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Electrostatic Risk Assessment for Combustible Dust Atmospheres

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Since June 2003 new and modified plants in Europe must comply with the requirements of the European Directive ATEX 137, aimed at improving the safety and health protection of workers potentially at risk from explosive atmospheres. Of all possible sources of ignition that must be considered under this legislation, the ATEX Directive draws explicit attention to one: Static Electricity.
Static is a common cause of fires and explosions, as it is present in a very wide range of industries, in some cases an inevitable outcome of the process being carried out. In others, unless specific measures have been taken, it may occur as a result of secondary actions such as movement of equipment and personnel. This paper shall firstly summarize the main characteristics of static electricity (charge generation, charge accumulation, types and modes of static discharges, such as sparks and propagating brush discharges). The paper shall then illustrate the methodology of an electrostatic risk assessment in a combustible dust environment, and the criteria to be adopted when assessing the effectiveness of the ignition. Lastly, the paper shall discuss prevention measures to reduce the electrostatic risk, such as solutions for avoiding charge generation and indications about proper grounding and bonding of conductive materials.

1. Introduction

Protons and electrons are present in all elements, and so charge is intrinsic to all materials. When a charged material releases the charge accumulated on its surface (e.g., through a spark discharge), it could release a quantity of energy high enough to be able to ignite a cloud of combustible dust, provided that this is within the flammability range (i.e., above the Minimum Explosible Concentration - MEC). Although statistically static is not the most common cause of fires and explosions - the European Standard EN 1127-1 (2019) indicates 13 ignition sources that can be present in the process industry - it is present in a very wide range of industrial environments.
When performing a DHA (Dust Hazard Analysis), particular care should be given to static hazards in order to properly manage the ignition risk: to do so, it is fundamental to understand the phenomena leading to the charge generation, accumulation and discharge, and to know which types of discharges can occur, depending on the particular plant configuration.

2. Understanding static electricity: charge generation, charge accumulation and discharge

To control and assess electrostatic hazards, the first step is to understand how it is generated.
Static electricity can give rise to a fire or explosion hazard when three conditions occur:

1. Static electricity charges are generated (charge generation);
2. The static electricity charge generated builds up on the surface of an object (charge accumulation);
3. A static discharge of sufficient energy occurs in the presence of a hazardous atmosphere (electrostatic discharge).

2.1 Charge generation

In common industrial situations there are several ways by which static charge may be acquired; the two main mechanisms are described below:

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- Charge generation through contact and separation
  Whenever two dissimilar materials contact one another, electrons will have a greater affinity for one material than the other, and some will move across the interface. When these materials are then separated, the electrons may not be able to fully return from where they came; if both materials are good conductors, the exchanged charge will flow back by conduction through the last point of contact, and there will be no evidence of the exchange of charge that took place. If one or both of the materials are insulating, the exchanged charge will not be able to flow back by conduction and one material will become positively charged and the other negatively charged.
  Charge generation due to separation cannot be entirely prevented because the origin of charge lies in the physics and chemistry at the interface of materials (as a rule of thumb, the greater the energy, speed and pressure of contact, the greater will be the level of charge generation). This phenomenon is most noticeable in:
  - Low conductivity liquids that are in contact with solid surfaces;
  - Solids that are in contact with other solids;
  - Gas streams containing particulate or droplets (the flow of clean gas over a solid surface produces negligible charging).

  Flammable liquids can accumulate charge and thereby present an electrostatic hazard. Liquids can become charged when they move relative to conductive solids (e.g., a pipe or a vessel wall. The charge that a flowing liquid carries through a pipe is referred to as “streaming current”) or if there are two or more immiscible phases with relative movement between the phases. The spraying of liquids can also create a highly charged mist or spray.
  Charges are generated in powders due to frictional and impact charging. The movement of powders in material handling operations such as pouring, scooping, or pneumatic transport, causes the powder particles to rub against each other and against equipment generating charge (This charge generation mechanism is referred to as “tribo-charging”). In the following table measured data on the charge levels on medium resistivity powders emerging from different processes are reported (IEC/TS 60079-32-1, 2018):

Table 1: Charge build up on powders (IEC/TS 60079-32-1, 2018)

Operation	**Mass charge density (μC/kg)**
Triboelectrical powder coating	10^4 to 10^3
Pneumatic conveying	10^3 to 10^{-1}
Micronising	10^2 to 10^{-1}
Grinding	1 to 10^{-1}
Scroll feed transfer	1 to 10^{-2}
Pouring	1 to 10^{-3}
Sieving	10^{-3} to 10^{-5}

- Charge generation through induction
  It is possible to generate charge if an object is in close proximity to another object that is already charged (in this case, the materials involved must have finite conductivity although they do not have to be good conductors); the charged object can be thought of as being surrounded by an electric field that will attract charge towards it.

2.2 Charge accumulation

Accumulation of electrostatic charge occurs when charge is added to an object at a rate faster than it can be discharged. Solid materials are classified into three groups depending on their volume resistivity:

a) low resistivity powders, with volume resistivities $\rho \leq 1\ M\Omega * m$
b) medium resistivity powders, with volume resistivities $1\ M\Omega * m < \rho \leq 10\ G\Omega * m$
c) high resistivity powders, with volume resistivities $\rho > 10\ G\Omega * m$

Low resistivity powders can retain the charge although they are in an earthed container or in contact with earthed material. The relaxation time (i.e., the time taken for the charge to decay to 1/e of its original value, where e = 2,718) is given by the equation reported below:

$$\tau = S\varepsilon_r\varepsilon_O \qquad (1)$$

where:

ε_r is the relative permittivity of the powder;
ε_0 is the permittivity of free space ($8{,}85 \cdot 10^{-12}$ F/m);
S is the volume resistivity of the powder.
It is important to highlight that, due to the highly insulating characteristic of air, charge decay for cloud of powder is not influenced by the volume resistivity of the powder. The charge remains on the powder particles until they interact with each other or with the equipment.

2.3 Electrostatic discharge

As electrostatic charge accumulates on an object, there is an increase in the electrical energy associated with those charges. This energy is related to the electrical potential or voltage of the object, its size, and its proximity to ground potential. Charge on a liquid or on a solid creates a hazard only if it is discharged to another body or, more usually, to earth: if a voltage or potential difference exists between two objects, as they approach one another, the electric field intensifies between the objects to a point where the breakdown strength of air is reached. At this point, the air is ionized, and charges flow from the object with the higher voltage to the object with a lower voltage. When this occurs the flow of charge is called an electrostatic discharge. There are several different types of electrostatic discharges that can occur. Each has different defining characteristics and discharge energies; some examples are reported below:

- Brush discharge
  Brush discharges are generated by insulating (non-conductive) objects being electrostatically charged to a conductor at a lower electrical potential, typically earth (zero potential). Brush discharges can occur when opening plastic bags or separating plastic sheets. Brush discharges are known empirically to have an effective energy of up to 4 mJ and are capable of igniting flammable gases and vapours, whereas the ignition of an explosive dust cloud by means of a brush discharge is not believed to be credible.
- Spark discharge
  Spark discharges occur between two conductors at different electrical potentials. For example, metal plant and equipment and workers can become electrostatically charged when isolated from earth; when such charged conductors are exposed to another conductor at a lower electrical potential - typically earth (zero potential) - a spark discharge can occur. The energy dissipated in a spark discharge from a conductor is well defied and related to its capacitance and the initial voltage before the discharge started (the relevant equation is reported below); the effective energy of spark discharges can be large (> 1 J) and is typically sufficient to ignite many flammable atmospheres, including flammable gases, vapours, and dust clouds.

  $$E = \frac{1}{2} C V^2 \tag{2}$$

  where:
  E is the energy dissipated in Joules;
  C is the capacitance of the conductor in Farads;
  V is the potential in Volts.

- Cone discharge
  Cone discharges can occur on the surface of highly charged insulating powders as they accumulate in vessels or containers. During this process, the electric field on the surface of the material intensifies and the strong electric field causes ionization of the air just above the surface of the material, resulting in cone discharges from the dust pile at the vessel walls.
  Although the effective energy of cone discharges depends on the volumetric resistivity, particle size, mass charge density of the solid and the diameter of the vessel in which it is accumulating (the relevant formula is reported below), it is empirically known that such discharges release effective energies of the order of 10-20 mJ and therefore are capable of igniting flammable atmospheres, including dust clouds, with relatively low MIE, developed during vessel filling.

  $$E = 5{,}22 * D^{3{,}36} d^{1{,}46} \tag{3}$$

  where:
  E is the upper limit of the energy of the cone discharge in millijoules;
  D is the diameter of the earthed conductive silo in metres;
  d is the mass median of the particle size distribution of the powder forming the cone in millimetres.

- Propagating brush discharge
  Propagating brush discharges are highly energetic electrostatic discharges capable of igniting many flammable atmospheres. The energy levels that can be released are up to several Joules, resulting from the formation of a bilayer charge on both sides of a surface; the charge is formed by atmospheric ionization when the charge on one side of an insulating surface (e.g., coating, film, fabric) is strong enough to induce an equal and opposite charge on the other side.

3. Electrostatic risk assessment: methodology

Static hazards can be assessed in a systematic way:

1. Identify all possible flammable atmospheres (i.e., HAC: Hazardous Area Classification) and establish the energy required to ignite them. For all powders it is necessary to test samples of the material being handled (i.e., MIE: Minimum Ignition Energy);
2. Identify those places where static charge could be generated and accumulated (considering the characteristics of the substances handled, the processes and the operating conditions);
3. Where static charge is generated and allowed to accumulate, sooner or later there will be an electrostatic discharge. The next stage of the assessment is to quantify the energy of discharges that could occur;
4. The final part of a static hazard assessment is to compare the MIEs for the previously identified flammable atmospheres and the energy released from the possible static discharges. If the discharge energy is greater than the MIE, there is a definite static hazard that must be addressed.
   For the assessment of electrostatic hazards, the most relevant value of MIE is that which has been determined using a capacitive circuit without an additional inductance (MIE tests can be conducted with or without inductance: the tests performed “without inductance” are representative of the “pure” static electric discharges since the duration of the spark is shorter; the tests performed “with inductance” that are representative of the electric discharges that can occur from machines or control equipment, simulating a longer duration of the discharge).

4. Risk management: preventive measures

Static hazards are dealt with by avoiding charge generation, preventing charge accumulation or by removing the charge before there is any possibility of a discharge:

- Avoiding charge generation is likely to require altering the process in some way. In many cases a small change in temperature or humidity may be all that is necessary;
- Prevention of charge accumulation is often achieved by ensuring all conducting items (including personnel, portable equipment, and fixed plant) are properly earthed. However, this has no effect on insulating equipment and materials. It is also often not appreciated that connecting metal plant to earth may have no effect on the materials being handled inside the plant;
- In some situations, there will be no alternative but to accept that charge will be generated and begin to accumulate: if the charge is accumulated on the insulating dust, one way forward is to neutralise the charge before it becomes a hazard, ensuring an appropriate relaxation time.

If none of these approaches are possible or practical, it will be necessary to either remove the risk of a flammable atmosphere by inert gas blanketing, or ensure that in the event of an ignition, the ensuing explosion is safely controlled or contained.
In the following paragraphs, common situations (i.e., dust collector filters, silos and containers, hybrid mixtures) are analysed in order to offer some practical suggestions useful for managing the risks associated with static electricity.

4.1 Dust collectors

In dust collector filters for combustible dusts, the insulating filtering fabrics must not interrupt the earthing connections of parts made of conductive or dissipative materials (e.g., filter bag support cages or metal clamps to keep the filter socks in position). In particular, when the MIE of the powder is less than 3 mJ, it is of great importance to ensure the earthing of all metal parts (such as clamps, etc.).
For this purpose, for example, the use of fiber filtering fabrics containing conductive threads is very useful. In the presence of flammable vapours or in the presence of non-metallic conductive dusts with MIE lower than 30 mJ, filter fabrics made with conductive material and connected to earth must always be used.

4.2 Silos and containers

The powders must be handled and processed in such a way as to avoid a dangerous accumulation of charge. A dangerous charge can accumulate on the bulk material as well as on the silo or container wall (this applies to large silos and containers as well as small mobile containers, bins, drums, bags, FIBCs or other packaging).
In some operations, particularly when handling dry powders in containers, it is convenient to use an internal liner, such as a plastic bag, as a precaution against contamination. Coatings based on insulating materials can accumulate an electrostatic charge during filling and emptying operations; furthermore, the separation of charges that occurs when such coatings are removed from containers can cause electrostatic discharges capable of providing an effective ignition.
In some processes (e.g., when filling a container with a highly charged, high resistivity powder) it is even possible to produce propagating brush discharges; such discharges can release a large amount of energy (> 1000 mJ) and could also cause severe electrostatic shock. A further consequence of using highly insulating coatings is that they insulate the material being handled, even when the outer container is conductive and grounded.
For these reasons, in areas with the presence of a flammable atmosphere, the use of insulating coatings must be avoided, preferring only conductive and dissipative coatings if they are connected to earth in a safe way and if they remain connected to earth when they are extracted from or inserted into the container. Otherwise, the conductive and dissipative coatings must not be pulled out or inserted into the container within a potentially explosive hazardous area.

4.3 Hybrid mixtures

The presence of flammable vapours or gases in a combustible dust cloud is called a "hybrid mixture". IEC 60079-10-2 (2015) defines the hybrid mixture as a combined mixture of a combustible dust with a flammable gas or vapour (a hybrid mixture is considered explosive if the concentration of the gas/vapour exceeds 25 % of the LFL or the concentration of the dust exceeds 25 % of the MEC). This hybrid mixture may behave differently than the gas/vapour or dust individually: the MIE of a hybrid mixture can be as low as that of the vapor/gas while the vapor/gas concentration remains below the LFL; similarly, the explosion severity (K_{st} - Deflagration Index) will generally increase above that of the dust alone because of the influence of the turbulence that is a characteristic of combustible dust clouds.
Particular care must be taken when handling solvent-wet powders as, when handling large quantities of insulating powders, brush discharges which could ignite the gas/vapour atmosphere, or the hybrid mixture developed, cannot be avoided. Handling of particularly resistive bulk materials (resistivity ≥ 100 MΩ m) damp with solvent should generally be avoided. Where this cannot be avoided, additional explosion prevention or protection measures are required, particularly when handling large quantities.
These measures are:

a) inerting;
b) treatment of wet solvent material under vacuum;
c) processing at a temperature significantly below the flash point;
d) working inside explosion-proof equipment;
e) exclusion of the hybrid mixture;
f) special construction measures.

Filling of bulk material into a container containing a solvent (which generates flammable vapours) can lead to the generation of dangerous charge levels on the container to be emptied, on the liner, on the funnel, on the product falling into the collection vessel, on the product in the collection vessel or on the operators.
It is therefore preferable to carry out the filling of bulk material with a closed and/or automated system, under an inert gas atmosphere. Manual addition of powders to an open container containing an explosive atmosphere should be avoided; if this is not possible, special measures should be taken to reduce charge accumulation:

a) The containers or packaging to be emptied must be made of conductive or dissipative material;
b) During emptying, conductive containers or packaging must be grounded while dissipative containers or packaging must be in contact with the earth. For coatings made of dissipative material (e.g., modified PE bags, paper bags) a contact to the ground by the hands of an operator is sufficient. In this case the floor, shoes and gloves must also be dissipative and the resistance to earth must not be increased by contaminants;
c) Dissipative coatings can be used in conductive or dissipative containers. It must be ensured that they are in good contact with the earthed container and remain in contact with the earth when being pulled out or inserted into the container; furthermore, during handling, the coating must not detach from the

container. Otherwise, such coatings must not be taken out or placed in the container in a hazardous area;

d) Insulating coatings must not be used if they can come into contact with flammable gases/vapours;

e) Auxiliary devices for adding bulk material (e.g., shovels, funnels, inclined planes) must be conductive and earthed. Any inclined plane or funnel should have a maximum length of 3 m;

f) The earthing of all operators involved must be guaranteed;

g) The bulk material feed rate should be limited to 1 kg/s.

It is worth noting that, during storage, the dissipative property of the packages can be lost due to ageing, adsorption or if the relative humidity is low. Measures to increase relative humidity in storage areas may be necessary, especially in winter. Furthermore, when handling bags and/or containers, it is advantageous to use conductive support shelves or tables, with a clean grounded surface.

5. Conclusions

Similarly to all types of risk analysis, knowledge of the characteristics of the substances handled, together with knowledge of the process and equipment involved, is essential to develop a reliable risk analysis. In particular, due to the intrinsic presence of electrostatic phenomena, the ignition risk analysis must necessarily identify how and where the charge is generated and accumulated, in order to define the discharge mechanisms and the respective levels of energy released.

These energy levels must then be compared with the MIE of the combustible powder (tested without inductance) to verify the effectiveness of any ignition (in the presence of hybrid mixtures, the energy level released by the electrostatic discharge must be compared with the MIE of flammable gases/vapours present): if the risk of ignition is present, adequate prevention measures must be taken in order to avoid discharge (e.g., avoiding the generation or accumulation of a charge, or promoting dissipation through a sufficient relaxation time) or avoid the simultaneous presence of an explosive atmosphere.

Abbreviations

DHA	Dust Hazard Analysis	LFL	Lower Flammability Limit
HAC	Hazardous Area Classification	MEC	Minimum Explosible Concentration
K_{st}	Deflagration Index	MIE	Minimum Ignition Energy

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