been prepared to assist equipment manufacturers in complying with Directive 94/9/EC. Some of those are also relevant for users of the equipment in the context of Directive 1999/92/EC. An example is the European Standard for hazardous area classification of flammable dusts [9].

4.3 Flammability characteristics

Table 2 below presents the full range of properties that may be required in the course of a risk assessment or during the specification of preventive or protective measures.

The data in Table 2 have been taken from the GESTIS-DUST-EX database ([10], these data have also been published in [11]) that contains data for over 4,000 samples, approximately 40 of which are in some way identified as “phenolic resin”. The data in the table have been included to show the range of values that can be found in practice. However, because the data depend strongly on the particle size (distribution), particle shape, moisture content, chemical composition of the material and any contamination present, it is possible that other values are found for another dust with the same nominal description.

All characteristics are determined by testing a sample of the material under consideration, using standardised test methods and interpretation. While this allows the values to be compared between materials, it does mean that often further interpretation is needed before the data can be applied to a practical situation. Such interpretation usually requires the input from specialists. Briefly, the various parameters have the following meaning:

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[5] Compliance with Directive 94/9/EC is compulsory for equipment for use in places where explosive atmospheres may occur, which is made available in the plant for the first time after 30 June 2003. Equipment that was already in use, or was made available for the first time before 30 June 2003 shall comply with a set of minimum requirements listed in Directive 1999/92/EC, but does not have to be ATEX compliant.

Table 2 Properties of flammable powders

Classification of data	Ignition sensitivity			Explosion severity		Electrostatic properties		Thermal decomposition	Burning behaviour	Limits	
Test parameters	Layer ignition temp. (LIT) °C	Minimum ignition temp. (MIT) °C	Minimum ignition energy (MIE) mJ	20 litre sphere P_{max} bar g	K_{st} (St class) bar m s^{-1}	Resistivity (low RH) ohm m	Charge relaxation time (low RH) hours	Onset temp. °C	BZ number	Minimum explosible conc. (MEC) g m^{-3}	Limiting oxygen conc. (LOC) $\%^v/_v$
Material											
Phenolic resin	> 450	530		9.6	198					15	
Phenolic resin	> 450	610		9.4	156				2	30	
Phenolic resin	> 450	610		9.3	129				2	15	
Phenolic resin					(St 2)				2 (2)	30	
Phenolic resin	> 450	520		9.8	168					30	
Phenolic resin				8.7	185				2	30	
Phenolic resin					St 1				3	30	
Phenolic resin			3 – 5 2 – 7 (n.i.)								
Phenolic resin		500 (BAM)	< 10 < 10 (n.i.)		St 1				2 (2)	30	
Phenolic resin (core material)		540 (BAM)	< 10 < 10 (n.i.)	8.9	218				2	30	
Phenolic resin foam	280	460		9.3	73						
Phenolic resin foam, cutting and saw dust					St 1				3	30	
Phenolic resin foam, ground					St 1				2	15	
Phenolic resin hard foam, cutter					St 1				3	100	
Phenolic resin hard foam, saw					St 1				3	100	
Phenolic resin processing			7 - 13								
Phenolic resin, modified	melts	650		8.9	140				2	30	
Phenolic resin, modified with natural resin	melts	450		9.5	172				2 (5)	15	
Phenolic resin, with additives				8.4	142					30	

Ignition sensitivity

Three parameters are commonly used to describe how sensitive a dust is to ignition. Unfortunately, these parameters are independent and it is not possible to predict one value from information on the others.

For ignition by hot surfaces, ignition can either ignite the dust cloud directly (for which the **MIT,** Minimum Ignition Temperature of the Dust Cloud, is the relevant parameter) or via the ignition of a dust layer (**LIT,** Minimum Ignition Temperature of a Dust Layer). Note that ignition of a layer does not have to result in a fire with an open flame before a dust cloud can be ignited. Two values for the MIT in the table were determined using an apparatus that differs from the European Standard one. This so-called “BAM furnace” tends to yield lower values than the standard apparatus; in these cases by about 40 K. LIT tests are only conducted up to about 400 °C. If no ignition occurs this is marked with a “greater than” sign. If a dust melts before it ignites there is no dust layer to ignite and that is reported instead.
To ensure that dust explosions cannot be ignited by hot surfaces, all surface temperatures must be limited based on MIT and, if deposits are possible, also LIT.

For ignition by electrical and electrostatic sparks, the **MIE** (Minimum Ignition Energy) is important, as this is the smallest spark energy that is just able to ignite the dust cloud in the tests. For electrostatics the values marked “n.i.” (for “no inductance”) are relevant: those values have been determined using a purely capacitive discharge circuit. The other values were obtained with an optimised discharge circuit that often results in lower MIE values, but those are not relevant for electrostatics. Because of the way the MIE tests are carried out, the results are usually quoted as a range: the lower energy level did not ignite the dust cloud in the tests and the upper energy level was the lowest energy that resulted in an ignition in the tests.

Other types of ignition sources can be assessed using the same three characteristics. For example, mechanical sparks can be assessed using both MIE (with inductance) and MIT data.

Explosion severity

The explosion severity is characterised by the pressure increase and the dust explosion constant of the worst-case explosion in a closed vessel. The maximum explosion overpressure P_{max} is independent of the test volume and is also similar for virtually all dusts (in the range between 8 – 10 bar g). The dust explosion constant K_{st} is the rate of pressure rise of the explosion, normalised to a 1 m^3 volume.

Often dusts are divided in “dust explosion classes” or “St classes” based on the K_{st} value. “St 1” covers the range of K_{st} between 0 and 200, “St 2” between 200 and 300 and “St 3” K_{st} values above 300. While this can be convenient when designing explosion protection measures for equipment, a lower St class does not necessarily indicate a lower level of hazard. In fact, the most devastating dust explosions have occurred with dusts in the lower ranges of the St 1 class.

Designing explosion protection measures requires knowledge of the explosion severity data. Explosion relief venting and explosion suppression require both P_{max} and K_{st}, while for explosion containment only P_{max} is needed. Explosion protection is by its very nature only suitable for closed process equipment. Occasionally such measures are also taken on process buildings to prevent more extensive damage, but since this does not protect the people in the plant, such measures are only appropriate for unmanned areas.

Electrostatic properties

Many materials are highly insulating and will therefore readily charge when handled. Once charged, they will retain their charge for long periods, even when in contact with "earth". The **Powder Volume Resistivity** and the **Charge Relaxation Time** are used to characterise the electrostatic properties of powders. Unfortunately these properties are not commonly reported in the open literature, while they can be essential for a detailed electrostatic hazard assessment.

Thermal decomposition

Many materials are thermally unstable and can self-heat or decompose exothermally. This can happen in storage, especially long-term storage or storage at elevated temperatures, as well as in driers. The "**Onset Temperature**" describes the critical temperature that could lead to ignition. Unfortunately, there is no unique onset temperature, since it depends on such factors as the scale, the temperature, the duration and the air availability. Small scale and rapid testing is usually unable to determine a meaningful value for the onset temperature.

Since thermal stability can cause an ignition without an apparent outside cause, it is very important to be aware of potential thermal stability issues and to ensure that any tests are carried out in a manner that is appropriate to the specific conditions being studied.

Burning behaviour

The burning behaviour of dust deposits can determine whether an initial ignition in a dust layer will propagate throughout the equipment or the plant, or be confined to the area of origin. The "**BZ**" parameter (from the German Brenn-Zahl), also called CC (Combustibility Class) describes the results of standardised testing, with the results ranging from BZ = 1 (meaning no ignition) to BZ = 6 (very rapid spread of an open fire). BZ = 2 means that the dust catches fire briefly and then extinguishes, BZ =3 indicates local burning or glowing without spreading the fire and BZ = 5 means spread of an open fire. A value between brackets in the table indicates a modified test for melting materials where the sample was mixed with 20% kieselgur (diatomaceous earth).

Limits

Two types of limits are usually reported for dusts. The **MEC** (Minimum Explosible Concentration) is similar to the Lower Explosion Limit for gases and vapours. However, the exact value for the MEC is not often used in plant design because dust clouds are inherently inhomogeneous. Although dust clouds will have an Upper Explosion Limit, in practice this parameter is not determined because it would be even less useful than the MEC.

The **LOC** (Limiting Oxygen Concentration) is used to establish a safe level for the oxygen content when explosion prevention is based on the exclusion of the oxygen from the atmosphere. This “inerting” can only be applied to closed vessels and the asphyxiation hazard for personnel must be carefully handled since LOC values are far below safe levels for humans.

4.4 Material Safety Data Sheets

The fact that a material poses a dust explosion hazard does not result in the classification of that material as hazardous under the classification and labelling regulations. Consequently, the standard categories on a Material Safety Data Sheet (MSDS) do not apply. Nevertheless, it is good practice to mention dust explosion hazards under “other hazards” (Section 2.3 in the standard MSDS lay-out), and this will be required under REACH [12][6].

There are no standard clauses for dust explosion hazards to use in an MSDS, and no prescribed set of data that should be included. Consequently, most MSDS will include a general statement that the material, as a fine powder, may present a dust explosion hazard when dispersed in air.

It would be useful for the user to have specific flammability data for the material, but the presentation of such data must be carefully considered in view of the fact that particle properties (particle size, etc) of the as-received material may be different from the material as tested and packaged. And once the material is handled on the customer’s site, particle properties and thus flammability data may change again.

4.5 Properties of phenolic resin

It has been indicated that the properties of flammable dusts depend strongly on a number of variables, and it is therefore essential that reliable data are obtained specific to the material being handled before any explosion prevention and protection measures are designed.

This is even more important when a mixture of dusts needs to be considered since the properties of a mixture are a blend of the data for the individual components. Normally the data for a mixture are in between those for the components. As a rule of thumb one can assume that when mixing two different dusts, the more sensitive or violent has a larger effect on the result than is to be expected based on the weight ratios.

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[6] At the time of preparation of these Guidelines, this was included in a proposed new version of Annex II to the REACH Regulations.

While the importance of obtaining reliable data cannot be overstated, the data in the table above provide an indication of the range of values that could be expected and as preliminary values one could assume:

- For explosion severity: P_{max} = 10 bar g and K_{st} up to 220 bar.m.s^{-1}
- For spark ignition sensitivity: MIE > 2 mJ
- For sensitivity to ignition by hot surfaces: MIT = 450 °C and LIT = 250 °C
- For explosion limits: MEC = 15 g.m^{-3}
- For burning behaviour: BZ = 3

The values mentioned do not yet take into account any safety factors that should be applied when using these data.

Of the above values, especially the spark ignition sensitivity stands out as high (i.e. MIE is low) compared to most other dusts. Approximately 60% of all dusts that have been tested over the years fall in Dust Explosion Class St 1 (K_{st} up to 200 bar.m.s^{-1}), which puts phenolic resin in the “explosion severity possibly higher than average” category.

5 UNIT OPERATIONS

5.1 General

When assessing the dust explosion hazards in a plant, it is common and useful to divide the plant into different unit operations that can be assessed individually. However, in most plants these operations are interlinked and that must be taken into account in the assessment. For example, an ignition source may be produced in one part of the plant where no explosive atmosphere exists, but it may then be conveyed to another part of the plant where there is an explosive atmosphere, leading to an explosion there. This explosion may then propagate through connecting ductwork to other equipment where the potential for dust explosions may not have been recognised.

When assessing various unit operations, and when deciding on an appropriate Basis of Safety for that operation, it is imperative that the assessment and Basis of Safety are appropriate to the specific operation. General information as presented in this section can provide useful guidance, but cannot take into account the details of each and every process plant.

This section will present guidance on some unit operations, but the fact that certain unit operations are not included does not imply that no dust explosion hazards exist or that no preventive and/or protective measures are required. Each section will briefly describe the hazards in the operation and then describe the most important and common safety measures.

Certain measures have to be taken throughout any plant handling flammable dusts, which will not be repeated for each unit operation. These include:

- The need for adequate training, operating and maintenance procedures, and emergency procedures as required under the ATEX Directive.

- Adequate control measures to prevent the occurrence of ignition sources such as flames, sparks and hot surfaces as the result of work, including “Hot Work”, using inappropriate equipment, smoking, etc.

- Thorough earthing and bonding of all conducting objects, including all metal objects as well as personnel. An MIE value of 2 mJ implies that even small objects, when charged electrostatically, can produce incendive sparks for phenolic resin dust clouds.

- The avoidance of the use of insulating (non-conducting) materials, since they can isolate conductors and so create a spark hazard.

- Using appropriately “ATEX compliant” equipment in all hazardous areas identified in a plant.

5.2 Housekeeping

Housekeeping plays a vital role in maintaining a safe plant. Preventing the presence of flammable dust in areas where it is not needed for the process, removes the main component needed for dust fires and explosions. In addition, removing the fuel is in accordance with the priorities set by the ATEX Directive for ensuring the safety of workers.

Poor housekeeping is primarily a concern[7] because dust deposits can provide the fuel for secondary dust explosions, which, as the incident descriptions have shown, are more devastating than most primary explosions. In addition, poor housekeeping can lead to equipment malfunction because of dust ingress into equipment.

A very good level of housekeeping is required to prevent secondary dust explosions. As soon as a dust layer obscures the colour of a surface, there is likely enough dust for a significant explosive atmosphere: a 1 mm thick layer of dust of an average powder bulk density of 500 $kg.m^{-3}$ will weigh 0.5 kg for every square metre of floor area. That is enough dust to create a 5 m high dust cloud with an average dust concentration of 100 $g.m^{-3}$ while the MEC of phenolic resin is only 15 $g.m^{-3}$.

While the hazards of poor housekeeping are clear, the housekeeping operations can also create hazards to personnel. When the operations create explosive dust clouds (typically so dense that it would be difficult to see through them and therefore much higher than acceptable occupational levels), the conditions are created that housekeeping was supposed to prevent. If an ignition source is present at the same time, then operators would be exposed to the fireball of the igniting dust cloud. It must be realised that most injuries and fatalities in dust explosions are caused by burns, and not by the overpressure effects of an explosion. Thus, the fact that during housekeeping the initial incident is more likely a fireball (without pressure effects) than an explosion, and may be of limited extent, is no mitigating factor when considering the safety of employees involved in the operation.

Based on the above it will be clear that housekeeping operations should avoid the generation of dust clouds. This means that using compressed air for cleaning is an unacceptable practice. It is equally undesirable to use brooms to sweep dust of high surfaces. Instead, suitable vacuum cleaners (mobile units or central vacuum cleaning systems) are preferred for dust cleaning operations.

Even more important than good housekeeping is the prevention of the dust release in the first place. This means that operations should wherever possible take place in closed systems, adequate dust extraction should be provided to capture dust before it can spread in the workplace, and maintenance should be of a high standard to ensure the equipment does not leak and that leaks are promptly repaired in a safe manner.

The building lay-out also has a significant influence on the required housekeeping efforts. Avoiding ledges and other surfaces where dust can accumulate, especially in inaccessible

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[7] This guidance is only concerned about dust fires and dust explosions. Considerations such as environmental damage, occupational hygiene and loss of product are outside the scope of this document.

locations, will reduce the amount of dust that needs to be removed by housekeeping. Dust that can enter voids such as above suspended ceilings will be especially difficult to detect and remove.

An activity that is related to housekeeping is the removal of blockages in equipment. Similar practices need to be applied as during housekeeping in the workplace. However, special procedures may have to be prepared, especially if the equipment cannot be totally shut down during the cleanup operation.

One common occurrence following repairs and blockage removal is that product removed from the equipment is left on the floor. This is bad practice and the workplace should be cleaned before normal operations resume.

5.3 Grinding of resins

Grinding resins is a common operation, both at manufacturers and end users of phenolic resins. Grinding applies considerable energy to the equipment and the product, and this can lead to the formation of ignition sources. In combination with the fact that the grinding operation both creates fine material and often disperses this in air, all the necessary ingredients for a dust explosion would appear to be present. As a consequence it is usually deemed necessary to provide grinding installations with some form of explosion protection in addition to the preventive measures. The details of any measures, and their priority, depend on the type of grinding installation used.

One aspect to be aware of is that in many grinding installations a high level of turbulence is present. While high turbulence will increase the violence of any dust explosion that might occur in the equipment, it actually makes it more difficult to ignite the mixture. Therefore it is not uncommon to find that an ignition source is generated in the grinder, but only becomes effective in downstream equipment where a lower level of turbulence is found, such as a receiving hopper or a dust collector. This needs to be taken into account when assessing the hazards in a grinding installation and in the design of protective measures.

5.4 Dust extraction and collection installations

Dust extraction and collection installations, here called dust extraction for simplicity, are very common in plant handling flammable dusts. Since the purpose of dust extraction is to collect the fine dust, ideal conditions for a dust explosion exist in the installation. In most cases the dust concentration inside an extraction system would be far below the MEC when calculated as the ratio between the extracted dust quantities and the air flow. However, in certain parts such as dust collectors the dust is accumulated and, whenever the filter elements are cleaned, the dust is dispersed in the equipment. Therefore the presence of explosive atmospheres is to be expected locally in normal operation, and in other locations they may occur in abnormal conditions.

Ignition sources may arise inside the dust extraction system, as well as being introduced from one of the extraction points. Because of the conditions encountered in dust extraction systems, most types will need explosion protection measures installed in addition to preventive measures.

Because dust extraction systems by their nature are connected to other equipment and work areas, any explosion inside the system can propagate to other (often multiple) locations. Therefore it is imperative that effective explosion isolation measures are incorporated in the connecting ductwork. It must be noted that measures to prevent explosion propagation are an explicit requirement in the ATEX Directive.

Many dust extraction systems are operated in non-ideal modes, either because of deficiencies in the original design or because of changes to the system or to the extracted plant. This may lead to inefficient capturing of dust (leading to release in the workplace, see Section 5.2) or to dust accumulations in the ductwork. Dust deposits in ducts can easily be raised into a cloud due to disturbances and this may create explosive conditions in large parts of the system where this would otherwise not be expected. This could lead to explosions in the ducts that are not protected by the aforementioned explosion isolation measures, with increased hazards to personnel and plant as a result. It is therefore important that any dust extraction system is well designed and operated, including balancing the air flows and air speeds in the system.

5.5 Transfer to blending/filling stations

A number of options exist for transferring phenolic resins from one area of the plant to another, for example blending or filling operations. Depending on the lay-out of the plant, gravity transfer can be used, but in many cases pneumatic conveying is used. Inside pneumatic conveying installations, explosive atmospheres must be expected. A simple calculation of the average concentration by dividing the mass flow by the air flow will not give a reliable prediction of the actual conditions. For example, even conveying systems designed to operate at high concentrations will experience explosive atmospheres during start-up, shut-down and in areas where the product is fed into the air stream and where the product is separated from the conveying air.

Most pneumatic conveying systems are fairly strongly built, so an ignition inside the system will not immediately cause great damage in many cases. However, an explosion in an associated vessel such as a blender or surge hopper can have more severe consequences. Similar to grinding installations (see Section 5.3) an ignition in the pneumatic conveying line will often be transported to downstream vessels before developing into an explosion because the conditions are often more favourable there.

The high particle velocities in a pneumatic conveying system make them ideal generators for static electricity, leading to charge densities on the product easily 1000 times higher than in the case of pouring or sieving. This means that the potential for static ignition sources is particularly high in, or downstream of, pneumatic conveying systems. For example, the high charge levels on very insulating particles will lead to cone discharges if the product is accumulating in a hopper. The larger the hopper and the larger the particle size, the higher the cone discharge energy will be. Propagating brush discharges can arise wherever an insulating coating on the (earthed) metal equipment wall becomes highly charged by friction from the phenolic resin particles. In rare cases the coating could even be made up of the product, although a layer of resin particles would not have the necessary high breakdown voltage. Of course, any isolated conducting part of the equipment will become highly charged by contact with the resin particles (or even without contact by induction).

Whenever pneumatic conveying is selected for transfer of phenolic resin from one part of the plant to another, a careful risk assessment has to be carried out to ensure that the combination of process parameters and product characteristics can safely handled in the plant. For example, the cone discharge hazard may put a limit on the size (diameter) of any receiving vessels. This limit may be smaller for larger particles (because of the higher cone discharge energy for larger particles) to ensure that the maximum cone discharge energy is lower than the MIE of the fines that are invariably part of the product. If that limit cannot be met, the only alternative may be inerting of the pneumatic conveying system and the receiving vessel. After all, explosion protection is only a feasible option if an explosion will be a rare event, not when the potential static discharge energy exceeds the MIE in normal operation.

5.6 Blending operations

There are many different types of blenders in industry. Some have internal moving parts, which can cause “mechanical” ignition sources in case of malfunction or when other objects such as “tramp” metal is caught between the blender arm and the blender wall. High speed blenders pose a greater ignition hazard from such sources.

When assessing the hazards in blending operations, it is important to consider the properties of all materials involved in the blending, whether phenolic resins with different particle sizes or a mixture of phenolic resin with other materials (see also Section 5.10). As a rule of thumb, the flammability characteristics of a mixture will be between those of the constituent components. However, typically the “worse” material will dominate; for example in a 50:50 blend the MIE will be lower than the average of the MIEs of the components and the K_{st} will be higher than the average of the individual K_{st} values. It is therefore safer to assume that the flammability characteristics of the blend are the worst values of the components, unless specific testing has shown otherwise. Of course the risk assessment must consider the possibility that an explosive atmosphere could be formed with just one material, e.g. during filling.

In operation, most blenders are essentially closed systems. In those cases, the actual blending process may have a different Basis of Safety than the filling and emptying stages. For example, it may be possible to avoid the most obvious ignition sources during filling and emptying by stopping the blender or running it very slowly; and maintain a very high dust concentration (over-rich atmosphere) during the actual blending phase. However, decisions about such Bases of Safety must be based on a through hazard and risk assessment, including the potential failure of control systems and human error.

5.7 Description of big bag types A – D

Big bags (Flexible Intermediate Bulk Containers or FIBCs) are convenient containers for intermediate storage as well as for shipping granules and powders. Because the standard big bag is made of non-conducting materials, typically polypropylene fabric or similar strong and heavy duty material, it poses electrostatic hazards both from the bag itself and from the contents, which will not be easily earthed like they would be in a metal container.

During filling and emptying, electrostatic charge will be generated on the fabric as well as on the product. Depending on the characteristics of the bag and the product, many different types of electrostatic discharge can be generated: spark discharges, brush discharges, cone discharges and propagating brush discharges. Such discharges may be incendive for explosive atmospheres in the bag, in connected equipment (such as a vessel into which the bag contents are dropped) or in the vicinity of the bag.

By their nature big bags are moved around a lot and may therefore be exposed to explosive atmospheres other than from the product in the bag. This is something that must always be considered as part of the hazard and risk assessment, but this is especially so with big bags because of the kind of applications found in industry. This has led to the development of a number of different types of big bags, nowadays identified as FIBC Type A – D. Only by selecting the correct choice of big bag and adhering to the conditions for its safe use can one ensure a safe operation. The type of FIBC only addresses the electrostatic ignition hazards. Consequently the risk assessment must still consider all other potential ignition sources, as well as the presence of explosive atmospheres.

The various FIBC Types are described below, where only the main characteristics are mentioned. When considering the FIBC Type, the complete system must be considered, including any coatings applied to the bag or liners placed inside the bag. None of the FIBC Types prevents the occurrence of cone discharges, as this is a phenomenon of the bulk product, not the container.

FIBC Type A: This a standard big bag made from non-conductive fabric without any measures to reduce the build-up of static.
Unless a big bag is specifically designated as Type B, C or D, it must be assumed that that bag is Type A.
This bag is only suitable for use in areas without any explosive atmospheres.

FIBC Type B: This bag is still made from non-conductive fabric, but the breakdown voltage is lower than 4 kV to avoid propagating brush discharges.
Because propagating brush discharges have been eliminated, this bag can be used as long as no flammable gases/vapours and no very sensitive dusts are present. In order to prevent spark discharges, the surface of the bag must not be contaminated or coated with a conducting material (e.g. water, oil or grease).

FIBC Type C: Also called “conductive FIBC”, this bag is either made from totally conductive fabric, or a non-conductive fabric contains a web of interconnected threads or filaments.

Due to the construction of the bag, incendive brush and propagating brush discharges will not occur. However, in order to prevent powerful spark discharges, the bag must always be earthed in use.

FIBC Type D: This type of bag removes the electrostatic charge by low energy corona discharges, usually by having conducting threads in the non-conducting fabric which are not interconnected. The performance of FIBC Type D cannot be simply assessed by measuring simple physical parameters, so it must be demonstrated that they are safe for use in an explosive atmosphere.
Earthing of this type of bag has only a minor effect on the charge dissipation and is therefore not required. In order to prevent spark discharges, the surface of the bag must not be contaminated or coated with a conducting material (e.g. water, oil or grease).

More details on the requirements for the various FIBC Types and their application can be found in CLC/TR 50404 [13], from which also the following table is taken, summarising the use of the different FIBC Types.

Table 3 Use of the different types of FIBC [13]

Bulk Product	**Surroundings**		
MIE of dust	**Non flammable atmosphere**	**Explosive dust atmosphere**	**Explosive gas and vapour atmosphere (group IIA or IIB)**
MIE > 1000 mJ	A, B, C, D	B, C, D	C, D
1000 mJ > MIE > 3 mJ	B, C, D	B, C, D	C, D
3 mJ > MIE	C, D	C, D	C, D

5.8 Filling of bags

Bag filling is a common operation, with bag sizes ranging from fairly small to big bags (FIBCs). For the latter, important information is contained in Section 5.7. Filling operations range from slow, manually controlled operations to fully automatic high-speed filling lines.

During filling, phenolic resin particles flow into the bag and fine particles will create a dust cloud in the void of the bag. Depending on the particle size of the phenolic resin, the dust cloud will be more or less dense, but it must generally be assumed that an explosive atmosphere is formed.

Given the non-conducting nature of phenolic resins, electrostatic charging of the material must be expected, especially where the flow rates are high. However, bag filling is typically a slower process than discharging of bags, so the electrostatic hazards would be expected to be less in filling than in discharging. Nevertheless, it is essential that, along with the other potential ignition sources, electrostatic hazards are properly controlled. This includes, for example, earthing of any bags that are conducting or static dissipative. On the other hand, if the bag is non-conducting, it is likely that the charged contents will create an electrostatic field around the bag, which would lead to charging of any conducting object in the vicinity that is not adequately earthed, creating a spark discharge hazard in the area. Earthing and bonding of all conducting object, including personnel, in the area is therefore of the utmost importance.

When filling bags, the bags are usually the weakest part of the equipment, and occasionally it must be expected that a bag will tear or will come loose from the filling nozzle. In that case a significant dust cloud would be released into the workplace. Effective LEV (local extraction ventilation) must capture as much as possible of this release. Any dust that is not captured immediately must be cleared up before hazardous dust deposits arise (see also Section 5.2).

5.9 Discharging of bags

At first sight, discharging bags would seem to be similar to filling bags, and one could expect that also the hazards are similar. This is, however, far from true.

Firstly, discharging bags often takes place at higher flow rates than filling them, which will lead to more charge generation on the phenolic resin particles. In addition, more of the charging will happen because of contact with the bag walls, instead of earthed metal plant items. Charge levels on the bag are therefore often higher. In addition, the receiving vessel is often significantly larger than the bag, so that explosive dust atmospheres that are formed will also be larger. And finally, if the phenolic resin is added to a process vessel, different explosive atmospheres may exist inside and around the process vessel (and hence the bag) than just the phenolic resin dust cloud.

When discharging a bag at a high flow rate it is also more difficult to contain the dust cloud to the inside of the receiving vessel and the bag. To prevent releasing dust into the workplace, special attention must be paid to sealing the connection between bag and equipment, and to the dust extraction.

The above effects are very noticeable when discharging big bags directly into vessels. In fact, because of the combination of high electrostatic charge generation and dust cloud formation, there is a history of incidents during this kind of process. Even selecting the correct type of bag (see Section 5.7) may not be sufficient to guarantee a safe process as it is essentially a “fail to danger” (instead of “fail safe”) situation, especially if flammable vapours or gases are present.

A careful hazard and risk assessment must take into account the specifics of the process and materials before a Basis of Safety is selected for the bag discharging operation.

5.10 Use of powder resins in production lines

Many of the observations in the previous sections (5.1 - 5.9) are also valid when phenolic resin powders are used in production lines. One difference is that other materials are also used, e.g. Novolak and Hexamethylene Tetramine. The following table compares literature data for these materials with the values for phenolic resin recommended in Section 4.5 to use as preliminary data until specific test data are available.

As before, the literature data have been taken from the GESTIS-DUST-EX database [10] and the data in the table have been included to show the range of values that can be found in practice. However, because the data depend strongly on the particle size (distribution), particle shape, moisture content, chemical composition of the material and any contamination present, it is possible that other values are found for another dust with the same nominal description. Obtaining proper data for the actual materials being used is always preferable over using generic data.

Table 4 Properties of Novolak and Hexamethylene Tetramine compared to phenolic resin

Classification of data	Ignition sensitivity			Explosion severity		Electrostatic properties		Thermal decomp-osition	Burning behav-iour	Limits	
Test parameters	Layer ignition temp. (LIT) °C	Minimum ignition temp. (MIT) °C	Minimum ignition energy (MIE) mJ	20 litre sphere P_{max} bar g	K_{st} (St class) bar m s^{-1}	Resistivity (low RH) ohm m	Charge relaxation time (low RH) hours	Onset temp. °C	BZ number	Minimum explosible conc. (MEC) g m^{-3}	Limiting oxygen conc. (LOC) $\%^{v}/_{v}$
Material											
Phenolic resin (see text)	250	450	> 2	10	220 (St 2)					15	
Hexamethylene tetramine				10.5	286 (St 2)					30	
Hexamethylene tetramine	melts	530		10.0	224 (St 2)						
Novolake	melts	630		8.4	144 (St 1)					30	
Novolake	> 450	560	< 1								
Phenol Novolak			2 – 4 3 – 7 (n.i.)								
Novolak / Hexamethylene tetramine – lubricant mix	490	530	< 10 < 10 (n.i.)	8.8	244 (St 2)				2	30	
Novolak / Hexamethylene tetramine – filler mix	500	510 (BAM)	< 10 < 10 (n.i.)	8.7	218 (St 2)				2	30	
Novolak / Hexamethylene tetramine mix	490	520 (BAM)	< 10 < 10 (n.i.)	8.9	212 (St 2)				2	30	

Comparison of the data in the table shows that both Novolak and Hexamethylene Tetramine (and their mixtures) can have similar flammability characteristics as the assumed values for phenolic resin, and in some case even worse: higher K_{st} and lower MIE. This must be taken into account in the hazard and risk assessment of all operations.

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Disclaimer:

This Guideline paper is intended to raise awareness of dust explosion hazards from phenolic resins by touching some important points seen by the EPRA Regulatory Committee and elaborated with the expert help of Chilworth Global/UK.

There is, however, no claim that these Guidelines are comprehensive and all recipients of the Guidelines remain fully self-responsible to retrieve and apply all relevant information and applicable legislation/guidance.