भारतीय मानक
Indian Standard

IS/IEC TS 60079-32-1 : 2013
+ AMD 1 : 2017

विसफोटी पर्यावरण

भाग 32 इलेक्ट्रोस्टैटिक खतरे

अनुभाग 1 मार्गदर्शिका

Explosive Atmospheres

Part 32 Electrostatic Hazards

Section 1 Guidance

ICS 29.260.20

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

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Electrical Apparatus for Explosive Atmospheres Sectional Committee, ETD 22

NATIONAL FOREWORD

This Indian Standard (Part 32/Section 1) which is identical to IEC TS 60079-32-1 'Explosive atmospheres Part 32-1: Electrostatic hazards, guidance' issued by the International Electrotechnical Commission (IEC) was adopted by the Bureau of Indian Standards on the recommendation of the Electrical Apparatus for Explosive Atmosphere Sectional Committee had been approved by the Electrotechnical Division Council.

This Indian standard gives guidance about the equipment, product and process propertiesnecessary to avoid ignition and electrostatic shock hazards arising from static electricity as well as the operational requirements needed to ensure safe use of the equipment, product or process.It can be used in a risk assessment of electrostatic hazards or for the preparation of product family or dedicated product standards for electrical or non-electrical machines or equipment.

The IEC standard has been approved as suitable for publication as an Indian Standard without deviations. Certain terminologies and conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, theyshould be read as 'Indian Standard'; and

b) Comma (,) has been used as a decimal marker, while in Indian Standards the currentpractice is to use a point (.) as the decimal marker.

In this standard, reference appears to International Standards for which Indian Standards also exists. The corresponding Indian Standards, which are to be substituted, are listed below alongwith their degree of equivalence for the editions indicated:

International Standard	*Corresponding IndianStandard*	*Degree of Equivalence*
IEC 60079-0 : 2011 Explosive atmospheres — Part 0: Equipment — General requirements	IS/IEC 60079-0 : 2017 Explosive atmospheres: Part 0 Equipment — General requirements (*third revision*)	Identical
IEC 60079-10-1 Explosive atmospheres — Part 10-1: Classification of areas — Explosive gas atmospheres	IS 5572 : 2009 Classification of hazardous areas (other than mines) having flammable gases and vapours for electrical installation (*third revision*)	Modified/Technically Equivalent
IEC 60079-10-2 Explosive atmospheres — Part 10-2: Classification of areas — Combustible dust atmospheres	IS/IEC 60079-10-2 : 2015 Explosive atmospheres: Part 10 Classification of areas, Section 2 Explosive dust atmospheres (*first revision*)	Identical
IEC 60079-14 Explosive atmospheres — Part 14: Electrical installations design, selection and erection	IS 16724 : 2018/IEC 60079-14 : 2013 Explosive atmospheres — Electrical installations design, selection and erection	Modified/Technically Equivalent
IEC 60079-20-1 Explosive atmospheres — Part 20-1: Material characteristics for gas and vapour classification — Test methods and data	IS/IEC 60079-20-1 : 2010 Explosive atmospheres: Part 20 Material characteristics for gas and vapour classification, Section 1 Test methods and data	Identical

International Standard	*Corresponding IndianStandard*	*Degree of Equivalence*
IEC 60079-32-2 Explosive atmospheres — Part 32-2: Electrostatic hazards — Tests	IS/IEC 60079-32-2 : 2015 Explosive atmospheres: Part 32 Electrostatics hazards, Section 2 Tests	Identical
IEC 60093 Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials	IS 3396 : 1979 Methods of test for volume and surface resistivity of solid electrical insulating materials (*first revision*)	Modified/Technically Equivalent
ISO 6297 Petroleum products — Aviation and distillate fuels — Determination of electrical conductivity	IS 1448 (Part 148) : 2019/ISO 6297 : 1997 Methods of test forpetroleum and its products [p : 148] petroleum products — Aviation and distillate fuels — Determination of electrical conductivity (*first revision*)	Identical
ISO 8031 Rubber and plastics hoses and hose assemblies — Determination of electrical resistance	IS 443 (Part 4) : 2022/ISO 8031 : 2020 Methods of test for rubber and plastics tubing, hoses and hose assemblies: Part 4 Rubber and plastics hoses and hose assemblies determination of electrical resistance and conductivity (*fourth revision*)	Identical
ISO 9563 Belt drives; electrical conductivity of antistatic endless synchronous belts; characteristics and test method	IS 16378 : 2017/ISO 9563 : 1990 Belt drives — Electrical conductivity of antistatic endless synchronous belts — Characteristics and test method	Identical
ISO 21178 Light conveyor belts — Determination of electrical resistances	IS 16381 : 2017/ISO 21178 : 2013 Light conveyor belts — Determination of electrical resistances	Identical
ISO 21179 Light conveyor belts — Determination of the electrostatic field generated by a running light conveyor belt	IS 16382 : 2017/ ISO 21179 : 2013 Light conveyor belts — Determination of the electrostatic field generated by a running light conveyor belt	Identical
ISO 21183-1 Light conveyor belts — Part 1: Principal characteristics and applications	IS 16385 (Part 1) : 2017/ ISO 21183-1 : 2005 Light conveyor belts: Part 1 Principal characteristics and applications	Identical
BS 5958 Code of practice for control of undesirable static electricity — Part 1: General considerations Part 2: Recommendations for particular industrial situations	IS 7689 : 1989 Guide for control of undesirable static electricity (*first revision*)	Modified/Technically Equivalent

The Committee has reviewed the provisions of the following international standards referred in this adopted standard and decided that they are acceptable for use in conjunction with this standard.

International Standard	*Title*
IEC 60167	Methods of test for the determination of the insulation resistanceof solid insulating materials
IEC 61340-2-3	Electrostatics — Part 2-3: Methods of test for determining the resistance and resistivity of solid planar materials used to avoid electrostatic charge accumulation
IEC 61340-4-1	Electrostatics — Part 4-1: Standard test methods for specific applications — Electrical resistance of floor coverings and installed floors
IEC 61340-4-3	Electrostatics — Part 4-3: Standard test methods for specific applications — Footwear
IEC 61340-4-4 : 2012	Electrostatics — Part 4-4: Standard test methods for specific applications — Electrostatic classification of flexible intermediate bulk containers (FIBC)
ISO 284	Conveyor belts – Electrical conductivity – Specification and test method
ISO 12100-1	Safety of machinery — Basic concepts, general principles fordesign — Part 1: Basic terminology, methodology
ISO 16392	Tyres — Electrical resistance — Test method for measuring electrical resistance of tyres on a test rig
ASTM D257	Standard test methods for dc resistance or conductance of insulating materials
ASTM D2624-07a	Standard test methods for electrical conductivity of aviationand distillate fuels
ASTM D4308-95	Standard test method for electrical conductivity of liquid hydrocarbons by precision meter
ASTM E582-88	Standard test method for minimum ignition energy and quenching distance in gaseous mixtures
ASTM E2019-03	Standard test method for minimum ignition energy of a dust cloud in air
ASTM F150	Standard test method for electrical resistance of conductive and static dissipative resilient flooring
ASTM F1971	Standard test method for electrical resistance of tires under load on the test bench
BS 7506	Methods for measurements in electrostatics — Part 2 Testmethods
DIN 51412-1	Testing of petroleum products; determination of the electrical conductivity, laboratory method
DIN 51412-2	Testing of petroleum products; determination of the electricalconductivity; field method
EN 1081	Resilient floor coverings — Determination of the electrical resistance
EN 1149-3	Protecting clothes — Electrostatic properties — Part 3: Test method for measuring the charge dissipation
EN 1149-5	Protective clothing — Electrostatic properties — Part 5: Material performance and design requirements

International Standard	*Title*
EN 1360	Rubber and plastic hoses and hose assemblies for measured fuel dispensing systems — Specification
EN 1361	Rubber hoses and hose assemblies for aviation fuel handling — Specification
EN 13463-1	Non-electrical equipment for potentially flammable atmospheres — Part 1: Basic principles and general requirements
EN 14125	Underground pipework for petrol filling stations
EN 14973	Conveyor belts for use in underground installations — Electrical and flammability safety requirements
International Safety Guide for Oil Tankers and Terminals (ISGOTT), fifth edition, International chamber of shipping, 2006.	
JNIOSH TR 42	Recommendations for requirements for avoiding electrostatic hazards in industry
NFPA 77	Recommended practice on static electricity
SAE J1645	Surface vehicle recommended practice — Fuel systems and components — Electrostatic charge mitigation

Only the English language text has been retained while adopting it in this Indian Standard, and as such, the page numbers given here are not the same as in the IEC publication.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding of numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

CONTENTS

INTRODUCTION

This IEC Technical Specification is based on CENELEC TR 50404:2003, *Code of practice for the avoidance of hazards due to static electricity* and a number of other documents:

- from the UK: BS 5958, Parts 1 & 2:1991, *Control of undesirable static electricity*,
- from Germany: TRBS 2153:2009, *Preventing risks of ignition due to electrostatic charges,*
- from Shell International Petroleum: *Static electricity – Technical and safety aspects,*
- from the US: NFPA 77, *Recommended Practice on Static Electricity (2007),*
- from Japan: JNIOSH TR42, *Recommendations for Requirements for Avoiding Electrostatic Hazards in Industry (2007),*
- from ASTM, EUROPIA, IEC, International chamber of shipping, ISO etc.

It gives the best available accepted state of the art guidance for the avoidance of hazards due to static electricity.

This document is mainly written for designers and users of processes and equipment, manufacturers and test houses. It can also be used by suppliers of equipment (e.g. machines) and flooring or apparel when no product family or dedicated product standard exists or where the existing standard does not deal with electrostatic hazards.

A second part, IEC 60079-32-2, *Electrostatic Hazards, Tests,* is under development.

Indin Standard

EXPLOSIVE ATMOSPHERES

PART 29 GAS DETECTORS

SECTION 3 GUIDANCE ON FUNCTIONAL SAFETY OF FIXED GAS DETECTION SYSTEMS

1 Scope

This part of IEC 60079 gives guidance about the equipment, product and process properties necessary to avoid ignition and electrostatic shock hazards arising from static electricity as well as the operational requirements needed to ensure safe use of the equipment, product or process. It can be used in a risk assessment of electrostatic hazards or for the preparation of product family or dedicated product standards for electrical or non-electrical machines or equipment.

The hazards associated with static electricity in industrial processes and environments that most commonly give problems are considered. These processes include the handling of solids, liquids, powders, gases, sprays and explosives. In each case, the source and nature of the electrostatic hazard are identified and specific recommendations are given for dealing with them.

The purpose of this document is to provide standard recommendations for the control of static electricity, such as earthing of conductors, reduction of charging and restriction of chargeable areas of insulators. In some cases static electricity plays an integral part of a process, e.g. electrostatic coating, but often it is an unwelcome side effect and it is with the latter that this guidance is concerned. If the standard recommendations given in this document are fulfilled it can be expected that the risk of hazardous electrostatic discharges in an explosive atmosphere is at an acceptably low level.

If the requirements of this document cannot be fulfilled, alternative approaches can be applied under the condition that at least the same level of safety is achieved.

Basic information about the generation of undesirable static electricity in solids, liquids, gases, explosives, and also on people, together with descriptions of how the charges generated cause ignitions or electrostatic shocks, is given in the annexes and in IEC/TR 61340-1.

This Technical Specification is not applicable to the hazards of static electricity relating to lightning or to damage to electronic components.

This Technical Specification is not intended to supersede standards that cover specific products and industrial situations.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60079-0:2011, *Explosive atmospheres – Part 0: Equipment – General requirements*

IEC 60079-10-1, *Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres*

IEC 60079-10-2, *Explosive atmospheres – Part 10-2: Classification of areas – Combustible dust atmospheres*

IEC 60079-14, *Explosive atmospheres – Part 14: Electrical installations design, selection and erection*

IEC 60079-20-1, *Explosive atmospheres – Part 20-1: Material characteristics for gas and vapour classification – Test methods and data*

IEC 60079-32-2:2015, *Explosive atmospheres – Part 32-2: Electrostatic hazards – Tests*

IEC 60093, *Methods of test for volume resistivity and surface resistivity of solid electrical insulating materials*

IEC 60167, *Methods of test for the determination of the insulation resistance of solid insulating materials*

IEC 61340-2-3, *Electrostatics – Part 2-3: Methods of test for determining the resistance and resistivity of solid planar materials used to avoid electrostatic charge accumulation*

IEC 61340-4-1, *Electrostatics – Part 4-1: Standard test methods for specific applications – Electrical resistance of floor coverings and installed floors*

IEC 61340-4-3, *Electrostatics – Part 4-3: Standard test methods for specific applications – Footwear*

IEC 61340-4-4:2012, *Electrostatics – Part 4-4: Standard test methods for specific applications – Electrostatic classification of flexible intermediate bulk containers (FIBC)*

ISO 284, *Conveyor belts – Electrical conductivity – Specification and test method*

ISO 6297, *Petroleum products – Aviation and distillate fuels – Determination of electrical conductivity*

ISO 8031, *Rubber and plastics hoses and hose assemblies – Determination of electrical resistance*

ISO 9563, *Belt drives; electrical conductivity of antistatic endless synchronous belts; characteristics and test method*

ISO 12100-1, *Safety of machinery – Basic concepts, general principles for design – Part 1: Basic terminology, methodology*

ISO 16392, *Tyres – Electrical resistance – Test method for measuring electrical resistance of tyres on a test rig*

ISO 21178, *Light conveyor belts – Determination of electrical resistances*

ISO 21179, *Light conveyor belts – Determination of the electrostatic field generated by a running light conveyor belt*

ISO 21183-1, *Light conveyor belts – Part 1: Principal characteristics and applications*

ASTM D257, *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*

ASTM D2624-07a, *Standard Test Methods for Electrical Conductivity of Aviation and Distillate Fuels*

ASTM D4308-95, *Standard Test Method for Electrical Conductivity of Liquid Hydrocarbons by Precision Meter*

ASTM E582-88, *Standard test method for minimum ignition energy and quenching distance in gaseous mixtures*

ASTM E2019-03, *Standard test method for minimum ignition energy of a dust cloud in air*

ASTM F150, *Standard Test Method for Electrical Resistance of Conductive and Static Dissipative Resilient Flooring*

ASTM F1971, *Standard Test Method for Electrical Resistance of Tires Under Load On the Test Bench*

BS 5958: *Code of practice for control of undesirable static electricity*
Part 1: *General considerations*
Part 2: *Recommendations for particular industrial situations*

BS 7506, *Methods for measurements in electrostatics – Part 2 Test methods*

DIN 51412-1, *Testing of petroleum products; determination of the electrical conductivity, laboratory method*

DIN 51412-2, *Testing of petroleum products; determination of the electrical conductivity; field method*

EN 1081, *Resilient floor coverings – Determination of the electrical resistance*

EN 1149-3, *Protecting clothes – Electrostatic properties – Part 3: Test method for measuring the charge dissipation*

EN 1149-5, *Protective clothing – Electrostatic properties – Part 5: Material performance and design requirements*

EN 1360, *Rubber and plastic hoses and hose assemblies for measured fuel dispensing systems – Specification*

EN 1361, *Rubber hoses and hose assemblies for aviation fuel handling – Specification*

EN 13463-1, *Non-electrical equipment for potentially flammable atmospheres – Part 1: Basic principles and general requirements*

EN 14125, *Underground pipework for petrol filling stations*

EN 14973, *Conveyor belts for use in underground installations – Electrical and flammability safety requirements*

International Safety Guide for Oil Tankers and Terminals (ISGOTT), fifth edition, International chamber of shipping, 2006.

JNIOSH TR 42, *Recommendations for Requirements for Avoiding Electrostatic Hazards in Industry*

NFPA 77, *Recommended practice on static electricity*

SAE J1645, *Surface vehicle recommended practice – Fuel systems and Components – Electrostatic Charge Mitigation*

3 Terms and definitions

For the purposes of this document the following terms and definitions apply:

3.1
antistatic
conductive or dissipative

Note 1 to entry: Used to describe 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.

Note 2 to entry: Preferred term is conductive or dissipative depending on which is correct.

3.2
conductive
having a resistivity or resistance below the dissipative range (see 3.7) allowing stray current arcs and electrostatic shocks to occur

Note 1 to entry: Conductive materials or objects are neither dissipative nor insulating and are incapable of retaining a significant electrostatic charge when in contact with earth.

Note 2 to entry: Boundary limits for the conductive range are given for solid materials, enclosures and some objects in 6.1 (Table 1), and for bulk materials in 9.1. For certain items, special definitions are maintained in other standards (see 3.3, 3.8 and 3.9).

Note 3 to entry: Product standards and other standards covering electrostatic properties often include specific definitions of "conductive" which apply only to items covered by those standards and may be different to the definitions given here. See e.g. ISO 8031 and ISO 8330 for hose and hose assemblies.

3.3
conductive footwear
footwear ensuring that a person standing on a conductive floor has a resistance to earth low enough to ensure dissipation of electrostatic charges even in particularly hazardous situations (e.g. when handling sensitive explosives) but not high enough to prevent a hazardous electrical shock at voltages less than 500 V

Note 1 to entry: See IEC 61340-4-3 and IEC 61340-4-5.

3.4
conductivity
electrical conductivity
reciprocal of volume resistivity, expressed in siemens per meter

3.5
conductor
conductive object

3.6
contaminated liquid
liquid containing more than 0,5 % by volume of free water or other immiscible liquids or more than 10 mg/l of suspended solids

3.7
dissipative
electrostatic dissipative
having an intermediate resistivity or resistance that lies between the conductive and insulating ranges (see 3.2 and 3.15)

Note 1 to entry: Dissipative materials or objects are neither conductive nor insulating but, like conductive items, safely limit contact charging and/or dissipate even the maximum charging currents associated with their designed application when in contact with earth.

Note 2 to entry: Boundary limits for the dissipative range are given for solid materials, enclosures and some objects in Table 1, and for bulk materials in 9.1. For certain items, special definitions are maintained in other standards (see 3.3, 3.8 and 3.9).

Note 3 to entry: Product standards often include specific definitions of “dissipative” which apply only to items covered by those standards and may be different to the definitions given here.

3.8
dissipative clothing
clothing that meets the material and design requirements specified in EN 1149-5

3.9
dissipative footwear
footwear ensuring that a person standing on a conductive or dissipative floor has a resistance to earth low enough to ensure dissipation of electrostatic charges but high enough to prevent a hazardous electrical shock at voltages less than 500 V

Note 1 to entry: See IEC 61340-4-3 and IEC 61340-4-5.

Note 2 to entry: Antistatic footwear as described in ISO 20345 may fulfil this function.

3.10
electrostatic shock
pathophysiological effect resulting from an electric current caused by an electrostatic discharge passing through human or animal body

3.11
enclosure
all the walls, doors, covers, cable glands, rods, spindles, shafts, coatings etc. which surround and enclose equipment

Note 1 to entry: For electrical equipment, the enclosure is likely to be identical to the enclosure defined in IEC 60079-0.

Note 2 to entry: Containers, e.g. drums and FIBC, are not equipment enclosures and, therefore, are considered separately in 9.6.

3.12
hazardous area
area in which flammable or explosive gas/vapour-air or dust-air mixtures or aerosols are, or can be, present in such quantities as to require special precautions against ignition

Note 1 to entry: See IEC 60079-10-1and IEC 60079-10-2. A short summary is given in Annex D.

3.13
high charging
a process that generates a higher rate of electrostatic charging than simple manual operations

EXAMPLE Rubbing, cleaning with a cloth, raising from a seat, walking, wiping of clothes etc.

Note 1 to entry: Typical examples of high charging operations include e.g. the flow of insulating liquids or powders and high voltage spray charging.

3.14
hybrid mixture

an explosible heterogeneous mixture, comprising gas or vapour with suspended particulate solid or liquid, in which the total flammable gas concentration is at least 10 % of its lower flammable limit (LFL) and the total suspended particulate concentration is at least 10 % of its minimum explosible concentration (MEC)

3.15
insulating

having a resistivity or resistance that is higher than the dissipative range (see 3.7)

Note 1 to entry: Insulating materials or objects are neither conductive nor dissipative. Electrostatic charges can accumulate on them and do not readily dissipate even when they are in contact with earth.

Note 2 to entry: Boundary limits for the insulating range are given for solid materials, enclosures and some objects in Table 1, for bulk materials in 9.1. For certain items, special definitions are maintained in other standards (see 3.3, 3.8 and 3.9).

Note 3 to entry: Product standards and other standards covering electrostatic properties often include specific definitions of “insulating” which apply only to items covered by those standards and may be different to the definitions given here. See e.g. ISO 8031 and ISO 8330 for hose and hose assemblies.

Note 4 to entry: The adjective “non-conductive” has often been used as a synonym for insulating. It is avoided in this document as it could be taken to mean either “insulating” or “insulating or dissipative” and this may lead to confusion.

3.16
isolated conductor

conductive object which can accumulate charge due to an earth leakage resistance exceeding the values given in Table 22

3.17
leakage resistance
resistance to earth

resistance expressed in ohms between an electrode in contact with the surface to be measured and earth

Note 1 to entry: The resistance depends upon the volume or surface resistivity of the materials and the distance between the chosen point of measurement and earth.

Note 2 to entry: One common configuration (e.g. in IEC 61340-4-1, ISO 10965 and ASTM F150) uses a circular electrode, (65 ±5) mm in diameter.

3.18
minimum ignition energy
MIE

minimum energy that can ignite a mixture of a specified flammable material with air or oxygen, measured by a standard procedure

Note 1 to entry: See ASTM E582-88 for gases and vapours, IEC 61241-2-3, ASTM E2019-03 and EN 13821 for dust clouds.

3.19
multiphase liquid

mixture of immiscible liquids that form separate phases with a distinct interfacial boundary, and solids suspended in liquids, and gas bubbles suspended in liquids

Note 1 to entry: Liquid-in-gas suspensions (mists or sprays) are covered separately.

3.20
relaxation time

time during which the electrostatic charge on a solid surface or in the bulk of a liquid or powder decays exponentially to 1/e (i.e. about 37 %) of its original value (see A.2.2)

Note 1 to entry: For high charge generation with high resistivity liquids, relaxation may be hyperbolic rather than exponential.

3.21

surface resistance

resistance expressed in ohms between two electrodes in contact with the surface to be measured

Note 1 to entry: One common configuration (e.g. in IEC 60079-0 and IEC 60167) uses parallel electrodes, 100 mm long and 10 mm apart)

Note 2 to entry: The surface resistance is dependent upon the electrode configuration. The surface resistance measured with the example electrode configuration is ten times lower than the surface resistivity.

Note 3 to entry: Soft conductive rubber strip electrodes are preferred over silver paint electrodes.

3.22

surface resistivity

resistance across opposite sides of a surface of unit length and unit width commonly expressed in ohms (or ohms/square)

Note 1 to entry: This configuration is used e.g. in ASTM D257 and BS 7506-2.

3.23

volume resistivity

resistance of a body of unit length and unit cross-sectional area expressed in ohm metres

4 Nomenclature

Electrostatic safety regulations use many adjectives to classify the conducting ability of materials and objects. Different regulations and different industries use different adjectives and, even when the same adjectives are used, their definitions can vary. The nomenclature that is systematically followed in this document is given here in order to avoid confusion and to assist with translation:

Solid materials are classified as conductive, dissipative or insulating according to their volume resistivity (see 3.2, 3.7 and 3.15). Boundary limits are given in Table 1.

Solid objects and **textiles** are classified as conductive, dissipative or insulating according to their surface or leakage resistance, depending on application (see 3.2, 3.7 and 3.15). Boundary limits for enclosures and some objects are given in Table 1. For certain items, special definitions are maintained in other standards (see 3.3, 3.8 and 3.9).

Bulk materials (powders etc.) are classified as low, medium or high resistivity according to their volume resistivity (see 9.1 for boundary limits).

Liquids are classified as high, medium or low conductivity according to their electrical conductivity (see 7.1.4 for boundary limits).

NOTE More details about electrostatic properties, concepts and terms are given in Annexes A to G.

Resistances have mainly been stated in exponential form in other documents. However, exponents are small figures, and the exponents 6, 8 and 9 mainly used in electrostatics are easily misread in printed or projected documents, and even unreadable if they occur in notes. For this reason this document uses SI prefixes instead of exponents:

$10^3\ \Omega = 1\ \text{k}\Omega$

$10^6\ \Omega = 1\ \text{M}\Omega$

$10^8\ \Omega = 100\ \text{M}\Omega$

10^9 Ω = 1 GΩ

10^{11} Ω = 100 GΩ

10^{12} Ω = 1 TΩ

Current is, for the same reasons, also given in SI prefixes instead of exponents:

10^{-3} A = 1 mA

10^{-6} A = 1 μA

10^{-9} A = 1 nA

10^{-12} A = 1 pA

5 General

Static electricity occurs commonly in industry and 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. In such situations, the hazard can generally be reduced by charge relaxation (see Annex A).

Hazards caused by electrostatic charge include:

a) ignition and / or explosion of flammable atmospheres, see IEC 60079-0 and EN 13463-1;
b) electrostatic shock in combination with another hazard (e.g. fall, trip) – see ISO 12100-1;
c) electrostatic shock giving rise to injury or death, see ISO 12100-1;
d) damage to electronics (not covered by this document).

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

Static electricity is generated by:

a) the contact and separation of solids e.g. the movement of conveyor belts, plastics film, etc. over rollers, the movement of a person;
b) the flow of liquids or powders, and the production of sprays;
c) induction phenomena, i.e. objects reach high potential or become 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 working environments, and to ignition and explosion hazards particularly in chemicals, pharmaceuticals, petroleum and food processing industries.

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

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

a) the handling of solids;
b) the storage and handling of liquids;
c) the handling of gases and vapours;
d) the storage and handling of powders;
e) the storage and handling of explosives

f) electrostatic problems caused by people;
g) avoidance of electrostatic shock;
h) earthing and bonding of plant and machinery;
i) measuring methods.

This document also contains some fundamental information relating to electrostatic charging and its problems. This is contained in Annexes A to G 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.

As this document is very complex, correctly evaluating the electrostatic hazards of products and processes may not be easy for new readers. For this reason a universally applicable informative Annex F has been appended which references the relevant sections of this document in the correct order.

It is very seldom that an electrostatic hazard can be treated by itself. 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 that covers all risks is adopted. 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.

6 Static electricity in solid materials

6.1 General considerations

Solid materials are usually characterised as insulating, dissipative or conductive according to their volume resistivity. Enclosures are usually classified according to their surface resistance or resistivity (measured according to IEC 60079-0, IEC 60167, IEC 60093 or IEC 61340-2-3 or equivalent methods). Measuring details will also be dealt with in IEC 60079-32-2[1]. The two surface classifications are equivalent because the surface resistivity is ten times higher than the surface resistance for the specified electrode geometries. For other specific applications different definitions may be applicable (e.g. leakage resistance in the case of floors). The thresholds most commonly used for these purposes are shown in Table 1.

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[1] To be published.

Table 1 – Boundary limits at (23 ± 2) °C and (25 ± 5) % RH for the characterisation of solid materials and examples for the classification of objects

Object	Unit	See subclause	Conductive	Dissipative[a]	Insulating[a]
Material	Volume Resistivity (Ω m)	6.2.1	< 100 kΩ m	100 kΩ m to < 1 GΩ m	≥ 1 GΩ m
Enclosure	Surface Resistance (Ω)	6.2.1	< 10 kΩ	10 kΩ to < 100 GΩ	≥ 100 GΩ
	Surface Resistivity (Ω)	6.2.1	< 100 kΩ	100 kΩ to < 1 TΩ	≥ 1 TΩ
Clothes	Surface Resistance, (Ω)	11.5	Not available	< 2,5 GΩ	≥ 2,5 GΩ
Footwear	Leakage resistance (Ω)	11.3	< 100 kΩ	100 kΩ to < 100 MΩ	≥ 100 MΩ
Gloves	Leakage resistance (Ω)	11.6	< 100 kΩ	100 kΩ to < 100 MΩ	≥ 100 MΩ
Floor	Leakage resistance (Ω)	11.2	< 100 kΩ	100 kΩ to < 100 MΩ	≥ 100 MΩ
Pipes	Resistance per length (Ω/m)	7.7.2.1	< 1 kΩ/m	1 kΩ/m to < 1 MΩ/m	≥ 1 MΩ/m
Hoses[b]	Resistance per assembly (Ω)	7.7.3.1	< 1 kΩ	1 kΩ to < 1 MΩ	≥ 1 MΩ

[a] Where local ambient conditions are significantly different from the stated worst case test condition of (23 ± 2) °C and (25 ± 5) % RH, other test conditions may be used after a careful hazard evaluation. In some countries, especially during winter, a relative humidity of (12 ± 3) % at (23 ± 2) °C is an appropriate test environment for qualifying equipment. As the resistance of non-metals usually depends strongly on the measuring voltage, the measuring voltages (typically 500 to 1 000 V) should be chosen to be consistent with the purpose of the measurement and stated with the test result.

[b] According to ISO 8031, the values for hoses are measured at (50 ± 5) % RH and are the latest ones taken from Table 15 in 7.7.3.1. In the past, slightly different values have been used in ISO and CENELEC documents. Other classifications may be used by industry standards for specific applications (e.g. in ISO 8031 conductive hoses for industry applications, dissipative antistatic hoses for automobile applications) which does not necessarily imply electrostatic safety.

Enclosure criteria are to prevent tribo-charging and thus do not necessarily dissipate charge deposited from unspecified processes within the enclosure.

Different values measured at 50 % RH have been applied in the past in the absence of a dehumidified test chamber and are considered to err on the safe side. This approach has now been discontinued, and limits at 50 % RH are, except for hoses, given in other documents only. They should only be used if an appropriate climate is not available. As the chargeability of materials is higher at 20 % RH compared to 30 % RH, the former value of 30 % RH has been reduced to (25 ± 5) % RH. A relative humidity at the lower part of the interval should be applied during measurements whenever possible.

When characterizing non-homogenous materials the measured values should be averaged and rounded to the nearest order of magnitude unless otherwise specified by the test method. Non-homogeneous materials may exhibit different resistivity in different directions

Instead of measuring resistance, the rate of charge decay may be used to characterize the dissipative behaviour of clothing (see EN 1149-3 and EN 1149-5).

Electrically insulating solid materials are commonly used in many forms, including pipes, containers, sheets, coatings and liners. The use of electrically insulating solid materials in hazardous areas can give rise to many electrostatic hazards, in particular:

a) conductive objects could be isolated from earth by the material and could then reach a high electrical potential and give rise to sparks (see A.3.2);

b) charges on the surface of the material could lead to brush discharges (see A.3.4);

c) a combination of conductive and insulating materials in the presence of prolific charge generators (see 12.3) could lead to energetic propagating brush discharges (see A.3.5).

Measures to address these hazards are given in 6.2, 6.3 and 6.4.

If insulating materials are used, a risk assessment is necessary to identify if there is any process that can lead to direct production of or indirect induction of electrostatic charging on insulated materials that are present in the location.

6.2 The use of conductive or dissipative materials in place of insulating ones

6.2.1 General considerations

It is generally good practice to minimise the use of insulating materials in hazardous areas. While this may be achieved primarily by the use of inherently conductive materials (e.g. metals), many materials which used to be available only in insulating forms (e.g. rubbers or plastics) are now available in grades which meet the requirements to be considered conductive or dissipative as given in Table 1. This increase in conductivity is typically achieved either by adding conductive ingredients (e.g. carbon black) to its composition, or by applying hygroscopic agents to its surface that attract atmospheric moisture – conductive polymers, laminates with conductive elements and metallised films have all been developed for improved static dissipation.

It is important that such conductive and dissipative materials are earthed reliably according to Clause 13 and are long lasting according to Clause 13. Also, if conductive or dissipative coatings are used to make an insulating material non-chargeable, it is important that such coatings are properly earthed, and that their durability and suitability for use in hazardous areas (particularly Zone 0 and Zone 1) is demonstrated for the particular application.

Another consideration is that the use of a high proportion of additives such as carbon black may degrade the physical properties (primarily strength and chemical resistance) of the material. This may render such materials unsuitable for certain applications. This can be avoided by using intrinsically conductive polymers as a conducting ingredient or coating. Care should be taken to ensure sufficiently high concentrations of dissipative additives and their uniform distribution.

NOTE It is not possible to determine whether materials may be dissipative or conductive by their colour. Black polymers may not be dissipative, and modern conductive or dissipative materials may be available in a variety of colours.

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.

6.2.2 Dissipative solid materials

A solid material is defined as dissipative if its surface resistance, surface resistivity or volume resistivity meet the combined criteria set out in 6.1.

In general, providing that dissipative materials are connected to earth according to Clause 13, no further protective measures need to be taken. However, in processes involving high speed separation (e.g. conveyor and transmission belts, see 6.4) lower resistivities and resistances can be required.

NOTE 1 For materials with resistivities at the top end of the dissipative range there will be significant constraints on the possible geometry of a manufactured item if the requirements of Clause 13 are to be met (e.g. long pipes or thin filaments will not meet the earthing requirements whilst thin sheets with a large earth contact area will).

In some cases, particularly with plastic films or sheeting, a material is added to attract atmospheric moisture to the surface, thus increasing surface conductivity. Care should be taken where this type of dissipative plastic film or sheeting is used in low humidity conditions: in environments with low humidity (typically <30 %), it can become insulating and accumulate electrostatic charge.

It should be ensured that a dissipative coating cannot be washed away or rubbed off and cannot lose its effectiveness over time. Otherwise such a coating would only be appropriate as a temporary measure to reduce accumulation of static electric charge.

Dissipative agents used in packaging should be compatible with the product contained within the package. Absorption of the dissipative agents by product with which it is in contact may cause product contamination and / or loss of dissipative properties of the package.

NOTE 2 New static dissipative additives are available which increase the volume resistivity and are, therefore, less sensitive to humidity but are also affected by aging as are other additives.

NOTE 3 The resistance of dissipative materials made from rubber vulcanized with carbon black may increase with decreasing temperature. Such materials may, for example, be dissipative (~100 MΩ) at 20 ˚C but insulating (~10 TΩ) at 0 ˚C.

6.2.3 Earthing of conductive and dissipative items

All metal and other conductive or dissipative material should be connected to earth according to Clause 13 with the exception of very small items. The capacitance of isolated items depends on their size, surrounding materials and proximity to other conductors and may be very different under installed or non-installed conditions. The maximum allowable capacitance of isolated items depends on the ignitability of the gases, vapours and dust expressed by the representative gas groups I, IIA, IIB and IIC (IEC 60079-20-1, see D.3) or dust group III (IEC 60079-0) and the classification of the hazardous area (IEC 60079-10-1 and IEC 60079-10-2, see D.2) as shown in Table 2, taking account of the following:

a) Capacitances below 3 pF need not be earthed provided that the object cannot reach a hazardous potential and is not situated in Zone 0 when gases or vapours belonging to Group IIC are used.
b) In Zone 1 where gases or vapours belonging to Group IIA are used, and in Zones 20 and 21 the maximum allowed isolated capacitance may be increased to 6 pF provided high charging processes do not occur.
c) In dust Zones 20 and 21 and in Group I the maximum allowed isolated capacitance may be further increased to 10 pF provided that either high charging processes do not occur or only powders with minimum ignition energies higher than 10 mJ are handled.
d) The limits in Table 2 are not absolute values that prevent incendive discharges, but they merely reduce the risk of occurrence to a generally accepted low level.
e) Hand held devices and hand tools are expected to be earthed via the user. In any case of doubt the user should ensure earthing of the device when working in hazardous areas.
f) People are conductive items having sufficient capacitance to produce an incendive discharge. They, therefore, should be earthed according to Clause 11 before entering a hazardous area Zone 0, 1, 20, 21 or Group I.

Capacitances should be measured according to IEC 60079-0, 26.15.

NOTE It is scheduled to revise this method and move it to IEC 60079-32-2[2].

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[2] To be published.

Table 2 – Maximum allowed isolated capacitance in Zones with explosive atmosphere

	Group I	Group IIA	Group IIB	Group IIC	Group III	Additional condition
Zone 0	10 pF	3 pF	3 pF	No isolated conductive objects allowed	-	No high charging processes
Zone 1		6 pF	3 pF	3 pF	-	
Zone 2		No requirements if charging processes capable of generating hazardous potentials are unlikely to occur during normal operation including maintenance and cleaning			-	
Zones 20,21 MIE < 10 mJ		-	-	-	6 pF	
Zones 20,21 MIE > 10 mJ		-	-	-	10 pF	
Zone 22		-	-	-	No requirements if charging processes capable of generating hazardous potentials are unlikely to occur during normal operation including maintenance and cleaning	

NOTE 1 The subdivisions are based on the maximum experimental safe gap (MESG) or the minimum ignition current ratio (MIC ratio) of the explosive gas atmosphere in which the equipment may be installed (see IEC 60079-20-1). More details can be found in C.6 and D.3.

NOTE 2 Manual rubbing is usually not considered to be a high charging process.

For dissipative materials with a surface resistance exceeding 10 GΩ earthing may not be necessary. In any case of doubt an additional test is necessary to prove electrostatic safety of unearthed objects (e.g. 6.3.9).

6.3 Precautions required when using insulating solid materials

6.3.1 General

The restrictions on the use of insulating materials in hazardous areas depend on the classification of the hazardous area according to IEC 60079-10-1 and IEC 60079-10-2:

a) in Zone 0, insulating solid materials should only be used if charging processes capable of generating hazardous potentials will not occur either during normal operation including maintenance and cleaning or even in the case of rare malfunctions;

b) in Zone 1, insulating solid materials should only be used if charging processes capable of generating hazardous potentials will not occur either during normal operation including maintenance and cleaning or in the case of likely malfunctions;

c) in Zone 2, insulating solid materials should only be used if charging processes capable of generating hazardous potentials are unlikely to occur during normal operation including maintenance and cleaning.

d) in Zones 20, 21 and 22 consideration should be given to spark, brush, cone, and propagating brush discharges (see A.3). However, practical experience, experimental evidence and the absence of incidents indicate that brush discharges do not ignite even ignition sensitive powder clouds in the absence of any flammable gas or vapour.

NOTE 1 Synthetic fabrics used in cloths for cleaning or wiping can develop sufficient static electric charge to produce discharges capable of igniting solvent vapours. Typically, charge generation increases with the speed and vigour of the wiping action. The material being cleaned or wiped, if insulating, also can accumulate sufficient charge to produce an incendive discharge. Cotton or synthetic fabric treated with a static dissipative compound may be required if static electric charge generation needs to be controlled, especially if flammable insulating solvents are being used for cleaning or wiping.

NOTE 2 The presence of contamination (e.g. grease or moisture) may affect the potential ignition hazard when using insulating materials.

NOTE 3 Conductive solids, objects or liquids may form hazardous isolated conductive islands if present on charged insulating surfaces.

In addition, to prevent incendive discharges the precautions given in 6.3.2 to 6.3.4 should be taken in all Zones where the use of insulating solid materials is unavoidable. The precautions given in 6.3.2 to 6.3.4 relate to the avoidance of incendive brush discharges, that given in 6.3.4 also relates to propagating brush discharges.

6.3.2 Restrictions on the size of chargeable insulating surfaces

Where the use of chargeable insulating material in a hazardous area is necessary, the maximum allowable size of insulating surface depends on the ignitability of the gases and vapours expressed by the representative groups I, IIA, IIB, IIC (IEC 60079-20-1) or the representative dust group III (IEC 60079-0) and the classification of the hazardous area (IEC 60079-10-1 and IEC 60079-10-2, see D.2) as shown in Table 3, taking account of the following:

a) for sheet materials the area is defined by the exposed (chargeable) area;

b) for curved or irregularly shaped 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); although when it is coiled it should be treated as for a sheet;

d) even smaller diameters can be required for narrow pipes or tubes containing flowing liquids or powders;

e) normal electric cables are usually acceptable in all zones. See IEC 60079-14. Very thick insulating layers on thick cables should, however, be tested experimentally e.g. according to IEC 60079-0:2007, 26.14.

NOTE It is scheduled to revise this method and move it to IEC 60079-32-2[3].

It is essential that non-conductive solid materials used in hazardous areas do not exceed the maximum area or width values given in Table 3 for the zone within which it is used unless it can be experimentally shown that hazardous electrostatic charges are not to be expected (see 6.3.9) or charging mechanisms will not occur at any time. An example of the last-named case is signs or lamps at the ceiling which are normally not exposed to any charging mechanisms. In this case, a warning “Clean with a water-wet cloth only and allow to dry naturally” is sufficient to avoid charging when cleaning.

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[3] To be published.

Table 3 – Restriction on size of insulating solid materials in hazardous areas

Zone	Group I		Group IIA		Group IIB		Group IIC		Group III	
	Max area (mm^2)	Max width (mm)	Max area (mm^2)	Max width (mm)	Max area (mm^2)	Max width (mm)	Max area (mm^2)	Max width (mm)	Max area (mm^2)	Max width (mm)
0	10 000	30	5 000	3	2 500	3	400	1	-	-
1			10 000	30	10 000	30	2 000	20	-	-
2			No size limit (but see 6.3.1)		No size limit (but see 6.3.1)		No size limit (but see 6.3.1)		-	-
20 21 22	-	-	-		-		-		No size limit (but see 6.3.1)	

NOTE 1 The width criterion applies to thin pipes, cable sheaths, and other insulating materials having small widths or diameters.

NOTE 2 Equipment marked IIB is suitable for applications requiring Group IIA equipment. Similarly, equipment marked IIC is suitable for applications requiring Group IIA or Group IIB equipment.

NOTE 3 These border limits are also used e.g. in IEC 60079-0, CENELEC TR 50404, TRBS 2153, JNIOSH TR42, and BS 5958.

NOTE 4 The subdivisions are based on the maximum experimental safe gap (MESG) or the minimum ignition current ratio (MIC ratio) of the explosive gas atmosphere in which the equipment may be installed (see IEC 60079-20-1). More details can be found in C.6 and D.3.

NOTE 5 The limits in Table 3 are not absolute values that prevent incendive discharges, they merely reduce it to a generally accepted low level.

NOTE 6 The present state of knowledge indicates that there is no ignition risk due to brush discharges in the case of sensitive dusts providing that there are no flammable gases or vapours (see Annex A.3.4). However, charge generation processes stronger than manual rubbing may create incendive propagating brush discharges under certain circumstances (see 6.3.4.2).

6.3.3 Earthed metal meshes

The areas given in Table 3 can be increased by a factor of four by incorporating an earthed mesh (or metal frame) into the insulating solid or by wrapping such a mesh around its surface. In addition:

a) the layer thickness above the mesh should be restricted to the values given in 6.3.4.2 to prevent brush discharges; and

b) propagating brush discharges should be prevented according to 6.3.4.3; and

c) special care should be taken to prevent or detect breaks which could lead to isolated conductive parts which present a greater electrostatic hazard than an insulating surface.

6.3.4 Insulating coatings on earthed conductive surfaces

6.3.4.1 General

Layers or coatings of insulating solids on earthed conductive surfaces (in particular metal surfaces) can give rise to brush and / or propagating brush discharges depending on several factors.

6.3.4.2 Avoidance of brush discharges

With regard to brush discharges, practical experience shows that these discharges are unlikely to be incendive if:

a) high electrostatic charging processes are avoided (e.g. repeated filling and emptying of a conductive drum containing an insulating liner); and,

b) the thickness of the layer does not exceed a value of 2 mm in the case of gases and vapours of groups I, IIA and IIB and a value of 0,2 mm in the case of gases and vapours of group IIC. For dusts there is no thickness limitation unless the powder layer can form a high resistance continuous film, e.g. by self-polymerization or reaction with water.

NOTE 1 Manual rubbing is usually not considered to be a high charging process.

NOTE 2 The thinner the coating the less incendive are the brush discharges created by manual rubbing of the surface, and the more incendive are the propagating brush discharges created by stronger electrostatic charging processes on the surface.

In those cases no special protective measures are necessary within hazardous areas. However, in the case of fluorinated polymers an experimental evaluation of the chargeability is recommended, e.g. according to IEC 60079-0:2007, 26.14.

NOTE It is scheduled to revise this method and move it to IEC 60079-32-2[4].

6.3.4.3 Avoidance of propagating brush discharges

Propagating brush discharges can occur when high or repeated electrostatic charging processes act on insulating layers or coatings on conductive surfaces. These discharges can be prevented by one or more of the following measures:

a) Avoid having thin insulating 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 10 mm;
b) Reduce the surface or volume resistivity of the coating. It is not known precisely what levels are required to prevent the occurrence of propagating brush discharges, but the values for dissipative materials given in Table 1 and a leakage resistance less than 100 GΩ are known to be sufficiently low;
c) Use a coating with a low dielectric strength (breakdown voltage for solid homogenous materials less than 4 kV, in the case of woven fabrics 6 kV, see A.3.5). Such coatings electrically break down before a propagating brush discharge can develop. The dielectric strength should be measured according to IEC 60243-2 in combination with IEC 60243-1, or IEC 60079-32-2[5].
d) Avoid high or repeated charging processes (e.g. air ions in the vicinity of high voltage electrodes, high speed flowing liquids and pneumatic transfer of powders, and paper or plastic foils transported by machines).

NOTE 1 Due to their slight porosity, layers of solvent or water based paint or loose powder usually have a low breakdown voltage so that propagating brush discharges are difficult to obtain from such layers.

NOTE 2 Coatings formed by baking on an applied powder and enamel usually have too high a breakdown voltage to avoid propagating brush discharges.

NOTE 3 Polymer films which are wound on to a reel or are lifted from a conductive or insulating 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.

NOTE 4 Manual rubbing is not normally considered a high charging process.

6.3.5 Conductive or dissipative coatings on insulating materials

Special care is necessary when applying a conductive or dissipative coating on an insulating surface to ensure a uniform distribution of the conductive particles. Non-uniform distribution may lead to isolated conductive islands which can be charged easily by insulated surfaces in their vicinity. Such isolated conductive islands present a greater electrostatic hazard than an insulating surface.

Conductive coatings should be earthed as other conductors in accordance with Clause 13.

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[4] To be published.

6.3.6 Static dissipative agents

Dissipative antistatic agents are frequently used on clothing and floors and to increase the conductivity of liquids and materials. Care should be taken to guarantee the presence of a sufficient concentration of these agents to achieve the desired function. For example, dissipative agents may become diluted or washed out. Therefore, their effectiveness needs to be monitored and maintained. Non-migratory permanent antistatic polymer additives have recently been developed to overcome these limitations.

6.3.7 Humidification

The surface resistivity of some insulating solid materials can be reduced to dissipative levels if the relative humidity is maintained above about 65 %. Even though damp air is not conductive, water / moisture may adsorb on the surface of many materials depending on the hydroscopic nature of the material. This may be sufficient to prevent accumulation of static electricity, provided there is a suitable path to earth.

However, whereas the surface of some materials (e.g. glass or natural fibres) can adsorb enough moisture to ensure a surface conductivity that is sufficient to prevent accumulation of static electricity, other materials do not (e.g. polytetrafluoroethylene or polyethylene) and are capable of accumulating a static electric charge even at high relative humidity. Also, when the humidity falls below about 30 %, materials which are susceptible to humidification generally return to being highly insulating. Increasing the relative humidity, therefore, is not effective in all cases and, in general, it should not be used as the sole protective measure. This is particular important in Zone 0.

6.3.8 Ionisation / Charge Neutralisation

6.3.8.1 General

Ionisation of the air is a method of making the air locally ion-rich so that charges on insulating solid materials can be neutralised. It is particularly useful for neutralising charge on insulating plastic sheets or films. Methods that may be employed include those given in 6.3.8.2 to 6.3.8.5. Neutralisation cannot succeed if the rate at which charge is generated exceeds the rate at which ions are supplied to the air, or can migrate to the charged surface, or if sufficient ions of the desired polarity are not present. Consequently, correct installation and regular maintenance is essential for those devices, taking into consideration factors that can influence their effectiveness such as environmental conditions (e.g. dust and temperature) and positioning of the device in relation to the material processed, machine parts, and people.

The reduction of charge at any one point in the operation does not prevent generation of charge in later steps of the process, so ionisers may be required at a number of locations. Positioning is important, and effectiveness of individual installations should be confirmed by field measurement of residual charge or voltage. In particular, for films and sheets it is necessary to ensure that ions are directed at the correct side to avoid forming a bipolar layer which could give rise to propagating brush discharges.

Corona points remain functional only as long as they are clean and sharp. Accumulation of contaminants (e.g. ink, coating solution, or paper dust) and corrosion products should be controlled by an effective maintenance program.

Ionisers should be selected by their charge generation rate or by their charge decay time. They should not be used in Zone 1, IIC unless the risks have been evaluated by an expert. Furthermore they should not be used in Zone 0 as the only safety measure.

6.3.8.2 Passive ionisers

Pointed electrodes such as earthed sharp needles, fine wires or conductive tinsel produce corona discharges when placed in the electric field from a highly charged surface. These provide ions which neutralize the charge on the body. This method, however, is limited in its effectiveness and may, in addition produce discharges if passive ionisers are not properly earthed.

6.3.8.3 Active ionisers

Active ionisers produce ions by applying a high voltage to a number of corona points. Commercial systems commonly use alternating voltages in the range 5 kV to 10 kV. The use of a high voltage power supply eliminates the limitation of passive neutralizers in control of charges having fields below the corona onset threshold. The currents from the corona points are limited either by high resistance or capacitive coupling.

Active ionisers should be suitable for the location in which they are used and should be designed and constructed to prevent being a possible source of ignition. They require careful design to ensure that the supply of ions is balanced with the requirements of the process.

6.3.8.4 Radioactive / soft x-ray ionisers

Radioactive and soft x-ray sources ionise the surrounding air and can be used to dissipate the charges from a charged body. Such ionisation itself does not present an ignition hazard but is, however, limited in its effectiveness (performance deteriorates with the decay of the radioactive material).

6.3.8.5 Ionised air blowers

Ionised 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 ionised air over large distances. The parts containing the high voltages should be placed in a non-hazardous area unless they have been appropriately certified.

NOTE The function of an ioniser can be tested by the method described in IEC 61340-4-7.

6.3.9 Methods to determine the incendivity of discharges

If the requirements in 6.3.2 to 6.3.8 are not applicable, an experimental determination of a value for the incendivity of possible discharges may be helpful.

One method is to charge the sample under worst case conditions as highly as possible (at least to the maximum level that could occur in service) to provoke discharges to an earthed sphere approaching and to pass such provoked discharges through gas mixtures of known MIE value. This method is described in IEC 61340-4-4.

The maximum charge transferred by a discharge is often used to give an indication of the incendivity of spark and brush discharges instead of using an explosive gas mixture. This method is described in IEC 60079-0:2007, 26.14. Table 4 shows a summary of all applicable threshold limits.

NOTE It is scheduled to revise this method and move it to IEC 60079-32-2[5].

Special care should be taken to ensure that the test sample is charged as highly as possible, that induced charges are compensated for and that only one single discrete discharge is recorded.

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[5] To be published.

Table 4 – Maximum acceptable transferred charge

Explosion Group	EPL Ma EPL Mb Mining	EPL Ga Zone 0	EPL Gb Zone 1	EPL Gc Zone 2	EPL Da Zone 20	EPL Db Zone 21	EPL Dc Zone 22
I	60 nC	-	-	-	-	-	-
IIA	-	25 nC	60 nC	60 nC	-	-	-
IIB	-	10 nC	25 nC	25 nC	-	-	-
IIC	-	No measurabl edischarge	10 nC	10 nC	-	-	-
III	-	-	-	-	60 nC [a]	200 nC [a]	200 nC [a]

[a] Values only valid for spark discharges from unearthed conductive or dissipative parts

NOTE 1 The limits for Zone 1 and Zone 21 ensure that incendive discharges should not occur during normal operation. The limits for Zone 0 and 20 are further reduced to account for abnormal situations and the high level of safety required for these zones.

NOTE 2 For the explanation of EPL see IEC 60079-0 or Annex E.

NOTE 3 All of the values contain a certain safety margin. Recent work indicates that the value hitherto used for IIB contains a lower safety margin than all other values. To equalize all safety margins the values for IIB have been reduced from 30 nC to 25 nC.

6.4 Conveyor belts and transmission belts

6.4.1 General

Belts used for transmission of power or the transportation of solid materials can generate a considerable amount of charge and become an ignition hazard due to the continuous separation of the contacting surfaces (primarily a driving shaft and a belt). 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, and increases with the velocity and tension of the belt and the width of the area of contact.

The charge acquired by the belt can only be safely dissipated to earth via the earthed conductive rollers if the conveyor belt is sufficiently dissipative. Material that is spilled from the end of a conveyor belt into a hopper or chute can carry a significant charge. Conductive or dissipative belts cannot be expected to remove charge from an insulating conveyed product.

6.4.2 Conveyor belts

Conveyor belts are endless belts which run over rollers (usually metallic) and transport materials. A conveyor belt is considered to be dissipative if

a) the surface resistances on both sides of the belt are below 300 MΩ measured according to ISO 284 and EN 14973, or

b) the surface resistances on both sides of the belt are below 75 MΩ measured with the electrode configuration in 3.21, or

c) in cases where the belt consists of layers of different materials the belt is considered to be dissipative if the resistance (measured at 23 °C and 50 % relative humidity) between the two opposite outer surfaces is below 1 GΩ.

NOTE Surface resistances measured according to ISO 284 and EN 14973 are at (23 ± 2) °C and (50 ± 5) % relative humidity and with an inner circular electrode of 25 mm in diameter, outer ring electrode with 125 mm inner and 150 mm outer diameter. Surface resistances measured with the electrode configuration described in 3.21 are exactly four times lower.

Table 5 shows a summary of all measures that are required for conveyor belts according to the classification of the hazardous area according to IEC 60079-10-1 and IEC 60079-10-2:

Table 5 – Requirements for conveyor belts

Belt Speed	**Zone 0**	**Zone 1**		**Zone 2**	**Zone 20**		**Zone 21**	**Zone 22**
		IIC	**IIA & IIB**		**MIE <10 mJ**	**MIE >10 mJ**		
≤0,5 m/s	Dissipative[a] belt and conductive pulleys, no belt connectors		Dissipative[a] belt and conductive pulleys, belt connectors permitted	No requirements beyond those outlined in 6.4.1 unless experience shows that incendive discharges occur frequently	Dissipative[a] belt and conductive pulleys, belt connectors permitted			No requirements beyond those outlined in 6.4.1 unless experience shows that incendive discharges occur frequently
0,5 – 5 m/s	Not permitted							
5 – 30 m/s			Dissipative[a] belt and conductive pulleys, no belt connectors		Not permitted	Dissipative[a] belt and conductive pulleys, no belt connectors		

[a] dissipative according to the definition of 6.4.2

NOTE No information is available for belt velocities >30 m/s.

For explosion Group I, the requirements of Zone 1 (IIA & IIB) apply. However, insulating coal dust conveyors transporting hardly ignitable conductive coal dust and similar conveyors may be used if a risk assessment provides a low risk of ignition.

Table 5 and the requirements in 6.4.2 do not apply to belts which dissipate charge by corona. Such belts have to be tested by experts e.g. by measuring their chargeability under worst case conditions.

A layer of wax or dirt on the belt could increase the chargeability of the belt and also its resistance and this could increase the charging hazard. Care should be taken to ensure that repairs do not increase the values given. It is essential that layers of insulating adhesives used to connect the belt do not interrupt the conductive path.

Light conveyor belts as described in ISO 21183-1 frequently have to comply with highly specialised customer's demands. For these cases, the specific standards ISO 21178, *Light conveyor belts – Determination of electrical resistances* and ISO 21179, *Light conveyor belts – Determination of the electrostatic field generated by a running light conveyor belt* exist and shall be used.

6.4.3 Transmission belts

Transmission belts are V-belts and flat belts which drive rotating parts or machines. 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. According to ISO 9563 and ISO 1813 a transmission belt material is deemed to be dissipative if:

$$R \times B / L \leq 600\ \text{k}\Omega$$

where L is the distance between two conductive electrodes (e.g. graphite, silver paint, metal electrode) on a transmission belt, B is the width of the flat belt or double the width of the side face of the V-belt, and R the measured resistance between the electrodes at (23 ± 2) °C, with no moisture condensation.

NOTE In older documents (e.g. CENELEC TR 50404), the acceptance criteria was $R \times B \leq 100\ \text{k}\Omega\ \text{m}$, 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. As the fulfilment of this R × B criterion depends on the distance between the two pulleys it is impossible to characterise a belt material as dissipative. For this reason ISO 9563 and ISO 1813 give a dissipative criteria which is independent from the length of the belt. If the distance between two pulleys exceeds 0,67 m the requirements of both ISO standards are automatically fulfilled by the R × B criterion in older documents stated above.

Table 6 shows a summary of all measures that are required according to the classification of the hazardous area according to IEC 60079-10-1 and IEC 60079-10-2:

Table 6 – Requirements for transmission belts

Belt Speed	**Zone 0**	**Zone 1**		**Zone 2**	**Zone 20**		**Zone 21**	**Zone 22**
		IIC	**IIA & IIB**		**MIE < 10 mJ**	**MIE > 10 mJ**		
≤ 0,5 m/s	Dissipative [a] belt and conductive pulleys, no belt connectors		Dissipative [a] belt and conductive pulleys, belt connectors permitted	Protective measures beyond those outlined in 6.4.1 not required unless experience shows that incendive discharges occur frequently	Dissipative [a] belt and conductive pulleys, belt connectors permitted			Protective measures beyond those outlined in 6.4.1 not required unless experience shows that incendive discharges occur frequently
0,5 – 5 m/s	Not permitted							
5 – 30 m/s			Dissipative [a] belt and conductive pulleys, no belt connectors		Not permitted	Dissipative [a] belt and conductive pulleys, no belt connectors		

[a] dissipative according to the definition in 6.4.3

NOTE No information is available for belt velocities >30 m/s.

For explosion Group I, the requirements of Zone 1 (IIA & IIB) apply.

Table 6 and the requirements in 6.4.3 do not apply to belts which dissipate charge by corona. Such belts have to be tested by experts e.g. by measuring their chargeability under worst case conditions.

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 1 GΩ (resistance measured at 23 °C and 50 % relative humidity).

A layer of wax or dirt on the belt could increase the chargeability of the belt and also its resistance and this could increase the charging hazard. Care should be taken to ensure that repairs do not increase the values given. It is essential that layers of insulating adhesives used to connect the belt do not interrupt the conductive path.

7 Static electricity in liquids

7.1 General considerations

7.1.1 Occurrence of flammable atmospheres

NOTE General information about the flammability and ignitability of gas and vapour atmospheres is given in Annex C.

Many operations with flammable liquids produce flammable atmospheres by evaporation of the liquid being handled. The flash point provides an approximate indication of the minimum liquid surface temperature required to produce a flammable atmosphere by this process. However, because of the uncertainties involved in flash point measurement, differences between flash point test conditions and those in a real industrial situation and the difficulty of establishing liquid surface (rather than bulk) temperature, it is prudent to assume that a flammable atmosphere could exist even when the liquid temperature is below the flash point by a certain safety margin. The margin depends on the level of uncertainty about temperature, liquid composition etc. For well-controlled conditions a margin of 5 °C for pure liquids and at least 11 °C for mixtures is typically needed.

Where tanks are exposed to direct sunlight and liquid temperatures are not monitored it should be assumed that a flammable atmosphere could be present when handling liquids with flash points up to 60 °C. In areas of high ambient temperature and strong sunlight, flammable atmospheres may occur even with liquids that have flash points above 60 °C.

When handling a liquid at a temperature that is well above its flash point, the saturated vapour may give an over-rich (i.e. non-flammable) atmosphere. However, the actual atmosphere above the liquid may not be saturated (e.g. because of ventilation) and so may be flammable. It is therefore necessary to assume that the atmosphere could be flammable unless it can be shown otherwise. Consequently, for low flash-point liquids, the presence of an over-rich atmosphere should not generally be relied upon as the only control measure.

In some circumstances, the flammable atmosphere is not due to the liquid being handled but due to residues of volatile liquid or vapour from earlier operations with the same equipment or from nearby operations. Residual vapours can occur during switch loading, in which a liquid having a high flash point (e.g. diesel) is loaded into a tank which previously contained a liquid with a low flash point (e.g. gasoline). A high proportion of road tanker fires has been associated with switch-loading.

7.1.2 Ignition sensitivity and limitations to the scope of advice

The sensitivity of a flammable atmosphere to electrostatic ignition depends on the concentration and minimum ignition energy (MIE – see C.6) of the flammable material. A helpful rule of thumb is that the most easily ignitable vapour concentration is approximately double the concentration at the lower flammable limit. Because of the concentration effect, a mixture made with a high MIE material at its most easily ignitable concentration may be more sensitive to ignition than a mixture made with a low MIE material at a vapour concentration that lies only just within the flammable range.

For equilibrium vapour/air mixtures created by flammable liquids, the most easily ignitable vapour concentration is typically achieved at temperatures of approximately 10 °C to 20 °C above the flashpoint. Flammable liquids of intermediate volatility tend to produce their most easily ignitable mixtures at common ambient temperatures: such liquids include toluene (flashpoint 6 °C), propyl acetate (flashpoint 10 °C) and acetonitrile (flashpoint 2 °C).

The general precautions given in this chapter are designed to prevent the ignition of materials with MIEs of 0,20 mJ or more when present at the most easily ignitable vapour concentration. They are thus applicable to the most easily ignitable mixtures in air of the vapours of common flammable liquids such as paraffinic and aromatic solvents, hydrocarbon fuels and many organic solvents (see list of MIE in Table C.2). At typical ambient temperatures, the safety margins are at a minimum when handling flammable liquids of intermediate volatility such as those listed above. In such operations, particular care should therefore be taken to ensure that all recommended precautions are diligently followed.

Although Explosion Groups are not assigned on the basis of MIE (see C.6), the precautions required in the presence of most Explosion Group IIA vapours are likely to be similar to those given here for MIEs of 0,20 mJ and above. Additional precautions are, however, likely to be required where the atmosphere above the liquid is more sensitive to ignition. This situation will arise, for example, with the most readily ignitable mixtures in air of volatile materials that have MIEs of less than 0,20 mJ (most Explosion Group IIB and IIC materials) or with oxygen-rich mixtures. Although general advice has not been developed for these more sensitive atmospheres, recommendations are given for a few specific activities. Where they are given, the additional precautions for the more sensitive materials are explicitly identified as such in the text.

7.1.3 Charging mechanisms

Liquids can become electrostatically charged when they move relative to contacting solids or if there are two or more immiscible liquid phases and there is movement. The 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 to A.1.7 (generation) and A.2.2 (accumulation).

7.1.4 Charge accumulation and conductivity classifications

The level of charge accumulation in a particular liquid, and therefore the electrostatic hazard that can be created, is strongly dependent upon its electrical conductivity and dielectric constant (relative permittivity), ε_r. To describe the possible hazards and associated means of prevention, the conductivities of liquids have been classified as follows:

high conductivity	$>$ 10 000 pS/m;
medium conductivity	between 25 × ε_r pS/m and 10 000 pS/m;
low conductivity	$<$ 25 × ε_r pS/m.

For liquids with a dielectric constant of around 2, (e.g. hydrocarbons), these classifications reduce to:

high conductivity	$>$ 10 000 pS/m;
medium conductivity	between 50 pS/m and 10 000 pS/m;
low conductivity	$<$ 50 pS/m.

For liquids with a dielectric constant that is substantially higher than 2 or for liquids whose dielectric constant is unknown, the border limit for low conductivity is usually set to 100 pS/m. The upper border limit of medium conductivity remains at 10 000 pS/m.

NOTE 100 pS/m is considered sufficient for unknown cases because few, if any, low conductivity liquids have a relative permittivity significantly higher than 4.

Hazardous levels of charge accumulation are most commonly associated with liquids of low conductivity. However, they can occur with medium or high conductivity liquids in processes that produce mists or sprays, when transporting medium conductivity liquids through insulating pipes or during two-phase mixing operations.

In general, polar solvents such as alcohols, ketones and water have a high conductivity, while saturated hydrocarbon liquids and purified aromatics have a low conductivity. The conductivities and relaxation times for a number of liquids are given in Table 7.

NOTE 1 A more complete list including a wider range of liquids and dielectric constant data is given in NFPA-77.

NOTE 2 Biofuels and hydrocarbon fuels blended with biocomponents can have a wide range of conductivity depending on their composition.

NOTE 3 Test methods for measuring the conductivity of a liquid are given in e.g. ASTM D4308-95, DIN 51412-1, DIN 51412-2 and ISO 6297.

Table 7 – Conductivities and relaxation times of some liquids

Liquid	Conductivity (pS/m)	Relaxation time (seconds)
Low conductivity		
highly purified paraffins	0,01	2 000
typical paraffins	0,1 to 10	2 to 200
purified aromatic compounds (toluene, xylene etc.)	0,1 to 10	2 to 200
typical aromatic compounds	5 to 50	0,4 to 4
gasoline	0,1 to 100	0,2 to 200
kerosene	0,1 – 50	0,4 to 200
gas oil	1 to 100	0,2 to 20
white oils	0,1 to 100	0,2 to 200
lubricating oils	0,01 to 100	0,02 to 2 000
ethers except glycols	0,1 to 100	0,2 to 200
proprietary aromatic solvent mixtures	1 to 1 000	0,02 to 20
natural gas condensate without corrosion inhibitor	10 to 100	0,2 to 2
Medium conductivity		
gasoline containing performance additives or 5 % ethanol	50 to 1 000	0,02 to 0,4
fuels and oils containing dissipative additives	50 to 1 000	0,02 to 0,4
heavy (black) fuel oils	50 to 10 000	2×10^{-4} to 0,4
esters	100 to 1 000 000	2×10^{-5} to 0,2
High conductivity	(μS/m)	
crude oil	≥ 0,001	≤ 0,02
gasoline containing 10 % ethanol or more	≥ 0,01	≤ 0,002
natural gas condensate with corrosion inhibitor	≥ 0,001	≤ 0,02
glycols and glycol ethers	1 to 100	2×10^{-7} to 2×10^{-5}
alcohols	1 to 100	2×10^{-7} to 2×10^{-5}
ketones	0,1 to 100	2×10^{-7} to 2×10^{-4}
pure water	5	10^{-6}
water (not distilled)	≥ 100	≤ 2×10^{-7}
NOTE Although ketones and esters usually have a high conductivity middle- and long-chained ketones and esters are often highly chargeable		

A liquid of high or medium conductivity should be considered as a conductive or dissipative item and needs to be earthed.

7.1.5 Incendive discharges produced during liquid handling operations

When a tank is being filled with a charged liquid of low conductivity, the charge that accumulates in the liquid inside the tank creates electrical fields and potentials both in the liquid and in the vapour space of the tank. With high liquid surface potentials, brush discharges can occur between the surface of the charged liquid and metallic parts of the tank structure. Studies indicate that aliphatic hydrocarbons such as propane can be ignited by brush discharges to a grounded electrode if the liquid surface potential exceeds 25 kV.

An ignition hazard can arise at much lower potentials (typically 5 kV to 10 kV) if isolated conductors such as floating metal cans or improperly bonded components are present in the tank, or if the container has an insulating lining, no contact point for earthing the liquid, and is splash filled with a liquid that is sufficiently conductive to produce sparks.

7.2 Summary of precautions against ignition hazards during liquid handling operations

7.2.1 Earthing and avoidance of isolated conductors

Isolated conductors such as metal tanks, tank structures or any other isolated metal objects either deliberately or accidentally associated with liquid handling can be raised to high potentials by charges on the liquid. This can lead to spark discharges. These are particularly hazardous because they can usually ignite flammable vapours at much lower potentials than brush discharges. Therefore, all conductive parts of a liquid handling system should be adequately connected to earth (see Clause 13). People handling flammable liquids should also be earthed (see 11.1).

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

7.2.2 Restricting charge generation

Charge generation can be restricted by controlling the relevant process parameters. Suitable control measures include:

1) tank filling operations:
    a) 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 7.3.2.2.3 and 7.3.2.3.2 to 7.3.2.3.5);
    b) provide sufficient residence time for charge relaxation downstream of pumps and filters (see 7.5 and A.2.2);
    c) avoid having a dispersed second immiscible phase in the liquid; this can be caused, for example, by stirring up the water present in the bottoms of oil tanks. Where the avoidance of a second dispersed phase is not possible restrict the velocity further (see 7.3.2.2.2 and 7.3.2.3.5.3);
    d) avoid splash filling by employing bottom entry or by using a fill pipe extending close to the bottom of the tank. If a short, top-entry fill-pipe must be used in the presence of a flammable atmosphere, reduce the flow velocity to 2 m/s and take the additional precautions in 7.3.2.3.2 (e.g. direct the liquid flow along the container wall). In the case of high conductivity liquids it is sufficient to provide a contact area to earth in the bottom of the container.
2) stirring or agitating operations (see 7.9):
    a) limit the power input to or tip speed of the stirrer (e.g. in BS 5958, a maximum power of 0,37 kW/m^3 was required for a suspension with a conductivity of 1 000 pS/m);
    b) avoid the presence of a second immiscible phase in the liquid;
    c) use a high conductivity continuous phase (conductivity exceeding 10 000 pS/m).
3) tank cleaning operations with liquid jets (see 7.10):
    a) limit the liquid pressure and throughput of the washing machines to the values recommended in 7.10;
    b) avoid the build-up of a second immiscible phase in the washing liquid, particularly if the washing liquid is recirculated;
    c) avoid unbroken jets that may form large isolated volumes of liquid (see 7.10).

7.2.3 Avoidance of a flammable atmosphere

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

a) avoid vapour spaces in the system;

b) inert the vapour space of the tank using inert gases such as nitrogen, carbon dioxide or purified flue gas (note the precautions given in 8.4);

c) avoid switch loading and common vapour collection systems that allow ignitable vapour-air mixtures to enter tanks not designed for this service;

d) after handling volatile liquids, clean and ventilate tanks to remove residual flammable liquids, gases and vapours;

e) ensure that sufficient fresh air is drawn continuously through the system. Regular gas tests and possible forced ventilation may be necessary;

f) purging a tank with air to avoid a flammable atmosphere should be done with caution in a tank that contains, or has previously contained, a flammable liquid with a low flash point due to the risk of residual liquid being present.

7.2.4 Promoting charge dissipation

In situations where it is not possible to avoid a flammable atmosphere, the risk of ignition can be controlled by limiting charge accumulation. For the components of the handling system, this involves bonding solid conductors and people to ground and, if necessary, replacing insulating system components with earthed dissipative or conductive components. For the liquids themselves, the most effective way of promoting dissipation is to increase the conductivity of the liquid by the use of commercially available static dissipative additives (SDA). When added to a liquid in very low concentrations of the order of parts per million, these additives can readily increase the conductivity to levels that prevent the hazardous build-up of charge (see 7.1.4).

NOTE 1 SDA are widely used in aviation fuels, and at the concentrations normally used the effects on both aircraft engine and filter/water separator performance are acceptable.

NOTE 2 Some SDA may lose efficiency in certain situations, e.g. at low temperatures, after contact with water, after clay filtration or due to interaction with other components.

Alternative methods of enhancing charge dissipation are to replace an insulating (low conductivity) solvent with a more conductive (medium or high conductivity) one or to add a miscible conductive solvent to an insulating one. The amount of conductive solvent needed will depend on the liquids involved and the conductivity level required.

7.3 Tanks and Containers

7.3.1 General

The possible hazards and the associated means of protection are divided according to whether the tanks, or their coatings and linings, are classified as conductive, dissipative or insulating (see 3.2, 3.7 and 3.15). Fully conductive tanks have a resistance to earth of 1 kΩ or less from everywhere on the shell; fully dissipative tanks have a resistance to earth of 1 MΩ or less from everywhere on the shell.

Following this classification, this section is divided into chapters as follows:

Conductive tanks and containers: 7.3.2

Tanks and containers made entirely of dissipative material: 7.3.3

Tanks and containers with insulating surfaces: 7.3.4

Use of liners in containers: 7.3.5

Operations that give rise to electrostatic hazards inside a tank include filling, transportation (of the tank and contents), emptying, gauging and sampling. If there could be a flammable atmosphere inside a tank when carrying out these operations, the precautions given below should be taken.

NOTE If there cannot be a flammable atmosphere (see 7.1.1), the precautions given in 7.3 are not necessary.

Other operations such as circulation of liquid, stirring, mixing, crystallisation and cleaning are dealt with in 7.9 and 7.10.

The standard restrictions on flow velocities given in 7.3.2 primarily apply to hydrocarbons. They may, however, be applied with caution to other solvents and fuels having kinematic viscosities less than about 6 mm^2/s at 20 °C but care may be needed with materials such as biofuel components (see C.8) or blends that are chemically different from hydrocarbons and for which there is limited experience of handling in high throughput systems. Further restrictions are known to be necessary for controlling charging in high viscosity liquids such as luboils (see 7.4).

7.3.2 Conductive tanks and containers

7.3.2.1 General

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

	Vertical axis cylindrical tanks and non-cylindrical tanks with square or nearly square cross-section (see NOTE 3)	Horizontal axis cylindrical tanks or non-cylindrical tanks with elongated cross section (see NOTE 3)
Large tanks (7.3.2.2)	diameter > 10 m	capacity > 500 m^3 (125 000 USG)
Medium tanks (7.3.2.3)	1,3 m < effective diameter ≤ 10 m	2 m^3 (500 USG) < capacity capacity ≤ 500 m^3 (125 000 USG)
Small tanks and containers (7.3.2.4)	effective diameter ≤ 1,3 m	capacity ≤ 2 m^3 (500 USG)

NOTE 1 In older documents, e.g. CENELEC TR 50404, the upper limit for medium tanks was 50 m^3 and the lower limit 1 m^3. Recent work (see A.2.2) has suggested that both the upper and lower boundary limits for medium tanks should be increased and that diameter limits are better than capacity limits for vertical axis tanks (voltages depend more strongly on diameter than capacity). The capacity limits given above for horizontal axis tanks correspond approximately to the diameter limits for vertical axis tanks combined with the lowest typical heights of these tanks.

NOTE 2 The capacity boundary limits are given in both m^3 and US gallons. They have been rounded to give convenient numbers in each set of units. As a consequence the boundary values are similar but do not exactly correspond. Either may be adopted at the users discretion.

NOTE 3 “Nearly-square” tanks have a length to width ratio not exceeding 1.5. “Elongated” tanks have a length to width ratio of more than 1.5. The rules given for square tanks are safe for elongated tanks of the same cross-sectional area but may be found to be conservative.

7.3.2.2 Large conductive tanks

7.3.2.2.1 General

Irrespective of the conductivity of the liquid or the tank structure, the following general precautions should be taken:

a) earth the tank and all associated structures such as pipes, pumps, filter housings, etc. (see Clause 13);

b) ensure that people entering or working near an opening of the tank are earthed (see Clause 11);

c) avoid splash filling by employing side-entry near the bottom, bottom-entry or by using a fill pipe reaching close to the bottom of the tank.

7.3.2.2.2 Fixed roof tanks

For medium or low conductivity liquids, inspect the tank regularly, especially after each opening of the manhole, for loose metal objects, e.g. cans, that could act as floating isolated conductors.

For low conductivity liquids the following additional precautions are necessary:

1) Pump and filter location. Locate pumps, filters and other strong charge generating elements at an adequate residence time upstream of the tank inlet to allow the extra charges to relax before the liquid enters the tank (see 7.5 and A.2.2).
2) Restrict the flow velocity. For an incoming flow of uncontaminated, single phase liquid, the flow velocity should be restricted to 1 m/s for an initial filling period that 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 Restriction a) is designed to prevent discharges to the fill pipe or the structure and 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 this initial filling period, the velocity for an uncontaminated, single-phase liquid 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.

   Because of the high charge generation that occurs in two phase flows (see A.1.4) the flow velocity for an incoming two phase or contaminated liquid (see 3.6) should be restricted to 1 m/s during the whole filling period.
3) Inlet design. Liquid should enter the tank horizontally to minimise both the possible disturbance to water bottoms or sediment and the jetting of highly charged incoming liquid to the surface. A good arrangement in this respect is to use a horizontal tee or cruciform end to direct the incoming liquid horizontally around the walls.
4) Control water bottoms. If there are water bottoms or sediment present in the tank, the level of the bottom layer should be carefully controlled by monitoring and draining to keep it at least two pipe diameters below the inlet. The inlet design requirements described in 3 should then ensure that the water bottom or sediment is not unduly disturbed by the incoming liquid during filling.
5) If a flammable atmosphere is present and it cannot be ensured that sediments or water bottoms will not be disturbed, then the velocity should be limited to 1 m/s when filling.

   NOTE It is not usually necessary to restrict flow speeds to 1 m/s throughout the fill just because a second phase is present in the form of water bottom or sediment in the tank. The risks associated with water bottoms can normally be dealt with by precautions 3 and 4.
6) If it can be avoided, liquid of low density should not be loaded into a tank containing a liquid of substantially higher density, because the resultant buoyancy effect would carry the incoming highly charged liquid to the liquid surface leading to a higher surface potential. For the same reason, loading warmer liquids into tanks partially filled with colder liquids, and entrainment of air or other gas into the incoming liquid should also be avoided where possible. If such operations cannot be avoided, the inlet flow speed should be reduced to 1 m/s to minimise charge generation.

7.3.2.2.3 Tanks with floating roofs or internal floating covers

In a tank with a floating roof or internal floating 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 flow velocity. However, the velocity should be restricted to 1 m/s until the roof is afloat. 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 13).

Sometimes floating spheres or balls are used in tanks to minimise evaporation. It is essential that they are made of dissipative or conductive material. These spheres should only be used on high conductivity liquids since, on a medium or low conductivity liquid, a ball or a group of balls could become isolated from earth thus leading to the possibility of sparks.

7.3.2.2.4 Summary of precautions for large conductive tanks

Table 8 summarises the precautions necessary for filling large conductive tanks with low conductivity liquids. If the electrical conductivity is raised above the low conductivity range, e.g. by using a static dissipative additive (SDA, see 7.1.4 and 7.2.4), these precautions are not necessary. However, in this case, it is essential to ensure reliable addition of the SDA because failure to incorporate the additive into the liquid could lead to a fire or explosion. The precautions for low conductivity liquids should be retained if there is any doubt about the reliability of the additive addition.

Table 8 – Precautions for filling large conductive 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 m/s	Essential until the roof or cover is afloat	Essential during the initial filling period, and when loading a contaminated or two phase liquid or a liquid with a substantially lower density than that already in the tank
Keep flow velocities below 7 m/s	Unnecessary when the roof or cover is afloat NOTE A flow rate limit will often be needed to avoid damaging the roof by too rapid movement.	Recommended in all cases in which the 1 m/s limit does not apply
Ensure an adequate residence time between strong charge generators (e.g. microfilters) and the tank	Essential until the roof or cover is afloat NOTE The residence time can be calculated using a velocity of 1 m/s 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 substantially higher density liquids (see 7.3.2.2.1)	Unnecessary	Recommended as far as practicable. If unavoidable keep the flow velocity below 1 m/s (see row 1 of this table)

7.3.2.3 Medium-sized conductive tanks

7.3.2.3.1 Scope

Medium sized conductive tanks (see 7.3.2.1 for size definitions) include both fixed storage tanks and mobile tanks such as road or rail tankers. Although aircraft fuel tanks generally fall within the medium size range, the loading of aircraft tanks is covered separately in 7.8.1.

7.3.2.3.2 Precautions for fixed tanks

7.3.2.3.2.1 Precautions for all types of liquid

a) Earthing: The earthing requirements given in 7.2.1 and item a) of 7.3.2.2 should be adopted.

b) Pipes and hoses: Pipes and hoses should comply with 7.7.2 and 7.7.3 respectively.

c) People: Hazards due to the charging of people should be avoided by compliance with the requirements in Clause 11.

d) Filling velocity: Flow velocities should be kept within the limits outlined in 7.3.2.3.5.2.

NOTE The flow limits vary with the tank design, pipe diameter and the nature of the liquid.

e) Air and gas: Do not clear lines with air or other gas unless it is certain that the operation will not overpressure the equipment. Nitrogen or nitrogen-air "mixed gas" should be considered for line clearing rather than compressed air. To avoid excessive flow velocities (relative to the limits given in 7.3.2.3.5.2), use the smallest source pressure that will successfully clear the line. Minimize the volume of entrained gas delivered sub-surface in the receiving tank.

f) Gauging and sampling: Gauging and sampling can introduce additional hazards. These should be dealt with as described in 7.6.

7.3.2.3.2.2 Additional precautions for low conductivity liquids

a) Filters and other high charging equipment: Fine filters, pumps and other high charging equipment installed in the pipeline upstream of a tank can generate high levels of charge. To deal with this, follow the advice given in 7.5.

b) Tank drainage: If the product is not fully miscible with water and it is possible that a water bottom may form (e.g. if the incoming product contains water or if there is dissolved water or contact with moist air and variable water solubility due to temperature cycling), the tank should be provided with a low level drain to enable the water bottom to be removed. The level of the water bottom should be monitored and controlled to keep it below the product inlet by at least two pipe diameters.

c) Tank inlet: The inlet should be located low in the tank but above the level to which a water bottom will be permitted to accumulate. This can be achieved either by top filling via a fill pipe reaching close to the bottom of the tank or by bottom filling (including side filling close to the bottom). The inlet should be designed to feed incoming liquid horizontally into the tank both to minimise the jetting of highly charge product to the surface and to minimise the disturbance of water bottoms or sediment. A tee-shaped inlet that directs the liquid parallel to the side walls is ideal in this respect.

NOTE For fixed tanks with side entry inlets, the use of a tee is more practical than the deflector plate because it keeps highly charged liquid near the tank base and minimises suspension of any water and sediment from the tank floor.

d) Splash Filling:

- For most applications, splash filling should be avoided by using a low level inlet with the incoming flow directed horizontally as described in the previous paragraph (see also 7.2.2).
- Splash top filling is sometimes essential for process reasons (e.g. to avoid interference with stirrers in chemical reaction vessels). In this case:
  i) The fill pipe should enter the vessel close to a side-wall and the incoming liquid should be directed downwards and slightly towards the wall (at an angle of 15° to 30° to the vertical).
  ii) The operation should be assessed in detail to determine an acceptable loading velocity. This should not exceed 50 % of the velocity derived from the normal velocity or vd limits (see 7.3.2.3.5) and should not be more than 2 m/s.
  iii) The distance from the end of the fill pipe (and other protrusions) to the maximum liquid level should be at least 200 mm so that discharges from the liquid surface are unlikely to occur.

Flammable liquids of low volatility (e.g. luboils) that are incapable of producing a flammable vapour atmosphere at the maximum handling temperature can be splash filled without the above additional loading restrictions (which are for cases where there could be a flammable atmosphere). However, with this approach it is essential to ensure that there are no other sources of flammable vapour and that the loading process does not produce enough mist or suspended droplets to render the atmosphere flammable.

7.3.2.3.3 Precautions for road tankers

The precautions for road tankers are the same as for fixed tanks (7.3.2.3.2) except for the use of different velocity limits as described in 7.3.2.3.5.4 and the following additional requirements:

1) Earthing and bonding
   a) The bonding resistance between the chassis, the tank and the associated pipes and fittings on the truck should be less than 1 MΩ. For wholly metallic systems, the resistance should be 10 Ω or less and if a higher value is found further investigations should be made to check for possible problems of e.g. corrosion or loose connection.
   b) An earthing cable should be connected to the truck before any operation (e.g. opening man lids, connecting pipes) is carried out. It should provide a resistance of less than 10 Ω between the truck and the gantry's designated earthing point and should not be removed until all operations have been completed.
   c) It is recommended that the earth cable required in b) be part of a static earth monitoring system that continuously monitors the resistance between the truck and a designated earthing point on the gantry and activates interlocks to prevent loading when this resistance exceeds 10 Ω. It is further recommended that the static earth monitoring system should be capable of differentiating between connection to the truck's tank (or earth connection point) and other metal objects. This type of system will prevent operators from connecting the earthing system to objects (e.g. the mud-guards) that may be electrically isolated from the truck's container.
2) Top loading
   a) The loading arm (or dip leg or drop pipe) should be inserted to the bottom of the tank before starting liquid flow.
   b) The drop pipe should:
      i) be positioned vertically,
      ii) reach the bottom of the compartment;
      iii) have a tee-piece or similar deflector on the bottom to deflect the flow along the base of the compartment.
3) Lightning

   When there is the possibility of lightning, road tankers should not be loaded in the open air with a liquid that can give rise to a flammable atmosphere outside the tank compartment. Loading may take place under canopies or where an adequate cone of lightning protection is provided.

7.3.2.3.4 Precautions for rail tankers

The precautions for rail tankers are the same as for fixed tanks (7.3.2.3.2) except for the use of different velocity limits (see 7.3.2.3.5.5) and the following additional requirements:

1) Bonding
   a) The rails of the track should be bonded to each other and to the gantry with a bonding resistance of less than 1 MΩ.
   b) The bonding resistance between the wheels, the tank and the rest of the car should be less than 1 MΩ. Independent bonding of the rail tank car is not needed as it is provided by the rails.
2) Circulating/stray currents
   a) An insulating 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.

b) The siding used for tank car filling should be isolated 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.

3) Top loading

The loading arm (drop pipe) should be inserted to the bottom of the tank before starting liquid flow. The drop pipe should:

a) be positioned vertically (automated top loading systems may insert the lance at a slight angle);

b) reach the bottom of the compartment;

c) have a tee-piece or similar deflector on the bottom to deflect the flow along the base of the compartment.

4) Lightning

When there is the possibility of lightning, rail tankers should not be loaded in the open air with a liquid that can give rise to a flammable atmosphere outside the tank compartment. Loading may take place under canopies or where an adequate cone of lightning protection is provided.

7.3.2.3.5 Flow velocity and *vd* limits

7.3.2.3.5.1 General explanatory notes

Flow limits are expressed either directly in terms of velocity or indirectly in terms of limits on the product of velocity and pipe diameter (*vd*). The key factors that influence these limits are:

a) The size and shape of the tank: The most critical size tends to lie in the range 3 to 10 m^3 and tall, narrow tanks give the highest voltages. Potentials are generally lower in larger or smaller tanks, in horizontally elongated tanks or in tanks for which the length and width (or diameter) are greater than the height.

NOTE Extremely narrow tanks would also give low voltages but the height to width ratios needed to realise this case fall outside the normal practical range.

b) The presence of a central conductor: In a near-cubic tank (i.e. all major dimensions of similar magnitude), the presence of a substantial conductor running vertically down the centre reduces the maximum potential by about a factor of two. Because of the reduced potential, a higher maximum fill velocity may be permitted. A central conductor is much less effective at reducing potentials in elongated horizontal tanks or tanks with a small height to width ratio. Examples of operations that can benefit from the presence of a central conductor are road tanker top-loading (the filling arm provides the conductor) and road tanker bottom-loading in compartments with dip tubes.

c) The nature of the liquid: The conductivity is important as is the presence or absence of multiple phases. In addition, the oil industry has found an increased risk of electrostatic ignition when loading vehicles with middle-distillate fuels that have low sulphur content (< 50 ppm).

NOTE The increased risk with low-sulphur diesel is thought to arise fundamentally from factors associated with diesel processing and there is, as yet, no evidence that other low sulphur liquids are similarly affected (e.g. gasolines, pure chemicals or solvents may be low in sulphur but there is no evidence that they have an increased risk of electrostatic ignition).

d) Whether the tank is fixed or mobile: Filling facilities for fixed tanks can be designed for a specific duty whereas facilities for mobile tanks have to deal with a range of tank sizes and shapes. For mobile tanks, the velocity or *vd* limit should be suitable for the worst case that could be encountered. Also mobile tanks tend to be elongated horizontally for stability in transit (e.g. rail tanker compartments) whereas fixed tanks are often tall and narrow (height/diameter > 1).

Because of these practical differences, there are separate velocity or *vd* limits for fixed tanks, road tankers and rail tankers. Also, for both road and rail tankers, there are separate limits for middle-distillate hydrocarbons and other liquids.

7.3.2.3.5.2 Region over which flow limits apply

Where velocity or *vd* limits are specified they should be met throughout a "relaxation region" upstream of the tank. The relaxation region consists of the pipework within a residence time of 30 seconds or 3 relaxation times upstream of the tank whichever is lower. Where the relaxation time is used to calculate the residence time it should be determined from the lowest possible conductivity that may be handled. If the lowest conductivity is not known, the 30 s criterion should be adopted.

To ensure that the *vd* or velocity limits are met throughout the relaxation region it is necessary only to ensure that they are met over the most critical section within the region.

For an un-branched system the critical section is the one with the smallest pipe diameter except that if the section with the smallest diameter is less than 5 m long and is only one nominal pipe size less than the section with the next smallest diameter, the latter may be taken as the critical one.

For a branched pipe system (e.g. a large feeder line splitting into smaller lines such that the upstream pipe segments feed several tanks whilst the downstream ones each feed just one tank), the critical section is the one with the highest value of F_s/d_s^m where F_s is the highest possible flow rate through the segment, d_s is the diameter of the pipe in the segment and $m=2$ for evaluating *vd* limits or $m=3$ for evaluating velocity limits (see A.1.4).

The maximum acceptable current in a critical segment filling multiple tanks simultaneously is N_s times that into each tank where:

$$N_s = F_s/F_T$$

F_s is the maximum possible flow rate through the segment and F_T is the volumetric flow rate into the tank. The increased current is acceptable in the segment because it is divided between the tanks. Because the streaming current varies as the square of the velocity, the permitted flow velocity or *vd* limit for the segment is correspondingly $N_s^{1/2}$ times higher than the limit for the tank (see A.1.4).

7.3.2.3.5.3 Limits for fixed tanks

Different limits apply, as follows, in an initial slow start period and in the main flow period:

Slow start: For medium and low conductivity liquids where there could be water bottoms or sediment present in the tank, the initial flow velocity should not exceed 1 m/s until the fill pipe outlet is submerged to two pipe diameters. This slow start is required to control the hazards associated with the disturbance of the sediment. Opinions differ as to whether a slow start is necessary where there is no possibility of water bottoms or sediment. Measurements have suggested that in this case slow starts do not significantly reduce the maximum voltage. Nevertheless, they may be advisable to avoid possible issues with displacement of water from the piping.

If a tank is filled in a series of separate stages, a slow start of 1 m/s is recommended for each individual stage.

Full flow: The flow velocity and *vd* limits for the full flow period depend, as follows, on the nature of the liquid and the tank:

1) All high conductivity liquids and single-phase medium conductivity liquids: There is no mandatory restriction on the flow velocity but a general precautionary limit of 7 m/s is recommended. If a high velocity is permitted only because the conductivity has been raised with a Static Dissipative Additive (SDA), it is essential to ensure reliable addition of the SDA because failure to incorporate enough additive into the liquid could then lead to a fire or explosion. If there is any doubt about the reliability of SDA addition, the velocity limits for low conductivity liquids should be used.

2) Contaminated or two-phase liquid of medium or low conductivity: When filling tanks with two-phase mixtures (e.g. contaminated liquids, liquids with suspended water or solids) for which the continuous phase has a medium or low conductivity there is a fixed velocity limit of 1 m/s. This limit should also be applied if water bottoms or sediment could be stirred up in a tank containing a medium or low conductivity liquid e.g. if water has accumulated until the product/water interface is close to (within one entry pipe diameter) or higher than the level of the inlet. Velocities should not be much below 1 m/s or water could accumulate at low points in the pipes.

3) Uncontaminated low conductivity liquids: For uncontaminated (clean), single-phase, low-conductivity liquids, the velocity restrictions are either given directly in terms of velocity or they are derived from vd limits where v is the average flow velocity in the pipe in metres/second and d the pipe diameter in metres. There are different limits, as follows, for vertical-axis and horizontal-axis tanks.

    a) Vertical-axis cylindrical tanks or vessels with vertical sides and square or near-square cross section:

NOTE Near-square tanks are those for which the ratio of length to width does not exceed 1,5.

When filling through an un-branched line, the filling velocity v in the critical section of the relaxation region (see 7.3.2.3.5.2) should be restricted to:

$v \leq K(D/d)^{1/2}$ m/s

subject to a maximum flow velocity of 7 m/s.

Here D is the tank diameter or, for near-square vessels of length, L, and width, W, an effective diameter determined from $D=2(LW/\pi)^{1/2}$ (for square-section vessels $L=W$), d is the pipe diameter (both D and d must be in the same units) and K is a constant that depends weakly on the dielectric constant of the liquid and has dimensions of velocity. It is shown in B.2.2, that K = 0,7 m/s for $\varepsilon = 2$ and that the maximum departure from this value is less than 6,3 % for the range of dielectric constants associated with low conductivity liquids (up to $\varepsilon \sim 5$). This small difference is within the uncertainties and safety margins of the analysis, so the value 0.7 m/s is adopted universally.

When filling multiple tanks through a branched line the critical section may occur at a location that feeds more than one tank. In this case, the maximum velocity in the critical section may be increased by a factor $N_s^{1/2}$ from the value given above, where N_s is the ratio of the maximum flow rate through the critical segment to the flow rate into the tank (see 7.3.2.3.5.2 and A.1.4).

Flow rates derived from the above expression for filling tanks through un-branched lines with schedule 40 wall thicknesses are given in Tables 9a (in m^3/min) and 9b (in USG/min).

NOTE In North America, pipes are defined by their NPS (Nominal Pipe Size, the outer diameter in inch) and a Schedule for their wall thickness. In Europe, pipes are defined by their DN (Diameter Nominal, the outer diameter in mm) and their IN (Inner diameter Nominal in mm).

Table 9 – Filling rate limits for filling medium-sized vertical-axis tanks through schedule 40 pipes

a) Flow rates in m^3/min

Pipe size			**Tank diameter,** m									
NPS	**DN**	**ID,** mm	**1**	**1,5**	**2**	**2,5**	**3**	**4**	**5**	**6**	**8**	**10**
1	**25**	**26,6**	0,14	0,18	0,20	0,23	0,23	0,23	0,23	0,23	0,23	0,23
1,5	**40**	**40,9**	0,27	0,33	0,39	0,43	0,47	0,55	0,55	0,55	0,55	0,55
2	**50**	**52,5**	0,40	0,49	0,56	0,63	0,69	0,79	0,89	0,91	0,91	0,91
2,5	**65**	**62,7**	0,52	0,63	0,73	0,82	0,90	1,04	1,16	1,27	1,30	1,30
3	**80**	**77,9**	0,72	0,88	1,01	1,13	1,24	1,44	1,60	1,76	2,00	2,00
4	**100**	**102**	1,08	1,32	1,53	1,71	1,87	2,16	2,41	2,64	3,05	3,41
5	**125**	**128**	1.51	1.85	2.14	2.39	2.62	3.03	3.39	3.71	4.28	4.79
6	**150**	**154**	1,99	2,44	2,82	3,15	3,45	3,99	4,46	4,89	5,64	6,31
8	**200**	**203**	3,01	3,69	4,26	4,76	5,21	6,02	6,73	7,38	8,52	9,52
10	**250**	**254**	4.24	5.19	5.99	6.70	7.34	8.47	9.47	10.4	12.0	13.4
12	**300**	**305**	5,51	6,75	7,79	8,71	9,54	11,0	12,3	13,5	15,6	17,4

b) Flow rates in USG/min

Pipe size			**Tank diameter, ft**									
NPS	**DN**	**ID, mm**	**4**	**5**	**6**	**8**	**10**	**12**	**16**	**20**	**26**	**33**
1	**25**	**26,6**	42	47	51	59	62	62	62	62	62	62
1,5	**40**	**40,9**	80	89	97	113	126	138	146	146	146	146
2	**50**	**52,5**	116	129	142	164	183	201	232	240	240	240
2,5	**65**	**62,7**	151	169	185	214	239	262	302	338	343	343
3	**80**	**77,9**	209	234	256	296	331	363	419	468	529	529
4	**100**	**102**	315	352	385	445	497	545	629	704	802	904
5	**125**	**128**	442	494	541	625	698	765	883	988	1130	1270
6	**150**	**154**	582	650	713	823	920	1010	1160	1300	1480	1670
8	**200**	**203**	878	982	1080	1240	1390	1520	1760	1960	2240	2520
10	**250**	**255**	1240	1380	1510	1750	1950	2140	2470	2760	3150	3550
12	**300**	**305**	1610	1800	1970	2270	2540	2780	3210	3590	4100	4620

b) *vd* limits for other medium sized tanks (e.g. horizontal-axis tanks or vertical-sided vessels with elongated non-square cross sections):

$vd \leq N \times 0{,}50$ m^2/s for top loading or bottom loading with a central conductor

$vd \leq N \times 0{,}38$ m^2/s for bottom loading without a central conductor

subject to a maximum flow velocity of 7 m/s.

In these limit expressions *N* is a factor that describes the influence of the tank length, *L*, which is the largest horizontal dimension. With *L* expressed in metres: $N = 1$ for $L < 2$, $N = \sqrt{L/2}$ for $2 \leq L \leq 4{,}6$ and, $N = 1{,}5$ for $L > 4{,}6$. Internal structures such as baffles need not to be taken into account when determining the tank length, but if the tank is subdivided into completely separate compartments, each compartment should be treated as a separate tank.

These limits apply to the critical section of the piping in the relaxation region upstream of the tank (see 7.3.2.3.5.2). When filling multiple tanks through a branched line the critical section may occur at a location that feeds more than one tank. In this case, the maximum velocity in the critical section may be increased by a factor $N_s^{1/2}$ from the value given above, where N_s is the ratio of the maximum flow rate through the critical segment to the flow rate into the tank (see 7.3.2.3.5.2 and A.1.4).

Flow velocity and volume flow rate limits for filling horizontal axis tanks through un-branched lines via a range of pipe sizes can be obtained by combining the *vd* and velocity limits and are given in Table 10.

Table 10 – Velocity and filling rate limits for loading low conductivity liquids into short (N=1), fixed horizontal axis tanks via schedule 40 pipes

Pipe size[a]			**Bottom loading or loading without a central conductor**		**Top loading or loading with a central conductor**	
			vd = 0,38 m^2/s		**vd = 0,50 m^2/s**	
NPS	**DN**	**ID,** mm	**Flow velocity,** m/s	**Filling rate,** m^3/min	**Flow velocity,** m/s	**Filling rate,** m^3/min
1	25	26,6	7,0	0,23	7,0	0,23
1,5	40	40,9	7,0	0,55	7,0	0,55
2	50	52,5	7,0	0,91	7,0	0,91
2,5	65	62,7	6,1	1,12	7,0	1,30
3	80	77,9	4,9	1,40	6,4	1,84
4	100	102	3,7	1,83	4,9	2,41
6	150	154	2,5	2,76	3,2	3,63
8	200	203	1,9	3,63	2,5	4,78
12	300	305	1,2	5,46	1,6	7,18

[a] *based on diameter of critical pipe section (see 7.3.2.3.5.2).*

The velocity, *vd*, and flow rate limits given in this section are derived on the assumption that all the requirements outlined in 7.3.2.3.2 are fulfilled. Sometimes this is difficult to ensure (e.g. it is not always certain that splash loading can be prevented). Where there is any doubt, a risk assessment should be carried out and additional control measures put in place if appropriate. Additional measures may include:

a) reducing the flow velocity below the level required by the limits in Table 10;

b) raising the conductivity using SDA (see 7.2.4).

7.3.2.3.5.4 Limits for road tankers

This subclause describes how the velocity or *vd* limits for loading uncontaminated, single-phase, low-conductivity liquids into road tankers differ from the limits for fixed tanks (7.3.2.3.5.3). Any velocity or *vd* limit that is not explicitly mentioned in this section (e.g. limits for slow starts and contaminated liquids) remains as given in 7.3.2.3.5.3 for fixed tanks:

Liquids other than petroleum fuels: Use the fixed-tank velocity limits in 7.3.2.3.5.3 except that if compartments of different length are to be filled at the same loading point, as will usually be the case, the *vd* limit and flow velocity should be calculated using the *N* value for the shortest compartment that will be filled. If the length of the shortest compartment is not known, $N = 1$ should be used. This will ensure that the maximum flow velocity is acceptable for the worst-case compartment lengths ($L \leq 2$ m). The flow velocities and flow rates for this case are given in Table 10.

Petroleum middle distillate fuels: To deal with differences in vehicle design, the oil industry has started to classify those road tankers for which a higher flow velocity can be tolerated in all compartments as “vehicles suitable for high-speed loading”. These vehicles have the features identified in Table 11 as promoting reduced potentials and may be loaded up to 33 % faster than standard vehicles if local regulations permit. A terminal that is set to load at the higher velocity limit should specify that only vehicles suitable for high speed loading be filled.

Table 11 gives a definition of the vehicles that may be considered suitable for high speed loading. Using this definition to classify vehicles, flow velocities should be set so that vd does not exceed the appropriate limit taken from Table 12. The vd limits in Table 12 depend on the type of product (low sulphur (< 50 ppm) or other middle-distillate product), the nature of the compartment (suitable for high speed loading or not) and the product conductivity.

Gasolines: Finished gasolines may be loaded at rates determined from a universal limit of $vd \leq 0{,}5\ \mathrm{m^2/s}$ (subject to $v \leq 7$ m/s) irrespective of vehicle type, gasoline conductivity or sulphur content. This rate is based on the degree of protection conferred by high volatility coupled with limited scope for air ingress in bottom loaded vehicles and its use is supported by operational experience. It should not be applied to the loading of individual gasoline components such as naphthas, which may have significantly lower volatility than finished gasolines. Such components should be loaded using the filling rules for middle distillates.

Flow velocities and volume flow rates derived from the vd limits in Table 12 and subject to the maximum flow velocity of 7 m/s are given in Table 13 for a range of pipe sizes.

Table 11 – Vehicles and compartments suitable for high-speed loading for ADR compliant vehicles

Vehicle	If a vehicle/tanker is to be classed as suitable for High Speed Loading, then all compartments on that vehicle must be High Speed Loading Compartments.
Compartment	A High Speed Loading Compartment is any compartment or chamber with a capacity of 2 000 l to 15 000 l equipped with a conductor which is either a) a full height baffle or surge plate, or b) an Internal Tube, or c) a Central Conductor Wire, so that no part of the liquid, in plan view, has a distance exceeding 0,8 m from any conducting surface. Larger compartment sizes do not require such a conductor to be classed as High Speed Loading Compartments. Where a compartment is fitted with an overfill, or other, probe which is at least 0,5 m from a "conductor", as defined above, the probe should be fitted with a "probe extender" to be fixed to the probe and located at the floor of the compartment.
Central Conductor	An electrically continuous cable/wire/tube with a diameter of at least 2 mm, fixed to the roof of the compartment or chamber and located at the floor. The cable/wire/tube should be of corrosion-resistant metal and have sufficient mechanical integrity to resist normal wear and tear.
Internal Tube	Any tube for dipping, service or vapour recovery that is electrically continuous with the shell of a compartment or chamber.
Chamber	A chamber is the space created in a compartment larger than 7 500 l when that compartment is subdivided by baffles or surge plates, in accordance with the ADR, into spaces of smaller capacity.
NOTE ADR is the European Agreement Concerning the International Carriage of Dangerous Goods by Roads.	

Table 12 – Influence of the sulphur content on middle distillate vd limits for road tankers

Product class	Conductivity, pS/m		
	> 50	> 10	< 10 or unknown
Diesel or gas oil with > 50 ppm sulphur and all other middle distillate fuels	$vd \leq 0,5$ m^2/s	$vd \leq 0,5$ m^2/s	$vd \leq 0,38$ m^2/s ($vd \leq 0,5$ m^2/s)
Diesel or gasoil with ≤ 50 ppm sulphur	$vd \leq 0,5$ m^2/s	$vd \leq 0,38$ m^2/s ($vd \leq 0,5$ m^2/s)	$vd \leq 0,25$ m^2/s ($vd \leq 0,35$ m^2/s)
NOTE Values in brackets apply to vehicles suitable for high speed loading (see Table 10).			

Table 13 – Velocity and filling rate limits for road tankers based on schedule 40 pipes; rates for hoses will be similar

Pipe size[a]			vd = 0,25 m^2/s		vd = 0,35 m^2/s		vd = 0,38 m^2/s		vd = 0,50 m^2/s	
NPS	**DN**	**ID, mm**	Flow velocity, m/s	Filling rate, m^3/min	Flow velocity, m/s	Filling rate, m^3/min	Flow velocity, m/s	Filling rate, m^3/min	Flow velocity, m/s	Filling rate, m^3/min
2,5	**65**	**62,7**	4,0	0,74	5,6	1,03	6,1	1,1	7,0	1,3
3	**80**	**77,9**	3,2	0,92	4,5	1,3	4,9	1,4	6,4	1,8
4	**100**	**102**	2,4	1,20	3,4	1,7	3,7	1,8	4,9	2,4
6	**150**	**154**	1,6	1,81	2,3	2,5	2,5	2,7	3,2	3,6

[a] *based on diameter of critical pipe section (see 7.3.2.3.5.2).*

If a vehicle is not ADR compliant, a detailed assessment should be carried out before it can be classified as suitable for High Speed Loading.

The *vd* limits in Table 12 and the velocities and filling rates in Table 13 are derived on the assumption that the requirements in 7.3.2.3.3 are fulfilled. Sometimes this is difficult to ensure (e.g. it is not always certain that splash loading can be prevented). Where there is any doubt, a risk assessment should be carried out and additional control measures put in place if appropriate. Additional measures may include:

a) reducing the flow velocity below the values required by the *vd* values in Table 12;

b) using SDA (see 7.2.4) in products that have low conductivity.

7.3.2.3.5.5 Limits for rail tankers

This subclause describes how the velocity or *vd* limits for loading uncontaminated, single-phase, low-conductivity liquids into rail tankers differ from the limits for fixed tanks (7.3.2.3.5.3). Any velocity or *vd* limit that is not explicitly mentioned in this chapter (e.g. limits for slow starts and contaminated liquids) remains as given in 7.3.2.3.5.3 for fixed tanks:

The given limits assume the use of standard rail tank compartments that are significantly larger than road tank compartments. If this is not the case, a risk analysis should be done to consider whether the (lower) road tanker *vd* limits ought to be adopted.

NOTE There is no top-loading/bottom-loading/central conductor distinction for standard rail tank car compartments as they are usually long and a central conductor is therefore not effective in reducing the maximum surface voltage.

a) *vd* limit for low-sulphur (< 50 ppm) petroleum middle-distillate fuels (diesel etc):

   $vd \leq 0,53$ m^2/s

b) *vd* limit for all other liquids:
   $vd \leq 0{,}75$ m^2/s

In case of doubt about product classification, a *vd* limit of 0,53 m^2/s should be used.

Flow velocities and volume flow rates corresponding to these *vd* limits and subject to the maximum flow velocity of 7 m/s are given in Table 14 for a range of pipe sizes.

Table 14 – Velocity and filling rate limits for loading rail tankers

Pipe size[a]			Low sulphur diesel		Standard products	
			vd = 0,53 m^2/s		vd = 0,75 m^2/s	
NPS	**DN**	**ID**	Flow velocity, m/s	Filling rate, m^3/min	Flow velocity, m/s	Filling rate, m^3/min
2	**50**	**52,5**	7,0	0,91	7,0	0,91
2,5	**65**	**62,7**	7,0	1,30	7,0	1,30
3	**80**	**77,9**	6,8	1,95	7,0	2,00
4	**100**	**102**	5,2	2,55	7,0	3,45
6	**150**	**154**	3,4	3,85	4,9	5,44
8	**200**	**203**	2,6	5,06	3,7	7,16
12	**300**	**305**	1,7	7,61	2,5	10,77

[a] *based on diameter of critical pipe section (see 7.3.2.3.5.2).*

The *vd* limits and flow limits in Table 14 are sufficient only if all the conditions set out in 7.3.2.3.4 are fulfilled. Sometimes this is difficult to ensure (e.g. it is not always certain that splash loading can be prevented). Where there is any doubt, a risk assessment should be carried out and additional control measures put in place if appropriate. Additional measures may include:

a) reducing the loading velocity below the values required by Table 14;
b) using SDA (see 7.2.4) in products that have low conductivity.

7.3.2.4 Small conductive tanks and containers

Examples of small conductive containers (see definitions in 7.3.2) are buckets, drums, petrol containers and Intermediate Bulk Containers (IBC) made of metal. Care should be taken to ensure that the metal containers and drums are not coated with an insulating coating, otherwise these containers have to be used according to 7.3.4.

NOTE Some forms of coating might be transparent and, consequently, hard to identify visually.

Hazards arise because the charges generated by liquid flow can lead to brush discharges from the surface of low conductivity liquids or to sparks from isolated metal containers or components such as drum pumps. People in the vicinity should be earthed to avoid becoming hazardously charged (see Clause 11).

The following precautions should be taken whenever a flammable atmosphere could be present inside or outside the container (e.g. when they are filled with flammable liquids, are filled in hazardous areas or are filled in the presence of flammable vapours remaining from previous loads).

a) During both filling and emptying the container, all conductive and dissipative parts of the system such as funnels and nozzles should be bonded together and earthed.
b) A metal funnel should be reliably earthed and should not, for example, be accidentally isolated from the container by an insulating bushing.

c) Plastic funnels should not be used unless the material is dissipative and earthed.

NOTE The use of plastic filler necks in cars is, at present, considered to be safe due to over-rich gasoline and too lean diesel fuel vapours. This statement may be not true for some biofuels.

d) For single-phase liquids, the *vd* and velocity limits set for medium-sized tanks should not, in principle, be exceeded. In practice these limits usually permit flow rates well above limitations of the filling equipment for small tanks. Therefore, there is usually no restriction on the filling rate. If an explicit flow limit is desired, it is suggested that the filling velocity should not exceed 2 m/s.

e) When filling a container with a two-phase or contaminated liquid, the flow velocity should not exceed 1 m/s when the continuous phase is of medium or low conductivity.

f) For ignition-sensitive liquids with MIE less than 0,20 mJ (see C.6 for a list of MIE) the flow velocity should not exceed 1 m/s.

g) If fine filters (e.g. microfilters) are used in the filling system upstream of the container, the precautions in 7.5 should be taken.

The only type of IBC that is acceptable for use with liquids of explosion group IIC (see also 7.3.4.5) is that made of conductive or dissipative material. Limited amounts of insulating material may be permissible (e.g. filler cap or areas around the filler cap) but chargeable areas should not exceed the limiting values given in 6.3.2.

7.3.3 Tanks and containers made entirely of dissipative material

These tanks may be treated exactly as the equivalent conductive tanks since they cause no additional hazards. They should be clearly marked "electrostatic dissipative" and provided with means for earthing.

Tanks made partly of dissipative and partly of insulating material may be treated as fully dissipative if the area of each piece of insulating material is less than the relevant maximum allowable area from Table 3. Otherwise, they should be treated like tanks with insulating surfaces.

7.3.4 Tanks and containers with insulating surfaces

7.3.4.1 General

For tanks with insulating surfaces (including metal tanks with insulating coatings), the precautions given in 7.3.4.2 to 7.3.4.6 apply in addition to the requirements already given for the equivalent metal tanks.

7.3.4.2 Tanks and containers made of conductive or dissipative material with insulating inner coatings

Additional hazards arise due to the possibility of charging of the inner coating by rubbing (e.g. cleaning) or by contact with the charged liquid.

When the coating thickness is less than 50 μm (e.g. paint, phenolic or epoxy coatings) there is no additional hazard (see 6.3.4.2) unless there are rapid repeat fills. The coating thickness may be increased to less than 2 mm if there is a contact point to earth for the liquid at the bottom of the container.

In all other cases the following additional precautions should be taken:

a) the coating should be in good contact with the wall (i.e. no separation or delamination);

b) irrespective of whether the tank or container is filled with a high, medium or low conductivity liquid, there should be a conductive path between the liquid and earth. This may be an earthed conductive dip tube projecting to the lowest point of the tank, a foot valve or a conductive 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 persons and hand tools from 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 people may walk), or by other means;

d) rapid repeated fillings should be avoided, because they can cause incendive propagating brush discharges. These can be avoided either if the breakdown strength of the coating is less than 4 kV (see A.3.5) or if the thickness of the coating exceeds 10 mm.

Insulating tanks buried underground are usually medium in size and are electrically similar to those covered in this clause. However, they are dealt with in 7.3.4.6.

7.3.4.3 Tanks and containers made of conductive or dissipative materials with insulating 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 are unlikely to occur. Propagating brush discharges are also unlikely, providing there are no strong external sources of charging (e.g. electrostatic spraying). All metal or dissipative objects, however, which could become isolated by the coating should be earthed. In particular the tank or container itself should be reliably earthed. Earthed conductive or dissipative walkways should be provided to prevent people becoming charged.

7.3.4.4 Tanks and containers with conductive layers embedded in the walls

These tanks are effectively conductive tanks with both inner and outer insulating coatings. Therefore the precautions given in both 7.3.4.2 and 7.3.4.3 should be taken together with the following:

a) the conductive layer should be robust and reliably earthed;

b) if 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 close 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 6.3.3 for Zone 0.

Where rapid repeated fills take place there is a possibility that the inner coating could become highly charged enabling propagating brush discharges to occur. These can be avoided if the breakdown strength of the coating is less than 4 kV (see A.3.5).

7.3.4.5 Containers and IBCs made of an insulating material surrounded by a conductive enclosure or coating

This form of construction is generally used for small tanks or containers with a capacity of around 1 m^3. Electrostatically, it is similar to that covered in 7.3.4.2. but the coverage provided by the conductive enclosure may be incomplete and there may be gaps between the enclosure and the container wall Examples are plastic containers, such as IBCs, surrounded by a conductive shield, grid, mesh or coating. The advice in this clause focuses on the application to IBCs and applies principally to containers of around 1 m^3 in capacity. Conductive enclosures are not normally provided for plastic containers much smaller than this. Although specific advice has not been developed for smaller vessels, the advice in this clause would provide for safe operation. Alternatively, the provisions of 7.3.4.6 may be used for vessels of this type with max. 5 l capacity.

Expert advice is recommended if the use of medium or large sized tanks with conductive enclosures is being considered in other contexts.

NOTE 1 Insulating tanks buried underground can be medium or large in size and are electrically similar to those covered in this clause. However, they are dealt with in 7.3.4.6.

The use of IBCs is one activity for which specific requirements for more ignition-sensitive materials are given. For IBCs and similar tanks, a full conductive enclosure, coating or an open mesh screen with open areas not exceeding 10 000 mm² prevents the outer surface of the plastic charging to a hazardous level (subject to the provisions given below about contact between enclosure and plastic) and helps to bind any charges present on the inner surface to reduce the risk of incendive brush discharges inside the container. Strict care should be taken to avoid conductive islands caused by inhomogeneous conductive coatings on insulating receptacles.

NOTE 2 The outer coating may be a non-chargeable layer co-extruded with the inner receptacle of the IBC. The receptacle may consist of several other layers.

To ensure that neither the inner and outer walls of the container nor the liquid inside can be charged to a hazardous level, all of the following precautions should be taken:

1) Requirements for containers that will only be used for liquids of explosion group IIA and ethanol, propanol, butanol, hexanol, heptanol, 1,2-ethanediol, ethylbenzene and 3-oxobutanoic acid ethyl ester.

   NOTE Only a few groups of liquids are not classed in explosion group IIA. See IEC 60079-20-1 for more details. A summary is given in Annex C.6.

   a) The container should be completely surrounded by a conductive shield, grid, mesh or coating except for limited design related areas (i.e. areas for which the consequences of incomplete coverage have been considered in the design process and shown to be non-hazardous). If the enclosure is a grid the open mesh area of each open mesh unit should be not more than 10 000 mm^2.
   b) Any limited areas not enclosed by the conductive shield, grid, mesh or coating (e.g. the filler cap or areas around the filler cap) should be either dissipative and earthed or protected by other measures so that ignition hazards for explosion group IIA in Zone 1 outside and Zone 0 inside of the container do not occur (e.g. limiting the chargeable area to the values of 6.3.2 or surface treatment). The effectiveness and durability of the surface treatment (e.g. profiling, homogenous coating with dissipative layers etc.) has to be demonstrated experimentally under the worst case conditions of charging, humidity and contamination (see 6.3.9).
   c) The shield, grid, mesh or coating should have good and close contact to the inner receptacle on all faces of the container except for limited design related areas. For a grid, with open mesh areas exceeding 3 000 mm^2 a local maximum distance of 20 mm between grid and inner receptacle should not be exceeded on the design related areas, e.g. the outlet valve area. Only in edges and corners of the containers a local maximum distance of up to 40 mm can be tolerated. For a solid shield, grid, mesh or coating or a grid with mesh sizes lower than 3 000 mm^2 a local maximum distance of 40 mm is allowed in design related areas, and edges and corners.

      NOTE It is generally impractical to achieve smaller distances. The resulting charged areas are small and generally present an acceptably low risk.
   d) All conductive and dissipative items should be bonded together and earthed.
   e) A conductive path with a maximum resistance of 1 MΩ should be provided between the liquid and earth, e.g. by using an earthed conductive fill pipe extended close to the bottom of the container or an earthed conductive foot valve or a sufficient large conductive plate at the base of the tank. Even small amounts of remaining liquid, e.g. 1 l, should be permanently in contact with the bottom earth point to prevent the liquid from becoming a charged isolated conductor.
   f) The container should be equipped with a yellow warning label concerning its safe use (see h) to m)).
   g) Before refilling, the container should be checked whether it still fulfils the requirements of a) to f).
   h) The container should not be filled with any other liquids.

   i) The container should not be used where a Zone 0 is present outside the container.
   j) Insulating liquids (e.g. toluene) should be added via an earthed conductive dip pipe. This dip pipe should go to within a few cm of the floor to avoid brush discharges from insulating liquids.
   k) The filling velocity should be restricted to 400 l/min and the flow velocity should not exceed 2 m/s.

      NOTE Both values are usually fulfilled when filling by gravity.

   l) Rapid repeated fillings or other high charging processes should be avoided. Such other high charging processes are dealt with in 7.5, 7.9 and 7.10.
   m) The container should not be filled immediately after cleaning, manufacturing etc. when it may be hazardously charged.

2) Requirements for containers which may be used for all liquids producing vapours of explosion groups IIB:
   a) The container should be surrounded by a continuous earthed dissipative or conductive outer wall surface, obtained e.g. by coating or co-extrusion.
   b) Grids or separate metal shields that are not physically bonded to the wall throughout should be earthed.
   c) Any limited areas not enclosed by the conductive outer wall surface (e.g. the filler cap or areas around the filler cap) should be either dissipative and earthed or protected by limiting the chargeable area to the values in 6.3.2.
   d) A conductive path with a maximum resistance of 1 MΩ should be provided between the liquid and earth.
   e) The container should be equipped with a green warning label concerning its safe use (see f)).
   f) Follow precautions h) to m) in section 1.
3) Liquids producing vapours of explosion group IIC may only be used with dissipative or conductive containers (see 7.3.3).
4) Although IBC are not constructed to be used as mixing vessels or reaction containers it may be necessary to homogenize the contents by stirring before filling or emptying the IBC. As these processes are likely to cause powerful charging the following precautions should be taken:
   a) Use only explosion-proof stirring devices.
   b) Use stirring devices with a large metal surface immersed in the liquid.
   c) Earth both the IBC and the stirring device including the metal stirrer immersed in the liquid.
   d) Do not activate the stirring device until fully immersed.
   e) The conductivity of the continuous liquid phase should exceed 1 000 pS/m.

      NOTE Water soluble liquid phases usually fulfil this requirement.

   f) Reduce the circumferential tip speed of the stirrer to 7 m/s for single phase liquids and 1 m/s for multi-phase liquids.
   g) If high charging liquids (see A.1.3) are used, strong charge generation is expected so that further measures, e.g. inerting, are necessary.
   h) Further measures are also necessary in the case of high speed mixing, e.g. use of surfactants.

7.3.4.6 Tanks and containers made entirely of insulating material

If the tank is buried underground it is electrically similar to a conductive tank with an insulating inner coating (see 7.3.4.2) or a tank surrounded by a conductive enclosure (see 7.3.4.5). In these circumstances, 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 7.10 should be taken to avoid this hazard.

In all other circumstances, tanks and containers without any conductive or dissipative layer present a higher risk than those described in 7.3.4.2 to 7.3.4.5 because of the following:

a) They can insulate conductive and dissipative objects, e.g. metal funnels, tools, lids, even pools of liquid, from earth;
b) Potentials are higher than with equivalent metal containers;
c) The insulating wall could be charged either by rubbing or by contact with the charged liquid;
d) The relaxation of charge from the liquid will usually be impeded by the insulating 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 sparks from external conductors charged by induction;
f) In the case of rapid repeat fills, strong brush discharges could occur.

For these reasons, insulating tanks should not normally be used above ground if a flammable atmosphere could be present inside or outside the tank. Where product purity requirements or other processing issues dictate the use of an insulating tank or container either the following precautions should be applied or an expert review of the hazards should be undertaken:

In external Zone 2, insulating containers with a nominal capacity exceeding 5 l should not be used for flammable liquids and should only be used for non-flammable liquids under the following conditions:

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;
d) Do not carry out operations such as fast mixing, stirring or wiping of the surface that may generate hazardous electrostatic charges.

In Zone 1 containers of insulating material with a capacity exceeding 5 l should not be used. Containers with a nominal capacity up to 5 l may be used with flammable and non-flammable liquids provided the flow velocity is limited to 1 m/s and the precautions for Zone 2 are met.

In Zone 0, insulating containers are strictly forbidden except small ones (≤ 1 l) for sampling inside tanks (see 7.6).

NOTE Small coextruded containers > 5 l with a dissipative outer and an insulating inner layer are available on the market which are preferable.

7.3.5 Use of liners in containers

The following assessments are based on the assumption that the handling of liners and containers occurs in a hazardous area (typically Zone 0, 1 or 2 with substances of explosion groups IIA and IIB).

Conductive or dissipative liners may be used in any container if they are earthed reliably and permanently. Removal of conductive or dissipative liners from any container is only permissible if the liner stays reliably earthed.

Where unearthed conductive or static dissipative removable liners are used in metal containers having painted coatings, the coating should have a maximum surface resistance of

1 GΩ and precautions should be taken to limit the charging current to no more than 1 microampere, such as by placing filters a safe distance upstream (see 7.5 and A.2.2). Alternatively measures should be taken to ensure a safe earth connection for the liner, such as by securely attaching a portion of it to an uncoated section of the drum.

Insulating liners should only be used in conductive containers or in conductive containers with insulating coatings, if they always remain in tight contact with the wall of the container and, in the case of a conductive liquid, if the liquid is properly earthed (e.g. by earthed dip pipe, earthing rod, etc.). In addition the thickness of the coating and liner in total should not exceed 2 mm. The removal of insulating liners in explosive atmosphere (e.g. the removal of solvent wet liners) should be avoided.

Solvent-wet conductive or dissipative liners should be handled by a properly earthed person wearing static dissipative gloves (see 11.6) and stored in a well-ventilated area outside the operating area. The liners should be stacked on an earthed conductive or dissipative surface such as concrete and placed in static dissipative bags pending disposal.

Users of conductive or dissipative container liners should adopt a simple performance test to check for batch defects. Such a procedure might involve resistance testing using a series of tera ohmmeter measurements between the top and bottom of the liner or similar testing. The specific performance standard should be provided by the supplier of the liner.

7.4 High viscosity liquids

High viscosity liquids (kinematic viscosity about 100 mm^2/s) tend to charge more readily than low viscosity liquids such as fuels or solvents like hexane (about 1 mm^2/s) during flow through pipes and especially filters. 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. Because of this, the restrictions on flow velocity recommended for low viscosity liquids in various parts of 7.3 are not adequate if a flammable atmosphere could be 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 switch-loaded into a road tanker that previously contained a volatile flammable liquid. Since reliable 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.

7.5 High charging equipment

7.5.1 Filters, water separators and strainers

Flow through fine filters (including water separators) and strainers, can produce significantly higher charge densities than flow through pipes.

Coarse wire mesh or gauze strainers (pore size < 150 μm) are not normally regarded as high charging although if partially blocked they can generate charge densities that considerably exceed those obtained in pipe-flow. Partial blockages can be detected by monitoring the pressure drop.

Microfilters (pore size < 30 μm) often generate very high levels of charge: for example, charge densities exceeding 5 000 μC/m^3 have been reported in systems that gave about 10 μC/m^3 from pipe flow. Moderately fine filters (30 μm ≤ pore size ≤ 150 μm) generate intermediate levels of charge.

Flow rate limits are based on the charging due to pipe flow. Therefore, if there could be a flammable atmosphere in the vapour space of a tank located downstream of a microfilter, moderately fine filter/strainer or blocked coarse-strainer, it is essential that there is sufficient residence time between the filter and the tank for the excess charge to relax to a safe level before the liquid enters the tank. The residence time could be provided by conductive pipe work downstream of the filter or, if necessary, by an additional conductive relaxation chamber.

The residence time requirements and additional precautions for filters and strainers are as follows:

1) Residence time requirements between filter and tank for microfilters, filters/strainers with pore size less than 150 μm and coarse strainers that may be subject to blockage:
   a) Liquids of (reliably) known minimum conductivity: the residence time should be at least three times the relaxation time based on the minimum conductivity (see Table 7 and A.2.2) although it is not necessary to provide more than the maximum values set out in the next paragraph for liquids of unknown conductivity.
   b) Upper limits for liquids of unknown conductivity: The maximum residence times required when the liquid conductivity is unknown or is very low, are as follows:
      i) For microfilters (pore size < 30 μm) and moderately fine filters (30 μm ≤ pore/mesh size ≤ 150 μm) with a tendency to partial blockage: 100 s;
      ii) For moderately fine filters (30 μm ≤ pore/mesh size ≤ 150 μm) with no tendency to partial blockage and coarse filters with a tendency to blockage: 30 s.

      NOTE These residence times are adequate for all conductivities except in the case of high viscosity liquids (see 7.4).
2) Other precautions:
   a) Ensure that all conductive parts on filters and in filter housings are 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.

If provision of the required residence time is impractical, consider using SDA to increase the conductivity of the liquid or replacing the liquid with a more conductive one. If this is not possible, the vapour space should be inerted.

The use of a shorter residence time than the upper limit value requires a reliable knowledge or control of the minimum liquid conductivity that could be encountered. In many practical cases, this minimum conductivity is not known and it is necessary to provide a residence time equal to the upper limit.

In the case of high-viscosity, low-conductivity liquids such as base lubricating oils (see 7.4) the usual maximum residence times are not adequate. When the required residence times are unknown or are too long to be practicable, it is essential to avoid a flammable atmosphere in the receiving tank.

For tanks with a floating roof or an internal floating cover, the residence time can be calculated from the reduced initial flow velocity of 1 m/s that applies before the roof or internal cover is floating (see 7.3.2.2.3). This is because there is no longer an ignition hazard after the roof or cover is afloat.

Free hanging filter bags, also known as end-of-line polishing filters, should not be used in explosive atmospheres. Even if the liquid is conductive such filters should be located upstream so that the fabric is not in contact with vapour-air mixtures. With low conductivity liquids the filter should be located an appropriate residence time upstream of the pipe end (see above).

7.5.2 Pumps and other equipment

Other equipment, such as pumps and partly closed valves, may also give increased charge generation. However these items do not usually generate as much charge as a microfilter. Therefore, if there could be a flammable atmosphere in the vapour space of a tank located downstream of such equipment, the residence time requirements for moderately fine filters should be applied (see 7.5.1, i.e. a residence time of at least three relaxation times (3τ) up to a maximum of 30 s should be allowed between the equipment and the tank).

7.6 Gauging and sampling in tanks

7.6.1 General

Gauging and sampling could cause electrostatic ignition in any size of tank if there is a flammable atmosphere present, and the gauging and sampling equipment or the people using the equipment could become charged. Also, for large and medium tanks, the risk of ignition is high if the liquid in the tank is highly charged by either filling processes or agitation, e.g. in a mixing operation (see 7.9). The latter risks are, however, eliminated if gauging or sampling takes place in a fixed, earthed dip-pipe extending to the bottom of the tank (gauge well).

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 these hazards, the recommendations in 7.6.2 should be followed.

7.6.2 Precautions during gauging and sampling

The following precautions should be taken:

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

b) Where the earthing of conductive gauging and sampling equipment for low and medium conductivity liquids cannot be ensured, small (≤ 1 l) glass or glass containers, preferably coated with a static dissipative coating, and wooden dip sticks should be used. This equipment should also be used in the case of unearthed high conductivity liquids.

c) Ensure that people engaged in gauging and sampling do not present an ignition risk and are earthed (see Clause 11).

Unless fixed gauging equipment is used or the gauging takes place in a fixed, earthed dip-pipe extending to the bottom of the tank, the following measures should also be applied:

a) 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. Charge generating operations include pumping or circulating low conductivity, single-phase liquids, pumping or circulating low or medium conductivity multi-phase liquids and many cleaning procedures.

b) Gauging and sampling should not take place while the components of a low conductivity mixture are settling. Therefore, a time delay of at least 30 min should be allowed after completion of the operation before gauging or sampling if a low conductivity liquid containing a second phase has been pumped into a tank or has been involved in a mixing operation in a tank. Examples of this include stirred up water or non-dissolved solid particles.

c) Gauging and sampling should not be carried out through the open manhole of an inerted container. In this case the inerting is destroyed even if the manhole is open for only a few seconds.

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.

7.7 Pipes and hose assemblies for liquids

7.7.1 General

When a liquid flows in a pipe or hose assembly, charge separation produces electrostatic charges of opposite polarity on the liquid and the inner pipe wall. If the pipe is entirely conductive or dissipative and is earthed, charges cannot accumulate on the wall and the electrostatic hazards are confined to the tanks where the liquid charges may accumulate. The hazards associated with tanks are dealt with in 7.3.

If the pipe or hose assembly contains insulating materials, charge accumulation on the pipe wall becomes possible and hazards may also be associated with the pipe or hose assembly itself. Thus, the wall could be charged by liquid flow or by rubbing and metal components could be isolated and accumulate charge. The hazards associated with charge accumulation on pipes or hoses that are wholly or partly insulating are dealt with in this clause. The degree of accumulation depends on the resistivity of the pipe material, the conductivity of the liquid and the physical geometry of the system. It can reach levels that produce incendive discharges.

Ignition hazards can occur both inside the pipe, if it runs partly empty when handling a flammable low flash point liquid, and / or outside, if the surrounding atmosphere is flammable. Discharges may also puncture the walls of insulating pipes and hence cause leakage. Leakage could generate an external flammable atmosphere that could be ignited by later discharges or it could lead to a toxic hazard (e.g. if the pipe carried a toxic liquid) or environmental harm. Additional requirements for petrol forecourt pipes are specified in EN 14125.

7.7.2 Pipes

7.7.2.1 Classification of pipes

Pipes are classified into the categories conductive (resistance < 1 kΩ/m), dissipative (resistance 1 kΩ/m to < 1 MΩ/m) and insulating (resistance $\geq$ 1MΩ/m) given in the Terms and definitions (3.2, 3.7 and 3.15) and Table 1.

7.7.2.2 Conductive or dissipative pipes

All sections of conductive or dissipative pipes should be adequately bonded and earthed (see 7.7.1). Unless the pipe is made entirely of conductive or dissipative materials, the possibility of puncturing insulating linings remains (see 7.7.2.3 and 7.7.2.4).

7.7.2.3 Conductive or dissipative pipes with an insulating inner lining

When a conductive or dissipative pipe with an insulating inner lining is used to convey a low or medium conductivity liquid, electrostatic charges could accumulate on the inner surface of the lining and produce discharges through the lining to the outer wall of the pipe. Theory indicates that the potential on the surface of a lining often increases in proportion to the thickness of the lining. 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 lining) discharges are unlikely to occur when the volume resistivity of the lining is less than about 100 MΩ m. Under typical conditions (charge density $< 1\ 000$ μC/m^3, pipe diameter about 100 mm, lining thickness < 5 mm) discharges will not occur unless the volume resistivity exceeds 100 GΩ m.

NOTE The thicker the insulating liner, the more likely the occurrence of brush discharges and the less likely the occurrence of propagating brush discharges. See A.3.4 and A.3.5.

The use of conductive or dissipative pipes with thicker and/or less conductive linings could still be acceptable for many liquid handling applications. In this case it is necessary that all conductive sections of the pipe are reliably earthed and the pipe remains full of liquid throughout the operations. The latter requirement ensures that there is no flammable atmosphere inside the pipe.

A pipe with a thick and less conductive lining 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.

Although there is no electrostatic ignition hazard if the pipe remains full of liquid, an electrical breakdown could puncture a highly insulating lining. Where it is essential to avoid this (e.g. to prevent corrosion) it can generally be prevented by using a lining with a low volume resistivity. A value of less than 100 GΩ m is usually adequate although, under high rates of charge generation, less than 100 MΩ m could be necessary.

7.7.2.4 Insulating pipes

7.7.2.4.1 General

The flow of low, medium and high conductivity liquids through insulating pipes can produce high surface charge densities, electric fields and potentials on the pipe walls. These may lead to the following hazards:

a) high fields and potentials may lead directly to incendive discharges inside or outside the pipe,
b) high fields will extend beyond the pipe and, consequently, sparks could occur by electrostatic induction from nearby conductive objects or people that are not earthed.
c) high charge densities on the inner surface of the pipe could lead to the electrical breakdown and puncture of the pipe wall.
d) damp air may enter the pipe and condense on the walls inside, creating conductive puddles that may give spark discharges to earthed objects.

7.7.2.4.2 Insulating pipes above ground

Above ground, hazards could arise from internal or external discharges, inductive sparks or wall puncture. The following requirements therefore apply if there could be a flammable atmosphere inside or outside the pipe (e.g. in hazardous areas or when handling flammable liquids in partly-filled pipes):

1) For low or medium conductivity liquids either:
   a) ensure that the pipe end-to-end resistance falls within safe limits developed specifically for the application using a detailed hazard analysis, or
   b) empirically adjust the pipe resistances and operating conditions until it can be demonstrated by experimental hazard assessments that incendive discharges will not be generated by the proposed operation even under worst-case conditions.

   NOTE Both these approaches are used, for example, in SAE J1645 for designing plastic fuel handling systems on motor vehicles.
2) For high conductivity liquids either follow the precautions for medium and low conductivity liquids or:
   a) ensure that the liquid is in direct contact with an earthed conductive component such as a valve or tank at the upstream end of the pipe, and
   b) ensure that the flow velocity does not exceed 1 m/s.
3) Use the precautions given in Clause 6 to ensure that the external wall of the pipe cannot be hazardously charged by external sources such as steam impingement or rubbing.
4) To avoid sparks due to induction-charging, earth all conductive components attached to the pipe (e.g. flanges, valves, balls of valves or conductive layers inside the pipe) and all such items in the vicinity of the pipe unless their installed electrical capacitance is less than 3 pF.

NOTE 1 Installed capacitance means the capacitance of the component as installed in the working assembly. It may be significantly higher than the capacitance of the isolated component if the component is mounted close to an earthed surface.

NOTE 2 In some circumstances it may be possible to prevent electrostatic discharges from conductive items by other means than earthing, e.g. by surrounding them with an airtight insulating material of sufficiently high breakdown strength.

5) Use the procedures given in item 1a or 1b as appropriate to set resistance limits and conditions that also prevent incendive discharges inside the pipe or eliminate the internal flammable atmosphere either:
   a) by ensuring that the pipe is permanently filled with liquid, or
   b) by inerting.
6) Prevent puncturing e.g. by using a wall with a high dielectric strength, by limiting the flow velocity, or by adopting the volume resistivity criteria given in 7.7.2.3 for insulating pipe linings.

The final precaution may be used on its own where the only issue is to prevent puncturing.

If the pipe passes through a zoned hazardous area the pipe should fulfil the requirements of 6.3.

7.7.2.4.3 Buried insulating pipes

When an insulating pipe is buried, its whole external surface is in contact with the earth and usually no further precautions are needed to prevent external incendive discharges. The external earth contact reduces the risk of internal brush discharge but does not remove it completely if the pipe wall has a very high resistivity. Therefore the following additional measures are needed:

High conductivity liquids:

a) Ensure that the liquid is, at some point, in contact with an earthed metal object, e.g. a valve, and
b) Prevent puncturing of the wall by discharges (e.g. by using a wall with a high dielectric strength, by limiting the flow velocity, by selecting a wall material with a low resistivity, and using the criteria given in 7.7.2.3 for insulating pipe linings), and
c) Earth isolated conductive items or surround them with an airtight insulating material of sufficiently high breakthrough strength to prevent discharges (e.g. close the connectors of electric welding sockets with insulating caps).

Medium or low conductivity liquids:

Buried insulating pipes may also be used for the passage of medium or low conductivity liquids but stronger measures (e.g. lower flow velocity, increased dielectric strength of the wall material, further reduction of the wall resistivity, avoidance of explosive atmosphere inside the pipe) are needed to prevent puncturing or explosion of the pipe. These should be guided by a detailed, case-specific hazard assessment.

Excavation of a section of buried pipe could increase the voltages arising from liquid flow and expose conductive or dissipative components. Therefore excavations should not be carried out whilst the pipe is in service and if there is any possibility of a flammable atmosphere, all conductive objects on or near the pipe which could be charged by electrostatic induction should be earthed. However, it can be hazardous to make an earthing connection in a potentially flammable atmosphere.

NOTE Requirements on buried pipes at filling stations can be found in 7.8.4.

7.7.3 Hoses and hose assemblies

7.7.3.1 General

Subclause 7.7.3 deals with hoses for chemical and mineral oil transfers. Paint hoses are dealt with in ISO 8028.

7.7.3.2 Design aims for electrostatic safety of hoses

1) Bonding equipment: Hoses are often used to electrically bond connected equipment and may also provide a second layer of protection in bonding of items such as nozzles and lances. The resistance of the hose between end couplings should not exceed a specified limit and the couplings should provide reliable electrical contact to attached equipment.
2) Preventing incendive discharges: Where flammable mixtures may be present inside or outside a hose assembly, hazardous charge accumulation should be avoided by a design that:
   a) Avoids isolation of conductive components such as hose connectors, reinforcing helixes and in-line valves. For hoses with one helix inside and one outside it has to be ensured that both of them, especially the inner, are reliably connected to the end fittings. This is especially important for hoses with helixes chemically protected by insulating coatings.

   NOTE In case of hoses made of conductive or dissipative hose material a direct contact of uncoated metallic helixes and end fittings may not be necessary.

   b) Limits accumulation on insulating surfaces by the placement of conductors or the utilisation of dissipative external and/or internal surfaces as appropriate.
   c) Avoids formation of charged, isolated liquid “slugs” within the hose.
3) Avoiding hose damage: Electrostatic discharges should not damage the hose in any way that compromises performance. In particular, discharges that create pinholes through the hose wall should be prevented.
4) Preventing stray currents: It is sometimes necessary to prevent significant levels of stray current from flowing along the hose whilst still ensuring that electrostatic charges can be dissipated. In this document, hoses designed to do this are classed as dissipative, hoses that may conduct significant stray currents are classed as conductive and those with too high a resistance to safely dissipate any electrostatic charging current are classed as insulating.

Although these definitions are somewhat different from those used to define hose grades in ISO 8031 and EN 12115 they help identifying hoses which are safe from the electrostatic point of view because the classification by resistance between end fittings in ISO 8031 does not necessarily imply electrostatic safety. These classifications for controlling hazards caused by electrostatic discharges and stray currents are summarised in Table 15 and compared to the hose grades in ISO 8031 in Table 16.

Table 15 – Classification of end-to-end hose resistances for control of hazards from static electricity and stray current

Classification	End-to-end resistance R limits	Comments
Conductive	$R < 1\ \text{k}\Omega$	Controls most static electricity hazards but may need additional measures due to high resistance covers or linings. Does not limit stray currents from power system faults, cathodic protection systems or earth loops.
Dissipative	$1\ \text{k}\Omega \leq R < 1\ \text{M}\Omega$	Controls most static electricity hazards but may need additional measures due to high resistance covers or linings. Limits stray currents to safe levels.
Insulating	$1\ \text{M}\Omega \leq R$	Cannot be relied upon to control static electricity hazards. Limits stray currents to safe levels.

In meeting the above criteria for controlling ignition, different design features may be needed depending on the conductivity of the liquid, the process requirements and the sensitivity of the atmosphere to ignition.

7.7.3.3 Application of design principles for avoidance of ignition in flammable atmospheres having MIE < 0,20 mJ

7.7.3.3.1 End-to-end electrical bonding (continuity)

End-to-end electrical bonding is usually provided by reinforcing helixes, wires embedded in the hose wall, or braided metal sheaths bonded to conductive end couplings. It is important that each bonding wire or reinforcing helix is securely connected to the end couplings. Connections between bonding wires and couplings should be robust and the resistance between the end couplings should be tested periodically. The frequency and type of testing will depend on the application and should be determined in consultation with the manufacturer.

7.7.3.3.2 Elimination of electrically isolated conductive elements

Conductive hose elements typically include end fittings, hose clips (clamps), reinforcing helixes, embedded wires and braided sheaths.

a) End couplings: Couplings are bonded together by a conductive or dissipative (antistatic) hose element to meet the end-to-end resistance requirements.

b) Hose clips: Isolated metal hose clips should be avoided for systems carrying flammable liquids since they may be raised to a high potential due to charging currents within the hose and thus become a potential ignition source.

c) Reinforcing helixes, bonding wires and braided sheaths: In the absence of a conductive or dissipative inner lining these objects may become charged by liquid flow. The capacitance of these components is usually high, therefore they may produce significant discharge energies if isolated. Since the only provision generally made for earthing/bonding is via the end couplings it is particularly important to ensure that each such component is bonded securely to the couplings at both ends of the hose. The end-to-end resistance of the hose should be checked regularly to ensure that this bonding remains intact. If there are multiple end-to-end conductors (e.g. two reinforcing helixes or two flexible bonding wires), an end-to-end continuity check does not reveal whether all conductors are properly bonded and the continuity check needs to be supplemented by careful quality control during construction and regular visual inspection for any damage that could compromise the integrity of a conductor. A hose of this type showing any sign of mechanical damage should be discarded or relegated to duties with non-flammable liquids.

7.7.3.3.3 Avoidance of incendive brush discharges from insulating surfaces

This may be done using one of the following measures:

a) Use a dissipative or conductive outer cover and/or inner lining bonded to the end couplings to eliminate the chargeable insulating surface(s).
b) Limit the extent of any chargeable insulating surface either by keeping the hose diameter low (see Table 3) or by limiting the gap between the turns of reinforcing helix(es) in accordance with 6.3.2. These limits may not prevent the erosion of pinholes particularly with thick and/or highly resistive (e.g. fluoropolymer) linings.

7.7.3.3.4 Avoidance of propagating brush discharges

Propagating brush discharges may occur when there is a thin layer of insulating material with a conductive backing and the breakdown voltage of the insulating layer exceeds 4 kV (see 6.3.4.2). This situation may arise if there are closely-spaced turns of a reinforcing helix that is not in direct contact with the liquid or if there is a thin wall with an external braided sheath, but it requires a large build-up of surface charge density. Usually the hose wall material is sufficiently conductive that dissipation through the wall to the reinforcing helix or sheath occurs before the charge density reaches the required level. This may, however, not be the case with fluoropolymer lined hose assemblies unless dissipative (e.g. carbon filled) fluoropolymer materials are used or the lining has a breakdown voltage that does not exceed 4 kV.

NOTE Although a breakdown voltage of less than 4 kV will prevent propagating brush discharges, it may encourage discharges that lead to pinholing.

7.7.3.3.5 Avoiding discharges from isolated masses of conductive liquid

A mass (slug) of conductive liquid could become charged as a result of flow if it is isolated from the earthed ends of the hose by vapour breaks and the hose has an insulating inner surface. A charged liquid slug could create an incendive spark as it approached an earthed end coupling. This scenario can be avoided by using a conductive or dissipative inner hose lining bonded to the end couplings or, for hoses up to about 200 mm (8 inches) in diameter, by using a hose with a thin lining (≤ 1 mm) and reinforcing helical wire having a pitch of 10 mm or less.

7.7.3.4 Practical hose classifications

Hoses should be clearly marked to prevent the use of a wrong type of hose. ISO 8031 defines six practical grades of hoses together with three subdivisions of the conductive and antistatic grades. The nomenclature and resistance limits for the hose grades, which differ from those in older editions of ISO 8031, are summarised in Table 16.

NOTE Hoses are usually supplied complete with end fittings that form a critical part of the static dissipation path. For these reasons, the classification of hose grades given in ISO 8031 covers only complete assemblies with end fittings.

In ISO 8031, the resistance boundary limits given for each hose grade apply to a variety of resistance measurements as described in that document for each type. When applied to the end-to-end resistance, these limits can be used to relate each grade to the dissipation categories given in Table 15. Table 16 includes a listing of the dissipation categories for each hose grade.

Table 16 – ISO 8031 classification of hose grades

ISO 8031 Grades			IEC 60079-32-1 static dissipation category
Grade ID	**Name/description**	**Resistance R per assembly between end fittings1)**	
M	Electrically bonded At least two flexible metal bonding wires with or without a metal helix.	R < 100 Ω	Conductive
-	Continuous electrically bonded Metal helix(es) connected electrically to both end fittings.	R < 100 Ω	Conductive
Ω	Conductive Incorporating conductive rubber or plastics layer(s).	R < 1 MΩ	Conductive or Dissipative
Ω-L	Conductive only on inner lining.		
Ω-C	Conductive only on outer cover.		
Ω-CL	Conductive cover and lining.		
Ω	Antistatic Incorporating antistatic rubber or plastics layer(s).	1 kΩ ≤ R ≤ 100 MΩ	Dissipative or Insulating
Ω-L	Antistatic only on inner lining.		
Ω-C	Antistatic only on outer cover.		
Ω-CL	Antistatic cover and lining.		
-	Insulating	100 MΩ < R	Insulating
-	Discontinuous	10 kΩ < R	Dissipative or Insulating

NOTE More details concerning grade classification and appropriate test methods for the different hose types specified in this Table are described in ISO 8031.

Antistatic hoses, grade Ω, are commonly used in automotive applications and in fluoropolymer lined hoses. In these and other applications that do not produce very high levels of electrostatic charging, the 100 MΩ limit is an appropriate upper bound for the dissipative range. However, where rates of charge generation could exceed 10 μA, hoses with resistances of up to 100 MΩ may not be able to dissipate charges safely (see 7.7.3.5 c)).

Other requirements in addition to end-to-end resistance are necessary to ensure the avoidance of hazardous brush discharges and propagating brush discharges, see 7.7.3.3.3 and 7.7.3.3.4. Consequently, the end-to-end resistance is not always the only criterion for hose suitability

Certain hybrid methods of hose construction provide both electrical bonding and conductive or antistatic (dissipating) liners or covers. This combination is used, for example, where equipment earthing requirements demand electrical bonding but the process requires a thick inner lining that would, if made of an insulating material, lead to internal discharges. These hybrid designs do not fit any of the grades defined in ISO 8031 and Table 16 but can be described by the hybrid grades defined in Table 17 that provide useful information for selecting or specifying hoses for particular duties.

Table 17 – Hybrid grades of hoses and hose assemblies

Hybrid classification based on ISO 8031			IEC 60079-32-1
Hybrid grade	**Name**	**Resistance R per assembly between end fittings**	**Static dissipation class**
M/Ω-L	Electrically bonded with conductive/antistatic inner liner.	R < 100 Ω	Conductive
M/Ω-C	Electrically bonded with conductive/antistatic outer cover.	R < 100 Ω	Conductive
M/Ω-CL	Electrically bonded with conductive/antistatic cover and liner.	R < 100 Ω	Conductive

The safety of the hybrid hose grades cannot be predicted on the basis of end-to-end resistance measurements alone. Other measurements such as the resistance between the inner lining and the end fittings should also be considered (see ISO 8031).

7.7.3.5 Properties and usage of ISO 8031 hose assembly grades

a) Electrically Bonded (Grade M), and Continuous Electrically Bonded hoses: Electrically Bonded (Grade M) and Continuous Electrically Bonded hose assemblies contain metallic end-to-end bonding. Regular continuity checks and visual inspections should be carried out as outlined in 7.7.3.3.2 to prevent one or more of the bonding components (i.e. bonding wire, reinforcing helix or sheath) from becoming electrically isolated.

   Usually, these hose grades prevent incendive brush discharges as described in 7.7.3.3.3 in which case, a well-maintained hose assembly does not introduce an electrostatic ignition hazard. However in some types of bonded hose assembly, e.g. fluoropolymer (PTFE) lined hoses or hoses with unusually thick linings or large gaps between conductive elements, the electrical bonding alone is not sufficient to prevent hazardous or damaging voltages occurring on one of the insulating surfaces. In this case hybrid Grade M/Ω-L or M/Ω-CL hoses with dissipative inner linings should be used rather than pure Grade M. The electrically bonded character of the hose then provides electrical continuity between the parts of the equipment it is connected to, and the dissipative character of the lining prevents hazardous charge build up on the hose surfaces.

   Because of their low end-to-end resistance, Grade M, M/Ω-L or M/Ω-CL hoses can conduct stray currents and create an ignition hazard when the stray currents are interrupted (e.g. when the hose is disconnected). Where stray currents may give rise to problems, these hoses should therefore be used in conjunction with an insulating flange.

b) Grade Ω, Conductive: Grade Ω, Conductive hose assemblies have conductive or dissipative layers on one or more of the hose surfaces. Grade Ω-L has a conductive or dissipative inner lining, Grade Ω-C has a conductive or dissipative outer cover and Grade Ω-CL has both. Conductive hose assemblies should be constructed so that all conductive components are bonded to the end couplings with a resistance per assembly as specified in Table 16.

   The construction of conductive hose assemblies is often such that electrical continuity cannot be lost whilst the hose remains usable. Regular continuity checks are unnecessary when electrical continuity is inherent to the hose construction in this way.

   As described in 7.7.3.4, conductive/dissipative covers or linings may be combined with electrical bonding to give the hybrid classification grades M/Ω-L, M/Ω-C and M/Ω-CL.

c) Grade Ω, Antistatic: Grade Ω, Antistatic hose assemblies have an intermediate resistance (see Table 16) that is low enough to dissipate electrostatic charges safely in most circumstances but high enough to restrict stray currents to safe levels. They differ from Grade Ω, Conductive hoses only in the resistance boundary limits although there is considerable overlap between the resistance ranges and Grade Ω. Antistatic hose assemblies may also be Grade Ω, Conductive.

   The charging currents due solely to flow through pipes or hoses can be estimated from the correlations given in A.1.4 (see also NFPA 77) and will usually be less than 10 μA. Where rates of charge generation can exceed 10 μA, Antistatic hoses, which may have resistances of up to 100 MΩ, may not be able to dissipate charges safely. In particular, the charging currents immediately downstream of high charging elements such as high-throughput fine filters may be higher. Immediately downstream of such devices and for a distance that enables the residence time requirements set out in 7.5 to be met, it is preferable to use fixed conductive pipes rather than hoses. If a hose must be used in such a location, resistances at the upper end of the Grade Ω, Antistatic range, may be too high to safely dissipate charge and should be avoided. In this case, if stray currents are not an issue, a Grade Ω-L or Ω-CL, Conductive hose should be used and if stray currents are an issue, a hose that meets both Grade Ω-L or Ω-CL, Conductive and Grade Ω-L or Ω-CL, Antistatic requirements, should be used.

The number of interconnected Grade Ω, Antistatic hose assemblies in a hose string should be limited to ensure that the resistance to earth, given in Table 16, is not exceeded anywhere on the string, otherwise additional earth bonding points should be provided.

d) Discontinuous: A hose that has no conductive end-to-end bonding. Usually this type of hose is made of insulating material. It may contain metallic wires or reinforcing helixes, but these are not connected to the end fittings.

Where stray currents may occur, Grade Ω, Antistatic hose assemblies with end-to-end resistances in the dissipative range (see Table 15) are preferred, if available, to electrically bonded ones since they protect against inductive sparks arising from the interruption of stray currents as well as against electrostatic discharges. Electrically bonded hose assemblies (Grade M or hybrid) may be used where Antistatic hoses are not available. In this case it may be necessary to insert an insulating flange, coupling or hose section to provide protection against inductive sparks from stray currents. Where this is done, the hose string on either side of the insulating piece should be separately earthed.

Insulating hoses should not be used where a flammable atmosphere could be present.

Table 18 summarises the duties for which each hose type can be used.

Table 18 – Hose selection Table for flammable liquid service

Grade	Construction	High conductivity liquids (>10 000 pS/m)	Medium and low conductivity liquids (<10 000 pS/m)
-	Flexible metal	Acceptable	Acceptable
M	Electrically bonded	Generally acceptable[a]	Generally acceptable[d,e]
-	Continuous electrically bonded	Generally acceptable[a]	Generally acceptable[d,e]
Ω-L	Conductive inner lining	Acceptable	Acceptable
Ω-C	Conductive outer cover	Review each application[a]	Review each application[d]
Ω-CL	Conductive inner lining and outer cover	Acceptable	Acceptable
Ω-L	Antistatic inner lining	Acceptable	Generally acceptable[f]
Ω-C	Antistatic outer cover	Review each application[a]	Review each application[d,f]
Ω-CL	Antistatic inner lining and outer cover	Acceptable	Generally acceptable[f]
M/Ω-L	Hybrid with bonding and conductive inner lining	Acceptable	Acceptable
M/Ω-C	Hybrid with bonding and conductive cover	Review each application[a]	Generally acceptable[d]
M/Ω-CL	Hybrid with bonding and conductive cover and inner lining	Acceptable	Acceptable
M/Ω-L	Hybrid with bonding and antistatic inner lining	Generally acceptable	Generally acceptable[d,f]

Grade	Construction	High conductivity liquids (>10 000 pS/m)	Medium and low conductivity liquids (<10 000 pS/m)
M/Ω-C	Hybrid with bonding and antistatic cover	Generally acceptable	Generally acceptable[d]
M/Ω-CL	Hybrid with bonding and antistatic cover and lining	Generally acceptable	Generally acceptable[d,f]
-	Insulating	Prohibited	Prohibited
-	Discontinuous	Generally prohibited[b,c]	Generally prohibited[b,c]

[a] Acceptable only if there is a continuous column of high conductivity liquid throughout the hose. Hazards may arise if the column is broken into isolated segments by insulating vapour gaps, the wall resistance is very high (e.g. thick linings, fluoropolymer linings) and the capacitance to the embedded conductor is low (thick lining, large gaps between bonding conductors). The hazards arising under these conditions may be mitigated by employing a slow flow (1 m/s) until the liquid column is continuous or by using a more conductive lining.

[b] It is not possible to ascertain the safety of discontinuous hoses from resistance data alone. Details of the hose construction need to be considered. In special cases, safe operation may be possible.

[c] For marine applications, single lengths of insulating marine hose, which corresponds to the ISO 8031 discontinuous Grade, are acceptable in lieu of an insulating flange as specified by ISGOTT.

[d] Hazards may arise if the lining resistance is very high (e.g. thick linings, fluoropolymer linings) and the capacitance to the embedded conductor or conductive cover is low (thick lining, large gaps between bonding conductors). Hazards may be mitigated by using a more conductive lining or hybrid grade (e.g. Grade M/Ω-L or M/Ω-CL).

[e] Hoses with embedded wires or external reinforcing helixes have been used in petroleum applications (e.g. truck deliveries) for many years without causing problems. However issues have arisen with very highly resistive linings such as PTFE. It is, therefore, recommended that high resistance lining materials are only used after careful evaluation of the risks.

[f] Antistatic Ω-L and Ω-CL grade hoses are acceptable in most circumstances but should be avoided immediately downstream of high charging devices such as high throughput fine filters that may generate more than 10 μA of current. In cases of doubt, a test resistance that meets the Grade Ω, Conductive standard or both the Conductive and Antistatic standards should be specified.

7.8 Special filling procedures

7.8.1 Aircraft fuelling

7.8.1.1 General

Aircraft are most frequently fuelled by means of mobile fuellers or by hydrant systems feeding the aircraft through mobile dispensers. Smaller airfields usually employ a cabinet dispenser system (similar to a retail station) and remote airfields may fuel ex-drum. Fuel transfers are made through flexible rubber 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 though future aircraft will employ composite materials for fuel tanks, wing components etc. Aircraft fuelling systems always contain either a filter monitor or, less commonly, a filter water separator.

NOTE Detailed requirements for aircraft fuelling are given in API/IP RP 1540.

Although not an electrostatic hazard, the possibility of sparks due to stray currents from, for example, electrical power installations or cathodic protection systems, exists when making or breaking hose connections. Precautions against static electricity ignitions should be consistent with the precautions for avoidance of these sparks. Hose designs are given in EN 1361.

7.8.1.2 Hose assemblies

Flexible hose assemblies for aircraft fuelling should normally be of the dissipative–type (see 7.7.3.2) so as to dissipate electrostatic charges while limiting stray currents. Electrically bonded (conductive) hoses may be used, however, in a few specific applications (e.g. on the suction side of a pump where the presence of a metal helix might resist hose collapse). For hydrant systems, the hose connecting the inlet coupler to the hydrant dispenser should be dissipative; electrically bonded hoses should not be permitted.

7.8.1.3 Earthing and bonding

7.8.1.3.1 General

All the metallic fuelling components of the fuelling vehicle (e.g. chassis, tank, filter, meter, pipework, sample equipment, bonding reel) should be in good electrical contact with each other. Good electrical continuity should exist within the hydrant system.

A bonding connection should always be made between the aircraft and the refuelling vehicle before the filling hoses are attached. According to aviation rules, the bonding cable should have an overall resistance below 25 Ω. It should remain in place until fuelling is completed and the hoses are disconnected. The aircraft bonding lugs should always be used. The use of other metal parts of aircraft, e.g. pitot tubes, landing gear doors etc is strictly forbidden by aviation industry guidelines (except for overwing fuelling – see below).

There should be a direct bond between the aircraft fuelling orifice and the metallic end of the fuelling hose. For underwing fuelling, this connection is provided by the metal-to-metal contact between the hose end-coupling and the aircraft fuelling adapter. For overwing fuelling, this connection is made by holding the fuelling nozzle in contact with the metal orifice during fuelling. A separate bonding wire between the nozzle and orifice may be used, although this arrangement is not always possible due to the lack of suitable connecting point. Where a nozzle bonding wire is not used, a maximum filling rate of 200 l/min should be applied.

In aviation industry guidelines, the use of a funnel is strictly forbidden for overwing fuelling because the funnel compromises the grade selectivity of the fuelling nozzle.

In some places earthing is required by the airport authority. Where there is a choice, earthing is not recommended because of potential issues caused by multiple earth points, earth loops and circulating currents. Where earthing is to be employed, the fuelling vehicle should be earthed either by a cable joined to the bonding cable or by a separate earthing cable attached to the vehicle bonding reel.

Fuelling from drums should follow the same procedures as other overwing fuellings. In particular it is necessary to bond the drum pump both to the aircraft and to the drum. Containers smaller than nominal 200 l drums are not allowed for aviation fuel use.

7.8.1.3.2 Flow velocities

The maximum flow velocity in aircraft fuelling hoses should not exceed 7 m/s for fuels with a conductivity greater than or equal to 50 pS/m or 5 m/s for fuels with a conductivity of less than 50 pS/m. Care has to be taken that sufficient residence time is provided downstream of the filters (see 7.5.1).

7.8.2 Road tanker deliveries

Deliveries from road tankers are performed via a hosereel or loose hoses using either gravity feed or pumps on the vehicle. Electrostatic ignition hazards may occur as a result of sparks from isolated 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:

a) Conductive or properly designed electrically bonded hose assemblies (see 7.7.3) should be used;
b) Ensure that the truck and all metallic couplings are bonded to the tank being filled. The recommended hose assemblies provide the required bonding so separate additional

bonding is not necessarily needed. If company standards require separate bonding these should be connected before the connection of the hoses (see 7.3.2.3.3 1b);

c) For deliveries via loose hoses, when connecting the truck to the receiving tank, first connect the hose to the tank fill pipe and then, before completing the hose connection to the truck, equalise the potentials by touching the end coupling of the hose on to a metallic part of the truck;

d) For deliveries via a hosereel, touch the hose-end fitting or nozzle on to a metallic part of the receiving tank assembly, piping or couplings before inserting the nozzle or making a connection. This initial touching should be done away from any region, such as the immediate vicinity of the discharge fitting of the tank, where residual traces of flammable vapour may be present;

e) Providing the maximum safe flow velocities for medium sized tanks are not exceeded (see 7.3.2.3.3) it is unlikely that there is an ignition hazard within the tank. If the liquid contains a second phase, the flow velocity should be restricted to 1 m/s;

f) The continuity and mechanical condition of electrically bonded hoses should be checked regularly (see 7.7.3.3).

7.8.3 Retail filling stations

7.8.3.1 General

Fuel handling operations at retail filling stations involve both the delivery of fuel into underground tanks at the station, usually from road tankers, and the dispensing of fuel from the underground tanks into customer's vehicles. Flash fires initiated by static electricity have occurred both whilst delivering fuel into the underground tanks and whilst dispensing gasoline to customer vehicles.

The production of explosive atmospheres during both delivery and dispensing operations depends on the fuel type. Based on the Flash Point of diesel fuel being at least 58 °C, diesel fuel vapours are usually too lean for combustion at ambient temperatures although hot diesel return lines on the vehicle may sometimes produce an explosive atmosphere within the vehicle tank. However, some countries permit diesel fuel to have a significantly lower flash point. In these countries diesel vapours may produce flammable mixtures at high ambient temperatures.

In contrast, gasoline vapour mixtures are generally too rich for combustion in enclosed spaces such as fuel tanks but may come into the explosive range where mixing with fresh air is possible (e.g. when fuelling a vehicle with gasoline there will always be a place near the filler inlet where the mixture strength is at the optimum for ignition, consequently, an electrostatic discharge near the filler inlet could lead to a fire and burn the person filling the vehicle). Ethanol-gasoline mixtures with high concentrations of ethanol may produce explosive atmospheres within closed tanks at standard ambient temperatures although these fuels are less likely to become electrostatically charged because of their high conductivity.

Based on the above, explosive atmospheres may occur in the following situations:

- inside gasoline-ethanol (e.g. E85) tanks or drained pipes,
- inside gasoline pipes when air is drawn in after hoses are disconnected following a delivery,
- around gasoline filler openings during refuelling,
- outside gasoline or gasoline-ethanol pipes due to leaks or spillage, particularly in enclosed underground “sumps” or “fill boxes” where the underground pipes are connected to tanks or truck hoses. Gasoline and diesel pipes are often housed in the same fill box so it is conceivable for a leak from the gasoline line to produce an explosive atmosphere that could be ignited during diesel loading.

The fuel at filling stations varies from low conductivity hydrocarbon~~s~~ blends without static dissipative additive (SDA) to high conductivity blends of oxygenated bio-components (e.g.

ethanol) and hydrocarbons. Even with the low conductivity fuels, the flow rates are sufficiently small to prevent hazardous potentials being generated by the accumulation of charge on the liquid either in the underground storage tanks or in the fuel tanks on customer vehicles.

However, if any of the conductors associated with the operations (e.g. the filler nozzle, pipe couplings, the vehicle being filled, the filler neck, or a person) are electrically isolated, charge accumulation on the isolated item could then give rise to incendive spark discharges. Also, charges accumulating on insulating pipes or other insulating components in the handling system could produce incendive brush discharges. An ignition could occur if any of these discharges occurred in an explosive atmosphere (see above). The precautions listed in 7.8.3.2 and 7.8.3.3 should be taken to avoid electrostatic ignitions in fuel delivery to underground tanks and fuel dispensing operations to customer vehicles respectively.

7.8.3.2 Delivering fuel to underground tanks

7.8.3.2.1 Systems with metal pipes

a) All pipe sections should be earthed in a manner that does not risk introducing electrical fault currents into the piping system (e.g. with a suitable isolating resistance).
b) The earthing should be regularly checked.
c) Equipment such as fine filters that may give enhanced fuel charging should be used only if there is enough relaxation time in the conductive pipe.

7.8.3.2.2 Systems with plastic pipes

Plastic pipes are increasingly being used for fuel delivery from road tankers to underground tanks, from underground tanks to fuel dispensers, and for vapour recovery lines and vents because they provide improved corrosion resistance and secondary containment.

NOTE Specific requirements for thermoplastic and flexible metal pipework for this application are covered in EN 14125.

Two main varieties of plastic pipe system are in use: the so-called “non-conductive” (insulating) pipes and the so-called “conductive” pipes (non-conductive pipes incorporating co-extruded dissipative inner linings). Typical plastic pipe systems use connectors which incorporate metal heating coils (electrofusion couplers, EFCs) to couple and seal pipe lengths and joints. These EFCs may have an installed capacitance of between 5 pF and 30 pF depending on the installation. Plastic pipes normally incorporate a co-extruded inner lining for countering fuel permeation. For pipes that also have a dissipative lining, the dissipative lining is usually the innermost.

Specific risks in these types of systems include:

a) Fuel flow could cause significant charging of low or medium conductivity fuels. Consequently:
    i) For fully insulating (“non-conductive”) pipes:
        1) High voltages could build up on unburied pipe walls or on associated non-earthed connectors.
        2) Discharges can occur on the inner surface of a charged pipe. The fill point where the hose from the lorry is attached is a critical point in this respect because discharges to earthed connectors or couplings or from highly charged to less charged plastic surfaces may cause ignition if air ingress occurs on disconnection.
        3) The electrostatic fields arising from the build up of charge on the pipe wall could cause high voltages to arise on nearby conductive EFCs, tools, and other items outside pipes and cause spark discharges to nearby earthed conductive items.
        4) High electric fields could occur in the walls of buried pipes leading to possible breakdown and pinholing by electrostatic discharges.
    ii) For insulating pipes with dissipative liners (so-called “conductive pipes”):

    1) Charge cannot accumulate if the lining is earthed, and the shielding provided by an earthed lining minimises the risk of flow-related high voltages on associated conductors such as EFCs.
    2) However, voltages may build up on any unearthed liner sections or on the connectors associated with them.

b) Charging of external insulating pipe surfaces by rubbing could give brush discharges.

c) Mixing of insulating and conductive pipes in a system could lead to isolated conductive parts. It is acceptable only if all conductive parts are certain to be earthed. Particular attention should be paid to earthing metal flanges, couplings and clips on insulating segments and earthing the lining of the conductive segments.

d) Where pipes are fitted during maintenance of a system, when a flammable atmosphere could be present, specific risks may arise. Both conductive and insulating pipes may charge during handling and give potentially incendive discharges.
    i) For insulating pipes, incendive brush discharges from the outer pipe surface are possible
    ii) For pipes with dissipative liners, the accumulated surface charge could induce high voltage on an erroneously un-earthed liner and this could be the source of shocks to people and incendive discharges.

The voltage build-up on insulating pipes from fuel charging depends on flow speed, fill volume and the length of unburied sections as well as on pipe and fuel properties. The variability of these charging characteristics and the variation of charge dissipation characteristics with age and temperature is still not well understood. Wide safety margins for dissipation should, therefore, be applied until the worst-case charging characteristics are better known.

There is, however, a considerable installed base of pipes and there are only few recorded incidents so existing practices seem to be broadly acceptable with today’s fuels. It is, however, unclear whether existing practices would continue to provide adequate safety margins if the increasing use of oxygenated biocomponents in gasoline were to give rise to higher charging.

NOTE There are indications that at least some ethers and esters are prone to higher charging than hydrocarbon fuels.

In order to prevent excessive electrostatic charge and voltage build-up on the pipe walls, valves and couplings the following precautions are recommended:

1) Insulating plastic pipes:
    a) To avoid pin holing insulating plastic pipes should have an electrical breakthrough strength across the pipe exceeding 100 kV, measured according to IEC 60243-2. A polyethylene layer of at least 4 mm in thickness usually exceeds this breakthrough strength.
    b) Unburied EFCs should be either long-lasting and reliably earthed or sealed using airtight seals.
    c) All other conductive parts of pipes or joints should be earthed.
    d) The earthing of all conductive and dissipative items should be regularly checked.
    e) Unburied fully insulating plastic pipe sections should be kept as short as practicable.
    f) Fuel flow rates should be limited to < 2,8 m/s.

       NOTE The possible future introduction of bio-components may change the charging behaviour of fuel.
    g) The earthing of the majority of each pipe by burial contributes significantly to the safe operation of the system. Consequently, following installation or repair, liquid should not be admitted into a pipe until all sections that are intended to be buried are confirmed to be fully covered with earth.
    h) Equipment such as fine filters that may give enhanced fuel charging should be used only with careful assessment of the likely hazards.

   - i) The fill point where the truck hose is attached should use a safety connection valve, preferably an interlocked system that does not allow air to enter the system and mix with the fuel vapours, e.g. a valve that is closed before disconnecting hose and pipe.
   - j) The exposure of pipes and joints in sumps where flammable vapours could accumulate should be minimised.
   - k) People should avoid brushing against external pipe surfaces where a flammable vapour may be present.
   - l) During system maintenance, care should be taken to avoid introducing a highly charged pipe into a flammable atmosphere.

2) Plastic pipes with dissipative linings:
   - a) The linings should be earthed. An earthed, dissipative liner prevents internal discharges and screens external conductors from flow charging.
   - b) Earthing may be achieved by a suitable arrangement of dissipative internal couplings linking to external grounding points.
   - c) The earthing of all conductive and dissipative items should be regularly checked.
   - d) Equipment such as fine filters that may give enhanced fuel charging should be used only with careful assessment of the likely hazards.
   - e) During system maintenance, care should be taken to avoid introducing a highly charged pipe into a flammable atmosphere. Dissipative liners should be grounded before the pipe is introduced into a flammable atmosphere and the ground connection should be maintained during the fitting process, until the liner is reliably grounded via the installed system.
   - f) People should avoid brushing against external pipe surfaces where a flammable vapour may be present.

7.8.3.3 Dispensing fuel to customer vehicles

The following precautions should be taken:

- a) The pump should be properly earthed.
- b) A conductive or properly designed electrically bonded hose assembly (see 7.7.3.2) should be used to connect the nozzle to the pump. The filling nozzle to earth resistance via the hose should be less than 1 MΩ for conductive hoses and less than 100 Ω for electrically bonded hoses. Detailed requirements can be found in EN 1360.
- c) The surfaces of forecourts should have a leakage resistance to earth of less than 100 MΩ, measured in dry condition at less than 50 % relative humidity, to enable the earthing of vehicles via their tyres.
- d) The dissipative surface of the forecourt around the pump should be big enough to assure that all four tyres of a private car will have contact to it in all filling positions.
- e) The grip of the filling nozzle should be designed with conductive or dissipative materials to ensure that earthing of the refuelling person is established during the refuelling process.

  NOTE To avoid electrostatic shocks dissipative materials are preferred.
- f) If there is a latch-open device on the filler nozzle it should meet any local requirements that may exist for automatic shut-off.
- g) Generally for vehicles, the resistance between a standard filler nozzle inserted into the filler neck and a metal plate on which each tyre stands in succession should not exceed 10 GΩ when all other tyres rest on an insulating surface. For tyres to be used in hazardous areas the border limit reduces to 1 MΩ. Detailed requirements can be found in ISO 16392 and ASTM F1971.
- h) The vehicle design should ensure that hazardous levels of charge will not accumulate on plastic filler system components on the vehicle and that metal filler system components on the vehicle are adequately bonded to the chassis. Detailed requirements can be found in SAE J1645.

These precautions will ensure earthing of:

a) the nozzle, directly via the conductive or dissipative hose assembly;
b) a person grasping it, unless wearing insulating gloves;
c) the vehicle chassis during filling, by contact with the nozzle and through the tyres;
d) conductive filling system components on the vehicle by bonding to the vehicle chassis.

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.

NOTE Most fires during car refuelling are caused by charged persons.

7.8.4 Mobile or temporary liquid handling equipment

Particular care should be taken when using temporary equipment that introduces filters or other restrictions into the system. An example of this is portable meter proving equipment that contains fine filters to protect the sensitive meters. When using such equipment, precautions should be taken to ensure that the temporary handling arrangement provides an adequate residence time between the portable equipment and any tanks being filled (see 7.5) and to ensure that all normal earthing requirements are met (see Clause 13).

7.9 Plant processes (blending, stirring, mixing, crystallisation and stirred reactors)

7.9.1 General

The processing of liquids or suspensions (mixing, stirring, blending or crystallisation) can give rise to ignition risks due to static electricity. When these processes involve low or sometimes even medium conductivity liquids the charge is retained in the continuous liquid phase, on suspended liquid or solid particulate matter, or on any isolated 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 7.9.2 to 7.9.6 should be followed as appropriate.

High levels of charge generation are often associated with fluids consisting of two immiscible liquid phases or a liquid with suspended solids. As a consequence, two-phase flows are subject to additional flow rate restrictions. These reduced flow rates are also required for handling “contaminated” liquids, which, in this context, are defined in 3.6 as liquids that contains more than 0,5 % by volume of free water or other immiscible liquid or more than 10 mg/l of suspended solids.

7.9.2 Earthing

All conductive parts of the equipment should be bonded and earthed, see Clause 13.

Ensure that people working in the vicinity of a blending operation are not an ignition risk by following the precautions in Clause 11.

7.9.3 In-line blending

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

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 for tank filling in 7.3 should be adopted as appropriate.

7.9.4 Blending in vessels or tanks

The blending of miscible liquids to produce a single phase is not unduly hazardous at any conductivity provided that the precautions appropriate to liquid handling operations are taken (see 7.3).

If the mixture contains dispersed liquid or solid particles, the generation of static electricity could be reduced by increasing the conductivity of any low conductivity liquids in the system. This could be done by using a more conductive solvent or by adding a SDA (see 7.2.4), provided that it is compatible with the intended use of the mixture.

If the phases in a mixture are all liquids it is usually sufficient to raise the conductivity of the continuous phase to above the low conductivity range. 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 100 pS/m (1 000 pS/m is generally, but not always adequate) and also to restrict the power input to the stirrer (e.g. in BS 5958 a maximum power of 0,37 kW/m^3 is recommended for suspensions of 1 000 pS/m).

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

If a blending vessel has an internal insulating lining, e.g. glass, ceramic or plastic, the relaxation of charge from the contents should be promoted by placing earthed conductive 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 or conductive enough to permit charge dissipation and to avoid a hazardous surface potential. The potential for propagating brush discharges which could cause pinhole damage to insulating linings should be considered where significant charge generation may be present due to handling of low conductivity or multiphase mixtures (see B.1.4).

The gauging and sampling of wholly liquid systems should be carried out in accordance with the recommendations of 7.6. The precautions for liquids containing a dispersed solid phase will depend upon the specific mixture and no general advice can be given.

As an alternative to raising liquid conductivities, the vapour space in the blending vessel could be inerted in accordance with the recommendations in 8.4. Limiting the power input to the stirrer is then no longer required.

7.9.5 Jet mixing

The jet mixing of liquids with conductivities exceeding the low conductivity range 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.

If a liquid has a low conductivity, SDA (see 7.2.4) could be added to raise it to the medium conductivity range, provided that it is compatible with the intended use of the mixture.

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 in 8.4.

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.

Gauging and sampling should be carried out in accordance with the recommendations given in 7.6.

7.9.6 High speed mixing

High speed mixing, for example to produce emulsions, generates more charge than normal blending. Expert advice should be sought on the amendments to the precautions given in 7.9.4 that will be necessary during high speed mixing of immiscible liquids.

7.10 Spraying liquids and tank cleaning

7.10.1 General

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 occurs in the centre of the tank, depends mainly on the size of the tank and the charge density of the mist. The charge density 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 additional ignition hazard could occur due to brush discharges to an earthed conductive 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 although such high potentials are seldom produced during tank cleaning.

If isolated conductors were present in the tank, incendive sparks could occur at much lower potentials. Typically, potentials in the range 5 kV to 20 kV are sufficient to produce sparks incendive to hydrocarbon/air atmospheres. The value depends on the size of the isolated conductors and the length of the spark gap. Isolated conductors are inevitably formed when washing with liquid jets from high-throughput nozzles because these produce large isolated liquid volumes called “slugs” as the jet breaks up. These slugs could be charged by induction to the potential at the tank centre and incendive sparks could occur when slugs with a potential of at least 15 kV approach earthed conductive objects. It is, therefore, recommended, as far as possible, to avoid nozzles that may form large isolated slugs during the jet breakup process. Care should also be taken that liquid does not gather and then spill fall from ledges or recesses near the roof of the tank.

After a cleaning operation, subsequent processes (e.g. inspection, gauging, sampling) should be delayed until any charged mist generated has settled. This can take several hours for very large tanks.

7.10.2 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, technical reports 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.

Technical reports show that cleaning a tank with a capacity of less than 100 m^3 presents a very low hazard level but cleaning a tank with a capacity of 10 000 m^3 or more 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)".

7.10.3 Tank cleaning with low conductivity liquids

Low conductivity liquids, e.g. hydrocarbons, charge less than water during spraying because they contain only a small concentration of dissociated ions. Spraying low conductivity solvents could be considered to be safe in the cases described above. However, the cleaning solvents should not contain either water or solid particles that 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 0,5 %.

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

7.10.4 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
   1) Cylindrical metal container up to 3 m diameter, and
   2) Spraying head operated at 500 bar maximum liquid pressure and maximum liquid flow rate of 5 l/s.
b) Spraying low conductivity liquids
   1) Cylindrical metal container of up to 5 m^3 volume, and
   2) Spraying head operated at 50 bar maximum pressure and 1 l/s maximum liquid throughput.

The washing liquids should not contain more than 0,5 % 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. Seek specialist advice in those cases.

In the case of containers with insulating walls the limits are unknown, but in any case they will be much lower than for metal containers. This is because even in small containers plastic walls charged by the cleaning process may create charged puddles of conductive liquids which are known to produce incendive spark discharges on coming into contact with earthed parts. Alternatively, using low conductivity liquids may create highly charged container walls able to produce incendive brush discharges.

For these reasons the presence of an explosive atmosphere inside insulating containers should be avoided during the cleaning process, e.g. by filling and emptying them with water beforehand, or by the use of cleaning liquids with a high flash point. Specialist advice may be necessary in those cases where electrostatic ignition hazards are expected and an explosive atmosphere is present.

7.10.5 Steam cleaning tanks

Steam cleaning tanks produces an electrostatically charged mist. Experimental evidence indicates that this does not result in an ignition hazard for tanks with volumes up to 100 m^3

which contain a flammable atmosphere. However, a hazardous situation may exist with larger volumes.

7.10.6 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.

7.11 Glass systems

7.11.1 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 uncoated glass surfaces at low relative humidity or, for example, if the surface temperature was well above the ambient temperature.

7.11.2 Precautions to be taken for low conductivity liquids

Hazards from low conductivity liquids can be reduced by taking the precautions recommended in 7.2. 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 IIC (see Annex D), all conductive parts, such as metal flanges, fittings, valves or measuring equipment should be connected to earth with a resistance of less than 1 MΩ. For all metal systems, a resistance of less than 10 Ω should be achieved. If a significantly higher value is found, further investigations should be made to check for possible problems, e.g. corrosion or a loose connection.

In case of gases and vapours in Group IIA and IIB it is only necessary to earth conductive items with an installed electrical capacitance of more than 3 pF. Thus it is not necessary to earth small bolts or screws (electrical capacitance equal to or less than 3 pF). Fittings, valves or seals with unearthed conductive parts with a capacitance above 3 pF and which cannot be earthed (for example due to having an insulating coating) are not suitable for use in glass systems.

If prolific charge generating elements such as microfilters are used, incendive brush discharges could occur from the glass to conductive surfaces. In those circumstances the flanges should be made from insulating materials.

In Zone 1 areas containing gases and vapours in Group IIB and IIC, the same requirement to earth conductive items with an electrical capacitance more than 3 pF applies. For Zone 1 areas in the presence of those in Group IIA, the electrical capacitance should not exceed 6 pF.

In Zone 2 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.

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 insulating systems and are summarised in 7.3.4.6. The precautions for handling conductive or dissipative content such as water, acids, bases or alcohols are the same as for uncoated glass.

Conductive liquids in glass and glass lined metal systems should be earthed, e.g. by conductive inlet or outlet pipes or an earthed metal plug at the bottom of the system (see also 7.3.4.2).

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

8 Static electricity in gases

8.1 General

The movement of pure gases or 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 isolated 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 insulating 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:

1) ensuring that all metal and other conductive objects are earthed (see Clause 13);
2) avoiding the use of insulating materials;
3) reducing charge densities by restricting flow velocities or by suitable nozzle design;
4) removing the particles.

For recommendations relating to the pneumatic transfer of powders see Clause 9. For recommendations for other industrial processes see 8.2 to 8.8.

8.2 Grit blasting

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.

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.

8.3 Fire extinguishers

Some types of pressurised 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 a flammable 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.

8.4 Inerting

Inerting a system, for example, by using pressurised carbon dioxide, can introduce large amounts of charged particles or droplets. If the system contains a flammable atmosphere this can lead to incendive discharges 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.

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.

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

8.5 Steam cleaning

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.

Experimental evidence indicates that this does not result in an ignition hazard for tanks with volumes up to 100 m^3 which contain a flammable atmosphere. However, a hazardous situation may exist with larger volumes.

For this reason, tanks with capacities greater than 100 m^3 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; and, where possible, dry or superheated steam should be used and condensate prevented from forming in the lines.

8.6 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 a flammable atmosphere, the containing vessel or pipe and any adjacent conductive objects should be earthed. Conductive objects that could be moved into an area containing a flammable atmosphere should be earthed before the object is moved. People going into the area of such leaks, for example to carry out repairs, should also be earthed (see Clause 13) and insulating objects should not be taken into the area.

8.7 Spraying of flammable paints and powders

8.7.1 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 sprayed and any other object (including people) 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. Even in the case of water based paints the occurrence of propagating brush discharges is possible, e.g. during electrostatic varnishing of metal car bodies. Local extract ventilation may also be required to control the flammability hazard.

NOTE The safety requirements for these processes are given in EN 50050, 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 8.7.2 should be observed. The level of charging with air-atomised spraying equipment is not usually high enough to cause concern. However, if sparking or electrostatic shocks are encountered, this equipment should also be subject to the precautions given in 8.7.2.

Operations to clean spray equipment and spray booths also need to be considered, particularly if flammable solvents are used.

8.7.2 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 13).

Paint or powder deposits can prevent earthing by the jigs and suspension hooks. This problem can be avoided by suitable design and regular cleaning. People operating the equipment should also be earthed (see Clause 11).

8.7.3 Plastic spray cabinets

Due to the risk of brush discharges spray cabinets made of insulating 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 or dissipative material are acceptable for all types of spraying, provided that they are earthed. The application of protective insulating foils on conductive or dissipative surfaces should be avoided as they may lead to hazardous propagating brush discharges.

8.8 Vacuum cleaners, fixed and mobile

8.8.1 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 discharges (see A.3.4) could also occur inside the system between accumulations of charged material and earthed metal.

8.8.2 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 dissipative (see Table 15 for liquids and 9.3.3 for solids). Electrically bonded hoses are also acceptable if they are constructed so that no brush discharges could be generated (see 7.7.3) or if no flammable gases and vapours are present. The hose should be bonded to the collecting system, which should also be earthed and, preferably, should be sited outside of the hazardous area.

In some cases where lines are long the use of dissipative hoses may not provide a sufficiently low resistance for earthing of end-of-line conductive components (e.g. nozzles) and a dedicated earth connection to such conductive components may, therefore, be necessary.

If the system may be used for collecting flammable liquids, vapours or gases, the system should be specially designed for this purpose to avoid the risk of brush discharges. The present state of knowledge indicates that there is no ignition risk due to brush discharges in the case of sensitive dusts providing that there are no flammable gases or vapours (see A.3.4).

Filter media made from earthed conductive material should always be used where flammable vapours are present or where non-metallic conductive powders with a MIE less than 30 mJ are handled. Such fabrics should also be used for combustible metallic dusts having MIE less than 30 mJ provided that dry media type dust collectors are not expressly prohibited by prevailing regulations. The resistance to earth should be below 100 MΩ. The use of fibres containing conductive threads also helps to reduce charge on the powder and filter by corona discharge.

To prevent electrostatic shock the conductive parts of all collecting systems should be earthed even when they are not used for collecting flammable materials (see Clause 13).

Large systems should be treated as systems for pneumatic transport (see Clause 9).

8.8.3 Portable 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 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 conductive or electrically bonded hose for the compressed air.

Equipment which cannot be earthed (e.g. because the outer shell is insulating, see 3.15) and which does not have electrical continuity between the nozzle and the receiver should not be used in hazardous areas (see Annex D).

8.8.4 Vacuum trucks

Vacuum trucks should be connected to a designated site earth before commencing any operations. In areas where site earths are not present, i.e. where portable earthing rods are required, or there is doubt regarding the quality of site earths, the resistance to earth should be verified prior to any operation. When the truck is connected to a verified earth, the connection resistance between the truck and verified earth should not exceed 10 Ω for pure metallic connections or 1 MΩ for all other connections.

This requirement should be verified with a truck mounted earthing system or portable ohmmeter. The electrostatic suitability of the hoses used should also be verified in accordance with 7.7.3 or 9.3.3.

9 Static electricity in powders

9.1 General

According to experience the ignitability of bulk material ranging from fine dust to granules or chips increases with decreasing particle size and decreasing minimum ignition energy (MIE).

Explosion hazard assessment should always be based on the minimum ignition energy of the finest particle size fraction that may be present. This fraction is usually obtained by sieving a sample through a 63 μm sieve.

NOTE 1 For a list of MIE of powders see BIA-Report 12/97 “Combustion and explosion characteristics of dusts”. A method for determining the MIE is given in IEC 61241-2-3, ASTM E2019-03 and EN 13821.

NOTE 2 MIE of powders are notoriously variable depending on many parameters not commonly detailed in literature data sources (particle size distribution, solvent/moisture content etc.).

If the relevant minimum ignition energy is above 1 J and there are no flammable gases and vapours present, special measures to avoid ignition hazards due to static electricity are usually not necessary. A possible exception to this is the case where propagating brush discharges are possible (see 9.2 d)).

NOTE Precautions might be necessary to minimise electrostatic shock risks. See 12.2.

Bulk materials are classified into 3 groups depending on their volume resistivity:

a) low resistivity powders, with volume resistivities $\rho \leq 1$ MΩ m;
b) medium resistivity powders, with volume resistivities 1 MΩ m $< \rho \leq$ 10 GΩ m;
c) high resistivity powders, with resistivities $\rho >$ 10 GΩ m.

NOTE For methods to measure the resistivity see IEC 60079-32-2[6].

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. An exception is, however, carbon black.

During handling of bulk materials electrostatic charging normally occurs. In addition to avoiding the hazardous accumulations of charge additional explosion protection measures may have to be taken as inerting, the use of explosion resistant equipment, explosion venting or explosion suppression.

9.2 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 (see C.6). Spark discharges can be avoided by earthing all conductive parts of equipment, conductive products and also people;
b) Brush discharges: The present state of knowledge indicates that independent of their MIE combustible powders cannot be ignited by brush discharges, providing there are no flammable gases or vapours (see A.3.4). When handling large amounts of medium or high resistivity powders, brush discharges cannot be avoided (see B.3.7);
c) The presence of contaminations (e.g. solvent, grease or moisture) may affect the potential ignition hazard when using insulating plastics in the presence of dusts.
d) Care should be taken when handling solvent wet powders, as they may release flammable vapours over a long period of time with a much lower MIE than the pure powder. Consideration should also be given to whether MIE results less than 1 mJ are actually due to such mechanisms, rather than the powder alone.

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[6] To be published.

e) Corona discharges: Corona discharges cannot ignite combustible powders. When handling large amounts of medium or non-conductive powders, corona discharges cannot be avoided;

f) Propagating brush discharges: The energy released in a propagating brush discharge can be calculated and values in excess of 1 J are typical. Examples of a calculation and more details of propagating brush discharges are given in B.3.9;

g) 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);

h) Lightning-like discharges: Such discharges, though theoretically possible, have not been observed in industrial operations.

9.3 Procedural measures

9.3.1 General

The process parameters should be set in a way that minimises electrostatic charging. This should be achieved by implementing some or all of the following precautions:

a) increasing the conductivity of the bulk material, e.g. by coating,

b) replace insulating equipment by earthed conductive equipment,

c) humidification of powders,

d) ionisation,

e) reducing the quantity of fines in the bulk, e.g. avoiding fine fractions caused by wear and abrasion,

f) limiting dispersion, e.g. dense phase conveying instead of dilute phase conveying,

g) reducing the conveying speed, throughput or air velocity,

h) avoiding big heaps of bulk material,

i) preferring gravity transport to pneumatic transport,

j) using conductive or antistatic hoses for pneumatic transport.

9.3.2 Humidification

If humidification is used as measure to dissipate charges from bulk material, usually 70 % relative humidity at 23 °C is necessary. This method may not be effective for high speed conveying and for warm products. It may also adversely affect the flow properties of some powders.

NOTE Air is a poor conductor of electricity. 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 – with the exception of most polymers – and, therefore, might increase the rate of charge decay on bulked powder.

9.3.3 Hoses for pneumatic transfer

The definitions of antistatic and conductive hoses in 7.7.3.4 do not apply for hoses for the use with pneumatic transport of bulk materials. For such pneumatic transport the leakage resistance from any place of the inner wall of the hose should be less than 100 MΩ (measured according to ISO 8031).

9.3.4 Ionisation

The conductivity of dust/air mixtures can be increased by ionisation. It may be possible to avoid dust deposits by ionisation. It is not possible to avoid hazards when dealing with large amounts of bulk material and of large dust clouds.

NOTE It is difficult to provide the necessary ionisation for relatively large distances, e.g. more than 100 mm. Furthermore the total charge to be neutralized is often larger than an ionisation system may provide.

Local discharges from pointed, earthed conductive 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. The earthed conductive probes or wires should not break off in total or in parts.

NOTE 1 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 an insulating container.

NOTE 2 Detached parts (e.g. if parts of the probe or wire break) might behave as charged capacitors and cause spark discharges.

NOTE 3 In the case of active ionisers, contamination of points might lead to ohmic heating possibly causing fires which needs to be prevented.

9.4 Bulk materials in the absence of flammable gases and vapours

9.4.1 General

For these purposes it is assumed that the powder is handled and processed free from any flammable gases and vapours, if:

a) with non-flammable bulk material the concentration of gases and vapours is below their lower explosive limit (LEL),
b) with flammable bulk material the concentration of gases and vapours is below 20 % of their LEL.

NOTE This is often met if immediately after a drying process the total residual concentration of solvent in the bulk material is below 0,5 %, the powder is subsequently handled at ambient temperature, and no further fine fraction generating process is carried out.

9.4.2 Equipment and objects made of conductive or dissipative materials

In hazardous areas all equipment and objects made of conductive and dissipative materials should be earthed, e.g. laminated packages with conductive layers and non-stationary coated containers.

For the following situations the earthing requirement may be abandoned/relaxed:

a) if it can be shown that objects made of conductive and dissipative materials do not become charged during normal operation and possible malfunctions; or
b) if the maximum energy that can be stored on the isolated objects is much lower than the MIE of the bulk material, or
c) if the capacitance of the object does not exceed the applicable value given in Table 2.

9.4.3 Equipment and objects made of insulating materials

Equipment and objects made of insulating materials are only permissible if no hazardous charge build up will occur. If equipment and objects made of insulating materials in the form of pipes, hoses, containers, sheets, coatings and liners are used charge build up has to be expected.

Charging of insulating surfaces may result in propagating brush discharges with typical energies in excess of 1 J when backed with conductive areas in a distance less than 10 mm. If insulating films, layers or coatings with a breakdown strength below 4 kV are used they will not result in propagating brush discharges incendive to bulk materials.

As charging of isolated conductive material may cause spark discharges, the combination of conductive, dissipative and insulating materials is only permitted providing that all conductive and dissipative parts are properly earthed.

9.4.4 Dust separators

In separators for flammable dusts insulating filter fabrics should not interrupt the earthing connections of parts made of conductive or dissipative materials, e.g. supporting cages of filter sleeves or metal clamps to keep the filter socks in place. Particularly when the MIE of the bulk material is lower than 3 mJ ensuring earthing of all metal parts such as clamps, etc. having a capacitance greater than 10 pF is of great importance. This limit is due to the practical experience that it is nearly impossible to make sure that even the smallest metal parts (single screws, clamps etc.) are always earthed by cable connections. The earthing and bonding should be guaranteed by the construction itself and/or by the properties of the materials used.

For this purpose the use of filter fabrics made of fibre containing conductive threads, or the use of normal filter socks with copper straps sewed around the end of the filter socks which automatically bond the supporting cages and metal clamps have proven to be very useful.

Filter fabrics made from conductive and earthed material should always be used where flammable vapours are present or where non-metallic conductive powders with a MIE less than 30 mJ are handled. Such fabrics should also be used for combustible metallic dusts having MIE less than 30 mJ provided that dry media type dust collectors are not expressly prohibited by prevailing regulation. The resistance to earth should be below 100 MΩ. The use of fibres containing conductive threads also helps to reduce charge on the powder and filter by corona discharge.

NOTE Al, Mg, Ti and Zr dusts usually have MIE of less than 30 mJ whereas Fe, Co, Ni, Cu and Mn dusts usually exceed this limit. More details can be found in NFPA 484, *Standard for combustible metal*.

9.4.5 Silos and Containers

9.4.5.1 General

Bulk materials should be handled and processed in such a way that a hazardous charge build up is avoided. A hazardous charge can be accumulated on the bulk material as well as on the wall of the silo or container.

NOTE This applies to large silos and containers as well as also to small mobile containers, bins, drums, bags, FIBC or other packages. The specific requirements for FIBC are given in 9.6.

Figures 1 to 3 detail how to analyse whether the bulk material itself can be charged to a hazardous amount during the filling of a silo or container. If required, measures against the occurrence of cone, lightning like or spark discharges have to be taken. The flow diagram to be chosen depends on the resistivity of the bulk material:

Figure 1: Assessment of low resistivity bulk material ($\rho \leq 1$ MΩ m)

Figure 2: Assessment of medium resistivity bulk material (1 MΩ m $< \rho \leq 10$ GΩ m)

Figure 3: Assessment of high resistivity bulk material ($\rho > 10$ GΩ m)

NOTE In Figures 2 and 3 $W_{cone\ discharge}$ means the maximum expected energy of the cone discharge (see A.3.7).

As an alternative to the measurement of the strength of the electrical field above the powder heap, this field strength may be estimated by modelling the electrical field within the silo taking into account charge relaxation during the filling procedure. Such model calculations should be based on the charge to mass ratio, bulk density and filling rate of the powder, the relative permittivity and resistivity of the bulked powder as well as on the silo geometry. If the radially directed electrical field stays below 3 MV/m, the criterion for the field of the bulked powder is fulfilled. The difference between the 500 kV/m average electrical field over the gap of the discharge and 3 MV/m limit value is based on the field distribution within silos, where the maximum field is always directed radially against the wall of the silo measured at the silo wall and not axially directed measured above the powder heap.

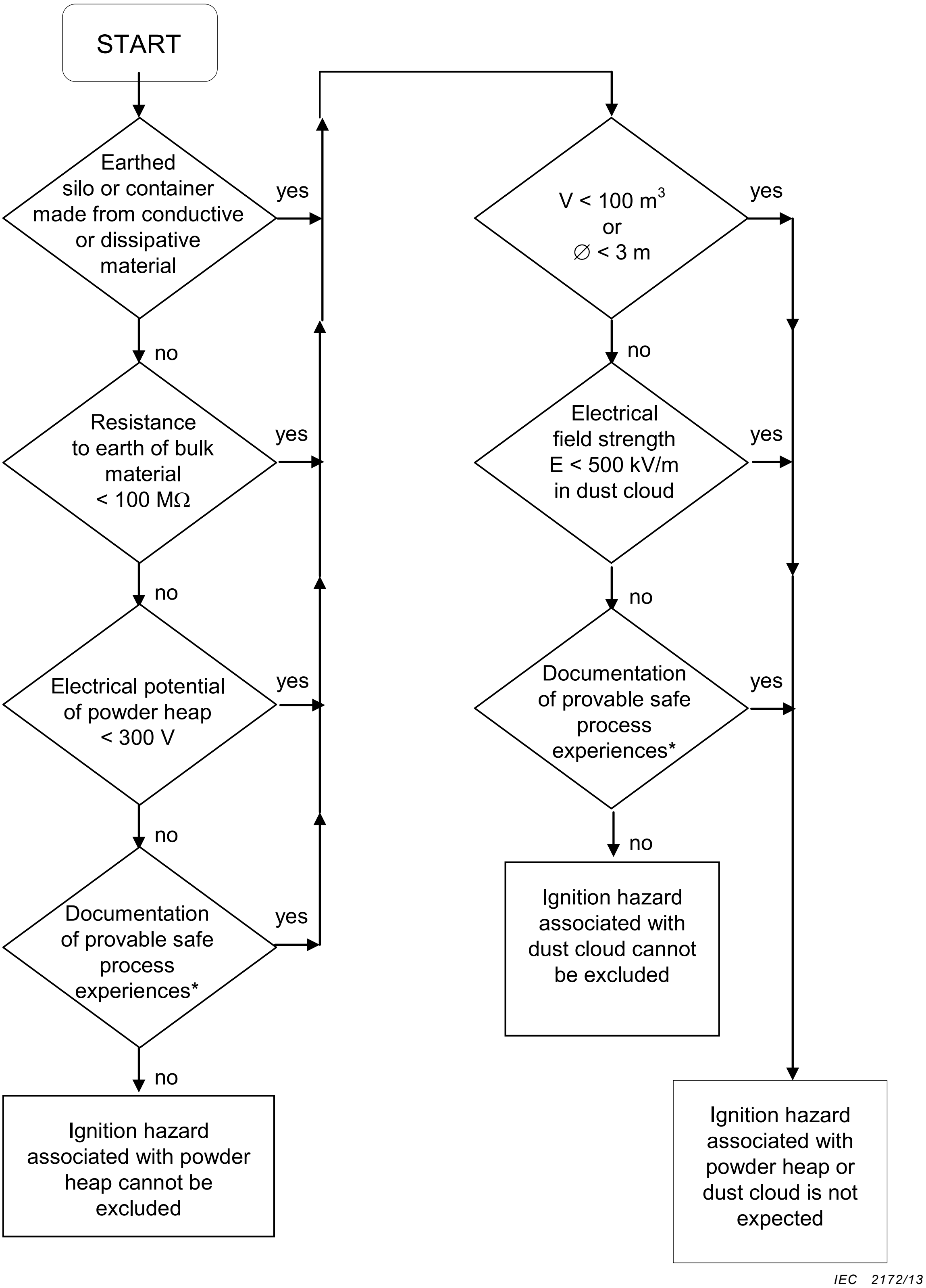
To assess the charge build up on the wall of the silos and containers 9.3 as well as 9.4 should be considered in addition.

During discharging of silos and containers in the absence of flammable gases and vapours no hazardous charge build up on the bulk material has generally to be expected. In addition all discharge and transfer devices require a separate analysis.

NOTE See also 9.3.

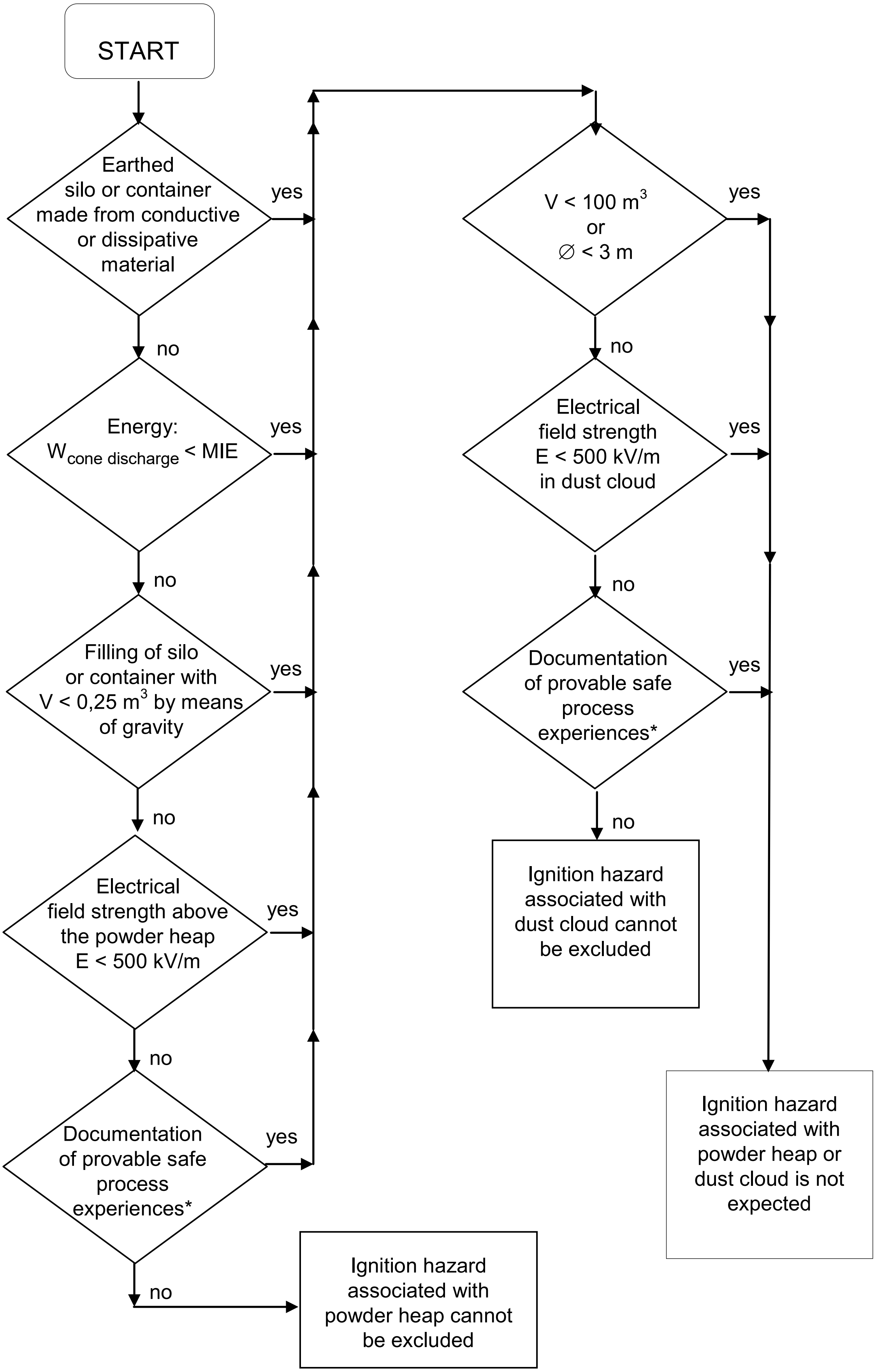
It should however be kept in mind that most discharging operations represent a filling operation for the successive silo or container.

Conductive silos and containers should be earthed and dissipative silos and containers should be in contact with earth during filling and emptying.



* see 9.4.5.2

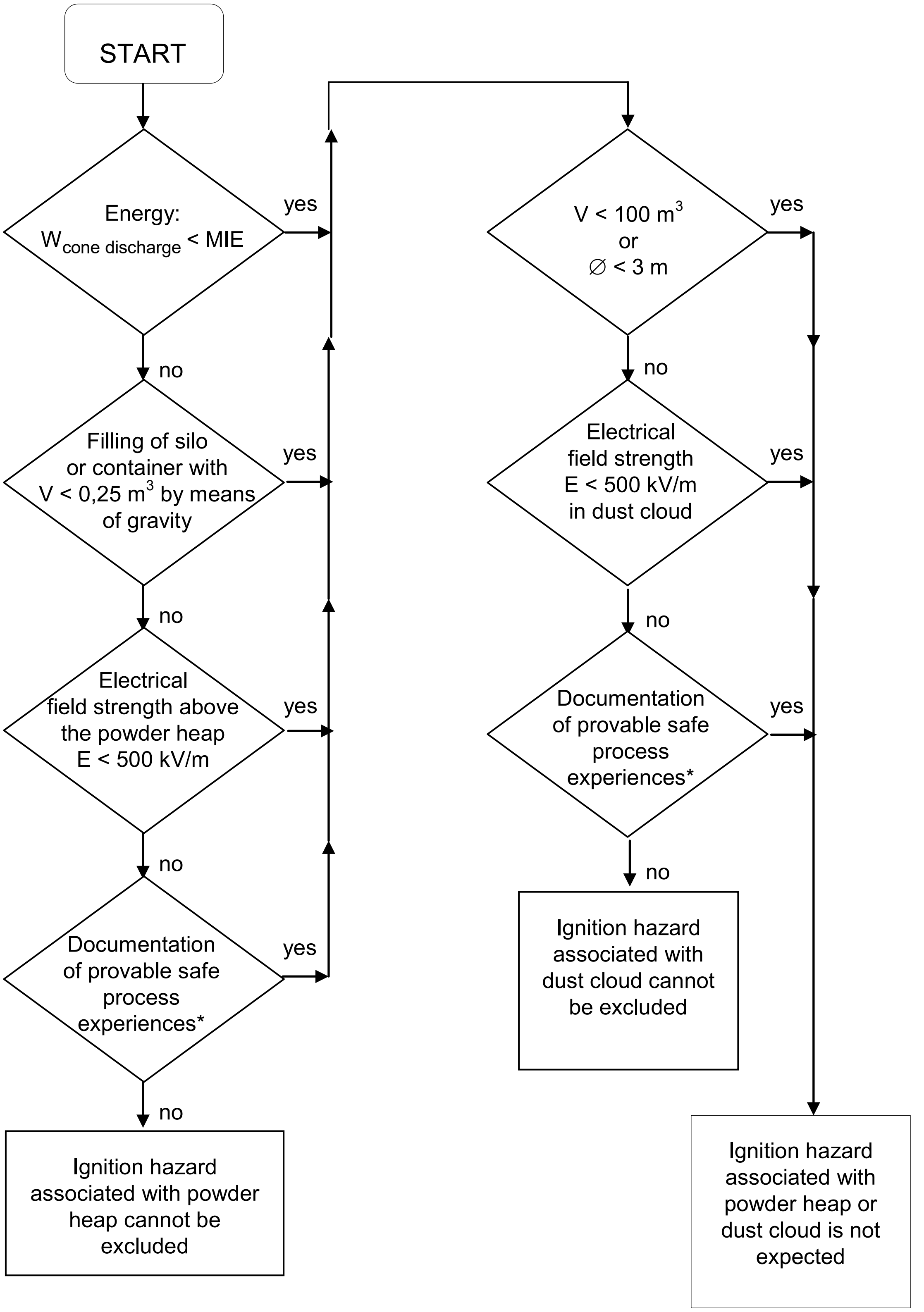
Figure 1 – Flow diagram: Assessment of bulk material with $\rho \leq 1$ MΩ m



* see 9.4.5.2

IEC 2173/13

Figure 2 – Flow diagram: Assessment of bulk material with 1 MΩ m < ρ ≤ 10 GΩ m



* see 9.4.5.2

Figure 3 – Flow diagram: Assessment of bulk material with $\rho > 10$ GΩ m

9.4.5.2 Documentation of provable safe process experiences

If according to one of the flow diagrams in Figures 1 to 3 the ignition hazard is excluded based on the decision step "Documentation of proven safe process experiences", the explosion hazards should have been analysed in detail and subjected to an assessment. In this context it has to be kept in mind that minor changes in the process, product, equipment, packages, etc. may have a significant effect on the occurrence and incendivity of discharges as well as on the occurrence and concentration of an explosive atmosphere. The relevant justification explaining even the most marginal changes and their possible consequences should be explained in an explosion protection document. In any case, protective measures should to be taken (e.g. explosion venting, inerting, design for containment) where credible ignition sources cannot be excluded and flammable atmosphere is present.

NOTE In Europe, the explosion protection document is written according to Directive 99/92/EC.

9.4.5.3 Conductive and dissipative containers with conductive or dissipative liners

In addition to the measures listed in 9.3, only conductive and dissipative liners should be used in hazardous areas if they are safely earthed and if they remain earthed when taken out of or put into the container. This can be established e.g. by a reliable contact to earth via the container and a reliable contact to earth via the person when the liners are taken out or put into the container. Otherwise conductive and dissipative liners should not be taken out of or put into the container in a hazardous area.

9.4.5.4 Conductive and dissipative containers with insulating liners

Insulating liners should in general be avoided due to the risk of propagating brush discharges. They may only be used if, in addition to the measures listed in 9.3, at least one of the following conditions is met:

a) Volume $< 0,25$ m^3,

b) Breakdown voltage $<$ 4 kV (6 kV in the case of woven materials),

c) Liner thickness $>$ 10 mm

d) Documented evidence that no propagating brush discharges will occur.

NOTE Propagating brush discharges may occur depending on the thickness, the resistivity and the breakdown voltage of the liner as well as on the electrical properties of the bulk material. They are not expected for thin paint and polymeric coatings < 50 µm typically found inside containers due to the low breakdown voltage of such coatings.

If the bulk material has a resistivity of less than 100 MΩ m it should be earthed.

Earthing can be achieved e.g. by introducing one or several metal rods or metal pipes into the container leading down to the bottom of the container. These should be introduced prior to the addition of the conductive bulk material.

9.4.5.5 Insulating containers

Insulating containers should in general be avoided due to the risk of propagating brush discharges. They may only be used, if in addition to the measures listed in 9.3 at least one of the conditions a) – d) in 9.4.5.4 is met. If the bulk material has a resistivity of less than 100 MΩ m it should be earthed. Cone discharges should be avoided.

NOTE Propagating brush discharges may occur depending on the thickness, the resistivity and the breakdown voltage of the container as well as on the electrical properties of the bulk material.

9.4.5.6 Insulating containers with liners

Conductive liners should not generally be used in insulating containers due to the risk of them being isolated from earth. If conductive liners are indispensable they should reliably be earthed.

Insulating liners in insulating containers should be assessed as insulating containers according to 9.4.5.5.

9.5 Additional requirements for bulk material in the presence of flammable gases and vapours

9.5.1 General

In the presence of flammable gases or vapours a combination of the gas or vapour concentration and the suspended bulk material concentration (see 3.14) determines whether a flammable gas or vapour/air mixture or a so called hybrid mixture (mixture of flammable gases or vapours and flammable dusts in air) is formed. The minimum ignition energy (MIE) of the mixture is mainly determined by the amount of gas or vapour and commonly lies below the MIE of the pure dust. The flammable gas/vapour may arise from another source (e.g. if a powder is added to a flammable liquid), or from the powder itself (e.g. if it contains significant solvent or may evolve flammable gas).

Special care should be taken when handling solvent wet powders, because when handling large amounts of medium or insulating powders, brush discharges incendive for the evolved gas / vapour or hybrid atmosphere cannot be avoided.

Rather than differentiating between low, average or high resistivities of bulk materials as is the case when no flammable gases or vapours are present, the important limit of the bulk material resistivity in the presence of flammable gases or vapours is only 100 MΩ m.

The following requirements do apply only to gases and vapours of the explosion groups IIA and IIB. In hazardous zones of explosion group IIC inerting is necessary.

9.5.2 Measures for resistivity greater equal 100 MΩ m

The open handling of solvent wet bulk materials with a resistivity greater equal 100 MΩ m should generally be avoided. Where handling of such materials cannot be avoided, additional measures of explosion prevention or protection are normally required, particularly when handling large quantities. Such measures are

a) inerting,
b) processing of the solvent wet material under vacuum,
c) processing at a temperature significantly below the flash point,
d) processing within explosion proof equipment,
e) exclusion of the hybrid mixture, or
f) special constructional measures.

NOTE As handling of bulk material with a resistivity greater equal 100 MΩ m commonly generates a high level of electrostatic charges, brush discharges cannot be avoided and ignition is therefore possible.

9.5.3 Measures for resistivity less than 100 MΩ m

If the resistivity of the bulk material is less than 100 MΩ m, e.g. in case of bulk material containing a polar solvent, the bulk material should be handled in conductive earthed equipment or any other type of equipment that provides a sufficiently large earth point for the bulk material.

NOTE 1 In case of large amounts of bulk material a representative sample is required for an assessment of the resistivity. Instead of the resistivity also the nature and the amount of the solvent content can be used for an assessment.

NOTE 2 The bulk material as well as the flammable liquid might become charged to a hazardous level when filled into a container or added to a liquid.

9.5.4 Filling of bulk material into a container

Filling bulk material into a container containing flammable gases or vapours may lead to the generation of hazardous charging levels at the container to be emptied, at a liner, at the chute pipe or funnel, at the product falling into the collecting receiver, at the collecting receiver, at the product in the collecting receiver or at the operators. Filling of bulk material is, therefore, preferably performed with a closed and / or automated system, typically under inert gas atmosphere.

NOTE 1 Charge build up during the filling of bulk material from metal or plastic drums or from plastic bags has caused many fires and explosions in the past.

NOTE 2 Charge build up occurs when bulk material is discharged from a container or bag or if it flows through a chute, pipe or funnel.

Manual addition to an open vessel should be avoided whenever possible. If the open addition of powder to a container containing an explosive atmosphere cannot be avoided, special measures should be provided to reduce the charge build up:

a) Containers or packages to be emptied should be made from conductive or dissipative material.

b) During emptying, conductive containers or packages should be earthed and dissipative containers or packages should be in contact with earth.

   NOTE 1 Examples of dissipative materials used to make containers include paper, dissipative composite material and some plastic laminated papers. For packages made from dissipative material, e.g. paper bags, an earth contact via the hands of an operator is sufficient. In this case the floor, the shoes, and the gloves should also be dissipative and the resistance to earth should not be increased by contaminants.

   NOTE 2 During storage the dissipative property of the packages may be lost by aging, adsorption or if the relative humidity is low. Steps to increase relative humidity in storage areas may be necessary, especially at wintertime.

   NOTE 3 Dissipative plastic bags are normally not earthed via an earthing clamp but by contact to earth, e.g. by the operator only.

   NOTE 4 It is advantageous to handle sacks and bags etc. on a conductive support shelf or table with a clean surface connected to earth.

c) Insulating liners should not be used if they may come into contact with flammable gases / vapours.

d) Conductive liners should only be used in conductive or dissipative containers. It should be ensured that they are in good contact with the earthed container and remain earthed when they are taken out or put into the container. Otherwise they should not be taken out or put into the container in a hazardous area. During handling the liner should not become detached from the container.

e) Dissipative liners may be used in conductive or dissipative containers. It should be ensured that they are in good contact with the earthed container and remain in contact with earth when they are taken out or put into the container. Otherwise they should not be taken out or put into the container in a hazardous area. During handling the liner should not become detached from the container.

f) Multiple layer packages or packages with insulating coatings should be avoided whenever possible. If they have to be used for other reasons, the following conditions have to be met:
   - The insulating coating should not be thicker than 2 mm, and
   - All conductive or dissipative layers of the package should always be earthed or in contact with earth.

g) Auxiliary devices for the addition of the bulk material should be conductive and earthed. Any chute or funnel should have a maximum length of 3 m.

   NOTE Examples of such auxiliary devices are shovels, funnels, chutes, etc.

h) Earthing of all involved operators should be ensured.

i) The rate of adding the bulk material should be limited to 1 kg/s.

However, due to the high level of risk inherent with such operations, it may still be necessary to use additional control measures to achieve the required level of safety.

If by the addition of the bulk material a suspension or emulsion is formed in the receiving vessel – even only for a short period of time – it should be considered that agitation of such a multiple phase system may generate a hazardous charge build up independent of the charging procedure. In these cases 7.9.4 has to be taken into account.

NOTE 3 A typical example is the addition of pigments when manufacturing dyes, lacquers and paints.

9.6 Flexible intermediate bulk containers (FIBC)

9.6.1 General

Flexible intermediate bulk containers (FIBC) are used in industry for storage and transport of powders and granules. They are commonly constructed from polypropylene fabric or similar strong and heavy duty insulating material.

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

The requirements and specifications which FIBC should meet depend on the nature and sensitivity of the flammable atmosphere present during filling and emptying. The final goal for the construction of FIBC is to exclude incendive discharges from the FIBC fabric during their intended use. Since discharges of different incendivity (i.e. different types of discharges, such as spark, brush or propagating brush discharges) may be generated, the necessity of their exclusion and thus the requirements for construction of the FIBC depends on the intended use of the FIBC. For this reason different types of FIBC have been developed, which are defined as Type A, B, C or D (see IEC 61340-4-4):

- Type A FIBC are made from fabric or plastic sheet without any measures against the build up of static electricity.
- Type B FIBC are made from fabric or plastic sheet designed to prevent the occurrence of sparks and propagating brush discharges.
- Type C FIBC are made from conductive fabric or plastic sheet, or interwoven with conductive threads or filaments and designed to prevent the occurrence of incendiary sparks, brush discharges and propagating brush discharges. Type C FIBC are designed to be connected to earth during filling and emptying operations.
- Type D FIBC are made from static protective fabric designed to prevent the occurrence of incendiary sparks, brush discharges and propagating brush discharges, without the need for a connection from the FIBC to earth.

Depending on the mechanism applied to exclude incendive discharges, the requirements which the different types of FIBC should meet, refer either to purely physical parameters such as breakdown voltage and conductivity (Type B and C) or to more general procedures in which it should be demonstrated that no incendive discharges occur (Type D). These requirements are given in IEC 61340-4-4.

The four different types of FIBC should be used as shown in Table 19. Other types of FIBC or FIBC of unknown type should only be used in the presence of flammable atmospheres after detailed evaluation by an expert.

Document pockets and pouches made from insulating material should fulfil the requirements of IEC 61340-4-4 which are similar to 6.3. In the case of document pockets for Type C it should be considered that they are usually backed with an earthed conductive fabric which helps to prevent a high surface charge.

Table 19 – Use of the different types of FIBC

Bulk Product in FIBC	**Surroundings**		
MIE of dust[a]	**Non flammable atmosphere**	**Dust zones 21-22**[b]	**Gas zones 1-2**[b] **(Explosion Groups IIA/IIB)**[c]
MIE > 1 000 mJ	A,B,C,D	B,C,D	C,D[d]
3 mJ < MIE ≤ 1 000 mJ	B,C,D	B,C,D	C,D[d]
MIE ≤ 3 mJ	C,D	C,D	C,D[d]

[a] Measured in accordance with IEC 61241-2-3, ASTM E2019 and EN 13821 with a capacitive discharge circuit (no added inductance).

[b] See D.2 for the definition of zones.

[c] See D.3 for an explanation of Explosion Groups.

[d] Use of Type D should be limited to Explosion Groups IIA/IIB with MIE ≥ 0,14 mJ.

NOTE 1 Additional precautions are usually necessary when a flammable gas or vapour atmosphere is present inside the FIBC, e.g. in the case of solvent wet powders.

NOTE 2 Non-flammable atmosphere includes dusts having a MIE > 1 000 mJ.

NOTE 3 The MIE limit of 3 mJ is based on the incendivity of cone discharges. Cone discharges might have a much higher energy in a Type B FIBC than in a Type C or D FIBC because the wall of a Type C or D FIBC will be at close to zero potential. Based on this fact the internal field distribution will be such that in Type C or D FIBC cone discharges will at most only jump across half the diameter of the FIBC. A calculation with the formula given in A.3.7 for the largest FIBC commonly used (diameter of 1,5 m) yields 3 mJ for powder with a median size of only 0,055 mm in a Type B FIBC, whereas in a Type C or D FIBC the 3 mJ limit is only reached with a coarse powder having a median size of 0,27 mm or higher. However, such coarse powders usually have a MIE higher than 3 mJ.

In order for a propagating brush to occur from a FIBC in practice, it is generally necessary to handle a high resistivity powder in a way that leads to high levels of electrostatic charge generation (e.g. pneumatic transfer). If these conditions are not met, particularly with medium or high MIE powders, then a detailed expert assessment may conclude that the risk of an incendive propagating brush discharge is acceptably low.

The ability to use FIBC safely in hazardous explosive atmospheres may change if an inner liner is installed in the FIBC. Combinations of FIBC and inner liner that can be used safely in hazardous atmospheres are shown in Table 20. In addition there are some precautions that certain combinations of FIBC and inner liner should meet. These precautions are also shown in Table 20.

Table 20 – Inner liners and FIBC: combinations that are permissible and not permissible in hazardous atmospheres

FIBC[a]	Inner Liner[b]		
	Type L1	**Type L2**	**Type L3**
Type B	Not permissible	Permissible	Permissible
Type C	Permissible[c]	Permissible	Not permissible
Type D	Not permissible	Permissible[d]	Not permissible

[a] Type A FIBC should not be used in hazardous explosive atmospheres irrespective of the type of liner used.

[b] Liners should not be removed from emptied FIBC in hazardous explosive atmospheres.

[c] To ensure the inner liner is properly earthed, the resistance from at least one side of the inner liner to the groundable points on the FIBC should be less than 10 MΩ, measured according to 9.3 of IEC 61340-4-4:2012 under the conditions specified in 8.1 of IEC 61340-4-4:2012.

[d] Combination of FIBC and liner should meet the requirements of 7.3.2 of IEC 61340-4-4:2012 tested under the conditions specified in 8.2 of IEC 61340-4-4:2012.

NOTE Electrostatic discharges from isolated conductive liners may cause painful shocks to operators or disrupt the operation of electric/electronic equipment.

- Type L1 inner liners are made from materials with surface resistivity on at least one surface of less than 10 MΩ and, where necessary, a breakdown voltage through the material of less than 4 kV.
- Type L2 inner liners are made from materials with surface resistivity on at least one surface between 1 GΩ and 1 TΩ and a breakdown voltage through the material of less than 4 kV.
- Type L3 inner liners are made from materials with surface resistivity of greater than 1 TΩ and a breakdown voltage through the material of less than 4 kV.

NOTE Breakdown voltage measurements are only necessary for certain configurations of Type L1 and Type L2 inner liners, i.e. when one of the surfaces has a surface resistivity of greater than 1 TΩ. More detailed specifications for Types L1, L2 and L3 inner liners are given in the IEC 61340-4-4.

Inner liners made from materials that contain a conductive layer sandwiched between two insulating layers should not be used in Type B or Type D FIBC. If such an inner liner is used in Type C FIBC, the conductive layer should be securely connected to earth.

Other types of inner liner or inner liners of unknown type should only be used in the presence of hazardous explosive atmospheres after detailed evaluation by an expert.

Insulating lifting belts and loops for FIBC should comply with the width restriction in Table 3. Metal fittings (shackles) for connection between belts and ropes for FIBC should not be used for FIBC Types B and D. For Type C they should be earthed.

9.6.2 Additional precautions when using FIBC

Isolated conductive objects (e.g. tools, bolts, clips, etc.) should not be stored on, attached to, or even temporarily placed on any type of FIBC during filling and emptying operations. Even with Type C FIBC, the rough nature of some FIBC materials may prevent conductive objects placed on the FIBC from contacting the conductive elements in the fabric of the FIBC.

In hazardous areas, all conductive objects within the immediate vicinity of any FIBC (i.e. less than about 1 m away) should be properly earthed during filling and emptying operations.

Precautions should be taken to prevent the contamination of any FIBC with substances (e.g. water, rust, oil, grease, etc.) that might create an ignition hazard or impair charge dissipation.

10 Static electricity when handling explosives and electro-explosive devices

10.1 Explosives manufacture, handling and storage

10.1.1 General

Static electricity accumulated on isolated conductors or people may cause the ignition of explosives with severe or even catastrophic results. There are various types of explosives (solid, powder or liquid) and they may be encountered in many forms such as bulk, bagged, plastics, pelleted, compacted, moulded or filled into metal or plastics containers. Before handling or processing explosives, consideration should be given to the specific recommendations given in 10.1.2 to 10.1.4, but in addition reference should be made to those clauses of this document that are relevant to the particular operations to be performed.

The energy required in a spark to cause ignition of an explosive varies with the type of explosive and its physical state. In general, primary explosives are much more sensitive than propellants or high explosives, while pyrotechnics exhibit a wide range of sensitivity.

The extent of the precautions that should be applied depends upon the minimum spark energy for ignition, and explosives may be divided into three classes depending upon this minimum spark energy. It is essential to understand that the minimum spark energy for ignition of explosives is measured by means of a specialised test for specific use with explosives.

The three classes of explosives and the precautions that should be adopted for them are given in 10.1.2, 10.1.3 and 10.1.4. Deviations from these recommendations should not be made without taking expert advice. Specialised earthing techniques are used in the explosives industry for sensitive or very sensitive explosives.

A relative humidity of more than 40 % should be maintained. Higher humidity may be required when handling more sensitive materials.

10.1.2 First degree protection

These comparatively insensitive explosives have a minimum spark energy for ignition greater than 450 mJ, and the precautions given here are sufficient when they are handled.

All large conductive objects, such as fixed plant and equipment systems, should be earthed. Where the earthing is by means of metallic conductors the resistance to earth should be less than 10 Ω. This resistance indicates a reliable earth connection with a metallic conductor. Non-metallic materials may also be used for earthing providing they meet the requirements of Clause 13.

10.1.3 Intermediate protection

These are sensitive explosives with sensitiveness between those dealt with in 10.1.2 and 10.1.4, and have minimum spark energies for ignition greater than 1 mJ and less than or equal to 450 mJ.

Depending on the properties of the particular explosive and the way in which it is handled, some relaxation of the full precautions given in 10.1.4 may be acceptable. Specialist advice should be sought to determine the level of precautions applicable to each specific case.

10.1.4 Second degree protection

The minimum spark energy for ignition of these very sensitive explosive materials is less than or equal to 1 mJ and the following precautions are required:

a) All equipment, including movable and portable items, should be earthed. The earth resistance should not exceed 10 Ω in the case of metal parts and 100 kΩ in all other cases. Insulating materials should be rigorously excluded.
b) All people should be earthed by means of floors with maximum leakage resistance of 50 kΩ, and footwear with maximum leakage resistance of 100 kΩ. A personnel resistance monitor should be installed at every entrance to any area where such footwear is required. When handling compositions having ignition energies of less than 0,1 mJ, consideration should be given to the installation of personnel resistance monitors at the individual work stations.
c) Outer clothing should not be made from insulating materials. Clothing should in no circumstances be removed in the area where the explosive is being handled (see 11.5).
d) Conductive objects which could act as spark promoters should be avoided, for example rings on people, wet fingers, conductive tools or wires.
e) The relative humidity of the atmosphere should not be less than 65 %.
f) Care should be taken to prevent a number of small capacitances becoming electrically coupled together to give a much larger capacitance.
g) Use of insulating gloves should be avoided. It is advisable to avoid use of gloves entirely where toxicity or other considerations do not prevent it.

10.2 Handling of electro-explosive devices

10.2.1 General

Electro-explosive devices such as electric detonators may inadvertently be ignited by a discharge of static electricity, either through the fusehead or between the metal case and the fusehead. Many electro-explosive devices can be more sensitive to electrostatic energy in this latter configuration. The static electricity may accumulate on an isolated person as a result of their movements, and people and items of equipment may become charged during thunderstorms, dust or dry sand storms. Charge may also be generated during the pneumatic loading of bore holes with granular blasting explosives.

Precautions to avoid the hazard are given in 10.2.2 to 10.2.4 inclusive and they should be observed at all times when electro-explosive devices are being handled, that is during storage, issue and preparation for use.

It should be recognised that there are other sources of hazard when handling electro-explosive devices, for example the pick-up of energy from sources of electromagnetic radiation and testing for continuity of the firing circuit. Appropriate manuals should be consulted for these.

10.2.2 Earthing

People should have an adequately conductive path to earth, for example by wearing conductive footwear, and preferably they should wear cotton type clothing. However, in some environments, for example mines, continuous earthing of people may not be feasible, and it is recommended that the procedures in 10.2.3 and 10.2.4 should therefore always be followed.

All conductive equipment in the area, such as rails and piping, and all machinery should be earthed. It should be noted that other codes of practice may also require conductors to be bonded to each other to avoid any difference in potential between them which might cause a current to flow through lead wires making contact with them.

If a granular type explosive is being loaded pneumatically into a bore hole, the loading equipment should be earthed. The hose assembly should be conductive or dissipative and should be connected to earth. Specialised codes of practice exist on this subject and should be consulted.

10.2.3 Precautions during storage and issue

Electro-explosive devices are received from the manufacturer with the leads folded and wrapped and the bare ends twisted together. If the bare ends are found to be unconnected, the operative should earth himself and reconnect them. If the possibility of significant electromagnetic fields exists then care will need to be taken to ensure that such procedures do not create a radio frequency ignition hazard. These devices should not be packaged or transported in insulating materials, e.g. polyethylene bags or polystyrene foam packs; the use of metallic or conductive packs is advised for this purpose and these may also provide some protection against any radio frequency hazard.

10.2.4 Precautions during preparation for use

When the firing cable has been laid out the bare wires at each end should be connected to each other and to a suitable earth, such as a metal rod driven into the ground, which should be wetted if very dry. This cable and all other leads should be kept separate from conductors in the area, such as rails and piping.

A check should be made to see that the device leads are connected together. After connecting them if necessary (see 10.2.3), they should be earthed to the earth rod or other suitable earth at the firing end. The device leads can then be uncoiled and laid along the ground.

The operative should then make sure that they are earthed before they handle the metal case of the device prior to connecting it to the firing cable.

Appropriate precautions should be taken against atmospheric electricity (e.g. lightning) according to the type of device used.

11 Static electricity on people

11.1 General considerations

It is very important that people who may be exposed to flammable atmospheres having a MIE less than 10 mJ should be earthed to prevent them from becoming electrostatically charged. Isolation from earth can occur due to the fact that many floor coverings and the soles of footwear are made from insulating materials. There are many mechanisms that can cause a person to become charged and the following are examples:

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

If an electrostatically charged person touches a conductive 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 a person are capable of igniting gases, vapours and even some of the more sensitive dusts.

It is very important that people who may be exposed to flammable atmospheres having MIE < 10 mJ should be prevented from becoming electrostatically charged by being earthed. This is best achieved by having a conductive or dissipative floor and ensuring that people wear dissipative footwear. However, in Zone 2 and in Zone 22 earthing of people is required only when charge generation is continuous.

NOTE The worst case voltage which may commonly be acquired by people is about 20 kV. With the typical capacitance of the human body being about 150 pF, the resulting maximum stored energy is about 30 mJ. However, due to the high ohmic resistance of the human skin about two thirds of the stored energy gets lost. For this reason, sparks from the human body have a maximum equivalent ignition energy of only 10 mJ except when handling large conductive tools.

11.2 Static dissipative floors

The recommended leakage resistance for floors is 1 MΩ to 100 MΩ (see Clause 13). In many factory environments the conventional flooring materials, for example, bare concrete or steel grids, are adequately conductive. In order to remain effective, the floor should not be covered by insulating paint, rubber mats or plastic sheet, etc., and care should be taken to prevent the build-up of contaminants such as resin or other insulating substances, and its resistance should be regularly checked.

In case of a bare metal surface floor (e.g. steel grating and plate) the use of appropriate footwear (see 11.3) is necessary to prevent dangerous electrical shocks to people.

There are several standards published with different measuring methods for testing the conductivity of a floor. In IEC 61340-4-1 the test is executed with a circular electrode, (65 ± 5) mm in diameter pressed to the floor with 2,5 kg (hard floor) or 5,0 kg (soft floor). In ISO 10965 measurement is done with a circular electrode, 65 mm in diameter pressed to the floor with 5,0 kg. ASTM F150 uses a circular electrode, 63,5 mm in diameter pressed to the floor with 2,5 kg. EN 1081 uses a three-footed electrode pressed to the floor by a person standing on it. As each method yields a somewhat different resistance it is important that the measuring method used is stated in product specifications and test reports.

NOTE 1 In ideal cases the differences between the measured resistances of the different methods described above are small. In reality, rough surfaces, e.g. external concrete forecourts with significant stone content standing proud may influence the measured resistance depending on the electrode surface used and the applied pressure. Improved results may be obtained with conductive foam pads under IEC 61340-4-1 electrodes to take up roughness of several mm. However, this may not replicate the practical situation of a person’s footwear with hard soles.

NOTE 2 The values in this paragraph do not necessarily apply to situations where sensitive explosives are handled. See Clause 10 for special requirements in this case.

11.3 Dissipative and conductive footwear

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

a) dissipative footwear has both an upper and a lower resistance requirement (see 3.9). The upper level is low enough to prevent the build-up of electrostatic charge in most situations 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;

   NOTE 1 ISO 20345 defines antistatic (dissipative) footwear as having resistance measured in accordance with ISO 20344 of between 100 kΩ and 1 GΩ. Antistatic (dissipative) footwear defined by ISO 20345 may not satisfy the resistance requirements specified in this document.

   NOTE 2 Dissipative shoes should not be worn as the primary protective measure against mains electricity as this may encourage people to work on live electrical systems, although under some circumstances (e.g. when wet) the shoes may be ineffective.

   NOTE 3 Resistance of dissipative materials made from rubber containing carbon black sometimes increases with decreasing temperature.

b) conductive footwear has a very low resistance (see 3.3) and is worn, for example, by people 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.

NOTE Except in the case of very sensitive explosives only dissipative footwear is usually required.

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

Dissipative footwear used in conjunction with conductive or dissipative flooring provides a means to control and dissipate static electric charges from the human body. Resistance to earth through dissipative footwear and conductive flooring should be between 100 kΩ and 100 MΩ. For handling explosive materials the resistance to earth through footwear and flooring should be less than 1 MΩ, or less than 150 kΩ if the minimum spark energy for ignition of the explosive is less than or equal to 1 mJ.

Resistances can be measured with commercially available footwear conductivity testers which measure the resistance between a hand-held metal bar via body and feet to a metal plate on which the person stands. Alternatively, the resistance between a shoe filled with shot pellets and a steel plate on which the shoe is pressed can be measured according to IEC 61340-4-3.

The resistance of footwear can increase with the accumulation of debris on the footwear, use of orthopaedic insoles, and reduced floor contact area. The conductivity of footwear should be tested frequently to confirm functionality.

11.4 Supplementary devices for earthing of people

Where dissipative footwear will not provide adequate earthing of the person, supplementary devices should be used. Such devices include wrist straps, heel/toe grounders and conductive overshoes.

Supplementary devices should be selected so that accumulation of hazardous static electric charge is prevented, while the risk of electrocution is not increased. In most practical situations, earthing of people is achieved by ensuring a resistance to earth of 100 MΩ or less. The need to protect against electrocution via an earthing device imposes a minimum resistance from skin to ground of 100 kΩ. Based on skin contact and contact with the floor, especially during activities where the entire sole of the footwear is not in contact with the floor (e.g., kneeling), effectiveness can be compromised. Earthing devices should have a minimum resistance of 100 kΩ for shock protection.

The simplest type of commercial device is an earthing bracelet with a built-in resistor typically giving a resistance to ground of about 100 kΩ for shock protection. Wrist straps of this type have the greatest utility at ventilation hoods and at other locations where limitation on the operator’s mobility can be tolerated. Breakaway wrist tether systems could be necessary where emergency egress is needed. A hood can be equipped with two external coiled earthing cords with cuff attachments that can be removed and kept by individual users. Earth continuity should be checked periodically to the manufacturer’s specified limits.

11.5 Clothing

In spite of the fact that modern clothing, made from synthetic textiles, can readily become electrostatically charged it is not, in many cases, an ignition risk providing that the wearer is earthed by means of suitable footwear (see 11.3) and flooring (see 11.2), or by other means such as a wrist strap and earth bonding cord. However, clothing should provide proper fitting and sizing (see ISO 13688) and allow full body movement with all closures fastened according to manufacturer’s instructions. Clothing should be as close fitting as is practical and should not be removed or unfastened in areas where there could be flammable atmospheres (e.g. Zone 0, Zone 1, Zone 20 and Zone 21).

Although the likelihood of ignition by a grounded person due to any type of clothing is usually very low, the charging of people (e.g. when a person is getting out of a forklift truck) is greatly increased by clothing that has high resistivity.

In situations where there is a combination of high charging activities and the presence of low MIE gases or vapours, the use of dissipative clothing may be required. Table 21 provides guidance on when dissipative clothing may be required. Border limits for dissipative clothing are given in Table 1.

Test methods and performance requirements for personal protective clothing for use in flammable atmospheres are contained in EN 1149. Dissipative clothing should cover all other clothing. The outer clothing should be earthed either through contact with the body of the wearer, or by direct earth connection. In the case of clothing with integrated conductive fibres earthing of the person with a resistance of less than 100 MΩ is sufficient.

Clothing for use in flammable atmospheres is Category II Personal Protective Equipment and should comply in Europe with the Essential Health and Safety Requirements of EC Directive 89/686/EEC.

NOTE 1 Although silk and most synthetic fibres are excellent insulators and undergarments made from these materials exhibit static phenomena, no evidence exists to indicate that wearing such undergarments constitutes a hazard.

NOTE 2 Clothing with integrated conductive fibres does not prevent the wearer from electric shocks.

NOTE 3 The resistance of dissipative materials made from rubber containing carbon black may sometimes increase with decreasing temperature.

Table 21 – Determination of requirement for electrostatic dissipative protective clothing and other items of personal protective equipment

Hazardous Zone	Probability of Charging	$0{,}02\ \text{mJ} \le \text{MIE} \le 0{,}20\ \text{mJ}$	$\text{MIE} > 0{,}20\ \text{mJ}$
Zone 0	High	Required	Required
	Low		Recommended
Zone 1	High		
	Low		Not Required
Zone 2	High	Recommended	
	Low	Not Required	
Zones 20, 21 or 22	-	Not Required	

In oxygen-enriched atmospheres, such as those that could be present in liquid oxygen filling plants, vapour from the cooled gas can permeate an employee’s clothing, increasing its combustibility. Clothing can then be easily ignited by static electricity discharges from charged people or clothing.

The MIE of oxygen-enriched atmospheres may be less than the MIE of the flammable substance commonly found in literature. If it is determined that an oxygen-enriched atmosphere may occur, care should be taken to ensure the value of the MIE used for the purposes of risk assessment is that measured using the oxygen-enriched atmosphere.

Expert advice should be obtained before selecting electrostatic dissipative protective clothing or equipment for use in hazardous zones with MIE less than 0,02 mJ. The requirements specified in EN 1149-5 are based on explosive atmospheres with MIE of 0,02 mJ or greater.

If clothing becomes contaminated with flammable solvents, there is a risk of electrostatic ignition if the clothing is removed or other high charging activities occur. Unless there is an immediate risk of chemical burn or toxicity, clothing that is contaminated with flammable solvents should be doused with water or the flammable solvent allowed to evaporate before the clothing is removed.

Metallic fibres (e.g. stainless steel, silver coated fibres, etc.) and other fibres of very low resistivity that may be used in dissipative clothing do not prevent electrostatic shock hazards. Such fibres should, therefore, only be used with caution in areas where there may be a risk of electrostatic shock.

NOTE Metallic fibres can cause small nuisance shocks to be felt where clothing contacts the skin (e.g. at the wrists and neck). Such shocks are caused by localised discharges between the skin and the metallic fibres.

The electrostatic properties of protective clothing may change with wearing time, after cleaning procedures or after exposure to extreme conditions. Clothing should be maintained in accordance with manufacturers' instructions. For example it may be necessary to re-treat clothing with a special finish each time it is washed.

11.6 Gloves

Gloves made from insulating materials could allow objects held in the hand to become and remain charged. Gloves worn in Zone 0 and Zone 1 should, therefore, be made from dissipative or conductive materials. They may be tested while worn in conjunction with footwear. Typically the resistance is measured between a hand-held metal bar and a metal plate on which the person stands. The same resistance limits as prescribed for footwear should be applied (see 11.3).

Gloves for use in flammable atmospheres are Category II Personal Protective Equipment and should comply in Europe with the Essential Health and Safety Requirements of EC Directive 89/686/EEC.

NOTE 1 The test procedures described in the paragraph above are suitable for end-user verification and daily checking of gloves within the glove/person/footwear system. For type qualification testing, additional product standards may apply, e.g. CEN are developing a product standard for personal protective gloves against electrostatic risks.

NOTE 2 In some cases the basis for hand protection will be prevention of exposure to toxic substances and it may not be possible to specify a glove which simultaneously meets the goals of static charge dissipation and chemical resistance. In such cases it may be necessary to provide an alternative means of earthing conductive hand-held objects.

When the intended path to earth for conductive objects or tools held in the hand is via a person wearing gloves, the electrical resistance measured through the gloves should be less than the overall resistance to earth limit. For general use the resistance to earth via the gloves should be less than 100 MΩ, and for more critical applications (e.g. handling sensitive explosives) the resistance to earth via the gloves should be less than 100 kΩ.

11.7 Other Items

Protective helmets, breathing apparatus, visors etc. made from plastics may become charged, but if they are used with care in accordance with manufacturer's recommendations, they are unlikely to present an electrostatic ignition risk in Zone 1, Zone 2, Zone 20, Zone 21 or Zone 22 areas, provided there are no high charging activities. As with clothing, there may be electrostatic ignition risks if there is a combination of high charging activities (e.g. wiping a visor) and low MIE gases or vapours present. The guidance given in Table 21 may also be interpreted for use with other items of personal protective equipment. In areas where the use of dissipative items is indicated in Table 21, personal protective equipment should be made from dissipative or conductive materials according to Table 1 and earthed via the body of the wearer. Any insulating materials used in the construction of personal protective equipment should be limited in area as indicated in Table 3.

12 Electrostatic shock

12.1 Introduction

The discharge of static electricity through a person's body can cause an electrostatic shock. The smallest discharge energy a person can feel to or from his body is about 1 mJ. As this energy is increased variations in response are observed. Some people find 10 mJ uncomfortable due to muscular contraction, whereas others can accept several hundred mJ before they experience sharp muscular contraction. 1 000 mJ, however, affects everybody severely. In incidents in which people have been rendered unconscious, the discharge energy was estimated to be several joules.

Since in most situations electrostatic discharge energies are below 100 mJ, serious physiological shocks are very rare. Irrespective of whether the shock itself is harmful, the involuntary muscular reaction resulting from the shock can cause an accident leading to injury or even death through e.g. dropping of an instrument or precipitating a fall. In addition to these hazards, the electrostatic discharge that normally precedes these shocks can also ignite flammable atmospheres.

Electrostatic 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 (several or tens of kV), and safe/hazardous levels are expressed in terms of energy or charge, as opposed to current.

12.2 Discharges relevant to electrostatic 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 electrostatic shocks to people:

a) brush discharges can occur when a person moves close to or touches a highly charged insulator (solid or liquid);

b) spark discharges can occur when a person makes contact with a highly charged conductive body;

c) propagating brush discharges can occur due to, for example, a person handling plastic sheets being charged positive on one side and negative on the opposite side, 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 isolated metal objects (funnels, cans, hand tools) do not cause electrostatic 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.

12.3 Sources of electrostatic shock

Many industrial and non industrial processes can lead to electrostatic shocks. There are two scenarios defined in 1 and 2 below that describe how such electrostatic shocks can occur:

1a) there is a prolific source of charging; and

1b) the charge is able to build up on an object, normally a conductor or a conductive backed insulator; and

1c) a person is able to make contact with the object.

or

2a) there is a prolific source of charging; and

2b) a person gains high voltage through direct charging or induction; and

2c) the charged person then touches an earthed conductor.

Examples of prolific charging processes are:

a) Belts or film passing rapidly over rollers;

b) Pneumatic conveying of materials;

c) Pumping low conductivity liquids through filters or other restrictions;
d) Spraying using electrostatic spraying equipment;
e) Filling of Type A FIBC with highly insulating powders or pellets;
f) Escape of wet steam;
g) Fire-extinguishers which emit charged drops or particles;
h) Moving of forklift trucks or other vehicles on insulating surfaces or with insulating tires.

12.4 Precautions to avoid electrostatic shocks

12.4.1 Sources of electrostatic shocks

Electrostatic shocks can be due to charge built-up on a person or on isolated conductive parts or on insulating materials in a process or equipment.

12.4.2 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.

The most effective precaution that can be taken to avoid electric shocks is to earth all metal and conductive parts of machinery and plant (for details see Clause 13). However, this precaution is not always possible and, even when it is done, there can still be problems due to highly charged insulating (solid and liquid) materials.

Other precautions include:

a) Reducing the rate of charge generation. This has limited application but the use of dissipative additives can be effective, mainly when used with liquids;
b) Reducing charge build up on non-conductors. Static eliminators are useful for removing charge on moving film and webs;
c) Preventing people from making contact with charged parts. This approach is useful for processes such as electrostatic spraying (see 8.7) or other processes that have highly charged parts. People can be protected from contact with such parts by using suitable insulation, earthed screens, etc;
d) Using a flooring or floor covering material having a resistance to earth of less than 100 MΩ. People, vehicles including forklift trucks or cars in car parks can become charged when moving on a high resistance floor.

12.4.3 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.

Typical charge generating situations are walking on high resistance flooring or rising from seats covered with certain materials. Activities such as pushing trolleys with insulating wheels can exacerbate charging of people while walking.

Shocks due to charge build-up while walking can usually be prevented by using floor coverings having a resistance to earth of less than 100 MΩ.

Direct charging of people can be reduced by wearing dissipative clothing and earthing the person e.g. through static dissipative or conductive flooring and footwear (see 11.2 and 11.3).

However, low resistance earthing (< 100 kΩ) of people should not be used generally since it can lead to more serious electric shocks, for example, when a person makes contact with a highly charged conductor or with mains electricity.

12.5 Precautions in special cases

12.5.1 Pneumatic conveying

Moving powders, granules or small objects from one place to another by blowing or sucking 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) A build-up of conductive objects inside an insulating pipe should be earthed before attempts are made to clear it. (A metal rod attached to an earthed conductive wire is suitable);
b) When pneumatically conveyed conductive objects collect in an insulating container there should be an earthed contact at the base of the container or people should be prevented from touching the contents;
c) When pneumatically conveyed insulating powder or granules collect in large ($\geq 1\ m^3$) insulating containers people should be prevented from touching the contents (see also 9.2 and 9.6).

12.5.2 Vacuum cleaners

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

The following precautions should be taken:

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

12.5.3 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:

a) Earth all conductive parts, especially the central former (or roller) before it is touched by a person;
b) Use static eliminators, especially at a suitable distance after points of high friction or pressure such as nip rolls, e.g. in printing machines between presser and first roller and before entering the print region;
c) Use dissipative materials for rolls, formers and sleeves;
d) Use paints, inks and glues with an electric conductivity of at least 10 000 pS/m;
e) Increase relative humidity;
f) Reduce film speed;
g) Reduce pressure and/or friction between film and rollers;
h) Where flammable gases or vapours are present, the maximum permissible electric field for a free span of film of at least 150 mm away from earthed contact points should be 200 kV/m. Alternatively, the maximum surface charge density should be less than $2\ \mu C/m^2$.

12.5.4 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. For this reason 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.

13 Earthing and bonding

13.1 General

By far the most effective method of avoiding hazards due to static electricity is to connect all conductors 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 flammable 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 medium or low conductivity liquids, and metal tools or pools of conductive liquid on the surface of insulating 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. Clause 13 deals only with protection against static electricity.

Bonding is used to minimize the potential difference between conductive objects to an insignificant level, even where the resulting system is not earthed. Earthing, on the other hand, equalizes the potential difference between the objects and the earth. Examples of bonding and earthing are illustrated in Figure 4.

NOTE 1 An often-used synonym for earthing is grounding.

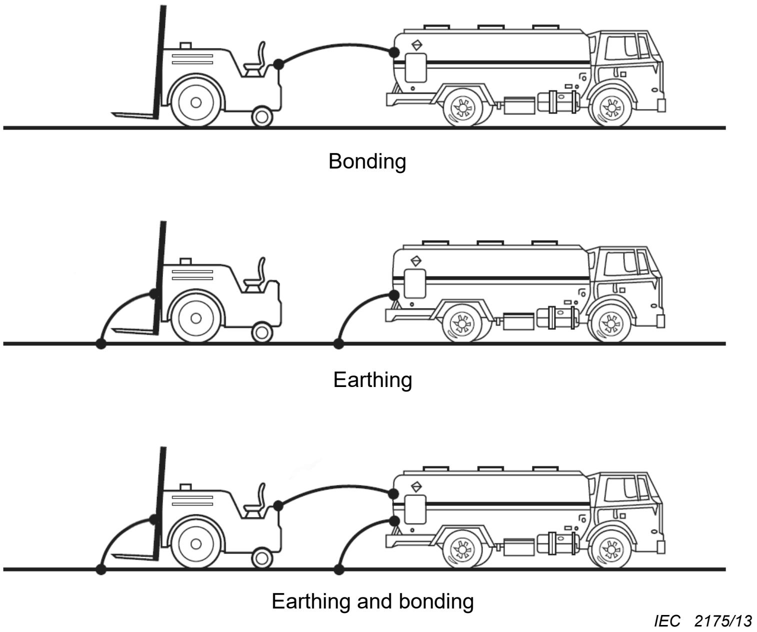


Figure 4 – Difference between earthing and bonding

A conductive object can be earthed by a direct conductive path to earth or by bonding it to another conductive object that is already connected to the earth. Some objects are inherently bonded or inherently earthed because of their contact with earth.

The total resistance between an earthed object and the ground is the sum of the individual resistances of the earth wire, its connectors, other conductive materials along the intended earthing path, and the resistance of the earth electrode (i.e. earth rod) to the ground.

Most of the resistance in an earth connection may exist between the earth electrode and the earth itself. This earth resistance is quite variable because it depends on the area of contact, the resistivity of the soil, and the amount of moisture present in the soil.

NOTE 2 Depending on their resistivity, dissipative objects may need to be earthed too. Insulating materials cannot be earthed.

13.2 Criteria for the dissipation of static electricity from a conductor

13.2.1 Basic considerations

The resistances of the electrical paths need to be sufficiently low to permit the relaxation of charge and to prevent the potential on a conductor building up a hazardous level. 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. Due to this principle the total resistance to earth should not exceed an acceptable maximum given by the equation:

$$V = I\,R$$

An incendive discharge occurs when two conditions are satisfied:

a) The field strength due to the potential of the conductor exceeds the breakdown strength of the atmosphere; and

b) 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 to 1 000 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 as follows:

$$R = \frac{100}{I}$$

where R is in ohms and I in amperes.

13.2.2 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 pA to 100 μA, the corresponding values of R are 10 TΩ and 1 MΩ. For the maximum value of I, a resistance to earth of 1 MΩ will ensure safe dissipation of static electricity in all situations. However, in most industrial operations I does not exceed 1 μA and the capacitance C of an isolated conductive object does not exceed 100 pF (see examples in Table A.2). In this case a resistance to earth of 100 MΩ is adequate.

Metallic items in good contact with earth should have a resistance to it of less than 10 Ω. Although a value of up to 1 MΩ is acceptable for static dissipation, values above 10 Ω may give an early indication of developing problems (e.g. corrosion or a loose connection) and should be investigated. It is important that all connections are reliable, permanent and not subject to deterioration.

Small conductive items, e.g. a person, are considered to be electrostatically earthed, if the time for charge relaxation is less than 0,1 s.

A clear distinction should be made between a value chosen for convenience in monitoring metal to metal connections, and the value of 1 MΩ, 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.

Movable conductive items require special earth connections which should have a resistance to earth of not more than 1 MΩ.

It is not possible to effectively earth insulating materials. For this reason other control measures are needed if these are to be used safely in areas where flammable atmosphere could be present. Refer to Clause 6 for details.

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 1 MΩ, although values up to 100 MΩ can be acceptable in most cases.

A brief review of earthing resistance recommendations is given in Table 22. A test voltage of 100 V should be used, but lower voltages may be more suitable at low resistance values.

Table 22 – Summary of maximum earthing resistances for the control of static electricity in hazardous areas

Subclause	Type of installation	Maximum resistance to earth [a-e]	Comments
13.3.1.1	Standard value	1 MΩ	Values up to 100 MΩ are acceptable in some cases, e.g. capacitance < 100 pF.
13.3.1.2	Large fixed metal plant (reaction vessels, powder silos, etc.)	1 MΩ	Earthing normally inherent in the structure. Special earthing could be required for items mounted on non-conductive supports.
13.3.1.3	Metal pipelines	1 MΩ	Earthing normally inherent in the structure. Special earthing connection required across joints if resistance could exceed the 1 MΩ criterion.
13.3.1.4	Movable metal items (drums, road and rail tankers, etc.)	1 MΩ	Earthing connections are normally required during filling and emptying. A 10 Ω connection between the earthing point and temporary connections to metal items is recommended for pure metal connections.
13.3.2	Metal plant with some insulating elements (valves, etc.)	1 MΩ	In special cases a limit of $100 / I$ Ω could be acceptable, but in general if a 1 MΩ criterion cannot be satisfied a special earthing connection should be used. Very small conductive items need not be earthed, see 6.2.3
13.3.3	Insulating 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.
13.3.4	Items fabricated from dissipative materials	1 MΩ to 100 MΩ	Materials at the border limit to insulating materials may not need to be earthed in the absence of strong charge generation processes
11.2	Floors in flammable atmosphere areas	1 MΩ to 100 MΩ	Resistance from floor surfaces to earth.

Subclause	Type of installation	Maximum resistance to earth [a-e]	Comments
11.3	Footwear used for earthing people in flammable atmosphere areas	100 MΩ	Resistance from hand-held metal bar to metal plate under one shoe sole.
11.3	Footwear used for earthing people in explosive device or material handling areas	1 MΩ	Resistance from hand-held metal bar to metal plate under one shoe sole. Where the minimum spark energy for ignition is ≤ 1 mJ, the maximum resistance to earth should be less than 150 kΩ.
13.3.5	Earthing of housings via intrinsic safety circuits	100 MΩ	This resistance behaves as an insulating resistance in low voltage applications.
13.3.6	Ships during loading and unloading	All metal parts bonded together	Use a single insulating flange and earth one line via the ship to the sea and the other via an earth connection at the shore.
7.8.1.3	Airplanes during refuelling	25 Ω	According to aviation rules.
7.8.3	Vehicles during refuelling	100 MΩ	Leakage resistance of the forecourt of the filling station.
		10 GΩ	Leakage resistance between filling nozzle and forecourt via one single tyre.
		1 MΩ	Leakage resistance between filling nozzle and earth via a conductive filling hose assembly. In case of electrically bonded filling hoses the border limit is 100 Ω.

[a] This Table should be read in conjunction with the paragraphs indicated in the text.

[b] The test method specified in the relevant subclause should be used.

[c] In Zone 2 and in Zone 22 earthing is required only when charge accumulation is continuous.

[d] 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.

[e] The values given in the Table should not be applied in the case of protecting electrostatic sensitive electronic devices or explosives.

13.3 Earthing requirements in practical systems

13.3.1 All-metal systems

13.3.1.1 General

The standard value for the resistance to earth is up to 1 MΩ, provided that it can be maintained. Special earthing connections are not normally required unless, for example, equipment is mounted on insulating supports, or contamination which affects the insulation could develop across a joint.

Values up to 100 MΩ are acceptable in some cases, especially when the capacitance of the conductor does not exceed 100 pF (see 13.2.2 and A.3.2).

For all-metal systems, a resistance of less than 10 Ω should usually be achieved. However, for systems using e.g. braided bonding cables, a resistance of less than 25 Ω is acceptable.

If a significantly higher value is found, further investigations should be made to check for possible problems (e.g. a loose connection or corrosion).

13.3.1.2 Main 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 deteriorating to a value above 1 MΩ. 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 13.3.2).

13.3.1.3 Pipelines

A pipeline is sometimes a temporary installation and it could include lengths of insulating pipe. As a result, special earthing connections may be needed where conductive pipe sections are isolated from earth by insulating sections or fittings. For this reason, installing an insulating pipe or hose midway in a section of otherwise entirely metal piping should be avoided because it is equivalent to a break in bonding. Moreover such a pipe or hose may cause propagating brush discharges. However, sometimes an insulating flange or section of pipe may be necessary to avoid an earthing loop (see 13.3.6).

The application of bonding connectors across all joints in a metal pipeline is not generally needed and should only be used when, because of the design, there is no metal to metal contact. This may occur where insulating gaskets are used, and paint on the outside of the pipe prevents bolts making a reliable electrical contact with the pipe.

13.3.1.4 Movable 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 1 MΩ, but this cannot be relied upon. To allow 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.

Portable conductive items (e.g. trolleys equipped with conductive rollers, metal buckets etc.) are earthed through their contact with dissipative or conductive floors. However, in the presence of contaminants like dirt, or paint on the contact surface of either the floor or the object the leakage resistance to earth may increase to an unacceptable value resulting in possible hazardous electrostatic charge on the object. Where such situations are expected, the object should be earthed by an alternative means (e.g. earthing cable). A connection resistance of 10 Ω between the cable and the item to be earthed is recommended.

Earthing and bonding need to be continuous during the period that charge build-up could occur and cause electrostatic hazards. Making or breaking an earth or bond connection in the presence of an electrostatic field could cause electrostatic charging by induction, thus being hazardous. (See A.1.10).

13.3.2 Metal plant with insulating parts

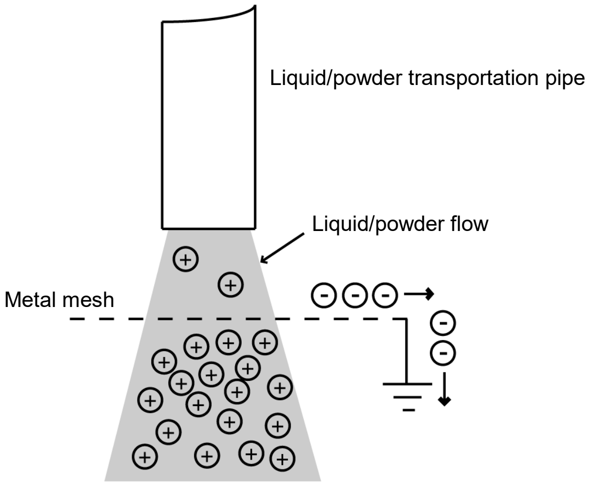
A plant of metal construction always contains insulating elements which could possibly affect electrical continuity and earthing. Examples are lubricating oils and greases and a wide range of polymers such as PTFE and polyethylene which have many applications. Normally, all metal parts of the plant are earthed either directly or through suitable earthing connections and all paths to earth have low resistances, but problems could arise because of the insulating elements. As already mentioned (see 13.2.2), a resistance to earth of less than 1 MΩ 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 kΩ. This is sufficient to allow dissipation of static electricity without special earthing devices.

NOTE In some high charging processes it has been experienced that ball bearings have a reduced operating life time due to electro-corrosion. The use of conductive/dissipative grease may reduce this problem (e.g. graphite grease).

When polymers are the insulating elements, a resistance in excess of 1 MΩ is almost inevitable and the only solution is to bond the isolated conductor to adjacent earthed metal components.

Examples of this situation are

a) Ball valves with PTFE packing and seals,
b) Pipe spacing rings isolated by PTFE coated gaskets,
c) Isolated metal pipeline sections between plastic connectors, and
d) Metal nozzles at the end of plastic lines.



IEC 2176/13

Figure 5 – Hazardous earthed conductor in contact with a flowing insulator

Putting an earthed conductor in contact with a flowing non-conductor as illustrated in Figure 5 may cause charge generation. Therefore an earth conductor should not be put into a flowing non-conductor for static dissipation purposes.

13.3.3 Insulating materials

Materials such as glass and insulating 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 hazards (see 13.2). Since those materials cannot be effectively earthed they could retain any charge they acquire for long periods.

Discharges from insulating 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 conductive objects isolated from earth by these materials. Examples of these are:

a) metal components such as connecting bolts and backing flanges in a plastic pipeline;
b) metal mesh extending throughout some types of insulating wall cladding; and
c) pools or layers of conductive liquid (e.g. water) on the surface of the material.

Because of their low conductivity and the general fire risk, the use of insulating 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).

13.3.4 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 resistance to earth calculated according to 13.2.1 is often in the range of 10 kΩ to 100 MΩ. For general use, a maximum value of 1 MΩ is appropriate, but if it cannot be met, the calculated value is acceptable. Values above 100 MΩ are acceptable only in special circumstances, e.g. in the absence of strong charge generation mechanisms, after assessment of the hazard, and monitoring systems may be advisable to demonstrate compliance.

13.3.5 Earthing via intrinsic safety circuits

Intrinsically safe equipment or intrinsically safe plants are mostly run without earthing due to plant process requirements. However, the conductive or dissipative housings of such equipment have to be electrostatically earthed in hazardous areas. In these cases a resistance to earth less than 100 MΩ is required to sufficiently earth the housing and maintain the currents at a safe level even in electrical equipment whose connections may not directly be connected to earth.

13.3.6 Earthing of ships

When loading or unloading flammable liquids from ships, electrostatic charge and explosive atmospheres may be generated simultaneously. For this reason care should be taken to ensure that all metal parts of the discharge line are at the same potential. On the other hand, the cathodic corrosion protection system of ships and the electrical equipment at the harbour, e.g. electric locomotives, produce stray currents which create a strong spark when connecting metal lines from ship and shore together. For this reason the ISGOTT recommends an insulating flange (insulating resistance ≥ 1 kΩ) or a single discontinuous hose assembly to be used in the hose string from ship to shore and an independent earthing of both conductive parts of the line via the ship and the shore. This method suppresses incendive sparks created by the stray currents when connecting the lines in possibly explosive atmospheres, and all parts of the line are maintained at the same electrical potential. However, care should be taken to ensure that there is no isolated conductor between the ship and the shore through, for example, the use of two insulating flanges in one line. For this reason, an upper limit of 100 MΩ would be reasonable for the insulating resistance of the flange or hose assembly.

13.4 The establishment and monitoring of earthing systems

13.4.1 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 13.3. Where no other form of earthing exists, it should be achieved by connections to metal rods or plates driven into, or buried in the earth. 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 movable 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.

f) If earthing has been forgotten in an explosive atmosphere it is recommended that the isolated item is slowly approached with a corona tip or a special earth clamp with a built in resistor to safely discharge the object.

Where the bonding/earthing system is all metal, the resistance in continuous earth paths typically is less than 10 Ω. Such systems include those having multiple components. A greater resistance usually indicates that the metal path is not continuous, usually because of loose connections or corrosion. An earthing system that is acceptable for power circuits or for lightning protection is more than adequate for a static electricity earthing system.

NOTE NFPA 77 contains diagrams of various earthing devices, connections and equipment.

Where wire conductors are used, the minimum size of the bonding or earthing wire is dictated by mechanical strength, not by its current-carrying capacity. Stranded or braided wires should be used for bonding wires that will be connected and disconnected frequently. See Annex A for additional information.

Earthing conductors can be insulated (e.g., a jacketed or plastic-coated cable) or not insulated (i.e. bare) conductors. Non-insulated conductors have the advantage that defects are easier to detect. However, coated conductors may be more resistant to physical damage and corrosion.

Permanent bonding or earthing connections should be made in a way to provide low resistance during its lifetime, e.g. by brazing or welding. Temporary connections can be made using bolts, pressure-type earth clamps, or other special clamps. Pressure-type clamps should have sufficient pressure to penetrate any protective coating, rust, or spilled material to ensure contact with the base metal with an interface resistance of less than 10 Ω.

13.4.2 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 minimise 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.

14 Special requirements for equipment according to IEC 60079-0

14.1 General

In this document, threshold limits are given for electrostatic testing of products which differ from the threshold limits in IEC 60079-0:2011. The threshold limits specified in this document are in some cases more conservative, as they apply to a broad range of industrial applications where the physical situation may be quite different to that in which electrical equipment complying with IEC 60079-0 is used. The more conservative limits are based on theoretical modeling supported by empirical data.

In order to have all relevant electrostatic requirements accessible in one place, the requirements from IEC 60079-0:2011 are included for information in this clause of this document, with the addition of helpful explanatory material and cross-references to other text in this document.

The test methods in IEC 60079-32-2:2015 are equivalent to those cited in IEC 60079-0:2011, but in some cases climatic conditions are different. Equipment within the scope of IEC 60079-0 may be tested in the climatic conditions specified in IEC 60079-0.

NOTE The use in apparatus of products and materials conforming to the threshold limits specified in IEC 60079-0:2011 is not known to have resulted in any accidental ignition.

14.2 Electrostatic charges on external non-metallic materials

14.2.1 Applicability

The requirements of this subclause only apply to external non-metallic materials of electrical equipment, including non-metallic parts which are applied to the external surface of an enclosure.

NOTE 1 Non-metallic paints, films, foils, and plates are typically attached to external surfaces of enclosures to provide additional environmental protection. Their ability to store an electrostatic charge is addressed by this subclause.

NOTE 2 It is generally acknowledged that glass is not susceptible to storing an electrostatic charge.

14.2.2 Avoidance of a build-up of electrostatic charge on Group I or Group II electrical equipment

Electrical equipment should be so designed that under normal conditions of use, maintenance and cleaning, danger of ignition due to electrostatic charges are avoided. This requirement should be satisfied by one or more of the following:

a) By suitable selection of the material so that surface resistance shall meet at least one of the criteria given below (see 6.2.1) when measured in accordance with IEC 60079-32-2:

   – ≤ 100 GΩ measured at (30 ± 5) % relative humidity

   – ≤ 1 GΩ measured at (50 ± 5) % relative humidity

   NOTE 1 For more information see 6.1.

b) By limitation of the surface area of non-metallic parts of enclosures, determined according to 6.3.2, to the values of Table 23.

   The values for surface area can be increased by a factor of four if the exposed area of non-metallic material is surrounded by and in contact with conductive earthed frames (see 6.3.3).

   Alternatively, for long parts with non-metallic surfaces, such as tubes, bars, or ropes, the surface area need not be considered, but the diameters or widths should not exceed the values shown in Table 23.

   NOTE 2 Electric cables for connection of external circuits are not in the scope of Clause 14. Information on external cables can be found in IEC 60079-14.

   NOTE 3 Requirements for pipes and hoses for liquids are not in the scope of Clause 14. Requirements for pipes and hoses for liquids are given in 7.7, and for solids in 9.3.3.

c) By provision of an insulating layer bonded to a conductive surface. This layer should meet at least one of the following criteria:

   1) the layer is not expected to be subject to high charging processes stronger than manual rubbing (see 3.13) and has a thickness ≤ 2 mm for Groups I, IIA, IIB or ≤ 0,2 mm for Group IIC (see Table 23 and 6.3.4.2).

   2) the breakdown voltage measured through the thickness of the insulating material is ≤ 4 kV (see 6.3.4.3) when measured as described in IEC 60079-32-2.

NOTE 4 According to IEC 60243-2, insulating materials stressed by DC have their breakdown voltage tested with DC and the method described in IEC 60243-1 with the additional requirements in IEC 60243-2. This method and the additional requirements are also given in IEC 60079-32-2.

d) By provision of a conductive coating (see 6.3.5). Non-metallic surfaces may be covered with a bonded durable conductive coating. The resistance between the coating and either the bonding point (in the case of fixed equipment) or the farthest point of possible contact with the enclosure (in the case of portable equipment) should not exceed 1 GΩ. The resistance should be measured in accordance with IEC 60079-32-2 but using the 100 mm^2 electrode at the worst case position of the surface and either the bonding point or the farthest point of possible contact.

NOTE 5 The environmental conditions that have an effect on the coating material can include influences from small particles in an air stream, solvent vapours, and the like.

e) By using any other safety measure in this Technical Specification to avoid the danger of ignition due to electrostatic charges.

f) By testing that the maximum transferred charge measured according to IEC 60079-32-2 under worst case conditions is within the threshold limits of Table 23.

g) In specific cases, IEC 60079-0 allows the use of fixed equipment which does not fulfill the requirements a) to f) and may have a risk from electrostatic discharges by marking them with “X”. In this case, the instruction manual should provide guidance for the user to minimize the risk from electrostatic discharges by operational measures. Where practicable, the equipment should also be marked with the electrostatic charge warning given in IEC 60079-0. However, this alternative should not be used if hazardous electrostatic charging is expected during use (e.g. for hand-held equipment or for constantly charging fixed installations).

NOTE 6 X-marking is used e.g. for insulating housings of electrical equipment that are touched by the operator only during cleaning, maintenance and repair.

Table 23 – Alternative restrictions on insulating solid materials and isolated conductive or dissipative parts in hazardous areas for equipment within the scope of IEC 60079-0

	Group I	Group II				Group III		
	EPL Ma, Mb	Sub group	EPL Ga	EPL Gb	EPL Gc	EPL Da	EPL Db	EPL Dc
A) Surface area	≤10 000 mm^2	A	≤5 000 mm^2	≤10 000 mm^2	≤10 000 mm^2	No limits		
		B	≤2 500 mm^2	≤10 000 mm^2	≤10 000 mm^2			
		C	≤ 400 mm^2	≤ 2 000 mm^2	≤ 2 000 mm^2			
B) Width of bars, rods	≤30 mm	A	≤3 mm	≤30 mm	≤30 mm	No limits		
		B	≤3 mm	≤30 mm	≤30 mm			
		C	≤1 mm	≤20 mm	≤20 mm			
C) Thickness of insulating coatings to avoid brush discharges	≤2 mm	A	≤2 mm			No limits		
		B	≤2 mm					
		C	≤0,2 mm					
Thickness of insulating coatings to avoid any incendive discharge	Not permitted	Not permitted	Not permitted			≥ 8 mm if area > 500 mm^2		
D) Transferred charge	≤60 nC	A	≤60 nC			No limits for insulating solids ≤200 nC[a]		
		B	≤25 nC					
		C	≤10 nC					
E) Capacitance of unearthed metal parts	≤10 pF	A	≤3 pF	≤10 pF	≤10 pF	≤10 pF[b]		
		B	≤3 pF	≤10 pF	≤10 pF			
		C	≤3 pF					

[a] Value only valid for spark discharges from unearthed conductive or dissipative parts

[b] For equipment intended for use in ducts or pipes subject to the presence of fast moving dust a lower limiting value of capacitance is under consideration

NOTE 1 The width criterion in B) applies to thin pipes, cable sheaths, and other insulating materials having small widths or diameters.

NOTE 2 The limits in A) and B) are not absolute values that prevent incendive discharges, they merely reduce it to a generally accepted low level.

NOTE 3 The limits in C) apply to insulating coatings and layers on conductive or dissipative materials.

NOTE 4 The limits in D) ensure that incendive discharges do not occur.

NOTE 5 All of the values in D) contain a certain safety margin. Recent work indicates that the value hitherto used for IIB contains a lower safety margin than all other values. To equalize all safety margins the values for IIB have been reduced from 30 nC to 25 nC. This does not mean that the former value was unsafe or retesting is necessary.

NOTE 6 The subgroups are based on the maximum experimental safe gap (MESG) or the minimum ignition current ratio (MIC ratio) of the explosive gas atmosphere in which the equipment may be installed (see IEC 60079-20-1). More details can be found in C.6 and D.3.

NOTE 7 The values in EPL Gc do not exclude the possibility of high charging processes. Manual rubbing is usually not considered to be a high charging process (see 3.13).

NOTE 8 It is generally accepted that an unearthed metal fastener such as a cover screw will present a capacitance of not more than 3 pF.

14.2.3 Avoidance of a build-up of electrostatic charge on equipment for Group III

It is not possible to create electrostatic discharges from insulating surfaces that are incendive for dust clouds or dust layers just by manual rubbing. However, if high charging processes (see 3.13) are not excluded, painted/coated metal equipment and equipment of plastic material should be so designed that under normal conditions of use, ignition caused by propagating brush discharges is avoided.

Enclosures of plastic material cannot be charged to such a critical charge density that propagating brush discharges can be generated. However, no extended flat conductive surfaces should be installed inside the enclosure within a distance of 8 mm to the outer surface.

NOTE 1 An internal printed circuit board can be considered to be an extended flat conductive surface, though this need not be applied in small hand-held equipment unless the equipment is likely to be subjected to a prolific charge generating mechanism (such as might occur in pneumatic transfer of powders or charge spraying in a powder coating process). Charging through normal handling of hand-held equipment is not considered to lead to a prolific charge generating mechanism and therefore would not lead to a situation where a propagating brush discharge might occur.

NOTE 2 A single flat conductive surface not exceeding 500 mm^2 is not considered to be an extended flat surface. This allows for the standoffs or brackets used for the mounting of conductive flat plates inside of an enclosure.

Using external insulation of at least 8 mm in thickness on metal parts such as measurement probes or similar components can prevent propagating brush discharges. When evaluating the minimum thickness of the insulation to be used or specified it is necessary to allow for any expected wear under normal usage.

If plastic with a surface area exceeding 500 mm^2 is employed as a covering on a conductive material, and high charging processes (see 3.13) stronger than manual rubbing are not excluded, the plastic should have one or more of the following characteristics (see 6.3.4.3):

a) material suitably selected so that surface resistance complies with the limits given in 14.2.2;

b) a breakdown voltage ≤4 kV, measured through the thickness of the insulating material according to the method described in IEC 60079-32-2;

c) a thickness ≥8 mm of the external insulation on metal parts.

14.3 Electrostatic charges on external conductive parts

All external conductive parts of the equipment (metal, conductive plastic etc.) should be earthed with a maximum earth resistance of 1 MΩ. For items having a capacitance of less than 100 pF, a maximum earth resistance of 100 MΩ is acceptable (see Table 22).

Accessible metal parts (e.g. aluminum labels on plastic enclosures) with a resistance to earth of more than 100 MΩ could be susceptible to electrostatic charges that could become a source of ignition, and should be tested in accordance with the capacitance test method in IEC 60079-32-2. The maximum allowed values are given in Table 23.

The requirements of 14.3 are not applicable if the capacitance requirements of unearthed metal parts in Table 23, section E), are fulfilled.

Annex A
(informative)

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. Conductive 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. Frozen water in air or frozen gases (e.g. carbon dioxide) caused by adiabatic expansion by the release of highly pressurized gases experience contact charging.

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. 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 interface. 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 or air bubbles, 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 insulating to prevent recombination. Such processes can occur at both solid/liquid and liquid/liquid interfaces.

A hazardous level of charging is encountered mainly 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.

Although high conductivity liquids usually charge only very little there exist highly chargeable conductive liquids, especially some organic acetates, ethers and higher ketones which may need extra safety measures. Such liquids include ethyl acetate and isopropyl acetate, but not acetone.

Biofuels are dealt with in C.8.

A.1.4 Charge generation on liquids flowing in pipes

A.1.4.1 Pipes of fixed diameter

When a liquid flows through a pipe, charge separation occurs resulting in charging of the liquid and an equal and opposite charging of the wall (wall charges are immediately dissipated if the pipe is conductive and earthed). Turbulent flow generates more charge than laminar flow. Since the flow in industrial installations is usually turbulent, only the more severe turbulent case is considered here. For turbulent flow the electrical streaming current generated in a long pipe is roughly proportional to the square of the velocity.

NOTE The streaming current is directly proportional to the velocity for laminar flow.

If the liquid enters the pipe uncharged, the charge density and hence the streaming current carried by the liquid will increase as it moves along the pipe and will gradually approach a stationary value, provided the pipe is sufficiently long. For most low conductivity liquids, in particular saturated hydrocarbon liquids, the stationary value of charge density $\rho\infty$ does not depend greatly on the conductivity or permittivity of the liquid and is approximately proportional to the flow velocity, v, divided by the pipe diameter, d:

$$\rho\infty \approx K\ v/d$$

where K is a constant with dimensions C s m^{-3}.

NOTE Other expressions have previously been suggested and $\rho\infty \approx K\ v$ (Schön's Law) is historically used more frequently than the expression proposed above and leads to the expression of flow limitations as vd limits. However $\rho\infty \approx K\ v/d$ seems to give a better match to reported measurements (Walmsley and Mills 1992, Britton and Smith 2012), is closer to theoretical expressions for pipe charging (Koszman and Gavis 1962, Walmsley 1982) and, by suitable choice of the constant, K, can be made to give the same currents for well explored conditions. The highest Schön constant was derived from measurements on relatively small diameter pipes (≤50 mm) and overestimates the highest currents measured in larger (e.g. 100 mm) pipes. When this data is matched to the above expression, the inverse diameter dependence gives lower charging in large pipes and fits the large pipe data better.

Various values have been proposed for K. A value of 1,0 μC s m^{-3} seems to be a reasonable value for most hydrocarbons although higher values may be needed for other, less documented, liquid types or where pro-charging additives are present. A value of 1,6 μC s m^{-3} covers all reported charging levels in normal piping.

For the practical range of velocities and pipe diameters (v = 1 m/s to 10 m/s, d=0,025 m to 0,2 m this gives charge densities between 5 μC/m^3 and 400 μC/m^3.

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

$$L \geq 3\ v\ \tau \text{ with } \tau = \varepsilon_r\ \varepsilon_o\ /\ \gamma$$

where

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

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

ε_r is the relative permittivity of the liquid ($\varepsilon_r \sim 2$ for hydrocarbons);

ε_o is the permittivity of free space ($8{,}85 \times 10^{-12}$ F/m);

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

There is evidence that the charge density generated by pipe flow is proportional to conductivity below a fuel-dependent conductivity threshold. Thus the highest charge densities are not found down to the lowest conductivities. The conductivity threshold for this behaviour seems to vary inversely with viscosity. For example, Hearn (2002) and Walmsley (2011) reported gasoline charging proportional to conductivity at conductivities up to 50 pS/m and ~200 pS/m respectively, whilst the data of Walmsley and Mills (1992) for diesel, which has approximately ten times the viscosity of gasoline, shows charge densities proportional to conductivity up to about 7 pS/m, and luboils, which have still higher viscosities, can give high charging down to very low conductivities (see 7.4). For fuels and solvents with viscosities no higher than that of automotive diesel it is, therefore, reasonable to assume that charging will start to decline at a conductivity of 3 pS/m as a worst case value.

NOTE This allows a margin below the diesel data cited above; for low viscosity liquids such as gasoline this margin may be large.

High viscosity liquids, such as luboils, are a special case and are considered separately in 7.4. For these liquids, the fall-off is expected to occur at very low conductivity. Consequently, the reduction in current below 3 pS/m should not be assumed to apply to any liquid more viscous than automotive diesel.

While the use of insulating pipes is not generally recommended, they are used for some specific duties. Very little published data is available for charging by liquid flow in insulating pipes or hoses. However for low conductivity liquids, < 25 ε_r pS/m, flowing through insulating pipes, the streaming currents appear to be similar to those produced in conductive pipes and the charge density for an infinitely long pipe can be estimated from the same expression as for conductive pipes.

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.

A.1.4.2 Pipe with multiple sections of different diameter

If the pipe leading to a tank changes diameter along its length so that there are N segments each with a different diameter then, assuming exponential (Ohm's Law) relaxation behaviour, the contribution from segment j to the tank inlet charge density is:

$$\rho_j = K(v_j/d_j^n)[1\text{-}\exp(\text{-}L_j/v_j\tau)]\exp(\text{-}t_{resj}/\tau)$$

where v_j, d_j and L_j are the flow velocity, diameter and length for segment j, t_{resj} is the residence time between the downstream end of segment j and the tank and τ is the relaxation time of the liquid. The power n, allows for either the recommended analysis ($n = 1$, charge density proportional to v/d) or a Schön's law analysis ($n = 0$, charge density proportional to v). The Schön's law analysis is not generally recommended but is still needed where vd limits are used.

In the case of $t_{resj} > 3\tau$ very little of the charge from segment j remains at the tank inlet so segments more than 3τ upstream of the tank can be ignored. This, with allowance for a maximum effective relaxation time of 10 s due to hyperbolic relaxation, leads to the definition of the relaxation region used in 7.3.2.3.5.2.

The total inlet charge density at the tank is the sum of all the segment contributions within the relaxation region, that is:

$$\rho = \Sigma^{j=N}{}_{j=1}\, \rho_j = K\, \Sigma^{j=N}{}_{j=1}\, (v_j/d_j^{\,n})[1\text{-}\exp(-L_j/v_j\tau)]\exp(-t_{resj}/\tau)$$

This expression is cumbersome for practical use and is therefore simplified by ignoring the exponential terms and applying the charging in the worst-case ("critical") segment to the whole line. Both of these simplifications increase the estimated charge density above the real value and therefore add a safety margin as well as simplifying the estimation process.

Without the exponential terms, the simplified contribution from segment *j* is:

$$\rho = K(v_j/d_j^{\,n}) = (4K/\pi)(F_T/d_j^{\,n+2})$$

where F_T is the volumetric flow rate to the tank. This shows that the worst-case (critical) segment is the one with the smallest diameter. Applying the charge density for the critical segment to the whole line, the estimated charge density at the tank inlet is:

$$\rho = (4K/\pi)(F_T/d_w^{\,n+2}) = \mathrm{k}V_w/d_w^{\,n+2}$$

where *w* indicates the worst case (smallest diameter) segment. The corresponding streaming current at the tank inlet is:

$$I = (\pi K/4)\; v_w^{\,2} d_w^{\,2-n}$$

A.1.4.3 Branched pipeline with multiple sections of different diameter

A branched pipeline is one in which a single upstream section splits, in one or more stages, into multiple downstream sections each of which feeds an individual tank. With this arrangement, the calculation of the contribution from a particular segment to the inlet charge density of a particular tank is slightly more complex as the flow rate can be higher in the upstream segments when multiple tanks are being filled simultaneously.

In this case the simplified contribution of segment *j* to the inlet charge density is still

$$\rho = \mathrm{k}V_j/d_j^{\,n}$$

and the critical segment is still the one with the highest value of $v_j/d_j^{\,n}$ but now the velocity v_j must be calculated from F_s, which is the highest possible flow rate through the segment when multiple tanks are being filled simultaneously rather than from F_T, the flow rate to the individual tank being assessed.

The worst-case contribution of an upstream segment to the streaming current at the tank inlet is then:

$$I = (\pi K/4)\; v_w^{\,2} d_w^{\,2-n} / N_s$$

where $N_s = F_s/F_T$ is the ratio of the maximum possible flow rate in the pipe segment to the flow rate into the tank being assessed. Thus the maximum velocity or *vd* limit (based on *n*=0 in the case of the *vd* limit) that can be accepted in a critical pipe segment that feeds several tanks simultaneously is increased by a factor $N_s^{\,1/2}$ from the standard (unbranched line) value established for the tank.

A.1.5 Charge generation in filters

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

The charge densities produced by fine filters can remain high at conductivities below 1 pS/m. This is unlike charging in pipeline flow. Charge arriving at a tank from a filter may, therefore, have a large charge density and very long relaxation time, resulting in unusually high potentials. It is therefore important to locate fine filters in an adequate distance upstream of tanks so that the residence time provided in the downstream pipe and/or relaxation tank is at least 3 relaxation times, allowing charge to dissipate to safe levels. Depending on the fineness of the filter a default residence time of 30 s or 100 s is used to approximate the worst practical case (see 7.5).

A.1.6 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.1.7 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. Aeration of the liquid, such as rising bubbles, is also able to stir up water bottoms or other deposits and may, therefore, increase the electric fields in tank.

A.1.8 Breakup of liquid jets

The disintegration of a liquid jet into small droplets, e.g. when the jet hits an obstruction during tank cleaning, can produce a highly charged spray or mist, irrespective of the conductivity of the liquid. In general, the more conductive 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.1.9 Contact charging of powders

The charge carried by a 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 insulating powders (see definitions in 9.1), typical values are between 10 pC/kg and 1 mC/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 powders

Operation	Mass charge density (μC kg^{-1})
Triboelectrical powder coating	10 000 to 1 000
Pneumatic conveying	1 000 to 0,1
Micronising	100 to 0,1
Grinding	1 to 0,1
Scroll feed transfer	1 to 0,01
Pouring	1 to 0,001
Sieving	0,001 to 0,000 01

A.1.10 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 isolated 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 electrostatic sparks.

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

A.1.11 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.1.12 Charging by corona discharge

A method for charging objects is spraying electrons from a metal tip which is at high negative potential of some tens of kilovolts. This charging mechanism can also happen accidentally, e.g. from high-voltage tips of electrostatic spraying equipment or from corona needles of a Type D FIBC.

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 an insulating object is retained because of the resistance of the material itself. But for a conductor to remain charged it has to be isolated from other conductors and from earth.

Under normal conditions, pure gases are insulators 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 that accumulates on an isolated conductor. For example, when a stream of charged liquid or powder flows into an isolated metal container, the potential on the isolated 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:

$$V = I\,R\,\{1 - \exp(-\,t / R\,C)\}$$

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 s the electrostatic charging current in amperes;

t is the time from the commencement of charging in seconds.

The maximum potential $V_{\max}$ is reached when t is large and is therefore:

$$V_{\max} = I\,R$$

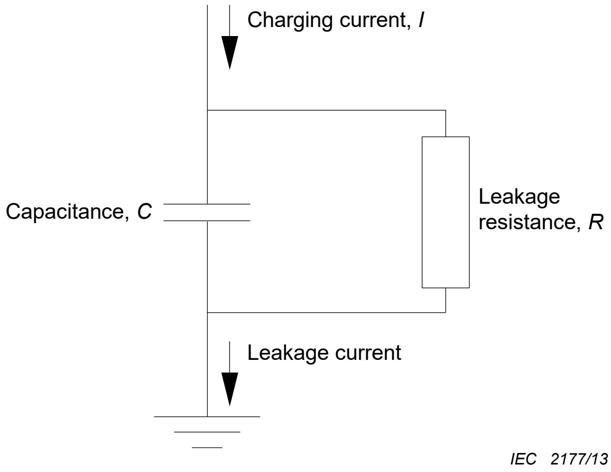


Figure A.1 – Equivalent electrical circuit for an electrostatically charged conductor

The leakage resistance and the capacitance of an isolated 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:

$$\tau = \varepsilon_r\,\varepsilon_o / \gamma$$

where:

τ is the relaxation time;

ε_r is the relative permittivity of the liquid (about 2 for saturated hydrocarbon liquids);

ε_o is the permittivity of free space ($8{,}85 \times 10^{-12}$ F/m);

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 $\gamma = 1$ pS/m (10^{-12} S/m) the relaxation time is $\tau = 18$ s. The time for the charge to decay to 50 % of its original value is 0,7 $\tau = 13$ 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 ($\gamma >$ 10 000 pS/m), medium (100 pS/m $< \gamma <$ 10 000 pS/m) or low ($\gamma <$ 100 pS/m). In the case of hydrocarbons 50 pS/m is used as border limit for low conductivity (see 7.1.4). The conductivities and relaxation times for a number of liquids are given in Table 7.

Hazardous levels of charge accumulation are associated mainly with low conductivity liquids. Such levels can also occur with medium conductivity liquids when the charging rate is high, e.g. high flow velocities or stirring certain suspensions (see 7.7 and 7.9). 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 insulating. 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:

$$\tau = S\, \varepsilon_r\, \varepsilon_o$$

where:

ε_r is the relative permittivity of the powder;

ε_o is the permittivity of free space ($8{,}85 \times 10^{-12}$ F/m);

S is the volume resistivity of the powder

A volume resistivity of 10 GΩ 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 insulating, 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 MV/m.

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 conductive body and a conductive earthed object can be calculated using the equation below:

$$W = \tfrac{1}{2}\, Q\, V = \tfrac{1}{2}\, C\, V^2$$

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[a]
Small metal items (scoop, hose nozzle)	10 to 20
Small containers (bucket, 50 l drum)	10 to 100
Medium containers (250 l to 500 l)	50 to 300
Major plant items (reaction vessels) immediately surrounded by earthed structure	100 to 1 000
Human body	100 to 200
[a] 1 pF = 1×10^{-12} 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 the charging current, I, can be 100 nA; the leakage resistance of the drum to earth R, 100 GΩ; and its capacitance C, 50 pF. The maximum voltage on the drum is then:

$$V_{\max} = I\,R = 10\text{ kV}$$

and the maximum energy released in a spark discharge would be

$$W_{\max} = \tfrac{1}{2}\,C\,V_{\max}^2 = 2{,}5\text{ mJ}$$

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 incendive. 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 insulating objects, for example, between a person's finger and a plastic surface, or between a grounded metal protrusion 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, vapours and hybrid mixtures. The present state of knowledge indicates however, that independent of their MIE combustible powders cannot be ignited by brush discharges, providing there are no flammable gases or vapours.

Experiments have shown that brush discharges are capable of igniting gas atmospheres with MIEs up to 3,6 mJ when transforming them into spark discharges through gases. These experiments, however, don't give any information concerning the incendivity of brush discharges for dust.

NOTE Brush discharges show a significantly different energy distribution in space and time compared to spark discharges. This results in differences in their incendivity towards gases and vapours compared to dusts.

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 conductive material (normally earthed).

The short circuit can be achieved:

a) By piercing the surface (mechanically or by an electrical break through);
b) By approaching both surfaces simultaneously with two electrodes electrically connected; or
c) 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 insulating 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 10 mm is sufficient to prevent propagating brush discharges. For sheets thinner than that value, a surface charge density of at least 250 $\mu C/m^2$ is required.

A further requirement is that the breakdown voltage through the charged sheet needs to be more than 4 kV for even surfaces like films, webs and sheets and 6 kV for fabrics. This means that charge on layers of paint does not normally give rise to propagating brush discharges.

NOTE 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 charged clouds or from such 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 atmospheres, but they have never been observed in charged clouds of the size encountered in industrial operations.

According to experimental investigations such discharges are unlikely to occur in silos of volume less than 100 m^3 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. In addition, no lightning-like discharges have been observed during the washing of ship's tanks of up to 30 000 m^3 in volume.

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

A.3.7 Cone discharges

When highly charged insulating 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 extensive experiments performed in earthed conductive silos the energy released in such discharges depends on the silo diameter and the particle size (mass 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 maximum 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 mass median of the particle size distribution of the powder forming the cone in millimetres.

For silos with diameters larger than 3 m and powders with a median larger than 3 mm the application of the above formula is not validated by measurements or experiments. Based on practical evidence the ignition efficiency is lower and therefore the equivalent energy of cone discharges is also lower than indicated by the above formula above these limits. Expert advice is recommended under these circumstances.

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 insulating granules are handled together with fine powder (fines) forming a dust cloud of low MIE.

In case of silos made from insulating material twice the diameter should be used in the above formula for the calculation of the equivalent energy of cone discharges. This recommendation is not based on experimental data but on the fact that – in contrast to an earthed conductive silo, where the highest potential is usually at the central axis – the silo wall is not at zero potential. If one side is forced to be at zero potential, the opposite side may have the highest potential and consequently the cone discharge may jump over the whole diameter and thus collect much more charges than in a conductive silo of similar dimensions.

A.4 Measurements for risk assessment

Measurements are often necessary for the identification of static electricity hazards and the assessment of ignition risks. In addition, they can verify whether precautions, which have been implemented against the hazards, work well. Computer modelling of potential and electrical field distribution based on the measurement of resistances, charge to mass and / or space charge densities may be very helpful in risk assessments when handling liquids or powders.

General methods for measuring electrostatic phenomena (charge, charge density, potential, electric field, chargeability, charge decay, current, and capacitance) and related properties of materials (resistivity and electrical strength) for a risk assessment have been described in IEC 61340-1. Measurement of transferred charges is described in IEC 60079-0:2007, 26.14.

NOTE It is scheduled to revise this method and move it to IEC 60079-32-2[7].

Another common practice is surface voltage measurement with a noncontact electrostatic voltmeter or field meter in order to locate a hazardous charge on a conductor or a non-conductor. The ignition risk associated with the measured values should be evaluated by comparing with the recommended safety levels in this document. In on-site measurements, care should be taken before introducing an earthed instrument into highly charged environment to avoid causing a discharge and the ignition risk should separately be assessed for such measurements.

Assessment of earthing and bonding should be conducted with a measurement of resistance either to ground or between bonded items. Resistance measurements can be used to check electrical connections that are prone to corrosion, movement, bonding clamps, insulating coatings, etc. For testing the earthing of personnel, methods of resistance measurements for floors and footwear are provided in IEC 61340-4-1 and 61340-4-3.

Appropriate procedures for the measurements of electrostatic properties of materials, such as resistivity (conductivity) and electrical strength, are given in the following standards:

a) For resistivity and conductivity of solid materials: IEC 60093, IEC 60167 and IEC 61340-2-3. Alternative national standards include ASTM D257, BS 7506-2, JNIOSH TR 42, and DIN 54345-5.
b) For liquid conductivity: ISO 6297. Alternative national standards include ASTM D2624-07a, ASTM D4308-95, JNIOSH TR 42, DIN 51412-1, and DIN 51412-2.
c) For powder resistivity: IEC 61241-2-2. Alternative national standards include JNIOSH TR 42.
d) For electrical breakdown strength: IEC 60243-1 and IEC 60243-2.

NOTE A comprehensive summary of all these test methods is given in IEC 60079-32-2[8].

Care should be taken as the measured resistance and resistivity depend on the electrode configuration. For example, the surface resistance measured with the electrode configuration described in the Note to 3.21 is ten times lower than the surface resistivity.

Minimum ignition energies and flammable limits of materials used should be measured by a specialist under practical conditions to evaluate their potential as an ignitable atmosphere. Related standard test methods are ASTM E582-88 for gases, IEC 61241-2-3, ASTM E2019-03 and EN 13821 for dusts.

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[7] To be published.

Annex B
(informative)

Electrostatic discharges in specific situations

B.1 Incendive discharges involving insulating solid materials

B.1.1 General

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

B.1.2 Sparks from isolated conductors

The use of insulating materials can isolate metal plant components or other conductive objects from earth. 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 isolated conductors; they should be bonded together and earthed (see Clause 13).

B.1.3 Brush discharges from insulating solid materials

Brush discharges can occur when earthed conductive objects approach highly charged insulating 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. The present state of knowledge indicates however, that independent of their MIE combustible powders cannot be ignited by brush discharges, providing there are no flammable gases or vapours.

The equivalent energies of brush discharges have been determined by transforming them into spark discharges through gases. These experiments, therefore, do not give any information concerning the incendivity of brush discharges for dusts.

Brush discharges from positively charged objects or materials, e.g. a positively charged liquid, are less incendive than those from negatively charged objects.

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).

Measurements for the ignition risk assessment of brush discharges are given in A.4 and 6.3.9.

B.1.4 Propagating brush discharges from insulating solid materials

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 an insulating sheet or layer with earthed 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 μC/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. It is, therefore, capable of igniting almost all flammable gases, vapours and powders and can cause severe electrostatic shocks. In special cases the bipolar charging of the insulating sheet can also be achieved without metal backing.

B.2 Incendive discharges produced during liquid handling

B.2.1 General

When a tank is being filled with a charged liquid of low conductivity, the charge accumulating in the liquid within the tank can create high potentials on the liquid surface and high electric fields in the ullage space. The field strength and potential distributions depend upon the size and shape of the tank, on the liquid depth and on the dielectric constant. They are proportional to the amount of accumulated charge and also depend on how the charge is distributed within the liquid.

With high liquid surface potentials, incendive brush discharges can occur between the surface of the liquid and metal protrusions into the ullage space. For a negatively charged liquid, an optimised hydrocarbon/air atmosphere and an ideal spherical 12,8 mm diameter protrusion, experiments have shown that brush discharges can be incendive if the surface potential adjacent to the protrusion exceeds about –25 kV.

An ignition hazard could arise at much lower potentials if isolated 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 an earthed metal protrusion or the tank wall.

Safe filling rules for many situations have been arrived at empirically (e.g. for road and rail tanker loading) but the rules for loading fixed vertical axis medium sized tanks have been derived theoretically (with quite similar results to the empirical methods where there is overlap) as empirical measurement data is not available for this class of tank. The theoretical method is summarised in B.2.2.

B.2.2 Calculated maximum safe flow velocities for filling medium-sized vertical axis storage tanks

The maximum safe flow velocity is the velocity that just keeps the maximum surface voltage below the specified hazard threshold (25 kV) throughout the fill. It has been calculated (Britton and Smith (2012), Britton and Walmsley (2012)) in order to obtain the velocity limits recommended in 7.3.2.3.5.3 for filling medium-sized vertical axis storage tanks.

The calculations are not generally useful for large tanks (diameter >10 m) because, in these, the assumption of uniform charge density, which is used in the calculations, tends to be a poor approximation. They could be applied to the filling of small metal containers such as drums and metal IBCs but, for these, the benefits of filling via a downpipe located near the axis of the container usually need to be taken into account and the flow rates in standard filling equipment are generally low enough that explicit velocity restrictions need not be given.

The results of the calculations are not well fitted by *vd* limits and consequently the approach adopted has been to directly calculate and tabulate the maximum safe velocity and the associated maximum safe flow rate as a function of tank and pipe diameter.

The maximum safe velocity calculation is based on:

a) A maximum surface potential of 25 kV on the liquid surface at any time during the fill (see B.2.1).

b) An inlet charge density derived for pipe flow charging using the expression given in A.1.4 with conductivity compensation below 3 pS/m and an empirical constant of 1,0 μC s m^{-3}.

c) An Ohm's Law relaxation model to derive the (uniform) internal tank charge density from the inlet charge density using an effective relaxation time, τ_{eff} that is double the relaxation time derived directly from the rest conductivity of the fuel. For most practical cases the total liquid charge is close to $I\tau_{eff}$ where I is the inlet streaming current (charge density × flow rate). Where the total charge departs from $I\tau_{eff}$ it is lower so the use of $I\tau_{eff}$ provides a worst-case. The calculated maximum safe velocities are therefore based on a total liquid charge of $I\tau_{eff}$. Below 3 pS/m the charge density (streaming current) is proportional to conductivity and the effective relaxation time is inversely proportional to streaming current so the total charge and the surface voltage are independent of conductivity. The voltage obtained at 3 pS/m (giving τ_{eff} = 12 s) is thus equal to the worst-case and the calculations were done with this conductivity.

d) An expression derived independently by Asano (1979) and Britton and Smith (1988) for the voltage at the centre of the liquid surface in a cylindrical metal vertical-axis storage tank that is partly filled with a uniformly charged liquid.

e) Work by Britton and Smith (2012) who performed many calculations with the Asano/Britton and Smith expression and used an empirical analysis of the resulting data to extract simplified results for the maximum potential on the liquid surface under different fill conditions.

It follows from equation (12) of Britton and Smith (2012) and the charge density equation in A.1.4 that the maximum safe filling velocity v is given by:

$$v = K(D/d)^{0,5}$$

where K is a constant with the dimensions of velocity that depends weakly on the dielectric constant, ε_L, of the liquid and may be expressed (Britton and Walmsley 2012) as:

$$K < 0,6\{(1+\varepsilon_L)/\varepsilon_L\}^{1/2}$$

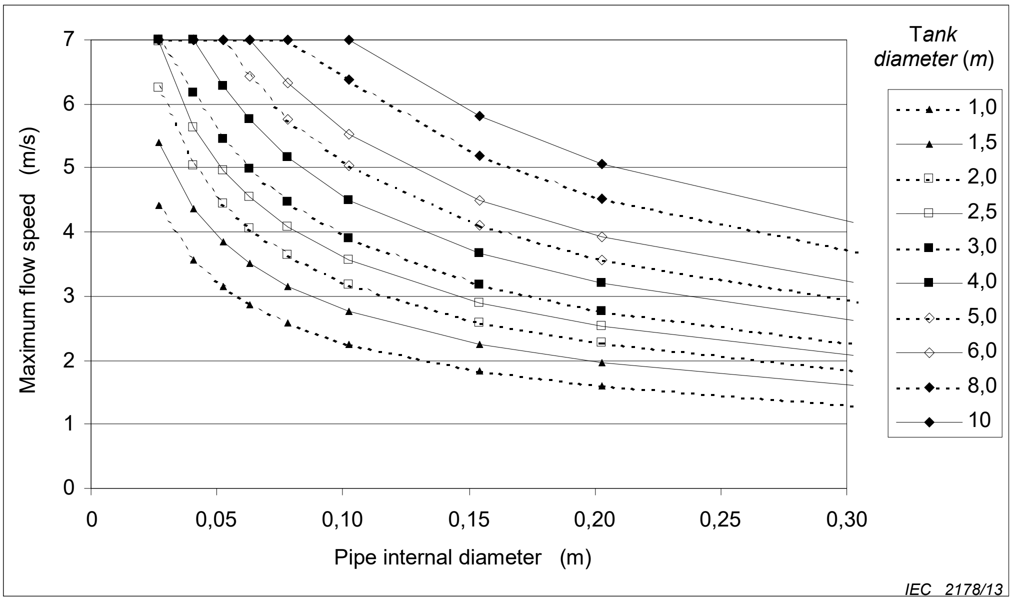

Figure B.1 – Calculated maximum safe filling velocities for medium sized tanks (see 7.3.2.2.5.2)

For ε_L= 2,2, K takes the value 0,72 m/s. Figure B.1 shows the limiting velocities obtained with this expression for a range of different pipe and tank diameters.

The uncertainties in the analysis (e.g. is the charge uniformly distributed in the liquid) do not warrant the use of a highly accurate value for the constant so in 7.3.2.3.5.3 of the main text the constant has been rounded down to K = 0,7 m/s for simplicity.

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 μm), except where flammable gas or a fine powder fraction is present (e.g. unpurged resin or powders containing residual solvent or a fine fraction caused by wear). But mixtures of granules and fine powder are potentially hazardous, since in both cases brush and the more incendive cone discharges can occur. These discharges have also been observed with particle distributions containing no granules, but their frequency of occurrence is lower.

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.

B.3.4 Discharges involving insulating containers and people

Charged powders inside an insulating container, or people close to such a container, can also lead to discharges which can cause ignitions. Discharges from powder to the inside wall of an insulating container can lead to polarisation across the container wall. If an earthed person or conductor touched the surface there could be a risk of a propagating brush discharge. Such a discharge is not only highly incendive but it can cause severe electrostatic shock. Insulating 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 powder processes

In some operations, particularly during 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 insulating 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. However, sparks from improperly grounded people are a far more important hazard.

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 electrostatic shock and precautions should be taken to prevent their occurrence.

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

B.3.6 Spark discharges in powder processes

Spark discharges can occur due to the charging of electrically isolated conductive parts of equipment, people 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 either by assessed by comparing the stored energy, as measured by $\frac{1}{2}\, C\, V^2$ (see A.3.2), with the minimum ignition energy (MIE) of the combustible powder in question (see C.6) or by measuring the transferred charge and comparing it with known threshold limits (see 6.3.9).

NOTE For the assessment of electrostatic hazards of isolated conductors, the most relevant value of MIE is that which has been determined using a capacitive circuit without an additional inductance (see C.6).

B.3.7 Brush discharges in powder processes

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 insulating surfaces of equipment, packaging material, or by highly charged insulating powder, either in bulk or in suspension in air.

The present state of knowledge based on practical experience, experimental evidence and the absence of incidents indicates that brush discharges do not ignite powder clouds unless they are mixed with flammable gases and vapours (see A.3.4).

Care should be taken when handling solvent wet powders, which can release flammable gases over a long period of time with a much lower MIE than the pure powder. When handling large amounts of medium or insulating powders brush discharges incendive for the evolving gas atmosphere cannot be avoided.

Consideration should also be given to whether MIE results of less than 1 mJ for powders are actually caused by evolving gas atmosphere rather than by the powder alone.

NOTE The presence of contaminants (e.g. solvent, grease or moisture) may affect the potential ignition hazard when using insulating materials in the presence of dusts.

B.3.8 Corona discharges in powder processes

Corona discharges occur in the presence of a sufficiently strong electric field 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 insulating powders, corona discharges cannot be avoided, but these discharges do not create an ignition hazard unless very sensitive explosive atmospheres are present, e.g. caused by oxygen enrichment or the presence of hydrogen or other gases having a very low MIE.

B.3.9 Propagating brush discharges in powder processes

Propagating brush discharges can occur from the surfaces of insulating 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 insulating material or through metal pipes with an insulating lining. High surface charge densities can also result from the deposition of ions such as are produced during the bulking of charged insulating powder.

Propagating brush discharges do not normally 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 $\varepsilon = 2$, surface charge density $\sigma = 1 \times 10^{-3}$ C/m^2, thickness $d = 150$ µm, and area $A = 0{,}25$ m^2, the stored energy W is given by:

$$W = \tfrac{1}{2} C V^2 = \frac{A\, d\, \sigma^2}{2\, \varepsilon\, \varepsilon_0} = 1\ \text{J}$$

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 insulating walls and coatings is less than 4 kV (see A.3.5).

Annex C
(informative)

Flammability 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.8.

C.2 Effect of oxygen concentration and ambient conditions

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

Operating at conditions other than ambient, in particular with high temperatures or oxygen levels above 21 %, can have a severe adverse effect on flammability characteristics (in particular MIEs).

C.3 Explosive limits for gases and liquids

For each substance there are upper and lower explosive limits and only mixtures within these limits can be ignited. For hydrocarbons in air those limits are between about 1 % and 15 % by volume. Substances with wide flammable limits, for example, hydrogen, acetylene, and carbon disulfide, 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 that is non-flammable, contains little or no oxygen~~,~~ and does not support combustion. Examples include nitrogen, boiler flue gas, steam, and carbon dioxide. 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. Some limiting oxygen concentrations (LOC), with nitrogen diluent, are 10 % by volume for methane, 8 % for ethylene and 3 % by volume for hydrogen. It is normal to include a safety factor and a maximum oxygen content of 5 to 6 % by volume is frequently specified for hydrocarbons.

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

NFPA 69, *Standard on Explosion Prevention Systems*, may help with defining controls to prevent the formation of flammable atmospheres for further information and provides a safety factor for explosion prevention which depends on the LOC and on the type of oxygen control system employed.

NOTE Depletion of oxygen content in air by displacement with inert gas is a potential hazard to people. Exposure to atmospheres containing 12 % or less oxygen will bring about unconsciousness without warning and so quickly that the individual cannot help or protect themselves. Exposure to atmospheres containing between 12 % and 14 % oxygen will have the following physical effects on people: respiration increases on exertion, raised pulse, and impaired co-ordination, perception and judgement. Exposure to atmospheres containing between 15 % and 19 % oxygen may impair co-ordination of people and may induce early symptoms in people with coronary, pulmonary or circulatory problems. National regulations and/or codes relating to specific industries or applications may exist and may be consulted.

Carbon dioxide is known sometimes to become a source of oxygen in combustion. Therefore, care should be taken when carbon dioxide is used for inerting.

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 °C below its flash point and, for mixtures containing liquids with a wide range of volatilities, this should be increased to at least 11 °C. In general, it is better to use a high rather than a low flash point solvent.

NOTE For a discussion of flash point safety factors including corrections for elevation above sea-level, see Britton and Smith (2012).

It should be noted that sprays or fine mists of flammable liquids can be ignited at temperatures well below their flashpoint (e.g. in a fuel oil burner).

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 provide a useful guide as to how easily the substance can be ignited by electrostatic discharges. For most gases and vapours the MIE lie between 0,1 mJ and 0,3 mJ. The value for dusts ranges from below 1 mJ to over 10 J.

The incendivity of spark discharges varies for sparks produced from electrical circuits containing different values of inductance, resistances and types of capacitors. In some circumstances ignitions may occur at energies lower than the MIE values obtained with mainly capacitive circuits. Care is needed to ensure that the values used in a risk assessment have been determined with a suitable circuit. For an electrostatic hazard assessment the values obtained from a capacitive discharge circuit with no additional inductance or resistance are used, as described for gaseous mixtures in ASTM E 582, *Standard test method for minimum ignition energy and quenching distance in gaseous mixtures* and for dust clouds in IEC 61241-2-3, *Method for determining minimum ignition energy of dust/air mixtures* and ASTM E 2019-03, *Standard test method for minimum ignition energy of a dust cloud in air*.

NOTE 1 ASTM E 582 gives the reproducibility as ±10 %.

NOTE 2 Special care is needed for condensable vapours whose liquid phases are conductive.

Methane has the highest MIE of any hydrocarbon (0,28 mJ). Ethylene (0,082 mJ) is used in testing as being distinct from paraffin test gases such as propane. Hydrogen is used in testing as being distinct from ethylene. Benzene (0,20 mJ) has the smallest measured MIE of any hydrocarbon not containing double or triple bonds or ring torsion. With this in mind one can define several MIE intervals as shown in Table C.1:

Table C.1 – Typical MIE intervals with examples

Name	Lowest value	Highest value	Examples
High MIE	> 10 mJ	-	Ammonia, dichloromethane, trichloroethylene
Elevated MIE	> 0,28 mJ	10 mJ	Halogenated organics
Normal MIE	0,20 mJ	0,28 mJ	Aromatic and aliphatic hydrocarbons without double bonds
Low MIE	0,08 mJ	≤ 0,20 mJ	Ethene, butadiene, cyclopropane, acetaldehyde, diethyl ether, styrene
Very Low MIE	-	< 0,08 mJ	Hydrogen, ethyne, arsin, chlorosilanes, carbon disulfide, ethylene oxide, fuel mixtures with oxygen

There exist only few measured values of MIE for sprays or dispersed droplets (e.g. 7 mJ for quiescent clouds of organic solvents with flash point 38 °C to 150 °C, and > 150 mJ for turbulent ones). These values are higher than those for the equivalent vapour/air mixtures since the heat of vaporization must be supplied.

In the 1960s and 1970s, liquids producing flammable vapours were often classified according to their Maximum Experimental Safety Gap (MESG) because this unit led to three significantly separated data clusters when drawing MESG against ignition hazard. In 1978, these three clusters were named IIA, IIB and IIC in EN 50014.

Subsequent checking of old MESG values has indicated that many were too high. As a consequence some IIA liquids (ethanol, propanol, butanol, hexanol, heptanol, 1,2-ethanediol, ethylbenzene, 3-oxobutanoic acid ethyl ester) were moved into the IIB region. In 1981 these liquids were, therefore, reclassified as IIA/IIB to indicate that although their MESG was in the IIB region, they only needed the same safety precautions as IIA liquids.

In 2003, these liquids were newly classified as IIB, but comparable to IIA liquids. However, as this expression is not very robust, many proposals have been made to overcome this problem (e.g. moving the MESG border limit from 0,90 mm to 0,88 mm, use of a MIE border limit of 0,20 mJ or 0,18 mJ). Because MIE and MESG values can be measured only with a relatively high degree of uncertainty, none of these proposals is really satisfactory. For this reason, all liquid previously classified as IIA/IIB (see above) were simply added to the explosion group IIA.

Table C.2 contains values for the minimum ignition energy MIE and minimum ignition charge MIQ of ignition optimised mixtures at 25 °C and atmospheric pressure published by the Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, in the Appendix of the German Technische Regeln Betriebssicherheit TRBS 2153, 2009. Note especially that the MIE of methanol has been redetermined as 0,20 mJ which is in contrast to an older extrapolated value of 0,14 mJ. Some values have been added from NFPA77 (2004). These values are marked with [a].

Table C.2 – Minimum ignition energy MIE and minimum ignition charge MIQ

Substance	**MIE** [mJ]	**MIQ** [nC]	**Ignition optimum** [Vol.-%]	**Explosion group according to IEC 60079-20-1**
Acetaldehyde	0,38	–	–	IIA
Acetic acid ethyl ester	0,46	120	5,2	IIA
Acetone	0,55	127	6,5	IIA
Acrolein[a]	0,13	–	–	IIB
Acrylonitrile	0,16	–	9,0	IIB
Allyl chloride[a]	0,77	–	–	IIA
Ammonia	14	1 500	20	IIA
Benzene	0,20	45	4,7	IIA
1,3-Butadiene	0,13	–	5,2	IIB
Butane	0,25	60	4,7	IIA
2-Butanone	0,27	–	5,3	IIB
2-Butyl chloride[a]	1,24	–	–	IIA
Carbon disulfide	0,009	–	7,8	IIC
Cyclohexane	0,22	–	3,8	IIA
Cyclopropane	0,17	–	6,3	IIB
1,2-Dichloroethane	1,0	–	10,5	IIA
Dichloromethane	9 300	880 000	18	IIA
Diethyl ether	0,19	40	5,1	IIB
Diethyl ether in oxygen[a]	0,0 012	–	–	–[b]
2,2-Dimethylbutane	0,25	70	3,4	IIA
Ethane	0,25	70	6,5	IIA
Ethanol	0,28	60	6,4	IIB
Ethylene	0,082	32	8,0	IIB
Ethylene in oxygen[a]	0,0 009	–	–	–[b]
Ethyne (Acetylene)	0,019	–	7,7	IIC
Ethyne in oxygen[a]	0,0 002	–	–	–[b]
Ethylen oxide	0,061	–	10,8	IIB
Heptane	0,24	60	3,4	IIA
Hexane	0,24	60	3,8	IIA
Hydrogen	0,016	12	22	IIC
Hydrogen in oxygen [a]	0,0 012	–	–	–[b]
Methane	0,28	70	8,5	IIA
Methanol	0,20	50	14,7	IIA
2-Methylbutane	0,21	63	3,8	IIA
Methylcyclohexane	0,27	70	3,5	IIA
Pentane	0,28	63	3,3	IIA
cis-2-Pentene	0,18	–	4,4	IIB
trans-2-Pentene	0,18	–	4,4	IIB
Propane	0,25	70	5,2	IIA
Propane in oxygen [a]	0,0 021	–	–	–[b]
1-Propyne (methyl acetylene)	0,11	–	6,5	IIB

Substance	MIE [mJ]	MIQ [nC]	Ignition optimum [Vol.-%]	Explosion group according to IEC 60079-20-1
Propylene oxide	0,13	–	7,5	IIB
Tetrafluoroethene	4,1	–	–	IIA
Tetrahydro-2H-pyrane	0,22	60	4,7	IIA
Toluene [a]	0,24	–	–	IIA
1,1,1-Trichloroethane	4 800	700 000	12	IIA
Trichloroethylene	510	150 000	26	IIA
Trichlorosilane [a]	0,017	-	-	IIC
Xylene[a]	0,20	–	–	IIA

[a] From NFPA77, 2007

[b] According to IEC 60079-20-1, the measuring method for the MESG values, on which the classification in explosion groups is based, is valid only for mixtures of gases and vapours with air.

C.7 Combustible powders

All solid combustible materials including metals may create a flammable 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/m^3 to several kg/m^3). The explosion hazard (explosion sensitivity and violence) for a given substance depends on particle size and many other factors. It is highest in the case of very fine dust.

NOTE The MIE of explosive powders is sometimes lower when they are deposited on a surface than when they are suspended in air. Therefore, the risk of electrostatic ignition of such explosive powders when deposited is higher than that of the suspended powders in air.

C.8 Biofuels

A biofuel is any fuel made from a regenerative biosystem. They are named according to their biocomponent (E = Ethanol, M = Methanol, B = Biodiesel) and its volume content in the fuel in percent.

Currently (2012) biodiesel made from natural plant oils and biogasoline which contains ethanol produced by alcoholic oxidation of biomass are already in use. Biofuels are, however, not just limited to ethanol/gasoline mixtures or plant oils but may become other mixtures in the future. As it is hard to generalise what will appear in the future the following statements are limited to bioethanol/gasoline mixtures:

a) If ethanol is added to gasoline it tends to clean the system. This may lead to an increased water and solid content in the flowing fuel which both increase chargeability.

b) The more ethanol is added to gasoline, the higher its conductivity and the lower its chargeability.

c) As a consequence of a) and b) the chargeability of biofuel usually increases in the following sequence: E100 < E10 < E0 < E5.

d) E50 to E100 fuels may create explosive atmosphere in tanks under certain conditions, especially as the tank becomes empty. For this reason Flexfuel vehicles may need special tank equipment, e.g. flame arresters in the filling tube. Too fine a flame arrester may, however, cause other problems, e.g. due to blockages.

Annex D
(informative)

Classification of hazardous areas

D.1 Concept of zoning

The degree of risk (e.g. 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 a flammable atmosphere. Precautions considered necessary to avoid electrostatic charging where there is often a flammable 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 flammable atmosphere occurring.

D.2 Classification

According to IEC 60079-10-1 and IEC 60079-10-2 hazardous areas are classified into the following Zones:

a) **Zone 0:** place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.

b) **Zone 1:** place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.

c) **Zone 2:** place in which an explosive atmosphere consisting of a mixture with air of flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

d) **Zone 20:** place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is present continuously, or for long periods or frequently for short periods.

   NOTE Places 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:** place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is likely to occur occasionally in normal operation.

f) **Zone 22:** place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

D.3 Explosion groups

D.3.1 General

According to IEC 60079-0, substances creating flammable gases, vapours and dusts are classified into the following explosion groups:

D.3.2 Group I

Equipment of Group I is intended for use in mines susceptible to firedamp.

NOTE The types of protection for Group I take into account the ignition of both firedamp and coal dust along with enhanced physical protection for equipment used underground.

Equipment intended for mines where the atmosphere, in addition to firedamp, may contain significant proportions of other flammable gases (i.e. other than methane), should be constructed and tested in accordance with the requirements relating to Group I and also to the subdivision of Group II corresponding to the other significant flammable gases. This equipment should then be marked appropriately (for example, "Ex d I/IIB T3" or "Ex d I/II (NH3)").

D.3.3 Group II

Equipment of Group II is intended for use in places with an explosive gas or vapour atmosphere other than mines susceptible to firedamp.

Equipment of Group II is subdivided according to the nature of the explosive gas or vapour atmosphere for which it is intended.

Group II subdivisions

IIA: A typical gas is propane, a typical vapour is hexane.
IIB: A typical gas is ethylene, a typical vapour is diethyl ether.
IIC: A typical gas is hydrogen, a typical vapour is carbon disulfide.

NOTE 1 This subdivision is based on the maximum experimental safe gap (MESG) or the minimum ignition current ratio (MIC ratio) of the explosive gas atmosphere in which the equipment may be installed. See IEC 60079-20-1.

NOTE 2 Equipment marked IIB is suitable for applications requiring Group IIA equipment. Similarly, equipment marked IIC is suitable for applications requiring Group IIA or Group IIB equipment.

D.3.4 Group III

Equipment of Group III is intended for use in places with an explosive dust atmosphere other than mines susceptible to firedamp.

Equipment of Group III is subdivided according to the nature of the explosive dust atmosphere for which it is intended.

Group III subdivisions:

IIIA: combustible flyings (e.g. flock).
IIIB: non-conductive dust (e.g. coating powder).
IIIC: conductive dust (e.g. metal dust).

NOTE Equipment marked IIIB is suitable for applications requiring Group IIIA equipment. Similarly, equipment marked IIIC is suitable for applications requiring Group IIIA or Group IIIB equipment.

Annex E
(informative)

Classification of equipment protection level

According to IEC 60079-0 equipment for use in explosive atmospheres is classified into the following equipment protection levels EPL:

EPL Ma

Equipment for installation in a mine susceptible to firedamp, having a "very high" level of protection, which has sufficient security that it is unlikely to become an ignition source in normal operation, during expected malfunctions or during rare malfunctions, even when left energized in the presence of an outbreak of gas.

EPL Mb

Equipment for installation in a mine susceptible to firedamp, having a "high" level of protection, which has sufficient security that it is unlikely to become a source of ignition in normal operation or during expected malfunctions in the time span between there being an outbreak of gas and the equipment being de-energized.

EPL Ga

Equipment for explosive gas atmospheres, having a "very high" level of protection, which is not a source of ignition in normal operation, during expected malfunctions or during rare malfunctions.

EPL Gb

Equipment for explosive gas atmospheres, having a "high" level of protection, which is not a source of ignition in normal operation or during expected malfunctions.

EPL Gc

Equipment for explosive gas atmospheres, having an "enhanced" level of protection, which is not a source of ignition in normal operation and which may have some additional protection to ensure that it remains inactive as an ignition source in the case of regular expected occurrences (for example failure of a lamp).

EPL Da

Equipment for explosive dust atmospheres, having a "very high" level of protection, which is not a source of ignition in normal operation, during expected malfunctions, or during rare malfunctions.

EPL Db

Equipment for explosive dust atmospheres, having a "high" level of protection, which is not a source of ignition in normal operation or during expected malfunctions.

EPL Dc

Equipment for explosive dust atmospheres, having an "enhanced" level of protection, which is not a source of ignition in normal operation and which may have some additional protection to ensure that it remains inactive as an ignition source in the case of regular expected occurrences (for example failure of a lamp).

Annex F
(informative)

Flow chart for a systematic electrostatic evaluation

This Technical Specification is extensive and for new readers may appear complex and difficult to work through. To make it easier for the new or infrequent reader, the flow chart given in Figure F.1 is designed to help in finding a systematic procedure for an electrostatic evaluation of any product or process.

The flow chart is divided in two paths: the first evaluates all conductive or dissipative materials, parts and sockets, the second all insulating parts. Every path either ends at “Test passed” or at the respective type of discharge expected to occur under the given conditions.

This flow chart is written in a style that it is as widely applicable as possible. However, there may be situations where it cannot be used. In this case, the user should search for a clause elsewhere in this Technical Specification dealing with the specific situation.

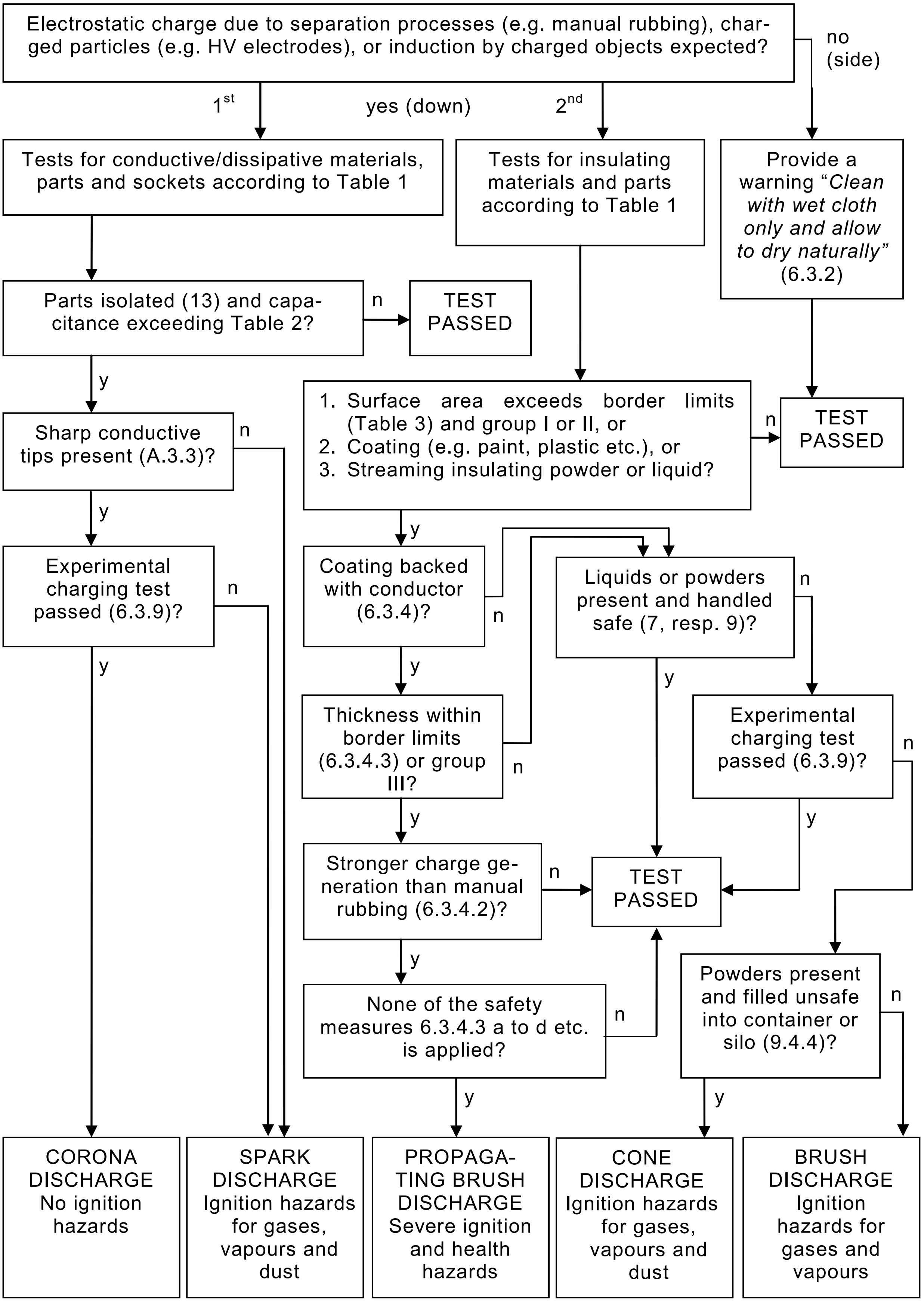

Figure F.1 – Flowchart for a systematic electrostatic evaluation

Annex G
(informative)

Tests

At present, IEC 60079-32-2[8], *Explosive atmospheres – Part 32-2: Electrostatic hazards – Tests* is in development. Its test methods are based on the principles listed below:

G.1 General

Variations in the results of the measuring electrostatic properties of materials is mainly due to variations in the sample (e.g. inhomogeneous surfaces, geometry and the state of the material) rather than uncertainties in voltage, current, electrode geometry or uncertainty of the measuring device. This is due to the effect that electrostatic properties are strongly influenced by very small differences so that statistical effects play an important role.

Typically, the accuracy and reproducibility of electrostatic measurements is about 20 % to 30 %. This is much higher than for a typical electric measurement which is less than 1 %. For this reason, electrostatic threshold limits contain a certain safety margin to compensate for the occurring statistical scatter.

To obtain comparable results all over the world, the samples should be acclimated and measured at the stated relative humidity and temperature (mostly 24 h at (23 ± 2) °C and (25 ± 5) % relative humidity). In countries which may experience lower or higher humidity and temperature levels, an additional value at the local higher or lower relative humidity and temperature may be reasonable (e.g. (40 ± 2) °C and (90 ± 5) % relative humidity for tropical climates and (23 ± 2) °C and (15 ± 5) % relative humidity for arctic climates).

G.2 Surface resistance

G.2.1 General

Surfaces which have a sufficiently low surface resistance cannot be electrostatically charged when in contact with earth. For this reason, the surface resistance is a basic electrostatic property concerning electrostatic chargeability. As surface resistances usually increase with decreasing relative humidity, a low relative humidity is necessary during measuring to replicate worst case conditions.

G.2.2 Principle

The surface is contacted with two conductive electrodes of distinct length and distance and the resistance between both electrodes is measured. As high resistances usually decrease with increasing voltage, the applied voltage should be increased to at least 500 V, preferably 1 000 V, at very high resistances.

G.2.3 Apparatus

The measuring apparatus according to IEC 60079-0 consists of two parallel electrodes with the dimensions given in Figure G.1. This may be realized by electrodes painted with silver paint through a suitable stencil, soft conductive rubber strip electrodes on spring-mounted metal tongues or conductive foam strips mounted on an insulating support.

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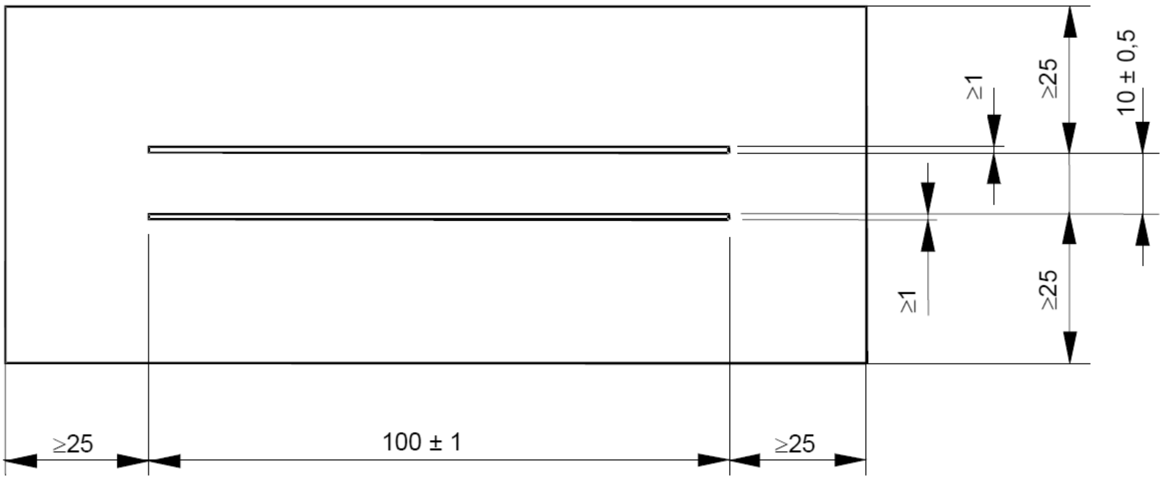
[8] To be published.



IEC 2180/13

Dimensions in millimetres

Figure G.1 – Test sample with applied electrodes

NOTE 1 The surface resistance is dependent upon the electrode configuration.

NOTE 2 This electrode configuration is also used e.g. in IEC 60167 and CENELEC TR 50404.

NOTE 3 Soft conductive rubber strip electrodes are preferred over silver paint electrodes to limit unwanted chemical surface interaction.

NOTE 4 In case of uneven samples, silver paint electrodes are preferred over soft electrodes because of their better adoption to the sample geometry.

NOTE 5 In the case of small samples, the area around the electrodes may be smaller than 25 mm as given in Figure G.1.

The electrodes are connected to a teraohm meter. A guard shield electrode may be placed over the electrodes to minimise electric noise. During the test, the voltage should be sufficiently steady so that the charging current due to voltage fluctuation will be negligible compared with the current flowing through the test sample.

The teraohm meter should be regularly checked with a high resistance of known value. The geometry of conductive rubber or foam electrodes should also be regularly checked by measuring their imprint. If the electrode pressure to reach the minimum resistance is higher than 20 N, the rubber electrodes should be replaced by softer ones.

G.2.4 Test sample

The surface resistance should be measured on the parts of actual specimen if size permits, or on a test sample comprising a rectangular plate with dimensions in accordance with Figure G.1. The test sample should have an intact clean surface. As any solvent may leave conductive residues on the surface it is best to clean the surface with a brush only. This is especially important in cases where the surface is treated with special antistatic agents.

If, however, fingerprints or other dirt is visible on the surface and no special antistatic agents are used on the surface the test sample should be cleaned with distilled water, then with isopropyl alcohol (or any other solvent that can be mixed with water and will not affect the material of the test sample and the electrodes), then once more with distilled water before being dried.

Untouched by bare hands, it should then be conditioned for at least 24 h at (23 ± 2) °C and (25 ± 5) % relative humidity.

G.2.5 Procedure

The measurement procedure is as follows:

a) Carry out the test under the same climate as the pre-conditioning.

b) Place the electrodes on the surface.

c) Apply a pressure of 20 N on the electrodes (not necessary in the case of painted electrodes).

d) Apply a measuring voltage of (10 ± 0,5) V for (15 ± 5) s between the electrodes.

e) Measure the resistance between both electrodes and record the value at the end of the measuring time.

NOTE Starting with low measuring voltage is necessary to avoid damage of the electrodes caused by high currents when measuring low resistance samples.

f) If the resistance is between 1 MΩ and 10 MΩ, the measuring voltage should be increased to (100 ± 5) V. Resistances between 10 MΩ and 100 MΩ should be measured with (500 ± 25) V. In case of surface resistances exceeding 100 MΩ apply a voltage of at least (500 ± 25) V, preferably (1 000 ± 50) V, for (65 ± 5) s.

NOTE In IEC 61340-4-1, 100 V are applied for resistances between 1 MΩ and 100 MΩ and 500 V for even higher ones. As high resistances usually decrease with increasing voltage and need a longer time for stable results, this document uses even higher voltages and measuring times for high resistances than the standard above.

g) Repeat the measurement nine times. If the object is not sufficiently large for nine additional measurements, a lower number of repeats is acceptable.

G.2.6 Acceptance criteria

The surface resistance is the quotient of the direct voltage applied at the electrodes to the total current flowing between them. Respective border limits can be found in Table 1. Test samples should be classified according to the measured resistance at the highest measuring voltage. For example, if the resistance at 10 V is 1,5 MΩ, and at 100 V is 900 kΩ, the test sample should be classed as having a resistance of 900 kΩ.

G.2.7 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- test results,
- applied measuring voltage
- number of measurements,
- geometric mean resistance.
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.3 Surface resistivity

The surface resistivity is ten times higher than the surface resistance measured according to G.2.

G.4 Leakage resistance

G.4.1 General

The leakage resistance of an object is an important electrostatic safety characteristic. There are several standards published with different measuring methods for testing the leakage resistance of a floor which mostly can be applied for other objects too (e.g. rotating cylinders, housings, bags with an earthing point). In IEC 61340-4-1 the test is executed with a circular electrode, (65 ± 5) mm in diameter pressed to the floor with (2,5 ± 0,25) kg (hard floor) or (5,0 ± 0,25) kg (soft floor). In ISO 10965 measurement is done with a circular electrode, (65 ± 2) mm in diameter pressed to the floor with (5,0 ± 0,1) kg. ASTM F150 uses a circular electrode, 63,5 mm in diameter pressed to the floor with 2,5 kg. EN 1081 uses a three-footed electrode pressed to the floor by a person standing on it. As each method yields a somewhat different resistance it is important that the measuring method used is stated in product specifications and test reports.

NOTE In ideal cases the differences between the measured resistances of the different methods described above are small. In reality, rough surfaces, e.g. external concrete forecourts with significant stone content standing proud may influence the measured resistance depending on the used electrode surface and the applied pressure. Improved results may be obtained with conductive foam pads under IEC 61340-4-1 electrodes to take up roughness of several mm. However, this may not replicate the practical situation of a person’s footwear with hard soles.

G.4.2 Principle

The floor or object is contacted with a specified electrode and the resistance between electrode and earth is measured.

G.4.3 Apparatus

Usually, a circular electrode, (65 ± 5) mm in diameter with a conductive rubber surface is pressed to the object with 2,5 kg, or 5 kg which is within the electrode specification of nearly all standards cited in G.4.1. However, three-footed electrodes described in EN 1081 may be more suitable if simulation of the body pressure on the floor is important.

NOTE Measured resistance tends to decrease with increasing electrode pressure, but only up to a certain point, after which further increase in pressure has little effect on measured resistance. It has been found that for many flooring materials, the pressure applied by a 5 kg, 65 mm diameter electrode is adequate for accurate measurement.

The electrodes are connected to a teraohm meter. A guard shield electrode may be placed over the electrode to minimise electric noise. During the test, the voltage should be sufficiently steady so that the charging current due to voltage fluctuation will be negligible compared with the current flowing through the test sample.

The teraohm meter should be regularly checked with a high resistance of known value. If the electrode pressure to reach the minimum resistance on a test sample is higher than 20 N, the rubber electrodes should be replaced by softer ones.

G.4.4 Test sample

The test floor or object should have an intact clean surface. If the floor or object being measured is outside (e.g. forecourt surfaces at filling stations), there should be no rainy or foggy weather within 24 h before the measuring time (relative humidity close to 50 % or even less). Floors or objects intended to be used inside should be conditioned at (23 ± 2) °C and (25 ± 5) % relative humidity for 24 h for laboratory measurements, or under ambient conditions for in situ measurements.

Additional conditioning time may be required for textile floor covering and other materials that readily absorb moisture (see ISO 10965).

G.4.5 Procedure

The test should be carried out according to G.2.5 except that measurement takes place between one electrode and earth. In case of floors, one measuring value per square metre is sufficient.

G.4.6 Acceptance criteria

The leakage resistance is the quotient of the direct voltage applied at the electrode to the total current flowing between electrode and earth. Respective border limits can be found in Table 1.

G.4.7 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- test results,
- measuring voltage,
- electrode description,
- applied pressure,
- number of measurements,
- median resistance
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.5 In-use testing of footwear

G.5.1 General

Laboratory testing of footwear is described in IEC 61340-4-3. For regular daily testing, the earth leakage resistance of a person wearing footwear can usually be determined with footwear conductivity testers (Personnel Grounding Tester). If such a device is not available, this resistance should be measured according to the following sections.

G.5.2 Principle

The resistance between a hand-held object and a metal plate where a person stands with both feet is measured. The resistance of the person is assumed to be negligible compared to the resistance of the shoes.

G.5.3 Apparatus

The measuring device consists of a metal plate on the floor and a hand-held metal object (e.g. a metal bar of 20 mm in diameter and 100 mm in length or a metal sphere 50 mm in diameter). A teraohm meter is connected between both electrodes measuring the resistance between hand-held metal object to the metal plate via body and feet. The teraohm meter should be regularly checked with a high resistance of known value.

The measuring voltage should not exceed 100 V to prevent an electric shock. When measuring with 100 V a protecting resistor of about 1 MΩ should be within the measuring circuit. This resistor may be omitted when measuring low resistances with 10 V.

G.5.4 Procedure

The measurement procedure is as follows:

a) Measure at (23 ± 2) °C and (25 ± 5) % relative humidity. If the relative humidity is exceeded, record the humidity at least.
b) Put on the shoes to be tested.
c) Wait five minutes to get sufficient humidity in shoes and socks.
d) Stand on the metal plate with both feet and grasp the metal object with one bare hand.
e) Record the displayed resistance of the footwear.

G.5.5 Acceptance criteria

Respective border limits can be found in Table 1.

G.5.6 Test report

In case of routine controls, a result in form of a red or green lamp is sufficient. In all other cases, the test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- test results,
- measuring voltage,
- number of measurements,
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.6 In-use testing of gloves

G.6.1 General

Laboratory testing of gloves is described in EN 420. For regular daily testing, the resistance of gloves may be measured together with the resistance of footwear. Unfortunately, this total resistance cannot always be determined with footwear conductivity testers (Personnel Grounding Tester). It may, therefore, necessary to measure the resistances according to the following sections.

NOTE A new CEN standard is being developed, currently identified as WI 00162317:2011.

G.6.2 Principle

The resistance between a glove-held and a hand-held metal object via body and feet to a metal plate on which the person stands with both feet is measured according to G.5.4. If the resistance of the footwear is not known, the resistance between glove-held metal object and a wrist strap of known resistance on the persons arm should be measured.

G.6.3 Apparatus

Same as in G.5.3

G.6.4 Procedure

The measurement procedure for persons earthed via their footwear is as follows:

a) Measure the resistance of the used footwear as described in G.5.4.
b) Repeat the measurement with gloves on the hand.
c) Report both values and their quotient.

The measurement procedure for persons earthed via wrist straps is as follows:

a) Earth the person via a wrist strap of known resistance.
b) Measure the resistance between the glove held metal object and the wrist strap.
c) Report both values and their difference.

G.6.5 Acceptance criteria

Respective border limits can be found in Table 1.

G.6.6 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- resistance of wrist-strap or footwear,
- test results,
- measuring voltage,
- number of measurements,
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.7 Powder resistivity

G.7.1 General

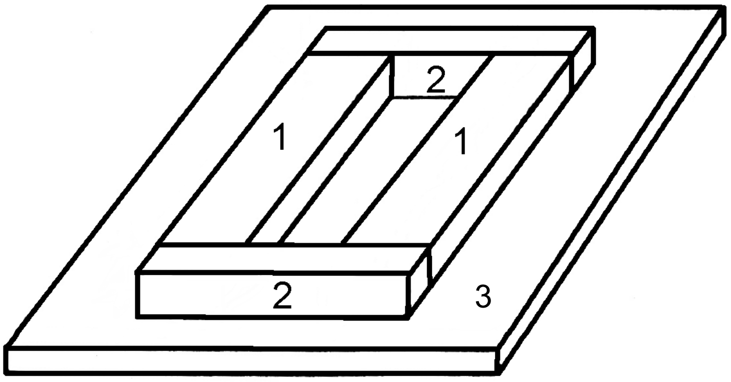
Different measuring methods exist for powder resistivity: measuring cell according to IEC/TS 61241-2-2 (groove cell), according to IEC 60093 (stamp cell) and a concentric cell with an outer and an inner ring electrode (Lucas, 2011, Stahmer et al, 2012). According to Stahmer et al, groove cell and concentric cell yield the same results. However, as a consequence of the compression of the dust, the stamp cell gives an up to ten times lower resistivity when measuring compressible dusts. For these reasons, the powder resistivity should be measured according to the following procedure based on IEC/TS 61241-2-2.

G.7.2 Principle

A constant volume of powder is filled in a specific measuring cell with two electrodes. The resistance between both electrodes is measured.

G.7.3 Apparatus

A measuring cell according to IEC 61241-2-2 consisting of two opposite electrodes of polished stainless steel bars (1), 10 mm in height, 100 mm in length and 10 mm distance, mounted together with two opposite walls of insulating glass bars (2), 10 mm in height, on an insulating base (3), should be used (Figure G.2). The thickness of the electrodes should be between 5 mm and 10 mm. The resistance *R* between the electrodes should exceed 100 TΩ. The exact values of the dimensions of the cell have to be known for the geometric correction factor in 4.7.4.



IEC 2181/13

Figure G.2 – Measuring cell for powder resistivity

The electrodes are connected to a teraohm meter. The teraohm meter should be regularly checked with a high resistance of known value. A guard shield electrode may be placed over the measuring cell without contacting the electrodes to minimise electric noise. During the test, the voltage should be sufficiently steady so that the charging current due to voltage fluctuation will be negligible compared with the current flowing through the test sample.

G.7.4 Procedure

The measurement procedure is as follows:

a) Acclimate the test dust to (23 ± 2) °C and (25 ± 5) % relative humidity for at least 24 h. Dusts which significantly dry up or absorb water and for which the dust resistance during a special technological process is important, should be measured at the climate conditions of this process.

b) Pour a quantity of the original untreated test dust between the test electrodes (3).

c) Remove excess dust by running a straight-edge along the top of the stainless steel bars (1).

d) Measure the resistance R of the filled test cell between the electrodes (1) with the following values of DC voltage applied for 10 s: (105 ± 10) V, (500 ± 25) V, (1 000 ± 50) V. The same sample of dust in the test cell may be used for all the tests at any one of the values of voltage. If no constant measuring value is reached after 10 s the measuring time should be elongated to (65 ± 5) s.

NOTE In most cases, a test voltage of (105 ± 10) V is sufficient. Higher voltages can lead to unwanted physical or chemical effects.

e) Calculate the resistivity ρ at all test voltages from the equation
   - $\rho = 0{,}001 \times R \times H \times W/L$
   - where ρ is the resistivity in Ωm, H is the height of the electrode in mm, W is the length of the electrode in mm and L is the space between electrodes in mm.

f) Repeat steps b) to e) twice and calculate the average value.

G.7.5 Acceptance criteria

Respective border limits can be found in 9.1.

G.7.6 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- test results,
- measuring voltage,
- number of measurements,
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.8 Liquid conductivity

G.8.1 General

Usually, conductivity meters with dip electrodes are sufficiently exact for electrostatic purposes. In any case, the temperature should also be reported because conductivity is strongly dependant on temperature.

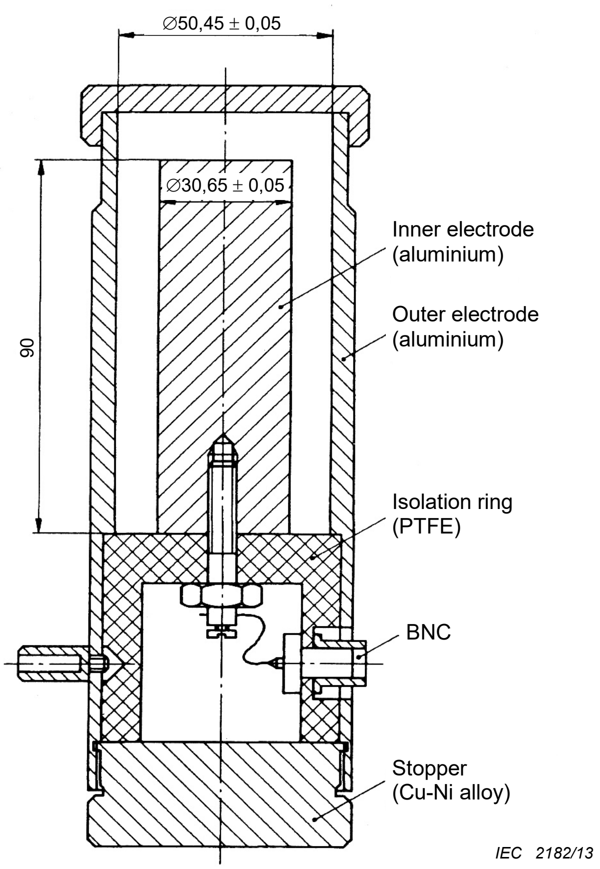
If more exact values are needed, a specific test cell such as the cell described in the following section should be used. The cell can be used for single phase and stable multiphase liquids. Alternatively, the conductivity may be determined according to IEC 60247.

G.8.2 Principle

A constant volume of liquid is filled in a specific measuring cell with two electrodes. The resistance between both electrodes is measured.

G.8.3 Apparatus

Figure G.3 describes a measuring cell according to DIN 51412-1 with a cell constant K of 1/m. Other cell dimensions are possible but the cell constant of this arrangement has to be determined from geometry. A DC voltage U of (100 ± 1) V should be applied between the inner and the outer electrode and the resulting current I should be recorded with a picoammeter coupled to an oscilloscope or Personal Computer.



Dimensions in millimetres

Figure G.3 – Measuring cell for liquid conductivity

G.8.4 Procedure

The measurement procedure is as follows:

a) Pour (100 ± 0,5) cm^3 of the original untreated test liquid in the measuring cell and close it with the lid.

b) Record the current I of the filled test cell between the electrodes at 100 V for the time t with an oscilloscope or Personal Computer coupled to a picoammeter.

NOTE In most cases, a test voltage of 100 V is sufficient. Higher voltages can lead to unwanted physical or chemical effects.

c) Extrapolate the current Io for t = 0 from the recorded course of I.

d) Calculate the conductivity σ in S/m according to

$\sigma = K \times Io/U$

– 1 pS/m = 10^{-12} S/m = 1 cu (conductivity unit)

e) Repeat the procedure twice

G.8.5 Acceptance criteria

Respective border limits can be found in 7.1.4.

G.8.6 Test report

The test report should include at least the following information:

– measuring laboratory,

- date of measurement,
- temperature,
- description and identification of the sample,
- median conductivity,
- measuring voltage,
- number of measurements,
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.9 Capacitance

G.9.1 General

Avoiding isolated conductors is one of the most important electrostatic rules. For this reason only small isolated conductive objects with low capacitances are allowed in hazardous areas. To check whether the suspected conductive object (e.g. metal screws of an enclosure, metal connecting sockets of hand-held equipment) is within the allowed limits, the following test should be executed. Metal sockets and contacts which are situated so deep in an enclosure that discharges to approaching earthed objects are not expected need not be tested.

G.9.2 Principle

The test sample is placed on an unearthed metallic plate and the capacitance between exposed conductive parts and the metallic plate is measured with a capacitance meter.

G.9.3 Apparatus

The measuring device consists of an unearthed metal plate that significantly exceeds the area of the test sample and a capacitance meter able to measure between 1 and 10 pF with a measuring uncertainty of less than 0,5 pF at a measuring frequency of at least 1 000 Hz. The applied voltage should be between 1 V and 9 V. The negative measurement lead is connected to the metal plate. The positive lead is freely available for capacitance measuring. The connection leads should be as short as possible to avoid stray currents. Metallic plates with surface oxidation should be avoided as this may lead to erroneous results.

NOTE A battery powered capacitance meter may be necessary to ensure stable readings without earth loops.

Other electrical equipment, especially fluorescent lamps, should be kept at least two meter away from the test sample.

G.9.4 Test sample

The test should be carried out on a fully assembled sample of the equipment. The sample should be conditioned in a climatic conditioning chamber for at least 1 h at a temperature of (23 ± 2) °C and a relative humidity of (25 ± 5) %.

G.9.5 Procedure for moveable items

The capacitance between each exposed metallic part on the test sample and the metal plate should be measured as follows:

a) Place the sample on the metal plate. The conductive part of the sample to be measured must remain isolated from the plate. If the sample requires support, it may be held in position with clamps made of insulating material, but should not be held by hand.

b) The positions of the samples are to be such that the exposed metallic test point being measured is as close as possible to the unearthed metal plate without contacting the plate. However, if the external metal part is in electrical contact with internal metal parts, it is necessary to measure the capacitance in all orientations of the equipment to ensure that the maximum capacitance has been determined.

NOTE 1 If a metallic part is not easily accessible to the meter leads, a screw may be inserted to extend the part and create a test point. The screw should be small compared to the metallic part and may not make electrical contact with any other internal metal part.

NOTE 2 Stray capacitance should be minimized by keeping conductive items and the human body at least 50 cm away from the sample under test.

c) Connect the negative measurement lead of the capacitance meter to the unearthed metal plate.
d) Position the positive measurement probe of the capacitance meter 3 mm to 5 mm away from the metallic test point and as far as possible from the metal plate. Record the value of this stray capacitance in air to the nearest pF.
e) Place the positive measurement lead of the capacitance meter in contact with the metallic test point and record the value of the capacitance to the nearest pF.
f) Compute the difference between the measurements in steps d) and e), and record the value.
g) Repeat steps d) through f) two times for each test point.
h) Calculate the average capacitance from the three measurements obtained.
i) Calculated capacitances less than 2 pF should be reported as < 2pF.

In cases where the capacitance of an isolated metal part is expected to be higher to other metal parts of the object than to earth, this capacitance should additionally be measured and evaluated.

G.9.6 Procedure for installed items

The capacitance between each exposed metallic part on the test sample and earth is to be measured in installed condition (e.g. metal parts within an earthed metal tank system) under worst case conditions. An unearthed counter metal plate is not needed. Measure the capacitance as follows:

a) Connect the negative measurement lead of the capacitance meter to an earth point. The positive measurement lead of the capacitance meter should be kept as far as possible from that cable.
b) Follow steps d) to i) of the test procedure described in G.9.5.

G.9.7 Acceptance criteria

The maximum allowed capacitance depends on the type of the hazardous area and is given in Table 2.

G.9.8 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- median capacitance,
- measuring voltage,
- measuring frequency,
- number of measurements,

- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.10 Transferred charge

G.10.1 General

According to IEC 60079-0 and IEC/TS 60079-32-1, the maximum allowed surface area of insulating materials is limited in explosive atmospheres. However, there are many cases where a sufficient safety level is still achieved with insulating materials. These cases include surfaces with embedded corona tips, enclosures backed with printed boards as well as materials with an internal breakthrough voltage of only a few kilovolts. For this reason the following charging test may be executed with the evaluated object if surface area requirements cannot be fulfilled.

In some cases the test has to be modified. For example, in case of evaluating a filler pipe for motor cars, a measurement of the charge generated on the filler pipe by streaming high chargeable fuels under worst case conditions is preferred.

NOTE One of the highest chargeable liquids is toluene in technical quality. However, toluene presents a significant fire risk. Therefore, in SAE J1645 a technical hydrodesulfurated heavy naphtha, boiling range 145 °C to 200 °C, flashpoint 40 °C, is proposed (commercial name: white spirit, Stoddard solvent, or Testbenzin).

In the case of garments, the test may produce results which conflict with other established test methods. For this reason, garments are usually tested by the method of charge decay in G.12 or EN 1149-3.

G.10.2 Principle

Sparks occur when a capacitance C charged to a voltage U is discharged via a spark gap. It is known from literature that every explosive atmosphere has a specific minimum ignition volume necessary to become ignited by a certain minimum ignition energy. Therefore, doubling the length of a spark gap results in halving U effective in one ignition volume (second law of Kirchhoff). Due to this linear correlation between incendivity and U, the transferred charge $C \times U$ correlates better with the incendivity of a discharge than its energy $\frac{1}{2} C \times U^2$.

These facts allow the measurement of the transferred charge of provoked discharges under worst case conditions to assess electrostatic ignition hazards.

G.10.3 Apparatus

The following items are needed:

1) A table or rigid sheet of dissipative material, e.g. untreated wood;

   NOTE The correct use of a dissipative table surface guarantees a strong charge accumulation on the charged surface due to charge binding effects. After lifting the sample from the table the charges are no longer bound by opposite charges of the table yielding optimal conditions for discharging.

2) Cloths made of materials free from finishes from the positive and negative end of a triboelectric series large enough to avoid contact between the test sample and the fingers of the testing person during the rubbing process, and a glove or other piece of smooth natural leather.

   NOTE 1 See IEC/TR 61340-1 for a triboelectric series.

   NOTE 2 Suitable positive materials for tribocharging are e.g. smooth natural leather, sheep wool felt, polyamide cloth for rain coats, cotton, and cat fur. Suitable negative materials for tribocharging are e.g. polyurethane and polyethylene table cloth.

3) A single pointed metal needle electrode or multi-needle electrodes having a connection of the electrode(s) to the minus pole of a high voltage power supply of 30 kV to 70 kV dc for corona charging.
4) One of the following or equivalent equipment for measuring charge transfer:
    a) A polished metal electrode of (25 ± 5) mm in diameter coupled to the 50 Ω input of an oscilloscope of at least 1 Gigasamples/s and 300 MHz bandwidth having a circular arranged earthed shunt resistance of (0,25 ± 0,05) Ω of at least 300 MHz in bandwidth (see Bibliography, von Pidoll), or
    b) A polished metal electrode of (25 ± 5) mm in diameter coupled to an earthed (100 ± 10) nF capacitor with a (15 ± 2) kΩ resistor in parallel, both connected to the input of a voltmeter automatically triggering and holding the highest value (see Bibliography, Schnier), or
    c) A polished metal electrode of (3 ± 1) mm in diameter in a smooth edged hole of (5 ± 1) mm in diameter of an earthed hollow sphere of (25 ± 5) mm in diameter, connected to an earthed (100 ± 10) nF capacitor at the input of a coulomb meter (see Bibliography, Chubb).
5) A flat round disk, less than 3 mm thickness, made of PTFE with an area exceeding 20 000 mm² as a highly chargeable reference (see Bibliography, von Pidoll).

G.10.4 Test sample

The test should be carried out on a fully assembled sample of the product or a material with the same fabrication parameters. This sample should not have been previously subjected to other tests and may consist of any combination of insulating, conductive or dissipative materials.

NOTE It is advantageous to test the fully assembled product because charge binding effects, e.g. due to internal conductive items, may help to prevent hazardous discharges.

The sample should be conditioned in an environmental conditioning chamber for at least 24 h at a temperature of (23 ± 2) °C and a relative humidity of (25 ± 5) % RH.

The test sample should have an intact clean surface. As any solvent may leave conductive rests on the surface it is best to clean the surface with a brush only. This is especially important in cases where the surface is treated with special antistatic agents.

If, however, fingerprints or other dirt is visible on the surface and no special antistatic agents are used on the surface the test sample should be cleaned according to G.2.4.

G.10.5 Procedure

All insulating parts of the test sample should be tested. Conductive parts should be earthed during testing if earthing is ensured during use.

The test is conducted as follows:

a) The correct operation of the measuring system should be confirmed e.g. by test pulses of approximately 50 nC from a spherical electrode at the input of a calibrated electrostatic voltmeter of known input capacitance (e.g. 10 pF) and known applied voltage (e.g. 5 kV). Alternatively, a very short connection of a 1,5 V battery (typically 1,65 V) to the input of a coulombmeter (typically 100 nF input capacitance) should display the transferred charge (typically 165 nC).
b) Check the test steps 3 to 12 with the reference PTFE disk and verify that at least 100 nC is obtained.
c) Rub the test sample with a material from the positive end of the triboelectric series. Whilst rubbing at least one stroke per second with medium force (approximately 40 N), in direction away from the test person. The test surface should not be contacted with the

bare hand. Rubbing should continue for (10 ± 1) s and should be terminated with a hard rubbing stroke.

NOTE The medium force of 40 N may be controlled by a weighing machine.

d) Grab the sample by using an isolated grip to minimize inadvertent discharge.
e) Lift the sample carefully at least 20 cm away from the table losing as little charge as possible.
f) Discharge the sample as quickly as possible by slowly moving the spherical electrode of the measuring equipment towards the test sample until a discharge occurs. Particular attention should be made to discharge the most hazardous parts of the sample, e.g. great surface areas and small conductive items.

NOTE Discharges occurring at gaps less than 2 mm for IIA, 1 mm for IIB and 0.5 mm for IIC are less incendive than expected by their transferred charge due to quenching effects at the electrodes.

g) Immediately remove the sample from the vicinity of the electrode.
h) Read the value from the display or integrate the recorded current (horizontal setting typically 40 ns/div) and multiply it with the known calibration factor.

NOTE Experts advice may be necessary if multiple discharges are recorded.

i) Repeat the test nine times.
j) Repeat steps 3-9 with a material from the negative end of the triboelectric series.
k) Repeat steps 3-9 with a second material from the positive end of the triboelectric series
l) Repeat steps 3-9 with a third material or hit the sample five times with the smooth part of a leather glove, for ten times.
m) Check whether the test sample contains insulating parts backed with a conductor or is dissipative or conductive. If yes continue with 16, if no go to step 14.

NOTE This is necessary to ensure that propagating brush discharges, which damage the measuring equipment, cannot occur.

n) Charge the sample by positioning the corona electrode slightly above the test sample and charge it with small circular motion. Remove the electrode after 5 s far away from the sample while the high voltage is still applied in order to avoid back spraying of charges from the charged sample to the electrode.

NOTE Circular motion is not necessary in case of a multi-needle electrode.

o) Continue with steps 4 to 9.
p) End of test.

G.10.6 Acceptance criteria

The highest value of all charging methods should be used for the assessment procedure.

The maximum allowed value depends on the type of the hazardous area and is given in Table 4.

Charging by corona and whipping with a leather glove are strong charge generating processes comparable to machine rubbing, charging by electrons in the vicinity of ionisers and electrostatic spraying equipment or charging by streaming liquids and powders.

G.10.7 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,

- description and identification of the sample,
- type of clothes used,
- corona voltage,
- maximum values obtained,
- number of measurements,
- maximum value obtained with the reference sample,
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

If results on corona charging and whipping with a leather glove have been discarded, it should be stated that the test sample may not be used in the presence of charge generating processes stronger than manual rubbing.

G.11 Ignition test

G.11.1 General

A second possibility to evaluate the incendivity of provoked discharges under worst case conditions are experiments with an ignition probe producing a defined explosive atmosphere in the region of the provoked discharges. A suitable discharge probe is described in IEC 61340-4-4 (Figures G.4 and G.5).

An equipment other than that specified may be used if it reproduces the principles of the test and can give comparable results.

G.11.2 Apparatus

The ignition probe according to IEC 61340-4-4 is a cylinder made from rigid non-conductive material such as polycarbonate or acrylic with an internal diameter of (70 ± 5) mm and an internal length of (100 ± 5) mm (Figure G. 4). The material used for constructing the probe should be of sufficient thickness and strength to withstand repeated ignition without cracking, distorting or otherwise failing.

One end of the cylinder is closed apart from a central port to allow the inflow of the flammable gas. The size of the inlet port is not critical but should be large enough to allow the required flow rate to be achieved without excessive pressure build-up. A suitable flame arrestor should be installed in the gas supply line as close as possible to the ignition probe.

A metal plate is fitted to the other end of the cylinder to form a fixing base for the discharge electrode (Figure G.5). The metal plate is drilled with holes, (5 ± 1) mm in diameter to allow the uniform flow of gas through it and around the discharge electrode.

A spherical metal electrode of diameter (20 ± 5) mm is mounted centrally to the metal plate. The electrode, metal plate and any other metal or conductive material in the ignition probe are connected to a common point earth via a low impedance (<10 Ω) connection. The earth point should be the common point earth for local structures and equipment. The common earth point may be connected to the electricity supply earth. The connection between the electrode, the metal plate and the earth connector should be sufficiently robust to withstand physical and thermal impacts. The electrical continuity between the discharge electrode and the earth connector should be checked prior to use.

The ignition probe is filled with glass or porcelain beads, nominally 1 mm to 2 mm diameter, which are retained by a fine metal gauze or mesh at either end of the main cylinder. The beads assist in the mixing of the gases and also contribute to preventing propagation of any flame back through the probe.

An adjustable shroud made from insulating material is fitted to the cylinder to direct gas over the discharge electrode and into the region in front of the discharge electrode where electrostatic discharges take place. The opening in this shroud is (40 ± 5) mm.

The flammable gas is generated by mixing the test gas (minimum 99,5 % purity) with air. The air used should contain (21,0 ± 0,5) % oxygen and (79,0 ± 0,5) % nitrogen. The gas control and mixing apparatus is used to direct the gas in the appropriate proportions to the ignition probe. The volume concentrations of the test gas used are shown in Table G.1.

Table G.1 – Volume concentrations of flammable gas mixtures

Test gas	Volume concentration	Minimum ignition energy[a]	Explosion group
Hydrogen	(22,0 ± 0,3) % in air	0,016 mJ	IIC
Ethylene	(8,0 ± 0,1) % in air	0,082 mJ	IIB
Propane [b]	(5,2 ± 0,1) % in air	0,25 mJ	IIA

[a] See C.6.

[b] See EN 50050.

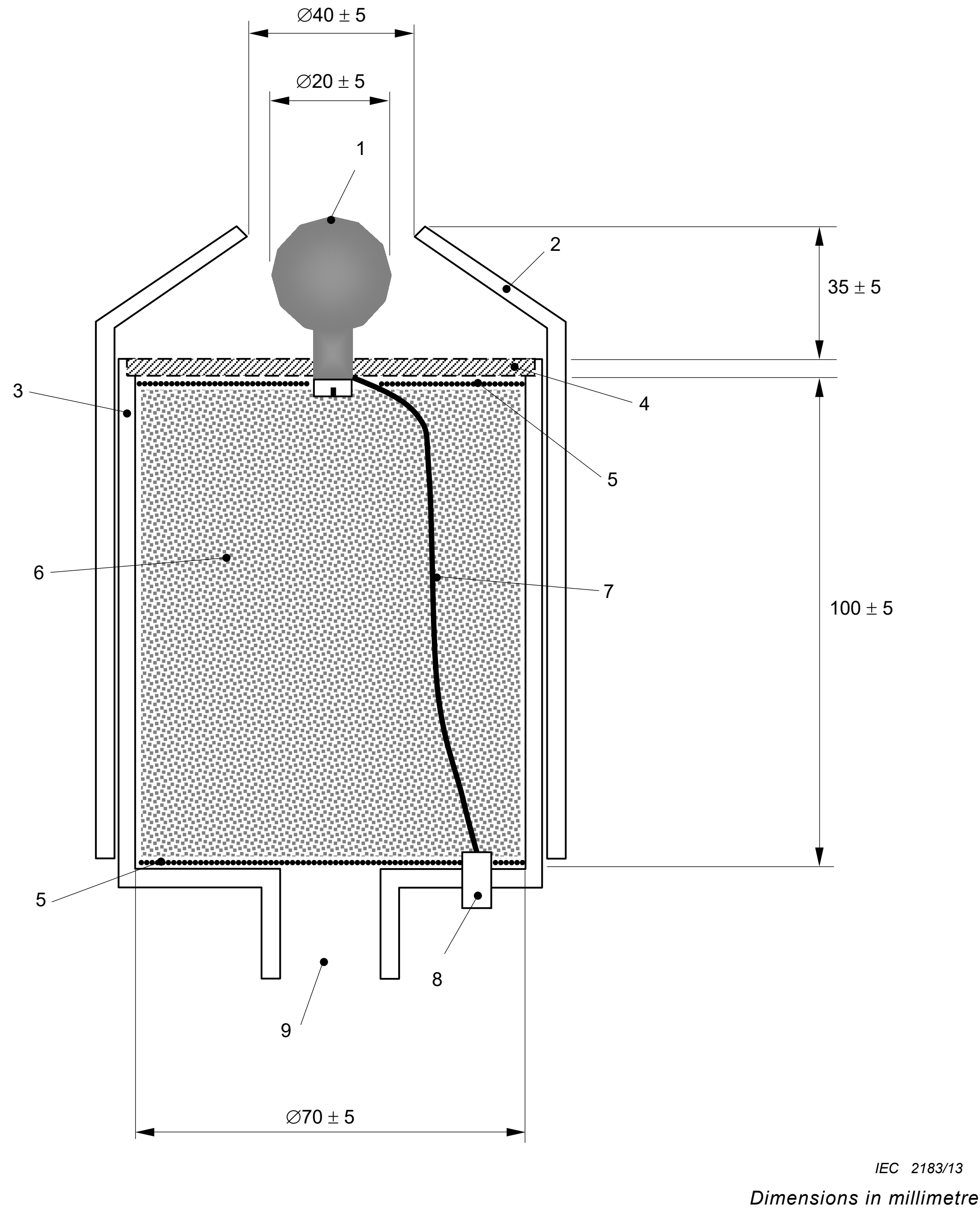
The control of the gas mixture within the specified tolerances should be checked using, for example, an infra-red gas analyzer sampling the gas mixture supply line.

If a gas mixture other than that specified in Table G.1 is used, the minimum ignition energy of the gas mixture should be verified using the ASTM E582-88 method.

It is convenient to use compressed gas cylinders for the gas supply, but other sources of supply may be used. If necessary, molecular sieve filters should be used to ensure the gases have low moisture content. This is particularly important, for example, when using air directly from a compressor.

Each gas supply is controlled and monitored using flowmeters and valves. The combined flow-rate of all gases through the ignition probe should be (0,21 ± 0,04) l/s.

A fast action shut-off valve is used to stop the flow of test gas when ignition occurs. The shut-off valve should stop the supply of test gas whilst leaving the air to flow freely to provide cooling and drying of the ignition probe after ignition has occurred. The type and location of the shut-off valve should be selected as appropriate to the specific design of the overall apparatus.

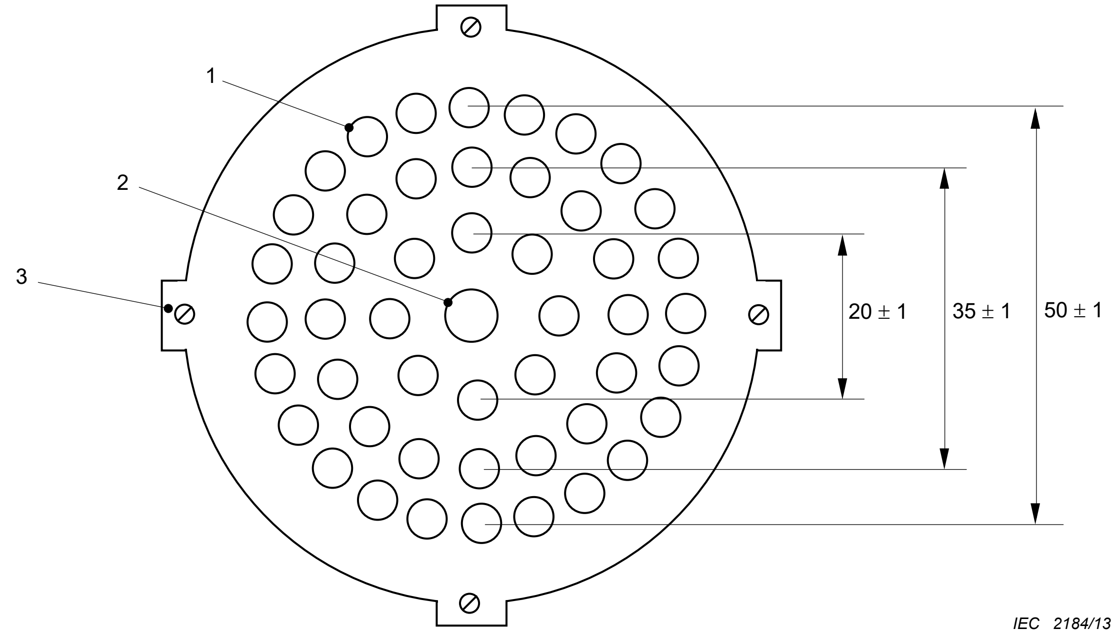


Dimensions in millimetres

Key

1 discharge electrode	5 fine metal mesh or gauze (e.g. copper)
2 adjustable shroud made from insulating material (e.g. polycarbonate or acrylic)	6 beads (e.g. glass or porcelain), 1–2 mm diameter (nominal)
3 cylinder made from insulating material (e.g. polycarbonate or acrylic)	7 robust earth connection
4 perforated metal plate (2mm nominal thickness)	8 earth connector
	9 inlet port for flammable gas

Figure G.4 – Ignition probe



Dimensions in millimetres

Key

1 perforation (5 ± 1) mm diameter

2 mounting hole for discharge electrode

3 screw for securing plate to body of ignition probe

Figure G.5 – Perforated plate of ignition probe

G.11.3 Procedure

Ignition tests are carried out by bringing the ignition probe close to the charged test sample with the flammable gas mixture flowing through the probe. The same test procedure as described in G.10.4, steps 2 to 16, should be executed except that the numbers of test sequences should at least be doubled to compensate statistical scatters.

G.11.4 Acceptance criteria

Any ignition occurring should be regarded as product failure for the explosion group given by the specific gas mixture.

Charging by corona and whipping with a leather glove are strong charge generating processes comparable to machine rubbing, charging by electrons in the vicinity of ionisers and electrostatic spraying equipment or charging by streaming liquids and powders.

G.11.5 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- type of clothes used,
- corona voltage,

- ignition test results,
- number of non ignitions obtained,
- ignition was obtained with the reference sample,
- identification of the used instrumentation,
- date of its most recent as well as its next check,
- number of this standard.

G.12 Measuring of charge decay

G.12.1 General

Another possibility to evaluate the chargeability of a material, and one that is preferable for garments, is measuring of its charge decay according to IEC 61340-2-1.

NOTE In Europe, the method described in EN 1149-3 is used to determine charge decay from personnel protective clothing.

G.12.2 Principle

The material is charged by corona and the decay of its surface equivalent voltage, measured with a field meter, is recorded in between a given voltage interval.

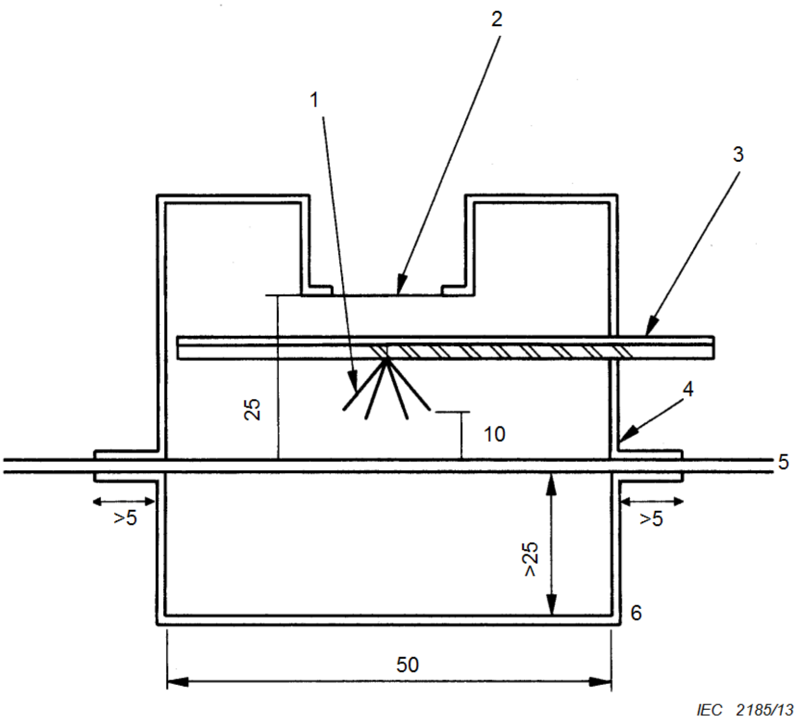
G.12.3 Apparatus

An example of the apparatus is shown in Figure G.6. The test aperture for deposition and measurement of deposited charge should be 50 mm diameter or an equivalent area quasi-square aperture. All the corona points are mounted in a 10 mm diameter circle on a movable plate 10 mm above the centre of the test aperture. The fieldmeter sensing aperture should be 25 mm above the centre of the test area. When the plate with the corona points is moved fully away, the test area should be clear up to the plane of the fieldmeter sensing aperture.

The field meter should be a field-mill type of instrument able to measure the surface voltage with an accuracy of 5 V to below 40 V with a respond time (10 % to 90 %) below 10 ms. The stability of zero should allow measurements of surface voltage with this accuracy over the longest decay times to be measured. Any rest ionization in the measuring chamber should be less than 10 V which can be evaluated with fully conductive garments.

The field meter should be connected to a Personal Computer or an oscilloscope to record charge decay.

NOTE More details about this measuring procedure and drawings of the necessary apparatus can be found in IEC 61340-2-1.



Dimensions in millimetres

Key

1	10 mm diameter circle of corona points
2	Fieldmeter sensing aperture
3	Movable plate: – insulating plate: to mount corona points (resistance to ground > 10^{14} Ω) – earthed top surface: to shield fieldmeter
4	Earthed casing
5	Sample
6	Open-shielded backing

NOTE All dimensions are nominal.

Figure G.6 – Example of an arrangement for measurement of charge decay

G.12.4 Test sample

The sample is typically a garment material of at least 60 mm in diameter. Remove any loose dust by gently brushing or blowing with clean air. Further cleaning should only be done if this is agreed to. However, do not test obviously contaminated parts.

The atmosphere for conditioning and testing should be (23 ± 2) °C and (25 ± 5) % relative humidity. The conditioning time prior to the testing should be at least 48 h, or as otherwise agreed.

G.12.5 Procedure

The test procedure is as follows:

a) Clamp the garment in the apparatus.

b) Move the middle plate so that the corona points are effectively placed and the field meter is shielded.

c) Apply 5 kV to 10 kV negative on the corona points for (1 ± 0,5) seconds.

d) Remove the middle plate so that the field meter can measure the equivalent surface potential of the probe.

e) Measure the charge decay from the initial voltage to the agreed lower voltage level.

f) Repeat steps b) to e) two times on different locations.

g) Repeat steps a) to f) with positive polarity.

G.12.6 Acceptance criteria

Acceptable decay time is dependent on the charging processes involved in the application. For manual processes where charging is dependent on human activity, a decay time from 1 000 V to 100 V in about 1 s to 2 s is generally acceptable. Where charging currents are higher, shorter decay times may be required.

G.12.7 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,
- description and identification of the sample,
- test results,
- applied corona voltage
- charging time,
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

G.13 Breakthrough voltage

G.13.1 General

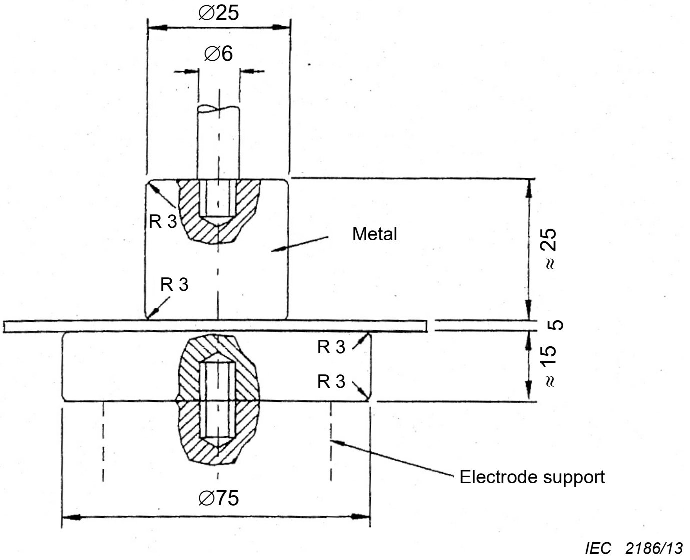
The electrical breakthrough voltage should be measured according to the short-time (rapid rise) test in IEC 60243-1 with the additional requirements of IEC 60243-2 for DC testing.

G.13.2 Principle

The test sample is placed between two metal electrodes. A DC voltage is applied and increased until breakthrough occurs.

G.13.3 Apparatus

In cases of plates, discs and sheets, the sample is placed between two metal cylinders. According to IEC 60243-1, the first is (25 ± 1) mm in diameter, (25 ± 1) mm in height, pressed with 1 kg on the sample, and the second one (75 ± 1) mm in diameter, (10 ± 1) mm in height (Figure G.7). The edges of the metal cylinders should be rounded with a radius of (3 ± 0,2) mm to avoid corona discharges. In the case of small hoses the electrodes should be a metal rod closely in contact with the inside of the hose and a metal foil tape at the outer side of the specimen.



Dimensions in millimetres

Figure G.7 – Electrodes for measuring breakthrough voltage of sheets

The electrodes are connected to a DC HV generator with calibrated voltage and current displays. For normal electrostatic purposes, a maximum voltage of 20 kV is sufficient. However, in the case of tube testing a maximum voltage of 120 kV is necessary.

G.13.4 Test procedure

The test procedure is as follows:

a) Acclimate the samples at (23 ± 2) °C and (25 ± 5) % relative humidity except when other conditions have been agreed.

b) Place a sample between the electrodes in the same climate.

c) Apply a DC voltage between the electrodes and slowly increase it from 0 V at a rate of 100 V/s.

d) Monitor the current monitored through this procedure.

e) Stop the test and record the actual voltage if either a rapid increase of current, often together with a bang and smoke, occurred, or an agreed upper limit of the current is reached.

f) If the output current of the DC power supply reaches 1 mA before the electrode voltage reaches 4 kV (6 kV in case of fabrics), the material under test should be deemed to have a sufficient low breakthrough voltage.

NOTE More details about this measuring procedure can be found in IEC 60243-1 and IEC 60243-2.

G.13.5 Acceptance criteria

The maximum allowed value depends on the type of the hazardous area and is given in 6.3.4.3 and 9.6.1.

G.13.6 Test report

The test report should include at least the following information:

- measuring laboratory,
- date of measurement,
- temperature and relative humidity,

- description and identification of the sample,
- median breakthrough voltage or reaching 1 mA limit, whatever is applicable.
- identification of the used instrumentation,
- date of its most recent as well as its next calibration,
- number of this standard.

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