Safety strategy against potential hazards due to the handling of powders in a blending unit

Norbert Jaeger *

Safety Testing Laboratory, Ciba Specialty Chemicals, Additives Division, McIntosh, AL, USA

Abstract

To ensure and maintain process safety in the chemical industry a systematic hazard search and evaluation, i.e. “Risk Analysis” is indispensable. The knowledge of the ignition behavior of dust-air is important for such a risk assessment in a chemical production plant. This paper describes, based on a practical example, the strategy of performing a Risk Analysis and the use of the minimum ignition energy and minimum auto ignition temperature as very important safety indexes in practice. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Minimum ignition energy; Dust explosion hazards; Hazard evaluations; Electrostatic discharges

1. Introduction

The knowledge of the ignition behavior of dust–air mixtures is important for risk assessments in chemical production plants.

This paper describes the systematic approach in searching for dust explosion hazards, the appropriate use of technical measures to eliminate the previous identified hazards or their reduction of the severity to an acceptable level.

Preventive measures against the occurrence of electrostatic discharges and mechanically generated sparks during powder handling operations will be also described by using practical examples from a blending unit for powders.

The aim of this paper is to assist people dealing with powders. It reflects the present state of the art and current knowledge of the assessment and measures associated with powder handling.

2. Process description

The blend unit is designed to produce two or three component blends for sale as powder and as a feed for a granulation unit. The blend components are manufactured in separate process units, adjacent to the granulation unit. All the components are conveyed with N₂ through pneumatic conveying systems into storage silos. Blend components are screw feed from surge bins into weigh hoppers. From there, the material can be transferred into a blender. Once the blend has been completed, the batch is discharged to a surge hopper and a new blend can be initiated. From the surge hopper the final blend can be transferred into the packaging facility for packaging in drums, FIBC’s and bulk containers. Fig. 1 shows a simplified schematic drawing of the unit.

3. Risk analysis

Safety guidelines, regulations and technical instructions facilitate control of the more commonly occurring safety problems. However, in practice, every chemical process constitutes a particular combination of chemicals, plant and process conditions. To ensure and maintain process safety in the chemical industry, therefore, a systematic predictive hazard search and evaluation, i.e. ‘Risk Analysis’, is indispensable. Its objective is to obtain ‘synthetic experience’ before the technical implementation of processes or plant start-up so that from the outset planned, appropriate measures can be taken Ciba-Geigy, 1992.

In evaluating Risk, consideration must be given to
both the Probability of occurrence of an incident and the Severity of the consequences.

3.1. Systematic approach

To obtain useful results, a risk analysis must incorporate the stages shown in Fig. 2.

A Risk Analysis for the blending unit was performed in accordance to the above described procedure, modified for the search of possible explosion hazards (see Fig. 3)

The necessary information to carry out a Risk Analysis in its full depth is not yet available in the fast development stages of a process. However, to acquire the desired level of integrated safety of the processes and facility, it is important that safety considerations of the process accompany the project from its earliest stages of development. As the project increases through the stages of development, these considerations will become more
detailed and will finally lead into the detailed risk analysis described below.

3.2. The steps in risk analysis

Deviations from safe working conditions can lead to hazards. A systematic search for hazards is therefore only possible if safe working conditions and their limits are defined and the consequences of deviations from them are known. In the forefront, therefore, are the chemicals involved in the process, the intended reactions and the criteria, which must be maintained for safe processing.

3.3. Compilation of basic data

The basic data give fundamental information on the inherent hazards of the chemicals and of the process. They form the basis of the whole risk analysis. They should have been compiled primarily in the course of process development from the knowledge available worldwide from practice and literature. The type of required safety data are based on various specific internal and external safety standards (NFPA 1997a,b, 1998; NFPA 1997c, 1993).

3.4. Systematic search for hazards

This is the most creative step of risk analysis. The chemical process is considered in the context of plant, personnel and operating practice. In addition to operating instructions and plant instructions therefore, the plant specific data and plant drawings must be available for the analysis. This analysis can only be successful if the drawings correspond to the actual situation. Furthermore, a site inspection is essential, since critical details and hazards such as, for example, cables carried over sharp edges, leaks, scale formation, dismantled fittings and also influence from neighboring plants, will not be found on any drawing.

In the systematic search for hazards, all possibilities are sought in the critical areas. For the specific powder handling operations one must focus on:

- chemicals
- physical processes
- plants
- energy
- personnel
- external influences

which could lead to deviations from the safe process conditions defined.

These deviations should be set out in the list of hazards together with statements of cause and effect, initially without evaluation or correlation. Various methods are available for a systematic search for hazards CCPS, 1995.

4. Dust explosion hazards in the blending unit

An explosion hazard can exist when dusts are produced, stored or processed in a plant and these materials are present as a mixture in air. An explosible mixture is present, when combustible dusts are present in such quantities in air that an explosion occurs after an ignition.

An explosion requires three conditions to exist simultaneously (see Fig. 4):

Fig. 4. Requirements for the occurrence of explosions ISSA, 1996.
fuel or flammable material in sufficient quantity and effectively mixed with
air and
an effective ignition source

Using preventive measures against explosions require the reliable exclusion of one of the conditions necessary to generate an explosion as shown in Fig. 5.

An explosion can thus be excluded with certainty by either

- avoiding the development of explosible mixtures (combustible dusts, flammable gases), or
- replacing the atmospheric oxygen with an inert gas, working in a vacuum or using inert dust, or
- preventing the occurrence of effective ignition sources.

All three measures are summarized under the heading ‘preventive explosion protection’. It should be ensured that at least one of the three conditions is eliminated or so strongly reduced, so that an explosion is no longer possible or at least very rare. Their appropriate elimination prevents an explosion from starting.

To determine the necessary explosion protection safety measures, the knowledge of the safety data of the materials being used in the production unit and the effectiveness of the identified ignition sources must be known.

4.1. Basic safety data information

In order to sufficiently survey the danger potential of a dust, one is normally forced to carry out a multitude of laboratory tests that are based on standardized methods. The test results are described in the form of parameters known as safety characteristics. Thorough knowledge of the ignition behavior of dust–air mixtures towards mechanically generated sparks or electrostatic discharges (Minimum Ignition Energy, MIE) and hot surfaces (Minimum Autoignition Temperature, MAIT) is extremely important for assessing the hazards in dust-carrying plants. The ignition behavior determines essentially the extent, and hence the cost of the protective measures, to be used. This is especially true for the use of the protective measure ‘prevention of ignition sources’ and also for the understanding of the ignition phenomena regarding static electricity, e.g. brush discharges, bulk surface discharges, spark discharges, propagating brush discharges. Knowledge of a powder’s minimum ignition energy, particle size distribution and specific resistivity allows one to define the necessary protective measures for different operations based on the vessel size and the conductivity of the material of construction Luettgens & Glor, 1989.

4.1.1. Burning class

The test is designed to determine the ignitibility and the combustibility of a dried product according to the following criteria:

Can the product be ignited at all?
Is the ignition propagated?
Is there a fire or a flameless reaction?

The tests are carried out in a ventilated laboratory hood. The air velocity at the test location is approx. 0.2 m/s. The superimposed light air stream is necessary to vent the inert gas which are generated upon ignition of the product and which may inhibit the combustion behavior of the dust (see Fig. 6).

If the combustibility of a product is of interest at elevated temperatures, the combustibility test can be done at elevated temperatures (e.g. at the anticipated drying temperature, see Fig. 7).
Table 1

<table>
<thead>
<tr>
<th>Test result</th>
<th>Class</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ignition</td>
<td>No spreading  of fire</td>
<td>1</td>
</tr>
<tr>
<td>Brief ignition, rapid extinction</td>
<td>Brief</td>
<td>2</td>
</tr>
<tr>
<td>Localized combustion or glowing with practically no spreading</td>
<td>Localized</td>
<td>3</td>
</tr>
<tr>
<td>Glowing without sparks (smoldering) or slow decomposition without flames</td>
<td>Glowing</td>
<td>4</td>
</tr>
<tr>
<td>Burning fireworks or slow quiet burning with flames</td>
<td>Burning</td>
<td>5</td>
</tr>
<tr>
<td>Very rapid combustion with flame propagation or rapid decomposition without flame</td>
<td>Very</td>
<td>6</td>
</tr>
</tbody>
</table>

The combustibility of the product is rated in accordance with the course of reaction and characterized as a class number (see Table 1).

4.1.2. Dust explosion characteristics

The Twenty-Liter Apparatus (see Fig. 8) is used in the determination of explosion indices of combustible dusts. Dust explosivity, lower explosion limit (LEL), maximum explosion overpressure ($P_{\text{max}}$), maximum explosion constant ($K_{\text{max}}$) and the limiting oxygen concentration (LOC) can be measured with this device. The maximum explosion pressure and the maximum explosion constant are necessary to design explosion venting or explosion suppression system.

4.1.3. Minimum autoignition temperature

The Minimum Autoignition temperature, MAIT, is defined as the lowest temperature of a heated surface at which the most readily ignitable mixture of a dust with air just ignites. It provides information on the ignition behavior of a dust suspension when quickly passing over a hot surface (see Fig. 9).

4.1.4. Minimum ignition energy (MIE)

The minimum ignition energy, MIE, of a combustible substance is the lowest value of the electrical energy stored in a capacitor, which on discharge just suffices to ignite the most readily ignitable fuel–air mixture at atmospheric pressure and room temperature. To help assure a standardized test procedure, a test apparatus known as MIKE 3 (Fig. 10) of the third generation has been specially developed by Kühner AG, Switzerland and has been made commercial available. Other test apparatus are also available to determine the MIE in accordance to an American Society for Testing Materials (ASTM) standard on MIE of dusts ASTM, 1999.

The MIE is usually quoted as a range: The lower value represents the highest energy at which no ignition is found in at least 10 experiments. The higher value, on the other hand, is the lowest energy at which the dust–air mixture is just ignited.

The method for the determination of MIE is described in the International Standard of the International Electrotechnical Commission (IEC) and in an ASTM standard. The MIE is generally obtained with an inductance in the discharge circuit. However, in order to assess the incidence of electrostatic discharges in industrial operations towards dust–air mixtures, the MIE must also be determined without an inductance in the discharge circuit. With flammable gases and easily ignitable dusts, the influence of the inductance is generally not detectable.
4.1.5. Powder volume resistivity

To characterize the static dissipative properties of a material, its powder volume resistivity, \( \rho_R \), has to be determined. It must be kept in mind that resistivity is not an absolute property of a powder and depends very strongly on moisture content and on the method used for measurement. From an electrostatic point of view, dusts are considered to be conductors, e.g. incapable of storing charge, if the resistivity is less than or equal to \( 10^{10} \, \Omega \cdot m \).

Table 2 summarizes the relevant generated safety data related to a dust explosion hazard of the handled material in the blending unit.

4.2. Ignition sources

The use of ‘Avoidance of Ignition Sources’ as a protective measure requires a comprehensive hazard evaluation as part of a detailed risk analysis, to determine all possible ignition sources that may occur during production. There are a large number of different ignition sources that one must consider in industrial operations (see Fig. 11). Not every ignition source has sufficient energy to ignite all types of exploisible atmospheres. Therefore, it is necessary to investigate the ignition sources in detail in order to determine the ignition hazard in conjunction with the expected exploisible mixtures.

Trivial ignition sources (welding, smoking etc.) must be excluded by using organizational measures. Ignition sources, which could result from the process itself introducing energy into the product being handled (e.g. mechanical, friction energies must be considered during a risk analysis. This holds particular true for products that have a tendency to form glowing particles and, if in the course of the process, glowing particles could be formed or entrained. Electrostatic discharges are ignition sources that are often underestimated in industrial operations. These discharges occur frequently in most products handling processes.

4.2.1. Mechanically generated sparks

Mechanically generated sparks and resultant hot surfaces together are regarded as one of the more important causes of ignition in industrial practice. With mechanically generated sparks, a distinction is made between grinding, impact and Friction sparks which are formed by brief contact (<5 s) between materials. Mechanically generated hot surfaces, on the other hand, are formed by relatively long rubbing (>>5 s) against steel. The hot surfaces show considerably better incendivity in com-

Fig. 11. Examples of possible ignition sources ISSA, 1996.
Table 3
Influence of the relative circumferential speeds \( v_c \) on the danger of ignition for combustible dusts

<table>
<thead>
<tr>
<th>( v_c ) (m/s)</th>
<th>Danger of Ignition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \leq 1 )</td>
<td>No danger for ignition</td>
</tr>
<tr>
<td>( &gt; 1 )</td>
<td>Every case has to be judged separately considering the product and material-specific characteristics</td>
</tr>
<tr>
<td>( &gt; 10 )</td>
<td>In every case there is danger for ignition</td>
</tr>
</tbody>
</table>

comparison with the short-lived mechanically generated sparks. Neither ignition source appears in industrial practice from the normal metallic materials of construction rubbing against each other or against stone if the relative circumferential speeds \( v_c \) are less than or equal to 1 m/s (see Table 3). This is not valid for cerium iron, titanium and zirconium Anon, 1991.

The ignition behavior of mechanically generated sparks in dust air mixtures depends on the minimum ignition energy MIE and the minimum autoignition temperature MAIT of the dust in question. The ignition effectiveness of mechanically generated is dependent from the combination of the materials. According to Fig. 12, it can be stated that the type of spark-producing material, together with the MIT and the MIE requirement, determines whether an ignition of dust air mixture has to be anticipated from friction, grinding or impact sparks Anon, 1991.

The mechanically generated sparks can thus be assigned different equivalent ignition energies towards dust air mixtures with a MIT \( \leq 500 \, ^\circ C \). For example, if the MIT of a dust is 300°C, steel-friction sparks can ignite this dust only with a MIE (equivalent energy) up to 3000 mJ. The equivalent energy, also known as the equivalent ignition energy EIE, is the amount of energy which when transformed into an electrical spark discharge has the same incendivity as the sparks shown in Fig. 12.

4.2.2. Mechanically generated hot surfaces

Mechanically generated hot surfaces represent an ignition hazard if, irrespective of the MIT and of the MIE, the surface temperature is 1100°C or higher and the hot surface area by itself is large enough (see Fig. 13) Bartknecht, 1993; Eckhoff, 1997.

Higher surface temperatures and larger surfaces have a better incendivity, lower temperatures and smaller surfaces a poorer incendivity.

4.2.3. Smoldering pockets

Lumps of smoldering material always represent a hazard when the dust can be classed as capable of forming such lumps, i.e. its burning behavior class at 100°C is greater than 3. A smoldering lump surface of a cube \( A_o = 9600 \, \text{mm}^2 \) and a surface temperature of \( T_o = 900 \, ^\circ C \) is sufficient to ignite the mixtures of dusts with a minimum ignition temperature MIT \( < 600 \, ^\circ C \) (see Fig. 13) Jaeger, 1989; Bartknecht, 1993. Higher surface temperatures and larger surfaces have a better incendivity, lower temperatures and smaller surfaces a poorer incendivity.

4.2.4. Nature and origin of static electricity in production plants

An electrostatic charge by itself does not necessarily represent an ignition hazard. Such a hazard exists only when the charge is so high that discharges occur owing to the high electrical field (Fig. 14) Britton, 1999.

The individual steps, which lead to the occurrence of charge build up and discharge, are always the same (Fig. 15):

- **Charge separation:** The separation process (usually between product and plant units) lead to charging of the surfaces in contact.
- **Charge accumulation:** Charges can accumulate on products, plant units, packaging containers and operators, etc.
- **Charge dissipation:** As soon as a connection of sufficient conductivity is established between the ground and the sites of the accumulated charge, the charge can...
In a powder handling production plant, static charges can occur at the surface of solids and powdery substances. At this point, it is important to make a distinction between conductors of electricity (e.g. metals) and non-conductors or insulators (e.g. plastics). Electrically charged particles (electrons) can move freely on a conductor, whereas on an insulator they are fixed in one place. If a substance has excess or a deficiency of charged particles, it is said to be charged.

If two uncharged (neutral) objects, of which at least one is an insulator, are brought into close contact with each other and then rapidly separated, both of the objects become charged. This occurs because charged particles will first of all pass from one object to the other but then, during separation, cannot return fast enough.

An electrostatic discharge can be incentive when the energy released is equal to or greater than the minimum ignition energy (see Section 4.1.4 for definition) of a mixture. The energy released depends, among other things, on the type of discharge. This in turn depends on the geometry and material of the participating surfaces as well as on certain other conditions. Table 4 summarizes the ignition behavior of several types of electrostatic discharges.

### 5. Protective measures

When combustible dusts are handled, avoiding an explosive atmosphere by keeping the dust concentration...
outside the explosive range is rarely possible due to sedimentation or whirling up of the material being handled. Thus, as a matter of principle, an explosive atmosphere can only be avoided with certainty by reducing the oxygen concentration, e.g. inerting. In practice, however, the possibilities to apply inverting are also limited. For such situations, avoidance of effective ignition sources and/or explosion-proof design are the only measures available.

In the following, protective measures are outlined for typical powder handling operations in the blending facility. As previously stated, the following product and plant properties are important for an accurate hazard assessment:

- Minimum ignition energy, MIE, of the bulk material (measured without inductance in the discharge circuit),
- Minimum Autoignition Temperature, MAIT, of the bulk material,
- Volume resistivity $\rho_R$ of the powder,
- Particle size distribution of the bulk material and mean value, $M$,
- Volume and shape of the silo or container (volume and shape of the product heap and of the dust cloud).

Unless otherwise stated, the following sections are based on the assumption that the bulk materials are handled without flammable gases or vapors being present.

5.1. Pneumatic conveying system

With pneumatic transport, potential ignition sources include: glowing particles from the product, mechanical sparks from connecting equipment and, in the case of highly insulating materials, electrostatic discharges (such as Propagating Brush Discharges, Fig. 16). Inside the transport duct, there is however, no need to consider ignition hazards due to electrostatic discharges if the following conditions are observed:

- The diameter of the duct is less than 1 m;
- The MIE of the bulk goods is $>1$ mJ;
- The duct is electrically conducting and is grounded;
- The duct is not lined with an insulating material of $>2$ mm or with a breakdown voltage of greater than 4 kV. In our experience, deposits of insulating products in the duct are not critical if they are not burnt or melted on.
- Normally, pneumatic transport is installed for filling silos or large vessels; consequently, the same requirements and considerations must be observed as for normal filling and emptying (see Section 5.2).

5.2. Filling and emptying operations

In filling and emptying operations, electrostatic ignition hazards are of prime importance due to the electrostatic charging occurring during separation process. The hazard comprises possible charge accumulation not only on plant units, incl. drum and container, but also—in the case of insulating bulk material—on the bulk material itself which is shown in Fig. 17.

Assuming the insulating bulk material carries a charge, filling represents the more hazardous of the two operations for the following reasons. In a filling operation, the bulk material undergoes dispersion (e.g. gravity feed, pneumatic transport, etc.) and can therefore be charged in the separation processes occurring in transport. The bulk material and hence its associated charge is then ‘packed’ in a small space in which the charge is not able to flow to ground sufficiently quick, even with a conductive and grounded receiver. This generates a high space charge density and hence a high electric field. In addition, consideration must also be given to the problems associated with heat accumulation and the possibility of entrainment of smoldering lumps.

Based on the product and plant properties mentioned

![Fig. 16. Examples of propagating brush discharges ISSA, 1996.](#)

![Fig. 17. Filling (charging) and emptying (discharging) operations.](#)
Table 5

<table>
<thead>
<tr>
<th>MIE* [mJ]</th>
<th>&lt;1</th>
<th>1–3</th>
<th>3–10</th>
<th>10–30</th>
<th>30–100</th>
<th>100–300</th>
<th>300–1000</th>
<th>&gt;1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAIT [°C]</td>
<td>Do not process</td>
<td>530</td>
<td>500</td>
<td>465</td>
<td>430</td>
<td>395</td>
<td>360</td>
<td>325</td>
</tr>
</tbody>
</table>

* The MIE values must be determined with an addition inductance in the discharge circuit.

above, a decision tree and the matrices are available providing guidance for the required safety measures Jaeger & Siwek, 1999.

5.3. Mixing

Even when handling highly sensitive dusts, the occurrence of effective ignition sources in mixing is unlikely, provided the following conditions are met:

- In the filling and emptying of the mixer, the measures applied are the same as those in the filling and emptying of containers.
- In the filling and emptying of the mixer, the mixing elements must be off or run at a circumferential speed (tip speed) which does not exceed 1 m/s. This restriction must be assured by technical safeguards.
- If the mixer is closed and is filled to fill level of 70 vol.% or more, the circumferential speed of the mixing elements is no longer restricted (see Fig. 14).
- Any insulating coating must have a breakdown voltage of less than 4 kV. Product build-up must be checked if a homogeneous layer can be formed.
- Circumferential speeds up to 10 m/s can be tolerated in a mixer with a product fill height of less than 70 vol.%, provided the combination of material values as listed in Table 5 are present.
- Nauta mixers with bottom support of the helical screw can heat up during operation and care must be exercised with substances capable of spontaneous decomposition. (Fig. 18)

5.4. Dust separation

In the case of dust separators, especially in filters, the dust explosion hazard must not be underestimated. The probability of occurrence of a fine dust atmosphere sensitive to ignition is large. In addition, the entrainment of ignition sources (e.g. formation of smoldering lumps) and the danger of ignition through electrostatic charging are of prime importance (see Fig. 19).

Electrostatic charging must be prevented by the following measures:

- Grounding of all conductive apparatus parts. Particular attention must be paid to the grounding of all conductive parts which could possibly be insulated from ground if a filter cloth made of insulating material is used (e.g. filter supports, clamps). This must be specially checked after repair and maintenance work.
- With a MIE<3 mJ or in the presence of flammable gases or vapors in the air being cleaned, electrically conducting filter materials must be used. An exception to this rule can be applied when the protective measure ‘inerting’ is employed. Continuity of the conductivity and safe grounding must be checked. Multiple washing can have an adverse effect on the continuity of the filter material conductivity and thus require repeat checking.
- All inner walls on which dust can impact at high speed must not have any insulating inner coatings with a high electrical breakdown strength (breakdown voltage must be less than 4 kV; periodic checks are required).

In general, with dusts with a MIE<10 mJ it is advisable
Table 6

<table>
<thead>
<tr>
<th>Environment/solid material</th>
<th>Explosion stable atmosphere</th>
<th>Explosive dust atmosphere</th>
<th>Flammable gases or vapors</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIE $&gt;1$ J</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>3 mJ $&lt;$ MIE $&lt;$ 1 J</td>
<td>B</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td>MIE $&lt;$ 3 mJ</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
</tbody>
</table>

* MIE measured without inductance in the electrical circuit.

to implement explosion protection measures which go beyond the avoidance of effective ignition sources or to consult the responsible specialist departments. It should further be noted that the fan must be installed on the clean airside of the filter and that dust deposits must be avoided in the pipe and fan housing (periodic check or install a dust control unit).

5.5. Use of flexible intermediate bulk container FIBC

Flexible intermediate bulk containers are used on ever increasing scale in the powder handling industry. Depending the hazard situation at the location where they are used, they must meet different requirements (see Table 6) in order to avoid ignition hazards caused by electrostatic charging (Fig. 20).

A: No special requirements.
B: Breakdown voltage of the FIBC wall material must not exceed 4 kV in order to prevent propagating brush discharges.
C: The bag material including the slings must be electrostatic conductive. The resistance to the ground measured at any bag location (inside and outside) must be less than 100 MΩ ($10^8$ Ω). The flexible bulk bag must have a grounding strap. The conductivity and the necessity for grounding must be clearly marked.

Most FIBC’s on the market today are made of polypropylene ribbon fabric. To pass the type B classification the following requirements are recommended:

- any inner PE coating/liner present is not thicker than 20–30 μm
- and the inliner is not made of plastic.

FIBC’s on the market that meet the requirement of a type C are constructed as follows:

- The basic fabric consists of conductive material (e.g. plastic with sufficient admixture of carbon)
- The basic fabric consists of non-conductive material, but web contains interwoven threads of conductive plastic material, which are interconnected.
- The basic fabric consists of non-conductive material, but the web contains interwoven metal threads, which are interconnected.
- The basic fabric consists of non-conductive material, but the FIBC has an internal conductive coating.

To meet the specification as a type C bag, the following requirements are recommended:

- The FIBC must be clearly labeled indicating that it is conductive and that grounding is required during charging and discharging (see Fig. 21).
- The FIBC must have a clearly marked area for the attachment of the grounding clamps.
- The lifting naps must also be made of conductive material and have a leakage resistance of less than $10^8$ Ω to the FIBC body.

It is extremely important to keep in mind that the discharge from an ungrounded bag can occur at single point. Such a discharge is strong enough to ignite dust
clouds. Using a type C bag requires a permanent grounding of the bag during the entire time that the bag is filled or discharged (see Fig. 21).

The generated charge in the product pile cannot fully dissipate to ground. Small discharges can occur along the surface of pile. These electrostatic discharges are too weak to ignite dust clouds if the volume of the bag is less than 2 m³ but strong enough to ignite solvent vapors.

6. Safety concept for the blending unit

Based on the determined hazards related to the different process operations in the unit it is obvious that the formation of an explosible dust atmosphere and the presence of ignition sources cannot be excluded with certainty. The following safety measures were used to reduce the probability and the severity of such an unwanted event:

- All electrical design within the confines of the facility are Class II Division 2 Group G with the exception of a three foot radius around the packaging machines which will be Class II Division 1 Group G. The classification was done in accordance to NFPA 499 NFPA, 1997a.
- There are no moving parts at tip speeds of greater than 1 m/s.
- All components are made out of conductive material.
- All conductive parts are reliably bonded and grounded.
- Tramp metal is rejected from the system through metal detectors.
- All units with a volume of greater than 1 m³ are protected by the use of constructional measures against explosions. This was necessary because the formation of a conical pile discharge cannot be excluded with certainty.
- Silos with a volume of 500 ft³ or less are equipped with explosion suppression systems (see Fig. 22) and extinguishing barriers (see Fig. 23) for each conveying line entering the silo. Silos and the conveying lines are rated to withstand a reduced explosion pressure of 15 psig. Explosion venting was ruled out as a protective measure in this case due to the indoor location of these silos.
- The three 3500 ft³ silos for the storage of the basic materials is protected by an explosion venting system and extinguishing barriers for each conveying line entering the silo. These three silos are rated to withstand a reduced explosion pressure of 50 psig. Installed vent discharge ducts will ensure a safe release from the enclosure to the outdoors NFPA, 1997b (see Fig. 24).
- Silos that do not receive product through pneumatic conveyors are inerted with nitrogen.
- All dust collectors are protected with explosion suppression systems.
- All pneumatic conveyings are done by nitrogen.
References

NFPA (1997a). NFPA 499, Recommendation for the classification of combustible dusts and of hazardous (classified) locations for electrical installations in chemical process areas.
NFPA (1997c). NFPA 654, Standard for the prevention of fire and dust explosions from the manufacturing, processing and handling of combustible particulate solids.

Norbert Jaeger is production manager optical brighteners with Ciba Specialty Chemicals, Grenzach, Germany. From 1994 until 2000 he was working for Ciba’s NAFTA Central Safety Testing Laboratory, where he was responsible for explosion technology and static electricity prevention. He joined Ciba in 1987 as a member of its Corporate Safety and Environment unit in Basle, Switzerland. From 1998 through 1994, he was the safety and loss prevention manager for Ciba’s additives production site in Lampertheim, Germany. Jaeger holds an MS in safety science from the University of Wuppertal, Germany. He is a member of ASTM Committee E-27 on Hazard Potential of Chemicals, Subcommittee 05. Explosivity and Ignitability of Dust Clouds, a member of AIChE’s Center for Chemical Process Safety’s reactive chemicals subcommittee, and a member of the working group on dust explosions of the International Social Security Association.