Electrostatic Ignition Hazards Associated with Flammable Substances in the Form of Gases , Vapors, Mists and Dusts

M.Glor

Swiss Institute for the Promotion of Safety & Security, WKL-32.3.01, PO box, CH-4002 Basel, Switzerland

Abstract. The paper deals with the assessment of the electrostatic ignition hazards when flammable gases, liquids or powders are handled and processed in industry. It reviews the present state of knowledge in this field based on information available from literature, codes of practice and guidelines. In a short introduction the prerequisites for the ignition of a flammable atmosphere are described. The steps from charge separation to ignition of flammable atmospheres by discharges are outlined and the different types and incendivities of electrostatic discharges occurring in practice are discussed. Associated with the different flammable substances such as gases, liquids and powders and with the typical operations performed with these substances in industry, the electrostatic ignition hazards are reviewed. In addition the electrostatic hazards related to the different types of FIBCs are highlighted.

1 INTRODUCTION

Build-up of static electricity is intrinsically related with most industrial processes. Static electricity may cause nuisance or damage and it may represent a fire or explosion hazard when flammable gases, liquids and powders are handled. Thus, it is of great concern in chemical, plastics, pharmaceutical, foodstuff, printing and paint industries. The decisive factor for assessing the risk of accidents due to static electricity is the probability of coincidence in space and time between a flammable atmosphere and a high level of charge accumulation. The probability of a coincidence of this kind is greatest when the handling of a product gives rise both to high electrostatic charge densities and to a flammable atmosphere. This is especially true when dealing with flammable, non-conducting liquids such as fuels and apolar solvents or with flammable substances in powder form. Ignition sources may occur in practice due to human errors, technical malfunctions or they are intrinsically related to a process. In contrast to most types of other ignition sources static electricity belongs to all categories. Therefore, it is considered to be the ignition source least amenable to control.

Fires and explosions attributed to static electricity have ranged from filling a plastic bucket with toluene, washing of cargo tanks of 200,000 tons oil tankers to the transfer of combustible powder into large silos. Typical other accident reports include the filling of dryers with solvent wet powders and emptying intermediate flexible bulk containers filled with flammable powder.

The reports of phenomena due to static electricity date back to the 6th century BC when the ancient philosopher and scientist Thales of Milet observed the attraction and repulsion between amber and light particles. In the last centuries these phenomena have been shown on market places, in saloons and clubs for the amusement and amazement of people. With the industrialization and the frequent use of petroleum products in the present century the phenomena of static electricity became more frequent and obvious. Industry and academia started to investigate these phenomena. This research resulted in industry based (1-5), national and international (6-9) guidance to industry on safe manufacturing practices.

2 SYSTEMATIC APPROACH TO THE ASSESSMENT OF ELECTROSTATIC IGNITION HAZARDS

For every assessment of an electrostatic ignition hazard the scheme shown in Figure 1 is extremely helpful. In all cases where a fire or explosion in industrial environments is caused by static electricity, the sequence of events passes through the same stages. These stages are shown in Figure 1. Though the scheme looks rather trivial at first sight, it is not always easy to localize each step within the diagram for a given process with respect to space and time. Of course, it often happens that several steps occur simultaneously. For example the level of charge accumulation is determined by the equilibrium between both the rate of charge separation and the rate of charge dissipation.

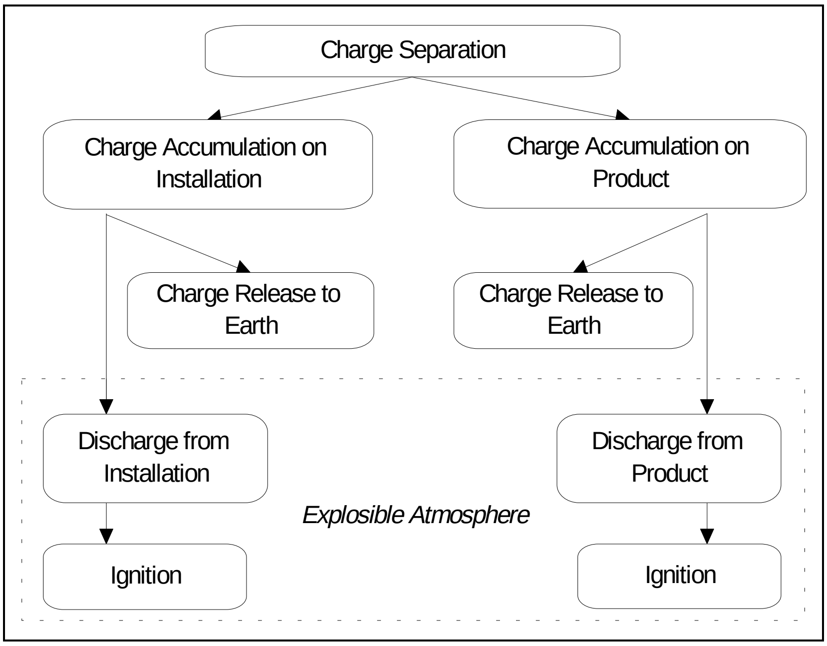

Fig.1: *Scheme showing the different steps from charge build-up to ignition*

Charge separation may occur if two surfaces which are in contact with each other are separated. If the mechanical separation process is fast enough compared to the mobility of the charge carriers, the surfaces are charged after separation. In other words, there is a separation of positive and negative charge carriers underlying every charging process. In practice this means that charge build-up has to be expected after every separation of two surfaces of different material when at least one surface is electrically insulating. Apart from mechanical separation, there exists another charging mechanism that is called "electrical induction". It occurs when a conducting surface becomes exposed to an electric field generated by any charge accumulation.

Surface contact, separation and movement involving poorly conducting materials are an intrinsic feature of many industrial processes. Examples are the flow or filtration of high resistivity liquids, the movement of powders in grinding, blending or sieving operations, the pneumatic transfer of powders, the movement of people or vehicles along insulating floors and the movement of transmission belting or other forms of sheet materials over pulleys or rollers. In these or similar processes static electricity can and does occur. It must be kept in mind that in all these processes always both surfaces in contact become charged after separation. When products are handled and processed within any kind of equipment, this means that both, the equipment and the product may become charged, as indicated in Figure 1. This fact has to be considered in every assessment of electrostatic hazards.

Charge separation does not, of itself, automatically lead to a hazardous situation. The amount of **charge accumulation** represents the decisive factor. This is determined by the rate of charge separation and charge dissipation. In practice, charge may accumulate on electrically insulated conductors, on insulating surfaces or on highly insulating products such as, e.g., hydrocarbon liquids or polymeric powders or on dust clouds and mists.

Fortunately **charge dissipation** occurs already at relatively high resistances to earth. The electric currents that usually occur in practice due to separation processes are very small. Typical values are 10^{-6} A or less. Under extreme conditions, values up to 10^{-4} A may be reached. For such low charging currents leakage of charge via resistances to earth in the range of 10^{6} to 10^{8} Ohm is sufficient to prevent a hazardous level of charge accumulation. However, it must be kept in mind that the use of high resistivity plastic materials such as polyethylene, polypropylene, etc., or of apolar liquids such as kerosene, hexane, toluene, etc., leads to resistances to earth far above this order of magnitude.

If the accumulation of charges always grows higher, the resulting electric field in the air may reach its limit value. This limit value is also called the dielectric strength of air. Under normal conditions it amounts to about 3 MV/m. At this limit a so called **discharge** may occur. The total or only part of the energy stored in the charge accumulation may be released in such a discharge forming a hot discharge channel that may ignite a given flammable atmosphere.

The energy released in the discharge and the sensitivity of a given flammable atmosphere measured in terms of its minimum ignition energy determine whether **ignition** will occur or not. The assessment of the occurrence and incendivity of discharges in different situations in practice represents the most important but also the most difficult step in the analysis of electrostatic hazards. Because of the difficulty to predict the occurrence and incendivity of discharges in industry by the laws of plasma physics a more or less phenomenological approach is commonly used. The discharges occurring in practice are classified into different discharge types. These types of discharges have different incendivities. The electrical properties of the products and installations, their geometrical arrangement and the operation determine which discharge type will occur in a given situation. The basic principles and typical examples are given in the following paragraphs. In addition, safety measures are described by which these discharges can be excluded. More details can be taken from different text books (10-12), codes of practice and guidelines (5-9).

3 DISCHARGES - OCCURRENCE, INCENDIVITY AND EXCLUSION

Every assessment of an ignition probability is based on a comparison of the igniting power (incendivity) of an electrostatic discharge with the sensitivity of the flammable atmosphere. In a first approximation the incendivity of a discharge has so far been estimated by its total energy and the ignition probability assessed by comparing this total energy with the minimum ignition energy of a flammable atmosphere determined with a spark discharge from a capacitive circuit. The first problem which arises in such an approach is the calculation of the energy of the discharge which is far from being trivial for most discharges other than sparks. In addition, due to the complexity of the ignition mechanisms this approach is too simplified, since the incendivity of a discharge depends not only upon its total energy but also upon the energy distribution with respect to space and time. This spatial power density varies widely among the different discharge types. Due to these problems energy released in a discharge is best determined in ignition tests with flammable atmospheres. The energy determined in this way is called equivalent energy of the discharge and is defined as follows: A discharge has the equivalent energy W if it is just able to ignite a flammable mixture with a minimum ignition energy W, as determined with capacitor spark discharges.

3.1 DISCHARGES FROM ISOLATED CONDUCTORS

3.1.1 SPARK DISCHARGES

Spark discharges occur between two conductors at different potential as soon as the electrical field in the gap reaches the breakdown value of about 3 MV/m at atmospheric conditions. In practice one of these conductors (including personnel) reaches a high potential since it is not connected to earth. Nearly the total energy stored in such systems (capacitors) is released in a single spark which generates a single discharge channel of rather high current density.. Therefore, these discharges are rather incendive and their energy release can simply be calculated by the energy stored on the capacitor.

Due to the increasing use of non conducting plastics in the construction of apparatus and equipment the probability that part of the system is electrically insulated from earth becomes always higher. Charge build-up on isolated conductors is responsible for the majority of all ignitions of flammable atmospheres in industry caused by static electricity. Typical examples are:

- Metal funnel mounted on top of a plastics pipe
- Ball valve with the metal ball isolated from the pipe of the valve by an insulating coating
- Piece of metal pipe insulated from earth by non-conducting gaskets
- Metal drum on a trolley with insulating tyres
- Metal shovel hold by an operator wearing insulating gloves
- Human body insulated from earth via insulating shoes and/or insulating floor
- Metal powder collected in a bin made from plastics
- Conducting liquid filled into a drum with non-conducting internal coating.

In all cases mentioned above, a so called spark discharge may occur as soon as the voltage becomes sufficiently high and an appropriate gap to a conducting earthed object exists. The energy W of such a spark discharge is calculated by the formula

$$W = \frac{1}{2} C U^2 \qquad (1)$$

C is the capacitance of the electrically insulated object and U its voltage. The energy obtained from formula (1) must be compared to the minimum ignition energy (measured without an additional inductance in the discharge circuit) of the flammable atmosphere in question to assess the ignition hazard. In principle gases, vapors and dust clouds can be ignited by spark discharges. The measures described in the following have therefore to be applied in areas where flammable atmospheres formed by these substances have to be expected.

Theoretically spark discharges can easily be excluded by earthing all conductors. Practical experience shows however, that earthing of all conductors is difficult to ensure in practice. Earthing can often only be achieved by organizational measures (the operator must be aware that it is necessary to earth containers, etc.) and, if conducting and non-conducting materials are used for construction, the chance of overlooking an isolated conductor is high. Therefore, adequate training of personnel and the exclusive use of conducting material for the construction of apparatus and equipment are important prerequisites for the exclusion of spark discharges.

It is commonly agreed (5-9) that a resistance to earth of less than 10^6 Ohm is generally sufficient in the case of equipment and 10^8 Ohm in the case of personnel to avoid spark discharges. In the plant it is of course reasonable to insist on much lower values for the resistance to earth of equipment if earthing is achieved by metallic connections. If in these cases the resistance amounts to several orders of magnitude the connection to earth is defective and may exceed the critical value of 10^6 Ohm at any time.

3.2 DISCHARGES FROM INSULATING SURFACES, INSULATING LIQUIDS AND INSULATING POWDERS

If charges are arranged on non-conducting surfaces or within non conducting products they cannot be released in a single spark discharge. The mobility of the charges along the surface or through the volume is too low (if there exists any mobility) compared to the duration of a spark discharge. Under these circumstances three other discharge types may occur. Their occurrence depends on the geometrical arrangement of the charges and the surroundings.

3.2.1 BRUSH AND CORONA DISCHARGES

If charges of one polarity are distributed on the surface or within the volume of non-conducting material, so called corona or brush discharges may occur as soon as an earthed conductive electrode is approached to the surface. The discharge results from the distortion of the electric field. If at the surface of the electrode the dielectric strength of air is reached (3 MV/m at atmospheric conditions) corona or brush discharges will be initiated. An exact mathematical treatment for a special arrangement of the field generating charges and of the electrode (cylindrical symmetry) is given in ref. (12).

It depends on many parameters such as radius of curvature of the electrode, speed at which the electrode is introduced into the electric field and polarity, whether a corona or a brush type discharge will actually occur in such situations. In practice, it can generally be assumed that only corona discharges occur if the radius of curvature of the electrode is below about 0.5 mm. Ignition of flammable atmospheres with a minimum ignition energy above 0.2 mJ by corona discharges has not to be expected. If the radius of curvature of the electrode is larger than 5 mm brush discharges are more likely to occur.

With regard to hazard assessment in practice it should, in the sense of a worst case consideration, always be assumed, that the more incendive (energetic) brush discharges will occur.

In addition to the situation with a charged insulating surface, brush discharges may always occur if an earthed conductive electrode is introduced into a high electric field. The high electric field may result from a highly charged insulating liquid or suspension, from a highly charged mist, from highly charged insulating powder in bulk or from a highly charged dust cloud. In what follows, examples of plant operations that are the most frequent sources of brush discharges are summarized:

- Approach of earthed conductive electrodes such as tools or a human finger tip to highly charged insulating surfaces (e.g., plastic pipe for the conveyance of liquids or dusts, plastic bags, common flexible intermediate bulk containers, plastic packing drums or filter cloths as well as film webs, non-conductive conveyor belts or V-belts).

- Discharging of solids from plastic bags, or shaking out of plastic bags in the vicinity of metal fittings (e.g. above an access port of a reaction vessel).
- Feeding of non-conductive liquids at high rate into a tank, approach of the charged liquid surface to internal fittings which can act as electrodes.
- Lowering of a conductive sampling baker onto a highly charged liquid surface for the purpose of taking samples.
- Projection of internal fittings into a highly charged dust cloud or a highly charged droplet cloud.
- Charging of non-conductive powder into packing drums, containers or silos, approach of the highly charged dust fill to the internal fittings or lowering of a conductive earthed sample baker for sampling or a level probe to determine the level.
- Projection of flagpoles, ship's masts, antennae or ice axes into powerful atmospheric electric fields (St. Elmo`s fire during thunderstorms).

The characteristics and incendivity of brush discharges have been investigated by different authors, see (13-16) for details. The values reported for the equivalent energy have been determined with gas/air-mixtures and lie in the range of 1 to 3.6 mJ. The parameters affecting the incendivity of brush discharges are the radius of curvature of the electrode, the polarity of the electric field and - if the electric field is generated by a highly charged non-conducting surface - the surface charge density and the area of the surface. Brush discharges from an earthed, metallic electrode opposite to a negatively charged surface are by far more incendive than from an electrode opposite to a positively charged surface.

On the basis of the values of the experimentally determined equivalent energy of brush discharges, it is expected that most flammable gas or solvent vapor atmospheres and hybrid mixtures can be ignited by brush discharges.

Although the minimum ignition energy of certain powders lie in the range of 1 to 10 mJ, no ignition of a dust cloud clearly caused by a brush discharge has yet been reported. Experiments performed in the laboratory (13-16) have so far also shown only negative results. Therefore, according to the present state of knowledge, brush discharges are very unlikely to ignite pure dust clouds containing no flammable gases and vapors.

In conclusion, brush discharges must be excluded in areas where flammable atmospheres formed by flammable gases or vapors may be present (Zone 0 and 1).

Brush and corona discharges associated with installations, containers and packing materials can be avoided by the use of conductive material or by a limitation of the area of insulating surfaces as specified in the different codes of practice and guidelines (6-8).

In this context the term "antistatic" is often used. In the German literature the antistatic property of a surface is defined in terms of the surface resistance (6). If the surface resistance lies below 10^{11} Ohm and above 10^{8} Ohm neither brush nor spark discharges have to be expected. Apart from the surface resistance, measurement of charge decay times is also used to characterize the charge retention behavior of non-conducting surfaces.

The incorporation of so called "antistatic additives" into the polymer is often used to decrease the charge retention of non-conducting surfaces. In this way the surface resistance can be reduced to the limits mentioned above. Problems associated with this measure are that the antistatic effect depends on relative humidity of the environment and that the antistatic additive may be absorbed by substances in contact to the treated surface.

The incorporation of carbon black into the polymer may drastically increase the conductivity (if sufficient carbon is added). Equipment made from such material is conducting from the point of view of electrostatics and must be earthed in practice.

Because of the effect of electrical induction, brush discharges do not occur from insulating coatings of conductive surfaces or from insulating walls having, at least on one side, an antistatic treatment. This only applies if the thickness of the insulating coating of the wall or the wall itself is not larger than a few millimeters. In these cases the electric field is directed through the dielectric layer.

3.2.2 PROPAGATING BRUSH DISCHARGES

If the charges are not arranged in form of one single layer of one polarity on a non-conducting surface but in form of a double layer of charges of opposite polarity on the opposite surfaces of a non-conducting material in form of a sheet, propagating brush discharges may occur. The level to which a non-conducting surface exposed to air can become charged in the form of a charge layer of one single polarity is limited to about $2.7 \cdot 10^{-5} C/m^2$. At this value of the surface charge density the field strength above the surface reaches the dielectric strength of the air and any additional charges would initiate a discharge into the air. However, when a double layer of charges of opposite polarity is generated across a non-conducting sheet of limited thickness more charges can be placed on each surface. This is explained by the fact that the electric field in the air due to one layer of charges is, to a certain extent, compensated by the field of the other layer of charges. Clearly the electric field across the non-conducting sheet will be very high. A quantitative treatment of such double layers of charges across dielectric materials is found in ref. (12).

Propagating brush discharges are initiated by an electrical short circuit of the two surfaces of the highly charged dielectric layer in form of a sheet. This electrical short circuit can be achieved either externally by the approach of electrodes to the two surfaces, or internally by a mechanical or electrical perforation of the dielectric layer. The discharge pattern looks always the same: Many discharge channels branch off to collect the charge from the entire surface. They all end in a bright discharge channel at the location of the actual short circuit. This central discharge channel bridges the gap between the approaching electrode and the insulating surface in the case of an external short circuit, or runs through the perforated sheet in the case of an internal short circuit.

For a long time it has been assumed that these discharges can only occur if one surface of the insulating layer is in intimate contact with an earthed metallic plate. In this case the second charge layer of opposite polarity is accomplished by the induced charges on the metallic plate. It can, however, be demonstrated, by spraying charges of opposite polarity to the two surfaces of a dielectric sheet, that the metallic plate in intimate contact with one surface of the insulating sheet is not essential for the build-up of the double layer. If a dielectric sheet in free space (e.g., the insulating wall of a container) becomes highly charged on one surface and the electric field is mainly directed through the dielectric sheet towards earth, the other surface of this sheet may become charged with charges of opposite polarity by corona or brush discharges. Such a charging mechanism is observed, for example, when filling an insulating container with highly charged polymeric powder.

From practical experience and experimental evidence, it is generally agreed that the high surface charge densities necessary for propagating brush discharges cannot be achieved by separation processes in manual operations such as wiping of insulating surfaces or discharging a powder from a plastic bag. Charging mechanisms associated with high separation velocity are necessary to build up the high surface charge densities necessary for propagating brush discharges. Such high charge build-up may be observed during the following industrial operations:

- High velocity pneumatic transfer of powder through an insulating pipe or a conductive pipe with an insulating internal coating.
- Use of inspection windows made from glass or Plexiglas in pneumatic transfer pipes.
- High velocity transportation of a highly insulating suspension through an insulating pipe or a conductive pipe with an insulating internal coating.
- Continuous impact of powder particles onto an insulating surface (e.g., a coated dust deflector plate in the cyclone of a dust separator).
- Fast rotation of conveyor or transmission belts made from insulating material or from conductive material which is coated with an insulating layer of high dielectric strength.
- Filling of large containers or silos made from insulating material (e.g., flexible intermediate bulk containers) or of metallic containers or silos internally coated with an insulating layer of high dielectric strength.

According to practical experience and experiments in the laboratory it is not expected that layers of insulating powders that are, for example, formed in metallic pipes during pneumatic transfer, or paints, will give rise to propagating brush discharges.

The energy released in propagating brush discharges is high enough to ignite most flammable gases and vapors and most combustible powders. Persons may suffer a serious shock when the human body acts as the initiating electrode for such a discharge. Propagating brush discharges must be excluded in areas where flammable atmospheres formed by flammable gases or vapors or by combustible powders may be present.

Propagating brush discharges can be excluded by the use of conductive materials or insulating materials of low dielectric strength at all locations where the build-up of high surface charge densities may occur. If the breakdown voltage across a non-conducting layer or sheet is less than 4 kV, propagating brush discharges will not occur.

3.2.3 CONE DISCHARGES

The phenomenon of discharges along the surface of highly charged bulked polymeric granules which nowadays is called “cone discharges” is known since about 20 years. First reports by Maurer and Blythe et al. (18,19) date back to 1979. These discharges are caused by the extremely high electrical fields resulting from the high space charge density which is generated when charged insulating particles are accumulated in silos or containers. Model calculations have shown that conditions necessary for the appearance of cone discharges do exist when filling silos with highly insulating powders or granules. The discharges may already be initiated at a low level of the charge to mass ratio of the incoming product (10^{-7} C/kg in the case of a powder heap with radius 1 m) (20).

A comprehensive research project on the occurrence and incendivity of cone discharges sponsored by German and Swiss chemical industries and other institutions has been performed. The results are published in numerous publications (21-25) and in two final reports (26-27). For the investigation of the cone discharges a test rig with a silo of 50 m^3 volume was set up. Cone discharges could reproducibly be generated in this silo. Special measuring techniques have been developed to characterize the occurrence and the strength of the cone discharges. Successful ignition tests with gases and powders have been performed. Based on these results a formula for an estimation of the upper limit of the equivalent discharge energy of cone discharges as a function of the silo diameter and of the median of the particle size distribution of the powder forming the powder heap within the silo can be given. This formula is

$$W_{Ae} = 5.22 \cdot D^{3.36} \cdot d^{1.462} \qquad (1)$$

With W_{Ae}: Upper limit of equivalent energy of the cone discharge in mJ

D: Diameter of the silo (metal and earthed) in m

d: Median of the particle size distribution of the powder forming the powder heap in mm

Based on the experimental data obtained in the research project mentioned above including data from the literature, the limits of application of formula (1) are the following: 0.5 m < D < 3.0 m and 0.8 mm < d < 3.0 mm

Recently measurements could be performed in a production site during normal production. Highly insulating, non polymeric, fine (median = 0.1 mm) product was filled into stainless steel silos by pneumatic transport (28). The results are in very good agreement with the numeric formula (1). Therefore the particle size limit for the application of formula (1) can be extended to :

$$0.5\ \text{m} < D < 3.0\ \text{m} \qquad (2)$$

$$0.1\ \text{mm} < d < 3.0\ \text{mm} \qquad (3)$$

This recent results clearly show that cone discharges may also be generated with fine powder and not only with granules, as was previously assumed. Cone discharges from fine powder have, however, much less energy compared to those associated with granules. Figure 2 is derived from formula (1) and shows the equivalent energy of cone discharges as a function of the silo diameter and the median of the particle size of the product generating the cone discharges. It is now possible to estimate the equivalent energy of cone discharges if the silo diameter and the particle size of the product generating the cone discharges are known and thus specify safe operating conditions. However, it is important to know that all values of minimum ignition energy (MIE) referred to in this paper have been determined with the commercially available apparatus Mike III using no additional inductance in the discharge circuit.

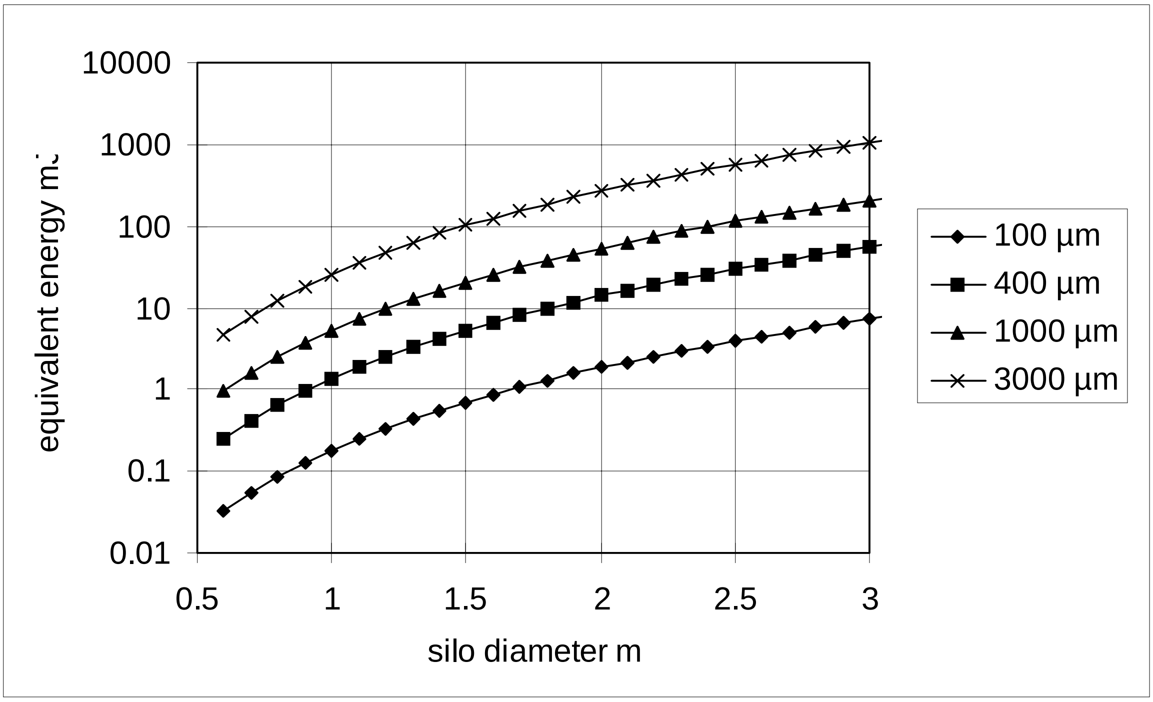

Fig.2: *Upper limit of the equivalent energy of cone discharges as a function of the silo diameter and the particle size*

Whether cone discharges will occur at all depends on other parameters such as, most importantly, on the resistivity of the bulk powder. Additional parameters are the charge to mass ratio, the mass flow rate and the geometry of the heap and of the silo.

Prevention of the accumulation of high charge levels on the product is the only measure to exclude cone discharges. In general, this can only be achieved in a reliable way by increasing the conductivity of the product. Such a treatment can, however, rarely be applied, because it will drastically change the properties of the product. Thus, measures to exclude the flammable atmosphere (e.g. reduction of oxygen) or measures of explosion protection of the equipment must be applied.

3.2.7 LIGHTING-LIKE-DISCHARGES

Before anything was known about cone discharges, the charged dust cloud was considered to represent the major electrostatic hazard in silos. This speculation was based on observations during the eruption of volcanoes, where lightning activity has been observed in the ash and dust clouds. However, so far no lightning like activity has been reported from industrial scale equipment. Systematic investigations with highly charged dust clouds in a 60 m^3 bunker also showed negative results (17). Thus, it can be concluded that lightning-like discharges are very unlikely to occur in industrial scale equipment.

4 HANDLING AND PROCESSING OF LIQUIDS

Extensive knowledge is nowadays available with respect to the ignition risks due to static electricity associated with the handling and processing of flammable liquids based on research and experience from the petroleum and chemical industries.

The hazards associated with charge build-up on packages, containers, apparatus and plant items have to be eliminated by an adequate choice of the material for construction and by earthing and bonding all conductive parts (see also spark, brush and propagating brush discharges). In addition earthing of the personnel via charge dissipative shoes and floors is mandatory.

The hazards associated with the charge on liquid products is given by the equilibrium resulting from charge separation, charge accumulation and charge dissipation (see Figure 1.) The parameters affecting this charge equilibrium state of the liquid are manifold. A summary is given in Table 1.

Table 1: Parameters affecting the hazards associated with the charge on liquid products

Charge generation	**Charge accumulation**	**Charge dissipation**

process
• flowing
  • flow velocity
  • filters, valves, obstacles
  • turbulence
• filling
• emptying
• stirring
• mixing
• sampling
• atomization
• liquid jet cleaning
	• quantity
	• volume
	• geometry
	• charge to mass ratio
	• presence of electrodes (intrusions such as level, temperature, etc. sensors influencing the electrical field)
		• conductivity of the liquid
		• conductivity of apparatus
		  • presence of liners or coatings in pipes, containers, etc.
		• electrical connection to earth

nature of liquid
• viscosity
• homogeneity
  • suspension
  • emulsion
  • multiple phase		

The most frequently applied measures to limit the charge accumulation on liquids to a safe level are the increase of the conductivity in case of liquids with a very poor conductivity such as e.g. the hydrocarbon liquids, or limiting the flow velocities of liquids in pipes. In special situations in industry it is, however, not possible to limit the charge accumulation on the liquid to a safe level. In these cases exclusion of the flammable atmosphere with inert gas blanketing is required. A typical example of this kind of situation is the handling and processing of multiple phase liquid systems of poor conductivity.

It is strongly recommended to use guidance for the safe handling of flammable liquids in different industrial situations. This guidance can be taken from the comprehensive literature in this field (1-9) or in the form of expert advice.

5 HANDLING AND PROCESSING OF POWDERS

Most organic and polymeric powders are poor conductors. Thus they may become highly charged even when handled and processed in earthed metallic equipment. For a long period of time the ignition sensitivity of powders in the form of dust clouds with respect to electrostatic discharges has been underestimated. Therefore, in the past the guidance given in the guidelines with respect to powders was rather poor.

A lot of new knowledge has, however, been collected during the last 10 to 15 years. The most important parameters in every hazard assessment for powders are:
- Minimum ignition energy
- Resistivity of the powder in bulk

- Particle size distribution
- Content of flammable solvent

Two important topics, the use of FIBCs and the occurrence and incendivity of cone discharges are highlighted in this paper. General guidance can be taken from the new CENELEC technical report (8). If large amounts of powders with a minimum ignition energy less than 10mJ (measured in purely capacitive circuit) or powders in the presence of flammable gases or vapors are processed expert advice is recommended.

5.1 FLEXIBLE INTERMEDIATE BULK CONTAINERS (FIBCs)

FIBCs or Big Bags are now commonly used for the packaging and transport of powder materials. Their construction, usually using a base fabric of insulating woven polypropylene may introduce an electrostatic ignition risk and much work has been carried out both to characterize the hazards associated with their use and also to develop FIBCs which can be safely used in the presence of potentially flammable atmospheres.

The initial work lead Maurer and co-workers in 1987 to propose a classification scheme for the different types of FIBCs (29). This essentially divided FIBCs into three types:

Type A which have no special safety precautions and are unsuitable for use with any potentially flammable material;

Type B in which the FIBC wall fabric has a breakdown voltage of less than 4 kV in order to prevent the occurrence of propagating brush discharges. These can be used in the presence of potentially flammable dust atmospheres provided its ignition energy is greater than ca. 3 mJ.

Type C which are constructed using a wall fabric which has a resistance to earth from any location on the FIBC, including the slings, of less than $10^8\Omega$. Such FIBCs, provided they are adequately earthed during use, are suitable for use in the presence of any potentially flammable atmosphere, both dust and gas or vapor.

Experience has shown that standard FIBCs constructed using woven polypropylene fabrics usually meet type B requirements provided any internal polyethylene coating is thinner than 20 to 30 µm and provided no liner is used in combination with the FIBC.

In order to meet the requirements for type C, FIBCs are usually constructed either from a fully conductive fabric or from a non-conductive fabric containing interwoven conductive threads which are connected together and which then have to be connected to earth. A further design involves the use of a non-conductive fabric coated with an internal conductive coating often of aluminum, this can meet the requirements for type C provided the integrity of the coating and its connection to earth can be ensured.

The need to ensure that type C FIBCs are adequately earthed during use and the difficulty that this presents in practice is illustrated by a range of incidents, described by Britton (30), which have occurred during powder handling operations involving FIBCs.

An alternative design of FIBC, commonly called type D FIBC, involves the use of a woven polypropylene fabric containing interwoven conductive threads that are not connected together. It was believed that any charge build-up on such FIBCs would be dissipated by corona discharge from the threads and the low capacitance of the individual threads would prevent the occurrence of incendive discharges for all except the most sensitive flammable gas mixtures e.g. hydrogen/air. The antistatic mechanism of such fabrics and the design criteria for FIBCs have been extensively studied in the laboratory (31-32).

Full scale filling trials have been carried out to confirm the range of applicability of such FIBCs. A "worst case" scenario was chosen for the tests in that the trials were carried out by pneumatically filling the FIBCs with 3 mm polyethylene granules of high resistivity to ensure a high rate of charge generation. In these trials ignition of a flammable propane air atmosphere occurred (33)

In the meantime new fabrics for the construction of type D FIBCs have been manufactured. In recent laboratory tests it was no longer possible to ignite a flammable propane air atmosphere with discharges from the FIBC fabric itself (34). It is however still possible to charge by electrical induction and corona spraying not earthed objects or personnel close to the FIBC to such a level that incendive sparks will occur.

6 CONCLUSIONS

Based on experience and industrial research the ignition hazards associated with static electricity can nowadays be assessed rather well. The present knowledge in this field is sufficient to prescribe safety measures for most common industrial processes. It must, however, be kept in mind that electrostatic phenomena are encountered so widely that it is not possible to cover all cases and that research in the field continues providing new information. In addition, new processes are developed, common processes are run under more hazardous conditions or conflicts of interests do not allow a standard solution. Thus, there are and there will be added in the future open questions concerning the assessment of electrostatic ignition hazards.

6 REFERENCES

(1) Schriftenreihe der ESCIS “Statische Elektrizität, Regeln für die betriebliche Sicherheit” Heft 2, Ausgabe 1997, zu beziehen bei Dr. R. J. Ott, Sektion Chemie, Abteilung Arbeitssicherheit, SUVA, Fluhmattstrasse 1, CH-6002 Luzern

(2) API 2003 “Protection Against Ignition Arising Out of Static, Lightning and Stray Currents” 5th Ed. American Petroleum Institute (1991)

(3) Model Code of Practice for the Petroleum Industry: Part 1. Electrical Safety Code. Institute of Petroleum, U.K. (1991)

(4) Shell Safety Committee “Static Electricity- Technical and Safety Aspects” June 1988

(5) ISSA Prevention Series No. 2017 (E) “Static Electricity, Ignition Hazards and Protection Measures” of International Section on the Prevention of Occupational Risks in the Chemical Industry of the International Social Security Association (ISSA). ISBN 92-843-1099-7, ISSN 1015-8022.

(6) Richtlinie für die Vermeidung von Zündgefahren infolge elektrostatischer Aufladungen, Richtlinien “Statische Elektrizität”. Hauptverband der gewerblichen Berufsgenossenschaften, Zentralstelle für Unfallverhütung und Arbeitsmedizin, D-5205 Sankt Augustin, Fachausschuss Chemie, ZH 1/200,1989

(7) Code of Practice for Control of Undesirable Static Electricity, Part 1. General Considerations and Part 2. Recommendations for particular industrial situations. British Standards Institution London. British Standards Institutions BS 5958, 198l/82.

(8) Draft CENELEC report R044-001"Safety of machinery - Guidance and recommendations for the avoidance of hazards due to static electricity, elaborated by an European expert team forming WG5 of TC44X.

(9) NFPA 77 ,"Static Electricity" 1988 Edition, National Fire Protection Association USA

(10) G.Lüttgens und M.Glor, Statische Elektrizität begreifen und sicher beherrschen", Expert Verlag, Ehningen bei Böblingen, 1993.

(11) G.Lüttgens and M.Glor "Understanding and Controlling Static Electricity", Expert Publishing Company, Ehningen bei Böblingen, 1989.

(12) M.Glor, "Electrostatic Hazards in Powder Handling", Research Studies Press Ltd., Letchworth, Hertfordshire, England 1988.

(13) N.Gibson und F.C.Lloyd, British Journal of Appl. Phys. 16 (1965) 1619.

(14) M.Glor, J. Electrostat., 10 (1981) 327.

(15) K.Schwenzfeuer und M.Glor, J. Electrostat., 30 (1993) 115

(16) K.Schwenzfeuer and M.Glor, J. Electrostat. 40&41 (1997) 383

(17) P.Boschung et al., J. Electrostat., 3 (1977) 303

(18) B.Maurer, Chem. Ing. Tech., 51 (1979) 98

(19) A.R.Blythe and W.Reddish, Inst. Phys. Conf. Ser. No 48, p.107, Oxford 1979.

(20) M.Glor, J. Electrostat. 15 (1984) 223

(21) B.Maurer, M.Glor, G.Lüttgens and L.Post, J. Electrostat. 23 (1989) 25

(22) M.Glor, G.Lüttgens, B.Maurer and L.Post, J. Electrostat. 23 (1989) 35.

(23) M.Glor and B.Maurer, Proceedings of the International Conference "Sichere Handhabung brennbarer Stäube", Nürnberg, 1992, VDI Berichte Nr. 975 (1992) 207.

(24) M.Glor and B.Maurer, J. Electrostat. 30 (1993) 123

(25) A.Kuttler and M.Glor, J. Electrostat. 30 (1993) 285

(26) M.Glor and B.Maurer, Fortschritt-Berichte VDI, Reihe 3 Nr. 181, VDI-Verlag, Düsseldorf 1989.

(27) M.Glor and B.Maurer, Fortschritt-Berichte VDI, Reihe 3 Nr. 389, VDI-Verlag, Düsseldorf 1995.

(28) M.Glor and K.Schwenzfeuer, J. Electrostat. 40&41 (1997) 511

(29) B.Maurer, M.Glor, G.Lüttgens and L.Post, Inst. Phys. Conf. Ser. No 85, Sect. 3, Oxford 1987.

(30) L.G.Britton, Process Safety Progress, 12, 4 (1993) 241-250

(31) N.Wilson, Symp. on "Recent Developments in the Assessment of Electrostatic Hazards in Industry", IBC London 1989.

(32) M.A.Nelson, R.L.Rogers and B.P.Gilmartin, J.Electrostat. 30 (1993) 135-148.

(33) M.Glor, B.Maurer and R.Rogers, Proceedings of the Conference on Loss Prevention and Safety Promotion in the Process Industries, published by Elsevier Science B.V., Volume 1 (1995) 219

(34) K.Schwenzfeuer and M.Glor, The Journal of Powder/Bulk Solids Technology, June 1998, 29