

R044-001

Safety of machinery
Guidance and recommendations for the avoidance
of hazards due to static electricity

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Foreword

This CENELEC Report has been prepared by the Technical Committee CENELEC TC 44X, Safety of machinery: electrotechnical aspects.

The text of the draft was approved by CLC/TC 44X on 1997-11-07. Publication was authorized by the CENELEC Technical Board on 1999-01-01. CENELEC BT decided that the maintenance of this CENELEC Report will be undertaken by the Technical Committee CENELEC TC 31, Electrical apparatus for explosive atmospheres - General requirements.

This CENELEC Report is based on a number of documents including two national Codes of Practice: from the UK, BS 5958: Parts 1 & 2:1991, *Control of undesirable static electricity*; and from Germany, ZH 1/200: October 1989, *Code of Practice for preventing risks of ignition due to electrostatic charges: Guidelines in static electricity*, and a document published by Shell International Petroleum: *Static electricity - Technical and safety aspects*. It recommends good, accepted practice as followed by competent practitioners and brings together the results of practical experience and scientific investigation for ease of access and use of information.

This CENELEC Report takes the form of guidance and recommendations. It should not be quoted as if it were a specification and particular care should be taken to ensure that claims of compliance are not misleading. It may be used after a risk assessment in the preparation of product family or dedicated product standards for machines (i.e. type C standards in CEN, as defined in EN 414: 1992, 3.1). The guidance can also be used by suppliers of equipment (e.g. machines) for which no product family or dedicated product standard exists. Where a product family or dedicated product standard exists its requirements take precedence.

1 Scope

This document gives guidance and recommendations for avoiding ignition and electric shock hazards arising from static electricity.

It deals with the problems of static electricity that can give rise to ignition of flammable substances and to electric shock. Basic information about the generation of undesirable static electricity in solids, liquids and gases, and also on persons, together with descriptions of how the charges generated cause ignitions or electric shocks, is given in the annexes.

The processes that most commonly give rise to problems of static electricity are described in detail. The processes include the handling of different types of liquids, powders, gases and sprays. In each case, the source and nature of the electrostatic hazard are identified and specific recommendations are given for dealing with them.

This report is not applicable to the hazards of static electricity relating to lightning, to damage to electronic components, to medical hazards nor to the handling and care of detonators and explosives.

2 Definitions

Regulations relating to safety and electrostatics make use of many adjectives in order to quantify the conducting ability of materials. Different regulations and different industries use different adjectives; even when the same adjectives are used their definitions can vary. In order to avoid confusion, and to assist with translation, the adjectives normally used to quantify the resistance of a material in this document are conductive, dissipative and non-conductive (see 2.6, 2.8 and 2.9). However, in parts of the document liquids are also described according to their conductivities (see 5.1) and powders according to their resistivities (see 7.2.1).

NOTES

1 - The values given in the following definitions are the generally accepted ones. However, in parts of the document the values quoted in the text differ from those in the definitions. This is because the process, the method of handling or the material being handled is sufficiently unusual that a different (higher or lower value) is required.

2 - Several types of electrical discharge are frequently mentioned in this document; they have not been defined but they are described in detail in annex A.

For the purpose of this report the following definitions apply:

2.1 **volume resistivity**: The resistance of a body of unit length and unit cross-sectional area.

2.2 **surface resistivity**: The resistance across opposite sides of a surface of unit length and unit width commonly expressed in ohms/square.

2.3 **surface resistance**: The resistance between two parallel electrodes, each 100 mm long and 10 mm apart, in contact with the surface to be measured.

2.4 **leakage resistance**: The resistance between an electrode (usually circular and 20 cm² in area) in contact with the surface to be measured and earth.

NOTE - The resistance depends upon the volume or surface resistivity of the materials and the distance between the chosen point of measurement and earth.

2.5 **conductivity**: The reciprocal of volume resistivity.

2.6 **conductive**: An adjective describing a material incapable of retaining a significant electrostatic charge when in contact with earth and having a volume resistivity equal to or lower than 10⁴ Ωm. (for certain items there are special definitions e.g. conductive hose).

2.7 **conductor**: A conductive object.

2.8 **dissipative (electrostatic dissipative)**: An adjective describing a material incapable of retaining a significant amount of electrostatic charge when in contact with earth. These materials have a volume resistivity

higher than $10^4 \Omega\text{m}$ but equal to or lower than $10^9 \Omega\text{m}$, or a surface resistivity less than $10^{10} \Omega$ (or surface resistance less than $10^9 \Omega$) measured at ambient temperature and 50 % relative humidity.

2.9 **non-conductive:** An adjective describing a material having a volume resistivity higher than $10^9 \Omega\text{m}$ measured at ambient temperature and 50 % relative humidity (many materials, e.g. polymers, have volume resistivities much higher than this value).

2.10 **non conductor:** A non-conductive object.

2.11 **antistatic (deprecated):** An adjective commonly used as a synonym for conductive or dissipative describing a material that is incapable of retaining a significant electrostatic charge when in contact with earth. In this context the word is commonly used to describe a type of footwear and antistatic additives (ASAs) for use with liquids.

2.12 **electric shock:** Pathophysiological effect resulting from an electric current passing through human or animal body. [IEV 826-03-04]

2.13 **relaxation time:** The time during which the electrostatic charge on a solid surface, in the bulk of a liquid or powder, or in a cloud of mist or powder, decays exponentially to $1/e$ (i.e. about 37 %) of its original value.

2.14 **hazardous area:** An area in which flammable or explosive gas/vapour-air or dust-air mixtures are, or can be, present in such quantities as to require special precautions against ignition.

2.15 **two-phase liquid:** A mixture of two immiscible liquids which, when settled, forms two separate phases with a distinct interfacial boundary.

2.16 **dissipative footwear:** Footwear that ensures that a person standing on a conductive or dissipative floor has a resistance to earth of more than $10^5 \Omega$ but less than $10^8 \Omega$.

2.17 **conductive footwear:** Footwear ensuring a resistance to earth typically of less than $10^5 \Omega$.

2.18 **dissipative clothing:** Clothing made from a material with a surface resistivity typically less than $5 \times 10^{10} \Omega$ per square (see EN 1149-1).

2.19 **minimum ignition energy (MIE):** The minimum energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure.

3 General

Static electricity occurs commonly in industry and in daily life. Many of the effects are harmless and either pass completely unnoticed or are simply a nuisance, but static electricity can also give rise to a hazardous situation. Hazards caused by electrostatic charge include:

- ignition and/or explosion;
- electric shock in combination with another hazard (e.g. fall, trip) - see EN 292-1, 4.3 and 4.10;
- electric shock giving rise to injury or death, see EN 292-1, 4.3.

In addition, static electricity introduces operational problems during manufacturing and handling processes, e.g. by causing articles to adhere to each other, or by attracting dust.

It is generated by:

- the contact and separation of solids e.g. the movement of conveyor belts, plastics film, etc. over rollers, the movement of a person;
- the flow of liquids or powders, and the production of sprays;
- an induction phenomenon, i.e. objects becoming charged due to being in an electric field.

The accumulation of electrostatic charge can give rise to hazards and problems in a wide range of industries, and to ignition and explosion hazards particularly in chemicals, pharmaceuticals, petroleum and food processing industries.

The purpose of this guidance is to provide recommendations for the control of static electricity. In some cases static electricity plays an integral part of a process, e.g. paint spraying, but more often it is an unwelcome side effect and it is with the latter that this guidance is concerned.

Because of the large number of industrial processes which could be involved it is not possible to give detailed information relevant to all of them. Instead, the guidance attempts to describe the problems associated with each process and to give recommendations on how to avoid them. This information should enable the plant operator to take whatever precautions could be necessary to avoid ignitions of potentially explosive atmospheres and electric shocks.

For convenience the guidance is divided into a number of clauses. These deal with problems associated with the following:

- the handling of solids;
- the storage and handling of liquids;
- the handling of gases and vapours;
- the storage and handling of powders;
- electrostatic problems caused by persons;
- avoidance of electric shock;
- earthing and bonding of plant and machinery.

The guidance also contains some fundamental information relating to electrostatic charging and its problems. This is contained in the annexes and it should enable the reader to better understand the advice given and also to extend the advice to processes that have not been dealt with in the guidance.

It is very seldom that an electrostatic hazard can be treated in isolation. Precautions against electrostatic hazards should be in addition to other precautions, e.g. explosion protection. They should also be consistent with precautions taken to avoid other hazards that may be present, such as ignitions due to other causes, and toxicity. It is important that all sources of risk in a system of work are considered and that a balanced approach to safety covering all risks be considered. In particular, care should be exercised in the provision of earthing systems where they can interfere with other protective systems, e.g. cathodic protection or intrinsically safe electrical equipment.

4 Static electricity in non-conductive solid materials

4.1 General considerations

Non-conductive solid materials are being used increasingly in equipment and structures in many forms including pipes, containers, sheets, coatings and liners. Many of these materials have volume resistivities greater than $10^{12} \Omega\text{m}$ and their use in hazardous areas can give rise to the following electrostatic hazards:

- the material could insulate conductive objects from earth which could become charged and give rise to sparks;
- charges on the surface of the material could lead to brush discharges;
- a combination of conductive and non-conductive materials in the presence of prolific charge generators (e.g. pneumatic transfers of powders, spraying of charges) could lead to very energetic propagating brush discharges.

The use of non-conductive materials needs to be restricted in some hazardous areas. The restrictions depend on the zone classification of the hazardous area (see annex D):

- in Zone 0, non-conductive solid materials should only be used if charging mechanisms capable of generating hazardous potentials will not occur either during normal operation (including maintenance and cleaning) or even in the case of rare malfunctions;
- in Zone 1, non-conductive solid materials should only be used if charging mechanisms capable of generating hazardous potentials will not occur either during normal operation (including maintenance and cleaning) or in the case of likely malfunctions;
- in Zone 2, non-conductive solid materials may be used unless their use results in the occurrence of frequent incendive discharges during normal operation;
- in the dust Zones 20, 21 and 22 there are, in general, no restrictions on the use of non-conductive materials unless there is a possibility of incendive discharges (see annex C).

NOTE - Many powders and dusts are non-conductive materials and recommendations for the avoidance of electrostatic hazards associated with powders are given in clause 7.

4.2 *Dissipative solid materials*

A solid material is defined as dissipative if its surface resistance does not exceed $10^{11} \Omega$. However, since surface resistance normally increases considerably with decreasing humidity the upper limit will depend on relative humidity. When testing materials, this value is acceptable only if it is measured at a relative humidity of less than 30 %. For measurements at 50 % relative humidity the upper limit is $10^9 \Omega$.

Providing that materials which meet these values of surface resistance are connected to earth no further protective measures need to be taken. In processes involving high speed separation (e.g. conveyor and transmission belts, see 4.5.3 to 4.5.5) other values can be required.

4.3 *The use of conductive or dissipative materials in place of non-conductive ones*

It is good practice to minimize the use of non-conductive materials in hazardous areas and there are many materials which used to be entirely non-conductive, e.g. rubbers or plastics, that are now available in grades which are dissipative, i.e. they comply with the requirements of 4.2. However these grades normally contain additives such as carbon black and the high proportion of carbon black required can degrade the physical properties of the material.

In some cases conductive or dissipative coatings are used to make the non-conductive material non-chargeable. However, the durability of these applications and their suitability for use in hazardous areas of Zone 0 and Zone 1 has yet to be proven. In any case, it is important that the conductive coating is properly earthed.

Fabrics, e.g. filter cloth, can be made dissipative by incorporating stainless steel or other conductive or dissipative fibres in the fabric. Care has to be taken to ensure that, as a result of washing or mechanical stress, the overall conductivity of the fabric is maintained and isolated patches of conductive fibres are not formed.

4.4 *Precautions required when using non-conductive solid materials*

4.4.1 General

To prevent incendive discharges the precautions given in 4.4.2 to 4.4.8 should be taken in all zones where the use of non-conductive solid materials is unavoidable.

The precautions given in 4.4.2 relate to avoidance of spark discharges, those given in 4.4.3 to 4.4.7 to incendive brush discharges, and those given in 4.4.8 to propagating brush discharges.

4.4.2 Unearthed metal and other conductive materials

With the exception of very small items, all metal and other conductive material should be bonded to earth (see Table 6, clause 10).

4.4.3 Restrictions on the size of chargeable surfaces

The restriction on the size of chargeable surfaces depends on the ignitability of the gases and vapours (expressed by the representative groups IIA, IIB and IIC, see EN 50014) and the classification of the hazardous area:

- (a) for sheet materials the area is defined by the exposed (chargeable) area;
- (b) for curved objects the area is the projection of the object giving the maximum area;
- (c) for long narrow materials, such as cable sheaths or pipes, the maximum size is defined by the transverse dimension (i.e. the diameter for a cable sheath or pipe); when it is coiled it should be treated as for a sheet (see item a).

It is essential that non-conductive solid materials used in hazardous areas do not exceed the maximum area or width values given in Tables 1(a) and 1(b) for the zone within which it is used.

Table 1: Restriction on area or width values of non-conductive solid materials in hazardous areas containing potentially explosive atmospheres of groups IIA, IIB and IIC

(a) Restrictions on areas

Zone	Maximum area, cm ²		
	Group IIA	Group IIB	Group IIC
0	50	25	4
1	100	100	20
2	No limit (see 4.1)	No limit (see 4.1)	No limit (see 4.1)

(b) Restrictions on widths of narrow materials (e.g. pipes, cable sheaths)

Zone	Maximum width, cm		
	Group IIA	Group IIB	Group IIC
0	0,3	0,3	0,1
1	3,0	3,0	2,0
2	No limit (see 4.1)	No limit (see 4.1)	No limit (see 4.1)

NOTE - Even smaller diameters can be required for narrow pipes (or tubes) containing flowing liquids or powders.

4.4.4 Brush discharges from thin non-conductive layers or coatings on conductors

Layers or coatings of non-conductive solids on earthed conducting surfaces (in particular metal surfaces) will not give rise to incendive brush discharges if the thickness of the layer does not exceed a value of 2 mm in the case of gases and vapours of groups IIA and IIB and a value of 0,2 mm in the case of gases and vapours of group IIC. In those cases no special protective measures are necessary within hazardous areas. It should, however, be noted that in the presence of very efficient charge generating mechanisms propagating brush discharges could occur (see 4.4.8).

4.4.5 Use of earthed metal meshes

If the restriction on size given in 4.4.3 cannot be met, incendive brush discharges can be avoided by incorporating an earthed mesh (or metal frame) into the non-conductive solid or by wrapping such a mesh around its surface. This method of protection is acceptable in hazardous areas providing that:

- the mesh size (i.e. the area contained by the wires) is restricted to a factor of four times the values given in Table 1(a);
- the layer thickness above the mesh is restricted to the values given in 4.4.4; and
- high charging mechanisms do not occur.

However, an internal mesh does not guarantee protection against propagating brush discharges (see 4.4.8).

4.4.6 Humidification

The surface resistivity of some non-conductive solid materials can be reduced to dissipative levels if the relative humidity is maintained above about 65 %. Even though damp air is not conductive, a film of moisture forms on the surface on many materials depending on the hygroscopic nature of the material. Whereas some materials such as glass or natural fibres form a sufficiently conducting film of moisture, other materials such as polytetrafluoroethylene (PTFE) or polyethylene do not. Increasing the relative humidity, therefore, is not effective in all cases and, in general, it should not be used as the sole protective measure, especially not in Zone 0.

4.4.7 Ionizing the air

4.4.7.1 General

Ionization of the air is a method of making the air locally conductive so that charges on non-conductive solid materials are dissipated. It is particularly useful for discharging plastic sheets or films. Methods that may be employed include those given in 4.4.7.2 to 4.4.7.4. Correct installation and regular maintenance is essential for those devices.

4.4.7.2 Passive ionizers

Pointed electrodes such as earthed sharp needles, fine wires or conductive tinsel produce corona discharges when placed in the electric field from a charged body. These provide ions which neutralize the charge on the body. This method, however, is limited in its effectiveness and should not be used in Zone 0.

4.4.7.3 Active ionizers

A more efficient method of producing ions is to apply a high voltage to a number of corona points. Commercial systems commonly use alternating voltages in the range 5 kV to 10 kV supplied to a row of points. The currents from the corona points are limited either by high resistance or capacitive coupling. For use in potentially explosive atmosphere of Zone 1 the ionizer has to be type tested and approved as electrical apparatus. Active ionizers should not be used in Zone 0.

4.4.7.4 Radioactive sources

Radioactive sources ionise the surrounding air and can be used to dissipate the charges from a charged body. Radioactive ionisation itself does not present an ignition hazard; however, it is limited in its effectiveness and should not be used in Zone 0.

4.4.7.5 Ionized air blowers

Ionized air blowers using either high voltages or radioactive sources are used mainly for dissipating charges from awkwardly shaped objects. However, the ion concentration can rapidly decrease downstream due to recombination or adsorption of the ions by the walls. As a result, it is difficult to convey the ionized air over large distances. Unless it is approved for use in a hazardous area, the parts containing the high voltages should be placed outside. This method of protection should not be used in Zone 0.

4.4.8 Propagating brush discharges from non-conductive layers and coatings on metal surfaces

Non-conductive layers or coatings can lead to propagating brush discharges (see B.3.9.) but this can be prevented by the following measures:

- (a) Avoid having thin non-conductive coatings on metals or other conductive materials. Propagating brush discharges tend to occur with thin coatings; they can normally be prevented by having thicknesses greater than about 10 mm;
- (b) Increase the surface or volume conductivity of the coating. It is not known exactly what value of surface resistance will prevent the occurrence of propagating brush discharges but the values of

surface and leakage resistances quoted in 4.2 and a leakage resistance less than $10^{11} \Omega$ are sufficiently low;

(c) Use a coating with a low dielectric strength (breakdown voltage <4 kV, see A.3.5) instead of one with a high dielectric strength. Coatings with a low dielectric strength tend to electrically break down before a propagating brush discharge can develop. Due to their slight porosity, layers of paint usually show a low breakdown voltage so that propagating brush discharges are difficult to obtain from such layers.

NOTE - Polymer films which are wound on to a reel or are lifted from a conductive or non-conductive surface can acquire bipolar charges i.e. equal and opposite charges on the two surface of the film. This can lead to brush discharges and occasionally even to propagating brush discharges.

4.5 Conveyor belts and transmission belts

4.5.1 General

Due to the continuous separation of the contacting surfaces, e.g. a driving shaft and a belt, the moving surface can acquire a considerable amount of charge and become an ignition hazard. The amount of charge acquired depends on the material of the conveyor belt as well as the materials of the driving shaft and the rollers. It will increase with the velocity and tension of the belt and the width of the area of contact.

4.5.2 Conveyor belts

Conveyor belts are endless belts which run over rollers and transport materials. Usually the conveyor belt is made of non-conductive material whereas the driving shaft and the rollers are made of metal.

The charge acquired by the belt can only be safely dissipated to earth via the earthed dissipative rollers if the conveyor belt is sufficiently dissipative (see 4.5.3).

4.5.3 Conductivity criteria for conveyor belts

A belt is considered to be dissipative if the surface resistances on both sides of the belt are below $3 \times 10^8 \Omega$. In cases where the belt consists of layers of different materials it is considered to be dissipative if the resistance through it does not exceed $10^9 \Omega$ (resistance measured at 23°C and 50 % relative humidity). Care should be taken to ensure that repairs do not increase the values given.

4.5.4 Conditions of use for conveyor belts

In Zone 0 and Zone 1 containing potentially explosive atmosphere of group IIC, conveyor belts which meet the criteria of 4.5.3 may be used providing the belt velocity is restricted to 0,5 m/s and belt connectors are not used.

In Zone 1 containing potentially explosive atmosphere of groups IIA and IIB, conveyor belts may be used if the belt velocity is restricted to 5 m/s; belt connectors are permitted. If the belt velocity exceeds 5 m/s the criteria for transmission belts apply (see 4.5.6).

In Zone 2 protective measures are not necessary unless experience shows that frequent discharges occur.

4.5.5 Transmission belts

Transmission belts are V-belts and flat belts which drive rotating parts or machines. Sometimes the belt materials are non-conductive whereas the pulleys are normally of metal. The amount of charge acquired by the belt due to the continuous separation of the contacting surfaces depends on the material of the belt and pulleys and increases with the velocity and tension of the belt and the width of the contact area.

4.5.6 Conductivity criteria for transmission belts

The belt material is sufficiently dissipative if:

$$R.B \leq 10^5 \Omega\text{m}$$

where R is the resistance measured at the inner side of the mounted transmission belt between an electrode halfway between the two pulleys and earth and B is the width of the flat belt or double the width of the side face of the V-belt.

In cases where the belt consists of layers of different materials the belt is considered to be dissipative if the resistance across it does not exceed $10^9 \Omega$ (resistance measured at 23°C and 50 % relative humidity). Care should be taken to ensure that repairs do not increase the value given.

4.5.7 Conditions of use for transmission belts

Transmission belts should not be used in Zone 0 and in Zone 1 containing potentially explosive atmosphere of group IIC.

In Zone 1 containing potentially explosive atmosphere of groups IIA and IIB, transmission belts may be used if the following criteria are met:

- (a) The belt velocity does not exceed 30 m/s (no information is available for higher velocities);
- (b) The belt material meets the conductivity criteria defined in 4.5.6;
- (c) The belt is earthed via the metal pulleys.

A layer of wax or dirt on the belt could increase the adhesiveness of the belt and also its resistance and this could increase the charging hazard. It is essential that layers of non-conductive adhesives used to connect the belt do not interrupt the conductive path. Belt connectors should not be used.

For low speed transmission belts, the criteria given in 4.5.4 for conveyor belts can be used.

5 Static electricity in liquids

5.1 General considerations

Liquids can become electrostatically charged when there is relative movement between the liquid and adjacent solids or there is a second immiscible phase. Spraying of liquids can also create a highly charged mist or spray. Further details of charge generation and charge accumulation in liquids are given in A.1.3 and A.2.2. The level of charge accumulation in a particular liquid (and therefore the electrostatic hazards that can be created) is strongly dependent upon the conductivity of the liquid. To describe the possible hazards and associated means of prevention the conductivities of liquids have been defined as follows:

high conductivities	> 1 000 pS/m;
medium conductivities	between 50 pS/m and 1 000 pS/m;
low conductivities	< 50 pS/m.

With the exception of processes that produce mists or sprays, a hazardous level of charging is encountered only with liquids of low electrical conductivity. The conductivities and relaxation times for a number of liquids are given in table 2.

NOTE: - For further details on the mechanisms of charging in liquids see annex A.

Table 2: Conductivities and relaxation times of some liquids

Liquid	Conductivity (pS m ⁻¹)	Relaxation time (seconds)
Low conductivity		
highly purified paraffins	10 ⁻²	2 000
typical paraffins	10 ⁻¹ - 10	2 - 200
purified aromatic compounds (toluene, xylene etc.)	10 ⁻¹ - 10	2 - 200
typical aromatic compounds	5 - 50	0,4 - 4
gasoline	10 ⁻¹ - 10 ²	0,2 - 200
kerosene	10 ⁻¹ - 50	0,4 - 200
gas oil	1 - 10 ²	0,2 - 20
white oils	10 ⁻¹ - 10 ²	0,2 - 200
lubricating oils	10 ⁻² - 10 ³	0,02 - 2 000
ethers	10 ⁻¹ - 10 ²	0,2 - 200
proprietary aromatic solvent mixtures	1 - 10 ³	0,02 - 20
natural gas condensate without corrosion inhibitor	10 - 10 ²	0,2 - 2
Medium conductivity		
fuels and oils containing dissipative additives	50 - 10 ³	0,02 - 0,04
heavy (black) fuel oils	50 - 10 ⁵	2 x 10 ⁻⁴ - 0,4
esters	10 ² - 10 ⁶	2 x 10 ⁻⁵ - 0,2
High conductivity		
crude oil	≥ 10 ³	≤ 0,02
natural gas condensate with corrosion inhibitor	≥ 10 ³	≤ 0,02
alcohols	10 ⁶ - 10 ⁸	2 x 10 ⁻⁷ - 2 x 10 ⁻⁵
ketones	10 ⁵ - 10 ⁸	2 x 10 ⁻⁷ - 2 x 10 ⁻⁴
water	≥ 10 ⁸	≤ 2 x 10 ⁻⁷
NOTE - In practice, liquids do not take more than 100 s for the charge to decay to a safe level.		

5.2 Ignition hazard

5.2.1 Occurrence of flammable atmosphere

NOTE - General information about flammability and ignitability of gaseous atmospheres is given in annex C.

When handling liquids, any flammable atmosphere that occurs is usually associated with the liquid being handled. If the flash point of the liquid is below that of its surface temperature, a flammable atmosphere should always be assumed to be present above the liquid surface. In cases where tanks are exposed to strong sunlight it should be assumed that a flammable atmosphere is present when liquids with a flash point up to 55°C are being handled. In areas of high ambient temperature and strong sunlight flammable atmospheres may occur with liquids with flash points above 55°C. When handling liquids with flash points well below the ambient temperature it should not be assumed that the atmosphere above the liquid is always saturated and, therefore, over-rich (i.e. non-flammable) unless it can be shown that a flammable atmosphere cannot be formed.

In some circumstances, however, the flammable atmosphere is not due to the liquid being handled but due to residues of volatile liquid from the previous load within the tank. This can occur during switch loading, i.e. when a liquid with a high flash point (e.g. gasoil) is being loaded into a tank which previously contained a liquid with a low flash point (e.g. gasoline). A high proportion of road tanker fires have been attributed to switch-loading.

5.2.2 Incendive discharges produced during liquid handling operations

When a tank is being filled with a charged liquid of low conductivity the charge accumulates in the liquid of the tank. This results in an electrical field (and potential) distribution both in the liquid and in the ullage space of the tank. At high levels of potential, brush discharges can occur between metallic protrusions in the ullage space and the surface of the charged liquid. Experience has shown that, with normal hydrocarbon/air mixtures, if the space potential at the surface of the charged liquid exceeds 58 kV these discharges can be incendive.

An ignition hazard can arise at much lower potentials if insulated conductors such as floating metal cans are present in the tank.

5.3 *Precautions against ignition hazards during liquid handling operations*

5.3.1 Earthing and avoidance of insulated conductors

Insulated conductors such as metal tanks, tank structures and any other insulated metal object either deliberately or accidentally associated with liquid handling can readily acquire a potential due to charge on the liquid. This can lead to spark discharges which are particularly hazardous since they usually dissipate much more energy than that required to ignite flammable vapours. Therefore, all conductive parts of a liquid handling system should be adequately bonded to earth (see clause 10).

Tanks should be regularly inspected to ensure there are no loose metal objects, e.g. a can, floating on the liquid.

5.3.2 Restriction of charge generation

Charge generation can be restricted by controlling the relevant parameters which determine the charge generation in a particular process. These are:

(a) in tank filling operations:

- 1) restrict the linear flow velocity in the feeding line of the tank by restricting the pumping rate or by increasing the diameter of the feeding line (see 5.4.4.2);
- 2) provide sufficient residence time for charge relaxation downstream of pumps and filters (see 5.4.8 and A.2.2);
- 3) avoid splash filling by employing bottom entry or by using a fill pipe extending close to the bottom of the tank;
- 4) avoid having a second immiscible phase in the liquid; this can be caused, for example, by stirring up the water bottoms in oil tanks.

(b) in stirring or agitating operations (see 5.7):

- 1) restrict the power input to the stirrer;
- 2) avoid a second immiscible phase in the liquid, if possible.

(c) in tank cleaning operations with liquid jets (see 5.8):

- 1) restrict the liquid pressure and throughput of the washing machines;
- 2) avoid the build up of a second immiscible phase in the washing liquid, particularly if the washing liquid is recirculated;
- 3) avoid steaming a tank.

5.3.3 Avoidance of a flammable atmosphere

The most effective way of avoiding ignition hazards is to prevent the occurrence of a flammable atmosphere, for example to:

- avoid liquid-free spaces in the system;
- inert the ullage space of the tank using inert gases such as nitrogen, carbon dioxide or purified flue gas (note the precautions given in 6.4).

NOTE - Purging a tank with air to avoid a flammable atmosphere should be used with caution in a tank which contains a flammable liquid with a low flash point.

5.3.4 Charge dissipation

In situations where it is not possible to avoid a flammable atmosphere, the risk of ignition can be reduced by limiting charge accumulation. The most effective way of doing this in a bulk liquid is to increase charge dissipation within the liquid. This can be achieved by the use of commercially available dissipative additives. When added to a liquid in very low concentrations of the order of parts per million, these additives can increase its conductivity to over 50 pS/m. This level normally prevents the build up of hazardous levels of charge (see 5.1).

NOTE - Dissipative additives are widely used for aviation fuels, and in the concentrations normally used they have no adverse effects on either the aircraft engine or the performance of the filter/water separators.

5.4 *Storage tanks*

5.4.1 General

Operations that give rise to electrostatic hazards inside a tank include filling, the circulation of liquid, stirring, mixing, gauging, sampling and cleaning. If there could be a flammable atmosphere inside a tank when carrying out these operations, the precautions given below should be taken.

The restrictions on flow velocities apply to solvents and fuels in the normal viscosity range. For high viscosity liquids, e.g. luboils, further restrictions are necessary (see 5.4.7).

NOTE - If there cannot be a flammable atmosphere, (see 5.3.3), these precautions are not necessary.

5.4.2 Tank sizes

In order to describe the possible hazards and associated means of prevention, tanks have been classified according to size as follows:

- large, of diagonal dimension > 5 m and volume > 50 m³;
- medium, of diagonal dimension < 5 m and volume of between 1 m³ and 50 m³;
- small, of volume less than 1 m³ (called containers).

5.4.3 Large metal storage tanks

5.4.3.1 Fixed roof tanks

Irrespective of the conductivity of the liquid the following general precautions should be taken:

- a) earth the tank and all associated structures such as pipes, pumps, filter housings, etc. (see clause 10);
- b) ensure that persons cannot become charged (see clause 10);
- c) avoid splash filling by employing bottom entry or by using a fill pipe reaching close to the bottom of the tank;

- d) inspect the tank regularly for loose metal objects, e.g. cans, that could act as floating insulated conductors (see 5.3.1)

For low conductivity liquids the following additional precautions are necessary:

- 1) The inlet should be designed to minimize turbulence and the agitation of any heavier immiscible liquid or sediment on the tank bottom. This can be achieved by, for instance, using an inlet pipe with an increasing cross section to minimize the velocity on entry into the tank. Avoiding substantial turbulence has the additional benefit that the incoming highly charged liquid is kept mainly at the bottom of the tank and is prevented from reaching the liquid surface;
- 2) Liquid of low density should not be loaded into a tank containing a liquid of substantially higher density, since the resultant buoyancy effect would carry the incoming highly charged liquid to the liquid surface leading to a higher potential in the ullage of the tank. For the same reason entrainment of air or other gas in the incoming liquid should be avoided;
- 3) If strong charge generating elements such as microfilters are in the feeding line of the tank, an adequate residence time should be provided between the charge generating elements and the tank inlet to allow the charges to relax before entering the tank (see 5.4.8 and A.2.2).

In addition to the recommendations already given, certain restrictions on the filling velocity are necessary to make the filling operation safe. The velocity limit depends on whether the liquid is contaminated or clean. In this context, the liquid is considered to be clean if it contains less than 0.5 % by volume of free water or other immiscible liquid and less than 10 mg/l of suspended solids. Otherwise, the liquid is considered to be contaminated. Because of the high charge generation in two phase flows (see A.1.4.) the filling velocity of contaminated liquid should be restricted to 1 m/s during the whole filling period. For a clean liquid the filling velocity needs to be restricted to 1 m/s for an initial filling period only. The initial filling period lasts until:

- a) the fill pipe and any other structure on the base of the tank has been submerged to twice the fill pipe diameter;
- b) any water which has collected in the pipework has been cleared.

NOTE 1 - The restriction for (a) is to prevent discharges to the fill pipe and the structure and also to reduce the disturbance of water or sediment.

NOTE 2 - For (b), it is necessary to wait either for a period of half an hour or until two pipe volumes have been loaded into the tank, whichever is the shorter.

After the initial filling period the velocity may be raised above 1 m/s. The maximum safe velocity has not been accurately determined but extensive experience has shown that hazardous potentials do not occur if the velocity is below 7 m/s.

5.4.3.2 Tanks with floating roof or internal floating cover

In tanks with a floating roof or internal cover the flammable atmosphere is shielded from the potentials developing during filling by the floating roof or cover. Therefore, after the initial period of filling and when the roof or cover is afloat there is no need for a restriction on the filling velocity. However, during this initial period the velocity should be restricted to 1 m/s. To ensure the desired shielding effect it is essential that the floating roof or internal cover is made from conductive material and is properly earthed (see clause 10).

Sometimes floating spheres or balls are used in tanks to minimize evaporation. These should not be used with liquids with conductivities below 50 pS/m since a ball or a group of balls could become insulated from earth thus leading to the possibility of sparks. It is essential that spheres or balls are made of dissipative or conductive material.

Table 3 summarizes the precautions necessary for filling large metal tanks with low conductivity liquids. If the electrical conductivity is raised above 50 pS/m, e.g. by using dissipative additives (see 5.3.4), these precautions are not necessary.

Table 3: Precautions for filling large metal tanks with low conductivity liquids

Precautions	Applicability to tank	
	With floating roof or internal cover	With fixed roof, no floating cover
Keep flow velocities below 1 ms ⁻¹	Essential until the roof or cover is afloat	Essential during initial filling period, or when loading a contaminated liquid
Keep flow velocities below 7 ms ⁻¹	Unnecessary when the roof or cover is afloat	Essential in all cases in which the 1 ms ⁻¹ limit does not apply
Ensure an adequate residence time between strong charge generators (e.g. micronic filters) and the tank	Essential until the roof or cover is afloat (Note - The Residence Time can be calculated using a velocity of 1 ms ⁻¹ in this instance)	Essential
Avoid disturbing water bottoms with incoming product, entrained air or by blowing out lines with gas	Essential until the roof or cover is afloat	Essential
Avoid charging low density liquids into tanks containing high density liquids due to buoyancy effects	Unnecessary	Recommended

5.4.4 Medium sized metal tanks (e.g. road/rail tankers)

5.4.4.1 General precautions

Irrespective of the conductivity of the liquid the general precautions given in items a), b), and d) of 5.4.3.1 should be taken together with the following:

- a) pipes and hoses should be made of dissipative material or comply with 5.5;
- b) avoid splash filling by employing bottom entry with a deflection plate to prevent an upwardly directed liquid jet (bottom filling) or by using a fill pipe reaching close to the bottom of the tank (top filling);
- c) avoid entrained air or other gases in the incoming liquid, do not clear lines with air or other gas when operating near the maximum allowable flow velocities.

5.4.4.2 Restriction on filling velocity

For low conductivity liquids the filling velocity needs to be restricted to a safe value and this depends on the size and shape the tank, the method of filling (top or bottom loading), the diameter of the pipeline leading to the tank and the conductivity of the liquid.

The most critical tank size and shape is a cuboidal (or spherical) tank of about 5 m³ volume, i.e. about the size and shape of a road tanker compartment. Larger and smaller tanks and tanks deviating from a cuboidal shape, i.e. those with one tank dimension being significantly larger than the other two dimensions, are less critical.

With top loading, the fill pipe acts as a central conductor. This lowers the maximum potential in the tank and a higher fill velocity may be tolerated. For this reason, unless a bottom loading road tanker compartment also has a central conductor, the filling velocity should be 25 % lower than that for top loading.

For two phase flow or if water bottoms could be stirred up in the tank, the filling velocity should be restricted to 1 m/s. Velocities should not be much below this value or water could accumulate at low points in the pipes.

The maximum filling velocity for one phase liquids, e.g. saturated hydrocarbon liquids which do not contain free water, is given by the following equations:

$$vd = 0.50N \text{ m}^2/\text{s} \quad \text{for top loading or bottom loading with a central conductor}$$

$$vd = 0.38N \text{ m}^2/\text{s} \quad \text{for bottom loading without a central conductor}$$

where:

v is the linear flow velocity in the pipe in metres/second;

d is the diameter in metres of the fill pipe or the smallest diameter pipe section upstream of the tank or compartment being filled (if, however, the smallest section is less than 10 m long and has a diameter of at least 67 % of the next smallest section, the diameter of the next smallest section may be taken);

N is a factor describing the dependence on the length L of the compartment. For $L < 2\text{m}$, N is 1; for compartment lengths between 2 m and 4,6 m, N should be taken as $N = \sqrt{L/2}$ and for lengths exceeding 4,6 m, N should be taken as 1,5. For determining the compartment length, baffles in the compartments need not to be taken into account.

These upper limits for filling velocity are considered to be safe for the whole range of liquid conductivities occurring in practice. Because of limited experience a filling velocity of 7 m/s should not be exceeded, even though the equations allow it.

Opinions differ as to whether or not the filling velocity should be reduced further during the period it takes for the fill pipe outlet to become fully submerged. However, recent experience has shown that this initial slow fill is not necessary for one phase liquids when filling medium sized tanks. For bottom loading a deflection plate is essential to prevent an upwardly directed liquid jet.

Fine filters installed in the pipeline upstream of the tank generate a considerable amount of charge and the methods for dealing with this are given in 5.4.8.

Gauging and sampling can introduce additional hazards and this is dealt with in 5.4.9.

If the conductivity of the liquid is raised above 50 pS/m (e.g. by using dissipative additives, see 5.3.4), there is no need to restrict the filling velocity to below the general limit of 7 m/s.

5.4.4.3 Road tankers

In addition to the other precautions and recommendations given in 5.4. the following precautions should be taken:

a) The bonding resistance between the chassis, the tank and the associated pipes and fittings on the truck should be less than $10^6 \Omega$;

b) An earthing cable should be connected to the tanker before any operation (e.g. opening man lids, connecting pipes) is carried out. It should provide a bonding resistance of less than $10^6 \Omega$ between the tank and the gantry and should not be removed until all operations have been completed. It is recommended that interlocks should be provided to prevent loading when the earthing cable is not connected;

c) If road tankers with different compartment lengths are to be loaded at the same loading point, then in order to avoid confusion, the filling velocity relevant to the smallest compartment length ($L = 2 \text{ m}$) should be used;

d) Where low conductivity liquids could be handled the filling velocity v should be restricted to:

$$vd = 0,5 \text{ m}^2/\text{s} \text{ for top loading or bottom loading with a central conductor; or}$$

$$vd = 0,38 \text{ m}^2/\text{s} \text{ for bottom loading without a central conductor.}$$

Examples are given in table 4;

e) In top loading the loading arm (dip leg) should be inserted to the bottom of the tank before starting liquid flow,

- f) Tankers in the open air and not under canopies should not be loaded with a liquid which can give rise to a flammable atmosphere when there is the possibility of lightning.

If the conductivity of the liquid is above 50 pS/m the filling velocity is not limited to below the general limit of 7 m/s.

5.4.4.4 Rail tankers

In addition to the precautions and recommendations given in 5.4.4.2 and 5.4.4.3 the following precautions should be taken:

- a) The rails of the track should be bonded to each other and to the gantry with a bonding resistance of less than $10^6 \Omega$,
- b) The bonding resistance between the wheels, the tank and the rest of the car should be less than $10^6 \Omega$. Independent bonding of the rail tank car is not needed as it is provided by the rails;
- c) A non-conductive flange may be installed in the filling line to prevent stray currents. In this case the fill nozzle should be bonded to the rail-car before filling commences,
- d) The siding used for tank car filling should be insulated from the rest of the railway track in order to avoid stray currents. This insulation should not be short circuited by rail equipment or rail cars;
- e) Where low conductivity liquids are loaded then, irrespective of compartment length, the filling velocity v should comply with:
 $vd = 0,75 \text{ m}^2/\text{s}$ for top loading or bottom loading with a central conductor; or
 $vd = 0,56 \text{ m}^2/\text{s}$ for bottom loading without a central conductor.
Examples are given in table 4;
- f) With top loading the loading arm should be inserted to the bottom of the tank before starting liquid flow;
- g) If the conductivity of the liquid is raised above 50 pS/m the filling velocity need not be restricted to below the general limit of 7 m/s.

Table 4: Maximum filling velocities for loading low conductivity liquids into road and rail tankers

Fill pipe diameter* mm	Road Tanker			
	Top Loading $vd = 0,50 \text{ m}^2/\text{s}$		Bottom Loading $vd = 0,38 \text{ m}^2/\text{s}$	
	Filling Velocity m/s	Fill Rate m^3/min	Filling Velocity m/s	Fill Rate m^3/min
50	7,0	0,83	7,0	0,83
80	6,3	1,90	4,7	1,40
100	5,0	2,40	3,8	1,80
150	3,3	3,50	2,5	2,70
200	2,5	4,70	1,9	3,50

Fill pipe diameter* mm	Rail Tanker			
	Top Loading $vd = 0,75 \text{ m}^2/\text{s}$		Bottom Loading $vd = 0,56 \text{ m}^2/\text{s}$	
	Filling Velocity m/s	Fill Rate m^3/min	Filling Velocity m/s	Fill Rate m^3/min
100	7,0	3,3	5,6	2,6
150	5,0	5,3	3,7	4,0
200	3,8	7,1	2,8	5,3
250	3,0	8,8	2,2	6,6
300	2,5	10,6	1,9	7,9

* or diameter of critical pipe section of feeding line, (see text).

5.4.5 Non-conductive tanks and tanks with non-conductive coatings

5.4.5.1 General

Large non-metallic tanks are uncommon and require special assessment; expert advice is recommended. In addition to the requirements for medium sized metal tanks, precautions for the different types of non-metallic tanks and metal tanks with non-metallic coatings given in 5.4.5.2 to 5.4.5.6 apply.

To describe the possible hazards and associated means of protection, the non-metallic materials for tank construction have been divided into the following two classes:

- dissipative, for materials of volume resistivity $< 10^9 \Omega\text{m}$ or surface resistance $< 10^9 \Omega$ when measured at 25°C and 50 % relative humidity;
- non-conductive for all other materials.

5.4.5.2 Tanks made entirely of dissipative material

These tanks may be treated exactly as metal tanks since they cause no additional hazards. Tanks made with dissipative plastic material or coatings should be clearly marked "electrostatic dissipative" and provided with means for earthing.

5.4.5.3 Tanks made of conductive or dissipative material with non-conductive inner coatings

Additional hazards arise due to charging of the inner coating by rubbing (e.g. cleaning) or by contact with the charged liquid. When the coating is less than 2 mm thick (e.g. paint or epoxy coatings) there is no additional hazard (see 4.4.8) unless there are rapid repeat fillings. In the case of rapid repeat fills high charge densities can be built up on the coating which may lead to incendive propagating brush discharges. These can be avoided if the breakdown strength of the coating is less than 4 kV (see A.3.5).

The following precautions should be taken:

- a) the coating should be in good contact with the main tank wall (i.e. no separation or delamination);
- b) irrespective of whether the tank is filled with a conductive or a non-conductive liquid, there should be a conductive path between the liquid and earth. This may be an earthed conductive dip tube, foot valve or metal plate at the base of the tank;
- c) if the tank can be entered by a person (e.g. for cleaning) precautions should be taken to prevent the person being charged. This can be achieved by ensuring the person is earthed by wearing dissipative shoes and providing an earthed conductive or dissipative walkway at the tank bottom (e.g. by providing dissipative coatings in the area where persons may walk), or by other means.

5.4.5.4 Tanks made of conductive or dissipative materials with non-conductive outer coatings

With these tanks there are the additional hazards that the outer coating could become charged or it could insulate conductive objects. With coatings less than 2 mm thick, brush discharges capable of igniting hydrocarbon/air atmospheres do not occur. Propagating brush discharges are also unlikely, providing there are no strong sources of charging (e.g. electrostatic spraying). All metal or dissipative objects, however, which could become insulated by the coating should be earthed. In particular the tank itself should be reliably earthed. Earthed conductive or dissipative walkways should be provided to prevent persons becoming charged.

5.4.5.5 Tanks with conductive layers embedded in the walls

These tanks are electrically similar to conductive tanks with inner and outer non-conductive coatings. The precautions given in 5.4.5.3 and 5.4.5.4 should be taken together with the following:

- a) the conductive layer should be robust and reliably earthed;
- b) where the liquid is not in contact with the conductive layer, a path to earth from the liquid should be provided via an earthed metal object in the base of the tank. This could be a metal plate, a foot valve or a fill pipe extending almost to the bottom of the tank;
- c) if the conductive layer is in the form of a conductive net or grill, the area of each mesh (i.e. the area contained by the wires) should not exceed the area value given in table 1 for Zone 0 (see 4.4.3).

Where rapid repeated fills take place there is a possibility that the inner coating could become highly charged enabling propagating brush discharges to occur. To avoid such discharges, the inner non-conductive layer should have a breakdown strength of less than 4 kV (see A.3.5).

5.4.5.6 Tanks made entirely of non-conductive material

Tanks without any conductive or dissipative layer present a higher risk than those described in 5.4.5.2 to 5.4.5.5 because of the following:

- a) potentials within the tanks are increased due to the absence of earthed walls;
- b) charged liquids inside the tank produce electric fields which extend outside the tank leading to the possibility of external brush discharges or even sparks from external conductors charged by electrostatic induction,
- c) the inner and outer tank surface can be charged by rubbing or by contact with charged liquid.

For reasons listed in items a) to c) this type of tank should not be used above ground whenever an explosive atmosphere can be present inside or outside the tank.

If the tank is buried underground it is electrically similar to a conductive tank with a non-conductive inner coating (see 5.4.5.3). The tanks may be used for flammable liquids providing there is an earthed metallic object (e.g. fill pipe or foot valve) in contact with the liquid and rapid repeated fills are avoided. Where the tank wall thickness exceeds 2 mm brush discharges could occur from the internal surface during cleaning operations. The precautions given in 5.4.5.3 should be taken to avoid this hazard.

In the case of rapid repeat fills propagating brush discharges could occur.

5.4.6 Metallic and non-metallic containers (small tanks $\leq 1 \text{ m}^3$) and containers with non-metallic coatings

5.4.6.1 General

Examples of this type of container are buckets, drums, petrol containers.

Hazards arise because the charges generated by rubbing or liquid flow can lead to sparks from insulated metal components (e.g. handles, containers, drum pumps) or to brush discharges from non-conductive solid or liquid surfaces. Care should be taken to prevent persons from becoming hazardously charged (see clause 10).

To describe possible hazards and associated means of prevention, container materials have been divided into the following three classes: conductive, dissipative and non-conductive (see definitions). Metallic materials are all conductive; non-metallic materials can be either dissipative or non-conductive; glass containers are generally dissipative; and plastic containers are likely to be non-conductive unless specifically designed to be dissipative.

The precautions given in 5.4.6.2 to 5.4.6.4 should be taken whenever an explosive atmosphere could be present inside or outside the container (e.g. when they are filled with flammable liquids or are in hazardous areas).

5.4.6.2 Containers made of conductive or dissipative material

During both filling and emptying the container, all conductive or dissipative parts of the system such as funnels and nozzles should be bonded together and earthed.

A metal funnel should not be allowed to be insulated from the container by a plastic bush. Plastic funnels should not be used unless the material is dissipative. When filling the container with two phase liquids the filling velocity should be restricted to 1 m/s when the continuous phase is of low conductivity. For one phase liquids the filling rates need not be restricted. For carbon disulphide and diethyl ether, however, the filling velocity should not exceed 1 m/s.

If fine filters (microfilters) are used in the filling system upstream of the container the precautions in 5.4.8 should be noted.

5.4.6.3 Containers made of conductive and dissipative material with inner and outer non-conductive coatings

Additional hazards could arise due to charging of the outer coating by rubbing or charging of the inner coating by contact with the charged liquid. When the coating is less than 2 mm thick (e.g. paint or epoxy coating, see 4.4.8) there is no additional hazard unless there are rapid repeat fillings. In exceptional cases, rapid repeat fillings could cause a build up of high charge densities on the inner coating which could lead to incendive propagating brush discharges. These can be avoided if the breakdown strength of the coating is less than 4 kV (see A.3.5).

The following precautions should be taken:

- a) All conductive items which could become insulated by the non-conductive coating should be earthed;
- b) The coating should be in good contact with the main container wall (i.e. no separation or delamination);
- c) If the container with an inner non-conductive coating is filled with a conductive liquid, a conductive path should be provided between the liquid and earth, e.g. by using an earthed conductive fill pipe extended almost to the bottom of the container. This will prevent the liquid from becoming a charged insulated conductor.

5.4.6.4 Containers made of non-conductive material

Due to the absence of a conductive or dissipative wall, these containers present an additional hazard in that:

- a) containers can cause conductive and dissipative objects, e.g. metal funnels, tools, lids, even pools of liquids, to be insulated from earth;
- b) potentials are higher than with equivalent metal containers;
- c) the non-conductive wall could be charged by rubbing or contact with the charged liquid;
- d) the charge relaxation of the charged liquid could be impeded by the non-conductive wall;
- e) the charge retained on the liquid or the wall of the container produces an external electric field. This could lead to brush discharges or even to sparks from external conductors charged by induction. The precautions necessary depend on whether there is an explosive atmosphere due to the liquid being handled or other sources and on the resultant zone.

In Zone 2, if non-conductive containers are used for non-flammable liquids the following precautions should be taken:

- a) all conductive and dissipative components, particularly metal funnels, should be earthed;
- b) during filling operations the liquid should be in good contact with earth, for example, by an earthed metal fill pipe reaching to the bottom of the container. During emptying operations the appropriate precautions should also be applied to the receiving vessel;
- c) the liquid flow rate during filling operations should not be greater than that recommended for a metal container of similar size.

In Zone 1 containers up to a nominal capacity of 5 l made of non-conductive material may be used with flammable and non-flammable liquids provided the restrictions on flow velocity for equivalent metal container are met.

Containers of larger capacity should only be used in Zone 1 if it can be shown that the electrostatic ignition risk is acceptable. There is a need to strike a balance between the electrostatic risk and the advantages of using a non-conductive container. These advantages can include better corrosion resistance and better behaviour in flame engulfment conditions. Reaching a decision can require the guidance of a specialist. In this case the precautions given for Zone 2 are the minimum and further precautions could be necessary.

In Zone 0, only very small non-conductive containers should be used for sampling inside tanks (see 5.4.9.2).

5.4.7 High viscosity liquids

High viscosity liquids (kinematic viscosity about 100 mm²/s) tend to charge more readily than low viscosity liquids such as fuels or solvents (about 1 mm²/s). They can also have an electrical conductivity as low as 0,01 pS/m enabling them to retain their charge for more than 1 h. The rate of charging of the higher viscosity liquids during flow through pipes and especially in filters is also very high. Because of this the restrictions on flow velocity recommended for low viscosity liquids (see 5.4.4.2) would not be adequate if a flammable atmosphere were present.

Fortunately, most high viscosity liquids are either of high conductivity (e.g. crude oil) or are not volatile enough to produce a flammable atmosphere (e.g. most lubricating oils). As a result, they do not normally give rise to an ignition hazard. In some cases, however, there is a high risk of ignition, e.g. when a low conductivity lubricating oil is switchloaded into a road tanker which previously contained a highly volatile flammable liquid. Since reliable safe flow limits for high viscosity liquids are not known the recommended precaution when low conductivity high viscosity liquids are being handled is to avoid a flammable atmosphere, e.g. by inerting.

5.4.8 Filters, water separators, strainers

Microfilters or water separators, i.e. filters with nominal pore sizes of 10 µm and less, produce very high charge densities (5 000 µC/m³ or more as opposed to about 10 µC/m³ in pipe flow) and special precautions are required to allow those excessive charge levels to be safely dissipated.

Wire mesh or gauze strainers normally produce only moderately higher charge densities than pipes. Blocked strainers can, however, generate charge densities of the order of $100 \mu\text{C}/\text{m}^3$ which considerably exceeds the charge densities obtained in pipe flow. The partial blockage of the strainer can be detected by monitoring the pressure drop across the filter.

If the atmosphere in the receiving tank could be flammable it is essential that a sufficient residence time is provided downstream of the filter for the charged liquid to relax to a safe level before it enters the tank. This could be provided by the conductive pipe work downstream of the filter or, if necessary, by an additional conductive relaxation chamber.

The following precautions should be taken:

- a) All conductive parts should be bonded together and earthed;
- b) Ensure that the filter housing and the relaxation chamber, if used, remain full of liquid during normal operation in order to prevent a flammable atmosphere;
- c) When the electrical conductivity of the liquid is reliably known, a residence time of at least three times the relaxation time (see table 2 and A.2.2) should be used;
- d) If the conductivity is not known, a residence time of 100 s should be provided downstream of fine filters (microfilters, water separators) before the liquid is allowed to enter the tank. With the exception of high viscosity liquids this is adequate for all conductivities;
- e) If the conductivity is not known, a residence time of 30 s is sufficient downstream of coarse filters (e.g. strainers) unless the filter becomes partially blocked.

In the case of high viscosity liquids such as low conductivity lubricating oils (see 5.4.7) the residence times given are not adequate. When the required residence times are impracticable, it is essential to avoid flammable atmosphere in the receiving tank.

For tanks with a floating roof or an internal floating cover the initial filling velocity should be restricted until the roof or internal cover is floating (see 5.4.3.2). In this case the residence time can be calculated from the initial filling velocity since after the roof or cover is afloat there is no longer an ignition hazard.

5.4.9 Gauging and sampling in tanks

5.4.9.1 General

Gauging and sampling could cause an electrostatic ignition in tanks of all sizes if there is an explosive atmosphere present. The risk is high if the liquid in the tank is highly charged due to it either being pumped or agitated, e.g. in a mixing operation (see 5.7). The gauging and sampling equipment and the persons using the equipment can also become charged.

An incendive discharge can occur between the liquid and the gauging or sampling equipment as they approach each other, or between the equipment, or the person handling it, and the rim of the manhole or dip hatch through which the operation is taking place. To avoid those hazards the recommendations in 5.4.9.2 and 5.4.9.3 should be followed.

5.4.9.2 Precautions during gauging and sampling

All conductive and dissipative parts of gauging and sampling equipment should be earthed either by connecting it to the tank, or if the tank is constructed of non-conductive material, directly to earth. The connections should be made of dissipative material. A metal chain should not be used.

A non-conductive (synthetic polymer) cord or dip stick is not acceptable, unless it is dissipative. On balance, small sampling containers (≤ 1 litre) of non-conductive material are considered to be safer than similar conductive containers.

Ensure that persons engaged in gauging and sampling do not present an ignition risk (see clause 10).

Gauging and sampling from above the liquid surface should not be carried out in a tank containing a flammable atmosphere while any charge generating operation is going on. Those operations include the pumping of low conductivity liquids (with conductivities up to and including 50 pS/m for single phase liquids and 1 000 pS/m for multiple phase liquids) into a tank and many cleaning procedures.

If a low conductivity liquid containing a second phase such as stirred up water or non-dissolved solid particles has been pumped into a tank or has been involved in a mixing operation in a tank, there should be a time delay before gauging or sampling. This delay should be such that at least 30 min has elapsed after completion of the operation. After a mixing operation involving a low conductivity liquid, gauging and sampling should not take place while the components of the mixture are settling.

After a cleaning operation, gauging and sampling should be delayed until any charged mist generated has settled, which can take several hours.

The above recommendations need not be followed with fixed gauging equipment, or if the gauging takes place in a fixed earthed dip pipe extending to the bottom of the tank.

Gauging and sampling of flammable liquids outdoors should not be carried out if there is a possibility of thunderstorms, snowstorms, hailstorms, or other disturbed atmospheric electrical conditions.

5.5 *Pipes and hoses for liquids*

5.5.1 General

When a liquid flows in a pipe charge separation occurs between the liquid and the internal surface of the pipe producing electrostatic charges of opposite polarity on the liquid and the inner pipe wall. The extent to which the charges are retained depends upon the resistivity of the pipe material and upon the conductivity of the liquid. In addition, metallic components which could be insulated because of the non-conductive pipe material can accumulate charges and the outer surface of the pipe can also be charged, e.g. by rubbing.

Ignition hazards can occur both inside the pipe, if it runs empty when handling a flammable low flash point liquid, and outside, due to the surrounding atmosphere.

5.5.2 Pipes made of dissipative material

From the point of electrostatics, dissipative pipes may be treated as conductive pipes.

5.5.3 Conductive pipes with non-conductive liners

When a conductive pipe with a non-conductive liner is used to convey a low or medium conductivity liquid, electrostatic charges could accumulate on the inner surface of the liner and produce discharges through the liner to the conductive wall of the pipe. Theory indicates that the potential on the surface of a liner should usually increase in proportion to the thickness of the liner. Hazardous discharges are therefore more likely to occur with thicker linings such as plastic sleeves than with thin linings such as epoxy coatings. Even under adverse conditions (high charge density in the liquid, large pipe diameter, thick liner) discharges are unlikely to occur when the volume resistivity of the liner is less than about $10^8 \Omega\text{m}$. Under typical conditions (charge density $< 10^3 \mu\text{C}/\text{m}^3$, pipe diameter about 100 mm, liner thickness $< 5 \text{ mm}$) discharges will not occur unless the volume resistivity exceeds $10^{11} \Omega\text{m}$.

The use of conductive pipes with thicker and/or less conductive liners could still be acceptable for many liquid handling applications provided all conductive sections of the pipe are reliably earthed and the pipe remained full of liquid throughout the operations. The latter requirement ensures that there is no explosive atmosphere inside the pipe when the pipe is full of liquid.

A pipe with a thick and less conductive liner should be filled and emptied slowly if a flammable atmosphere could be present. In general, the velocity of the liquid/air interface should not be allowed to exceed 1 m/s. Lower velocities could be necessary downstream of microfilters.

There is no electrostatic hazard if the pipe remains full of liquid but an electrical breakdown could puncture a highly non-conductive lining. Where it is essential to avoid this (e.g. in preventing corrosion) it can generally be prevented by using a liner with a low volume resistivity. A value of less than $10^{11} \Omega\text{m}$ is usually adequate although, under high rates of charge generation, less than $10^8 \Omega\text{m}$ could be necessary.

Conductive pipes with non-conductive liners are permissible for conveying liquids but they should not be used for the pneumatic conveying of powders. This is because, with powders, an explosive atmosphere could exist within the pipe and the strong charge generating mechanisms could lead to propagating brush discharges (see A.3.5).

5.5.4 Non-conductive pipes

5.5.4.1 Non-conductive pipes above ground

The flow of low conductivity liquids in non-conductive pipes can produce very high surface charge densities on the internal surface of the pipe wall. The high electric field outside the pipe produced by those charges could lead to incendive brush discharges. They could even lead to spark discharges from insulated metal objects near the pipe which were charged by electrostatic induction.

The high surface charges could even lead to electrical breakdown and puncture of the pipe wall. This could cause a leak of liquid that could be hazardous and environmentally harmful.

In hazardous areas, non-conductive pipes should not be used for the passage of liquids with a conductivity of less than 50 pS/m. However, they may be used for liquids with a conductivity greater than 50 pS/m if the liquid is in direct contact with an earthed conducting component such as a valve or tank at the upstream end of the pipe. Precautions should be taken to ensure that the external wall of the pipe cannot be hazardously charged by external sources such as steam impingement or rubbing. This can be avoided by using the precautions given in Clause 6. It is essential that all conductive components such as flanges or valves are earthed unless their electrical capacitance is less than 3 pF.

5.5.4.2 Buried non-conductive pipes

When a non-conductive pipe is buried its whole external surface is in contact with the earth and no further earthing of conductive or dissipative components of the non-conductive pipe is necessary. The pipe may be used for the passage of liquids with a conductivity exceeding 50 pS/m provided the liquid is at some point in contact with an earthed metal object, e.g. a valve.

Excavation of a section of pipe could expose conductive or dissipative components. If there is any possibility of an explosive atmosphere, these, and all conductive objects nearby which could be charged by electrostatic

induction, should be earthed. However, it is hazardous to make an earthing connection in a potentially explosive atmosphere.

5.5.5 Flexible hoses

Three types of hose are available:

(a) **Semi-conductive hose** A semi-conductive hose has an intermediate resistance which is low enough to dissipate electrostatic charges but high enough to restrict stray currents to safe limits. Usually the outer layer of the hose is made of dissipative materials and provides the low resistance of the hose when the layer is in contact with the metal end fittings. The resistance per unit length of a semi-conductive hose should be in the range $10^3 \Omega\text{m}^{-1}$ to $10^6 \Omega\text{m}^{-1}$.

The construction of semi-conductive hoses is often such that electrical continuity cannot be lost whilst the hose remains usable. This electrical continuity, which is inherent to the hose construction, means that regular continuity checks are unnecessary. The resistance of hoses that are not constructed in this way should be checked regularly.

(b) **Conductive hose** A conductive hose has conducting elements and an electrical resistance per unit length, as determined by end to end resistance measurement, of less than $10^3 \Omega\text{m}^{-1}$. They are designed to prevent brush discharges from the outside. Normally, conductive hoses are made from non-conductive materials and electrical continuity is provided by reinforcing or bonding wires that are electrically bonded to metal end fittings. This type of hose has a low enough resistance to dissipate electrostatic charges, but because of its low resistance, it could conduct stray currents which could create an ignition hazard when the stray currents are interrupted.

If there are no stray currents, a properly designed and well-maintained conductive hose is not an electrostatic ignition hazard. However, due to broken bonding wires or faulty construction, it is possible for one or more of the conductive components of the hose (i.e. end couplings, reinforcing helices and sheaths) to become electrically insulated. If a low conductivity liquid is then passed through the hose these components could accumulate an electrostatic charge leading to incendive sparks. Therefore, the electrical continuity of the hose should be checked regularly. Care should be taken to ensure that all internal metal helices are bonded to the end coupling.

(c) **Non-conductive hose** This type of hose is made of non-conductive material. It does not incorporate conducting wire or braid and it is not capable of dissipating electrostatic charges. Therefore, electrostatic charges could accumulate on the hose material or on insulated conductive parts (e.g. metal couplings, wet patches on the hose) leading to incendive brush discharges or even sparks.

For most applications semi-conductive hoses are preferred to conductive hoses since they protect against electrostatic charge accumulation on the hose as well as against inductive sparks due to interruption of stray currents.

Conductive hoses are also acceptable but, in special cases, a non-conductive flange should be inserted to provide protection against inductive sparks. In this case the hose string on either side should be separately earthed. In addition, conductive hoses require regular continuity checks.

Non-conductive hoses are not recommended if an explosive atmosphere could be present.

5.6 *Special filling procedures*

5.6.1 Aircraft fuelling

5.6.1.1 General

Aircraft are most frequently fuelled by means of mobile fuellers or by hydrant systems feeding the aircraft system through mobile dispensers. Fuel transfers are made through flexible hoses and ignition hazards due to static electricity can arise during these operations. Charge can be generated on the fuel in the system feeding the aircraft or in the aircraft tank which is normally made of metal. Usually, the fuelling system contains a fine particle filter and/or water separator.

Although not an electrostatic hazard, the possibility exists of sparks when making or breaking hose connections. Sparks are due to stray currents from, for example, electrical power installations or cathodic protection systems. Precautions against static electricity ignitions need to be consistent with the precautions for avoidance of sparks resulting from leakage currents.

5.6.1.2 Hoses

Flexible hoses should preferably be of the semi-conductive type so as to assist the dissipation of electrostatic charges while limiting stray currents (see 5.5.5(b)). If conductive hoses are used in a hydrant system, a non-conductive flange should be installed at the end of the hydrant riser. The conductive hoses should be regularly checked for electrical continuity.

5.6.1.3 Earthing and bonding

All the metallic parts within each fuelling vehicle should be in good electrical contact with each other. Good electrical continuity should exist within the hydrant system and also within each hydrant dispenser.

A bonding connection should be made between the aircraft and the refuelling vehicle or hydrant dispenser before the filling hoses are attached. It should remain in place until loading is completed and the hoses are disconnected. If an earthing point is available, the refuelling vehicle (or hydrant dispenser) should first be bonded to the earthing point and then to the aircraft. Earthing or bonding connections should be well separated from fuelling hoses etc. to minimise the risk of ignitions from sparks when the earth contact is being connected or disconnected.

Where possible, bonding lugs should be used, alternative bonding connections should be firm and made to unpainted metal parts on the aircraft. Bonding to equipment such as pitot head tubes, aerals and propellers should be avoided.

There should be a direct bond between the aircraft fuelling orifice and the metallic end of the fuelling hose. With underwing fuelling there should be metal-to-metal contact between the hose end coupling and the aircraft fuelling adapter. With overwing fuelling the hose nozzle should be bonded to the aircraft by a separate cable before the filler cap is removed and the bond should remain in position until the operation has been completed and the filler cap replaced. With some light aircraft, bonding may not be possible because of the absence of a bonding lug near the fuelling orifice, and dissipative hose is then strongly recommended.

Some overwing operations could require the use of a funnel. This should be metallic or dissipative and should be bonded both to the fuelling nozzle and to the aircraft before the aircraft filler cap is removed.

Deliveries from drums or other containers require the same bonding arrangement as deliveries via vehicles. In addition it is necessary to bond the drum pump both to the aircraft and to the drum.

5.6.1.4 Filling rates

When dissipative additives are used to raise the conductivity above 50 pS/m, filling velocities of up to 5 m/s are permitted. Where no additive is used, the maximum safe velocity in delivery hoses has not been established. However, as the tanks of aircraft are usually of a shallow shape, filling velocities up to the velocities permitted for road tanker filling (see 5.4.4.2) may be accepted if sufficient residence time is provided downstream of the filters.

5.6.2 Road tanker deliveries

Deliveries from road tankers to medium sized tanks are performed via flexible hoses using either gravity feed or pumps on the vehicle. Electrostatic ignition hazards may occur as a result of sparks from insulated conductors (e.g. hose couplings or the road tanker as a whole), brush discharges from non-conductive hoses or brush discharges within the receiving tank.

The following precautions are recommended:

- Conductive or semi-conductive hoses (see 5.5.5) should be used;
- Ensure that the truck and all metallic couplings are bonded to the tank being filled. Separate bonding is not needed when the hoses are conductive or semi-conductive as bonding is provided by the hose;
- When connecting the truck to the receiving tank, first connect the hose to the truck and then, before removing the tank fill pipe cap or making any other hose connections, equalize the potentials by touching the end coupling of the hose on the fill pipe cap or any other metallic part of the tank;
- Providing the maximum safe filling velocities for medium sized tanks are not exceeded (see 5.4.4) there is unlikely to be an ignition hazard within the tank. If the liquid contains a second phase, the filling velocity should be restricted to 1 m/s;
- The continuity of conductive hoses should be checked regularly.

5.6.3 Motor vehicle fuelling

This subclause covers the filling of fuel tanks of road vehicles. Diesel vapours are normally too lean to cause an ignition risk. The vapours within petrol tanks are normally too rich but during fuelling the escaping vapours could form an explosive atmosphere near the tank inlet. An electrostatic ignition could lead to a fire at the tank inlet which could burn the person filling the tank.

The flow rates at filling stations are sufficiently small to prevent hazardous potentials being generated in the liquid either inside or outside the tank. But insulated conductors associated with the operation (e.g. the nozzle, the vehicle itself, the filler neck, or the person) could give rise to incendive sparks.

The following precautions should be taken:

- a) The pump should be properly earthed;
- b) A semi-conductive or conductive hose (see 5.5.5) should be used to connect the nozzle to the pump;
- c) The surfaces of forecourts should have a leakage resistance to earth of less than $10^8 \Omega$ to enable earthing of vehicles via their tyres;
- d) There should be electrical contact between the vehicle and the nozzle.

These precautions will ensure earthing of: the nozzle, directly via the conductive or semi-conductive hose; a person grasping it, unless wearing non-conductive gloves; and, the vehicle during filling, by contact with the nozzle.

The vehicle will be earthed through its tyres, even if their resistance is not low enough to be classed as dissipative they will almost certainly be capable of dissipating any charges on the vehicle before filling.

Experience indicates that earthing via the nozzle and the tyres is sufficient to dissipate the relatively small amounts of charge that are generated during filling.

The use of plastics fuel tanks in the vehicle does not introduce additional hazards. But the tank inlet, and all its parts which are made of metal, should be properly bonded to the vehicle.

5.6.4 Additional considerations

Particular care should be taken when using temporary equipment which introduces filters or other restrictions into the system. (An example of this is portable meter proving equipment which contains fine filters to protect the sensitive meters). When using such equipment, precautions should be taken to allow for an adequate residence time to ensure that all normal earthing requirements are met.

5.7 *Plant process (liquid/liquid and solid/liquid blending and mixing)*

5.7.1 General

The mixing of liquids or of liquids and solid particles can give rise to ignition risks due to static electricity. Charge could be generated when mixing takes place in systems containing one or more low conductivity liquids. It is then retained in the continuous liquid phase, on suspended liquid or solid particulate matter, or on any insulated metallic object. If a flammable vapour/air mixture, mist or foam is present there is an ignition hazard and to avoid this the recommendations in 5.7.2.1 to 5.7.2.5 inclusive should be followed.

5.7.2 Earthing

5.7.2.1 All metallic parts of the equipment should be bonded and earthed, see Clause 10.

5.7.2.2 If a blending vessel has an internal non-conductive lining, e.g. glass, ceramic or plastic, the relaxation of charge on the contents should be promoted by placing earthed metal strips or plates on or near the bottom of the vessel. It is possible that this precaution is not necessary if the lining is thin enough to permit charge dissipation or to avoid a hazardous surface potential.

5.7.2.3 Ensure that persons working in the vicinity of a blending operation are not an ignition risk by following the precautions in clause 10.

5.7.3 In-line blending

5.7.3.1 In this process, mixing takes place within a pipe into which the various constituents are pumped at prescribed rates. There is therefore no vapour space in which a flammable mixture can occur, and hence no ignition risk where the mixing is taking place.

5.7.3.2 To avoid ignition hazards in the receiving tank arising from charge generated in the mixing operation or in subsequent flow to the tank, the recommendations in 5.3.1 to 5.3.4, as appropriate, should be adopted.

5.7.4 Blending in vessels or tanks

5.7.4.1 The mixing of liquids to produce a single phase of low conductivity is not unduly hazardous provided that the precautions appropriate to liquid handling operations are taken (see 5.3).

5.7.4.2 If the mixture contains dispersed liquid or solid particles the generation of static electricity could be reduced by increasing the conductivities of the low conductivity liquids in the system. This could be done by adding dissipative additives, provided that they are compatible with the intended use of the mixture.

5.7.4.3 If the phases in a mixture are all liquids it is usually sufficient to raise the conductivity of the continuous phase to above 50 pS/m.

5.7.4.4 If one or more of the dispersed phases is a solid it could be necessary to increase the conductivity of the continuous phase to much greater than 50 pS/m, (1 000 pS/m is adequate) and also to restrict the power input to the stirrer.

NOTE - The conductivity of the continuous phase can be considerably reduced by the absorption of ions by the solid phase.

5.7.4.5 The gauging and sampling of wholly liquid systems should be carried out in accordance with the recommendations of 5.4.9. The precautions for liquids containing a dispersed solid phase will depend upon the specific mixture and no general advice can be given.

5.7.4.6 As an alternative to raising liquid conductivities, the vapour space in the blending vessel could be inerted in accordance with the recommendations of clause 6. Limiting the power input to the stirrer is then no longer required.

5.7.5 Jet mixing

5.7.5.1 The jet mixing of liquids with conductivities greater than 50 pS/m is not hazardous provided that the jet does not break the liquid surface and that the liquid and all metal parts of the equipment are earthed.

5.7.5.2 If a liquid has a low conductivity any dissipative additive could be used to raise it to above 50 pS/m, provided that it is compatible with the intended use of the mixture.

5.7.5.3 As an alternative to raising liquid conductivities, the vapour space in the tank may be inerted. The use of inerting agents should be in accordance with the recommendations of clause 6.

5.7.5.4 If a liquid has a low conductivity and neither the use of a dissipative additive nor inerting is possible, the degree of risk will depend upon circumstances. It could be necessary to seek expert advice in order to control the surface potential of the liquid in the tank. Factors to be considered include:

- (a) the proximity of internal projections in the tank to the liquid surface, since a high field strength could occur in the vapour space due to charges in the incoming liquid being carried up to the surface by the jet;
- (b) the presence of a separate phase (usually water) at the bottom of the tank;
- (c) whether the tank is being filled whilst the mixing is taking place;
- (d) the time elapsed since the completion of a filling operation.

5.7.5.5 Gauging and sampling should be carried out in accordance with the recommendations given in 5.4.9.

5.7.6 High speed mixing

High speed mixing, for example to produce emulsions, generates more charge than normal blending. Expert advice should be sought on the precautions given in 5.7.4 that will be necessary during high speed mixing of immiscible liquids.

5.8 *Spraying liquids and tank cleaning*

5.8.1 Cleaning tanks with liquid jets

When the washing jet impinges on the tank wall or any protrusion in the tank, it forms a mist of fine droplets which is usually charged. Due to turbulence created by the washing jets, the charged mist is usually distributed uniformly throughout the tank.

The charged mist produces high electrical potentials and the maximum value, which is in the centre of the tank, depends mainly on the size of the tank and the charge density of the mist. This depends on the nature of the liquid being used for cleaning (e.g. water or oil, use of detergents) and the type of cleaning system being used (liquid pressure and throughput, nozzle diameter).

An ignition hazard could occur due to brush discharges to an earthed conducting object protruding into the interior of the tank. If the space potential in the tank exceeds about 58 kV the brush discharges could ignite hydrocarbon/air atmospheres (see 5.2.2).

At much lower potentials, incendive sparks could occur if insulated conductors were present in the tank. Space potentials in the range 5 kV to 20 kV are sufficient to produce incendive sparks in hydrocarbon/air atmospheres. The value depends on the size of the insulated conductors and the length of the spark gap. Insulated conductors are inevitably formed when washing with water jets because the jets produce large isolated volumes of water called slugs. These water slugs could be charged by induction to the potential at the tank centre and incendive sparks could occur when the slugs approach earthed conductive objects.

5.8.2 Tank cleaning with low or medium pressure water jets (up to about 12 bar)

Following explosions on board three very large crude carriers while cleaning tanks with water jets in 1969, investigations showed that the maximum potential in the tank is proportional to the charge density of the mist and to the square of the linear dimension of the tank (or in other words proportional to $V^{2/3}$ where V is the tank volume). This means the ignition hazard increases with the volume of the tank.

Available evidence shows that cleaning a tank with a volume of less than 100 m³ is not hazardous but cleaning a 10 000 m³ tank is hazardous. The threshold volume lies between these limits. A more precise value can only be given if all the conditions are known. The International Maritime Organisation (IMO) regulations for seagoing tankers require that the tanks of tankers with 50 000 dwt and more should only be cleaned when the tanks are inerted. Detailed instructions are given in the "International Safety Guide for Oil Tankers and Terminals (ISGOTT)".

5.8.2.1 Non-conductive liquids

Non-conductive liquids, e.g. hydrocarbons, charge less than does water during spraying because they contain only a small concentration of dissociated ions. Spraying non-conductive solvents could be considered to be safe in the cases described above.

The cleaning solvents should not contain either water or solid particles which could form a second phase in the liquid. For this reason the cleaning solvent should not be recirculated unless the foreign matter content is less than 1 %.

The liquid in the tank should be drained during cleaning to avoid the build-up of charge in liquid that accumulates.

5.8.3 Tank cleaning with high pressure water or solvent jets (above 12 bar)

In the chemical industry, containers and smaller vessels (e.g. stirring vessels) are often cleaned using high pressure spraying heads operated at pressures of up to 500 bar. It is suspected that these sprays could create very high charge densities and potentials in the tank during cleaning. Experimental evidence, however, has shown that the ignition risk for tanks which contain a flammable hydrocarbon/air atmosphere is acceptable in the following circumstances:

a) Spraying water

- cylindrical metal container up to 3 m diameter (or other container of similar geometrical size);
- spraying head operated at 500 bar maximum liquid pressure and maximum liquid flow rate of 5 l/s.

b) Spraying hydrocarbon solvents

- cylindrical metal container of up to 3 m diameter (or other container of similar geometrical size);
- spraying head operated at 50 bar maximum pressure and 1 l/s maximum liquid throughput.

The washing liquids should not contain more than 1 % foreign liquid or particles which can form a second phase and they should be drained during washing to avoid accumulations of charge. In addition, all conductive parts should be earthed.

Safe operation has only been verified within the above limits but exceeding them does not necessarily create a hazardous situation.

5.8.4 Steam cleaning tanks

Steam cleaning tanks produces a charged mist and for tanks which contain a flammable hydrocarbon/air atmosphere it is acceptable only for sizes up to 100 m³ (for details see 6.5).

5.8.5 Water deluge systems

Water deluge systems are used mainly to knock down and disperse flammable atmospheres. They do not operate at high pressures and do not produce highly charged clouds of mist. Since they tend to disperse rather than to concentrate charged droplets, they are unlikely to lead to electrostatic ignition problems.

5.9 Glass systems

5.9.1 General

Incendive discharges within glass systems are due mainly to charging by low conductivity liquids or dust/air-mixtures. Charge accumulation is strongly increased by having a low conductivity plastic coating on the glass surface.

Spark discharges could occur from conductive parts (metal flanges, fittings, valves) and, under usual ambient conditions, brush discharges from plastic coated glass surfaces.

Brush discharges could only occur from glass surfaces at low relative humidities or, for example, if the surface temperature was well above the ambient temperature.

5.9.2 Precautions in the case of low conductivity liquids

Hazards from low conductivity liquids can be reduced by taking the precautions recommended in 5.3. For systems made mainly from uncoated glass, however, the following earthing requirements need to be considered.

In Zone 0 areas containing gases and vapours in Groups IIA, IIB and IIC, and in Zone 1 areas only in the presence of those in Group IIC (see annex D), all conductive parts, such as metal flanges, fittings, valves or measuring equipment should be bonded to earth with a resistance of less than 10⁶ Ω. If prolific charge generating elements such as microfilters are used, incendive brush discharges could occur from the glass to externally earthed metalwork. In those circumstances the flanges should be made from non-conductive materials but it is not necessary to earth small bolts or screws (electrical capacitance equal to or less than 3 pF).

In Zone 1 areas containing gases and vapours in Group IIA and IIB, or in Zone 2 areas in the presence of those in Group IIC, it is usually sufficient to earth conductive flanges only in the vicinity of strong charge generating elements such as pumps, microfilters and nozzles providing the pipes do not exceed 50 mm diameter.

For pipes of diameter 50 mm and above, all flanges and metallic parts of comparable size should be earthed. Fittings, valves or seals with unbonded conductive parts with a capacitance above 3 pF and which cannot be earthed (due for example, to having a non-conductive coating), are not suitable for use in glass systems.

The restrictions for the handling of low conductivity liquids in systems made from plastic coated glass (glass with external plastic coating) are comparable to those for the handling of such liquids in non-conductive systems and are summarised in 5.4.5.6. The precautions for handling conductive or dissipative content such as water, acids, bases or methanol are the same as for uncoated glass.

Glass lined metal systems may be treated as entirely metal. Conductive contents should be earthed, e.g. by an earthed metal plug at the bottom of the system (see also 5.4.5.3).

Expert advice is recommended when handling solvent wet powders in glass systems.

6 Static electricity in gases

6.1 General

The movement of pure gases or of a mixture of gases generates little, if any, static electricity but if the gases contain solid or liquid particles these can become charged. In industrial processes such particles are common. They can be due to contamination, such as dust or water droplets, they can be a condensed phase of the gas itself, such as carbon dioxide snow, or the droplets in wet steam, or they can be deliberately introduced, e.g. shot blasting or paint spraying.

Examples of processes where particle charging can give rise to significant amounts of electrostatic charging include: pneumatic transfer of materials; the escape or release of any compressed gas containing particles; the release of liquefied carbon dioxide; the use of industrial vacuum cleaners; and spray painting.

Charged particles produced by these mechanisms can give rise to a number of types of incendive discharges: spark discharges (see A.3.2), can occur when charge builds up on insulated conductors as a result of impingement or collection of particles; brush discharges (see A.3.4), can occur when charged clouds or jets of charged particles are close to earthed metal projections; propagating brush discharges (see A.3.5), can occur due to charged particles impinging on thin layers of non-conductive material; and cone discharges (see A.3.7), can occur when charged particles collect and form a cone, as in a silo. There is no evidence to suggest that lightning-like discharges (see A.3.6) can occur in industrial scale equipment.

It is not possible to prevent the electrostatic charging of particles but ignition can be avoided either by ensuring that the atmosphere is not flammable or by preventing incendive discharges. The precautions that can be taken to avoid incendive discharges include the following:

- ensuring that all metal and other conducting objects are earthed (see clause 10);
- avoiding the use of highly non-conductive materials;
- reducing charge densities by restricting flow velocities or by suitable nozzle design;
- removing the particles.

For recommendations relating to the pneumatic transfer of powders see clause 7. For recommendations for other industrial processes see 6.2 to 6.9.

6.2 Grit blasting

6.2.1 Grit (or shot) blasting of surfaces is used for cleaning or preparation prior to painting. The process can lead to charging of the grit, the grit blasting equipment, the hose and any nozzle attached to the end of the hose. Sparks can occur as a result of grit accumulating or impinging on unearthed metal objects or directly from parts of the blasting equipment.

6.2.2 If such equipment is used where there could be flammable atmospheres, all metal parts in the area and all parts of the blasting equipment, particularly the nozzle attached to the end of the hose, should be earthed. The hose should be conductive or dissipative.

6.3 *Fire extinguishers*

Some types of pressurized fire extinguisher, particularly those using carbon dioxide, can generate highly charged clouds. If there is a fire this is of little importance. However, if such equipment is situated where an explosive atmosphere could be present, the container and the associated pipework should be earthed. In the absence of fire, the system should not be operated for testing, demonstration or inerting until it has been established that there are no flammable mixtures in the area.

6.4 *Inerting*

6.4.1 Inerting a system, for example, by using pressurized CO₂, can introduce large amounts of charged particles or droplets. If the system contains an explosive atmosphere this can lead to incendive sparks occurring before sufficient inert material has been added to ensure that the atmosphere is no longer explosive.

To avoid the risk of ignition when inerting vessels containing flammable gas mixtures or dust suspensions, avoid injecting particles. Where possible, use gases that do not contain particulate matter or which do not condense to a liquid or solid phase when released at high pressure, e.g. clean dry nitrogen.

6.4.2 Wet steam should not be used for inerting a vessel containing a flammable mixture of any kind. Dry steam is acceptable provided that all condensed water is removed from the lines prior to the inerting operation.

6.4.3 Whatever substance is used for inerting, it is advisable to introduce it slowly through a large orifice. This will both minimize the pick-up of dirt and scale from the lines and also the raising of dust or spray within the vessel.

6.5 *Steam cleaning*

6.5.1 Steam issuing from a nozzle could contain charged water droplets. Inside a vessel the charged mist could lead to high electric fields giving rise to incendive discharges.

6.5.2 Tanks with capacities greater than 100 m³ that could contain a flammable atmosphere should not be steam cleaned. Tanks smaller than this may be steam cleaned providing that: the steam nozzles and other metal parts of the system are reliably earthed; the vessel or container being cleaned is earthed; where possible, dry or superheated steam should be used and condensate prevented from forming in the lines.

6.6 *Accidental leakage of compressed gas*

Hazardous charges could be produced when either flammable or non-flammable gases containing liquid or solid particles are accidentally released. If there is the possibility of a leak where there could be an explosive atmosphere, the containing vessel or pipe and any adjacent conducting objects should be earthed. Conducting objects that could be moved into an area containing an explosive atmosphere should be earthed before the object is moved. Persons going into the area of such leaks, for example to carry out repairs, should also be earthed (see Clause 8) and non-conducting objects should not be taken into the area.

6.7 *Spraying of flammable paints and powders*

6.7.1 General

The clouds of droplets or particles produced by paint or powder spraying are often highly charged. As a result, the spraying equipment, the object being charged and any other object (including persons), within range of the spray could also become charged. If the cloud of droplets or particles is flammable there can be an ignition hazard.

The risks are greatest with electrostatic paint, powder and flock spraying and the safety requirements for these processes are given in EN 50050, EN 50053, EN 50059, EN 50176, EN 50177 and EN 50223. Airless spraying processes can also give rise to high charge levels and the precautions given in 6.7.2 should be observed.

The level of charging with air-atomized spraying equipment is not usually high enough to cause concern. However, if sparking or electric shocks are encountered, this equipment should also be subject to the precautions given in 6.7.2.

6.7.2 Earthing

The spraying equipment, all metallic objects in the vicinity of the paint or powder cloud, and, in particular, the object being sprayed should be earthed (see Clause 10).

NOTE - Paint or powder deposits can prevent earthing by the jigs and suspension hooks. This problem can be avoided by suitable design and regular cleaning. Persons operating the equipment should also be earthed (see Clause 8).

6.7.3 Plastic spray cabinets

Spray cabinets of non-conductive materials should not be used for spraying flammable paints. They are acceptable for spraying powders only if it can be shown that there is no ignition risk. Cabinets of conductive material are acceptable for all types of spraying, provided that they are earthed.

6.8 *Extraction systems*

Under consideration

6.9 *Vacuum cleaners, fixed and mobile*

6.9.1 General

Vacuum cleaning systems can generate large amounts of electrostatic charge. The material, in the form of dust, particles, liquid drops or small objects, can become charged as it is sucked in through the nozzle and the hose into the collecting system. If there are metal parts within the system which are not bonded to it and earthed, they could acquire a high voltage. Incendive spark discharges (see A.3.2), could occur either between the metal parts or from the system to earth. Brush discharge (see A.3.4) could also occur inside the system between accumulations of charged material and earthed metal.

6.9.2 Fixed systems

If the equipment is used for collecting flammable materials, all metal and conductive parts of the system should be bonded together and earthed. It is particularly important to ensure that a metal nozzle is, and remains, bonded to the flexible connecting hose. That hose should be either conductive or semi-conductive (see 5.5.5(a) and 5.5.5(b)). It should be bonded to the collecting system, which should also be earthed and, preferably, should be sited outside.

If the system is used for collecting flammable liquids or sensitive dusts (those with a minimum ignition energy (MIE) less than 3 mJ), any collecting bag within the system should be conductive to minimise the risk of brush discharges.

To prevent electric shock all collecting systems should be earthed even when they are not used for collecting flammable materials (see clause 10).

6.9.3 Portable systems

If the equipment is used for collecting flammable materials, all metal and conducting parts of the system should be bonded together and earthed. It is particularly important to ensure that the container is always earthed when in use. This could be done using the mains lead or, in the case of compressed air driven equipment, by using a conducting hose for the compressed air.

Equipment which cannot be earthed (e.g. because the outer shell is non-conductive, see 2.9) and does not have electrical continuity between the nozzle and the receiver should not be used in hazardous areas (see annex D).

7 **Static electricity in powders**

7.1 General

In this clause the term powder means particles with sizes ranging from those of fine dust to granules or chips. The ignition sensitivity of a given product with respect to ignition by discharges due to static electricity is characterised by the minimum ignition energy (see C.6). The minimum ignition energy (MIE) depends strongly on the fineness of the powder, the lowest values relate to very fine powder. Hazard assessment should therefore always be based on the minimum ignition energy of the finest particle size fraction which may be present in the processes. This fraction is usually obtained by sieving a sample through a 63 μm sieve. If the relevant minimum ignition energy is above 10 J and there are no flammable gases and vapours, special measures to minimise static electricity ignition hazards are usually not necessary. Precautions could be necessary to minimise electric shock risks (see 9.4).

7.2 Powders in the absence of flammable gases and vapours

7.2.1 General

In all parts of 7.2 it is assumed that the powder is handled and processed free from any flammable gases and vapours, i.e. the powder does not contain significant levels of flammable solvent and flammable gases or vapours are not present in the process nor could they be added from neighbouring processes.

To assist with the guidance, powders have been divided into 3 groups depending on their volume resistivity:

- (a) low resistivity powders, e.g. metals, with volume resistivities up to about $10^6 \Omega\text{m}$;
- (b) medium resistivity powders, e.g. many natural organic powders, with volume resistivities in the range $10^6 \Omega\text{m}$ to $10^{10} \Omega\text{m}$;
- (c) high resistivity powders, e.g. polymers, some synthetic organic powders and very dry natural organic powders with resistivities of $10^{10} \Omega\text{m}$ and above.

In practice, low resistivity powders are rare. Even metal powders do not remain conductive for very long because oxide films form on the surface and increase their resistivity.

7.2.2 Charging of powders

Contact charging occurs extensively in powders. The charging characteristics are often determined at least as much by surface contamination of the particles as by the chemical composition of the powder itself and the amount of charge build is usually difficult to predict. Charging can be expected whenever a medium or non-conductive powder comes into contact with a dissimilar surface. It occurs, for example, during mixing, grinding, sieving, pouring, micronising and pneumatic transfer. Examples of the amount of charge that a powder can acquire are shown in table 5.

Table 5: Charge acquired by medium resistivity powders

Operation	Mass charge density (μCkg^{-1})
Sieving	10^{-3} to 10^{-5}
Pouring	10^{-1} to 10^{-3}
Scroll feed transfer	1 to 10^{-2}
Grinding	1 to 10^{-1}
Micronising	10^2 to 10^{-1}
Pneumatic conveying	10^3 to 10^{-1}

7.2.3 Charge retention

Charge will accumulate on and be retained by a powder if the charge generation rate exceeds the rate at which the charge dissipates. For further details about charge accumulation on powders see A.2.3

7.2.4 Discharges, occurrence and incendivity

The build up and retention of charge on powder or equipment creates a hazard only if the charge is suddenly released in the form of a discharge which can cause an ignition. Charged powder and equipment can give rise to several types of discharge and they vary greatly in incendivity (see A.3.2 to A.3.7). The incendivity and other details of these discharges relevant to powder handling are as follows:

- (a) Spark discharges. The incendivity of spark discharges can usually be assessed by comparing the stored energy (see A.3.2), with the MIE of the combustible powder in question. Spark discharges can be avoided by earthing all conductive parts of equipment, conductive products and also persons;
- (b) Brush discharges. The present state of knowledge indicates that combustible powders with MIEs greater than 3 mJ are unlikely to be ignited by brush discharges, providing there are no flammable gases or vapours. When handling large amounts of medium or non-conductive powders, brush discharges cannot be avoided;
- (c) Corona discharges. Corona discharge cannot ignite combustible powders. When handling large amounts of medium or non-conductive powders, corona discharges cannot be avoided;
- (d) Propagating brush discharges. The energy released in a propagating brush discharge can be calculated and values of 1 J are typical. Examples of a calculation and more details of propagating brush discharges are given in B.3.9;
- (e) Cone discharges. Cone discharges can occur when highly charged powder is loaded into a silo. It is considered likely that flammable gases and vapours and also combustible powders can be ignited by these discharges (see also A.3.7);
- (f) Lightning-like discharges. Such discharges, though theoretically possible, have not been observed in industrial operations.

7.2.5 Precautions

7.2.5.1 General

In some powder handling processes it is not possible to avoid having both an explosive atmosphere and a hazardous build up of charge. In those situations measures should be taken that protect against or prevent explosions. These include inerting, the use of explosion resistant equipment, explosion venting or explosion suppression

7.2.5.2 Earthing and bonding

To avoid incendive spark discharges from conductors which could become charged, items such as metal plant, conductive materials, low resistivity products and persons should be earthed (see clause 10). The risk of incendive discharges due to charge build-up on unearthed conductors may only be ignored if:

- a) the object does not become charged during normal operation and possible malfunctions; or
- b) the maximum energy that can be stored on the conductor is much lower than the MIE of the explosive atmosphere (this could be due to the conductor having a small capacity or a low voltage).

7.2.5.3 Use of non-conductive materials

Non-conductive materials in the form of pipes, containers, sheets, coatings and liners, are being used increasingly in equipment and structures. Charge can build up on their surfaces often as a result of the process. This occurs, for example, during pneumatic transfer of a powder through a non-conductive pipe or when filling a non-conductive container with charged powder.

In the absence of flammable atmospheres with MIE < 3 mJ, brush and corona discharges may be tolerated. As a result, non-conductive materials are permitted providing that they do not cause propagating brush discharges (see A.3.5).

Where there could be high surface charging processes, non-conductive materials in the form of sheets, layers or coatings should not be used, unless the breakdown voltage across the material is less than 4 kV (see A.3.5).

7.2.5.4 Control of charge accumulation

In contrast to the situation with liquids, control of the charge build up on powders is rarely possible. For example, the build up of charge during pneumatic conveying is influenced by many parameters such as, particle size, mass flow rate, air velocity, etc. Powder transport velocities, unlike liquid flow velocities, can often not be limited for technical reasons. However, some improvements can be made by changing a particular process or by selecting another. For example, the use of high density (semi-bulked) flow rather than low density flow can reduce the charge build up on non-conductive powders.

7.2.5.5 Charge reduction by humidification

Normal atmospheric air is a poor conductor of electricity, irrespective of its relative humidity, and humidification is not effective as a means of dissipating the charge from a dust cloud.

However, high relative humidity does decrease the surface resistivity of many powders and increases the rate of charge decay on bulked powder in earthed metal containers. But for this to be effective, most materials need a relative humidity well in excess of 70 % and it is often impracticable to operate powder processing units at these high levels of humidity. In addition, this method may not be effective for high speed conveying and for warm products.

7.2.5.6 Charge reduction by ionisation

The electrical conductivity of the gas in which a powder is suspended can be increased by ionisation, produced either by corona discharge from pointed conductors or by the use of radioactive sources. Such systems are occasionally used to prevent dust deposition on surfaces but they are not widely used for removing charge from powders. This is because it is difficult to ensure that the ionisation required is provided throughout the relatively large volume of dust cloud enclosures. Also, the total charge to be neutralised is often greater than the charge that can be delivered by a radioactive ionisation system. Similar restraints apply to the use of ionisation for removing charge from bulked powders.

Localised discharges from pointed, earthed, conducting probes or wires can be of value in both dust clouds and bulked powders when the electric field strength is close to the breakdown value, a situation likely to be encountered with non-conductive powders. Such earthing probes or wires placed at the bulking point as powder enters a container can reduce the energy of individual discharges to a low level. They can also provide a safe route to earth for accumulated charge when powder enters a non-conductive container, thereby avoiding propagating brush discharges. Such systems are not without problems, however, since if parts of the probe or wire break off they could form a charged capacitor and give rise to spark discharges.

7.2.5.7 Charge reduction by dissipative additives

With powders there is no equivalent to the dissipative additives used for reducing the resistivity of liquids. Additives may be used for solid polymers but they are not normally present when the materials are being handled as granules.

7.2.6 Precautions in particular cases

7.2.6.1 General

Several types of discharge can arise during the handling and storage of dusts and powders and they include; sparks; brush discharges; propagating brush discharges; cone discharges; and corona discharges. The properties of these discharges relevant to powder handling are discussed in annex B.

If there is an explosive concentration of powder and the energy released by one of these discharges exceeds the MIE of the material handled, there could be a fire or an explosion.

To avoid these hazards, the recommendations given in 7.2.6.2 should be followed. The subject is a difficult one and in many instances it could be appropriate to take expert advice.

7.2.6.2 Summary of precautions for all situations

7.2.6.2.1 All metallic or conductive non-metallic parts of the equipment, including containers, fill pipes, funnels, etc., should be earthed.

7.2.6.2.2 In a flammable atmosphere (e.g. a dispersion of dust and air) with a MIE less than 30 mJ, persons exposed to the dust cloud who could become charged to a hazardous level should be earthed.

7.2.6.2.3 In addition to earthing, protective measures to deal with cone discharges may be necessary when handling mixtures of highly non-conductive dust and granules (resistivity $>10^9 \Omega\text{m}$). Expert advice is recommended under these circumstances.

7.2.6.2.4 Depending on material resistivity, volume of equipment and the process, handling a dust with a MIE $< 3 \text{ mJ}$ could require the use of explosion protective systems. Expert advice should be sought.

7.2.6.3 Conductive and dissipative containers

7.2.6.3.1 These containers are constructed from materials with a surface resistivity and volume resistivity which are below $10^8 \Omega$ and $10^6 \Omega\text{m}$ respectively. In addition, the leakage resistance to earth from any point of the container should be $< 10^8 \Omega$. In addition to 7.2.6.2.1 to 7.2.6.2.4 the recommendations given in 7.2.6.3.2 to 7.2.6.3.4 inclusive apply to these types of containers.

7.2.6.3.2 For containers of any volume having one dimension of less than or equal to 3 m (e.g. a silo of up to 100 m^3 capacity) the following precautions apply:

- a) with flammable mixtures of materials with MIEs greater than 10 mJ, see 7.2.6.2.1 to 7.2.6.2.4;
- b) with flammable mixtures with MIEs up to and including 10 mJ, protective measures in addition to 7.2.6.2.1 to 7.2.6.2.4 should be considered. These include: reduction of the quantity of charge on the incoming powder; installation of explosion protection by inerting, air purging, explosion suppression or explosion venting.

NOTE - In the absence of flammable vapours experience has shown that such additional precautions are seldom needed.

7.2.6.3.3 For containers having a smallest dimension exceeding 3 m (e.g. a silo of greater than 100 m^3 capacity) the probability of an incendive discharge from the charged powder suspension in air is, as yet, unknown. In addition to precautions 7.2.6.2.1 to 7.2.6.2.4, the installation of some form of explosion protection should be considered. The measures taken should be based on the MIE of the powder and expert advice should be sought.

7.2.6.3.4 If it can be shown that incendive discharges from a charged powder suspension in air cannot occur, precautions 7.2.6.3.3 may be relaxed and precautions 7.2.6.2.1 to 7.2.6.2.4 should provide adequate protection. Examples of situations where incendive discharges are unlikely are: containers up to $0,2 \text{ m}^3$; containers up to 2 m^3 unless there is a high rate of charge input such as e.g. from micronizing.

7.2.6.4 Conductive and dissipative containers with conductive or dissipative liners

7.2.6.4.1 These liners have a surface resistance of less than $10^8 \Omega$ and a resistance to earth of less than $10^8 \Omega$ from any point on the liner. A dissipative liner is also defined as a material with a surface resistance less than $10^{11} \Omega$.

In addition to 7.2.6.2.1 to 7.2.6.2.4 the recommendation given in 7.2.6.4.2 to 7.2.6.4.3 apply to these types of containers and liners.

7.2.6.4.2 If there is a possibility of a sensitive dust cloud, then, in most situations, it is essential that the liner should not be removed from the container, for example to shake out any residues. However, that is acceptable if the liner remains in contact with earth.

7.2.6.4.3 All the precautions recommended for the equivalent unlined container in 7.2.6.3 should be applied.

7.2.6.5 Conductive and dissipative containers with a non-conductive liner

7.2.6.5.1 A non-conductive liner is a material with a surface resistance greater than $10^{11} \Omega$.

In addition to 7.2.6.2.1 to 7.2.6.2.4, the recommendation given in 7.2.6.5.2 to 7.2.6.5.6 should be applied to these types of containers and liners.

7.2.6.5.2 Non-conductive liners should be used only if they are essential, for example, for reasons of chemical compatibility between the liner and the material being handled. The ignition risk and the possibility of electric shock from propagating brush discharges depend very much on: the thickness and resistivity of the liner; the handling procedure; the electrical properties of the material being handled; and for ignitions, the nature of any flammable mixture that could be present. In general, propagating brush discharges will not occur provided that the non-conductive liner has a breakdown voltage lower than 4 kV (see A.3.5). Each situation should be considered on its merits, taking expert advice if necessary.

7.2.6.5.3 Ideally non-conductive liners should not be used in the presence of a flammable gas or vapour/air mixture.

7.2.6.5.4 In the presence of a flammable vapour/air mixture or dust cloud with $MIE < 3 \text{ mJ}$ it is essential that the liner should not be removed from the container, for example to shake out any residue. This is to prevent ignition by brush discharges.

7.2.6.5.5 If the powder volume resistivity is less than $10^6 \Omega\text{m}$ the contents should be earthed (see 7.2.6.6.2).

7.2.6.5.6 If it can be shown that propagating brush discharges cannot occur and there are no flammable vapour/air mixtures or dust clouds with $MIE < 3 \text{ mJ}$ the precautions 7.2.6.3.1 to 7.2.6.3.4 should be used.

7.2.6.6 Non-conductive container

7.2.6.6.1 A non-conductive container is defined as one made from materials with volume resistivities greater than $10^8 \Omega\text{m}$ and/or surface resistances greater than $10^{11} \Omega$. In addition to 7.2.6.2.1 to 7.2.6.2.4, the recommendations given in 7.2.6.6.2 to 7.2.6.6.5 inclusive apply to these types of containers.

7.2.6.6.2 The contents of containers used for powders with volume resistivities of less than $10^6 \Omega\text{m}$ should be earthed, for example, by providing one or more vertical metal rods or a metal fill pipe into the vessel. The pipe and rods should be earthed and placed into the vessel prior to the addition of flammable powder.

7.2.6.6.3 For containers with capacities up to and including 5 m^3 that are used for dry powders, the following precautions should be used:

a) 7.2.6.2.1 to 7.2.6.2.4 for flammable mixtures with MIEs greater than 10 mJ;

b) 7.2.6.2.1 to 7.2.6.2.4. for flammable mixtures with MIEs less than 10 mJ. But it could be necessary to use additional protective measures unless it can be shown that the rate of charging is insufficient to cause incendive discharges. These protective measures include the reduction of charge on the

incoming powder and the installation of some form of explosion protection, such as inerting, air purging, explosion suppression or explosion venting;

c) where propagating brush discharges could occur the breakdown voltage across the container wall should be less than 4 kV (see A.3.5) to avoid the risk of ignition. To avoid the risk of electric shock, one or more earthed rods may be inserted into the container to assist relaxation of charge from the powder.

NOTE - The possibility of a propagating brush discharge can be reduced by prebulking the incoming powder in an earthed metal hopper. The precautions given in 7.2.6.3 should be applied to the hopper.

7.2.6.6.4 For containers exceeding 5 m³ the risk of incendive discharges from the bulk powder and the container wall increases. In addition to precautions 7.2.6.2.1 to 7.2.6.2.3, consideration should be given to installing some form of explosion protection. The decision should be based on the MIE of the material and on expert advice.

7.2.6.6.5 If propagating brush discharges and incendive cone discharges are not possible, precautions 7.2.6.2.1 to 7.2.6.2.4 apply. For example, incendive discharges are unlikely in containers up to 2 m³ unless a flammable gas or vapour atmosphere is present.

7.2.6.7 Non-conductive containers used with liners

7.2.6.7.1 Precautions are the same as for non-conductive containers without a liner (see 7.2.6.6). Conductive liners should only be used within non-conductive containers if they are prevented from becoming charged e.g. by being earthed.

7.2.6.7.2 The liner should not be removed from the container, for example, to shake out any residue, if there is a possibility of a sensitive dust cloud, gas or vapour. (See 7.2.6.5.3).

7.2.6.8 Flexible intermediate bulk containers

Flexible intermediate bulk containers (FIBCs) are used in industry for storage and transport of powders and granules. They are often constructed from polypropylene fabric or similar strong and heavy duty material. Some have conducting or electrostatically dissipative threads woven into the fabric and some are treated to modify their surface resistivity.

Electrostatic charge can be generated during filling and emptying and it can accumulate on the powder, the fabric from which a FIBC is constructed or the conducting elements within the fabric. An ignition could occur if the accumulated charge is released in the form of an incendive discharge in the presence of a flammable atmosphere. Spark, brush, cone and propagating brush discharges are all possible when FIBCs are used.

The risk of incendive discharges from an FIBC is reduced when the fabric is modified in certain ways. An FIBC constructed from conducting fabric or from fabric containing interconnected conducting threads removes charge from its surface through connection of the conducting components to earth. An FIBC containing disconnected conducting threads removes charge by corona discharge, and resistivity modifying treatments can help reduce the incendivity of discharges from the surface of some FIBCs.

NOTE - Propagating brush discharges from the FIBC material can be prevented by ensuring that the electrical breakdown voltage of the material is lower than 4 kV (see A.3.5).

7.2.6.8.1 FIBC constructed from conducting fabric

Recommendations for metallic and conductive non-metallic containers (see 7.2.6.3) also apply to these FIBCs. It is essential that all conducting components are earthed. If these FIBCs could be used with a liner, the recommendations given in 7.2.6.4 and 7.2.6.5 should be used.

7.2.6.8.2 FIBC constructed from non-conductive fabric

The recommendations for non conducting containers (see 7.2.6.6) should be used for these FIBCs. In addition, if they are used with liners, the recommendations for liners in non-conductive containers apply (see 7.2.6.7).

7.2.6.8.3 FIBC constructed from non-conductive fabric containing woven earthed conducting filaments

The recommendations for conductive and dissipative containers (see 7.2.6.3) also apply to these FIBCs provided the conducting filaments or threads are spaced less than 20 mm apart and are interconnected at least once (preferably at one end) and earthed, or the conducting filaments or threads form an interconnected grid of maximum 50 mm mesh size and are earthed. The resistance between any conducting element and earth should be less than $10^8 \Omega$.

7.2.6.8.4 FIBC constructed from two layers of fabric laminated together with the inner and/or outer layer constructed of non-conductive fabric containing earthed conducting elements, filaments or threads

The recommendations for a non conducting fabric containing woven earthed conducting filaments (see 7.2.6.8.3) also apply here.

NOTE - It is not possible to make recommendations for the safe use in flammable atmospheres of all the different types of FIBCs. It is considered that insufficient data are available for the following examples and expert advice should be sought:

- FIBC constructed from non-conductive fabric containing woven unearthed conducting filaments or threads;
- Two loose layered FIBC with outer containing conducting elements and the inner constructed of non-conductive fabric;
- Two loose layered FIBC with outer constructed from non-conductive fabrics and the inner constructed from conducting plastic.

7.3 *Powders in the presence of flammable gases or vapours*

7.3.1 General

There is usually a higher risk of ignition when handling powders in the presence of flammable gases or vapours since the MIE of most gases and vapours is much lower than the MIE of powder clouds. Even if the gas or vapour is below the flammable concentration, it is possible to form a flammable hybrid mixture with a MIE well below that of the powder cloud alone. The risk is also more serious with hybrid mixtures because the charge to mass ratio is generally much higher than it is for liquids. Brush discharges could occur, even with a small amount of product, and they could ignite most flammable gases, vapours and hybrid mixtures.

Since in many cases, there is both an explosive atmosphere and the possibility of incendive discharges, inerting could be the only solution. However, expert advice could provide an alternative.

7.3.2 Solvent-wet powders

7.3.2.1 If the powder is wet with solvent and can produce a flammable gas or vapour atmosphere the recommendations for flammable liquids apply (see clause 5).

7.3.2.2 In addition to precautions 7.3.2.1, protective measures such as inerting could be necessary unless it can be shown that incendive discharges from the product could not occur.

7.3.2.3 The precautions in 7.3.2.2 could be relaxed if the volume resistivity of the solvent-wet product is below $10^8 \Omega m$ and all metal equipment is earthed.

7.3.3 Manual addition of powders to flammable liquids

7.3.3.1 General

The manual addition of powder into flammable liquids from metal and plastic drums and from paper and plastic sacks has caused fires and explosions. A significant number of these has been attributed to electrostatic discharges. Electrostatic charges can be generated by pouring the powder from the container or due to its passage down a chute into the receiving vessel. Unless precautions are taken, hazardous potentials could develop on the container being emptied, a liner in the container, the receiving vessel, the loading chute, the powder stream, the vessel contents and on persons carrying out the operation.

The direct (open) loading of powders into a flammable atmosphere (e.g. a reaction vessel containing flammable solvent) should be avoided whenever possible. This can be achieved in the following ways:

- a) by closed loading into an inerted vessel using rotary star valves, screw feeders or similar devices. However, these methods could allow air to enter and it is essential to maintain a non-flammable atmosphere. If necessary the level of oxygen in the vessel should be monitored;
- b) by adding the dry powder to the vessel before filling with flammable liquid;
- c) by cooling the flammable liquid to well below its flashpoint. However, it is important to remember that flammable hybrid mixtures could still occur. Additional measures such as air purging could be necessary.

7.3.3.2 Direct (open) loading of powder into flammable liquids

NOTE - If open loading cannot be avoided and if it is not possible to separate the bag or container emptying operation from the flammable atmosphere, recommendations 7.3.3.2.1 to 7.3.3.2.5 should be used.

7.3.3.2.1 General

To avoid hazards due to fire and toxic materials, the flammable vapour should be contained within the vessel and powder should be prevented from forming a cloud around the loading point. For recommendations 7.3.3.2.2 to 7.3.3.2.5 it has been assumed that flammable vapour and dust clouds will be formed only within the receiving vessel and the immediate vicinity of the entry point.

7.3.3.2.2 Container being emptied

7.3.3.2.2.1 Containers should be of metal, paper or other dissipative material and they should be earthed before and during emptying. It is often not practicable to use earth clips for paper sacks and these could be earthed using the earthed plant or the earthed operator.

7.3.3.2.2.2 In general, high resistivity containers should not be used where flammable atmospheres due to solvent vapour could be present.

7.3.3.2.2.3 In general, high resistivity liners should not be used where flammable atmospheres due to solvent vapour could be present.

7.3.3.2.2.4 Conductive or electrostatically dissipative liners may be used in combination with earthed metallic or conductive non-metallic containers. But the liner should not be removed from the container, for example to shake out residue, in a flammable atmosphere (solvent vapour or a powder cloud), unless the liner is always in contact with earth.

7.3.3.2.2.5 Conductive or dissipative containers coated with a non-conductive coating may be used providing:

- the coating is no thicker than 2 mm;
- the coating does not become detached from the container during emptying; and
- the container is earthed.

7.3.3.2.3 Receiving vessel and loading chute

7.3.3.2.3.1 Metal or conductive non-metallic receiving vessel and loading chute should be earthed.

7.3.3.2.3.2 In general, non-conductive receiving vessels and loading chutes should not be used.

7.3.3.2.3.3 For receiving vessel and loading chute with liners or coatings recommendations 7.3.3.2.2.3 to 7.3.3.2.2.5 should be used.

7.3.3.2.4 Materials being handled

7.3.3.2.4.1 The conditions for obtaining an incendive discharge from an electrostatically charged powder stream as it enters a vessel cannot be defined precisely. However, the risk of ignition is low except when:

- a) the length of the charge chute exceeds 3 m; or
- b) non-conductive powders are involved

In both cases risk can be reduced by limiting the filling rate to a maximum of 1 kg/s. If this is not possible expert advice should be sought.

7.3.3.2.4.2 Providing the conductivity of the single phase mixture in the vessel remains greater than 50 pS/m and it is in contact with earth there should be no hazardous accumulation of charge. With some multiphase mixtures, however, a conductivity greater than 1 000 pS/m could be required to prevent hazardous charge accumulation.

NOTE - An uncoated metal vessel provides the necessary earth path but if the vessel has an insulating lining then a special earth point should be provided near to its base.

7.3.3.2.4.3 If the conductivity of the liquid in the vessel is less than 50 pS/m, (or 1 000 pS/m in the case of multiphase mixtures), a hazardous level of charge could be retained on the liquid. The degree of risk depends on the conductivity of the liquid and the levels of charge generated during the loading operation. The risk could be reduced by the use of a suitable dissipative additive but if this is not possible expert advice should be sought.

7.3.3.2.5 Plant operator

The plant operator should be properly earthed (see clause 8).

8 Static electricity on persons

8.1 General considerations

Persons who are insulated from earth can easily acquire and retain an electrostatic charge. The insulation from earth can be due to the fact that the floor covering or the soles of their footwear are made from a non-conductive material. There are many mechanisms that can cause a person to become charged and the following are examples:

- walking across a floor;
- rising from a seat;
- removing clothing;
- handling plastics;
- pouring from or collecting charged material in a container;
- standing close to highly charged objects, e.g. a moving belt;
- induction.

If an electrostatically charged person touches a conducting object (e.g. door handle, hand rail, metal container) a spark can occur at the point of contact. Such sparks, which are unlikely to be seen, heard or even felt by the person, can cause ignitions. Sparks from persons are capable of igniting gases, vapours and even some of the more sensitive dusts.

It is very important that persons who work where there could be flammable atmospheres should be prevented from becoming electrostatically charged. This is best achieved by having a conducting or dissipative floor and ensuring that persons wear dissipative footwear.

8.2 *Conducting floor*

In many factory environments the conventional flooring materials, for example, bare concrete or steel grids, are adequately conducting. The methods for checking this and the recommended levels of resistance are given in clause 10. In order to remain effective the floor should not be covered by rubber mats or plastic sheet, etc., and care should be taken to prevent the build-up of contaminants such as resin or other non-conductive substances.

8.3 *Dissipative and conductive footwear*

There are two types of footwear which are used for earthing persons in order to prevent them from becoming electrostatically charged:

- a) dissipative footwear has both an upper and a lower resistance requirement (see 2.16). The upper level is low enough to prevent the build up of electrostatic charge and the lower level offers some protection in the event of accidental contact with mains electricity. This type of footwear is suitable for general use;
- b) conductive footwear has a very low resistance (see 2.17) and is worn, for example, by persons who have to handle sensitive explosives. This type of footwear should not be worn where there is any risk of accidental contact with mains electricity and it is not suitable for general use.

Socks or stockings do not normally adversely affect the properties of either types of footwear; however, some types of overshoes can do so.

8.4 *Clothing*

In spite of the fact that modern clothing can readily become electrostatically charged it is not, in general, an ignition risk providing that the wearer is earthed by means of suitable footwear (see 8.3) and flooring (see 8.2). However, clothing should not be removed in areas where there could be flammable atmospheres (e.g. Zone 0, Zone 1, Zone 20 and Zone 21). In Zone 0 highly non-conductive clothing should not be worn.

In special areas, for example where there is oxygen enrichment of the air, it could be necessary to wear dissipative (specially treated) outer clothing (see 2.18). It is important to note that it could be necessary to re-treat this type of clothing each time that it is washed.

8.5 *Protective Gloves*

Because gloves made from non-conductive materials could allow objects held in the hand to become and remain charged, gloves made from dissipative materials should be used in Zone 0 and Zone 1 areas.

8.6 *Other Items*

Protective helmets or visors made from plastics could become charged but the risk of igniting a surrounding flammable atmosphere is small. In most circumstances the advantages of wearing such protective equipment outweigh the disadvantages due to electrostatic charging.

9 *Electric shock*

9.1 *Introduction*

The discharge of static electricity through a person's body can cause an electric shock. Such shocks rarely cause direct harm but the involuntary movement resulting from the shock can lead to injury or even death. In addition to these hazards, the electrical discharge that normally precedes these shocks can also ignite explosive atmospheres (see clause 8).

Electric shocks due to static electricity differ to some extent from other forms of electric shock in that they are of short duration (less than 1 ms), they normally involve high voltages (1 000s or 10 000s of volts), and safe/hazardous levels are expressed in terms of energy or charge, as opposed to current.

9.2 *Discharges relevant to electric shocks*

Static electricity gives rise to several types of discharge and their properties are fully discussed in A.3.2 to A.3.7. The following are considered to be most relevant to electric shocks to persons:

- brush discharges can occur when a person moves close to or touches a highly charged non-conductor (solid or liquid);
- spark discharges can occur when a person makes contact with a highly charged metal or conductive body;
- propagating brush discharges can occur due to, for example, a person handling bipolar charged plastic sheets or touching highly charged powders or granules inside a large plastic skip.

Electrostatic discharges are considered to be a direct hazard to health if the discharge energy exceeds 350 mJ or the charge transferred exceeds 50 μC . It follows that brush discharges or spark discharges from small insulated metal objects (funnels, cans, hand tools) do not cause electric shocks which are directly harmful. But spark discharges from large objects and some propagating brush discharges can be harmful since the energies from both these types of discharge can exceed 1 J.

Discharge energies as low as a few mJ can be an indirect hazard to health due to involuntary movement. Such shocks can cause injury due to contact with moving machinery or to falls. Even minor shocks are undesirable since they can cause unnecessary anxiety and lead to loss of concentration.

9.3 *Sources of electric shock*

Many industrial (and non industrial) processes can lead to electric shocks. These can occur when:

- there is a prolific source of charging;
- the charge is able to build up on an object, normally a conductor; and
- a person is able to make contact with the object.

Examples of prolific charging processes are:

- belts or film passing rapidly over rollers;
- pneumatic conveying of materials;
- pumping low conductivity liquids through filters or other restrictions;
- spraying using electrostatic spraying equipment;
- escape of wet steam;
- fire-extinguishers which emit charged drops or particles.

9.4 *Precautions to avoid electric shocks*

The most effective precaution that can be taken to avoid electric shocks is to earth all metal and conducting parts of machinery and plant (for details see clause 10). However, this is not always possible and, even when it is, there can still be problems due to highly charged non-conductive (solid and liquid) materials .

Other precautions include:

- reducing the rate of charge generation. This has limited application but the use of dissipative additives can be effective, mainly when used with liquids;
- reducing charge build up on non-conductors. Static eliminators are useful for removing charge on moving film and webs;
- preventing persons from making contact with charged parts. This approach is useful for processes such as electrostatic spraying (see 6.7) or other processes that have highly charged parts. Persons can be protected from contact with such parts by using suitable insulation, earthed screens, etc.

9.5 *Precautions in special cases*

9.5.1 Pneumatic conveying

Moving powders, granules or small objects from one place to another by blowing them through pipes often causes large amounts of charging. The material being conveyed and all parts of the conveying system, including the pipework and the containers at either end, can all become highly charged.

In addition to earthing the following precautions should be taken:

- A build-up of conducting objects inside a non-conductive pipe should be earthed before attempts are made to clear it. (A metal rod attached to an earthed conducting wire is suitable);
- When pneumatically conveyed conducting objects collect in a non-conductive container there should be an earthed contact at the base of the container or persons should be prevented from touching the contents;
- When pneumatically conveyed non-conductive powder or granules collect in large (1 m³) non-conductive containers persons should be prevented from touching the contents (see also 7.2.6.6.3).

9.5.2 Vacuum cleaners

Vacuum cleaners are similar to pneumatic conveying systems; the material that is picked up is charged as it passes through the hose and collects in the system.

The following precautions should be taken:

- Fixed systems should be earthed and metal or conductive hoses and nozzles bonded to them;
- Portable systems are not normally a problem but external metal parts should be earthed if they are to be used near moving machinery or on elevated platforms.

9.5.3 Reels of charged film or sheet

Film and sheet material can become charged due to passing over rollers leading to the storage of large amounts of charge on reels. Rolls of such material are best handled by machines but the following precautions should also be taken:

- The charge collecting on the material can be reduced by using static eliminators;
- The central former, (or roller), should be earthed before it is touched by a person.

9.5.4 Fire extinguishers

The release of material from an extinguisher can cause large amounts of charging and the system, (or parts of it), that are not earthed can acquire a high voltage.

The following precaution should be taken:

- All metal or conductive parts of fixed systems should be earthed.

Although it is possible to get shocks from portable extinguishers this is rare. On balance the advantages of using this equipment outweigh the possible shock risk.

9.5.5 Reported shocks from equipment or processes

Many types of equipment and processes cause electrostatic charging but it often goes unnoticed. However, reports by operatives that they are receiving shocks should always be investigated. It is likely that they are harmless, but this is not always the case; it can indicate that equipment is faulty and hazardous.

9.5.6 Shocks as a result of people being charged

People often become electrically charged, either directly (by removing a garment or walking across a carpet) or by induction (due to being close to highly charged objects). This can lead to shocks which, although not directly harmful, can be very annoying.

In some situations such shocks can be prevented by earthing the person e.g. by the use of dissipative footwear.

However, direct (low resistance) earthing of people should not be used since it can lead to more serious electric shocks should, for example, a person make contact with a highly charged conductor or with mains electricity.

10 Earthing and bonding

10.1 *General*

By far the most effective method of avoiding hazards due to static electricity is to bond all conductors together and to earth. This will avoid the most common problem which is the accumulation of charge on a conductor and the release of virtually all the stored energy as a single spark, to earth or to another conductor.

In industrial environments where there can be potentially explosive atmospheres, there are many conductors which, if not suitably earthed, can become charged to a hazardous level. Some of these are necessary parts of the plant or the equipment used and these include: plant structure, reaction vessels, pipes, valves, storage tanks and drums. Others are there mainly by accident, or due to carelessness; for example, lengths of redundant wire, metallic cans floating on non-conductive liquids, and metal tools or pools of conductive liquid on the surface of non-conductive materials.

NOTE - Earthing and bonding techniques are also used for electricity power supply systems and lightning protection, but the requirements are not necessarily the same. This clause deals only with protection against static electricity.

10.2 *Criteria for the dissipation of static electricity from a conductor*

10.2.1 Basic considerations

The resistances of the electrical paths need to be sufficiently low to permit the relaxation of charge and to prevent the build up on a conductor of a hazardous level of potential. If this potential is V , the maximum permitted value of resistance R depends upon the rate at which the conductor is receiving charge, i.e. the charging current I . The same principles apply to both earthing and bonding; in both cases, the total resistance to earth should not exceed an acceptable maximum given by the equation:

$$V = IR$$

An incendive discharge occurs when two conditions are satisfied:

- the field strength due to the potential of the conductor exceeds the breakdown strength of the atmosphere; and
- the energy released in the spark exceeds the minimum ignition energy of any flammable material present.

With few exceptions, earthing is intended to prevent all incendive discharges. In order to do this, it is necessary to ensure that the conductor does not achieve the potential required to initiate an incendive discharge. For typical industrial operations, this potential is at least 300 V. Using 100 V as the limit for the safe dissipation of static electricity, the value of R , the total resistance to earth, can be calculated.

10.2.2 Practical criteria

When specifying earthing requirements each situation, i.e. each individual value of charging current I , should be taken into account. Since it is known that charging currents range from 10^{-11} A to 10^{-4} A, the corresponding values of R are 10^{13} Ω and 10^6 Ω . For the maximum value of I , a resistance to earth of 10^6 Ω will ensure safe dissipation of static electricity in all situations. However in most industrial operations I does not exceed 10^{-6} A and a resistance to earth of 10^8 Ω is adequate, especially when the capacitance of the conductor does not exceed 100 pF.

Conductors in good contact with earth have a resistance to it of less than 10^6 Ω and, for convenience, a much lower resistance (in the range 10 Ω to 100 Ω) is often specified for convenience in monitoring. A clear distinction should be made between a value chosen for convenience, and the value of 10^6 Ω , which is the upper limit for the resistance to earth of a conductor in all situations. What is most important, however, is that all connections are reliable, permanent and not subject to deterioration.

10.3 *Earthing requirements in practical systems*

10.3.1 All-metal systems

10.3.1.1 Fixed structures

The main structure of a plant and its major components, such as reactors, mills, blenders or tanks, and also items such as pipelines, are permanent metallic installations normally with bolted or welded joints. They are usually in direct contact with the electricity power supply earthing system, their resistance to earth is low and there is little risk of it deteriorating to a value above 10^6 Ω . Satisfactory earthing will be achieved without special earthing connections which are recommended only when the plant design and usage make it difficult to maintain a low resistance to earth.

In some plants items of equipment are not in direct electrical connection with the main structure, e.g. those mounted on flexible or vibratory mountings or on load cells. Those should have special earthing connections to ensure a good contact to earth, unless a higher prescribed resistance may be accepted (see 10.3.2).

A pipeline is sometimes a temporary installation and it could include lengths of non-conductive pipe. As a result, it could be inadequately connected (electrically) to the structure of the plant and special earthing connections may be needed.

The general application of bonding connectors across all joints in a metal pipeline is not recommended and should only be used when, because of the design, there is no metal to metal contact.

10.3.1.2 Moveable metal items

There are items of equipment, such as drums, funnels and trolleys, which cannot be permanently connected to earth through the main plant structure. In many cases, their resistance to earth could be well below $10^6 \Omega$, but this cannot be relied upon. To allow for this, suitable temporary earthing connections should be used. The minimum requirement is that each item should be earthed whenever a flammable mixture could be present and, at the same time, there is a possibility of electrostatic charging, such as, for example, during the filling or emptying of a container.

10.3.2 Metal plant with non-conductive parts

Plant of metal construction always contains non-conductive elements which could possibly affect electrical continuity and earthing. Examples are lubricating oils and greases and a wide range of polymers such as PTFE and polyethylene which have many applications. Normally, all metal parts of the plant are earthed either directly or through suitable earthing connections and all paths to earth have low resistances. But problems could arise because of the non-conductive elements.

As already mentioned (see 10.2.2), a resistance to earth of less than $10^6 \Omega$ is adequate for the relaxation of static electricity, and in many cases, advantage can be taken of this. An important example is the use of oils and greases for lubricating rotating shafts, stirrers, etc. Tests have shown that the resistance across a lubricating film in a bearing is unlikely to exceed $10^3 \Omega$. This is sufficient to allow dissipation of static electricity without special earthing devices.

When polymers are the non-conductive elements, a resistance in excess of $10^6 \Omega$ is almost inevitable and the only solution is to bond the insulated conductor to adjacent earthed metal components. Examples of this situation are:

- ball valves with PTFE packing and seals;
- pipe spacing rings insulated by PTFE coated gaskets;
- insulated metal pipeline sections between plastic connectors; and
- metal nozzles at the end of plastic lines.

10.3.3 Non-conductive materials

Materials such as glass and non-conductive polymers are increasingly being used as major items of equipment. With those materials it is not possible to comply with the appropriate criteria for resistance to earth to avoid electrostatic hazard (see 10.2). Since those materials cannot be effectively earthed they could retain any charge they acquire for long periods.

Discharges from non-conductive materials are of comparatively low energy, but can be sufficient to ignite sensitive flammable mixtures. There is also the possibility of high energy sparks from conducting objects insulated from earth by these materials. Examples of these are:

- metal components such as connecting bolts and backing flanges in a plastic pipeline;
- metal mesh extending throughout some types of non-conductive wall cladding; and
- pools or layers of water on the surface of the material.

Because of their low conductivity and the general fire risk, the use of non-conductive materials in association with flammable mixtures or flammable liquids should be avoided whenever possible. There are, however, situations where such materials are virtually essential, even in areas from which flammable mixtures cannot be wholly excluded (for example, for handling highly corrosive liquids).

10.3.4 Conductive and dissipative materials

Materials are increasingly becoming available which combine the desirable properties of polymers, such as corrosion resistance, with a volume resistivity sufficiently low to prevent the retention of hazardous levels of charge provided that they are in contact with earth. The requirement is for a resistance to earth of less than $100/I \Omega$ and this is often in the range of $10^4 \Omega$ to $10^8 \Omega$.

For general use, a maximum value of $10^6 \Omega$ is probably the most appropriate, but if it cannot be met, $100/I \Omega$ is acceptable. Values above $10^8 \Omega$, however, are acceptable only in special circumstances after assessment of the hazard.

10.3.5 Summary of earthing requirements

For practical convenience, a resistance up to $10^6 \Omega$ may be acceptable provided that it can be maintained. Special earthing connections are not normally required unless, for example, equipment is mounted on non-conductive supports or contamination which affects the insulation could develop across a joint.

Moveable metal items require special earth connections which should have a resistance of not more than $10^6 \Omega$.

The use of non-conductive materials (e.g. polymers) for the construction of plant for use in the presence of flammable mixtures is not recommended. It is not possible to effectively earth such materials, and safety measures need to be developed for each individual plant to reduce the risk to an acceptable level. In Zone 2 and in Zone 22, areas where the risk of electrostatic generation is sufficiently low, earthing of metal components solely for the control of static electricity may not be necessary. Dissipative or conductive materials may then be used to avoid the retention of static electricity. The most appropriate maximum value for the resistance to earth from all parts of such equipment is $10^6 \Omega$, although values up to $10^8 \Omega$ can be acceptable in some cases.

A brief review of earthing resistance recommendations is given in Table 6.

Table 6: Summary of maximum earthing resistances for the control of static electricity

Subclause	Type of installation	Maximum resistance to earth, ohms	Comments
10.3.1.1	Main plant structure	10^6	Earthing normally inherent in the structure
10.3.1.1	Large fixed metal plant (reaction vessels, powder silos, etc.)	10^6	Earthing normally inherent in the structure. Special earthing could be required for items mounted on non-conducting supports.
10.3.1.1	Metal pipelines	10^6	Earthing normally inherent in the structure. Special earthing connection required across joints if resistance could exceed the $10^6 \Omega$ criterion.
10.3.1.2	Moveable metal items (drums, road and rail tankers, etc.)	10^6	Earthing connections are normally required during filling and emptying.
10.3.2	Metal plant with some non-conductive elements (valves, etc.)	$10^6 *$	In special cases a limit of $100/I \Omega$ could be acceptable, but in general if a $10^6 \Omega$ criterion cannot be satisfied a special earthing connection should be used.
10.3.3	Non-conductive items with or without isolated metal components (e.g. bolts in plastic pipeline)	No generally applicable value*	The general electrostatic ignition risk and the fire hazard normally preclude the use of such materials unless it can be shown that significant charge accumulation will not occur. In the absence of charge accumulation earthing is not required in Zone 2 and in Zone 22.
10.3.4	Items fabricated from non-conductive or dissipative materials	10^6 to 10^8	
<p>* It is only necessary to earth small items with capacitance below 10 pF in Zone 0 and in Zone 1 where gases or liquids belonging to Group IIC are used. Items with capacitances below 3 pF need not be earthed.</p> <p>NOTES</p> <p>1 - This table should be read in conjunction with the paragraphs indicated in the text.</p> <p>2 - In Zone 2 and in Zone 22 earthing is required only when charge accumulation is continuous.</p> <p>3 - In order to provide protection against lightning or to meet the electricity power supply earthing requirements a lower value of resistance to earth is normally required.</p>			

10.4 *The establishment and monitoring of earthing systems*

10.4.1 Design

At the design stage, the plant should be examined to identify possible electrostatic hazards and the earthing requirements should be determined using the guidance given in 10.3. Where no other form of earthing exists, it should be achieved by connections to copper rods or plates driven into, or buried in the ground. However, special earthing devices, such as bonding cables, straps or brushes, should be kept to the minimum essential.

Important features in the design of earthing devices are:

- a) They should be recognised as such and be accepted as essential to the safe operation of the plant;
- b) They should either be clearly visible or be essential to the correct functioning of the plant, so that any shortcomings are quickly detected;
- c) They should be robust and so installed that they are not affected by high resistivity contamination, for example, by corrosion products or paint;
- d) They should be easy to install and to replace;
- e) Cables for earthing moveable items should be equipped with a strong clip capable of penetrating through paint or rust layers. The clip should be attached before the operation commences and should remain in place until the operation has been finished and all hazardous electrostatic charges have been eliminated.

10.4.2 Monitoring

The checking of earthing as a protection against static electricity should be recognised as quite distinct from that for other reasons, such as the maintenance of earthing systems associated with electricity power supply and lightning protection installations. Checks should be made before the plant is brought into use, at each scheduled maintenance, and after any other maintenance or modification.

The basis of monitoring is the measurement of the resistances between the different parts of the plant and earth, but it is important that this should be supplemented by visual inspection. This will help to detect any incipient malfunction of the earthing devices, and to minimize the risk of modifications leading to the disconnection of a conductor.

The monitoring system should be capable, not only of monitoring resistances, but also of drawing attention to any changes in resistance.

Annex A

Fundamentals of static electricity

A.1 Electrostatic charging

A.1.1 Introduction

The primary source of electrostatic charge is contact charging (electrification). If two previously uncharged substances come into contact, charge transfer will generally occur at their common boundary. On separation, each surface will carry an equal charge but of opposite polarity. Conducting objects can become charged by induction if they reside in an electric field produced by other charged objects, or by conductors at high potential in the vicinity. Any object can also become charged if charged particles or ionised molecules accumulate on them.

A.1.2 Contact charging

Contact charging can occur at solid/solid, liquid/liquid or solid/liquid interfaces. Gases cannot be charged in this way, but if a gas has solid particles or liquid droplets in suspension, those could be charged by contact so that such a gas can carry an electrostatic charge.

In the case of dissimilar solids initially uncharged and normally at earth potential, a small amount of charge is transferred from one material to the other when they make contact. The two materials are therefore oppositely charged and consequently there is an electric field between them. If the materials are then separated, work has to be done to overcome the attraction between the opposing charges and the potential difference between them, therefore, increases linearly with distance. This higher potential difference tends to drive charge back to any point of residual contact. In the case of two conductors the recombination of charges is virtually complete and no significant amount of charge remains on either material after separation.

If one, or both, of the materials is a non-conductor, the recombination cannot take place completely and the separating materials retain part of their charge. Because the distance between the charges when in contact is extremely small the potential generated on separation can easily reach many kilovolts despite the small amount of charge involved. For practical surfaces which are rough, the charging is enhanced if the contact and separation involves rubbing, since the area of real contact is increased.

A.1.3 Contact charging of liquids

Contact charging in liquids is essentially the same process but it can depend on the presence of ions or sub-microscopic charged particles (the latter are usually less important). Ions (or particles) of one polarity could be adsorbed at the interface and they then attract ions of opposite polarity which form a diffuse layer of charge in the liquid, close to the surface. If the liquid is then moved relative to the interface, it carries away some of this diffuse layer, thereby bringing about separation of the opposing charges. Typical examples are the flow of a liquid past a solid wall (e.g. pipe, pump, filter), the stirring or agitation and the spraying or atomisation of a liquid. If the liquid contains a second immiscible phase in the form of suspended fine solids or finely dispersed liquids, the charging is greatly enhanced because of the large increase of the interfacial area.

As in the case of solids, a high voltage is generated because of the work done to bring about separation, provided that the liquid is sufficiently non-conductive to prevent recombination. Such processes can occur at both solid/liquid and liquid/liquid interfaces.

Usually a hazardous level of charging is encountered only with liquids of low electrical conductivity. Due to the fast charge separation process, however, spraying of liquids could create a highly charged mist or spray, irrespective of the conductivity of the liquid.

A.1.4 *Charge generation on liquids flowing in pipes and filters*

When a liquid flows through a pipe, charge separation occurs resulting in a charging of the liquid. Turbulent flow generates more charge than laminar flow; for a single phase liquid the electrical streaming current generated in a long pipe is roughly proportional to the velocity in the case of laminar flow, and to the square of the velocity in the case of turbulent flow. Since the flow in industrial installations is usually turbulent, only the more severe turbulent conditions will be considered.

If the liquid enters the pipe uncharged, the streaming current and hence the charge density carried by the liquid will increase with the length of the pipe and will gradually approach a stationary value, provided the pipe is sufficiently long. For low conductivity liquids, in particular saturated hydrocarbon liquids, the stationary value of charge density which theoretically corresponds to an infinite length of pipe does not depend greatly on the conductivity and permittivity of the liquid. It can be estimated from the following expression:

$$\rho_{\infty} = 5v$$

where

ρ_{∞} is the charge density for an infinitely long pipe (in $\mu\text{C}/\text{m}^3$);

v is the linear velocity of the liquid in the pipe (in m/s).

For the practical range of velocities of $v = 1$ m/s to 10 m/s the charge densities are between $5 \mu\text{C}/\text{m}^3$ and $50 \mu\text{C}/\text{m}^3$.

For practical purposes the pipe can be considered to be of infinite length, if

$$L \geq 3 v \tau \text{ with } \tau = \epsilon \epsilon_0 / \gamma$$

where

L is the length of the pipe (in m);

τ is the relaxation time of the liquid (in s);

ϵ is the relative permittivity of the liquid ($\epsilon \approx 2$ for hydrocarbons);

ϵ_0 is the permittivity of free space ($= 8.85 \times 10^{-12}$ F/m);

γ is the electrical conductivity of the liquid (in S/m)

The expression may be used to predict the charge density of the liquid emerging from a pipe line, e.g. during the filling of a tank.

When liquids containing a second immiscible phase such as dispersed liquids or suspended solids are pumped through pipes, the rate of charge generation is much greater than with a single phase. Due to the large number of influential factors, however, the level of charge generation is not predictable.

Filters in a pipe line are known to be prolific charge generators. Whereas coarse filters cause a charge generation similar to that encountered in pipe flow, very fine micronic filters could exceed the charge generation in pipe flow by orders of magnitude.

A.1.5 *Charge generation during stirring and mixing of liquids*

Stirring and mixing processes create a relative motion between the liquids and solid surfaces in contact. The resultant charge generation is usually moderate providing that the liquid does not contain a second immiscible phase. Stirred liquids with dispersed liquids or suspended solids, however are prone to an extremely high charge generation if the continuous phase has a low conductivity.

A.1.6 *Settling potentials*

The settling of solid particles or liquid droplets suspended in a low conductivity liquid can lead to charge separation thus creating a potential differential across the liquid in the direction of the gravity force. In large tanks, e.g. after a mixture of water and oil has been pumped into the tank or the water bottom has been stirred up, the resultant settling potential could constitute an ignition hazard.

A.1.7 *Splashing of liquid jets*

The disintegration of a liquid jet into small droplets, e.g. when the jet hits an obstruction, can produce a highly charged spray or mist, irrespective of the conductivity of the liquid. In general, the more conducting the liquid, the greater the charge generation. For example, a water jet produces more charge than an oil jet, but water/oil mixtures can produce more charge than either water or oil.

A.1.8 *Contact charging of powders*

The charge carried by unit mass of powder (charge to mass ratio) is usually the important parameter in considering the level of charge accumulation on powders. For medium resistivity and non-conductive powders, typical values are between 10^{-5} $\mu\text{C/kg}$ and 10^3 $\mu\text{C/kg}$ and the value depends mainly on the process itself (speed of separation after contact), on the fineness of the powder (specific surface area) and on its chemical composition including contaminations (resistivity and relative permittivity). Table A.1 gives measured data on the charge levels on medium resistivity powders emerging from different processes.

Table A.1: Charge build up on medium resistivity powders

Operation	Mass charge density (μCkg^{-1})
Sieving	10^{-3} to 10^{-5}
Pouring	10^{-1} to 10^{-3}
Scroll feed transfer	1 to 10^{-2}
Grinding	1 to 10^{-1}
Micronising	10^2 to 10^{-1}
Pneumatic conveying	10^3 to 10^{-1}

A.1.9 *Charging by induction*

There is an electric field around any charged object. A conductor introduced into this field changes the distribution of potential in the field in its vicinity and causes separation of opposing charges within the conductor. If it is insulated from earth, the conductor takes up a potential dependent upon its position in the field and is said to be charged by induction. By virtue of its potential, coupled with the separated charges that it carries, the conductor can produce an electrostatic spark.

If the conductor is momentarily earthed while it is in the field, its potential is reduced to zero but it acquires a net charge. This remaining charge can cause a spark when the insulated conductor is removed from the vicinity of the original charged object. This type of induction sparking can be hazardous, for example, when an insulated person moves about near electrostatically charged materials.

A.1.10 *Charge transfer by conduction*

Whenever a charged object touches one that is uncharged, the charge is shared between them. This can be a potent source of electrostatic charging and examples of it are charged sprays, mists or dusts impinging or settling on solid objects. A similar transfer of charge can also take place when a stream of gaseous ions collects on an initially uncharged object.

A.2 **Accumulation of electrostatic charge**

A.2.1 General

After separation during the charging process electrostatic charges can quickly recombine, either directly by contact or via the earth. Charge on a non-conductor is retained because of the resistance of the material itself. But for a conductor to remain charged it has to be insulated from other conductors and from earth.

Under normal conditions, pure gases are non-conductors and the charge on suspended particles in clouds of dust, mist or spray can often remain for long periods, irrespective of the conductivity of the particles themselves.

In all cases the charge leaks away at a rate determined by the resistances of the non-conductors in the system; the process is known as relaxation. The levels of resistance, resistivity or conductivity which can lead to hazardous situations depend greatly upon the industrial process and this will be discussed later.

In many processes there is continuous generation of charge which accumulates on an insulated conductor. For example, when a stream of charged liquid or powder flows into an insulated metal container, the potential on the insulated conductor is the result of a balance between the rate of input of charge and the rate of leakage. The equivalent electrical circuit is shown in Figure A.1 and the potential of the conductor is given by the equation:

$$V = IR \{1 - \exp(-t/RC)\}$$

where:

- V is the potential of the conductor in volts;
- C is its capacitance in farads;
- R is the leakage resistance to earth in ohms;
- I is the electrostatic charging current in amperes;
- t is the time from the commencement of charging in seconds.

The maximum potential is reached when t is large and is therefore:

$$V_{\max} = IR$$

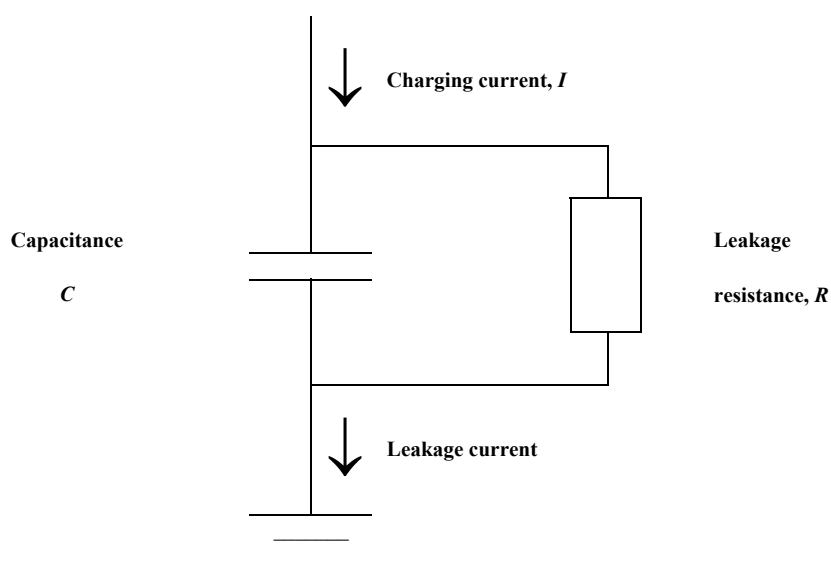


Figure A.1: Equivalent electrical circuit for an electrostatically charged conductor

The leakage resistance and the capacitance of an insulated conductor can often be measured and this can be used to establish if hazardous levels of charges can accumulate. However, this assessment cannot be carried out for dusts and mists suspended in air.

A.2.2 Charge accumulation on liquids

Charge accumulation in a liquid is determined by the two opposing effects of charge generation and charge relaxation.

Charge relaxation in a container of liquid is governed by its electrical conductivity. In the absence of charge generation, the charge density in the liquid decays according to an exponential law of relaxation with the characteristic relaxation time:

$$\tau = \epsilon \epsilon_0 / \gamma$$

where:

- τ is the relaxation time;
- ϵ is the relative permittivity of the liquid (about 2 for saturated hydrocarbon liquids);
- ϵ_0 is the permittivity of free space;
- γ is the electrical conductivity of the liquid

Exponential relaxation means that within the relaxation time the charge decays to about 37 % (more precisely: to $1/e$, where e is the base of natural logarithms) of its original value. For example, for a hydrocarbon liquid with a conductivity of $\gamma = 1 \text{ pS/m}$ (10^{-12} S/m) the relaxation time is $\tau = 18 \text{ s}$.

The conductivity of a very low conductivity liquid is significantly higher when the liquid has a high charge density than when it is uncharged. This leads to what is known as "hyperbolic relaxation". It results in charge being dissipated more rapidly from liquids of very low conductivity and high charge density than would be expected on the basis of the calculation above.

This has a beneficial effect; it means that, irrespective of conductivity or very high charge densities, residence times of 100 s are sufficient to reduce the charge density in receiving tanks downstream of fine filters to the level encountered in pipe flow.

Conductivities of liquids are classified as high ($\gamma > 1\,000 \text{ pS/m}$), medium ($50 \text{ pS/m} < \gamma < 1\,000 \text{ pS/m}$) or low ($\gamma < 50 \text{ pS/m}$). The conductivities and relaxation times for a number of liquids are given in Table 2.

Hazardous levels of charge accumulation are associated mainly with low conductivity liquids. Such levels are rare with medium conductivity liquids and they are attained only when the charging rate is unusually high, e.g. when stirring certain suspensions (see 5.7). Hazardous levels are virtually unknown with high conductivity liquids providing that the liquids are earthed.

Suspensions of charged droplets in mists and sprays retain their charge because the surrounding atmosphere is highly non-conductive. Charge relaxation is not by electrical conduction but by processes such as: settling or impingement of the droplets on the tank structure; and, at high charge density levels, corona from protrusions in the tank. For these reasons charge relaxation in charged mists is usually slow, irrespective of the conductivity of the liquid.

A.2.3 *Charge accumulation on powders*

If the volume resistivity of the powder in bulk is high, charge could be retained on powder even if it is in an earthed container or in contact with earthed metal. The time taken for the charge to decay to $1/e$ of its original value (where e is 2.718) is known as the relaxation time. It is given by the equation:

$$\tau = S \epsilon \epsilon_0$$

where:

- ϵ is the relative permittivity of the powder;
- ϵ_0 is the permittivity of free space ($8.85 \cdot 10^{-12} \text{ F/m}$);
- S is the volume resistivity of the powder

A volume resistivity of $10^{10} \Omega\text{m}$ and a relative permittivity of 2 gives a relaxation time of approximately 0,2 s. This means that after 0,2 s about two thirds of the charge has been released from the bulked powder to earth.

Because air is very highly non-conductive, charge decay for a powder in suspension in air (dust cloud) is not influenced by the volume resistivity of the powder. The charge remains on the powder particles until they interact with each other or with the equipment. In those circumstances, charge decay is mainly affected by particle movement caused by air drift, gravity and space charge fields.

For both powder in bulk and powder in suspension in air, charge levels are limited by the onset of discharges. These will occur when the electric field, which is highest at the boundary of the heap or the dust cloud, reaches the dielectric strength of air, 3 MVm^{-1} .

A.3 Electrostatic discharges

A.3.1 Introduction

Charge on a liquid or on a solid creates a hazard only if it is discharged to another body or, more usually, to earth. These discharges vary greatly in type and incendivity. They are described in A.3.2 to A.3.7.

A.3.2 Sparks

A spark is a discharge between two conductors, liquid or solid. It is characterised by a well defined luminous discharge channel carrying a high density current. Ionisation of gas in the channel is complete over its whole length. The discharge is very rapid and gives rise to a sharp crack.

A spark occurs between conductors when the field strength between them exceeds the electric strength of the atmosphere. The potential difference between the conductors necessary to cause breakdown depends upon both the shape and the distance between the conductors. As a guide, the breakdown strength for flat or large radius surfaces 10 mm or more apart is about 3 MVm^{-1} in normal air and it increases as the gap decreases.

Because the objects between which the spark passes are conductors, most of the stored charge passes through the spark. In most practical cases, that dissipates most of the stored energy. The energy of a spark between a conducting body and a conducting earthed object can be calculated using the equation below:

$$W = \frac{1}{2} QV = \frac{1}{2} CV^2$$

where:

- W is the energy dissipated in joules;
- Q is the quantity of charge on the conductor in coulombs;
- V is its potential in volts;
- C is its capacitance in farads.

This is the maximum value of energy and the energy in the spark is less if there is resistance in the discharge path to earth.

Typical values for the capacitances of conductors are given in Table A.2.

Table A.2: Values of capacitances for typical conductors

Object	Capacitance pF*
Small metal items (scoop, hose nozzle)	10 to 20
Small containers (bucket, 50 litre drum)	10 to 100
Medium containers (250 litres to 500 litres)	50 to 300
Major plant items (reaction vessels) immediately surrounded by earthed structure	100 to 1 000
Human body	100 to 300
* 1 pF = $1 \times 10^{-12} \text{ F}$	

An example of a calculation of spark discharge energy is as follows:

An unearthed metal drum is filled with powder from a grinding unit. In such a situation; charging current I , can be 10^{-7} A; the leakage resistance of the drum to earth R , 10^{11} Ω ; and its capacitance C , 50 pF. The maximum voltage on the drum is then:

$$V_{\max} = IR = 10 \text{ kV}$$

and the maximum energy released in a spark discharge would be

$$W_{\max} = \frac{1}{2} CV^2_{\max} = 2,5 \text{ mJ}$$

A.3.3 *Corona*

This type of discharge occurs at the sharp points or edges of conductors, i.e. surfaces with a small radius of curvature. They can occur when such a conductor is earthed and moved towards a highly charged object or, alternatively, if the conductor is raised to a high potential. The discharge arises due to the fact that the electric field at the sharp surface is very high (above 3 MV/m). Since the field away from the surface drops off rapidly the region of ionisation does not extend far from it. It can be directed towards the charged object or, in the case of a high potential conductor, it can simply be directed away from the conductor.

Corona discharges are difficult to see but under subdued lighting a glow can be seen adjacent to the point. Outside this ionised region ions can drift away, their polarity being dependent on the field direction. The energy density in the discharge is much less than in a spark and for this reason corona discharges are not normally incensive. However, in certain circumstances, for example, if there is an increase in the potential of the pointed conductor, corona can develop into a spark between it and another object.

A.3.4 *Brush discharges*

These discharges can occur when rounded (as opposed to sharp) earthed conductors are moved towards charged non-conductive objects, for example, between a person's finger and a plastic surface, between a metal dipleg and the surface of liquid in a tank.

They are short duration events which, under suitable circumstances, can be seen and heard. Unlike spark discharges they tend to involve only a small fraction of the charge associated with the system and the discharge does not link the two objects. In spite of this, brush discharges can ignite most flammable gases and vapours. There is, as yet, no evidence to show that even the most sensitive dusts can be ignited by brush discharges.

A.3.5 *Propagating brush discharges*

For this type of discharge it is necessary to have a sheet (or layer) of a material of high resistivity and high dielectric strength with the two surfaces highly charged (high surface charge density) but of opposite polarity.

The discharge is initiated by an electrical connection (short circuit) between the two surfaces. It often has a bright tree-like structure and is accompanied by a loud crack. The bipolar charged sheet can be in "free space" or, as is more normal, have one surface in intimate contact with a conducting material (normally earthed).

The short circuit can be achieved:

- by piercing the surface (mechanically or by an electrical break through);
- by approaching both surfaces simultaneously with two electrodes electrically connected; or
- when one of the surfaces is earthed, by touching the other surface with an earthed conductor.

The discharge collects most of the distributed charges from the non-conductive surface and channels them to where the short circuit takes place. The conditions necessary for this type of discharge can be difficult to achieve, particularly for thick sheets. In most circumstances, a thickness of more than 8 mm is sufficient to prevent propagating brush discharges. For sheets thinner than that value, a surface charge density of at least $2,5 \times 10^{-4}$ C/m² is required.

A further requirement is that the breakdown voltage through the non-conductor needs to be more than 4 kV. This means that charge on layers of paint does not normally give rise to propagating brush discharges.

NOTE - Care should be taken when using the 4 kV criterion for testing materials. For example, thick layers of woven or porous materials can withstand voltages greater than 4 kV but are unable to give rise to propagating brush discharges unless they incorporate a layer of impervious material, i.e. one able to withstand voltages greater than 4 kV.

The energy released in such discharges can be high (1 J or more); it depends on the area, thickness and surface charge density of the charged sheet. The discharges can ignite explosive gas, vapour and dust atmospheres.

A.3.6 *Lightning like discharges*

In principle lightning like discharges can occur within dust clouds or from dust clouds to earth when the field strength due to the charged particles is high enough. Such lightning like discharges have been observed in large ash clouds during the eruption of volcanoes. They are obviously capable of igniting flammable dusts, but they have never been observed in dust clouds of the size encountered in industrial operations.

According to experimental investigations such discharges are unlikely to occur in silos of volume less than 60 m³ or in silos of diameter less than 3 m and of any height. Those dimensions are not necessarily the upper safe limits, they are based solely on the size of the equipment in the above mentioned investigations.

Such discharges are unlikely to occur in larger silos or containers providing that field strengths remain below 500 kV/m.

A.3.7 *Cone discharges*

When highly charged non-conductive powder is filled into silos or large containers it generates a region of very high space charge density within the heap of bulked powder. This leads to high electrical fields at the top of the heap. Under those circumstances large discharges running (radially, in the case of cylindrical containers) along the surface have been observed.

The conditions necessary for this type of discharges are complex; the influencing factors are resistivity of bulked powder, charging current, volume and geometry of bulked powder and particle size. It has been reported that atmospheres of flammable gases and vapours as well as atmospheres of sensitive combustible powders can be ignited by this type of discharge.

Based on recent results the average energy released in such discharges depends on the silo diameter and the particle size (median) of the products forming the powder heap. For silos with diameters in the range 0,5 m to 3,0 m and powders with a median range of 0,1 mm to 3,0 mm, the energy released in cone discharges can be estimated using the numerical formula:

$$W = 5,22 \times D^{3,36} \times d^{1,46}$$

where:

W is the upper limit of the energy of the cone discharge in millijoules;

D is the diameter of the earthed conductive silo in metres;

d is the median of the particle size distribution of the powder forming the cone in millimetres.

As follows from the above formula, cone discharges formed from coarse powder are of much higher energy than those from fine powder. Thus the most hazardous situation is when highly non-conductive granules are handled together with fine powder (fines) forming a dust cloud of low MIE.

Annex B

Electrostatic discharges in specific situations

B.1 Incendive discharges involving non-conductive solid materials

B.1.1 *General*

Non-conductive materials can give rise to various types of discharge either directly from their surfaces or by insulating conducting parts and enabling them to become charged.

B.1.2 *Sparks from insulated conductors*

The use of non-conductive materials can cause parts of metal plant or other conductive objects to be unearthed. By being close to charged material, such conductors can become charged by induction, charge sharing or by collecting sprayed charge or charged particles. These conductors can acquire a large amount of charge and energy and can store it for a long time. Most of that energy can eventually be released as an incendive spark to earth.

For this reason it is important to avoid having insulated conductors; they should be bonded together and earthed (see clause 12).

B.1.3 *Brush discharges*

Brush discharges can occur when earthed conducting objects approach highly charged non-conductive materials. Such materials, normally plastics, are very common and they are used extensively in industry. Examples are buckets, pipes, scoops, bags and all types of containers, belts, floor and wall coverings, instrument containers and many constructional materials. Those can become charged in many ways: by being handled; by being rubbed; by having materials poured in, through, or out of them; and by collecting charged particles on their surfaces.

The incendivity of brush discharges depends on a number of parameters, in particular on the size of the charged area, but it is virtually independent of the type of the charged material. It is, however, well known that brush discharges are capable of igniting gas mixtures with MIEs below about 4 mJ.

If the charged material is in the form of a sheet with the uncharged surface in contact with an earthed metal sheet, the brush discharges are rather weak (note, however, B.1.4).

B.1.4 *Propagating brush discharges*

In the presence of prolific charge generating mechanisms (e.g. pneumatic transfer of powders, charge spraying in the powder coating process) very high levels of surface charge can be generated on a non-conductive sheet or layer with metal backing. If the breakdown strength of the layer is sufficient to withstand the large field strength in the layer, surface charge densities of the order of $300 \mu\text{C}/\text{m}^2$ enable the discharge to change from a brush discharge into a propagating brush discharge.

A propagating brush discharge can release a lot of energy and it is capable of igniting almost all flammable gases, vapours and powders. In special cases the bipolar charging of the non-conductive sheet can also be achieved without metal backing.

B.2 Incendive discharges produced during liquid handling

When a tank is being filled with a charged liquid of low conductivity, the charge accumulates in the liquid of the tank. This results in an electrical field within the liquid and also in the ullage space of the tank. The field strength (and potential) distribution depends upon the size, shape and ullage of the tank and is proportional to the amount of accumulated charge. At high levels of potential, brush discharges can occur between metal protrusions in the ullage space and the surface of the charged liquid. Experiments have shown that for hydrocarbon/air atmospheres these brush discharges could be incendive if the potential at the surface of the charged liquid in the tank exceeds a value of about 58 kV.

An ignition hazard could arise at much lower potentials if insulated conductors were present in the tank. For example, a can floating on the liquid surface could acquire the potential of its surroundings and give rise to an incendive spark if it moved close to a metal protrusion or the tank wall.

B.3 Incendive discharges produced during powder handling and storage

B.3.1 *General*

With few exceptions, all particles, including chips and granules, readily become charged during transport through pipes and ducts. This is especially true when the particles remain well separated from each other, as in pneumatic transport. Charge retention on powder or equipment creates a hazard only if the charge is suddenly released in a discharge giving rise to a high local energy density and thus acting as a possible ignition source. Discharges from charged powder and equipment vary greatly in type and incendivity (see A.3.2 to A.3.7).

B.3.2 *Discharges from bulk powder*

When highly charged particles are bulked in a container, cone discharges could occur between the powder and the container (see A.3.7) and these could cause an ignition if there is a suspension of powder and air.

There is no risk of ignition with systems containing only granules (particle size $> 500 \mu\text{m}$). But mixtures of granules and fine powder are potentially hazardous, since in both cases brush and the more incendive cone discharges can occur.

B.3.3 *Discharges from powder clouds*

In principle, discharges could occur within powder clouds or from powder clouds to the wall of the container if the field strength due to the charged particles were high enough. Recent work involving operations such as pneumatic conveying in medium sized silos has indicated that such discharges are brush or corona. Spark and lightning like discharges due to powder clouds have not been detected. Evidence so far indicates that, with the possible exception of sensitive atmospheres, the risk of an ignition due to powder cloud discharges is very low.

For powders with MIEs lower than 3 mJ it could be necessary to carry out an evaluation.

B.3.4 *Discharges involving containers and persons*

Charged powders inside a container, or persons close to such a container, can also lead to discharges which can cause ignitions. Discharges from powder to the inside wall of a non-conductive container can lead to polarization across the container wall. If an earthed person or conductor touched the inner surface there could be a risk of a propagating brush discharge. Such a discharge is not only highly incendive but it can cause severe electric shock. Non-conductive containers can also be charged externally by rubbing or by other charge generating mechanisms such as steam impingement; these charges could be an ignition risk.

B.3.5 *The use of liners*

In some operations, particularly the handling of dry powders in drums, it is convenient to use an inner liner, such as a plastic bag, as a precaution against contamination. Liners made from non-conductive materials can be charged during filling and emptying. The separation of charges which occurs when such liners are removed from containers can cause incendive discharges. In principle, very sensitive powder clouds could be ignited and the possibility of such ignitions should be considered for dust with a MIE less than 3 mJ.

In some processes, for example, when filling a container with a highly charged, high resistivity powder, it is even possible to produce propagating brush discharges from the liner. Such discharges would be very incendive and could also cause serious electric shock and precautions should be taken to prevent their occurrence.

A further consequence of using highly non-conductive liners is that they can insulate the material being handled, even when the outer container is conducting and earthed.

B.3.6 *Spark discharges*

Spark discharges can occur due to the charging of electrically insulated conductive parts of equipment, persons or accumulations of low resistivity powders. In most cases, virtually all the stored electrostatic energy is dissipated in the spark. The incendivity of spark discharges can be assessed by comparing the stored energy, as measured by $\frac{1}{2} CV^2$ (see A.3.2), with the minimum ignition energy (MIE) of the combustible powder in question.

NOTE - For the assessment of electrostatic hazards, the most relevant value of MIE is that which has been determined using a capacitive circuit without an additional inductance. Spark discharges can be avoided by earthing all conductive parts of equipment, including low resistivity products and persons.

B.3.7 *Brush discharges*

Brush discharges can occur from the tips of earthed objects, for example, projections of equipment, measuring probes, working tools, a person's finger tip, etc. which are in high electrical fields. Such fields can be generated by highly charged non-conductive surfaces of equipment, packaging material, or by highly charged non-conductive powder, either in bulk or in suspension in air. (see A.3.4).

Practical experience, and the absence of incidents, indicate that, with regard to powder clouds, brush discharges are of low incendivity.

Experimental evidence tends to support this but not enough work has been done for the incendivity of brush discharges to be related to a specific value of ignition energy applicable in all situations. Based on the present state of knowledge, combustible powders with MIE > 3 mJ are unlikely to be ignited by brush discharges unless they are mixed with flammable gases and vapours.

NOTE - Care should be taken when measuring the MIE of powders such as polyethylene, which can release flammable gases over a period of time forming a hybrid mixture with a much lower MIE than the pure powder. When handling large amounts of medium or non-conductive powders brush discharges cannot be avoided.

B.3.8 *Corona discharges*

Corona discharges occur under similar conditions as for brush discharges, i.e. when the electrode is very small and pointed, or has a sharp edge (see A.3.3). The incendivity of corona discharges is far too low for ignition of combustible powders. When handling large amounts of medium or non-conductive powders, corona discharges cannot be avoided.

B.3.9 *Propagating brush discharges*

Propagating brush discharges can occur from the surfaces of non-conductive walls of containers or from coatings on equipment (see A.3.5). The high surface charge density required for these discharges can be generated where powder particles hit such surfaces. This can occur, for example, during the pneumatic transport of powder through pipes of non-conductive material or through metal pipes with a non-conductive lining. High surface charge densities can also result from the deposition of ions such as are produced during the bulking of charged non-conductive powder.

Propagating brush discharges do not occur due to charge on layers of powder; there has to be a layer of material with a high dielectric strength.

The energy released in a propagating brush discharge can be estimated by assuming that the (bipolar) charged sheet behaves like a parallel plate capacitor with the sheet as dielectric. For example, a sheet with relative permittivity $\epsilon = 2$, surface charge density $\sigma = 10^{-3} \text{ C/m}^2$, thickness $d = 75 \text{ }\mu\text{m}$, and area $A = 0,5 \text{ m}^2$, the stored energy W is given by:

$$W = \frac{1}{2} CV^2 = \frac{Ad\sigma^2}{2\epsilon\epsilon_0} = 1 \text{ J}$$

Since most of the charge is released in a single discharge, its ability to ignite can be assessed by comparing the stored energy with the MIE of a given powder.

Propagating brush discharges can be avoided by using only conductive or dissipative material for walls of equipment and for coatings or by ensuring that the breakdown voltage across all non-conductive walls and coatings is less than 4 kV (see A.3.5).

Annex C

Flammability and igniting properties of substances

C.1 General

Most hydrocarbons and many other substances used in industry are flammable. These substances, in the form of gas, vapour, liquid droplets or powder, when mixed with air or some other oxidising agent could be ignited by electrostatic discharges. The ease with which they can be ignited depends upon a number of factors, some of which are given in C.2 to C.7.

C.2 Oxygen concentration and ambient conditions

The igniting properties are much affected by the oxygen concentration, temperature and pressure of the atmosphere. Most of the comments and values quoted in C.3 to C.6 relate to normal atmospheric conditions. Those are mixtures with air at 0,8 bar to 1,1 bar and at -20°C to 60°C.

C.3 Explosive limits: gases and liquids

For each substance there are upper and lower explosive limits and only mixtures within these limits can be ignited. For most mixtures of hydrocarbon and air those limits are between about 1 % and 15 % by volume. Substances with wide flammable limits, for example, hydrogen and carbon disulphide, are particularly hazardous.

Ventilation is often the most effective way of reducing a mixture to below its lower explosive limit and making it incapable of ignition.

C.4 Inerting

An inert gas is one which is non flammable and contains little or no oxygen, for example, nitrogen, boiler flue gas. The addition of such a gas to a flammable atmosphere can reduce the oxygen concentration to such a low level that ignition is not possible at any concentration of flammable substance. The required limiting oxygen concentrations are, for example, about 11 % by volume for hydrocarbon gases and 5 % by volume for hydrogen. It is normal to include a safety factor and a maximum oxygen content of 8 % by volume is frequently specified for hydrocarbons.

The inerted atmosphere could become flammable again, should air be added. Therefore it is important to recognize that it is possible to ignite gas or vapour escaping into air from an inerted vessel.

NOTE - Depletion of oxygen content in air by displacement with inert gas is a potential hazard to personnel.

EXPOSURE TO ATMOSPHERES CONTAINING 12% OR LESS OXYGEN WILL BRING ABOUT UNCONSCIOUSNESS WITHOUT WARNING AND SO QUICKLY THAT THE INDIVIDUAL CANNOT HELP OR PROTECT HIMSELF.

EXPOSURE TO ATMOSPHERES CONTAINING BETWEEN 12% AND 14% OXYGEN WILL HAVE THE FOLLOWING PHYSICAL EFFECTS ON PERSONNEL: RESPIRATION INCREASES IN EXERTION, PULSE UP, IMPAIRED COORDINATION, PERCEPTION AND JUDGEMENT.

EXPOSURE TO ATMOSPHERES CONTAINING BETWEEN 15% AND 19% OXYGEN MAY IMPAIR COORDINATION OF PERSONNEL AND MAY INDUCE EARLY SYMPTOMS IN PERSONS WITH CORONARY, PULMONARY OR CIRCULATORY PROBLEMS.

National regulations and/or codes relating to specific industries or applications may exist and should be consulted.

C.5 Flash point

It is not normally possible to ignite the vapour/air mixture above a liquid which is below its flash point. To avoid ignition, however, it is advisable to keep the temperature of a liquid at least 5 K below its flash point and, for mixtures containing liquids with a wide range of volatilities, this should be increased to at least 15 K.

In general, it is always better to use a high rather than a low flash point solvent. But sprays or fine mists of such liquids can also be ignited by electrostatic sparks if the energy is high enough (see C.6).

C.6 Minimum ignition energies

Flammable gases, vapours and dusts are often classified according to their minimum ignition energies (MIEs). These values normally relate to the most easily ignitable mixture of the substance and air, and they are obtained using capacitor spark discharges. They are a useful guide as to how easily the substance can be ignited by electrostatic discharges. For most gases and vapours the MIEs lie between 0,01 mJ and 0,3 mJ. The value for dusts ranges from below 1 mJ to over 10 J.

Capacitor and propagating-brush discharges are capable of igniting gases, vapours and most dusts. Brush discharges can ignite most gases and vapours but there is, as yet, no evidence to show that even the most sensitive dusts can be ignited by such discharges. Cone discharges can ignite gases and vapours and also some of the more sensitive dusts.

There is no comprehensive list of MIEs for sprays or dispersed droplets, but it is likely that the values are higher than those for the equivalent liquid vapour/air mixtures.

Contamination of a flammable dust/air mixture by a flammable gas (hybrid mixture) can lead to ignition energies lower than the minimum for the dust/air alone, even though the vapour concentration could be well below the lower flammable limit. There is little general information available and it could be necessary to assume that the ignition energy is that of the flammable gas.

C.7 Combustible powders

All solid combustible materials including metals could create an explosive atmosphere when finely dispersed in air in the form of a dust cloud. A dust explosion hazard could exist if the particle size is below 0,5 mm and the dust concentration is within the explosive limits (for most organic powders typically about 20 g/m³ to several kg/m³). The explosion hazard (explosion sensitivity and violence) for a given substance is highest in the case of very fine dust.

Annex D

Classification of hazardous areas

D.1 Concept of zoning

The degree of risk (i.e. the likelihood) of fire or explosion due to electrostatic charging depends not only on the probability that the charging will lead to an incendive spark but also on the probability that there will be an explosive atmosphere. Precautions considered necessary to avoid electrostatic charging where there is often an explosive atmosphere are not always necessary where such an atmosphere occurs infrequently. The concept of zoning divides areas into zones according to the probability of a hazardous explosive atmosphere occurring.

D.2 Classification

For the purposes of this standard hazardous areas are classified into the following zones:

- a) **Zone 0:** area in which a flammable vapour or gas atmosphere is continuously present, or is present for long periods.
- b) **Zone 1:** area in which a flammable vapour or gas atmosphere is likely to occur during normal operation.
- c) **Zone 2:** area in which a flammable vapour or gas atmosphere is unlikely to occur during normal operation but, if it does occur, it will exist only for a short period.
- d) **Zone 20:** area in which a hazardous explosive atmosphere formed by a dust cloud in air is present continuously or for a long period or frequently, and where dust layers of unknown or excessive thickness may be formed.

NOTE - Areas where piles of dust are present but where dust clouds are not present continuously, or for a long period, or frequently are not included in this zone.
- e) **Zone 21:** area in which a hazardous explosive atmosphere formed by a dust cloud in air is likely to occur during normal operation, and in which layers of combustible dust will usually be present.
- f) **Zone 22:** area where a hazardous explosive atmosphere formed by a dust cloud is unlikely to occur in normal operation, but if it does occur it will exist only for a short period, or in which accumulations of layers of combustible dust are present.

NOTE: The definitions of the zones are at present under discussion in Europe. Users of this Report are recommended to consult the latest editions of EN 60079-10 and EN 61241-3 for the outcome of this discussion.

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