

## 6007-32-1: The new standard on avoidance of electrostatic hazards

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A new standard IEC/TS 60079-32-1: *Explosive Atmospheres – Part 32-1: Electrostatic hazards, Guidance* was published by IEC in 2013 on avoidance of electrostatic hazards in industrial processes. This paper introduces the subject of electrostatic hazards, how they arise and how they can be avoided. It gives an overview of the new standard and some of the industrial situations that are covered by it.

### Introduction

Static electricity can cause two main problems in industrial processes. Firstly, where flammable vapours, gases or dust clouds are present, static electricity can provide an unexpected ignition source and cause a fire or explosion. Secondly, static electricity build-up on personnel, equipment or materials can give unpleasant electrostatic shocks to personnel working in the area. While these shocks are rarely in themselves injurious, they can cause inadvertent reactions that may cause accidents or injury.

These electrostatic risks are often poorly understood in industry and can appear in unexpected ways. Various guidance documents have been written to assist industrial personnel identify these risks in common industrial situations and apply typical prevention techniques. In Europe CENELEC TR50404:2003 remained the most comprehensive document available until publication in 2013 of the IEC60079-32-1 *Explosive Atmospheres – Part 32-1: Electrostatic hazards, Guidance*. This document has been produced by a Joint Working Group of IEC TC31 (Equipment for explosive atmospheres) and IEC TC101 (Electrostatics) and has drawn on several similar earlier documents worldwide, and experts of 15 countries from Europe, Asia and the Americas. The scope of the document includes guidance about equipment, product and process properties necessary to avoid ignition and electrostatic shock hazards arising from static electricity. It also covers operational requirements for safe use of equipment, products and processes. It gives standard recommendations for control of static electricity, such as earthing of conductors, reduction of charging and restriction of areas of insulating materials with specific recommendations for a range of industrial process areas. Measurement methods for use with this document are described in an Annex.

The 60079-32-1 document consists of about 170 pages and detailed review is clearly not possible here. This paper explains some key recommendations of the document for electrostatic control in industrial processes, and gives an overview of some of the industry situations that are addressed in the document. The standard should be consulted for full details of the risks and control measures appropriate to particular situations. In many cases the document gives “guidance” rather than “requirements” because industrial processes are extremely variable with many factors contributing to the hazard analysis. A control measure may be essential in one situation but unnecessary and unreasonably restricting in another, due to the particular combination of circumstances.

### How electrostatic hazards arise

Flammable atmospheres of gases, vapours or dust clouds may arise in industrial processes, that could be ignited if an ignition source is present. Electrostatic discharges arising from static electricity built up on people, their clothing, or equipment they use, or on plant, equipment or materials or products being manufactured or processed, can potentially ignite these atmospheres. A brief summary of the issues is given here.

Static electricity can easily and quickly build up in a many different situations. When two material surfaces touch, some electrical charges (present in the atoms of each material) move from one material to the other. When the materials are separated, one material is left with a positive charge and the other has an equal negative charge. This can happen as a person walks across a floor, clothing rubs against a seat, a polythene sheet is pulled from a roll, a material moves along a web, a material is stirred, ground, filtered or poured, or dust particles impact on a duct wall.

If these charges are free to move, they will attempt to recombine or dissipate. If they succeed, no electrostatic effects will be noticed. Electrically conducting materials like metals, water and alcohols allow such free charge movement.

Insulating materials such as plastics and many hydrocarbon liquids prevent free movement and dissipation or recombination of charge. These materials will charge easily in any process that involves contact between materials. The rate and level of charging increases with increasing contact areas, such as increasing web speeds or flow rates, turbulence or splashing in liquids. The electrical voltage can rise until an electrostatic discharge occurs.

Electrically isolated conductors that do not have an electrically conducting path to allow the charges to dissipate to earth can accumulate charge until a discharge occurs. Fortunately in practice earth paths are often present by chance, but for safety they must often be provided deliberately in the form of a wire or electrically conductive path through a material to earth. This is known as earthing or grounding the conductor. Insulating materials cannot be earthed, because they do not allow the charge to freely move from their surfaces.

The electrical resistance of a material indicates the ease with which charge can travel within it. A high resistance (low conductivity) material impedes the movement of charge within and across it. A simple electrical model of charge build-up in

many situations is given in Figure 1. Contact and frictional charge generation acts as an electrical current source. A conductor on which charge is generated has charge storage properties, equivalent to capacitance,  $C$ , in an electrical circuit. The charge also tries to recombine via an external circuit that has a resistance,  $R$ .

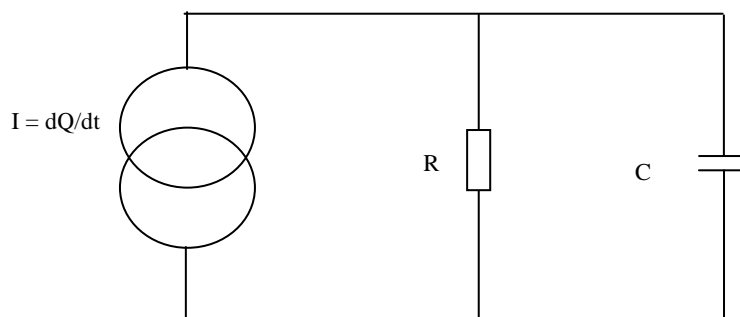


Figure 1. A simple electrical model of electrostatic charge build up

From Ohm's Law the voltage build up,  $V$ , will be the product of the charge generation current,  $I$ , and the circuit resistance,  $R$

$$V = IR$$

If, for example, the charge generation current is around  $0.1 \mu\text{A}$  and the resistance is  $10 \text{ M}\Omega$ , the voltage built up is only  $1 \text{ V}$ . If the resistance is increased to  $10 \text{ G}\Omega$  ( $10^{10}\Omega$ ) the voltage built up would be  $1 \text{ kV}$ . If resistance is increased to over  $100 \text{ G}\Omega$ , a voltage of over  $10 \text{ kV}$  would be expected. Modern insulating materials such as plastics, and insulating liquids such as hexane, toluene and many other solvents, often have resistance over  $1000 \text{ G}\Omega$ .

The resistance and capacitance also determine the time taken to dissipate charge, which is related to the "decay time constant" product  $\tau = RC$ . This gives the time taken for an initial charge or voltage to decay to 37% of its initial value. For materials the product of material resistivity and permittivity gives the equivalent decay time. If  $\tau$  is much less than a second, then we are unlikely to see electrostatic charge build-up unless we have continuous charge generation at high charging currents. If  $\tau$  is much greater than a second we start to see residual charge even for short term charge generation. High resistance (low conductivity) materials like polymers and hydrocarbon liquids,  $\tau$  exceeds hundreds of seconds and the material can retain high charge levels for minutes or hours. 60079-32-1 considers that a small item is electrostatically earthed if the relaxation time  $\tau$  is  $<0.1 \text{ s}$ .

If an item of capacitance  $25 \text{ pF}$  (e.g. bucket) is placed on a material (e.g. floor) with leakage resistance to ground of  $10^{11}\Omega$ , any initial voltage would drop to 37% in 2.5 seconds and to 5% in  $3\tau$  or 7.5 seconds. A floor material of leakage resistance  $10^{12}\Omega$  to earth would increase the decay time to 25 seconds (to 37%) and 75 seconds to 5% respectively. Modern materials often have higher resistance than this, and electrostatic charge and voltage can remain for long periods forming a significant risk.

The presence of high electrostatic voltages produces electrostatic fields in the vicinity, that introduces another less well recognised risk. Any conducting object within the electrostatic field has induced on it some voltage due to the field. If the object is not earthed, the voltage will remain high giving the possibility it will become of an electrostatic discharge source. No contact is required for the voltage to be induced in this way, and so it can happen unseen and unexpected.

### Flammable atmospheres and Minimum Ignition Energy

For ignition of a flammable atmosphere to occur, the energy in an electrostatic discharge must equal or exceed the ignition energy of the atmosphere. Ignition energy depends on the relative concentrations of fuel and oxygen present in the mixture. The most efficient burning occurs when the fuel and oxygen are near the stoichiometric mixture and this also approximately corresponds to the minimum ignition energy (MIE).

Many hydrocarbons form vapour mixtures with MIE around  $0.2 \text{ mJ}$ . Some materials such as hydrogen, acetylene and oxygenated hydrocarbons can form mixtures with MIE of the order  $0.01 \text{ mJ}$ . Dust clouds have very variable MIE, depending on the materials and particle size distribution and other factors. Dust cloud MIE can range from around  $1 \text{ mJ}$  to hundreds of  $\text{mJ}$ . Dust fines generally have much lower MIE than coarser particles of the same material. Whilst tables of MIE data on dusts of various materials are published (e.g. Eckhoff 1991), it is normally necessary to measure the MIE of these materials as part of a hazard evaluation.

### Electrostatic discharges

Electrostatic discharges are classified into several types, each having its own range of ignition risks (Table 1). Electrostatic spark between two conductors is one of the most common incendiary discharge types. All the stored charge on the conductor can dump its energy quickly and efficiently into the discharge. Personnel are electrical conductors, and discharges from charged personnel form a particular risk in manual processes involving flammable vapours and gases. Other examples of conductors found in the workplace include metal parts, equipment and hand tools.

Table 1 Summary of electrostatic discharges and their relevance to ignition risk

Type of discharge	Ignition energy range	Occurrence	Ignition risks
Spark	Up to several J depending on size (capacitance) of conductor	Between conducting objects	Incendive to gas/vapour and to dust
Human body	Up to a several mJ	Between a person and a conducting object	Incendive to gas/vapour and possibly to sensitive dust
Brush	Up to about 3.6 mJ	From surface of insulator to a conductor (including personnel)	Incendive to gas/vapour but not to dust clouds in the absence of gas or vapour
Propagating brush	Up to over 1 J	From surface of insulator <10mm thick with breakdown voltage >4kV that is backed by a conductor, to a conductor	Incendive to gas/vapour and to dust
Cone	Depends on silo size	Along the surface of a bulk powder cone in a silo	Incendive to gas/vapour and to dust
Corona	Not normally incendive	From sharp points or edges in high electrostatic fields	Not incendive if sparks cannot occur. Can be used to neutralise electrostatic charge buildup

The energy,  $E$ , stored in a spark source of capacitance,  $C$ , at voltage,  $V$ , before discharge, can be derived from a simple equation

$$E = 0.5CV^2$$

The capacitance of a conductive object, as well as the voltage which it may attain, are highly important in determining electrostatic ignition risk. Small capacitances must attain higher voltages before the MIE of a flammable mixture is approached. IEC/TS 60079-32-1 recommends that where small, isolated conductors are permitted, the maximum capacitance of the conductors should be 3 pF, 6 pF or 10 pF depending on the hazard zone, (as defined in IEC 60079-10-1 and IEC 60079-10-2) and the gas or dust group (as defined in IEC 60079-0).

Capacitance is related to the size of objects. A small bolt on equipment may have capacitance of only a few picofarads (pF) and it may be practically impossible to generate sufficiently high voltage on such an object to give a incendive spark energy. A metal drinks can might have capacitance around 10 pF and exceed the MIE of typical hydrocarbon vapours at only a few kV, quite a moderate voltage by electrostatic standards. Table 2 shows the capacitance range of some common objects

Brush discharges from insulating surfaces to conductors are less incendive than discharges between conductors, but can still be energetic enough to present an ignition risk to flammable vapour or gas. Charge on the insulator surface cannot move quickly to the discharge, so, only a small part of the surface may act as the ESD source, leaving surrounding areas still charged for further ESD events. Insulating materials are commonplace as packaging and engineering materials in modern environments and also in Personal Protective Equipment and clothing. Brush discharges can occur from the insulating surface to nearby metal plant parts or to personnel.

Table 2. Approximate capacitance of common conductive objects

Object	Capacitance (pF)
small metal items such as scoop or hose nozzle	10-20
small containers (bucket, 50 litre drum)	10-100
medium containers 250 or 500 litre drum	50-300
person	100-200
large plant items (e.g reaction vessels) surrounded by earthed structure	100-1000

## The 60079-32-1 document

The 60079-32-1 document is organised into sections on static electricity in solid materials, liquids, gases, powders, explosives and electro-explosive devices, static electricity on people, electrostatic shock, and earthing and bonding. Annexes describe the fundamentals of static electricity, flammable properties of substances, classification of hazardous zones, classification of equipment protection level, systematic electrostatic evaluation, and tests.

The first step in any hazard evaluation is to correctly identify the zone where flammable atmospheres occur (IEC 60079-10-1 and IEC 60079-10-2) and the gas or dust group (IEC 60079-0), and the likely MIE of flammable materials present. The MIE of many vapours have been documented (e.g. Walmesley) but the MIE of the dust fines should be measured by a specialist.

For dust clouds in the absence of flammable gases or vapours, it may be sufficient to consider the possibility of spark discharges. These may be avoided by making sure all conductors of significant size are earthed. What is “significant size”? The answer depends in part on the MIE of the material. It is essential that items are earthed if they have sufficiently large capacitance that there may be a risk of the electrostatic stored energy approaching the MIE. If high charge generation mechanisms are present with insulators backed by nearby conductors, it may be necessary to consider the possibility of a propagating brush discharge occurring. Where flammable gas or vapours are present, then spark and brush discharges should also be considered.

Materials and some items used in hazards avoidance work are usually classified as insulating, dissipative or conductive according to their surface resistance or surface or volume resistivity. Unfortunately these classifications vary widely in industry with different products and materials. For example, dissipative hoses have resistance between 1k $\Omega$  and 1M $\Omega$ , whereas dissipative footwear has resistance between 100k $\Omega$  and 100M $\Omega$ , and dissipative clothing has surface resistance less than 2.5G $\Omega$ . So, care must be taken when using such terminology – it is necessary to check what specific resistance measurements and limits are required in a particular application, product or circumstance.

## Solid materials

60079-32-1 gives twelve pages covering static electricity in solid materials. These can arise in many forms such as pipes, containers, sheets, coatings and liners. The hazards that may arise include

- Material surfaces may charge and lead to brush discharges
- Conductors may become electrically isolated leading to spark discharges
- Propagating brush discharges may occur if high charge generating processes are present with some combinations and arrangements of materials

A key control measure is to replace insulating materials with dissipative or conductive ones. The chapter commences with an explanation of the different resistance and resistivity characterisation practices used with various types of material and product. The importance of atmospheric relative humidity in resistance (resistivity) measurements is discussed. While 25% r.h. is the recommended humidity condition for these tests, other humidity levels may be used by different product standards and as a result of specific hazard evaluation. Charge decay can be used instead of resistance to characterise materials in some circumstances (e.g. evaluation of PPE clothing materials).

Some materials are rendered “dissipative” by including a substance that leaches to the surface and attracts moisture from the air, increasing surface conductivity. Under low humidity conditions, these materials can lose their ability to dissipate charge and become insulating. These and other coatings may also lose their effectiveness over time if the surface layer is washed or rubbed away.

## Earthing conductors

Earthing of conductive parts is a primary requirement, including personnel, mobile equipment and all metallic parts of equipment that might be used in a flammable atmosphere. Even small isolated items having capacitance as low as a few pF can pose a risk in some circumstances. 60079-32-1 gives maximum allowed capacitances for explosive atmosphere zones and equipment group combinations (Table 3). In general capacitances below 3pF need not be earthed providing they cannot charge to high voltage, and are not in a Zone 0 area with equipment Group IIC materials.

This guidance does not eliminate the risk of incendive discharges, but it reduces the risk to an accepted low level for most purposes. In particular the presence of high charging processes (or a possibility of high induced charge occurring) could increase the risk unacceptably. However the capacitance of an item changes with the proximity of earthed conductors, personnel or other materials, and small capacitances can be difficult to measure with confidence, so these limits should be treated with caution.

It is often not necessary to earth bond items using cables or wires; a resistance to earth of up to 100 M $\Omega$  may be acceptable based on a hazard evaluation.

In hazards evaluation, it has been found that the charging current is unlikely to exceed 1 microamp and is often orders of magnitude less. Limiting the resistance to less than 100 M $\Omega$  will lead to voltages no greater than 100 V, which is a safe level for electrostatic ignition prevention in most circumstances. Nevertheless 60079-32-1 specifies a general maximum resistance of 1M $\Omega$  for metal items. This can be increased to 100M $\Omega$  where the item capacitance is <100pF. For earthing

using direct metal-metal bonding, the resistance should be  $<10\Omega$  as higher resistance may be an indicator of corrosion of the bond.

Table 3. Maximum allowed capacitance in explosive atmosphere Zones (with no high charging processes present)

	Group I	Group IIA	Group IIB	Group IIC	Group III
Zone 0	10pF	3pF	3pF	no isolated conductors allowed	
Zone 1		6pF	3pF	3pF	
Zone 2		No requirements if hazardous voltages are unlikely to occur during normal operation including maintenance and cleaning			
Zones 20, 21 MIE $<10$ mJ					6pF
Zones 20, 21 MIE $>10$ mJ					10pF
Zone 22					No requirements if hazardous voltages are unlikely to occur during normal operation including maintenance and cleaning

Where conductive or dissipative coatings are used in a hazard zone, it is important that the coating is earthed and cannot crack or break up into isolated patches. Isolated patches of conductors could become the source of an electrostatic discharge. Fabrics are often rendered conductive or dissipative by inclusion of conducting fibres. The properties of the fabric must be maintained for its lifetime despite mechanical stress, flexing or cleaning, and isolated patches of conductive fibres must not be formed.

### Restriction of area of insulating materials

IEC 60079-32-1 recommends that where flammable gases or vapours may be present, use of insulating materials should be avoided or the surface area restricted (Table 4) in order to prevent incendive brush discharges. In general it is good practice to replace insulating materials with earthed dissipative or conductive materials where practical, unless it can be shown that the risk incurred due to possible electrostatic charging is negligible. In Zone 2 insulating materials may only be used if the process cannot generate hazardous voltages during normal operation, maintenance, cleaning. In Zone 1 likely malfunctions, and in Zone 0 rare and likely malfunctions must also be considered. In Zones 20, 21, 22 only the possibility of propagating brush discharges or sparks from isolated conductors need be considered.

Table 4. Examples of restrictions on areas or widths of insulating materials used in hazard zones given in IEC 60079-32-1

Zone	Group I		Group IIA		Group IIB		Group IIC	
	Max area (mm <sup>2</sup> )	Max width (mm)	Max area (mm <sup>2</sup> )	Max width (mm)	Max area (mm <sup>2</sup> )	Max width (mm)	Max area (mm <sup>2</sup> )	Max width (mm)
0	10 000	30	5 000	3	2 500	3	400	1
1			10 000	30	10 000	30	2 000	20
2			No size limit					

High resistance particulate materials can charge highly due to rubbing and impact of the particle surfaces against other particles and pipes. Fines can be generated from the particles that can have comparatively low MIE compared to the coarse particles and can easily form combustible dust clouds.

In practice, of course, the variability of ways in which conductors and insulators are part of the manufacturing processes, product and environment, can make evaluation and avoidance of ignition risk a far from simple task. For fuller details of common recommended precautions 60079-32-1 should be consulted.

Insulating coatings on earthed conductors could give brush or propagating brush discharges under some circumstances. These are unlikely to become incendive if high charging or repeated charging processes are avoided, and the layer is less than a maximum thickness (2mm thick for Group I, IIA and IIB, and 0.2mm for Group IIC).

Propagating brush discharges can occur with high charging processes. They are usually avoided if the insulating layer thickness is over 10mm or has breakdown voltage less than 4kV (or 6kV for woven fabrics).

## Use of ionisation

Ionisers use corona discharges to “spray” ions into a region of air. These can then migrate to materials to neutralise electrostatic surface charges. This process will only work if the supply of ions, and the rate at which they can travel to the surface, is greater than the rate at which surface charges are generating. The item to be neutralised must also remain in the ion rich region long enough for the neutralisation to occur.

## Liquid handling applications

60079-32-1 devotes forty seven pages to static electricity in liquids, which reflect the importance of this area in industry and number of processes and situations in which electrostatic problems can arise. Often a liquid in a process may simultaneously provide a flammable atmosphere, and be the source of electrostatic charging and possible discharge. The liquid flashpoint gives an indication of the minimum liquid surface temperature required to produce a flammable atmosphere, but it is often prudent to assume a flammable atmosphere could exist until the liquid surface is below the flash point temperature by a safety margin. Exposure of the liquid to heat sources including sunlight, and ventilation, can influence the presence of a flammable atmosphere and its ignition sensitivity.

The flammable vapour mixture most easily ignited by electrostatic discharges is approximately twice the lower flammable limit (LFL) vapour concentration and 10-20°C above the LFL temperature. Liquids around 0-10°C flashpoint often are most ignitable in ambient temperatures .

Liquids can become highly charged when they move relative to a solid (e.g. pipe), or when there are immiscible phases present. Items such as fine filters and processes such as stirring or mixing can increase charging. Even settling of solid particles or droplets can give electrostatic charging.

Liquids are classified as high, medium or low conductivity for hazards evaluation. Hazardous levels of charge accumulation are most often associated with low conductivity liquids. In 60079-32-1 these are liquids having conductivity  $< 25 \epsilon_r \text{ pSm}^{-1}$ , here  $\epsilon_r$  is the relative permittivity of the liquid. Many liquids such as hydrocarbons have  $\epsilon_r \approx 2$  and this corresponds to conductivity  $< 50 \text{ pSm}^{-1}$ . Alcohols, ketones and water have high conductivity. Low conductivity also corresponds to a long charge decay time (known in this case as relaxation time). Typical paraffins and aromatic compounds have conductivity around  $0.1 - 10 \text{ pSm}^{-1}$  and relaxation times of the order 2-200 seconds, and high charge levels and voltages can be maintained for considerable times.

All conductive parts of a liquid handling system should be earthed. High and medium conductivity liquids are effectively conductors, and need to be earthed, usually through pipes or other equipment with which they make contact. A sufficiently conductive liquid splash filled into a tank that has insulating lining and no earthing path, could become sufficiently charged to give incendive sparks. Personnel handling flammable liquids must also be earthed.

A low conductivity liquid passing through a pipe will become charged. If the liquid accumulated within a container or tank then the charge, and surface voltage, will also accumulate and high voltages can arise within the liquid and the vapour space. If the surface voltage exceeds about 25kV, incendive discharges could occur between the liquid surface and metal parts of the tank. If isolated metal parts are present, including floating cans, ignitions could occur at much lower voltages.

Restricting charge generation and accumulation can be a useful control measure. Typically this can involve reducing flow rates and providing sufficient residence time for charge relaxation, particularly after high charge generating stages such as pumps and filters. Specific guidance for flow rate limiting in various situations is given in the document. Avoiding splash filling and avoiding stirring up immiscible phases (e.g. water at the bottom of a tank), and limiting stirring or agitation, and reducing pressure and throughput in liquid jet tank cleaning can also help reduce charge generation.

Avoidance of a flammable atmosphere can be one of the most effective ways of avoiding ignition hazards. This may entail avoiding or inerting vapour spaces. Switch loading practices that can leave an ignitable vapour in the vapour space should be avoided. Tanks that have contained volatile liquids may be cleaned and ventilated to remove flammable liquids and vapours.

Tanks are a topic that has considerable variation in practical applications. 60079-32-1 has about 16 pages on this topic, discussing specific hazards and control measures arising with use of tanks of large, medium and small sizes with high, medium and low conductivity liquids. Tanks and containers made from conductive and dissipative materials, and those having insulating surfaces, are covered. The use of liners, and design features such as floating roofs are also covered. Specific precautions for road and rail tankers are given.

The chapter goes on to discuss high charging equipment such as filters, water separators and strainers and pumps.

Procedures such as gauging and sampling can cause ignition risk due to charged personnel or charged liquid surface. Typical prevention measures include that personnel and conductive or dissipative equipment involved in the process must be earthed. These measures will not, however, reduce the risk of a discharge from charged liquid surface. This risk may be addressed by using fixed gauging or gauging within a fixed earthed dip pipe extending to the bottom of the tank. Otherwise, gauging and sampling from above the liquid surface should not be done during charge generating operations (e.g. pumping liquid or cleaning procedures). For a low conductivity liquid, a delay of 30 minutes may be needed to allow mixing or settling, including water or particles. Gauging or sampling should not be done through the open manhole of an inerted container as the inerting will be compromised by even a few seconds opening. They should not be done if there is a possibility of thunderstorms, snow or hailstorms or other adverse atmospheric electrical conditions.

The topic of pipes is another of great variation with application and conditions. 60079-32-1 classifies pipes according to their electrical resistance per unit length as conductive, dissipative, insulating, or conductive or dissipative with an insulating lining. Different considerations apply depending on whether they are above, or below ground. Insulating pipes are classified as those having a resistance per unit length  $\geq 1\text{M}\Omega/\text{m}$ . Liquids flowing through insulating pipes can generate high charge levels and voltages at the pipe walls. These can lead to incendive discharge inside or outside the pipe. High electrostatic fields can extend outside the pipe and give discharges between nearby conductive objects and personnel. High field strengths can lead to breakdown and puncturing of the pipe wall. If damp air can enter, moisture may condense and form conductive puddles that can provide spark discharges to other conductive items. Consequently, use of insulating pipes may often need to be avoided unless the risks have been evaluated carefully.

One area in which insulating pipes have found widespread application is in retail petroleum forecourt filling station applications. This has been a hot topic in the industry and 60079-32-1 includes a section specifically on the application, outlined below.

About three pages are given to plant processes that can provide ignition risks due to static electricity. These include blending, stirring, mixing, crystallisation and stirred reactors. Electrostatic charge can develop in low or even medium conductivity liquids or on suspended liquid or particulates or isolated metal parts. High levels of charge generation often occur where immiscible phases are present and so these are subject to flow rate restrictions. As usual, all metal or conductive parts including personnel must be earthed.

Where a mixture being blended contains dispersed liquid or solid particles with low conductivity liquids, using a more conductive liquid or static dissipative additive can reduce static charge generation. If a dispersed solid phase is present it may be necessary to increase the conductivity of the continuous phase to as much as  $1000\text{psm}^{-1}$  and reduced the power input into the stirrer. If the blending vessel has an insulating lining, earthed conductive plates should be present near the bottom of the vessel to help charge relaxation. The possibility of propagating brush discharges and pinhole damage to the insulating lining should be considered.

Jet mixing of medium or high conductivity liquids is not normally problematic providing the jet does not break the liquid surface and all metal parts of the equipment are earthed. Where a low conductivity liquid is used and inerting or use of a static dissipative additive is not possible, expert analysis may be needed to control the risks. High speed mixing of immiscible liquids is another area where specialist advice may be needed.

60079-32-1 also covers liquid spraying and tank cleaning with water or solvent jets and low conductivity liquids and steam. Spraying liquids can produce a highly charged mist. The risks in liquid spraying and tank cleaning depend on the circumstances. When washing tanks with liquid jets from high throughput nozzles, liquid "slugs" can form that can be a source of incendive discharges. Liquid gathering and spilling from ledges can produce a similar risk.

Surprisingly, low conductivity liquids charge less than water during spraying. However the presence of a second phase such as water or particulates can change the situation, and solvent should only be recirculated if the contaminant is less than 0.5%. Liquid should be drained from the tank to prevent charge build-up with the accumulating liquid.

Tank cleaning using high pressure water or solvent jets can produce high charge and voltage levels but experience has shown that the ignition risk for tanks containing hydrocarbon/air atmospheres is acceptable in some circumstances. Spraying water in cylindrical container up to 3m diameter with a spray head operating up to 500 bar and flow rates up to  $1\text{ l s}^{-1}$  is considered acceptable. Spraying low conductivity liquids is limited to containers up to  $5\text{ m}^3$  volume with the spray head operating up to 50 bar and  $1\text{ l s}^{-1}$  maximum throughput.

Stem cleaning produces an electrostatically charged mist but this does not give an ignition risk for tanks up to  $100\text{ m}^3$  volume.

### Static electricity in gases

Movement of pure gases does not produce significant static electricity any solid or liquid particles present can become highly charged. This is common in industrial processes either as contamination or as a material that is part of the process. This can lead to spark discharges from isolated conductors, or brush or propagating brush discharges from insulator surfaces. Where particles collect e.g. in a silo, cone discharges can also occur. The preventive measures include grounding of conductors, avoiding use of insulating materials, reducing charge densities on material (by flow restriction or other means). Specific guidance is given for grit blasting, fire extinguishers, inerting, steam cleaning, accidental leakage of compressed gas, paint and powder spraying and vacuum cleaners.

### Powder handling

Explosion hazard evaluation of powders must always be based on the MIE. This must be measured using the smallest particle fraction, passed through a  $63\mu\text{m}$  sieve. If the MIE is  $>1\text{J}$  and there are no flammable vapours or gasses present no electrostatic precautions are probably required, unless there is a risk of propagating brush discharges. Where solvent vapours or gasses are also present these may form a much lower MIE atmosphere.

Powders and particulate materials are classified also according to their volume resistivity and low, medium or high resistivity. Electrostatic charging will normally occur during powder handling. This can lead to spark, brush or propagating brush or cone discharges. In practice brush discharges do not form an ignition risk to powders unless there is a flammable vapour or gas present.

The usual precautions of earthing conductive parts and replacing insulating materials with earthed conductive or dissipative materials also apply to powder handling. Earthing a conductive object is not required if it can be shown that the maximum possible spark energy is less than the MIE of the material. There are also other specific measures that may be considered. The conductivity of the bulk material may be increased using a conductive coating, and increasing humidity to 70% r.h. may be used to assist charge dissipation. Ionisation may be used to neutralise charge, and charge generation may be reduced by limiting conveying speed. Avoiding large heaps of material will help avoid charge accumulation and reduce the risk of cone discharges.

Specific precautions are given for dust separators and silos or containers. Filter fabrics made from earthed conductive material should always be used if flammable vapours or non-metallic conductive powders with MIE <30mJ are present. These should also be used where metallic dusts with MIE < 30mJ are present providing dry media dust collectors are not prohibited for the material.

Static electricity risks can arise with bulk powders in all sizes of container including small mobile containers, bins, drums, bags and FIBCs, and silos. 60079-32-1 gives three flow diagrams to aid assessment of the electrostatic charging based on materials of low, medium or high conductivity. Conductive and dissipative silos and containers should be earthed during filling and emptying.

Insulating liners should in general be avoided due to the risk of propagating brush discharges occurring. They may be used if the volume is <0.25m<sup>3</sup> or the breakdown voltage is < 4kV (or <6kV for woven materials) or the liner thickness is > 10mm. If the bulk material has resistivity <100MΩ it must be earthed, for example by inserting an earthed metal rod into the bottom of the container before adding material. Insulating containers should also in general be avoided. Conductive liners should not in general be used in insulating containers, as there is a risk they may become isolated from earth and a source of an incendive discharge.

Great care and additional precautions may be needed where flammable gasses and vapours are present while handling bulk materials. Handling materials over 100MΩ in the presence of vapours or gases should be avoided where possible although it may be possible using measures such as inerting, processing under vacuum or well below flash point, within explosion proof equipment or other measures. Materials < 100 MΩ resistivity should be handled in equipment that provides a reliable earthing for the material.

Filling a container that has flammable gases or vapours can produce various risks and should preferably be done in a closed inerted automated system. Manual addition of powders to an open container with flammable atmosphere present should be avoided where possible, although special measures that can be taken to reduce charge build-up are given in the document. .

Fabric Flexible Intermediate bulk containers (FIBC) are widely used for storage and transport of powders and granules. Electrostatic charge can be generated during filling and emptying and on the material or any part of the FIBC. Spark, brush, propagating brush and cone discharges can occur. Several types of FIBC are available to address the risks arising in different circumstances. The usage of the different types is shown in Table 5.

Type A FIBCs are made from ordinary fabric or plastic sheet and do not include any protection against static electricity. They may only be used with dusts of MIE >1000mJ

Type B FIBCs are designed to eliminate the risk of sparks or propagating brush discharges. They are made from fabric or sheet designed to have breakdown voltage <4kV (sheet) or 6kV (fabric).

Type C FIBCs are made from conductive fabric or sheet or fabric interwoven with conductive threads. They are designed to prevent sparks, brush and propagating brush discharges when connected to earth during filling and emptying. It is extremely important to have an effective reliable earth connection as an unearthed bag could become the source of an incendive discharge.

Type D FIBCs are made from static protective material. They are designed to prevent sparks, brush and propagating brush discharges without the need for a connection to earth. They should only be used with gas or vapours having MIE ≥ 0.14mJ.

Table 5. Usage of FIBC types

Bulk product MIE	Flammable atmosphere		
	Non flammable atmosphere	Dust Zone 21, 22	Zone 1, 2 (Group IIA, IIB)
MIE > 1000mJ	A, B, C, D	B, C, D	C, D
3 mJ < MIE ≤ 1000mJ	B, C, D	B, C, D	C, D
MIE < 3 mJ	C, D	C, D	C, D

Three liner types are also defined for use with FIBCs. The permitted combinations are given in Table 6.

Type L1 liners are made from materials having surface resistivity ≤10<sup>7</sup>Ω on at least one surface, and where necessary, breakdown voltage through the material <4kV.

Type L2 liners are made from materials with surface resistivity on at least one surface between 10<sup>9</sup>Ω and 10<sup>12</sup>Ω, and breakdown voltage through the material <4kV.



Type L3 liners are made from materials with surface resistivity  $>10^{12}\Omega$ , and breakdown voltage through the material  $<4kV$ .

Table 6. Permitted combinations of inner liner and FIBC

FIBC Type	Liner		
	L1	L2	L3
B	not permitted	permissible	permissible
C	permissible	permissible	not permitted
D	not permitted	permissible	not permitted

Isolated metal items such as tools, bolts, clips can be the source of incendive discharges and should not be placed on, or attached to, FIBCs. Contamination with water, oil, grease or other materials can create an ignition risk. All conductive items within about 1m of FIBCs should be earthed during filling and emptying.

### Static electricity on people

Personnel have a capacitance around 100 - 200 pF and energy stored on the body can exceed the MIE of hydrocarbons when charged to a few kV. This level of voltage can easily accumulate on the body due to everyday actions such as walking on an insulating floor material or rising from a seat. For this reason personnel working with a flammable atmosphere with MIE  $< 10mJ$  must be earthed. Usually this is best done by having a conductive or dissipative floor and wearing dissipative footwear, but other methods may occasionally be used.

60079-32-1 recommends that when operating in hazardous areas, the electrical resistance from a person's body to earth should be less than 100 M $\Omega$ . This is achieved using dissipative footwear and a dissipative floor. The floor should have resistance to earth less than 100 M $\Omega$ . Some conventional floor materials such as concrete and steel grids have suitable leakage resistance. Common coatings such as paints and epoxy, and plastic or rubber mats, put an insulating layer over the floor and prevent earthing of personnel. Build-up of contaminants over time can cause a similar effect.

The "dissipative" resistance range for footwear in 60079-32-1 is within the range called "antistatic" in ISO20345, but the range for "antistatic" footwear extends to  $10^9\Omega$  whereas the "dissipative" range upper limit is  $10^8\Omega$ . When purchasing "antistatic" PPE footwear to ISO 20345 for use in Zone 1 or 2, it would be prudent to check that the resistance of the footwear, when worn, falls within the required range.

Although modern clothing is often made from synthetic materials that can become highly charged, it is not normally an ignition risk providing it is reasonably close fitting and the wearer's body is reliably earthed. Loose and unfastened clothing can provide a risk, and clothing should never be removed in a hazard Zone 0, 1, 20 or 21. Static dissipative clothing may be required where high charging activities and low MIE gases or vapours are present.

Metal hand tools can become electrically isolated if insulating gloves are worn. When the intended path to earth for conductive objects or tools held in the hand is via a person wearing gloves, for general use the resistance to earth via the gloves should be less than 100 M $\Omega$ .

Table 7. Requirement for electrostatic dissipative protective clothing or PPE

Zone	Probability of charging	$0.02 \text{ mJ} \leq \text{MIE} \leq 0.2 \text{ mJ}$	$\text{MIE} > 0.2 \text{ mJ}$
0	High	required	required
	Low		recommended
1	High	recommended	not required
	Low		
2	High	recommended	not required
	Low	not required	
20, 21, 22		not required	

Protective clothing, helmets and visors and other PPE made from polymer materials may often exceed the area limits specified above and could become charged. 60079-32-1 gives specific recommendations for use of static dissipative clothing and PPE in Zones (Table 7). Some activities such as wiping a visor or removal of clothing can give high charge generation and ignition risks. Clothing should be as close fitting as practical and should not be unfastened or removed in a flammable atmosphere Zone 0, 1, 20 or 21.

## Earthing and bonding

A chapter on earthing and bonding covers criteria for dissipation of static electricity from a conductor, earthing requirements in practical systems, and establishment and monitoring of earthing systems.

### Annexes

Fifty three pages of informative Annexes are given in the document. The first of these covers the fundamentals of static electricity (electrostatic charging, accumulation of charge, electrostatic discharges and measurements for risk assessment).

Annex B gives detailed information on electrostatic discharges likely in specific situations. This includes incendive brush, spark, propagating brush and cone discharges produced from solid insulating materials and during liquid and powder handling. Annex C reviews the flammability properties of flammable materials including the effect of oxygen concentration and ambient conditions (temperature and pressure), explosive limits, inerting, flash point, minimum ignition energies, combustible powders and biofuels. Annex D summarises classification of hazardous areas including the concept of zoning, zone classification and explosion Groups. This is just a summary of other standards in the IEC 60079 series such as IEC 60079-10. Similarly, Annex E summarises classification of protection level of equipment to be used in a hazardous area. Annex F gives a flow chart methodology for systematic electrostatic evaluation.

Annex G gives test methods for use in electrostatic control. It includes basic test methods such as surface resistance and resistivity, and leakage resistance to earth for floors and other items. There are also other material measurements such as powder and liquid resistivity (conductivity). Methods of in-use footwear personal grounding test, and in-use testing of gloves, are given.

There are also material test methods that are not related to resistance or conductivity. These include charge decay after corona charging, and breakdown voltage of a sheet sample.

A method of measuring the capacitance of isolated conductors using a hand-held capacitance meter is described. There are also more specialist tests including the measurement of charge transferred in a discharge, and ignition test (IEC 61340-4-4) for evaluating the incendivity of a discharge.

## Some specific industrial situations

The 60079-32-1 document gives specific advice on some common situations and facilities, although the full range occurring in industry cannot of course be covered.

### Aircraft fuelling

The topic of aircraft fuelling is discussed, although this is covered in detail in API/IP RP 1540. Fuel transfers can involve mobile fuelling equipment and hoses, filters pumps and water separators, or on small airfields simple transfer from a drum. Charge is generated during fuel transfer and earthing and bonding of the aircraft and fuelling equipment is important. However stray earth currents from power or cathodic protection systems must be avoided and can also form an ignition risk. Precautions against these must be consistent with precautions against electrostatic ignition risks.

### Retail petroleum filling stations

Plastic pipes have found widespread application in retail petroleum forecourt installations in recent decades, in moving fuel between road tanker delivery, tanks and filling dispensers. As well as insulating pipes there are so-called “conductive” pipes that typically have a co-extruded dissipative lining layer. There has been much debate in the industry regarding the safety of using insulating pipes. 60079-32-1 has responded with a 4 page summary of the electrostatic considerations on use of different pipe systems and specific risks that could arise with each.

A significant risk with insulating pipes is that fuel flow could lead to charging and high voltage build up on the pipe internal surfaces. This could lead to internal surface discharges, or discharges through the pipe wall forming pinholes. High electrostatic fields can be produced externally that can cause high voltages and discharges between conductive objects outside the pipes. Pipes are joined using connectors that have integral metal ElectroFusion Couplers (EFCs), and these can become charged and the source of a discharge. For “conductive” pipes with an earthed inner dissipative lining, charge build-up is prevented and the lining acts as a shield that prevents external electrostatic fields. If, however, lining sections become unearthed, voltages could build up on the lining and associated connectors. These could then be a possible source of incendive discharges and external electrostatic fields are once again present. This could happen if insulating and conductive pipes are mixed in an installation.

There is, however, a substantial record of safe use of both types of pipe with few recorded incidents. The risks are greatly reduced by following recommended precautions. Pipes have a minimum breakdown voltage of 100kV to avoid pin holing. Burial eliminates the risk of external flammable atmospheres and discharge for much of the system, and unburied systems are kept as short as possible. In particular, pipes and joints in sumps where vapours could accumulate are minimised.

Fuel flow rates are limited to  $0.28\text{ms}^{-1}$  to reduce fuel charging. Fine filters are not used without careful evaluation of the risks. Personnel avoid brushing against plastic pipe surfaces where flammable atmospheres may be present. During maintenance, care must be taken to avoid bringing a highly charged pipe into a flammable atmosphere.

All conductive and dissipative elements in the pipe system are earthed, either by burial or earth bonding. EFCs may alternatively be sealed with an airtight seal to prevent discharges occurring. Earthing must be checked on a regular basis. During maintenance, dissipative liners must be earthed before the pipe is introduced into a flammable atmosphere and the ground connection maintained until reliably grounded in the installed system.

At the dispensing facility, the pump and nozzles must be connected using an electrically bonded hose and earthed. The nozzle should be designed so that the operator is earthed via the nozzle during operation. The forecourt surface must have leakage resistance to earth  $<100\text{M}\Omega$  in order to earth vehicles via their tyres. Other guidance is given regarding the design of the vehicle and tyres for safe fuelling.

## Some specific requirements for products

In some cases, specific requirements for products used in avoidance of electrostatic hazards or effects are given. A selection of these are outlined here.

### Conveyor belts and transmission belts

Conveyor and transmission belts can generate charge due to the contact of the belt with its rollers or pulleys. If the belt is made of insulating materials the charge can build up and incendive discharges could occur. Charge generation increases with the operating speed, tension and belt width. This can be prevented if the belt is made of sufficiently dissipative materials and a path to ground is provided through pulleys or rollers.

A conveyor belt is considered dissipative if the surface resistances on both sides of the belt are  $<300\text{M}\Omega$  measured according to ISO 284 and EN14973 or  $75\text{M}\Omega$  when measured according to a method specified in 60079-32-1. Where a belt is made from material layers, the resistance between the two opposing surfaces must be  $<1\text{G}\Omega$ . However other standards exist (e.g. ISO 21183-1 and ISO 21178 and ISO 21179) for conveyor belts used in particular applications, and must be used if applicable.

60079-32-1 gives a table of specific requirements for use of conveyor belts in flammable atmosphere Zones 0, 1 and 2 for equipment Groups IIA, IIB and IIC, and Zones 20, 21 and 22 and with dusts having MIE  $<10\text{mJ}$  and  $>10\text{mJ}$ , for various belt speed ranges. The reader is referred to the standard for full details of these. Similar information, guidance and requirements are given for transmission belts.

### Hoses and hose assemblies

Hoses have been developed in different industries for different purposes. Often they are defined and classified by product specific standards such as ISO 8031, ISO 8028 and EN 12115. They may have electrical requirements unrelated to static electricity, such as for prevention of stray earth currents or electrical bonding of equipment. The topic of hoses alone takes nearly 8 pages!

Once again, 60079-32-1 gives an overview of the electrostatic risks associated with use of these with flammable liquids or vapours present. Aspects such as avoidance of isolated conductors such as clips and fittings, measures for avoidance for brush and propagating brush discharges, and discharges from isolated conductive liquid pools are covered. ISO 8031 hose classification, properties and usage are explained.

## Conclusions

The new IEC 60079-32-1:2013 document gives a substantial amount of information and guidance for avoidance of electrostatic hazards and shocks to personnel in industrial processes, compiled by a team of experts from 15 countries. It gives a substantial amount of instructive information on the principles of static electricity and its control, with particular application to flammable atmosphere ignition risks. As well as this, about 70% of the document is devoted to specific application of these principles in various industry process situations involving flammable gas and dust cloud hazard zones. Hazards arising with solid materials, liquid handling and gaseous systems are covered. Various types of electrostatic discharge source including charged personnel are described and methods of preventing these are specified. This document is expected to be an extremely valuable resource and source of guidance for process industry where flammable materials are handled or electrostatic nuisance shocks or other effects may arise.

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