

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

ICS 13.110

National foreword

This Published Document reproduces verbatim CENELEC Report R044-001:1999
The UK participation in its preparation was entrusted to Technical Committee GEL/44, Safety of machinery - Electrotechnical aspects, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled “International Standards Correspondence Index”, or by using the “Find” facility of the BSI Standards Electronic Catalogue.

Summary of pages

This document comprises a front cover, an inside front cover, the CENELEC Report title page, pages 2 to 69 and a back cover.
The BSI copyright notice displayed throughout this document indicates when the document was last issued.

This Published Document, having been prepared under the direction of the Electrotechnical Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 August 1999

© BSI 08-1999

ISBN 0 580 32823 6

Amendments issued since publication

Amd. No.	Date	Comments

English version

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

This CENELEC Report has been prepared by the Technical Committee CENELEC TC 44X, Safety of machinery: electrotechnical aspects. It was approved by the Technical Committee on 1997-11-07 and endorsed by the CENELEC Technical Board on 1999-01-01.

CENELEC members are the national electrotechnical committees of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

© 1999 CENELEC - All rights of exploitation in any form and by any means reserved worldwide for CENELEC members.

Contents

	Page
Foreword	4
Clause	
1 Scope	5
2 Definitions	5
3 General.....	6
4 Static electricity in non-conductive solid materials.....	7
4.1 General considerations	7
4.2 Dissipative solid materials	8
4.3 The use of conductive or dissipative materials in place of non-conductive ones.....	8
4.4 Precautions required when using non-conductive solid materials	8
4.5 Conveyor belts and transmission belts.....	11
5 Static electricity in liquids	12
5.1 General considerations	12
5.2 Ignition hazard.....	13
5.3 Precautions against ignition hazards during liquid handling operations.....	14
5.4 Storage tanks	15
5.5 Pipes and hoses for liquids	25
5.6 Special filling procedures	28
5.7 Plant process (liquid/liquid and solid/liquid blending and mixing)	30
5.8 Spraying liquids and tank cleaning	31
5.9 Glass systems.....	33
6 Static electricity in gases.....	34
6.1 General	34
6.2 Grit blasting.....	34
6.3 Fire extinguishers	35
6.4 Inerting	35
6.5 Steam cleaning.....	35
6.6 Accidental leakage of compressed gas	35
6.7 Spraying of flammable paints and powders	35
6.8 Extraction systems	36
6.9 Vacuum cleaners, fixed and mobile.....	36
7 Static electricity in powders.....	37
7.1 General	37
7.2 Powders in the absence of flammable gases and vapours.....	37
7.3 Powders in the presence of flammable gases or vapours	43

8	Static electricity on persons	45
8.1	General considerations	45
8.2	Conducting floor.....	46
8.3	Dissipative and conductive footwear	46
8.4	Clothing.....	46
8.5	Protective gloves	46
8.6	Other items	46
9	Electric shock.....	46
9.1	Introduction	46
9.2	Discharges relevant to electric shock.....	47
9.3	Sources of electric shock	47
9.4	Precautions to avoid electric shocks	47
9.5	Precautions in special cases.....	48
10	Earthing and bonding.....	49
10.1	General	49
10.2	Criteria for the dissipation of static electricity from a conductor	49
10.3	Earthing requirements in practical systems.....	50
10.4	The establishment and monitoring of earthing systems	53

Tables

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.....	9
2	Conductivities and relaxation times of some liquids.....	13
3	Precautions for filling large metal tanks with low conductivity liquids	17
4	Maximum filling velocities for loading low conductivity liquids into road and rail tankers.....	20
5	Charge acquired by medium resistivity powders	37
6	Summary of maximum earthing resistances for the control of static electricity.....	52
A.1	Charge build up on medium resistivity powders.....	56
A.2	Values of capacitances for typical conductors	60

Figures

A.1	Equivalent electrical circuit for an electrostatically charged conductor.....	57
-----	---	----

Annexes (informative)

A	Fundamentals of static electricity.....	54
B	Electrostatic discharges in specific situations	62
C	Flammability and igniting properties of substances	66
D	Classification of hazardous areas	68

	Bibliography	69
--	--------------------	----

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:

$$R.B \leq 10^5 \Omega m$$

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:
 $vd = 0,5 \text{ m}^2/\text{s}$ for top loading or bottom loading with a central conductor; or
 $vd = 0,38 \text{ m}^2/\text{s}$ 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).